COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

BACHELOR'S DEGREE IN ENGINEERING FOR INDUSTRIAL TECHNOLOGIES

Final Degree Project

LARGE SCALE PHOTOVOLTAIC SOLAR PLANT FEASIBILITY STUDY

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Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

"Large Scale Photovoltaic Solar Plant Feasibility Study"

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el
curso académico 2021/2022 es de mi autoría, original e inédito y
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de otros documentos está debidamente referenciada.

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ACKNOWLEDGEMENTS

LARGE SCALE PHOTOVOLTAIC SOLAR PLANT FEASIBILITY STUDY

Author: **Córdoba Ocaña, Miguel**
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Collaborating Entity: **ICAI - School of Engineering - Pontifical University of Comillas**

ABSTRACT:

1. Introduction:

The photovoltaic effect is a physical phenomenon that consists of direct solar irradiance over a surface to generate electricity.

As of today, we have enhanced technology at our disposal to take advantage of this phenomenon to produce energy in a competitive market with a neutral carbon footprint. This technology is the main core of this Project. Namely, the generating solar panels that form the power plant.

The Project, with a 50.00 MWp capacity, is located within an 11.4 km radius of the electrical substation of Riega (transmission grid, 132 kV) in the province of Ciudad Real in Spain.

2. Development:

The main steps followed for this project were:

a) Analyzing different solar irradiance data from solar bases (Meteonorm)
b) Analyzing slopes in the terrain (Google Earth)
c) Selecting the appropriate number of hectares (Google Earth)
d) Selecting the electrical substation for energy injection (2018 R.E.E. Electrical Map)
e) Energy Simulation for component selection (PVSyst program).
f) Selecting the appropriate inverters
g) Selecting the appropriate trackers
h) Budgetary calculations
i) Profitability analysis
j) Project plans

3. Results:

The results obtained while analyzing and simulating were the following:

- Installed peak power (P_p): 50.00 MWp
- Inverters nominal power (P_n): 48.00 MWac

- Ratio (P_p/P_n): 1.042
- Overload loss: 0.0%
- Unitary bifacial photovoltaic solar panel nominal power: 530 W
- Yearly energy production: 99.9 GWh/year
- Yearly specific production: 1998 kWh/kWp/year
- Performance ratio: 85.27%
- Design overview:
    - Number of modules: 94338 (3494 strings of 27 modules each)
    - Module area: 241132 m^2
    - Shed area: 242525 m^2
    - Total physical area: 65.6 hectares
    - Number of trackers: 295
    - Number of inverters: 10
    - Number of transformation stages: 2

Where models for every element in the power plant are the following:

- Panels: LONGI SOLAR 'LR5-72 HBD 530 MBD M Bifacial', 530 Wp, 35 V, monocrystalline silicon (Si-mono)

- Inverters: SIEMENS 'SINACON PV4800', 4800 kW, 962-1500 V, 50/60 Hz

- Trackers: IDEEMATEC 'SafeTrack H4plus bifacial' (single-axis tracker)

Grid injection system elements:

- LV lines (per inverter):

    - Voltage: 660 V
    - Length: 9.2 m x 10 inverters
    - Loss fraction at STC: 0.08%
    - Wire section: 4000 mm^2
    - Material: Aluminum

- MV Lines:

    - Voltage: 20 kV
    - Length: 1000 m x 4 lines
    - Loss fraction at STC: 0.32%
    - Wire section: 300 mm^2
    - Material: Aluminum
    - Covering: XLPE
    - Manufacturer: 'Eland Cables'
    - Model: 'YMz1Krvasdlwd-AL 12/20kV Cable'

- HV Line:

    - Voltage: 132 kV
    - Length: 10400 m
    - Loss fraction at STC: 0.50%
    - Wire section: 185 mm^2
    - Material: Aluminum

- MV/LV Transformation stage:

    - Number of transformation centers: 4
    - Number of transformers per center: 5
    - Vector group: Dy11y11
    - Voltages: 20 kV/660 V
    - Nominal apparent power at STC: 49261 kVA (12315 kVA/center)
    - Iron loss: 0.20%
    - Copper loss: 0.80% at STC
    - Transformer manufacturer: 'Power Electronics'
    - Model: 'Twin Skid Compact'

- HV/MV Transformation stage:

    - Number of transformation centers: 1
    - Voltages: 132/20 kV
    - Nominal apparent power at STC: 52000 kVA
    - Iron loss: 0.10%
    - Copper loss: 0.22% at STC

4. <u>Conclusions:</u>

Simulating on PVSyst software provided optimizations subjected to different constraints that made possible the design of a realistic solar power plant model.

As for the components used, bifacial panels make a difference between the ones that do not take advantage of the albedo effect, given that the latter are only able to transform irradiance directly originating in the sun and not the one reflecting on the ground. Moreover, single-axis trackers are competitive in prices and higher efficiency as they follow the motion of the sun.

Having obtained an NPV of €13,778,419.15 and an IRR of 9% with a WACC of 5%, the project is fit to be given green light, recovering the €31,152,040 initial investment by the 15th year with an expected 30-year lifetime period.

ESTUDIO DE VIABILIDAD DE PLANTA SOLAR FOTOVOLTAICA DE GRAN POTENCIA

Autor: **Córdoba Ocaña, Miguel**
Directora: **Alonso Alonso, Consolación**

Entidad Colaboradora: **ICAI-Universidad Pontificia de Comillas**

RESUMEN DEL PROYECTO:

1. Introducción:

El efecto fotovoltaico es un fenómeno físico que consiste en la irradiación solar sobre una superficie con el fin de generar electricidad.

A día de hoy, contamos con tecnología desarrollada para aprovechar este fenómeno y producir energía en un mercado competitivo con huella de carbono neutra. Esta tecnología es el núcleo principal de este Proyecto. A saber, los paneles solares generadores que forman la central eléctrica.

El Proyecto, con una capacidad de 50.00 MWp, se ubica en un radio de 11.4 km de la subestación eléctrica de Riega (red de transporte, 132 kV) en la provincia de Ciudad Real en España.

2. Desarrollo:

Los pasos principales seguidos para llevar a cabo este proyecto han sido:

a) Análisis de diferentes datos de radiación solar en bases solares (Meteonorm)
b) Análisis de pendientes en el terreno (Google Earth)
c) Selección de la cantidad adecuada de hectáreas (Google Earth)
d) Selección de la subestación eléctrica para la inyección de energía (Mapa Eléctrico R.E.E. 2018)
e) Simulación energética para selección de componentes (programa PVSyst).
f) Selección de los inversores adecuados
g) Selección de los seguidores apropiados
h) Cálculos presupuestarios
i) Análisis de rentabilidad
j) Planos de proyecto

3. Resultados:

Los resultados de análisis y simulación han sido los siguientes:

- Potencia pico instalada (Pp): 50.00 MW
- Potencia nominal de los inversores (Pn): 48.00 MWa
- Relación (Pp/Pn): 1.042

- Pérdida por sobrecarga: 0.0%
- Potencia nominal del panel solar fotovoltaico bifacial unitario: 530 W
- Producción anual de energía: 99.9 GWh/año
- Producción específica anual: 1998 kWh/kWp/año
- *Performance ratio*: 85.27%
- Descripción general del diseño:

- Número de módulos: 94338 (3494 cadenas de 27 módulos cada una)
- Área del módulo: 241132 m^2
- Área de cobertizo: 242525 m^2
- Área física total: 65.6 hectáreas
- Número de seguidores: 295
- Número de inversores: 10
- Número de etapas de transformación: 2

Donde los modelos de cada elemento de la planta son los siguientes:

- Paneles: LONGI SOLAR 'LR5-72 HBD 530 MBD M Bifacial', 530 Wp, 35 V, silicio monocristalino (Si-mono)

- Inversores: SIEMENS 'SINACON PV4800', 4800 kW, 962-1500 V, 50/60 Hz

- Seguidores: IDEEMATEC 'SafeTrack H4plus bifacial' (a un eje)

Elementos del sistema de inyección a la red

- Líneas BT (por inversor):

  - Tensión: 660 V
  - Longitud: 9.2 m x 10 inversores
  - Fracción de pérdidas en STC: 0.08%
  - Sección de cable: 4000 mm^2
  - Material: Aluminio

- Líneas MT:

  - Tensión: 20 kV
  - Longitud: 1000 m x 4 líneas
  - Fracción de pérdidas en STC: 0.32%
  - Sección de cable: 300 mm^2
  - Material: Aluminio
  - Recubrimiento: XLPE
  - Fabricante: 'Eland Cables'
  - Modelo: 'YMz1Krvasdlwd-AL 12/20kV Cable'

- Línea AT:

  - Tensión: 132 kV
  - Longitud: 10400 m
  - Fracción de pérdidas en STC: 0.50%
  - Sección de cable: 185 mm^2
  - Material: Aluminum

- Etapa de transformación MT/BT:

  - Número de centros de transformación: 4
  - Número de transformadores por centro: 5
  - Grupo de conexión: Dy11y11
  - Tensiones: 20 kV/660 V
  - Potencia aparente nominal en STC: 49261 kVA (12315 kVA/center)
  - Pérdidas en el hierro: 0.20%
  - Pérdidas en el cobre: 0.80% en STC
  - Fabricante de transformador: 'Power Electronics'
  - Modelo: 'Twin Skid Compact'

- Etapa de transformación AT/MT

  - Número de centros de transformación: 1
  - Tensiones: 132/20 kV
  - Potencia aparente nominal en STC: 52000 kVA
  - Pérdidas en el hierro: 0.10%
  - Pérdidas en el cobre: 0.22% en STC

4. **Conclusiones:**

La simulación en el software PVSyst proporciona optimizaciones sujetas a diferentes restricciones que permiten el diseño de un modelo de planta de energía solar realista.

En cuanto a los componentes utilizados, los paneles bifaciales marcan la diferencia con los que no aprovechan el efecto albedo, ya que estos últimos sólo son capaces de transformar la irradiación que se origina directamente en el sol y no la que se refleja en el suelo. Además, los seguidores de un solo eje plantean competitividad entre precio y mayor eficiencia ya que siguen el movimiento del sol.

Habiendo obtenido un VAN de 13,778,419.15 € y un TIR del 9% con un WACC del 5%, el proyecto resulta ser rentable, recuperando la inversión inicial de 31.152.040 € el año 15, considerando un periodo de 30 años de vida útil.

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PROJECT NARRATIVE

0. <u>Project objectives:</u>

The Project at hand's main aim is the design of a photovoltaic solar power plant whose peak power reaches 50.00 MW, located in the province of Ciudad Real in Spain. The substation to which it will be connected is the 132 kV substation in Riega.

The main steps that were taken in order to carry out the project have been:

1) Location selection according to the following issues:

- Appropriate solar irradiance
- Ground characteristics (local slopes less than 10%)
- Accessibility (near a road or highway)
- Possibility of energy injection in the transmission grid (as much as 20 km distance between the power plant and the nearest substation)
- Civil work possibilities according to current environmental legislation (natural spaces protected under law)

Therefore, the selected location has the following coordinates:

- Longitude: -2.865427°
- Latitude: 39.161530°

These angular coordinates were chosen according to the constraints stated above. The main characteristics of this location are its easy accessibility to the A-43 highway, its low local slopes and the high solar irradiance over the ground. Furthermore, no protected spaces are being put in jeopardy and the high-voltage substation of Riega is at an 11.4 km distance from the connection points in the power plant to the energy injection system.

2) Solar irradiance and software simulation for energy production:

METEONORM was the base used to provide the solar data to the PVSyst software and PVGIS was used to provide the form of the terrain in which the plant lies.

Moreover, several simulation scenarios were carried out in order to choose the main components, in other words, the panels, the trackers and the inverters.

3) Main elements in the solar generators' design:

- Solar generating technology (panel model)
- Tracking technology:
  - Fixed-tilt structure
  - Single-axis tracker
  - Dual-axis tracker

- Inverter model

4) Electrical design overview:

- Medium and high voltages selection according to the plant's output voltage and the substation's grid voltage.

- Connection system:
  - Lines length
  - Wire section
  - Material for cables

5) Budgetary/Profitability analysis:

It mainly encompasses the investment's profitability after analyzing all of the data provided by PVSyst software.

1. Introduction:

Sun-generated energy is the outcome of a fusion reaction in such a star. This process involves hydrogen atoms that, when put together at the required conditions, form helium atoms delivering a high amount of energy *(see Figure 1)* quantified in Einstein's famous formula for the theory of general relativity. *(see Formula 1)*

$$4\ H_1^1 \rightarrow He_2^4 + 2e_1^0 + E$$
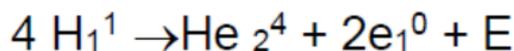
Figure 1: Sun fusion reaction (Source: [2])

$$E = mc^2$$

Formula 1: Einstein's formula for the theory of general relativity (Source: [10])

Where:

- *E* is the energy delivered in the fusion reaction [J]
- *m* is the mass difference [kg]
- *c* is the light speed *in vacuo* whose value is 299 792 458 [ms^{-1}]

Given the climate expectations stated in the 2030 agenda, formally called "Sustainable Development Goals" *(see Figure 2)*, solar technology has become ever more attractive to western governments, especially Europeans, due to its neutral carbon footprint and government-financing prospects over other energy sources.

Figure 2: 2030 Agenda Sustainable Development Goals (Source: [4])

In this case, the Project's sustainable development goals would be:

- Goal 7: Affordable and clean energy (solar energy is profitable and has a neutral carbon footprint)

- Goal 9: Industry, Innovation, and Infrastructure (investigation and development of new solar panels allow the enhancement of their efficiency. Therefore, an easier and more attractive industrial application is possible)

- Goal 11: Sustainable cities and communities (The application of this technology would make communities emit 0 CO_2 tons)

- Goal 12: Responsible consumption and production (As solar technology is characterized by a neutral carbon footprint, the environment is believed not to be harmed)

- Goal 13: Climate action (United Nations bets on renewable energy, in this case solar, in order to protect the environment)

2. A brief history of solar technology:

Solar technology has always revolved around the photovoltaic effect.

NOTE: The following historical facts are a direct translation from Spanish to English by the author of this Project. They are quoted from *Slide 2, Source [5]*.

"The photovoltaic effect was first recognized by French physicist Alexandre-Edmond Becquerel in 1839. His studies about the solar spectrum, magnetism, electricity, and optics are photovoltaic energy's main pillar.

In 1883, the American inventor Charles Fritts built the first solar cell with [no more than] 1% efficiency.

In 1905, Albert Einstein managed to explain the photovoltaic effect and was awarded the Physics Nobel Prize in 1921 for his services to *the theory of Physics*, *especially his discovery of the photovoltaic effect laws.*

The silicon cell used nowadays originated in the American inventor Russell Ohl's patent. It was built in 1940 and patented in 1946.

The modern times for the silicon cell began in 1954 in Bell Telephone Labs. By accident, while experimenting with semiconductors, it was found that silicon with minimum impurities was highly light-sensitive.

In 1958, the USA launched the *Vanguard I* satellite to space with the first photovoltaic system being part of it and operated with success. [The photovoltaic system] was constituted of 6 panels mounted on an outer sphere-shaped area. Every panel contained 18 polycrystalline silicon cells. Its [whole] output power oscillated between 50-100 W for 6 years."

3. State of the art in solar energy:

"Power generation from solar PV in 2020 is estimated to have increased by a record 156 TWh, marking 23% growth from 2019. Solar PV accounted for 3.1% of global electricity generation, and it remains the third-largest renewable electricity technology behind hydropower and onshore wind after overtaking bioenergy in 2019." (*Source: [18]*)

As for solar energy in Spain, it accounted for 4,854 MW in 2015, and 9,071 MW in 2020. With regards to the objectives for the future, it is intended to increase the installed power by reaching 21,713 MW in 2025, and 39,181 MW in 2030. In 2021, solar energy accounted for 8.1% of the energetic mix. It is intended to increase that number to 24.1% by the end of the year 2030 as stated in the 2030 Agenda. (*Source: [19]*)

Moreover, the implications of increasing solar energy installed power along with other renewable sources would be a lesser energetic dependence from abroad as it is planned to progressively shut down all generation plants that do not harness renewable energy. In the case of Spain, the fuel is imported in this instance. Consequently, if following this reasoning, solar PV technology is a perfect substitute for an energetic self-supply.

The following figure shows the installed capacity of renewable technologies from 2015 to 2030 (with estimations beginning after 2020).
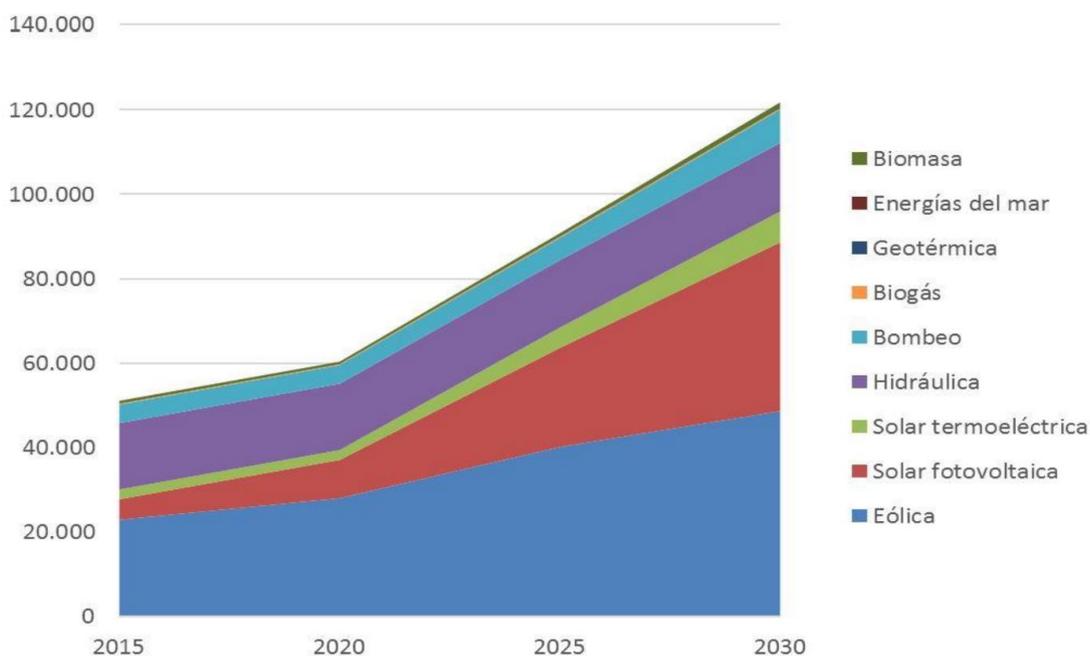
Figure 3: Installed capacity for renewable technologies (Source: [19])

4. **Photovoltaic solar power plant general description:**

The part of a PV solar plant designed to harness solar energy is the array. This array is composed of strings. The strings are formed by solar modules containing solar cells. These solar cells are the unitary basic element of the generators manufactured with semiconductors.

The power is DC-generated (*direct current*). Nevertheless, it must be injected into an AC (*alternating current*) power grid. In order to achieve this, the inverter modifies the voltage from DC to AC. Once the output energy is AC, it must be injected into the grid.

The injection requires 3 different cables. These are LV (*low voltage*), MV (*medium voltage*), and HV (*high voltage*). The LV cables go from each inverter to the MV/LV transformation stage. On the MV side, the cables go to the HV/HV transformation stage, where the HV lines drive power to the nearest substation.

Furthermore, the trackers also play an important role in any solar plant. They are the structures that hold the plant's panels. They can be fixed-tilt, single-axis, or dual-axis. The two last follow the motion of the sun, hence presenting attractiveness to buyers.

5. Photovoltaic solar technologies:

5.1. The photovoltaic effect:

The photovoltaic effect consists of direct solar irradiance over a surface made of semiconductor materials that transform this solar energy into electricity.

In order to produce electricity, electrons must be freed from the element they belong to by absorbing photonic energy. Namely, if a light photon meets an atom, one of its electrons in the atom's outer shell will change its energy level. Therefore, if the photon has enough energy, it can make the electron move to the atom's highest energy level and free it with kinetic energy. The necessary energy is always a discrete value that is quantified in *Formula 2*.

$$E = \frac{hc}{\lambda}$$

Formula 2: Photon energy formula (Source: [5])

Where:

- *E* is the energy of one photon [J]
- *h* is Planck's constant with a value of $6.62607015 \times 10^{-34}$ [m²kgs⁻¹]
- *c* is the light speed *in vacuo* whose value is 299 792 458 [ms⁻¹]
- *λ* is the photon's wavelength [m]

5.2. Photovoltaic materials:

Any element is clustered into 3 categories:

- conductors
- insulators
- semiconductors

Conductors are characterized by their low impedance, whereas insulators present a high one. However, semiconductors are in the middle and can work both as insulators and conductors depending on the physical conditions they work under. Furthermore, one property of interest is the existence of 2 subgroups each:

- P-type: The semiconductor has an electron-vacancy excess
- N-type: The semiconductor has an excess of electrons

This property, as stated above, is of special interest given that putting one of each conductor type together, while photon-irradiated, makes electrons from the N-type go to the P-type, thus creating a voltage drop as shown in the following figure.
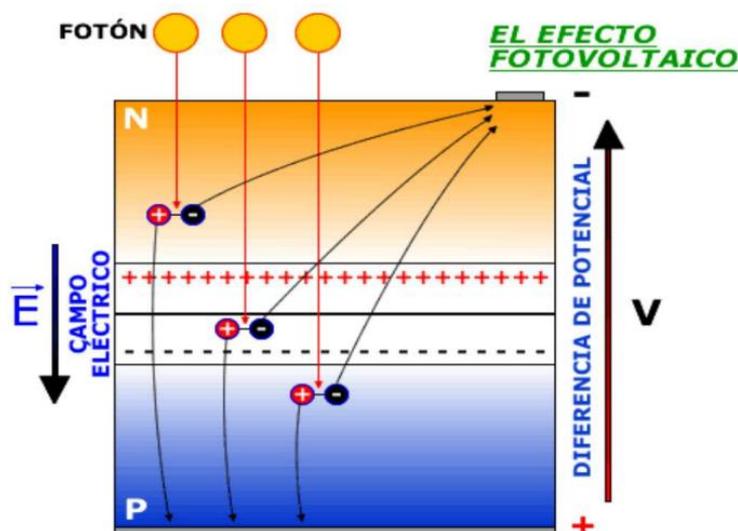
Figure 4: The photovoltaic effect (Source [5])

This is exactly the solar panels' working principle.

5.3. The photovoltaic panel:

5.3.1. General aspects:

A photovoltaic panel is a set of module strings that when connected in series and/or in parallel to form what is called an array, generate a DC voltage drop. This voltage drop is caused by the photovoltaic effect as stated in all of the above.

