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SIZING OF A GRID- CONNECTED PHOTOVOLTAIC SYSTEM FOR YEARLY NET SELF-SUFFICIENT ENERGY SUPPLY

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DIPLOMA THESIS

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SELF-SUFFICIENT ENERGY SUPPLY

Diploma Thesis

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ABSTRACT

The objective of this thesis is the generation of electricity from solar energy for yearly net self-sufficient supply of a household with electricity. Therefore, it is the aim to design a solar photovoltaic installation connected to grid with a consumption of 5000 kWh per year.

The main objective is to study and compare two aforementioned PV plants located two places, where the weather conditions and solar irradiation are completely different: one location is Maribor, in Slovenia, and the other is Murcia, in the south of Spain.

The thesis defines the technical conditions of the installation from solar radiation recorded in the chosen locations.

Like points to emphasize in the thesis, may be considered data obtained from PVSYST to size the installation program.

It is important to carry out these projects if we want to achieve a sustainable energy supply. They should be aligned with policies that promote efficiency and energy saving. However, further investigations to improve the utilization of solar energy and other renewable energies should be performed as well.

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1. Introduction

The increasing and continuing degradation of the environment, due to emissions of greenhouse gases such as CO₂ from the massive use of fossil fuels, gives renewable energy a key role in the sustainable development of our planet.

That is why, especially during the last decade renewable energies, such as wind or solar photovoltaics, are proliferating, being the beginning of the last the conversion of solar radiation incident on the solar cells into electrical current (DC) thanks to semiconductor material, which is made of silicon. It is also about forms of energy that are being applied in many cases, consumption, or the design of microgrids, applications that are not greatly advanced today, but due to the economic aid, which often comes with and the need for a change of energy consumption mode, are steadily advancing.

A photovoltaic system is the set of electric and electronic equipment that produces electrical energy from solar radiation. The main component of this system is the photovoltaic module, composed of solar cells that can transform light energy into electrical energy. Broadly speaking, photovoltaic systems can be classified into three groups: grid connected, off-grid and pumping.

The grid connected systems produce electric power to be injected entirely on the conventional electricity network. Since they must not satisfy any consumer demand directly or warrant it, they do not need to incorporate energy storage equipment. In this thesis, two photovoltaic plants, suitable for a yearly net self-sufficient energy supply of a household with an average consumption of 5000 kWh, located in Maribor and Murcia, are going to be studied and compared

The Meteonorm software will be used to export radiation data for Maribor and Murcia, whilst the PVSYST software will be used to calculate power generation.

The final purpose of this thesis is to obtain the size of the installation and the number of modules required designed, considering local irradiation data. The yearly energy produced by the photovoltaic systems should be in par with yearly energy consumption of a household, which is 5000 kWh.

The thesis is going to be developed following the next structure:

Solar Energy

In this part we will give the theoretical background of solar energy. The PV systems and technologies will be discussed together with their rapid spread to new markets and current energy model. The evolution of renewable energy in Spain will be analyzed. Finally, we will focus on PV global capacity.

Photovoltaic Effect and Solar radiation

In this part we will describe Photovoltaic Effect and then we will deepen into solar radiation with its solar constant, depending of the distance Sun-Earth.

Description of Installation Elements

First, we will describe a grid-connected PV system followed by the description of elements that make the system.

Installation design

The analysis of local conditions and the designs of the two PV plants, one in Maribor and the other one in Murcia, will be presented in this chapter.

Conclusion:

This final chapter will be dedicated to the conclusions drawn from the thesis development.

2. Solar energy

Solar energy is mainly used in two ways:

- Direct conversion into electricity: takes place in semiconductor devices called solar cells.
- Accumulation of heat in solar collectors.

The direct conversion of solar radiation into electricity is often described as a photovoltaic (PV) energy conversion, because it is based on the photovoltaic effect. In general, the photovoltaic effect means the generation of a potential difference at the junction of two different materials in response to visible or other radiation. The whole field of solar energy conversion into electricity is therefore denoted as the “photovoltaics”.

Developing the PV solar energy is a clean and environmentally friendly energy source. The motifs that were behind the development and application of the PV solar energy were in general the same as for all renewable energy sources, and were based on the prevention of climate change and environment consciousness, and providing clean energy for people. There are three main categories in which we can divide PV development interest: energy, ecology and economy.

Energy

There is a growing need for energy in the world and since the traditional energy sources based on the fossil fuels are limited and will be exhausted in future. PV solar energy is considered as a promising energy source candidate. Large-scale application of PV solar energy will also contribute to the diversification of energy sources resulting in more equal distribution of energy sources in the world.

Ecology

Large-scale use of PV solar energy could lead to a substantial decrease in the emission of gases such as CO₂, SO_x and NO_x coming from fossil fuels. The contribution of the PV solar energy to the total energy production in the world is very small; at present, the total installed power is estimated to be 1.6×10^{10} kW, compared to 1.0×10^6 kWp installed PV power worldwide. With an annual growth of PV solar energy production around 15%, it is expected that in year 2050 solar cells would produce 2.0×10^8 kWp.