A photovoltaic cell is the union of several P-N semiconductor materials so that the photovoltaic effect takes place. As seen in the previous part, the current is DC-generated. Nevertheless, it is not constant. This fact is due to a recombination of the electron carriers. Consequently, the I-V curve has the shape shown in *Figure 5.*
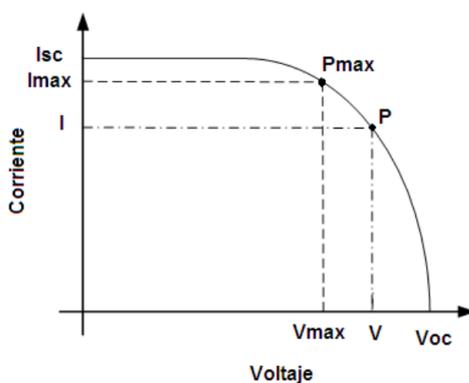
Figure 5: I-V curve for a photovoltaic cell (Source: [2])

Where:

- I_{sc} represents the current when voltage equals 0V (short-circuit equivalent)
- V_{oc} represents the output voltage when current equals 0A (open-loop equivalent. 0.6V is a reasonable value for silicon cells).
- P_{max} represents the maximum power that a cell can deliver.

P_{max} can also be calculated with V_{oc} and I_{sc} and through this, the Form Factor (*FF*) is defined as shown in *Formula 3*.

$$FF = \frac{Pmax}{Voc * Isc}$$

Formula 3: Form factor definition (Source: [6])

Moreover, efficiency can also be defined with the available variables as shown in *Formula 4.*

$$\eta = \frac{Isc * Voc * FF}{A * G}$$

Formula 4: Cell efficiency definition (Source: [6])

Where:

- I_{sc}, V_{oc} and *FF* have already been defined
- *G* is the irradiance per area unit in standard conditions (measurement: G=1000 W/m^2)
- *A* is the area of the panel [m^2]

5.3.2. **Specific aspects:**
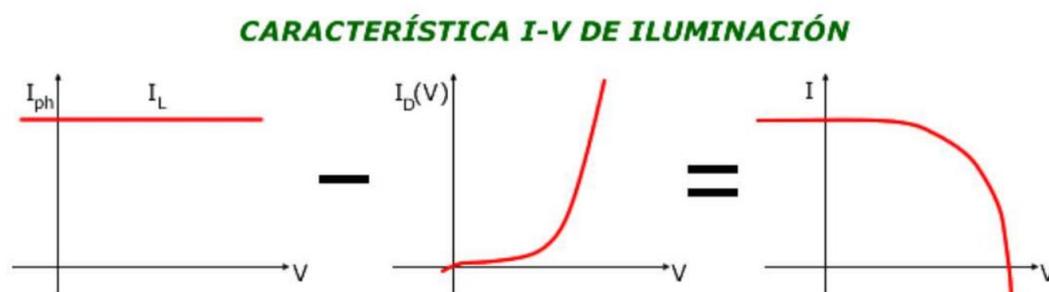
Figure 6: Composition of the I-V curve (Source: [6])
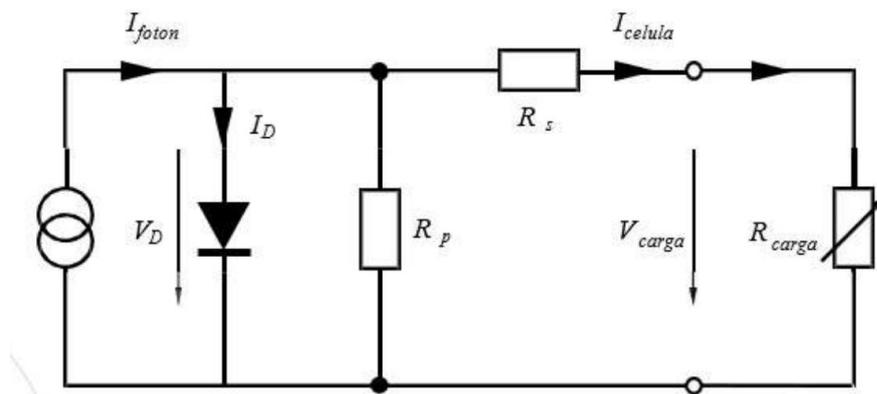
Figure 7: Solar cell equivalent circuit (Source: [6])

As shown in *Figure 6* and *Figure 7,* and as it has already been explained, the current in a solar cell has two components:

- Lighting current due to the direct impact of photons over the semiconductor (I_L or I_{foton})
- Dark current due to the recombination of electron carriers (I_D)
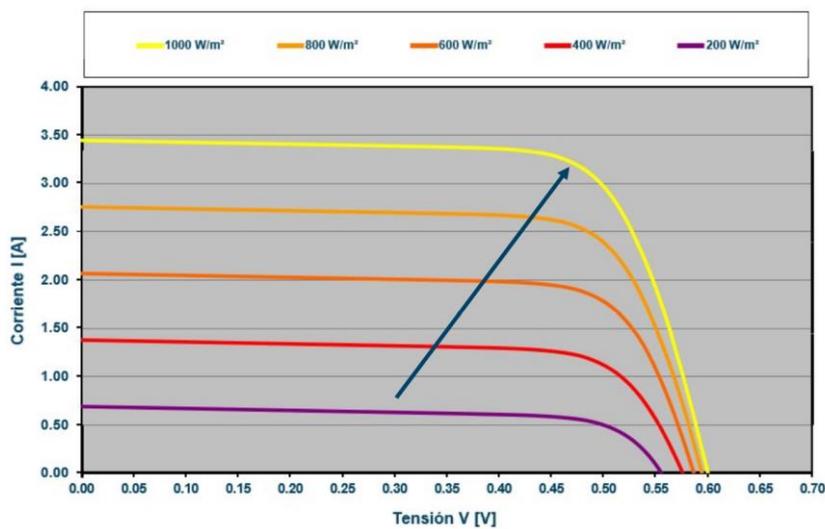
Figure 8: I-V curve modifications due to irradiance variations (Source: [6])
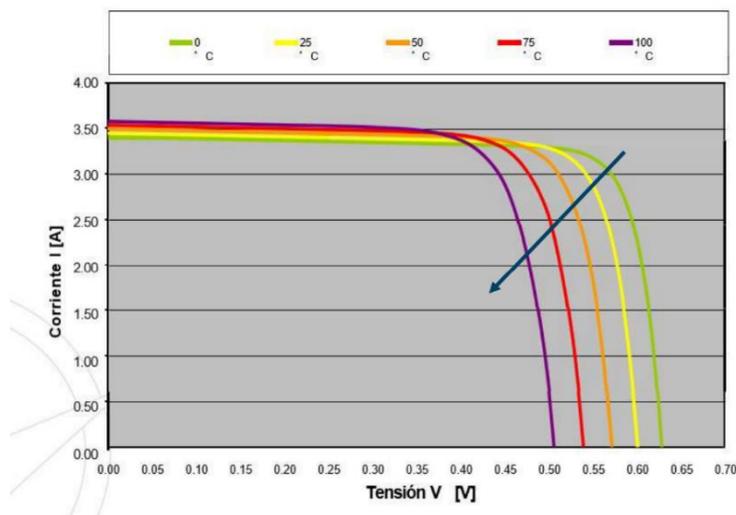
Figure 9: I-V curve modifications due to temperature variations (Source: [6])

As shown in *Figure 7* and *Figure 8*, weather conditions play an important role in energy production. The lower the temperature outside and the higher the solar irradiance, the higher the output power. The higher the temperature outside and the lower the solar irradiance, the lower the output power.

5.3.3. Further aspects of interest:

5.3.3.1. Bifaciality:

Bifacial panels are designed to work on both of their sides. This feature helps the panel absorb not only direct horizontal irradiance as classic ones do but absorb a considerable amount of diffuse and reflected irradiance due to the albedo effect.

As for the panel selection in this Project, they will be bifacial for the reason stated above.
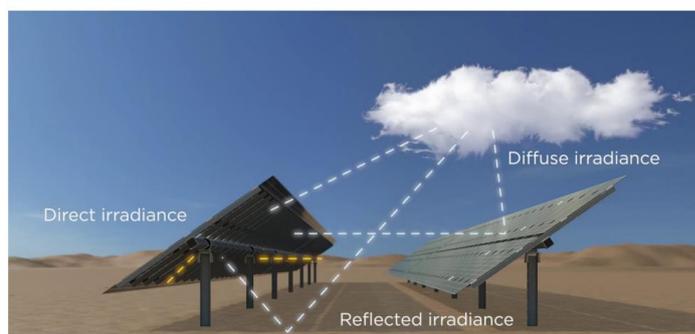
Figure 10: Bifaciality principles (Source: [2])

5.3.3.2. Mismatch losses:

Solar cells, as previously seen, have a maximum current they can withstand. Therefore, when building cell strings and connecting the cells in series, just one current will be the only one in the equivalent circuit. Namely, if two cells connected in series have a different I_{max}, the lowest one is the string determinative maximum current.

A manufacturer builds a panel connecting its cells in series or parallel depending on the main properties he or she wishes to equip it with.

5.3.3.3. LID loss factor:

LID (Light Induced Degradation) losses are due to the degradation of crystalline silicon modules in the first operating hours with respect to the manufacturing flash test STC (standard conditions) values.

5.3.3.4. Module quality:

Deviation of the average effective module efficiency with respect to manufacturer specifications.

5.3.3.5. IAM losses:

Losses due to the panels' inclination.
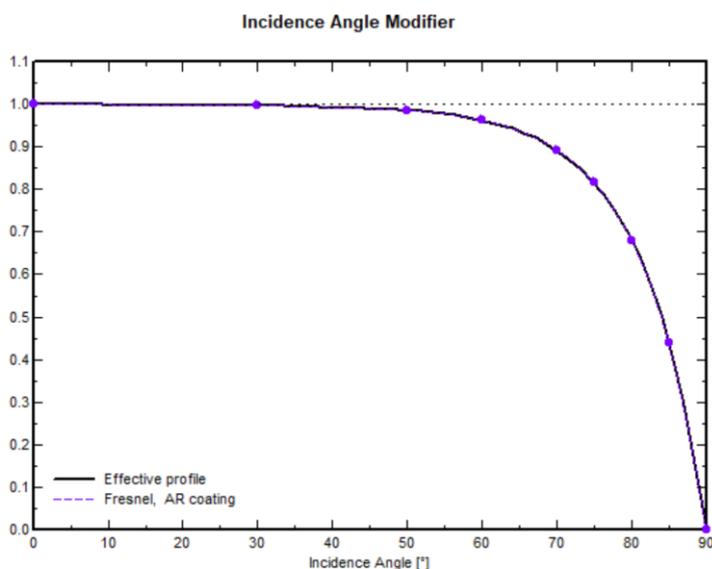
Figure 11: IAM-incidence angle curve (Source: PVSyst)

5.3.3.6. Backtracking:

Solar backtracking is a tracking control program that aims to minimize panel-on-panel shading, thus minimizing possible production losses.

6. The inverter:

As has already been mentioned, the panel generates a DC voltage. Yet, the power must be injected into an AC grid. In order to do so, the inverter converts the DC voltage into a three-phase AC voltage.

As for the model to be chosen, its nominal power must be similar to the plant's peak power to avoid overload losses due to undersizing or a P_p/P_n ratio smaller than 1 due to oversizing. As this Project consists of a high-power plant, more than one inverter is needed. All of them will be connected in parallel. The connecting structure will be similar to the one below in *Figure 12*.
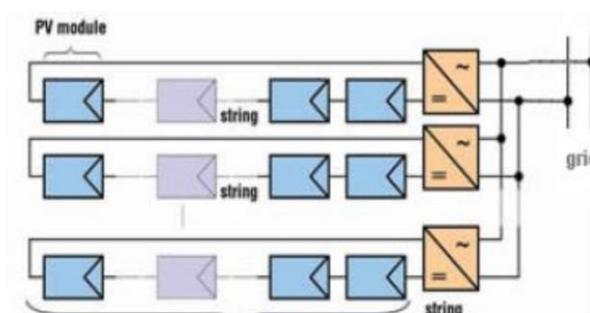
Figure 12: Connection of strings to the inverters' DC ports (Source: [8])

7. Panel support structures:

7.1. Fixed-tilt structure:

This structure does not follow the motion of the sun. As a consequence, there are times during the day when the energy generated is excessively low due to considerable shadings.
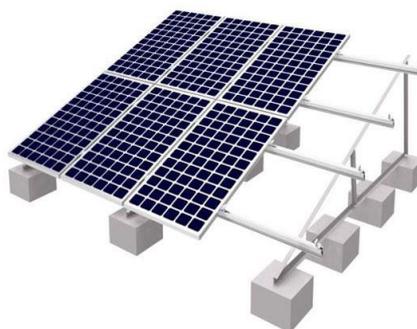
Figure 13: Fixed-tilt structure (Source: [22])

7.2. Single-axis tracker:

A single-axis tracker is the simplest tracking system and the most profitable given it follows the motion of the sun on just one axis (North-South), hence maximizing energy production and optimizing the power plant's efficiency. Furthermore, its price and energy-optimizing ease make it the most market-competitive among others.

Figure 14: Single-axis tracker (Source: [1])

7.3. Dual-axis tracker:

A dual-axis tracker has a North-South and an East-West axis which both enable it not only to follow the sun but correct the modules' orientation to absorb the maximum amount of solar irradiance perpendicularly to its surface. This feature makes this tracker the most competitive in terms of efficiency. Nevertheless, its cost is much higher than others, thus not being the most profitable one.

Figure 15: Dual-axis tracker (Source: [1])

8. Grid interconnections:

Once the solar energy has gone through the inverter it needs to be injected into a power system. Namely, a substation. The inverter has an LV output voltage which needs to be transformed into an appropriate grid voltage. The following transformations are the ones to be undergone in this process:

-LV to MV

-MV to HV (substation voltage)

The number of transformers will be the one that withstands the power flow. All of them will be connected in parallel.

Moreover, with respect to the lines, HV lines must be considerably longer than MV lines given that the lower the voltage, the bigger the losses. Consequently, most of the interconnection system needs to be HV. As for the line elements, they can be made from copper or aluminum. Copper is more conductive, yet heavier than aluminum. For this reason, aluminum is more attractive to manufacturers due to its cheaper transportation costs.
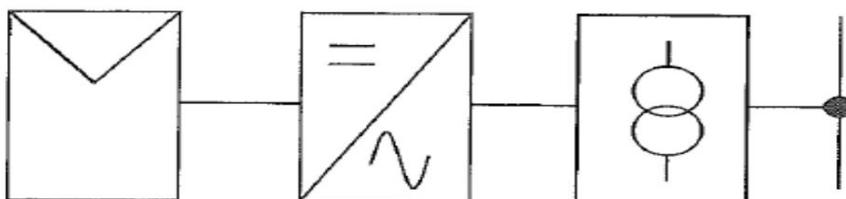
Figure 16: Simplified block diagram for the plant (Source: [8])- From left to right: GENERATION-INVERSION-TRANSFORMATION-INJECTION

9. Project - TECHNICAL LAYER:

All of the above is meant to provide insight into how the project at hand should be tackled. From this part on, project results will be exposed as well as the steps taken to deliver them.

9.1. Initial constraints for site selection:

- Peak power: 30-50 MWp (50 MWp is the value of the peak power)

- Area: Maximum 2 hectares/MWp

- Local slopes: Maximum 10%

- Proximity to a substation: Maximum 20 km radius

- The site should be out of any protected area

- Easy accessibility: There should be roads nearby. Otherwise, transportation and civil work costs might increase.

- Solar irradiation should be considerable. Namely, GHI (*Global Horizontal Irradiance*) values must be as high as possible. To that effect, a site in the province of Ciudad Real is advisable.

9.2. Site:

9.2.1. Location, surroundings, and ground properties:

Considering the constraints above, the location of the site has the following coordinates also stated in the introduction of this document:

- Longitude: -2.865427°
- Latitude: 39.161530°

The area is 65 hectares approximately (approximately 1.3 hectares/MWp) with less than 4% local slopes and is next to the A-43 highway without trespassing any protected area.

Tomelloso is the nearest town in the province of Ciudad Real and the nearest interconnection point is the 132 kV substation of Riega (11.4 km radius).

Figure 17: Solar plant location, height: 26.68 km (Source: Google Earth Pro)

9.2.2. <u>Physical data:</u>

The following figures and table show the physical data of interest for the Project.

- **Monthly global and diffuse radiations graph:**
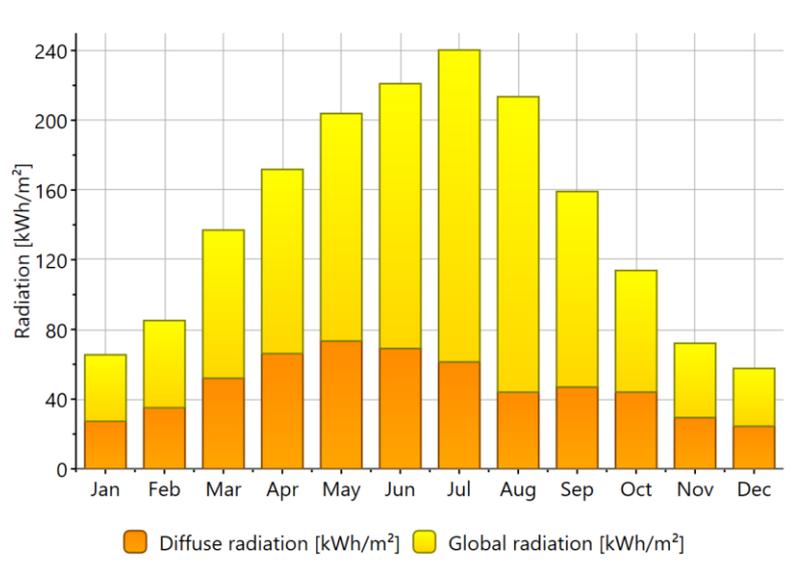
Figure 18: Monthly global and diffuse radiations (kWh/m^2) (Source: Meteonorm)

- **Monthly sunshine graph:**
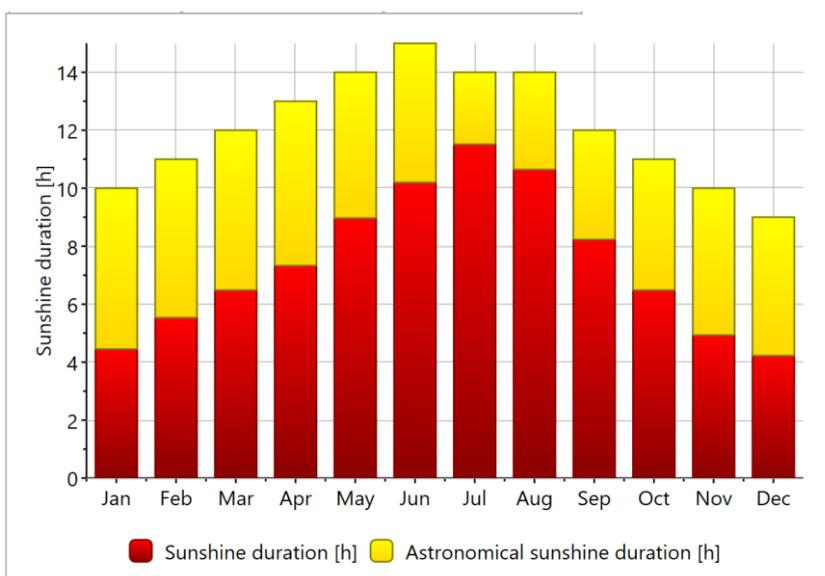
Figure 19: Monthly sunshine graph (Source: Meteonorm)

- **Daily global radiation graph:**
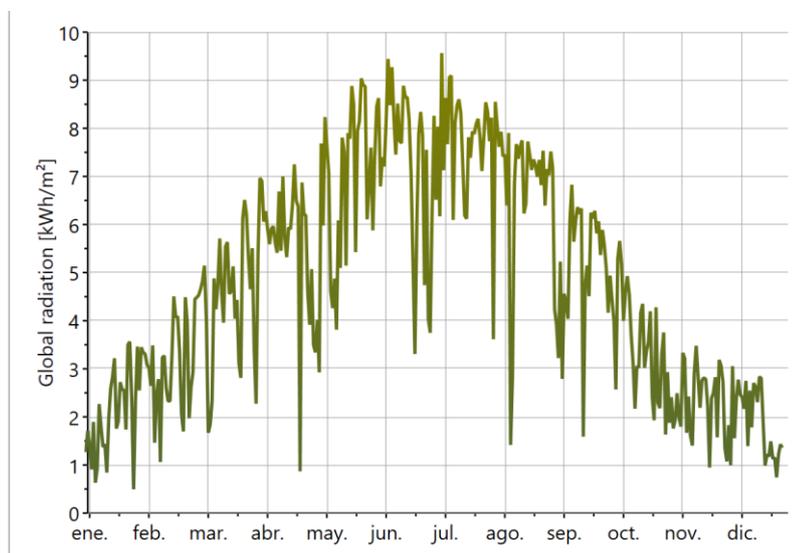
Figure 20: Daily global radiation (kWh/m^2) (Source: Meteonorm)

- **Monthly temperature-estimation boxplot diagram:**
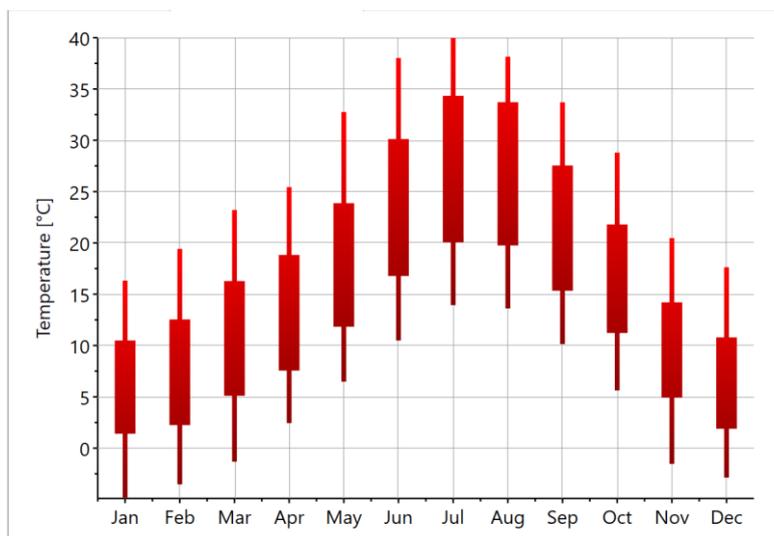
Figure 21: Monthly temperature-estimation boxplot diagram (Source: Meteonorm)

- **Maximum and minimum daily temperature graph:**
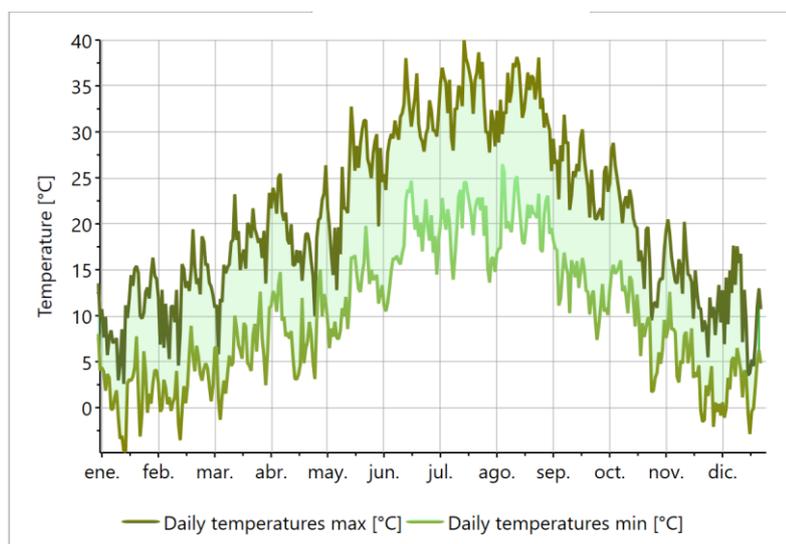
Figure 22: Maximum and minimum daily temperature graph (Source: Meteonorm)