Economy

Solar cells and solar panels are already on the market. An advantage of the PV solar energy is that it is a modular technology, and can be combined in such a way that they fit exactly the required power. Reliability, little operations and maintenance costs, as well as modularity and expandability, are enormous advantages of PV solar energy.

Around two billion people, mostly in rural areas, have no access to electricity; for them, PV technology is the most cost effective solution.

Some of the advantages and drawbacks of the PV solar energy are the following:

Advantages:

- Environmentally friendly
- No noise, no moving parts
- No emissions
- No use of fuel or water
- Minimal maintenance
- Long lifetime, up to 30 years
- Electricity is generated wherever there is light
- PV operates even in cloudy weather conditions
- Modular or “custom-made” energy can be designed for any application, from small PV farms to big multi-megawatts power plant.

Drawbacks:

- PV cannot operate without light
- High initial costs
- Large areas needed for large scale applications
- PV generates direct current: special DC appliances or inverters are required
- Off-grid applications require energy storage, such as batteries, which are expensive [1]

2.1. Photovoltaic (PV) system

The solar energy conversion into electricity takes place in a semiconductor device called solar cells. Solar cells provide electrical power under certain voltage and current conditions. To make solar electricity practical, a certain number of solar cells are connected together to form a solar panel, also called a PV module. For large scale generation, solar panels are connected together into a solar array.

Solar panels are part of a complete PV solar system, which, depending on the application, comprises batteries for electricity storage, dc/ac inverters that connect a PV solar system to the electrical grid, transformers, and other miscellaneous electrical components and elements. These additional parts of the PV solar system form a second part of the system that is called Balance of System (BOS).

2.2. Photovoltaic technologies

The first practical use of solar cells was in the aerospace industry, in 1958. These first solar cells were made from single crystal silicon wafers and had efficiency of 6 %. The energy crisis in the seventies of the 20th century accelerated a search of new energy sources, resulting in a growing interest for PV solar energy. The major obstacles were the higher energy price of the solar electricity when compared to the price of electricity generated from the traditional sources. In order to increase the efficiency of solar cells and to lower their price, the crystalline silicon solar cell technology has improved dramatically in the past twenty years and today it is the dominant solar cell technology. Examples of crystalline silicon solar cell technology are the single crystal silicon wafer-based solar cells, and also multicrystalline silicon solar cells. Both technologies that deal with “bulk” crystalline silicon are considered the first generation solar cells for terrestrial applications. As this technology has matured, costs have become increasingly dominated by material costs, namely those of the silicon wafer, the glass cover sheet, and encapsulants.

In order to decrease the material costs, research has been directed to develop low cost thin-film solar cells, which represent a second generation solar cells for terrestrial application. The efficiency of commercial second generation solar modules is likely to reach 15%.

Conversion efficiency has to be increased substantially in order to progress further. Calculations based on thermodynamics demonstrate that the limit on the conversion efficiency of sunlight to electricity is 93% as opposed to the upper limit of 33% for a single junction solar cell, such as a silicon wafer and most present thin-film solar cells. This suggests that the performance of solar cells could be improved 2-3 times when different concepts were used to produce a third generation of high efficiency, thin-film solar cells [1].

2.3. Solar PV: rapid spread to new markets

Solar PV is starting to play a substantial role in electricity generation in some countries as rapidly falling costs have made unsubsidised solar PV-generated electricity cost-competitive with fossil fuels in an increasing number of locations around the world. In 2014, solar PV marked another record year for growth, with an estimated 40 GW installed for a total global capacity of about 177 GW.

China, Japan, and the United States accounted for the vast majority of new capacity. Even so, the distribution of new installations continued to broaden, with Latin America seeing rapid growth, significant new capacity added in several African countries, and new markets picking up in the Middle East. Although most EU markets declined for the third consecutive year, the region—particularly Germany—continued to lead the world in terms of total solar PV capacity and contribution to the electricity supply.

The solar PV industry recovery that began in 2013 continued in 2014, thanks to a strong global market. Consolidation among manufacturers continued, although the flood of bankruptcies seen over the past few years slowed to a trickle. To meet the rising demand, new cell and module production facilities opened (or were announced) around the world [2].

2.4. Current energy model

As we all know the current energy model we are using in today's society, especially in more developed countries, is not the most optimal, since the current rate of growth we have, we could soon reach the depletion of fossil resources that the earth has been stored for millions of years, and we are wasting in just a few decades.



Figure 1. Global light pollution.

Even before the exhaustion of fossil raw materials, increased economic conflicts over scarce natural resources seems inevitable due to the convergence of two opposing trends: decreasing availability of fossil fuels and the increase in consumption (especially in those countries with a strong economy). Therefore, the current scheme of energy consumption, both in Spain and globally, is simply not sustainable, namely cannot be maintained indefinitely.

Figure 1 shows the global light pollution, where a large heterogeneity between developed countries and populated can be seen, with developing countries or very small populations.

On the other hand, the mass consumption of oil is producing changes in the global atmosphere. The carbon dioxide levels currently detected are significantly higher than those that existed in 1950. This produces the well-known greenhouse effect, which causes an increase in average temperatures worldwide, and arguably that we are experiencing a serious and long climate crisis, as well as economic.

2.4.1. *Kyoto Protocol*

In 1997 the industrialized countries agreed, in the city of Kyoto, to implement a series of measures to reduce greenhouse gases. Signatory governments agreed to reduce by 5% on average emissions between 2008 and 2012, with reference to the levels of 1990. The agreement came into force in February 2005, after ratification by Russia in November 2004.

The main objective is to reduce the climate change caused by humans whose base is the greenhouse effect. According to UN¹ estimates, it is expected that the average temperature of the planet's surface increase between 1.4 and 5.8 ° C by 2100, although the winters are colder and violent. This is known as global warming.

According to the Kyoto Protocol, Spain promised to limit the growth of emissions of six gases covered (CO₂, CH₄, N₂O, HFCs, PFCs and SF₆) by 15% in the commitment period 2008-2012 regarding the emissions by 1990. But it was the member country least likely to fulfill the agreement.

2.4.2. *Prospects to assume*

The global solution is, as we have previously explained the Kyoto protocol, but its need that developing countries and the industrialized, perform the agreement. Therefore, we must adopt a series of measures individually, rather than collectively. These measures are basic and very easy to follow: efficiency, energy saving and renewable energy utilization.

Efficiency means that we must use products or production measures that offer us high performance, because although tend to be more expensive, they end up turning out to be more economical in the long run. A clear example is the energy saving bulbs, class A household appliances or efficient building construction.

Saving means making good use of energy, i.e. not to waste anything of this energy, making small everyday acts such as not using the stand-by household appliances (consumption 2% of all electricity in Spain in 2007) or using light bulbs. So we get 100% optimize all energy production that takes place in Spain.

Renewable energy, as a whole, are those that have an inexhaustible potential: waterfalls, solar radiation, tides, winds, etc.

Thus renewable energies are all those clean and unlimited duration energies such as hydro, photovoltaic, thermal, biomass and wind. These energies are based on the use of solar radiation to produce electricity through silicon, heat production for thermal

¹ UN: The United Nations is an international organization founded in 1945. It is currently made up of 193 Member States. The mission and work of the United Nations are guided by the purposes and principles contained in its founding Charter.

processes, burning energy stored such as in the case of biomass or by carrier fluids such as water or air.

The use of these energies could slow the process of global warming and minimize the energy dependence of countries and people, and contribute to greater efficiency in certain industrial processes. This would help us reach a sustainable energy scenario and ensure the quality of life of future generations.

2.5. Consumption evolution of renewable energy in Spain

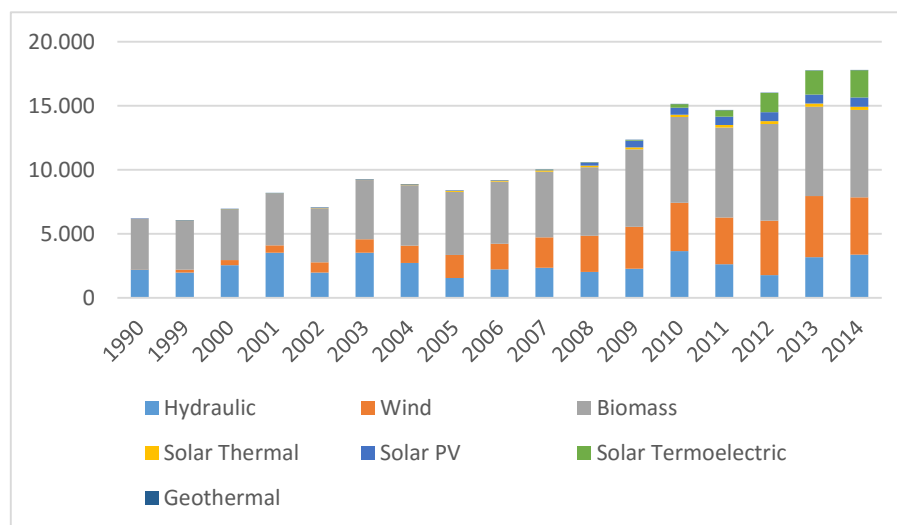


Figure 2. Consumption evolution of renewable energy in Spain (ktoe)

Since 2000, the renewable energy consumption has more than doubled, following a trend of continuous growth. The composition of renewable resources in so far this century has also undergone significant changes.

While in 2000 biofuels (biomass, biogas, solid waste and biofuels) and hydropower clearly dominated the renewable supply, with a market share of 57% and 37%, respectively, in 2014 a greater diversity is observed technologies.

Biofuels continue dominating the renewable market, although the incorporation and expansion of new technologies such as wind or solar thermoelectric have involved a significant reduction in the share of the first of nearly 19%.

Also hydropower, despite the high availability of resources registered in 2014, that year represented 18% less in market share compared to that in 2000.

Wind power has become the second technology in terms of participation in the primary consumption of renewable resources, rising from about 6% in 2000 to 25% in 2014.