- **Monthly precipitation graphs:**
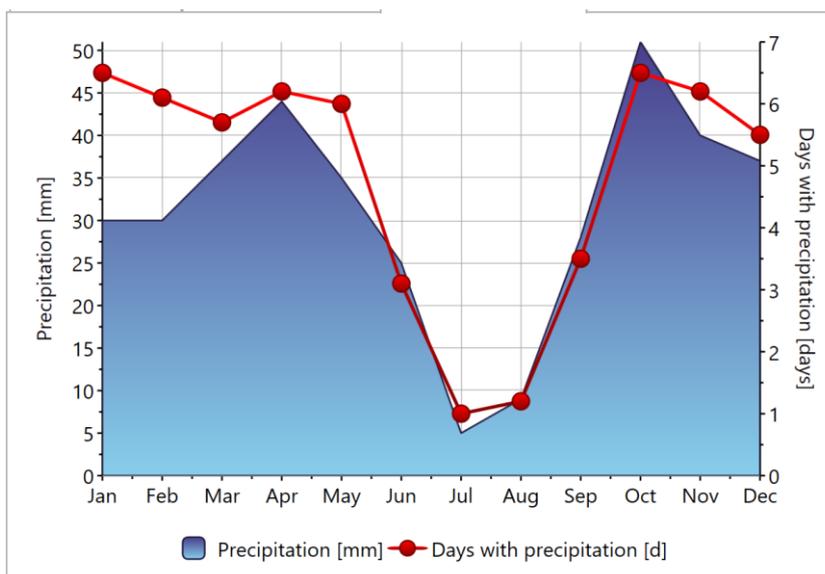
Figure 23: In blue: Precipitation mm per month. In red: Days with precipitation per month (Source: Meteonorm)

- **Monthly solar data**

	GHI (kWh/m²)	DHI (kWh/m²)	Bn (kWh/m²)	Ta (ºC)	Td (ºC)	W (m/s)
January	65	27	101	5.7	1.9	2.9
February	85	35	109	7.3	1.7	3.3
March	137	52	156	10.5	3.4	3.4
April	172	66	174	13.4	5.9	3.2
May	204	73	203	17.8	7.7	2.9
June	221	69	229	23.6	9.3	3
July	240	61	269	26.9	10.2	3
August	214	44	264	26.3	11	2.9
September	159	47	195	21.4	10.5	2.7
October	114	44	140	16.1	9.2	2.5
November	72	29	107	9.4	4.7	2.8
December	58	24	95	6.2	2.9	2.7
Year	**1741**	**571**	**2042**	**15.4**	**6.5**	**2.9**

Table 1: Monthly solar data I (Source: Meteonorm)

Where:

- GHI is the Global Horizontal Irradiance
- DHI is the Diffuse Horizontal Irradiance
- Bn is the Direct Horizontal Irradiance
- Ta is the ambient temperature
- Td is the dewpoint temperature
- W is the wind speed

Among the six types of data, from left to right, in the "Year" row, the first three are a sum of their respective columns, while the three last are an arithmetic average.

	GHI (kWh/m^2)	Ta (ºC)	W (m/s)
January	70.27	4.5	2.59
February	89.58	6.05	2.74
March	139.12	9.15	2.83
April	167.33	11.81	2.8
May	204.09	16.49	2.57
June	223.03	22.28	2.47
July	234.09	26.01	2.48
August	204.3	25.77	2.44
September	153.51	20.89	2.42
October	108.95	14.98	2.54
November	72.87	8.87	2.65
December	61.66	5.65	2.62
Year	**1729**	**14.37**	**2.59**

Table 2: Monthly solar data II (Source: NASA, Own elaboration)

Among the three types of data, from left to right, in the "Year" row, the first column is a sum of all its data, while the two last are an arithmetic average.

As to what base is more accurate to introduce the data in PVSyst software, Meteonorm may well be more appropriate given that the site is in Europe and Meteonorm's developer is European as well. Nevertheless, to select the most appropriate base, we must analyze the GHI data:

- Meteonorm: 1741 kWh/m^2
- NASA: 1729 kWh/m^2

The values slightly differ between themselves, therefore being of no consequence the fact of selecting one base or the other. Nonetheless, since Meteonorm is the most optimistic one, we will choose it according to this criterion.

The following graphs offer a visual approach of the GHI.
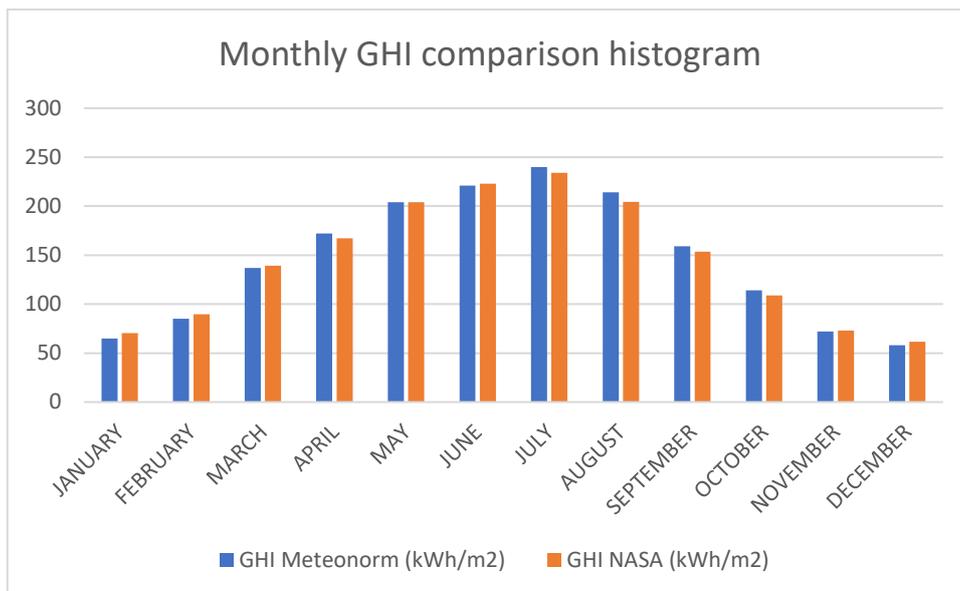
Figure 24: Monthly GHI comparison histogram for Meteonorm and NASA databases (Source: Own elaboration)
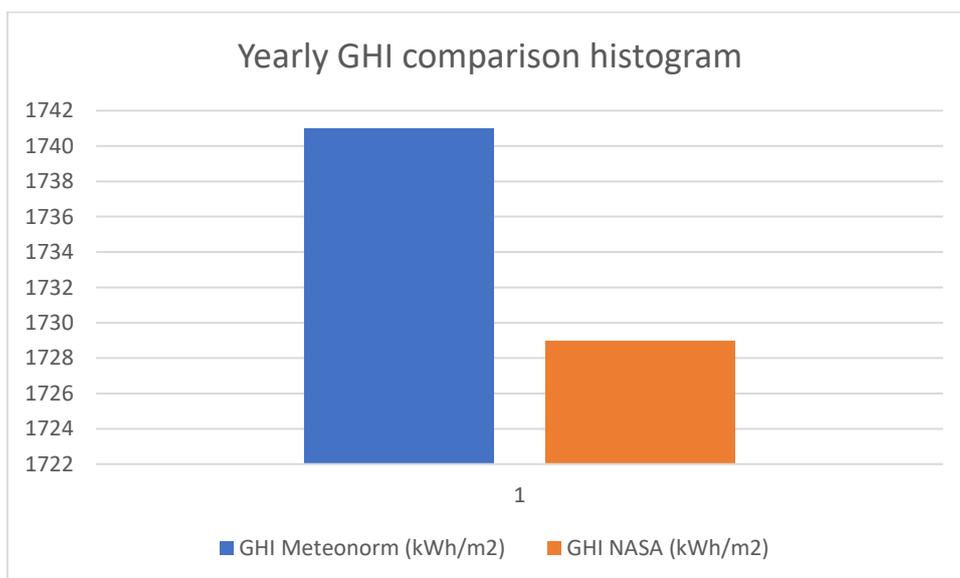
Figure 25: Yearly GHI comparison histogram for Meteonorm and NASA databases (Source: Own elaboration)

	GHI (kWh/m^2)	DHI (kWh/m^2)	Ta (ºC)	W (m/s)
January	64.7	27.4	5.1	2.8
February	83.9	32.9	6.7	3.29
March	136.1	49.8	10.3	3.4
April	171.8	57.6	13.2	3.2
May	204.6	71.4	18	2.91
June	220.7	66.6	23.8	3
July	238.1	62.2	27.8	3
August	212.3	51.9	27.1	2.89
September	158.6	46.8	21.4	2.7
October	113.8	43	16.2	2.5
November	71.8	28.1	8.9	2.79
December	57.3	27.3	5.6	2.69
Year	**1734**	**565**	**15.3**	**2.93**

Table 3: Monthly solar data III (Source: Meteonorm from PVSyst, Own elaboration)

9.3. PVSyst simulation:

PVSyst is a solar energy software designed to simulate photovoltaic systems. It has been developed by the University of Geneva for this purpose. In the project at hand, it enables the user to simulate different elements, such as panels and inverters, whose main data are uploaded to the program database, in different scenarios. To that effect, multiple combinations of elements allow the most accurate optimization.

Moreover, system losses and tracker dimensioning can also be analyzed to obtain optimal results.

In order to carry out the simulation, a concise analysis of solar irradiance data in different databases has to be previously conducted to select the most appropriate base. PVSyst software is able to connect to these databases and extract the necessary information. However, the data from a PVSyst extraction, if compared to the data extracted directly by the user from the same base, might well differ although within an acceptable range due to differences in the period taken.

9.3.1. Component selection:

One of the main aims of this project is to design a solar plant with the maximum peak power possible. In this case 50.00 MWp. As a consequence, all the components (panels, trackers, inverters, and grid connection systems) must be selected in order to cover the nominal and peak powers.

Variations on the P_p/P_n ratio and the E-W pitch shall be done to choose the most appropriate components to comply with the statements above.

9.3.1.1. __Panels and array:__

All the modules will be bifacial to take advantage of the energy produced thanks to the albedo effect. Moreover, reaching the maximum possible peak power was set as an aim for this project.

The following table shows multiple options considered:

Model	Power (W)	Number of modules (per string)	Number of strings	Assigned plant's peak power (MW)	Required area (m^2)
LR5-72 HBD 530 M Bifacial (Longi Solar)	530	27	3494	50	241132
LR5-72 HBD 525 M Bifacial (Longi Solar)	525	27	3527	50	243479
LR5-72 HBD 525 M Bifacial (Longi Solar)	520	27	3561	50	245825

Table 4: Decision table for module selection (Source: Own elaboration)

Given that the first option requires the less amount of area, the model 'LR5-72 HBD 530 M Bifacial (Longi Solar)' will be the one selected. What follows is the categorization of this panel and array models:

- Panels:

  - Model: LR5-72 HBD 530 M Bifacial
  - Manufacturer: Longi Solar
  - Nominal power: 530 W (at STC)
  - Technology: monocrystalline silicon

  - Reference conditions: Gref = 1000 W/m^2
  - Reference Temperature: T$_{ref}$ = 25ºC

  - Short-circuit current: I$_{sc}$ = 13.710 A
  - Open-circuit voltage: V$_{oc}$ = 49.20 V
  - Maximum power output: P$_{max}$ = 531.1 W; with V$_{mpp}$ = 41.35 V and I$_{mpp}$ = 12.820 A; FF = 0.7874

  - Number of cells in series: 72 x 2 (in parallel as cells are bifacial)
  - Cell area: 165.1 cm^2
  - One Module Length: 2256 mm
  - One Module Width: 1133 mm
  - One Module Thickness: 35.0 mm
  - One Module Area: 2.556 m^2
  - One Module Weight: 32.30 kg

PV module: Longi Solar, LR5-72 HBD 530 M Bifacial
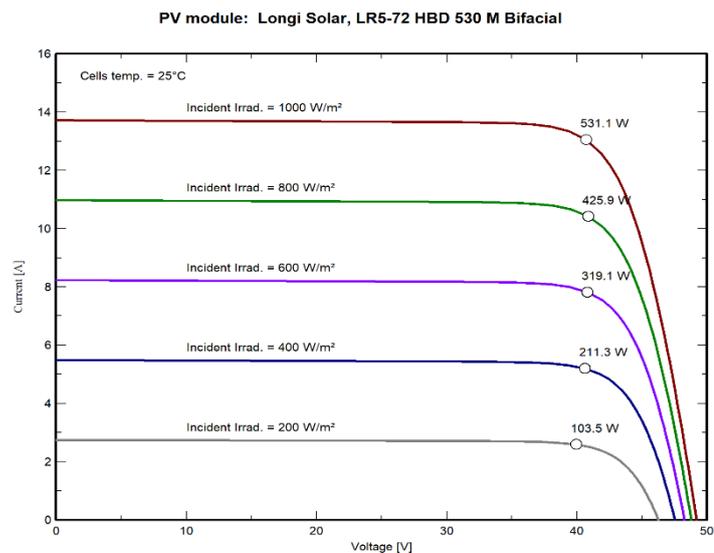
Figure 26: I-V curves of a PV module for different irradiance values at 25ºC (Source: PVSyst)

PV module: Longi Solar, LR5-72 HBD 530 M Bifacial
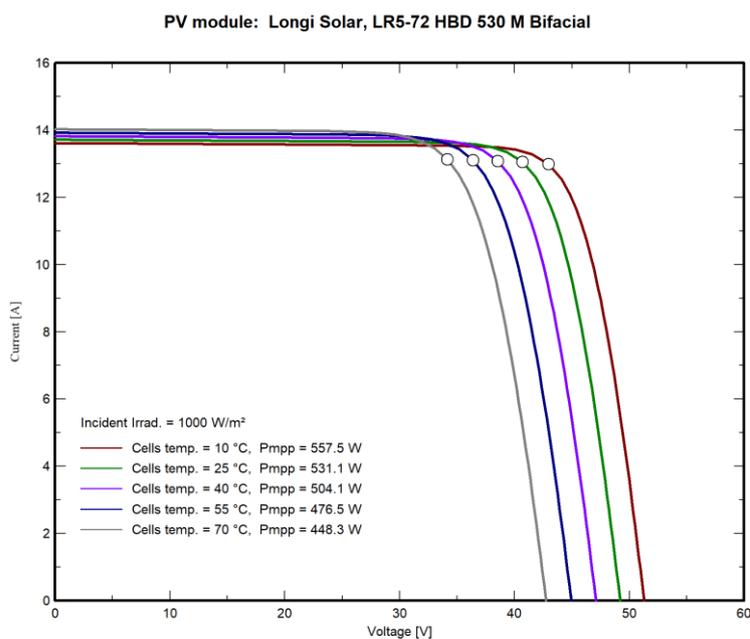
Figure 27: I-V curves of a PV module for different temperature values with 1000 W/m² irradiance (Source: PVSyst)

- Array:

  - Modules in series per string: 27
  - Number of strings: 3494
  - Total number of modules: 94338
  - Module area: 241132 m²

  - Nominal power: 49999 kW (at STC)

- Overload loss: 0.0%
- Module efficiency loss: -3.0%
- Module mismatch loss: 2.0%
- Strings voltage mismatch loss: 0.1%
- LID loss factor: 1.5%
- Soiling loss factor: 2.0%
- IAM losses: 1.03%

- I_{mpp} (STC) = 45708 A
- V_{mpp} (60ºC) = 962 V
- V_{mpp} (20ºC) = 1119 V

- V_{oc} (-10ºC) = 1458 V
- I_{sc} (STC) = 47903 A

9.3.1.2. Inverters:

In order to drive all the energy produced by the panels to the electrical injection system, the inverters need to have a nominal power that withstands 50 MWp. One around 48 MW is reasonable as the inversion stage is neither oversized nor undersized. The following table shows the options considered.

Model	Power (kW)	Number of MPPT's (half an inverter)	Inverter loss during operation (%)	Pp/Pn ratio
SIEMENS Sinacon PV4800	4800	20	1.20%	1.042
WSTECH GmbH APS4800-PV-4-660-5	4800	20	1.20%	1.042
WSTECH GmbH APS4360-PV-4-600-5	4360	22	1.31%	1.043

Table 5: Decision table for inverter selection (Source: Own elaboration)

Considering a ratio of around 1.04 (48 MW nominal power with 50 MW peak power), the options for the inverter selection above met the requirements. 'WSTECH GmbH APS4360-PV-4-600-5' can automatically be discarded as there is a need for more inverters and more losses are present during the operation than in the other two cases. The final decision was to select 'SIEMENS Sinacon PV4800' as fewer operation losses exist, and fewer inverters are needed. Yet, 'WSTECH GmbH APS4800-PV-4-660-5' could have been selected instead for the exact same reasons since the parameters evaluated are the same in both cases.

What follows is the categorization of the inverter selected:

- Number of inverters: 10

- Model: Sinacon PV4800
- Manufacturer: Siemens

- Minimum V_{mpp} = 962 V (input side – DC)
- Maximum V_{mpp} = 1500 V (input side – DC)

- If we compare these voltage values with the ones in the array, we can certainly state that the inverter is appropriately designed to withstand the array's voltage.

- Nominal input power: 4836 kW
- Maximum PV power: 9600 kW (DC- input)

- Grid voltage: 660 V (AC-output)

- Nominal AC output power: 4800 kVA

- Maximum efficiency: 98.92%

- Width: 3503 mm
- Depth: 1142 mm
- Height: 3734 mm
- Weight: 3900 kg
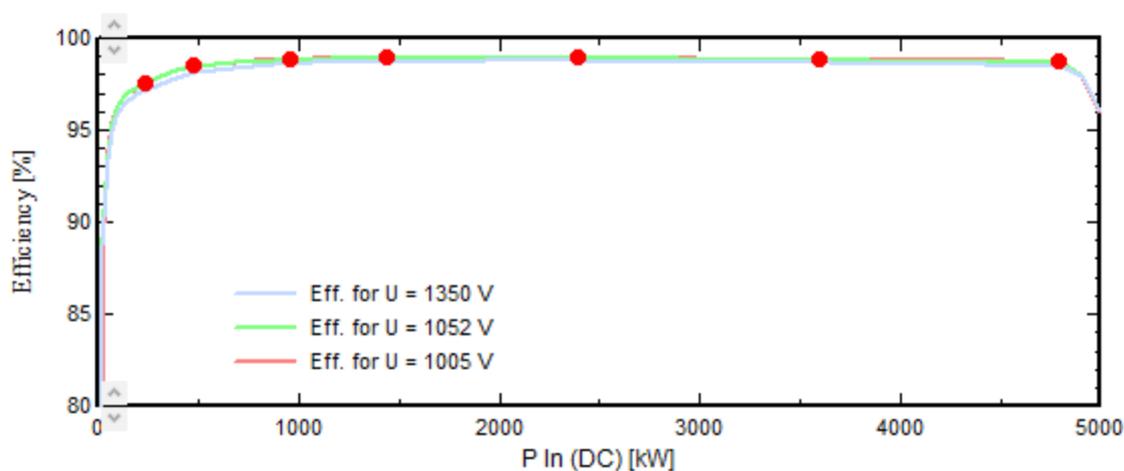
Figure 28: Efficiency-Input Power curve for the inverter (Source: PVSyst)
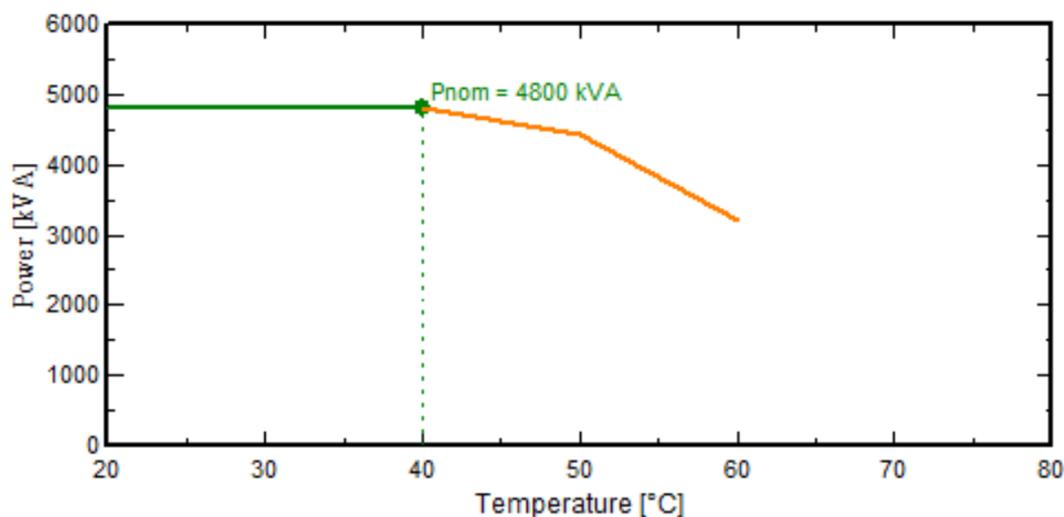
Figure 29: Apparent Power-Temperature curve for the inverter (Source: PVSyst)

As it happens with an increasing temperature in the panels, the output power decreases in the inverter as well.

9.3.1.3. **Trackers:**

Two tracker-model options were considered:

- SOLTEC "SF8 SINGLE AXIS TRACKER" (4-6 strings/tracker)
- IDEEMATEC 'SafeTrack H4plus bifacial' (up to 360 modules/tracker)

	Maximum capacity	strings	modules	Number of trackers
SOLTEC	6 strings/tracker	3494		583
IDEEMATEC	360 modules/tracker		94338	263

Table 6: Decision table for tracker selection (Source: Own elaboration)

In light of the results in *Table 6,* IDEEMATEC is more profitable than SOLTEC as fewer trackers are required. However, when running simulations, 263 IDEEMATEC trackers did not cover the minimum required area for our plant. Therefore, the number of trackers had to be increased to 295 in order to meet this requirement.

Furthermore, the E-W pitch had also to be taken into account. In order to select it in an interval between 10 and 12 meters, the following selection table was elaborated:

E-W pitch (m)	Energy delivered (GWh)	Performance ratio (%)	GCR (%)	Near shadings losses (%)
10	95.2	83.20%	44.20%	1.81%
11	98.9	85.20%	40.20%	1.75%
12	99.9	85.32%	36.80%	1.69%

Table 7: Decision table for pitch selection (Source: Own elaboration)

In light of these last results, the greater the pitch, the bigger the energy delivered to the grid, since GCR (*Ground Coverage Ratio*) and near shading losses decrease. Therefore, a 12-meter pitch is the most appropriate option even though this might require a larger amount of area.