Regarding solar, solar thermal has evolved from 0.4% in 2000 to 1.5% of renewable primary consumption in 2014, multiplying by more than three times their share of renewable energy mix; photovoltaics, with very little presence at the beginning of the century, reached in 2014 4% of primary energy and renewable solar technology thermoelectric, which in 2000 had no facilities in operation now accounts for 12% of renewable inputs the demand for primary energy.

Finally, geothermal energy, despite progress in recent years, represents only 0.1% of primary demand for renewable energy [3].

2.6. Solar PV Global capacity

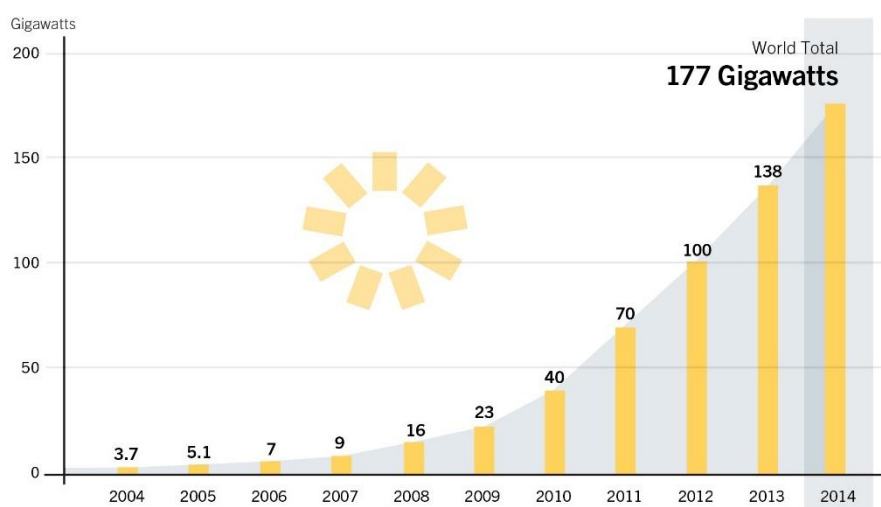


Figure 3. Solar PV Global capacity (2004-2014) [2]

We can see that the installation of solar energy around the world has experienced an exponential increase in recent years. By the end of 2014 there was a global solar capacity of 177 GW, which means an increase of 173.3 GW since 2004.

The year 2014 marked the 60th anniversary of the first public demonstration of a solar PV cell. The strong market in 2014 came despite the substantial decline in new installations in the European Union, challenges reaching targets (particularly for distributed systems) in China, and slower-than-expected emergence of promising new markets. More than 60% of all PV capacity in operation worldwide at the end of 2014 was added over the past three years.

Once again, the top three markets were China, Japan, and the United States, followed by the United Kingdom and Germany. [2]

3. Photovoltaic Effect and Solar radiation

3.1. Photovoltaic Effect

The energy conversion of solar radiation into electrical energy is a physical phenomenon known as the photovoltaic effect. When sunlight is incident on certain materials called semiconductors, photons are able to transmit their energy to the valence electrons of the semiconductor to break the bond that keeps them bonded to the respective atoms, leaving a free electron to circulate within the solid by each broken bond. The lack of electron in the broken bond, called a gap, can also move freely inside the solid, being transferred from one atom to another due to the displacement of electrons remaining bonds.

Gaps behave in many ways like positively charged particles equal to that of the electron. The movement of gaps and electrons in opposite directions generates an electric current in the semiconductor capable of circulating in an external circuit. To separate the electrons and gaps thus prevent restore the bond, an electric field which causes their movement in opposite directions is used, resulting in said electric current. In solar cells this electric field is achieved in joining two regions of a semiconductor crystal of conductivities of different types.

For silicon solar cells, one of the regions (type region "n") is doped with phosphorus. The procedure is performed by replacing some silicon atoms per phosphorus atoms. As a chemical element silicon has 14 electrons of which 4 are valence, being available to join with valence electrons from other atoms. Phosphorus has 5 valence electrons. And four of them will be used to carry out chemical bonds with adjacent silicon atoms, while the fifth atom may be separated by stimulation provided by an external source of energy.

The other region (region type "p") is doped with boron, which has 3 valence electrons, so it will be a region with as many gaps and electrons. Thus an electric field directed from the region "p" to the region "n" due to differences in concentrations of gaps and electrons occurs.

If we focus a little more on the physical principle, what happens is that solar radiation is composed of elementary particles called photons. Such particles carry a value associated energy, which depends on the wavelength of the radiation. The relationship between these parameters is shown below [4][5].

$$E = \frac{h \cdot c}{\lambda}$$

Where:

- E : energy of photon (J)
- h : Plank constant (J·s)

- c : lightning speed ($3 \cdot 10^8$ m/s)
- λ : wavelength (m)

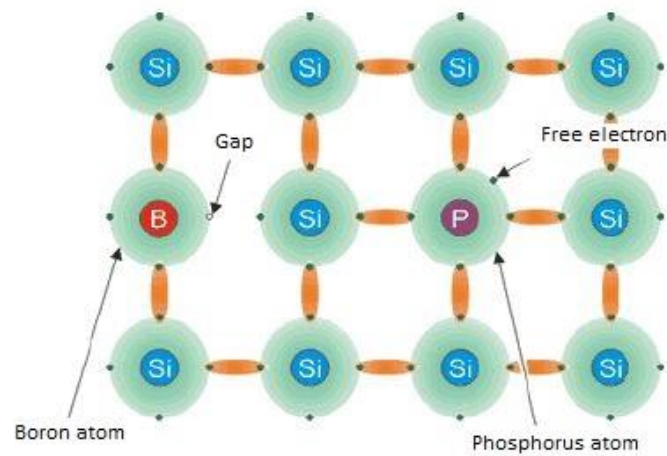


Figure 4. Atomic structure of a solar cell.

3.2. Solar radiation

3.2.1. Solar constant

The irradiance coming from the Sun that is received on a perpendicular surface can be considered as constant and equal to 1350 W/m^2 (data accepted by NASA in 1971). This is the value of the solar constant.

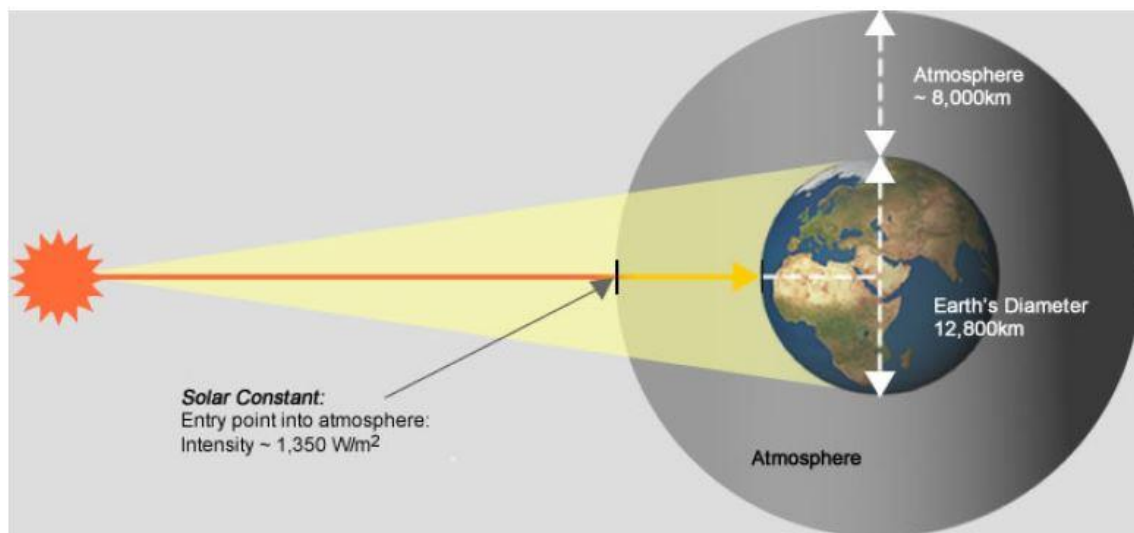


Figure 5. Solar constant [6].

The solar constant is a defined magnitude to determine the flow of energy received per unit perpendicular to solar radiation, at an average distance from Earth to the Sun, and located outside any atmosphere surface. The Earth-Sun distance is variable due to

the elliptical orbit that takes the Earth, so to calculate the solar constant has to be considered an average distance.

It can be considered that the sun is a constant source of energy, since several studies have shown that the variation of energy from the sun during a solar cycle (about 22 years) is less than 1%. These variations, as long as affect the design of a photovoltaic system can be said to be affected more by the effect of weather variations rather than solar cycles.

3.2.2. Sun-Earth distance

As already mentioned, the distance between the Sun and Earth varies throughout the year because of the elliptical orbit that takes the Earth. The eccentricity of the elliptical orbit can be calculated as:

$$e_0 = 1 + 0,33 \cdot \cos \frac{360 \cdot d_n}{365}$$

Being d_n the day of the year ($1 \leq d_n \leq 365$).