Having chosen the previous features, the trackers' characteristics are the following:

- Sensitive area:

  - Shed area: 242525 m^2
  - Required area: 241132 m^2
  - Table area: 822.12 m^2
  - Length: 186 m
  - Width: 4.42 m

- Tracking parameters:

- Model: SafeTrack H4plus bifacial (single-axis tracker)
- Manufacturer: Ideematec
- Number of trackers: 295
- Pitch E-W: 12 m
- Backtracking activated
- Rotating limits: -/+ 55º

9.3.1.4. Electrical grid-injection system design overview:

9.3.1.4.1.   MV lines design:

Sección (mm²)	EPR		XLPE		HEPR	
	Cu	Al	Cu	Al	Cu	Al
25	125	96	130	100	135	105
35	145	115	155	120	160	125
50	175	135	180	140	190	145
70	215	165	225	170	235	180
95	255	200	265	205	280	215
120	290	225	300	235	320	245
150	325	255	340	260	360	275
185	370	285	380	295	405	315
240	425	335	440	345	470	365
300	480	375	490	390	530	410
400	540	430	560	445	600	470

Table 8: Maximum allowed currents (A) in steady state and AC for underground insulated unipolar cables with 18/30 kV maximum grid voltages (Source: [21])

First and foremost, when designing high voltage lines, the parameter to consider is the maximum current through it without taking into account voltage drops. These are relevant in lower voltage levels.

The following table shows some options considered. The criterion followed for this selection is mainly economic, since building a line tends to be expensive. Hence, the minimum number of lines with the minimum wire section is the most appropriate for designing the MV system. Furthermore, the material used not only for MV lines but also for all the others will be aluminum as it is lighter than copper despite being less conductive.

Number of lines	Minimum wire section (mm²)	Current (A)
1	1200	1422
2	700	711
3	400	474
4	300	356

Table 9: Selection table for MV cables (Source: Own elaboration)

Options 1 and 2 must be discarded as their minimum section does not comply with *Table 8*. Moreover, option 3 cannot be implemented as the maximum current is greater than the maximum allowed values.

Therefore, the most suitable option is 4 MV lines, 300 mm² wire section each. The insulation will be XLPE-type (*Cross-Linked Polyethylene*).

The manufacturer and model will be: 'Eland Cables', 'YMz1Krvasdlwd-AL 12/20kV Cable'.

9.3.1.4.2. MV/LV transformers design:

Two options were considered to design the MV transformers. The following table shows them:

	MV Skid Compact	Twin Skid Compact
Minimum power at 40ºC (kVA)	1525	3050
Maximum power at 40ºC (kVA)	4390	8780
Minimum power at 50ºC (kVA)	1415	2830
Maximum power at 50ºC (kVA)	4075	8150
Required apparent power (kVA)	49261	49261
Minimum number of transformers for every option	33	17
	12	6
	35	18
	13	7

Table 10: Selection table for MV/LV transformers (Source: Own elaboration)

The 'Twin Skid Compact' model requires fewer transformers than its counterpart. However, in order to choose it is necessary to consider the least favorable case. Namely, at least 18 transformers.

Since the power flow should be as uniform as possible and all the transformers need to withstand a limited power, considering that we have 4 MV lines, thus requiring 4 transformation centers, 20 MV/LV transformers are needed.

9.3.1.4.3. Connection of elements:

- Number of strings: 3494
- Number of inverters: 10

For every inverter, 349 strings must be connected to them. Among these 10 inverters, 4 will host 350 strings instead of 349.

All the inverters, as their output voltage is the same (660 V at STC), will be connected to a single bar that will be connected to 4 MV/LV transformation centers composed of 5 transformers each.

On the MV side, the 4 lines previously designed will go to a connection bar to a HV/MV transformation center. A line will go from the HV side to the substation for energy injection.

9.3.1.4.4. **Electrical design results:**

- LV lines (per inverter):

  - Voltage: 660 V
  - Length: 9.2 m x 10 inverters
  - Loss fraction at STC: 0.08%
  - Wire section: 4000 mm^2
  - Material: Aluminum

- MV Lines:

  - Voltage: 20 kV
  - Length: 1000 m x 4 lines
  - Loss fraction at STC: 0.32%
  - Wire section: 300 mm^2
  - Material: Aluminum
  - Covering: XLPE
  - Manufacturer: 'Eland Cables'
  - Model: 'YMz1Krvasdlwd-AL 12/20kV Cable'

- HV Line:

  - Voltage: 132 kV
  - Length: 10400 m
  - Loss fraction at STC: 0.50%
  - Wire section: 185 mm^2
  - Material: Aluminum

- MV/LV Transformation stage:

  - Number of transformation centers: 4
  - Number of transformers per center: 5
  - Vector group: Dy11y11
  - Voltages: 20 kV/660 V
  - Nominal apparent power at STC: 49261 kVA (12315 kVA/center)
  - Iron loss: 0.20%
  - Copper loss: 0.80% at STC
  - Transformer manufacturer: 'Power Electronics'
  - Model: 'Twin Skid Compact'

- HV/MV Transformation stage:

  - Number of transformation centers: 1
  - Voltages: 132/20 kV
  - Nominal apparent power at STC: 52000 kVA

- Iron loss: 0.10%
- Copper loss: 0.22% at STC

9.3.2. Plant global overview:
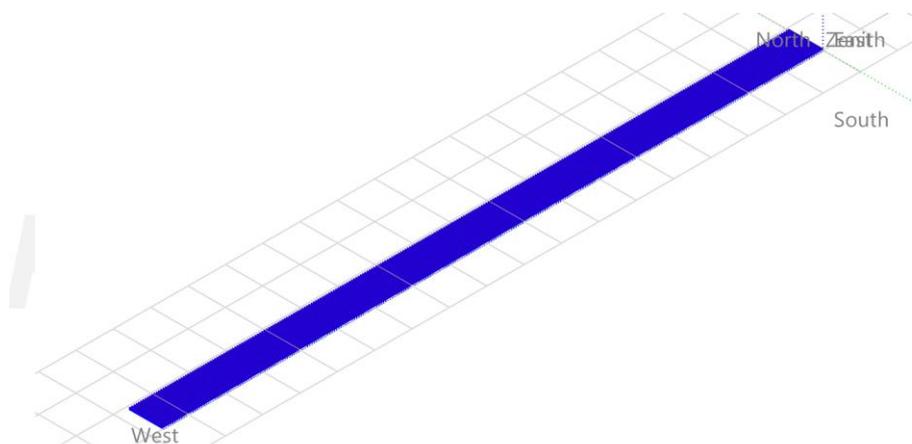
Figure 30: Perspective of the PV-field and surrounding shading scene (Source: PVSyst)

The solar plant's physical dimensions are 186 m in width and 3528 m in length which makes a total area of 65.6 hectares.
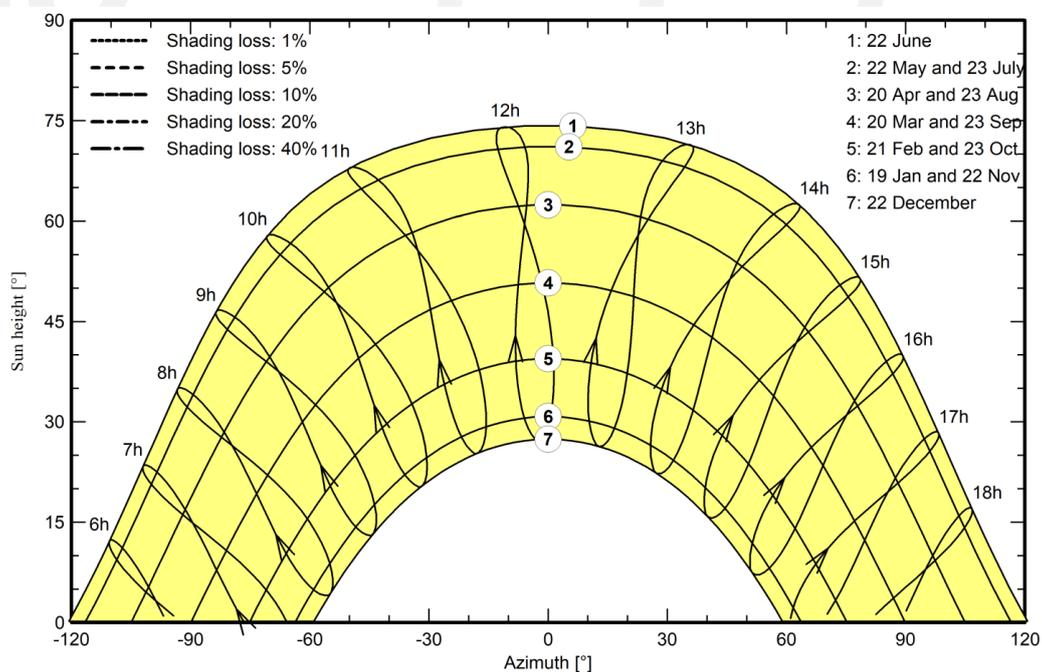
Figure 31: Shadings Diagram (Source: PVSyst)

Almost no shadings are visible given that the terrain has low local slopes. Moreover, we can appreciate the sun is higher in the middle of the year than at the beginning and the end of it.

Loss diagram

1733 kWh/m²		**Global horizontal irradiation**
	+35.2%	**Global incident in coll. plane**
	-1.69%	Near Shadings: irradiance loss
	-0.87%	IAM factor on global
	-2.00%	Soiling loss factor
	+0.32%	Ground reflection on front side
		Bifacial
		Global incident on ground
		889 kWh/m² on 654658 m²
	-85.00% (0.15 Gnd. albedo)	Ground reflection loss
	-81.00%	View Factor for rear side
	+31.13%	Sky diffuse on the rear side
	+0.00%	Beam effective on the rear side
	-7.00%	Shadings loss on rear side
	3.74%	Global Irradiance on rear side (84 kWh/m²)
2245 kWh/m² * 241132 m² coll.		**Effective irradiation on collectors**
efficiency at STC = 20.78%		PV conversion, Bifaciality factor = 0.70
115.4 GWh		**Array nominal energy (at STC effic.)**
	-0.22%	Module Degradation Loss (for year #1)
	-0.19%	PV loss due to irradiance level
	-5.22%	PV loss due to temperature
	+0.30%	Module quality loss
	-1.50%	LID - Light induced degradation
	-2.10%	Mismatch loss, modules and strings
	-0.37%	Mismatch for back irradiance
	-0.78%	Ohmic wiring loss
104.1 GWh		**Array virtual energy at MPP**
	-1.20%	Inverter Loss during operation (efficiency)
	-0.01%	Inverter Loss over nominal inv. power
	0.00%	Inverter Loss due to max. input current
	0.00%	Inverter Loss over nominal inv. voltage
	0.00%	Inverter Loss due to power threshold
	-0.08%	Inverter Loss due to voltage threshold
	-0.01%	Night consumption
102.8 GWh		**Available Energy at Inverter Output**
	-0.30%	Auxiliaries (fans, other)
	-0.05%	AC ohmic loss
	-1.37%	Medium voltage transfo loss
	-0.22%	MV line ohmic loss
	-0.58%	High voltage transfo loss
	-0.34%	HV line ohmic loss
99.9 GWh		**Energy injected into grid**

Figure 32: Plant's Sankey Diagram for year 1 (Source: PVSyst)

For year 1, the results shown below are the ones that best summarize the plant's production and efficiency which will decrease each year.

- Energy produced: 99.9 GWh
- Specific production: 1998 kWh/kWp
- Performance ratio: 85.27%

The following table shows the previous results for year 1 and an estimation for the next 29 years. The first 4 years are the results of a simulation while the rest is an estimation for the following years through the Excel program. Furthermore, the last data were compared to a simulation for year 30 and the error resulted to be between 2.0% and 2.6% depending on the variable, making our estimations reliable and acceptable (*criterion*: acceptable if the error is less than 5.0%)

Year	Total energy production (GWh)
1	99.9
2	99.5
3	99.0
4	98.6
5	98.2
6	97.7
7	97.3
8	96.8
9	96.4
10	95.9
11	95.5
12	95.1
13	94.6
14	94.2
15	93.8
16	93.3
17	92.9
18	92.4
19	92.0
20	91.6
21	91.1
22	90.7
23	90.2
24	89.8
25	89.4
26	88.9
27	88.5
28	88.0
29	87.6
30	87.2

Table 11: Yearly energy production table (Source: Own elaboration)

Yearly energy production (GWh)
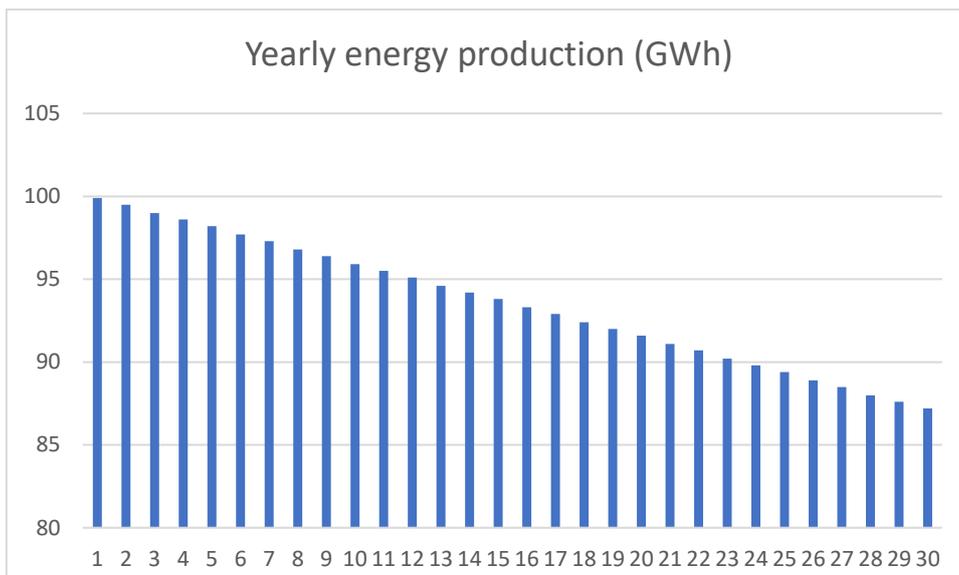
Figure 33: Yearly energy production histogram (Source: Own elaboration)

9.4. Savings on CO_2:
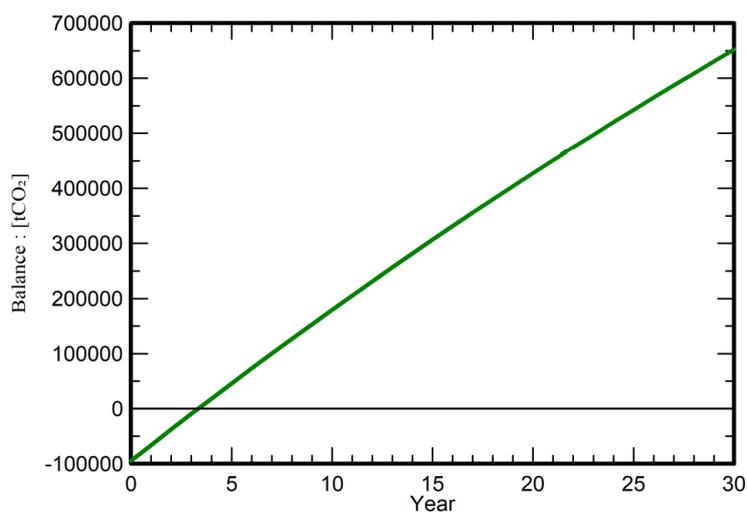
Figure 34: CO_2 saved in a 30-year lifetime (Source: PVSyst)

As the graph above shows, when doing the initial investment, 100,000 tCO_2 are emitted. It is, nonetheless, after the 3rd functioning year that there is a positive net CO_2 saving balance, reaching 650,000 tCO_2 in the 30th year.

9.5. Conclusions:

Bifacial panels present a significantly higher amount of absorbed irradiance than conventional ones. Absorbed irradiance on the rear side makes up 51.3% of the global horizontal irradiation value. Nevertheless, efficiency at STC is only around 21%. This means most of the energy is transformed into heat. However, if compared to the best panels' efficiency, 26%, it is an acceptable value (*Source: [16]*).

10. Project – ECONOMIC LAYER:

This part consists of evaluating the profitability or non-profitability of the project. For this, the NPV (*Net Present Value*) indicator, if it is greater than 0 it will mean the project is profitable, however, if this indicator is a negative value, the project should not see the light given that in all likelihood losing money is inevitable.

$$NPV = -Io + \sum_{i=1}^{n} \frac{CFi}{(1+k)^i}$$

Formula 5: NPV formula (Source: [13])

Where:

- I_o is the initial investment
- CF_i is the cash flow for the ith year
- k is the WACC (*Weighted Average Cost of Capital*)
- n is the number of years

Another way to evaluate the profitability of a project is through its IRR (*Internal Rate of Return*). If the IRR is greater than the WACC, the project will be profitable. On the contrary, if it is less than the WACC, it should not see the light.

Moreover, before calculating the NPV, calculations of the amortization *A* of the investment for the cash flows are necessary. The following formula is useful to estimate it.

$$A = k * \frac{(1+k)^n}{(1+k)^n - 1} * Io$$

Formula 6: Amortization formula (Source: [13])

Where:

- k is the WACC (*Weighted Average Cost of Capital*)
- n is the project's lifetime
- I_o is the initial investment

10.1. Initial investment:

The initial investment comprehends the purchase of the modules, trackers, and transformation centers (with the inverters as a part of them), as well as the price of the lines, the interconnection, development, and EPC (*Engineering, Procurement and Construction*) costs.

The following table shows the cost of the elements above.

Costs	USD/Wp	EUR/km
Modules	0.26	
Trackers	0.1198	
Transfomation centers and inverters	0.04	
Lines		120,000
Interconnection		
Development		
EPC	0.2567	

Table 12: Investment costs table (Source: Own elaboration)

Where:

- The peak power is 50.00 MWp
- $1 is equivalent to €0.84 (*average 2021: Source: [17]*)

	LV	MV	HV
Number of lines	10	4	1
Unitary length (km)	0.0092	1	10.4
Length (km)	0.092	4	10.4

Table 13: Length of the lines table (Source: Own elaboration)

<u>NOTE:</u> For the lines, the cost is per distance unit and for every 3 electrical phases

The following table shows the calculation of the initial investment I_0.

Costs	Total amount (EUR)
Modules	10,920,000.00
Trackers	5,031,600.00
Transfomation centers and inverters	1,680,000.00
Lines	1,739,040.00
TOTAL AMOUNT MAIN ELEMENTS	**19,370,640.00**
Interconnection	**400,000.00**
Development	**600,000.00**
EPC	**10,781,400.00**
INITIAL INVESTMENT	**31,152,040.00**

Table 14: Calculation of the initial investment table (Source: Own elaboration)

10.2. <u>Yearly amortizations:</u>

Given an initial investment of €31,152,040, the yearly amortizations are calculated with *Formula 6*. Using a WACC of 5% and a 30-year lifetime period, the results are the ones that follow:

WACC	Lifetime period	Amortization (EUR)
5%	30	**2,026,484.91**

Table 15: Amortization table I (Source: Own elaboration)

Amortization years	Final Amortization payment (EUR)
15.37245103	**754,766.38**

Table 16: Amortization table II (Source: Own elaboration)

Considering the results above, the amortization period will be 15 years with €2,026,484.91 and a 16th year when it will be €754,766.38.

10.3. Income:
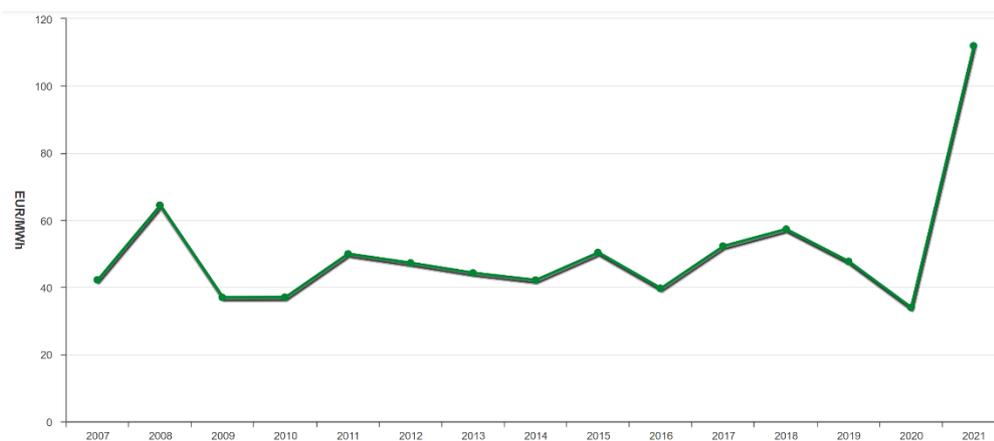
Figure 35: Yearly average price evolution curve for Spain (Source: [14])

Year	Average Price (EUR/MWh)
2007	42.19
2008	64.43
2009	36.96
2010	37.01
2011	49.93
2012	47.23
2013	44.26
2014	42.13
2015	50.32
2016	39.67
2017	52.24
2018	57.29
2019	47.68
2020	33.96
2021	111.93

Table 17: Values for the average price per year in Figure 35 *(Source: Own elaboration)*
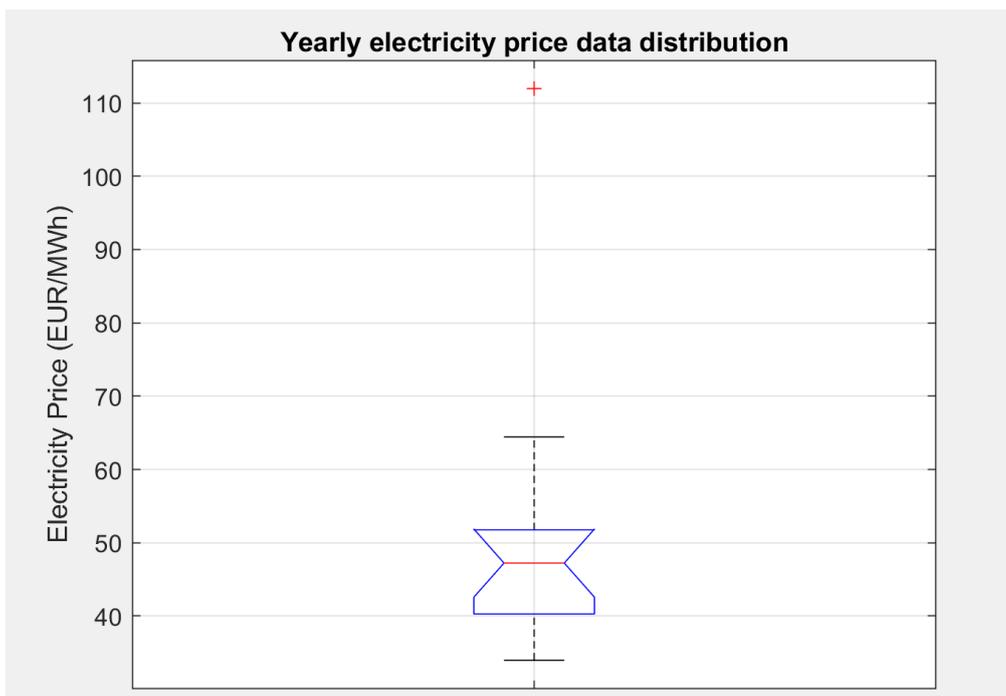
Figure 36: Yearly electricity price boxplot diagram (Source: Own elaboration)

The previous boxplot highlights that the price in 2021 is an outlier. This is due to a lack of primary resources, uncontrolled inflation, and a plan of invasion of Ukraine by the Russian Federation that is currently ongoing, all of which made gas prices skyrocket, therefore making European electricity prices extremely high as most of Europe is dependent on Russian gas. Not to mention that this primary resource is the one that matches the final price in the electricity bills given that it fuels combined cycle plants.