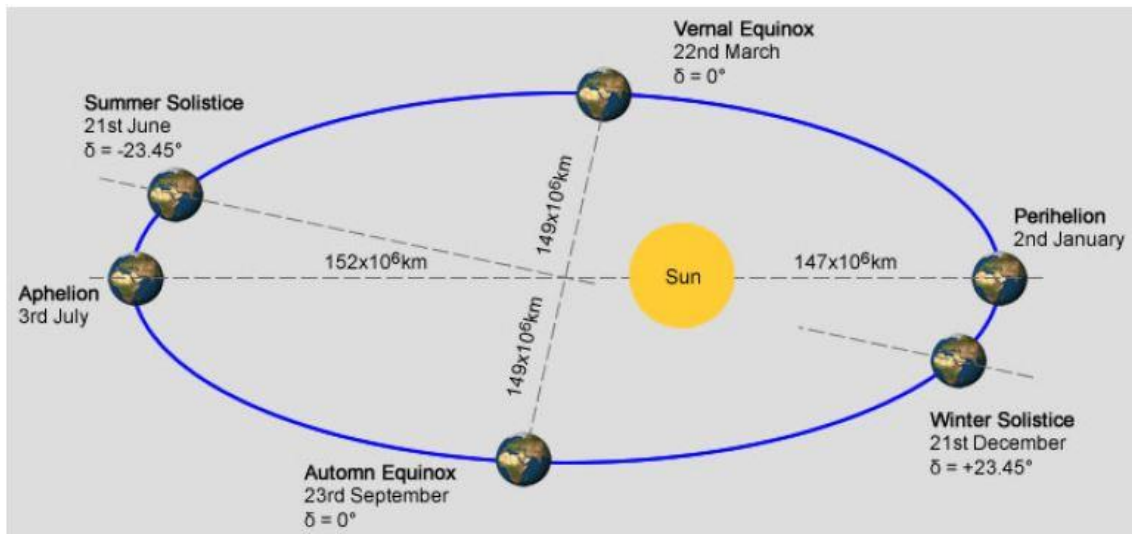


Figure 6. Changes due to the eccentricity in Earth's orbit [6].

This distance is important because when you have a light source emitting in all directions, the energy flow varies inversely with the square of the distance from the emission source.

3.2.3. Solar radiation

To reach the Earth's surface solar radiation must pass through the atmosphere, where it undergoes various phenomena of reflection, absorption and diffusion which

reduce the final energy received. The global radiation incident on an inclined surface on the Earth's surface can be calculated as the sum of three components: direct, diffuse and albedo component (or reflected).

- **Direct sunlight:** "solar radiation incident on a given plane from a small solid angle centered on the solar disk." It can also be defined as the radiation coming directly from the sun.
- **Diffuse sunlight:** "difference between hemispherical solar radiation and direct sunlight". Or radiation prior to reaching the surface is absorbed and diffused by the atmosphere.
- **Hemispheric sunlight:** "solar radiation incident on a plane surface given, received from a solid angle of 2π sr (the hemisphere situated above the surface). Must specify the inclination and azimuth of the receiving surface. "
- **Reflected radiation:** radiation, from reflection of solar radiation on the ground and other objects, falls on a surface. Reflection depend on the characteristics and nature of the reflective surface (albedo).
- **Global solar radiation:** "hemispherical solar radiation received on a horizontal plane" [7].

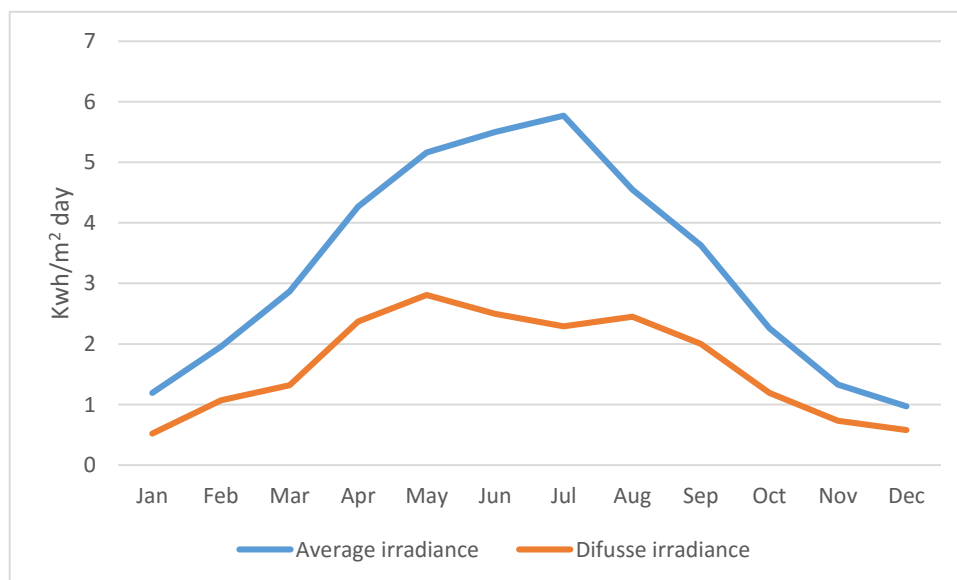


Figure 7. Global and diffuse irradiance on a horizontal surface in Maribor (own creation)

4. Description of Installation Elements

4.1. Definition of a grid connected photovoltaic system

A PV system connected to the grid is a system whose function is to produce electric energy in suitable conditions to be injected into the conventional electricity network. As shown in figure 8, it consists of photovoltaic generator, a DC/AC converter called inverter and a set of electrical protections.

The energy produced by this system will be partially or totally consumed nearby, and the excess energy will be fed into the grid for distribution to other consumers.

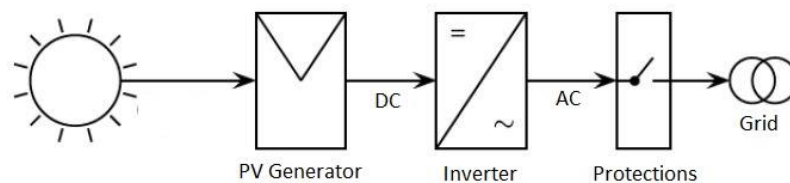


Figure 8. Grid-Connected PV system scheme.