Furthermore, in 2020, all the coal plants were closed in Spain, being a contributing factor to the rise in prices.

As the electricity price in 2021 is an outlier because of an extremely exceptional geopolitical situation, we will estimate our yearly price for year 1 with the average of the prices from 2007 to 2020 with a 1% increase every year as shown respectively in the following table and histograms.

Year	Average Price (EUR/MWh)	Yearly income (EUR)
1	46.09	4,604,676.43
2	46.55	4,632,101.68
3	47.02	4,654,913.03
4	47.49	4,682,466.36
5	47.96	4,710,105.26
6	48.44	4,732,984.28
7	48.93	4,760,742.72
8	49.42	4,783,641.26
9	49.91	4,811,512.89
10	50.41	4,834,422.48
11	50.92	4,862,400.63
12	51.42	4,890,454.90
13	51.94	4,913,390.15
14	52.46	4,941,540.87
15	52.98	4,969,763.26
16	53.51	4,992,704.70
17	54.05	5,021,012.75
18	54.59	5,043,928.89
19	55.13	5,072,314.63
20	55.69	5,100,763.70
21	56.24	5,123,650.32
22	56.80	5,152,165.03
23	57.37	5,175,000.43
24	57.95	5,203,571.94
25	58.53	5,232,197.38
26	59.11	5,254,963.88
27	59.70	5,283,632.69
28	60.30	5,306,319.47
29	60.90	5,335,021.84
30	61.51	5,363,767.62

Table 18: Yearly expected average price and income (Source: Own elaboration)
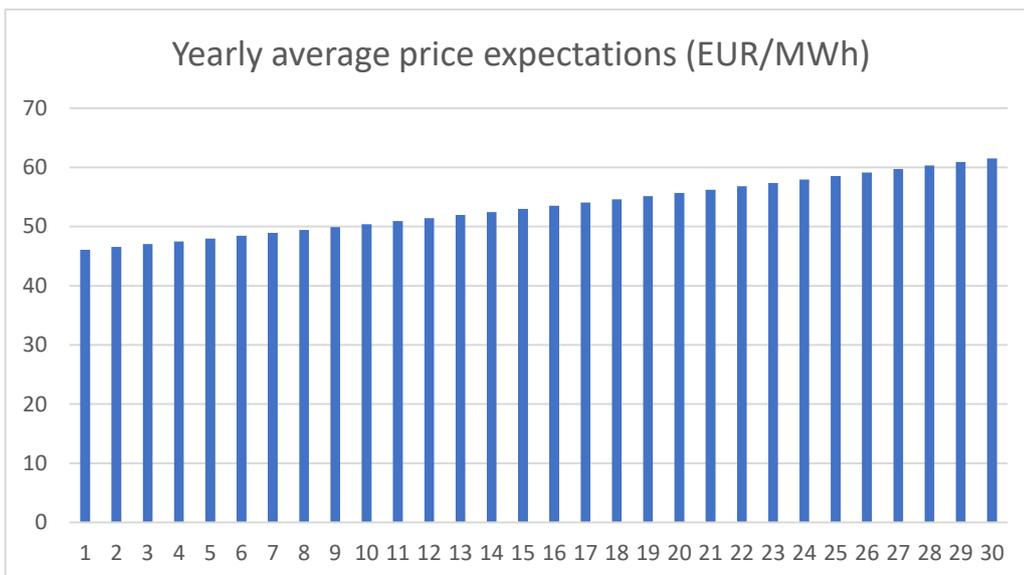
Figure 37: Yearly average price expectations histogram (Source: Own elaboration)
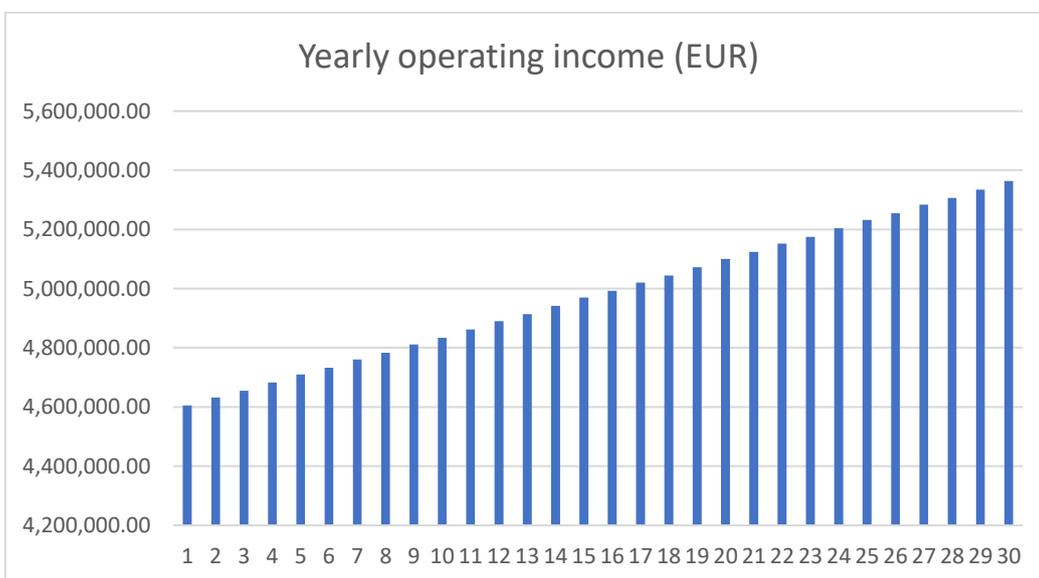
Figure 38: Yearly expected operating income histogram (Source: Own elaboration)

10.4. **Profitability analysis:**

With the Operating Income, O&M (*Operation and Maintenance*) costs *($12/kW estimation)*, the Generation Tax (*7% on income*), the amortizations, the Corporation Tax (*25% on profits*), the initial investment, and the Operating Funds Requirement Investment (*7% on income*), the yearly cash flows are respectively calculated and represented in the following table and histogram.

NOTE: An inflation rate of 1.50% was considered for the calculation of the O&M costs.

Year	Cash flows (EUR)
0	-31,152,040.00
1	3,018,055.69
2	3,029,595.03
3	3,038,154.11
4	3,049,602.44
5	3,061,016.85
6	3,069,355.51
7	3,080,665.73
8	3,088,834.74
9	3,100,031.37
10	3,108,019.92
11	3,119,093.19
12	3,130,116.98
13	3,137,829.88
14	3,148,715.30
15	3,159,544.00
16	2,849,026.07
17	2,671,008.96
18	2,678,193.69
19	2,688,702.67
20	2,699,141.84
21	2,705,979.38
22	2,716,235.70
23	2,722,813.69
24	2,732,874.83
25	2,742,851.79
26	2,749,032.49
27	2,758,795.31
28	2,764,681.00
29	2,782,691.74
30	2,792,254.20

Table 19: Yearly cash flows table (Source: Own elaboration)
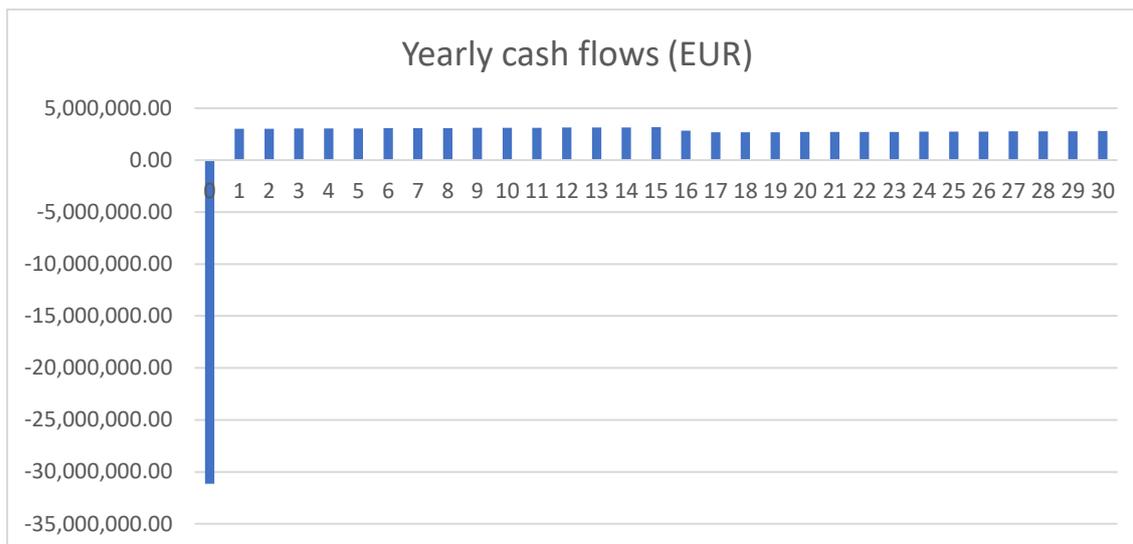
Figure 39: Yearly cash flow expectations histogram (Source: Own elaboration)

The results were:

NPV	€13,778,419.15
IRR	9%
WACC	5%
Investment recovery year	15

Table 20: Profitability parameters (Source: Own elaboration)

10.5.   **Conclusions:**

In light of the profitability results, the investment will be recovered by the 15th year, which is half of its lifetime, with a positive NPV and an IRR of 9% having previously considered a WACC of 5%. Therefore, the project is profitable, and can be given green light.

NOTE: The attachment XI shows a Gantt diagram for the different stages of the plant from the Basic Engineering to Starting Process.

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ATTACHMENTS

LIST OF ATTACHMENTS

ATTACHMENT I. Simulation report

PVsyst - Simulation report

Grid-Connected System

Project: FinalDegreeProject

Variant: Nueva variante de simulación_ELE
Trackers single array, with backtracking
System power: 50.00 MWp
LocationTFG - Spain

Author
Miguel Córdoba (Spain)

Project: FinalDegreeProject

Variant: Nueva variante de simulación_ELE

Miguel Córdoba (Spain)

PVsyst V7.2.17
VC4, Simulation date:
12/08/22 12:06
with v7.2.17

Project summary

Geographical Site	Situation		Project settings	
LocationTFG	Latitude	39.16 °N	Albedo	0.20
Spain	Longitude	-2.87 °W		
	Altitude	699 m		
	Time zone	UTC		

Meteo data
LocationTFG
Meteonorm 8.0 (1996-2017), Sat=100% - Sintético

System summary

Grid-Connected System
Simulation for year no 1

Trackers single array, with backtracking

PV Field Orientation

Orientation	Tracking algorithm	Near Shadings
Tracking plane, horizontal N-S axis	Astronomic calculation	Linear shadings
Axis azimuth 0 °	Backtracking activated	

System information

PV Array		Inverters	
Nb. of modules	94338 units	Nb. of units	10 units
Pnom total	50.00 MWp	Pnom total	48.00 MWac
		Pnom ratio	1.042

User's needs
Unlimited load (grid)

Results summary

Produced Energy	100 GWh/year	Specific production	1998 kWh/kWp/year	Perf. Ratio PR	85.27 %

Table of contents

Project: FinalDegreeProject
Variant: Nueva variante de simulación_ELE
Miguel Córdoba (Spain)

PVsyst V7.2.17
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with v7.2.17

General parameters

Grid-Connected System	**Trackers single array, with backtracking**	

PV Field Orientation

Orientation	**Tracking algorithm**	**Backtracking array**	
Tracking plane, horizontal N-S axis	Astronomic calculation	Nb. of trackers	295 units
Axis azimuth 0 °	Backtracking activated	Single array	

Sizes

Tracker Spacing	12.0 m
Collector width	4.42 m
Ground Cov. Ratio (GCR)	36.8 %
Phi min / max.	-/+ 55.0 °

Backtracking strategy

Phi limits	+/- 68.3 °
Backtracking pitch	12.0 m
Backtracking width	4.42 m

Models used

Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon	**Near Shadings**	**User's needs**
Free Horizon	Linear shadings	Unlimited load (grid)

Bifacial system

Model	2D Calculation
	unlimited trackers

Bifacial model geometry		**Bifacial model definitions**	
Tracker Spacing	12.00 m	Ground albedo	0.15
Tracker width	4.42 m	Bifaciality factor	70 %
GCR	36.8 %	Rear shading factor	7.0 %
Axis height above ground	2.30 m	Rear mismatch loss	10.0 %
		Shed transparent fraction	0.0 %

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	LR5-72 HBD 530 M Bifacial	Model	Sinacon PV4800
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	530 Wp	Unit Nom. Power	4800 kWac
Number of PV modules	94338 units	Number of inverters	20 * MPPT 50% 10 units
Nominal (STC)	50.00 MWp	Total power	48000 kWac
Modules	3494 Strings x 27 In series	Operating voltage	962-1500 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.04
Pmpp	45.83 MWp		
U mpp	1003 V		
I mpp	45708 A		

Total PV power		**Total inverter power**	
Nominal (STC)	49999 kWp	Total power	48000 kWac
Total	94338 modules	Number of inverters	10 units
Module area	241132 m²	Pnom ratio	1.04
Cell area	224256 m²		

Project: FinalDegreeProject

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Miguel Córdoba (Spain)

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Array losses

Array Soiling Losses		**Thermal Loss factor**		**DC wiring losses**	
Loss Fraction	2.0 %	Module temperature according to irradiance		Global array res.	0.24 mΩ
		Uc (const)	29.0 W/m²K	Loss Fraction	1.0 % at STC
		Uv (wind)	0.0 W/m²K/m/s		

LID - Light Induced Degradation		**Module Quality Loss**		**Module mismatch losses**	
Loss Fraction	1.5 %	Loss Fraction	-0.3 %	Loss Fraction	2.0 % at MPP

Strings Mismatch loss		**Module average degradation**	
Loss Fraction	0.1 %	Year no	1
		Loss factor	0.46 %/year
		Mismatch due to degradation	
		Imp RMS dispersion	0 %/year
		Vmp RMS dispersion	0 %/year

IAM loss factor
Incidence effect (IAM): User defined profile

0°	25°	45°	60°	65°	70°	75°	80°	90°
1.000	1.000	0.995	0.962	0.936	0.903	0.851	0.754	0.000

System losses

Auxiliaries loss
Proportionnal to Power   3.0 W/kW
0.0 kW from Power thresh.

AC wiring losses

Inv. output line up to MV transfo
Inverter voltage	660 Vac tri
Loss Fraction	0.08 % at STC

Inverter: Sinacon PV4800
Wire section (10 Inv.)	Alu 10 x 3 x 4000 mm²
Average wires length	9 m

MV line up to HV Transfo		**HV line up to Injection**	
MV Voltage	20 kV	HV line voltage	132 kV
Average each inverter		Wires	Alu 3 x 185 mm²
Wires	Alu 3 x 300 mm²	Length	10400 m
Length	1000 m	Loss Fraction	0.50 % at STC
Loss Fraction	0.32 % at STC		

AC losses in transformers

MV transfo
Medium voltage	20 kV

Operating losses at STC
Nominal power at STC	49261 kVA
Iron loss (24/24 Connexion)	24.63 kW/Inv.
Loss Fraction	0.20 % at STC
Coils equivalent resistance	3 x 0.28 mΩ/inv.
Loss Fraction	0.80 % at STC

Project: FinalDegreeProject

Variant: Nueva variante de simulación_ELE

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AC losses in transformers

HV transfo

Grid voltage	132 kV		
Transformer from Datasheets		**Operating losses at STC**	
Nominal power	52000 kVA	Nominal power at STC	49261 kVA
Iron loss	50.00 kVA	Iron loss (24/24 Connexion)	50.00 kW
Loss Fraction	0.10 % of PNom	Loss Fraction	0.10 % at STC
Copper loss	120.00 kVA	Coils equivalent resistance	3 x 17.75 mΩ
Loss Fraction	0.23 % of PNom	Loss Fraction	0.22 % at STC

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Project: FinalDegreeProject

Variant: Nueva variante de simulación_ELE

Miguel Córdoba (Spain)

Near shadings parameter

Perspective of the PV-field and surrounding shading scene

Iso-shadings diagram

Orientation #1

Shading loss: 1%	1: 22 June
Shading loss: 5%	2: 22 May and 23 July
Shading loss: 10%	3: 20 Apr and 23 Aug
Shading loss: 20%	4: 20 Mar and 23 Sep
Shading loss: 40%	5: 21 Feb and 23 Oct.
	6: 19 Jan and 22 Nov
	7: 22 December

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with v7.2.17

Project: FinalDegreeProject

Variant: Nueva variante de simulación_ELE

Miguel Córdoba (Spain)

Main results
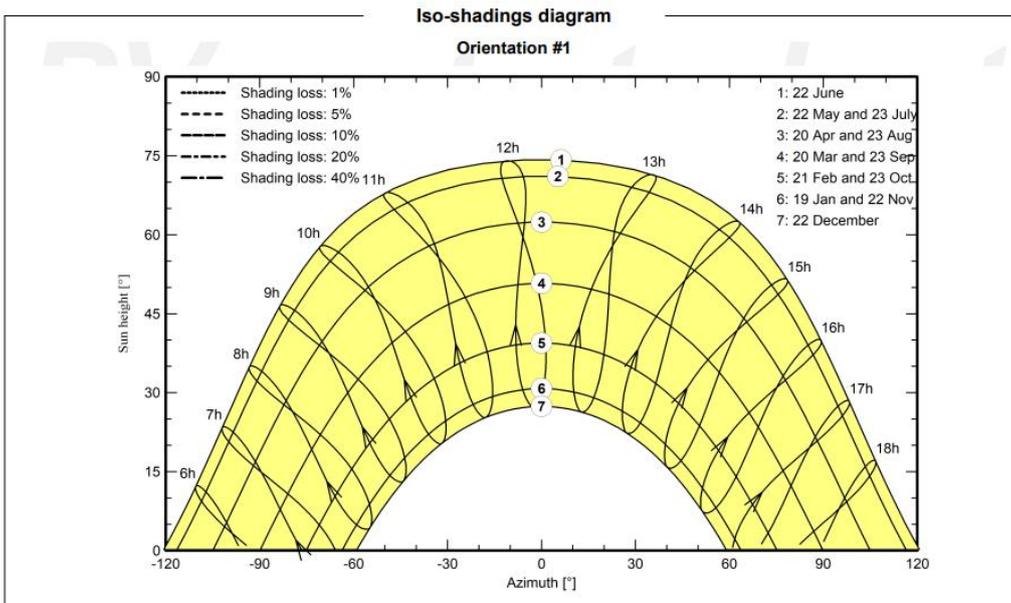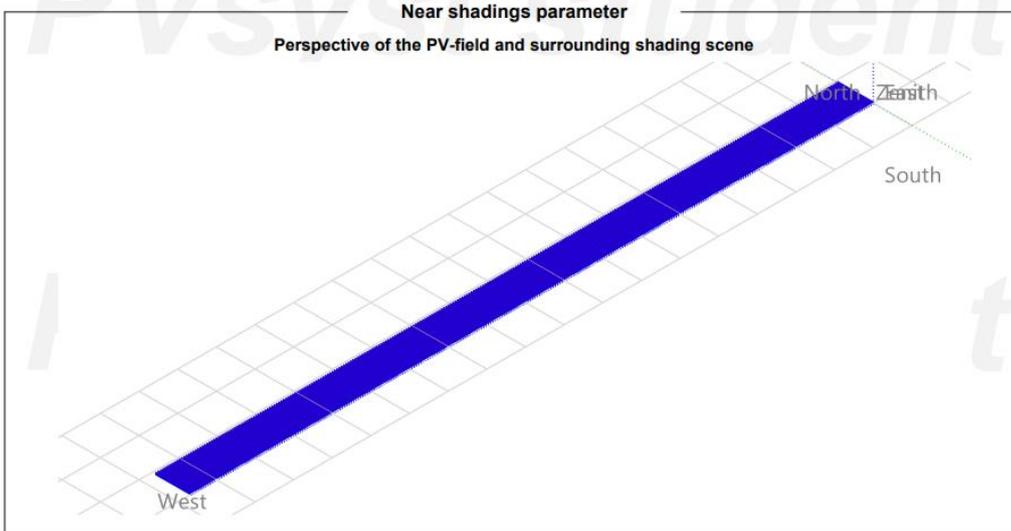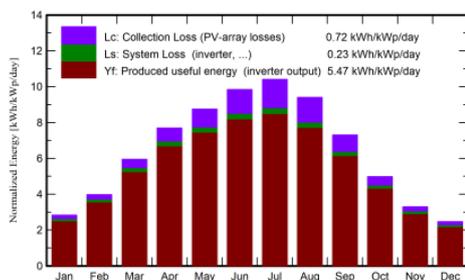
System Production

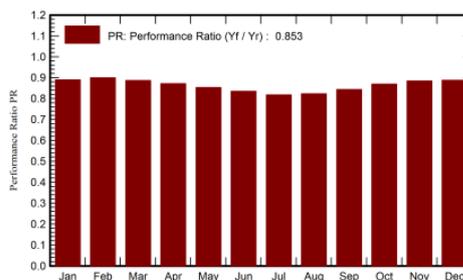|			
Produced Energy	100 GWh/year	Specific production	1998 kWh/kWp/year
		Performance Ratio PR	85.27 %

Normalized productions (per installed kWp)

Lc: Collection Loss (PV-array losses) 0.72 kWh/kWp/day
Ls: System Loss (inverter, ...) 0.23 kWh/kWp/day
Yf: Produced useful energy (inverter output) 5.47 kWh/kWp/day

Performance Ratio PR

PR: Performance Ratio (Yf / Yr) : 0.853

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	GWh	GWh	ratio
January	64.7	27.41	5.05	87.6	82.3	4.11	3.90	0.890
February	83.9	32.93	6.71	111.2	105.8	5.24	5.00	0.900
March	136.1	49.85	10.30	184.3	176.3	8.51	8.17	0.886
April	171.8	57.62	13.15	230.8	221.6	10.46	10.05	0.871
May	204.6	71.43	18.02	271.1	260.4	12.03	11.57	0.854
June	220.7	66.62	23.77	295.0	284.0	12.79	12.31	0.835
July	238.1	62.16	27.79	322.6	311.0	13.69	13.19	0.818
August	212.3	51.88	27.12	291.4	280.8	12.45	11.98	0.823
September	158.6	46.79	21.36	218.9	210.2	9.61	9.23	0.843
October	113.8	43.05	16.20	154.5	147.4	7.00	6.72	0.869
November	71.0	28.12	8.95	99.1	93.6	4.60	4.38	0.885
December	57.3	27.29	5.62	76.4	71.3	3.58	3.39	0.887
Year	1732.9	565.13	15.39	2342.9	2244.8	104.06	99.89	0.853

Legends

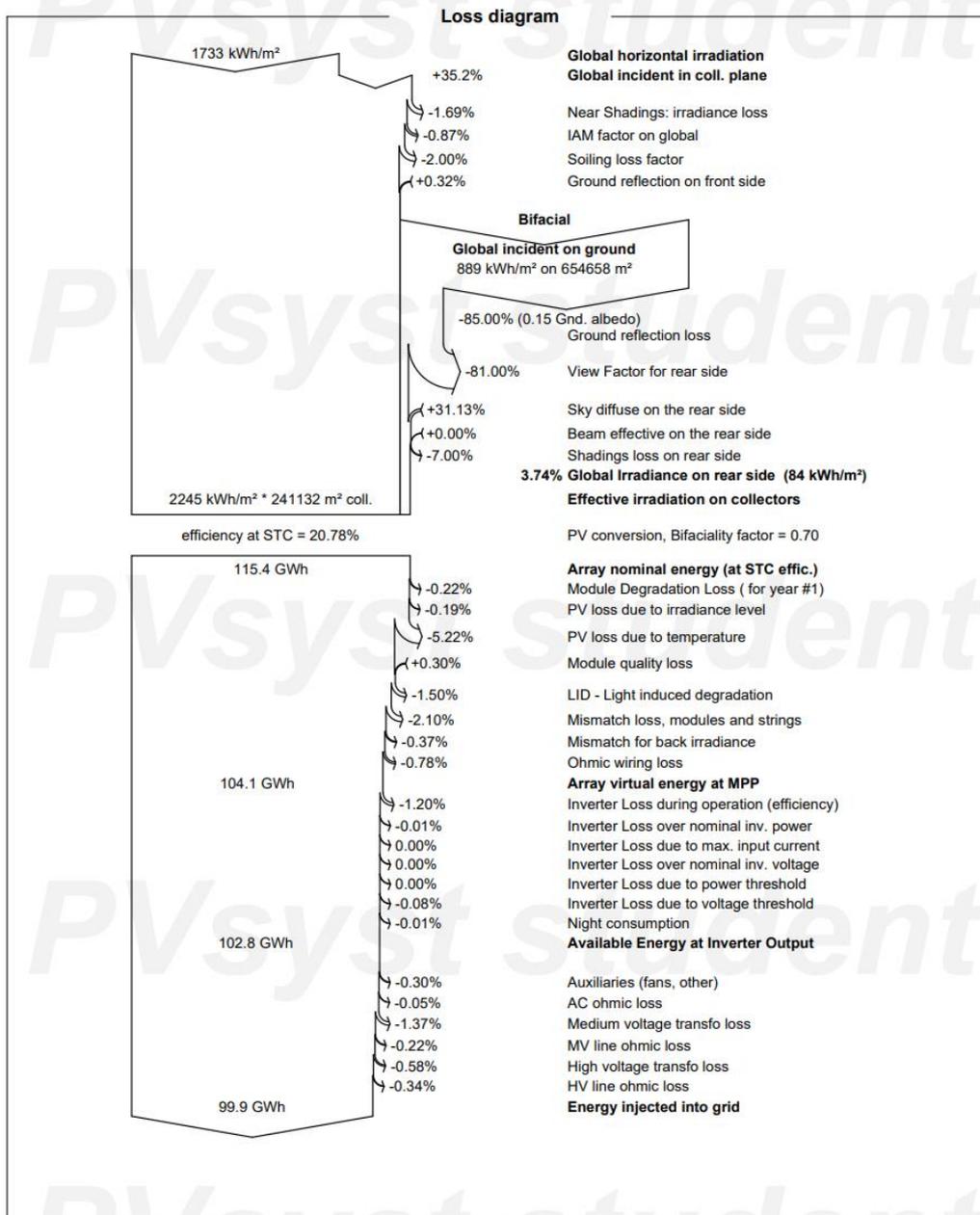|			
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

PVsyst V7.2.17
VC4, Simulation date:
12/08/22 12:06
with v7.2.17

Loss diagram

1733 kWh/m²

+35.2%	**Global horizontal irradiation** **Global incident in coll. plane**
-1.69%	Near Shadings: irradiance loss
-0.87%	IAM factor on global
-2.00%	Soiling loss factor
+0.32%	Ground reflection on front side

Bifacial

Global incident on ground
889 kWh/m² on 654658 m²

-85.00% (0.15 Gnd. albedo)	Ground reflection loss
-81.00%	View Factor for rear side
+31.13%	Sky diffuse on the rear side
+0.00%	Beam effective on the rear side
-7.00%	Shadings loss on rear side
3.74%	**Global Irradiance on rear side (84 kWh/m²)**

2245 kWh/m² * 241132 m² coll.

Effective irradiation on collectors

efficiency at STC = 20.78%

PV conversion, Bifaciality factor = 0.70

115.4 GWh

	Array nominal energy (at STC effic.)
-0.22%	Module Degradation Loss (for year #1)
-0.19%	PV loss due to irradiance level
-5.22%	PV loss due to temperature
+0.30%	Module quality loss
-1.50%	LID - Light induced degradation
-2.10%	Mismatch loss, modules and strings
-0.37%	Mismatch for back irradiance
-0.78%	Ohmic wiring loss

104.1 GWh

	Array virtual energy at MPP
-1.20%	Inverter Loss during operation (efficiency)
-0.01%	Inverter Loss over nominal inv. power
0.00%	Inverter Loss due to max. input current
0.00%	Inverter Loss over nominal inv. voltage
0.00%	Inverter Loss due to power threshold
-0.08%	Inverter Loss due to voltage threshold
-0.01%	Night consumption

102.8 GWh

	Available Energy at Inverter Output
-0.30%	Auxiliaries (fans, other)
-0.05%	AC ohmic loss
-1.37%	Medium voltage transfo loss
-0.22%	MV line ohmic loss
-0.58%	High voltage transfo loss
-0.34%	HV line ohmic loss

99.9 GWh

Energy injected into grid

Project: FinalDegreeProject

Variant: Nueva variante de simulación_ELE

Miguel Córdoba (Spain)

Special graphs

Daily Input/Output diagram
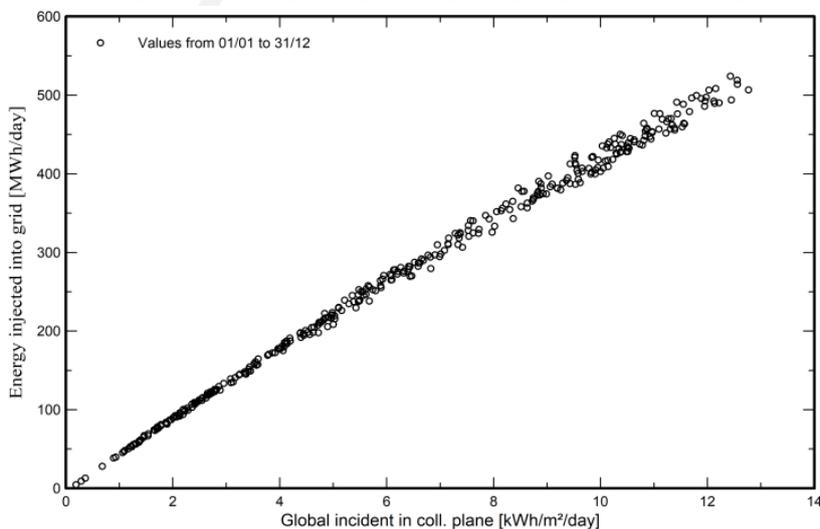
Distribución de potencia de salida del sistema
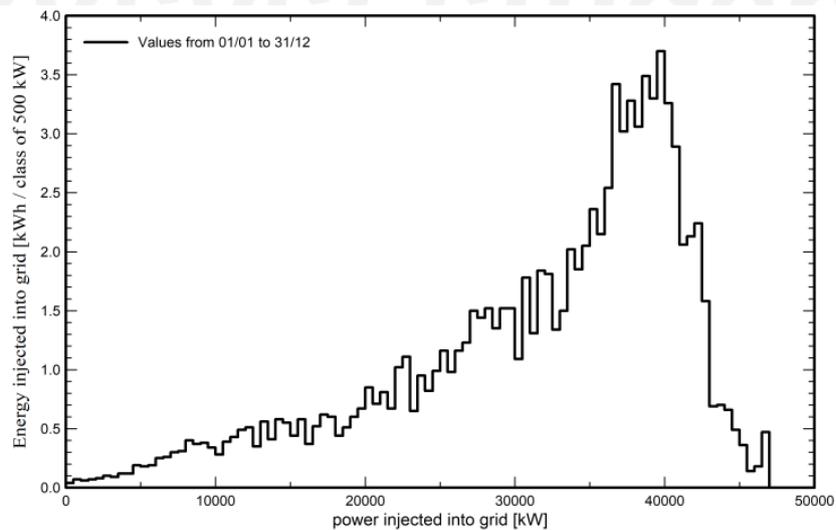
Project: FinalDegreeProject

Variant: Nueva variante de simulación_ELE

Miguel Córdoba (Spain)

PVsyst V7.2.17
VC4, Simulation date:
12/08/22 12:06
with v7.2.17

CO$_2$ Emission Balance

Total:	651599.2 tCO$_2$
Generated emissions	
Total:	94665.94 tCO$_2$
Source: Detailed calculation from table below:	
Replaced Emissions	
Total:	860084.0 tCO$_2$
System production:	99893.62 MWh/yr
Grid Lifecycle Emissions:	287 gCO$_2$/kWh
Source:	IEA List
Country:	Spain
Lifetime:	30 years
Annual degradation:	1.0 %

Saved CO$_2$ Emission vs. Time
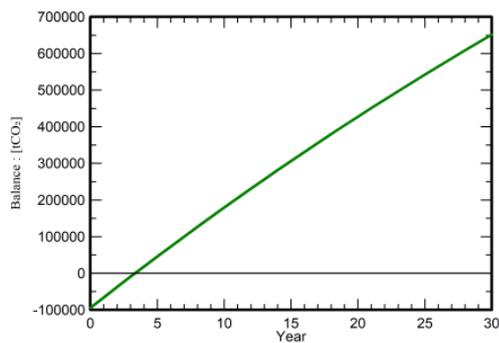
System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[kgCO$_2$]
Modules	1713 kgCO2/kWp	49999 kWp	85634527
Supports	1.91 kgCO2/kg	4716900 kg	9029515
Inverters	190 kgCO2/units	10.00 units	1896

ATTACHMENT II. Module datasheet

Hi-MO 5

LR5-72HBD
530~550M

- Based on M10-182mm wafer, best choice for ultra-large power plants

- Advanced module technology delivers superior module efficiency
  - M10 Gallium-doped Wafer • Smart Soldering • 9-busbar Half-cut Cell

- Globally validated bifacial energy yield

- High module quality ensures long-term reliability

12 12-year Warranty for Materials and Processing

30 30-year Warranty for Extra Linear Power Output

Complete System and Product Certifications

IEC 61215, IEC 61730, UL 61730
ISO 9001:2015: ISO Quality Management System
ISO 14001: 2015: ISO Environment Management System
TS62941: Guideline for module design qualification and type approval
ISO 45001: 2018: Occupational Health and Safety

LONGi

Hi-MO 5

LR5-72HBD 530~550M

| **21.5%** MAX MODULE EFFICIENCY | **0~3%** POWER TOLERANCE | **<2%** FIRST YEAR POWER DEGRADATION | **0.45%** YEAR 2-30 POWER DEGRADATION | **HALF-CELL** Lower operating temperature |

Additional Value

30-Year Power Warranty
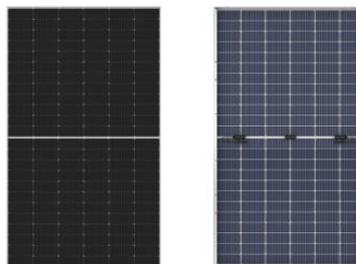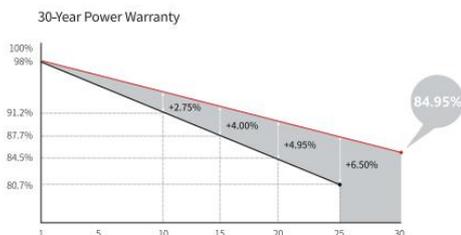
Mechanical Parameters

Cell Orientation	144 (6×24)
Junction Box	IP68, three diodes
Output Cable	4mm², +400, -200mm/±1400mm length can be customized
Glass	Dual glass, 2.0+2.0mm heat strengthened glass
Frame	Anodized aluminum alloy frame
Weight	32.3kg
Dimension	2256×1133×35mm
Packaging	31pcs per pallet / 155pcs per 20' GP / 620pcs per 40' HC

Units: mm

Tolerance:
Length: ±2mm
Width: ±2mm

Electrical Characteristics

STC : AM1.5 1000W/m² 25°C   NOCT : AM1.5 800W/m² 20°C 1m/s   Test uncertainty for Pmax: ±3%
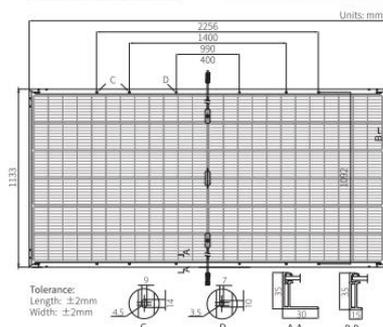
Module Type	LR5-72HBD-530M		LR5-72HBD-535M		LR5-72HBD-540M		LR5-72HBD-545M		LR5-72HBD-550M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	530	396.2	535	399.9	540	403.6	545	407.4	550	411.1
Open Circuit Voltage (Voc/V)	49.20	46.26	49.35	46.40	49.50	46.54	49.65	46.68	49.80	46.82
Short Circuit Current (Isc/A)	13.71	11.07	13.78	11.12	13.85	11.17	13.92	11.23	13.99	11.29
Voltage at Maximum Power (Vmp/V)	41.35	38.58	41.50	38.72	41.65	38.86	41.80	39.00	41.95	39.14
Current at Maximum Power (Imp/A)	12.82	10.27	12.90	10.33	12.97	10.39	13.04	10.45	13.12	10.51
Module Efficiency(%)	20.7		20.9		21.1		21.3		21.5	

Operating Parameters

Operational Temperature	-40°C ~ +85°C
Power Output Tolerance	0 ~ 3%
Voc and Isc Tolerance	±3%
Maximum System Voltage	DC1500V (IEC/UL)
Maximum Series Fuse Rating	30A
Nominal Operating Cell Temperature	45±2°C
Protection Class	Class II
Bifaciality	70±5%
Fire Rating	UL type 29 IEC Class C

Mechanical Loading

Front Side Maximum Static Loading	5400Pa
Rear Side Maximum Static Loading	2400Pa
Hailstone Test	25mm Hailstone at the speed of 23m/s

Temperature Ratings (STC)

Temperature Coefficient of Isc	+0.050%/°C
Temperature Coefficient of Voc	-0.265%/°C
Temperature Coefficient of Pmax	-0.340%/°C

LONGi

No.8369 Shangyuan Road, Xi'an Economic And Technological Development Zone, Xi'an, Shaanxi, China.
Web: en.longi-solar.com

Specifications included in this datasheet are subject to change without notice. LONGi reserves the right of final interpretation. (20211101V14)

ATTACHMENT III. Inverter datasheet

SIEMENS
Ingenuity for life

SINACON PV
Photovoltaic Central Inverter

Technical data 01/2020

The SINACON PV inverter is used in medium and large utility-scale photovoltaic power plants to achieve high efficiency. It is equipped with 3-level IGBT modules for input voltages of up to DC 1,500 V to maximize energy efficiency. The integrated DC and AC distribution makes the SINACON PV inverter cost efficient. Standardized interfaces for easy plug and play reduce engineering hours.

- Designed for harsh environments
- IP65 without humidity limits
- Liquid cooling (-40 °C ... +60 °C possible)
- Late power derating over 40 °C
- Extreme high quality standards
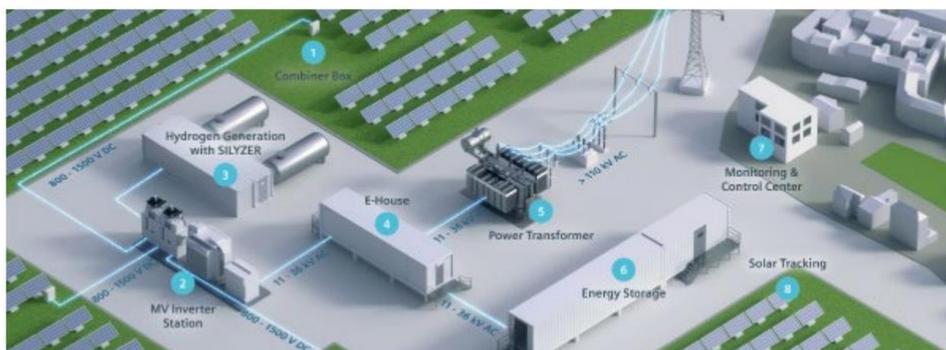
The SINACON PV inverter is part of the MV-Inverter Station with the transformer and RMU (Ring Main Unit) in the eBoP solution (electrical Balance of Plant).

1

83

Storage, transportation and operation	
Temperature	-40 °C ... +60 °C
Relative humidity	0% ... 100%
Maximum altitude of installation site without derating	< 1,500 m above MSL

Cooling	
Cooling method	Forced cooling by means of fans and liquid cooling

Applicable standards and conformity	
BDEW (Germany)	BDEW Guideline, FGW TG3, TG4 and TG8
IEC 61683 (efficiency)	IEC 61683: 1999
IEC 62116 (anti islanding)	IEC 62116: 2014 (at 50 Hz)
EMC Emission	IEC 61000-6-4: 2007 + A1: 2011
EMC Immunity	IEC 61000-6-2: 2005
Electrical Safety	IEC 62109-1: 2010, IEC 62109-2: 2011, IP65 according to IEC 60529: 1989
Degree of protection: IP65 (cabinet only)	IEC 60529

General data		
Control strategy	MPPT	
Efficiency (PV 5000)	(97.6|98.5|98.9|98.9|99.0|98.9|98.8|98.7)%	For (5|10|20|25|30|50|75|100)% power at 1,006 V_{DC} without self-consumption for cooling
EU and CEC efficiency	98.8%	Without internal consumption
Infeed starts from	260 W ... 2,500 W	Depending on cooling
Standby loss	80 W ... 150 W	–
Max. self-consumption for cooling	5,000 W	Without cabinet heating

Mechanical data				
Mounting position	Vertical		–	
Type of mounting	Floor mounting		–	
Number of Power Units	1	2	3	4
SINACON PV series	PV1000 ... PV1250	PV2000 ... PV2500	PV3000 ... PV3750	PV4000 ... PV5000
Dimensions (without pallet, with heat exchanger); (W x H x D)	2,120 x 3,760 x 1,170 mm		3,690 x 3,760 x 1,170 mm	
Weight[1]	< 1,600 kg	< 2,200 kg	< 3,300 kg	< 3,900 kg
Color	RAL 7035			

Input data (DC)		
Independent inputs	1 ... 2	Depending on configuration
Nominal voltage	min. MPP voltage	–
DC voltage (max. MPP)	1,500 V	Depending on application
DC voltage (min. MPP)	802 V / 882 V (AC 550 V) 838 V / 922 V (AC 575 V) 875 V / 962 V (AC 600 V) 919 V / 1,010 V (AC 630 V) 962 V / 1,058 V (AC 660 V) 1,006 V / 1,107 V (AC 690 V)	For 100 % / 110 % nominal grid voltage
DC current (max.)	1 ... 4 x 1,200 A	–
Short-circuit current (max.)	6,4 kA / 7 kA	250 A / 315 A DC fuses
Nominal power	1 ... 4 x 1,016 kW 1 ... 4 x 1,062 kW 1 ... 4 x 1,108 kW 1 ... 4 x 1,159 kW 1 ... 4 x 1,209 kW 1 ... 4 x 1,270 kW	–
Capacitance to ground (max.)	2,000 µF	Per IT system

[1] The weight refers to a complete system without extra options.

2

Output data (AC)		
Apparent power (max.) and nominal power	PV1000 ... PV4000 kVA (AC 550 V) PV1045 ... PV4180 kVA (AC 575 V) PV1090 ... PV4360 kVA (AC 600 V) PV1140 ... PV4560 kVA (AC 630 V) PV1200 ... PV4800 kVA (AC 660 V) PV1250 ... PV5000 kVA (AC 690 V)	With nominal grid voltage, cos φ = 1
Number of independent systems	1 ... 2	–
Grid voltage	550 ... 690 V (±10% at $U_{n\,(AC)}$)	–
Nominal frequency	50 Hz / 60 Hz (±10%)	–
Output current (max.)	1 ... 4 x 1,050 A	–
Short-circuit current (max.)	50 kA	–
Power factor cos φ	–	Adjustable to local requirements
Harmonic distortion	< 3%	–

Measured values[2] without internal consumption for AC 600 V (PV4360)
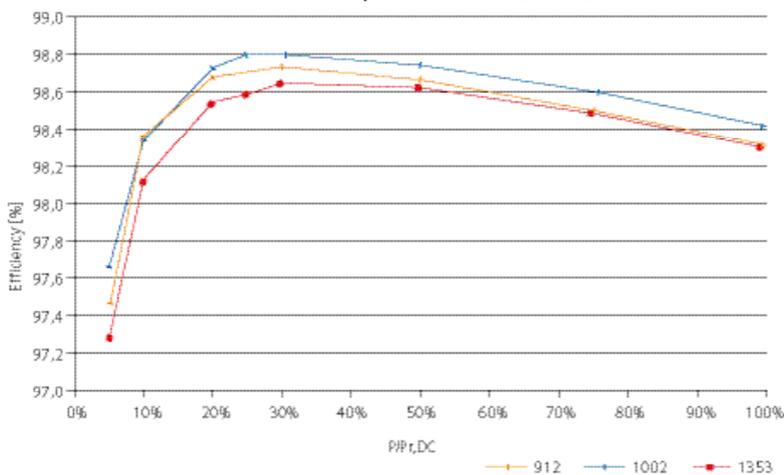
Derating
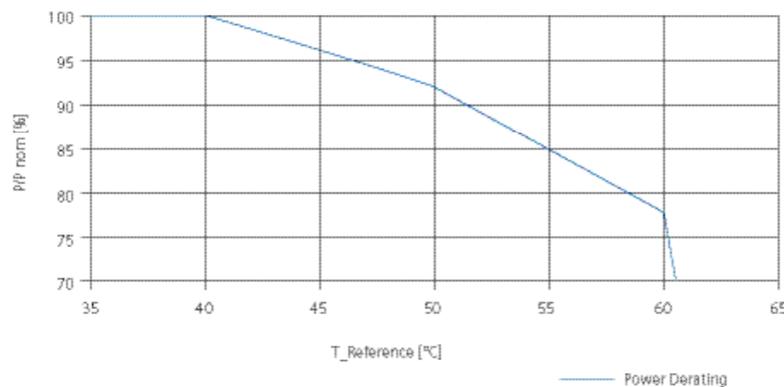
[2] Measured by Fraunhofer ISE

3

Order information – The order number consists of several digits depending on the configuration.