4.2. Photovoltaic module

The photovoltaic module is a unit that provides support for a number of electrically connected photovoltaic cells. The right choice of them will largely determine the final production of the installation. Therefore, a brief introduction to them will be made:

4.2.1. PV cells

The modules are made up of a set of electrically connected photovoltaic cells that produce electricity from photovoltaic effect. Solar cells are manufactured from semiconducting materials. When light falls on them, photons are able to transmit their energy to the valence electrons to break the bond that keeps them bonded to the respective atoms. Each broken bond is a free electron, which moves freely inside the semiconductor [5].

There are several classifications of photovoltaic cells:

By type of material used:

- **Simple material:** especially silicon, but also Germanium and Selenium. Germanium has a lower bandwidth than silicon, so it is suitable for absorbing longer wavelengths, such as infrared light.

- **Binary compounds:** CdTe, GaAs, InP, CdS, Cu₂S (materials from the periodic table groups III and IV).
- **Ternary compounds:** AlGaAs, and compounds based on chalcopyrite structure Cu as CuInSe₂, CuInS₂ and CuInTe₂. Highlight the first for its practical use and good performance.
- **Others**

By the internal structure material:

Monocrystalline: silicon cell processed as a single crystal. Good efficiency (silicon cell which has higher efficiency) but high manufacturing cost due to the high purity and the large amount of silicon.

- **Polycrystalline:** During cooling silicon in a mold, several crystals are formed. The cell is of bluish aspect, but not uniform, different colors created by the various crystals are distinguished.
- **Amorphous:** only applicable to silicon. Although the absorption coefficient is 40 times that of monocrystalline silicon, its performance is even lower than in multicrystalline (8-10%). But its manufacturing cost is lower.

By the device structure:

- **Homogenous bond:** p-n union is created on a single material dopant diffusion from opposite sides of the cell.
- **Heterogeneous bond:** material on both sides of p-n union are different.
- Depending on the number of p-n bonds.
- Depending on the number of devices used in the same cell.

By the type of application:

- Cells for terrestrial applications without concentration.
- For building integration.
- For terrestrial applications concentration.
- For special applications.

4.2.2. PV Module structure

PV modules act as support base of photovoltaic cells, in addition to giving them the necessary protection by proper encapsulation. The structure of the modules can be seen in Figure 9 [5].

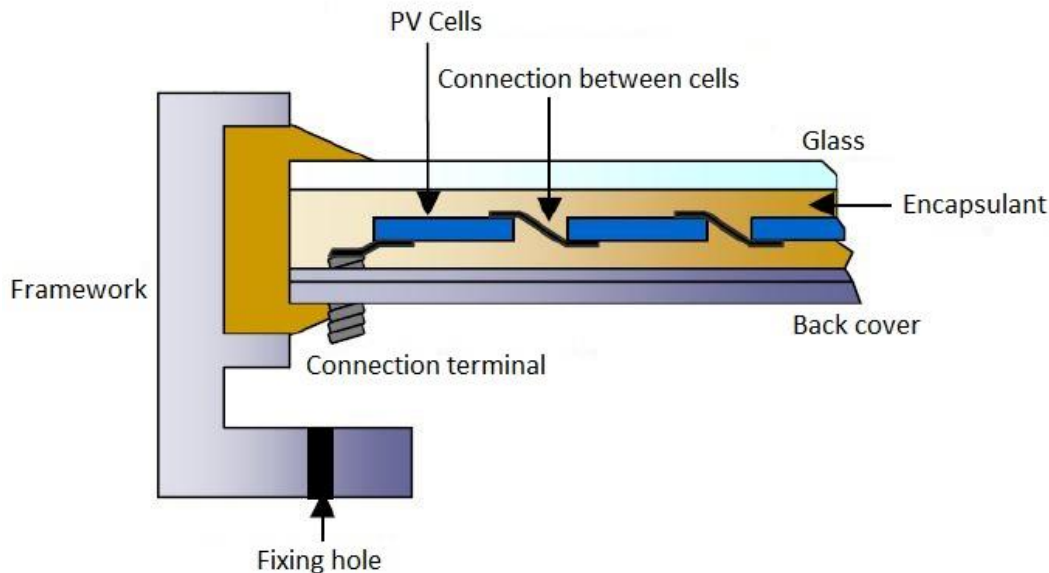


Figure 9. Module structure.

- **Front cover:** It must have a high transmission in the wavelength range and a low reflection from the front surface to maximize the solar energy conversion. Besides, the material must be waterproof, have good impact resistance, have a low thermal resistivity and be stable to prolonged UV exposure. This front cover, also has as its main function, giving rigidity and hardness mechanical module.
- **Encapsulant:** responsible for giving adhesion between cells, the front surface and the back of the module. The most commonly used is the EVA (ethylene-vilin acetate).
- **Back cover:** it must be impermeable and low thermal resistance.
- **Solar cells and connections:** are usually made of aluminum or stainless steel.
- The edges of the block are protected with a neoprene sleeve and the whole is embedded in an aluminum frame, bonded with silicone, which provides mechanical strength. In the back of the module is the connection box with two terminals (positive and negative) to enable the connection of the modules.