Description	1.	2.	3.	4.	5.	6.	7.	–	8.	9.	10.	11.	12.	–	13.	14.	15.	16.
SINACON PV inverter for medium voltage supply	6	S	P	1														
Number of power units																		
• 1 power unit					1													
• 2 power units					2													
• 3 power units					3													
• 4 power units					4													
Input connections (per power unit on plus and minus)																		
• 7 x M10 bolt and nut						0												
Initial current measurement at DC input																		
• Each + input measured							1											
Minimum operating ambient temperature																		
• Up to -10 °C									0									
• Up to -25 °C, with cabinet heating									1									
• Up to -40 °C, with cabinet heating and insulation									2									
Applied standards																		
• IEC with external AC connection										E								
• UL with external AC connection										U								
Network-/optical fiber switch connection																		
• Singlemode unmanaged											S							
• Multimode unmanaged											M							
• RJ45											R							
Seismic design																		
• Without seismic design												0						
• With seismic design												1						
Frequency																		
• 50 Hz													5					
• 60 Hz													6					
Inverter output AC voltage																		
• 550 V (PV1000 … PV4000)															4			
• 575 V (PV1045 … PV4180)															5			
• 600 V (PV1090 … PV4360)															6			
• 630 V (PV1140 … PV4560)															7			
• 660 V (PV1200 … PV4800)															8			
• 690 V (PV1250 … PV5000)															9			
Grounding / Insulation monitoring																		
• Insulation monitoring internal																I		
• Negative-pole grounding without isolation monitoring																N		
Inverter options																		
• None																	N	
• AC precharge																	A	
Additional internal transformer																		
• 63 A fuse																		2
• Transformer with 8 kVA, AC 400 V																		3
• none																		9
Example:	6	S	P	1	4	0	1	–	0	E	S	0	5	–	6	N	N	3

4

ATTACHMENT IV. Tracker datasheet
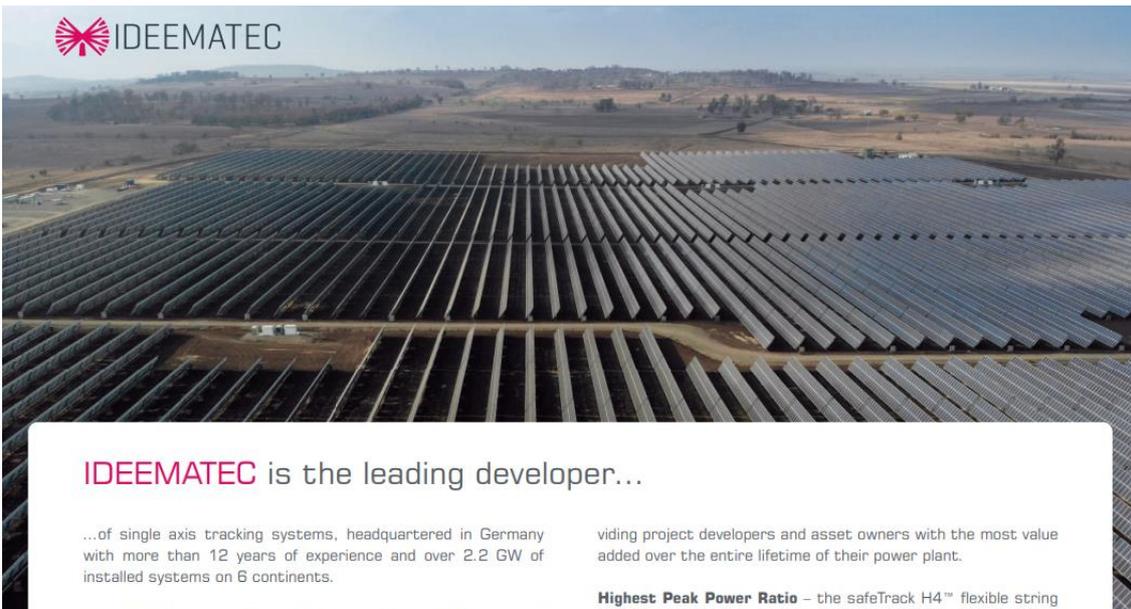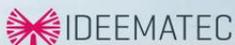
✳ IDEEMATEC

IDEEMATEC is the leading developer…

…of single axis tracking systems, headquartered in Germany with more than 12 years of experience and over 2.2 GW of installed systems on 6 continents.

IDEEMATEC's innovative high-span safeTrack H4 tracker™ offers an outstanding design DNA. As first two-in-portrait tracker in the market, powered by its core patented drive technology, IDEEMATEC's solar tracker offers a superior safety and uptime level. Now available **safeTrack H4ᴾᴸᵁˢ bifacial tracker™** for an even higher yield at maximum reduced shading.

Established technology for challenging conditions – suited for sites with challenging soils, high winds, and irregular terrain, IDEEMATEC's safeTrack H4 trackers™ reduce the risk for Engineering, Procurement & Construction Companies by pro-viding project developers and asset owners with the most value added over the entire lifetime of their power plant.

Highest Peak Power Ratio – the safeTrack H4™ flexible string configuration allows for a max. number of modules per tracker and requires only 1 Drive Unit for 360 Modules to provide support for up to 12x 1500-volt strings – **currently the market benchmark**. With only 0.5 pcs. SIGMA foundations per DC string, the high-span safeTrack H4™ reduces tracker installation costs by offering the least amount of posts at the lowest embedding depth.

THE DEFINITION OF 2P TRACKING

DISCONNECTED DRIVE

- 2.5 Hz natural frequency
- Zero torsion table
- Galloping excluded

ZERO STOW POSITION

$Pressure[\frac{N}{m^2}]$

Wind Load 150km/h

ZERO DEGREE

Angle [°]
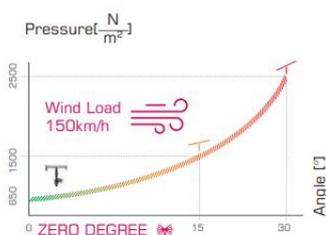
- Up to 300 % less stress
- 360 ° wind protection
- Best in practice stow strategy

DYNAMIC ABSORBERS

- Damping ratio 15%
- 0° stow position safe & stable over entire length
- Dynamic stability in any position

IDEEMATEC

THE LONGEST TRACKER IN THE MARKET
up to 180 meters | 360 modules

H4 PLUS
BIFACIAL

GENERAL MECHANICAL FEATURES

Tracking type	Horizontal single axis tracker – unlinked row
Typical tracker size	2 Portrait II 183 mtr. (max.)
Array height	2.20 m (7'22") Standard
H4PLUS bifacial features	**H4PLUS – tracker height gain compensation**
Tracking range	± 55°
Wind protection	Stow Position 0° / multi damping
Foundations	Sigma shape
Materials	Galvanized steel
Warranty	10 Years II Standard

▲ HIGHER YIELD
MORE RAIL DISTANCE
▼ LESS SHADING

±36%
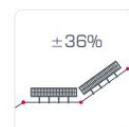
EXTREMELY ADAPTABLE
TO ANY TERRAIN

POWER AND CONTROLL SYSTEM

Software	KoRoNa™ by IDEEMATEC
Solar tracking method	Astronomical algorithm II 3D adaptive backtracking
Communication	Full wired II redundant data transfer and control flow
Drive type	High accuracy slew gear – disconnected
Motor type	CE 400V 50Hz/ UL 480V 60Hz
Operating temperature range	-20°C up to +55°C
Warranty	5 Years II Standard

BARRIER FREE
ROBOT-CLEANING

ONLY 1 DRIVE UNIT
FOR 150 KWP

MODULES AND CONFIGURATION

2P configuration 1500 Volt	Modules Pcs.		Strings	Width	Length
6 Table	336	360	12	72 cell / 78 cell	174m / 186m
5 Table	280	300	10		145m / 155m
4 Table	224	240	8	4.0m / 4.4m	116m / 124m
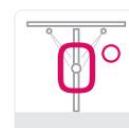
SAFE AND STABLE
0° STOW POSITION

ATTACHMENT V. MV cables datasheet

ELAND® CABLES

YMz1Krvasdlwd-AL 12/20kV Cable

Eland Product Group: **B1E**

APPLICATION

LSZH Medium Voltage cable with aluminium conductors offering a lightweight alternative to copper conductor alternatives. Suitable for use in conduit and for fixed, protected installation. For installations where fire, smoke emission and toxic fume create a potential risk to life and equipment.

CHARACTERISTICS

Voltage Rating Uo/U
12/20kV

Temperature Rating
Fixed: 0°C to +90°C
Maximum Conductor Short-Circuit Temp up to 5 sec: 250°C

Minimum Bending Radius
Single Core: 15 x overall diameter
Multi Core: 12 x overall diameter

CONSTRUCTION

Conductor
Class 2 Stranded Aluminium

Inner Semi-Conductive Layer
Semi-Conductive Material

Insulation
XLPE (Cross-Linked Polyethylene)

Outer Semi-Conductive Layer
Semi-Conductive Material

Screen
Copper wires and tape

Tape
Longitudinal and Radial Water Blocking

Outer Sheath
LSZH (Low Smoke Zero Halogen) UV Resistant

Core Identification
Multi Cores: ● Brown ● Black ● Grey

Sheath Colour
● Red

STANDARDS

Generally to HD 620-10J / NEN 3620
Fire Resistant to IEC/EN 60332-1-2, IEC/EN 60332-3-24 Cat.C

ISO/IEC 17025 LABORATORY TESTED

This product is subject to the Quality Assurance protocols of The Cable Lab®, an ISO/IEC 17025 accredited cable testing laboratory. Testing includes vertical flame, conductor resistance, tensile & elongation, and dimensional consistency, verified to published standards and approved product drawings.

UKAS	ISO/IEC 17025	bsi. ISO 9001	ISO 14001	ISO 45001
	Accredited Testing Laboratory	Quality Management	Environmental Management	Occupational Health and Safety Management
8578		FS 672069	EMS 672067	OHS 672066

REGULATORY COMPLIANCE

This cable meets the requirements of the RoHS Directive 2011/65/EU. RoHS compliance has been tested and confirmed by The Cable Lab® as meeting the requirements of the BSI RoHS Trusted Kitemark™.

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technicalspecification | 1 of 3

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DIMENSIONS

ELAND PART NO.	NO. OF CORES	NOMINAL CROSS SECTIONAL AREA mm²	NOMINAL CROSS SECTIONAL AREA OF SCREEN mm²	NOMINAL DIAMETER OVER CONDUCTOR mm	NOMINAL THICKNESS OF INSULATION mm	NOMINAL THICKNESS OF SEMI-CONDUCTIVE LAYER mm		NOMINAL THICKNESS OF SHEATH mm	NOMINAL OVERALL DIAMETER mm	NOMINAL WEIGHT kg/km
						Inner	Outer			
B1E20KV01050RD	1	50	25	8.10	4.50	0.50	0.40(fully bonded)	2.50	30	1100
B1E20KV01070RD	1	70	25	9.70	4.50	0.50	0.40(fully bonded)	2.50	31	1200
B1E20KV01095RD	1	95	25	11.40	4.50	0.50	0.40(fully bonded)	2.50	33	1300
B1E20KV01120RD	1	120	25	12.60	4.50	0.50	0.40(fully bonded)	2.50	34	1400
B1E20KV01150RD	1	150	25	14.10	4.50	0.50	0.40(fully bonded)	2.50	36	1500
B1E20KV01185RD	1	185	25	15.80	4.50	0.50	0.40(fully bonded)	2.50	37	1700
B1E20KV01240RD	1	240	25	18.10	4.50	0.50	0.40(fully bonded)	2.50	40	1900
B1E20KV01300RD	1	300	25	20.20	4.50	0.50	0.40(fully bonded)	2.50	42	2200
B1E20KV01400RD	1	400	50	23.00	4.50	0.50	0.40(fully bonded)	2.50	45	2750
B1E20KV01500RD	1	500	50	26.00	4.50	0.50	0.40(fully bonded)	2.50	48	3250
B1E20KV01630RD	1	630	50	30.10	4.50	0.50	0.40(fully bonded)	2.50	52	3750
B1E20KV03050RD	3	50	70	8.10	4.50	0.50	0.40(fully bonded)	3.20	60	3250
B1E20KV03070RD	3	70	70	9.70	4.50	0.50	0.40(fully bonded)	3.20	63	3700
B1E20KV03095RD	3	95	70	11.40	4.50	0.50	0.40(fully bonded)	3.20	67	4000
B1E20KV03120RD	3	120	70	12.60	4.50	0.50	0.40(fully bonded)	3.20	70	4500
B1E20KV03150RD	3	150	70	14.10	4.50	0.50	0.40(fully bonded)	3.20	73	4900
B1E20KV03185RD	3	185	70	15.80	4.50	0.50	0.40(fully bonded)	3.20	77	5400
B1E20KV03240RD	3	240	70	18.10	4.50	0.50	0.40(fully bonded)	3.20	82	6200

ELECTRICAL CHARACTERISTICS
Single Core

NOMINAL CROSS SECTIONAL AREA mm²	NOMINAL SHORT-CIRCUIT OF CONDUCTOR CURRENT FOR 1 SECOND kA	MAXIMUM CONDUCTOR DC RESISTANCE AT 20°C Ω/km	CONDUCTER AC RESISTANCE BY MAXIMUM TEMPERATURE Ω/km	CURRENT CARRYING CAPACITY A		CONDUCTOR LOSSES IN THE GROUND kW/km
				In Ground 20°C	In Air 30°C	
50	4.70	0.0641	0.825	195	217	31.4
70	6.58	0.0443	0.570	237	270	32.0
95	8.93	0.320	0.412	282	328	32.8
120	11.28	0.253	0.328	320	378	33.6
150	14.10	0.206	0.268	353	425	33.4
185	17.39	0.164	0.213	396	485	33.4
240	22.56	0.125	0.163	457	573	34.0
300	28.20	0.100	0.132	511	652	34.5
400	37.60	0.0778	0.103	566	740	33.0
500	47.00	0.0605	0.0810	630	838	32.1
630	59.22	0.0469	0.0640	701	882	-

ELECTRICAL CHARACTERISTICS
Multi Core

NOMINAL CROSS SECTIONAL AREA mm²	NOMINAL SHORT-CIRCUIT OF CONDUCTOR CURRENT FOR 1 SECOND kA	MAXIMUM CONDUCTOR DC RESISTANCE AT 20°C Ω/km	CONDUCTER AC RESISTANCE BY MAXIMUM TEMPERATURE Ω/km	CURRENT CARRYING CAPACITY A	
				In Ground 20°C	In Air 30°C
50	4.70	0.641	0.825	167	167
70	6.58	0.443	0.570	205	208
95	8.93	0.320	0.412	244	251
120	11.28	0.253	0.328	279	291
150	14.10	0.206	0.268	312	329
185	17.39	0.164	0.213	355	379
240	22.56	0.125	0.163	412	446

ATTACHMENT VI. MV/LV transformer datasheet

**Combine the Freemaq PCSK &
Multi PCSK with our MV solutions.**

MV Skid Compact & Twin Skid Compact

From low to medium voltage
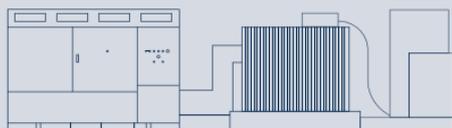
MV SKID COMPACT
Page. 32 — 33
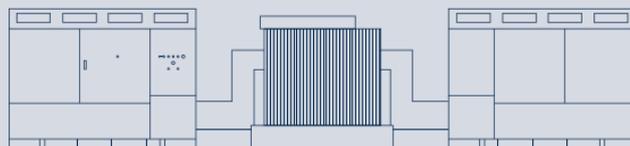
TWIN SKID COMPACT

Twin Skid Compact

RATINGS	Power range @ 40 °C	3050 kVA - 8780 kVA
	Power range @ 50 °C	2830 kVA - 8150 kVA
MEDIUM VOLTAGE EQUIPMENT	MV voltage range	6.6 kV / 11 kV / 13.2 kV / 15 kV / 20 kV / 22 kV / 23 kV / 25 kV / 30 kV / 33 kV / 34.5 kV
	LV voltage range	480 V / 500 V / 530 V / 600 V / 615 V / 630 V / 645 V / 660 V / 690 V
	Transformer cooling	ONAN
	Transformer vector group	Dy11y11
	Transformer protection	Protection relay for pressure, temperature (two levels) and gassing.
		Monitoring of dielectric level decrease.
		PT100 optional.
	Transformer index of protection	IP54
	Transformer losses	IEC standard or IEC Tier-2.
	Oil retention tank	Galvanized steel. Integrated with hydrocarbon filter. Optional
	Switchgear configuration	Double feeder (2L)
	Switchgear protection	Circuit breaker (V)
	Switchgear short circuit rating [1]	16 kA 1 s
	Switchgear IAC [1]	A FLR 16 kA 1 s
CONNECTIONS	LV-MV connections	Close coupled solution (plug & play)
	LV protection	Motorized circuit breaker included in the inverter
	HV AC wiring	MV bridge between transformer and protection switchgear prewired
ENVIRONMENT	Ambient temperature range [2]	-10 °C... +50 °C (T > 50 °C power derating)
	Maximum altitude (above sea level) [1]	Up to 1000 m
	Relative humidity	4% to 95% non condensing
AUXILIARY SERVICES ELECTRICAL PANEL	User power supply options	5 kVA / 40 kVA at 400 V (3-phase), 50 / 60 Hz (Integrated in the inverter)
	User cabinet	Integrated in the inverter (by default). Optionally, LV cabinet in the skid.
	Cooling	Forced air
	HW communication	Ethernet (fiber optic or RJ45)
	UPS system [1]	1 kVA/0.8 kW (10 minutes). Optional
OTHER EQUIPMENT	Safety mechanism	Interlocking system
	Fire extinguishing system	Transformer oil tank retention accessory. Optional.
STANDARDS	Compliance	IEC 62271-212, IEC 62271-200, IEC 60076, IEC 61439-1

NOTES

[1] Consult with Power Electronics for other options.
[2] For lower temperatures, consult with Power Electronics.

ATTACHMENT VII. Software list

- **PVSyst**

Simulating the solar plant's model and providing results.

- **Meteonorm**

Obtaining solar irradiance data in order to simulate the model with these as input.

- **NASA**

Obtaining solar irradiance data in order to compare them with the ones provided by Meteonorm, thus discerning the most appropriate set of data.

- **Google Earth**

Obtaining global coordinates to later obtain solar irradiance data, hence discerning the best location for the project.

- **Matlab**

Elaborating *Figure 36*

- **SolidEdge**

Elaborating the project plans

ATTACHMENT VIII. Matlab algorithm for *Figure 36* elaboration

```matlab
clear all
clc
close all force

X=[42.19
64.43
36.96
37.01
49.93
47.23
44.26
42.13
50.32
39.67
52.24
57.29
47.68
33.96
111.93
];

boxplot(X,'Notch','on')
grid on
title('Yearly electricity price data distribution')
ylabel('Electricity Price (EUR/MWh)')
```

ATTACHMENT IX. Official PVSyst output tabs

Output tab 1: Orientation settings (Source: PVSyst)

Output tab 2: Modules and inverters settings (Source: PVSyst)
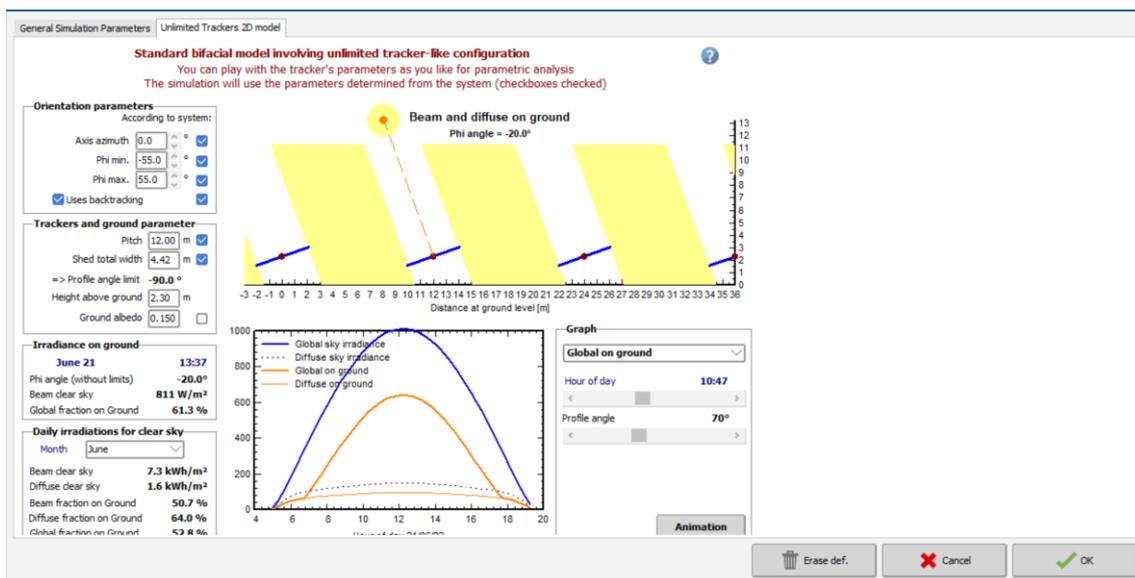
Output tab 3: Bifacial menu – General tracking settings (Source: PVSyst)

Output tab 4: Modules setting menu (Source: PVSyst)

Output tab 5: Inverters setting menu (Source: PVSyst)
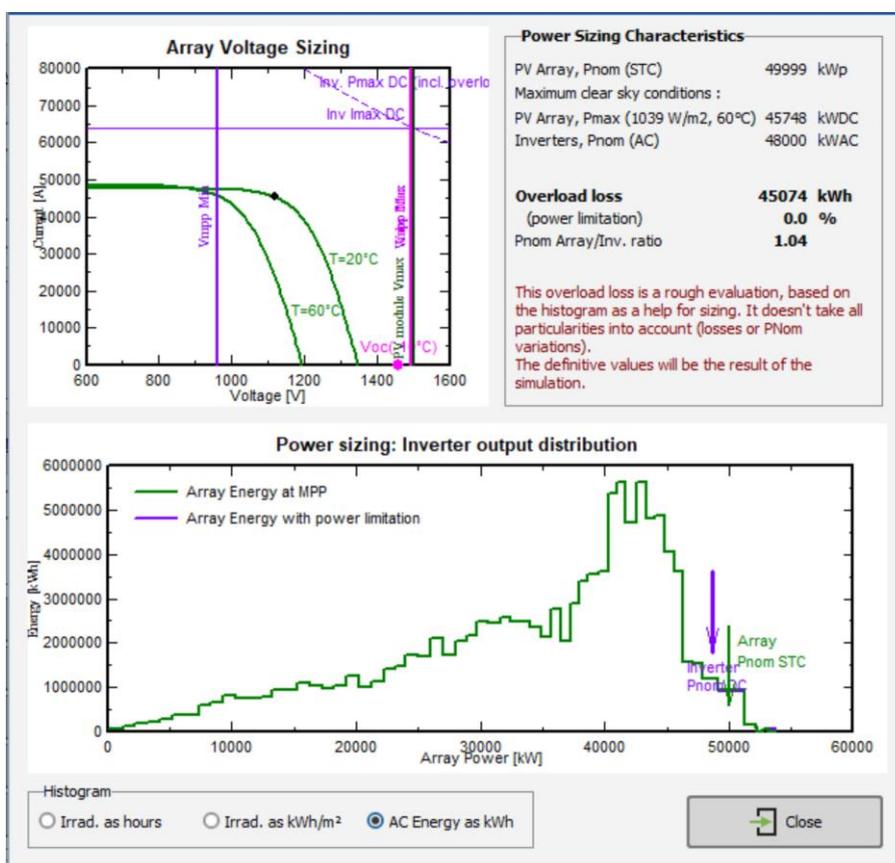
Output tab 6: Array sizing menu (Source: PVSyst)

Output tab 7: Ohmic losses – electrical system design tab (Source: PVSyst)

Output tab 8: Aging losses menu (Source: PVSyst)

Output tab 9: Shading factor table with backtracking activated (Source: PVSyst)
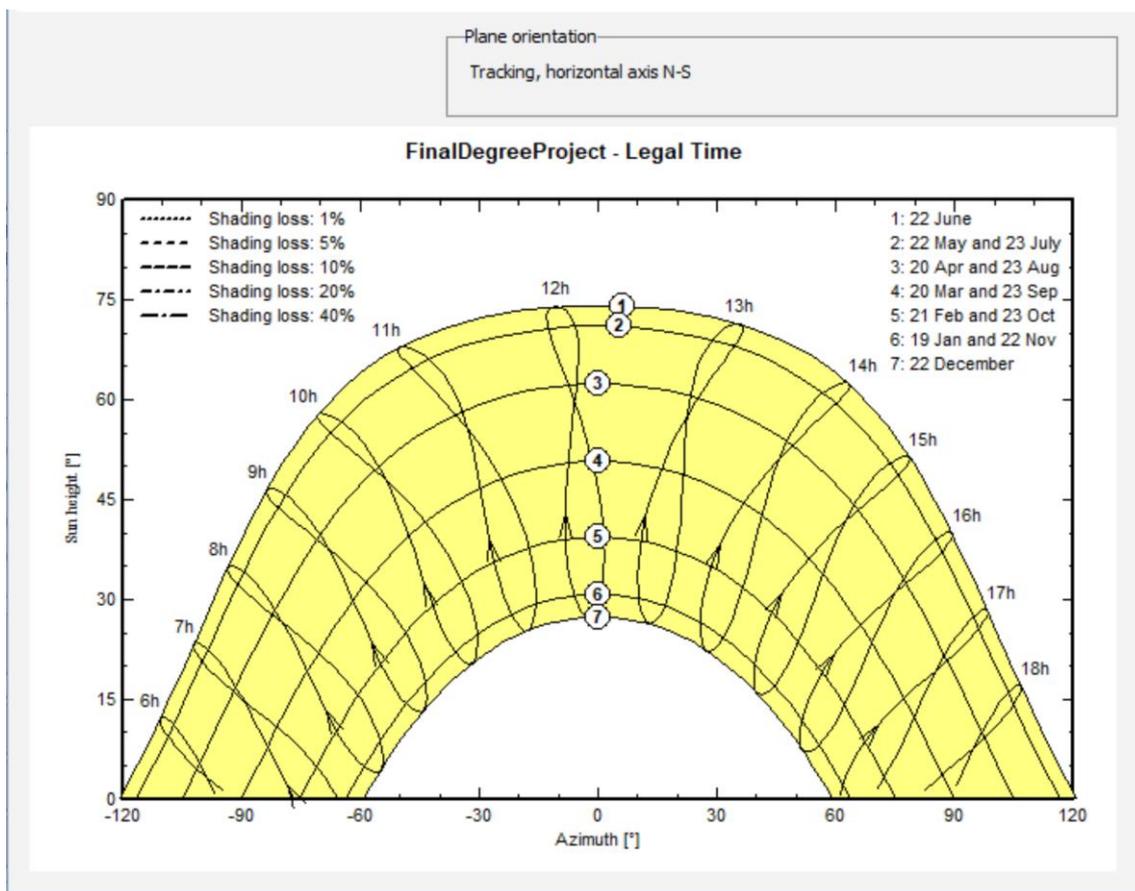
Output tab 10: Plane orientation – Tracking, horizontal axis N-S (Source: PVSyst)
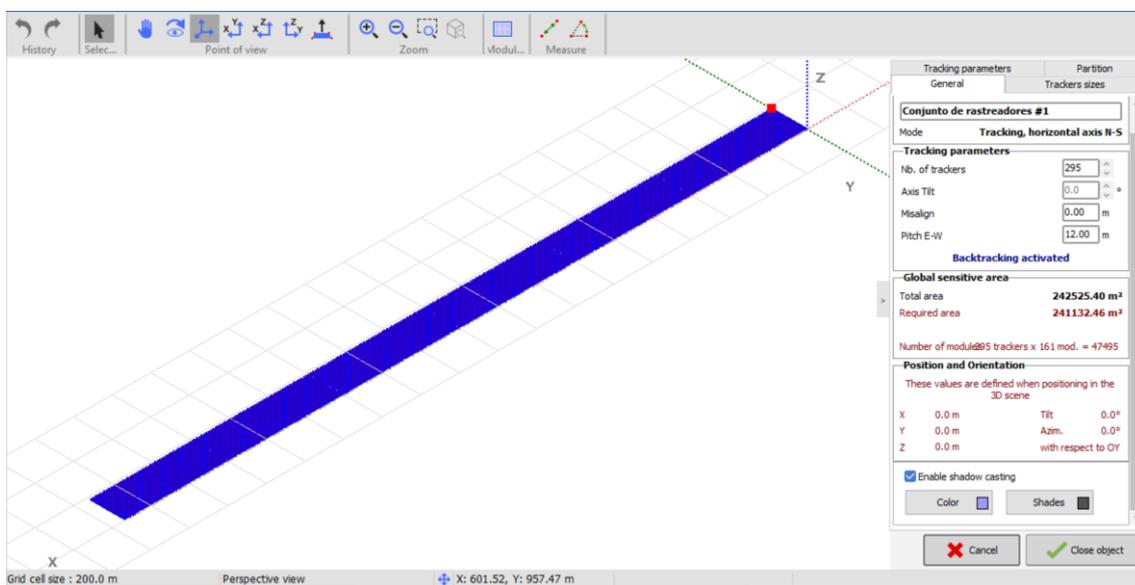
Output tab 11: Tracking settings menu (Source: PVSyst)
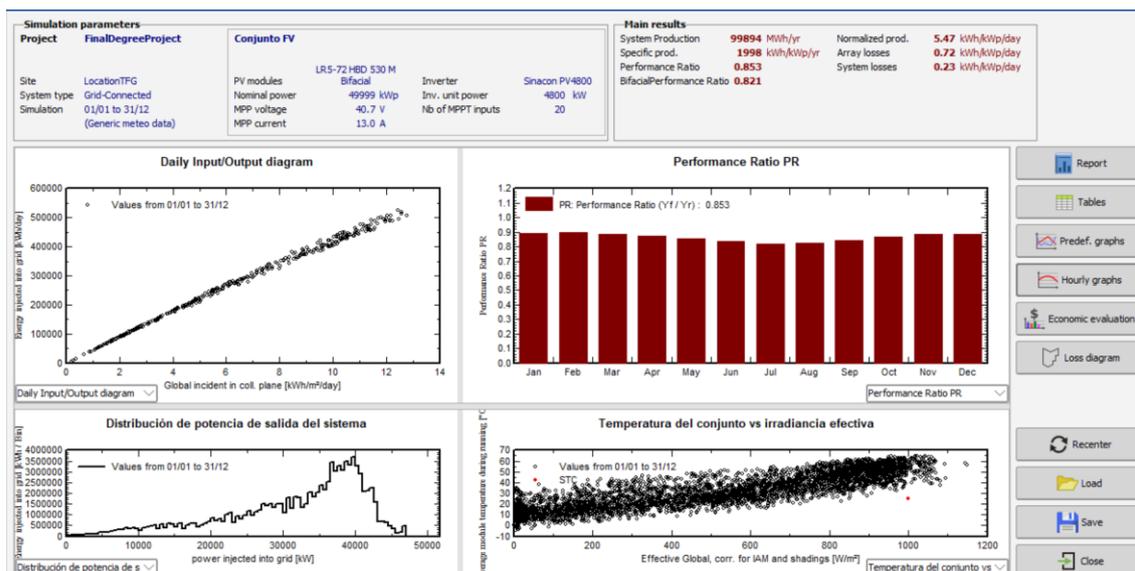
Output tab 12: Simulation graphs – elaborated while running simulation (Source: PVSyst)

ATTACHMENT X. Natural spaces currently protected under Spanish law

ESPACIOS NATURALES PROTEGIDOS
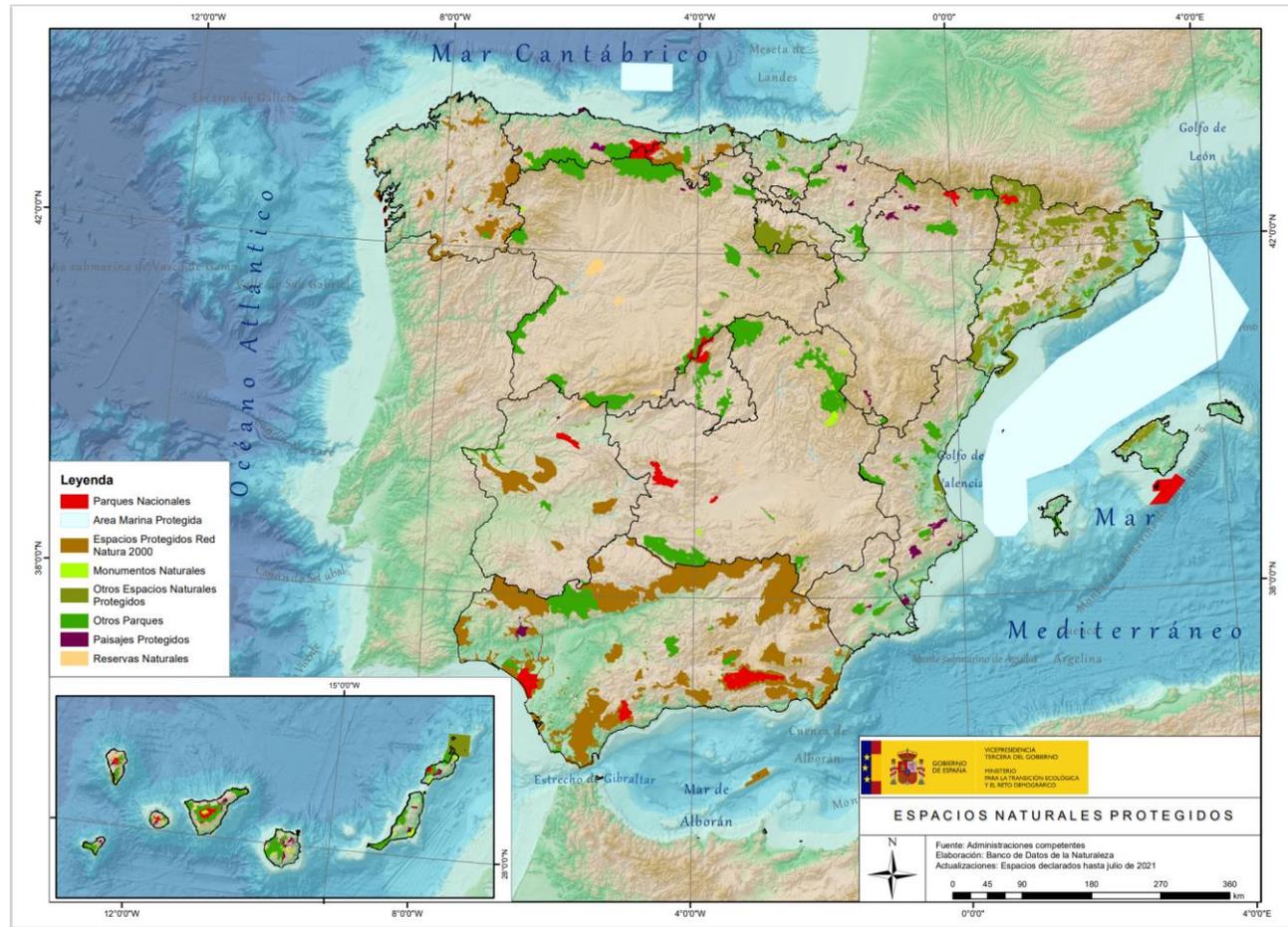
ATTACHMENT XI. Gantt diagram

Project schedule (Gantt chart). Each month is divided into 4 weeks (1–4). Blue bars (█) indicate summary/phase tasks; dark bars (▓) indicate sub-tasks; light grey (░) indicates a lighter-shaded extension.

Task	M1·1	M1·2	M1·3	M1·4	M2·1	M2·2	M2·3	M2·4	M3·1	M3·2	M3·3	M3·4	M4·1	M4·2	M4·3	M4·4	M5·1	M5·2	M5·3	M5·4	M6·1	M6·2	M6·3	M6·4	M7·1	M7·2	M7·3	M7·4	M8·1	M8·2	M8·3	M8·4	M9·1	M9·2	M9·3	M9·4	M10·1	M10·2	M10·3	M10·4	M11·1	M11·2	M11·3	M11·4	M12·1	M12·2	M12·3	M12·4
Basic Engineering	█	█	█	█	█	█	█	█																																								
Basic Project	▓	▓	▓																																													
Environmental Impact Evaluation			▓	▓	▓	▓	▓																																									
Detail Engineering									█	█	█	█	█	█	█	█																																
Civil Works									▓	▓	▓	▓	▓	▓																																		
Electrical Facilities									▓	▓	▓	▓	▓	▓	▓	▓	░	░	░	░																												
Construction and Assembly															█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█				
Roads															▓	▓	▓	▓	▓	▓																												
Ditches																					▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓												
Trackers																																	▓	▓	▓	▓	▓	▓	▓	▓								
Others																																					▓	▓	▓	▓	▓	▓	▓	▓				
Electrical Facilities															█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█				
LV cables and auxiliaries																									▓	▓	▓	▓	▓	▓	▓	▓																
MV cables and auxiliaries																																																
Electrical Substation MV/HV																	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓				
Overhead Electrical Line HV																					▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓				
PV Modules																									█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█	█				
Starting Process																																													█	█	█	█
Tests																																													▓	▓		
Provisional Reception																																																0

ATTACHMENT XII. Acronym table

Acronym	Meaning
LV	*Low Voltage*
MV	*Medium Voltage*
HV	*High Voltage*
DC	*Direct Current*
AC	*Alternating Current*
EPR	*Ethylene Propylene Rubber*
XLPE	*Cross-Linked Polyethylene*
HEPR	*Hard-grade Ethylene Propylene Rubber*
STC	*Standard Test Conditions*
PV	*Photovoltaic*
GHI	*Global Horizontal Irradiance*
DHI	*Diffuse Horizontal Irradiance*
GCR	*Ground Coverage Ratio*
EPC	*Engineering, Procurement, and Construction*
O&M	*Operation and Maintenance*
WACC	*Weighted Average Cost of Capital*
NPV	*Net Present Value*
IRR	*Internal Rate of Return*

DOCUMENT II.
PROJECT PLANS

INDEX

MATERIAL	-			Final Degree Project	
TOLERANCIA	-				
	NOMBRE	FECHA		Site view	
DIBUJADO	M.C.O				
COMPROBADO		8/4/22			
HEIGHT: 40.25 km	FIRMA:			I.C.A.I.	Nº DE LÁMINA: 1

Site view: Location and Substation

MATERIAL	-			Final Degree Project		
TOLERANCIA	-					
	NOMBRE	FECHA		Site view: Location and Substation		
DIBUJADO	M.C.O	8/4/22				
COMPROBADO						
HEIGHT: 18.10 km	FIRMA:			I.C.A.I.	Nº DE LÁMINA: 2	

DOCUMENT III.
CASH FLOW TABLES

INDEX

1. Cash flow table for years 0 to 5

Profit and Loss Account (EUR)			Year	0	1	2	3	4	5
Operating Income					4,604,676.43	4,632,101.68	4,654,913.03	4,682,466.36	4,710,105.26
-Operating Costs					504,000.00	511,560.00	519,233.40	527,021.90	534,927.23
- Generation Tax (7% on income)					322,327.35	324,247.12	325,843.91	327,772.65	329,707.37
-Amortization					2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91
Profits before tax					1,751,864.17	1,769,809.65	1,783,350.81	1,801,186.90	1,818,985.75
Free Cash Flow (EUR)			Year	0	1	2	3	4	5
=Profit before tax					1,751,864.17	1,769,809.65	1,783,350.81	1,801,186.90	1,818,985.75
- Corporation Tax (-25 %)					437,966.04	442,452.41	445,837.70	450,296.73	454,746.44
+Amortization					2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91
-Fixed Asset Investment				-31,152,040.00					
-Operating Funds Requirement Investment (7% on income)					322,327.35	324,247.12	325,843.91	327,772.65	329,707.37
-Free Cash Flow (FCF)				-31,152,040.00	3,018,055.69	3,029,595.03	3,038,154.11	3,049,602.44	3,061,016.85

2. Cash flow table for years 6 to 10

Profit and Loss Account (EUR)		Year	6	7	8	9	10
Operating Income			4,732,984.28	4,760,742.72	4,783,641.26	4,811,512.89	4,834,422.48
-Operating Costs			542,951.14	551,095.41	559,361.84	567,752.26	576,268.55
- Generation Tax (7% on income)			331,308.90	333,251.99	334,854.89	336,805.90	338,409.57
-Amortization			2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91
Profits before tax			1,832,239.34	1,849,910.42	1,862,939.63	1,880,469.82	1,893,259.45
Free Cash Flow (EUR)		Year	6	7	8	9	10
=Profit before tax			1,832,239.34	1,849,910.42	1,862,939.63	1,880,469.82	1,893,259.45
- Corporation Tax (-25 %)			458,059.83	462,477.61	465,734.91	470,117.45	473,314.86
+Amortization			2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91
-Fixed Asset Investment							
-Operating Funds Requirement Investment (7% on income)			331,308.90	333,251.99	334,854.89	336,805.90	338,409.57
-Free Cash Flow (FCF)			3,069,355.51	3,080,665.73	3,088,834.74	3,100,031.37	3,108,019.92

3. Cash flow table for years 11 to 15

Profit and Loss Account (EUR)			Year	11	12	13	14	15
Operating Income				4,862,400.63	4,890,454.90	4,913,390.15	4,941,540.87	4,969,763.26
-Operating Costs				584,912.58	593,686.26	602,591.56	611,630.43	620,804.89
- Generation Tax (7% on income)				340,368.04	342,331.84	343,937.31	345,907.86	347,883.43
-Amortization				2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91
Profits before tax				1,910,635.10	1,927,951.88	1,940,376.38	1,957,517.67	1,974,590.03
Free Cash Flow (EUR)			Year	11	12	13	14	15
=Profit before tax				1,910,635.10	1,927,951.88	1,940,376.38	1,957,517.67	1,974,590.03
- Corporation Tax (-25 %)				477,658.78	481,987.97	485,094.09	489,379.42	493,647.51
+Amortization				2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91	2,026,484.91
-Fixed Asset Investment								
-Operating Funds Requirement Investment (7% on income)				340,368.04	342,331.84	343,937.31	345,907.86	347,883.43
-Free Cash Flow (FCF)				3,119,093.19	3,130,116.98	3,137,829.88	3,148,715.30	3,159,544.00

4. Cash flow table for years 16 to 20

Profit and Loss Account (EUR)			Year	16	17	18	19	20
Operating Income				4,992,704.70	5,021,012.75	5,043,928.89	5,072,314.63	5,100,763.70
-Operating Costs				630,116.96	639,568.72	649,162.25	658,899.68	668,783.18
- Generation Tax (7% on income)				349,489.33	351,470.89	353,075.02	355,062.02	357,053.46
-Amortization				754,766.38				
Profits before tax				3,258,332.02	4,029,973.14	4,041,691.62	4,058,352.93	4,074,927.07
Free Cash Flow (EUR)			Year	16	17	18	19	20
=Profit before tax				3,258,332.02	4,029,973.14	4,041,691.62	4,058,352.93	4,074,927.07
- Corporation Tax (-25 %)				814,583.01	1,010,422.90	1,010,422.90	1,014,588.23	1,018,731.77
+Amortization				754,766.38				
-Fixed Asset Investment								
-Operating Funds Requirement Investment (7% on income)				349,489.33	351,470.89	353,075.02	355,062.02	357,053.46
-Free Cash Flow (FCF)				2,849,026.07	2,671,008.96	2,678,193.69	2,688,702.67	2,699,141.84

5. Cash flow table for years 21 to 25

Profit and Loss Account (EUR)			Year	21	22	23	24	25
Operating Income				5,123,650.32	5,152,165.03	5,175,000.43	5,203,571.94	5,232,197.38
-Operating Costs				678,814.92	688,997.15	699,332.10	709,822.09	720,469.42
- Generation Tax (7% on income)				358,655.52	360,651.55	362,250.03	364,250.04	366,253.82
-Amortization								
Profits before tax				4,086,179.87	4,102,516.33	4,113,418.30	4,129,499.82	4,145,474.15
Free Cash Flow (EUR)			Year	21	22	23	24	25
=Profit before tax				4,086,179.87	4,102,516.33	4,113,418.30	4,129,499.82	4,145,474.15
- Corporation Tax (-25 %)				1,021,544.97	1,025,629.08	1,028,354.57	1,032,374.95	1,036,368.54
+Amortization								
-Fixed Asset Investment								
-Operating Funds Requirement Investment (7% on income)				358,655.52	360,651.55	362,250.03	364,250.04	366,253.82
-Free Cash Flow (FCF)				2,705,979.38	2,716,235.70	2,722,813.69	2,732,874.83	2,742,851.79

6. Cash flow table for years 26 to 30

Profit and Loss Account (EUR)			Year	26	27	28	29	30
Operating Income				5,254,963.88	5,283,632.69	5,306,319.47	5,335,021.84	5,363,767.62
-Operating Costs				731,276.46	742,245.61	753,379.29	753,379.29	764,679.98
- Generation Tax (7% on income)				367,847.47	369,854.29	371,442.36	373,451.53	375,463.73
-Amortization								
Profits before tax				4,155,839.95	4,171,532.80	4,181,497.82	4,208,191.02	4,223,623.91
Free Cash Flow (EUR)			Year	26	27	28	29	30
=Profit before tax				4,155,839.95	4,171,532.80	4,181,497.82	4,208,191.02	4,223,623.91
- Corporation Tax (-25 %)				1,038,959.99	1,042,883.20	1,045,374.46	1,052,047.76	1,055,905.98
+Amortization								
-Fixed Asset Investment								
-Operating Funds Requirement Investment (7% on income)				367,847.47	369,854.29	371,442.36	373,451.53	375,463.73
Free Cash Flow (FCF)				2,749,032.49	2,758,795.31	2,764,681.00	2,782,691.74	2,792,254.20