4.3. Inverter

Inverters are responsible for the conversion of direct current from photovoltaic modules to alternating current for electric transport network.

A fundamental requirement for inverters is a high performance, for any value of the input signal as it will depend on the irradiation the modules receive. For this reason, it is essential that inverters have a low consumption and are well adapted to the load to be fed, so that most of the time work in conditions of high efficiency.

5. Installation design

The objective of this thesis is to analyze and compare two photovoltaic solar installations located in zones with totally different weather conditions, such as Maribor (Slovenia) and Murcia (Spain). Each of them should yearly produce 5000 kWh of electric energy which is enough to provide yearly net self-sufficient energy supply of a household.

5.1. Situation and location

The exact locations selected for this analysis are:

5.1.1. Maribor PV Plant:

Geographical coordinates:

- Latitude: $46^{\circ}32'5,24''$ S
- Longitude: $15^{\circ}38'24,17''$ W



Figure 10. Maribor location.

5.1.2. Murcia PV Plant:

Geographical coordinates:

- Latitude: $37^{\circ}59'49,8''$ S
- Longitude: $1^{\circ}6'36,42''$ W

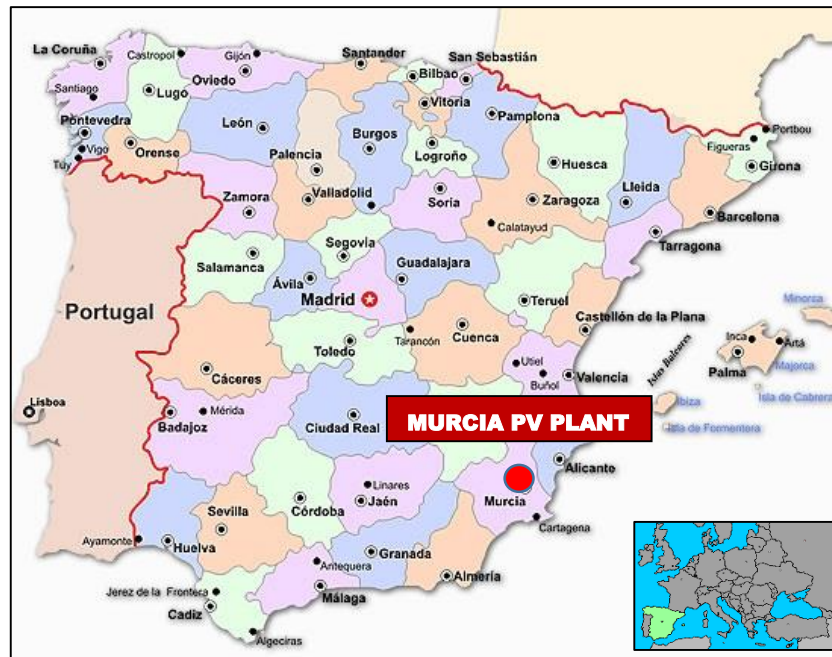


Figure 11. Murcia location.

5.2. Weather

The calculations of electric energy production are based on meteorological data provided by the program called Meeonorm, which is a comprehensive climatological database for solar energy applications. It comprises not only numerous databases from all parts of the world, but also a large number of computational models developed in international research programs.

Meeonorm is primarily a method for the calculation of solar radiation, on arbitrarily orientated surfaces, and at any desired location.

5.2.1. Maribor

Maribor has a humid continental climate, bordering on oceanic climate. Average temperatures hover around zero degrees Celsius during winter. Summer is generally warm. Average temperatures during the city's warmest month (July) exceed 20 degrees Celsius. The city sees on average roughly 900 mm of precipitation annually, and it's one of the sunniest Slovene cities, with an average of 266 sunny days throughout the year.

Table 1 and figures 12 to 17 show the irradiation and temperature data for this city [8]:

Table 1. Maribor Solar radiation and Temperature.

	Gh kWh/m ²	Dh kWh/m ²	Bn kWh/m ²	Ta °C	Td °C	FF m/s
January	37	16	72	-0,8	-3,8	1,8
February	55	30	65	1,8	-2,7	2,1
March	89	41	97	5,9	0	2,5
April	128	71	98	11	4,3	2,4
May	160	87	117	16,2	9,2	2,1
June	165	75	138	19,4	12,4	2,1
July	179	71	166	20,8	13,7	2
August	141	76	111	20,2	14	1,7
September	109	60	96	15,1	10,4	1,7
October	70	37	76	11,2	7,6	1,8
November	40	22	58	6,1	2,9	2
December	30	18	46	0,7	-2	1,8
Year	1201	604	1141	10,6	5,5	2

Where:

- *Gh*: Horizontal Global Irradiation (kWh/m²)
- *Dh*: Horizontal Diffuse Irradiation (kWh/m²)
- *Bn*: Irradiation of the Normal Direct Radiation (kWh/m²)
- *Ta*: Ambient Temperature (°C)
- *Td*: Temperature Difference (max-min) (°C)

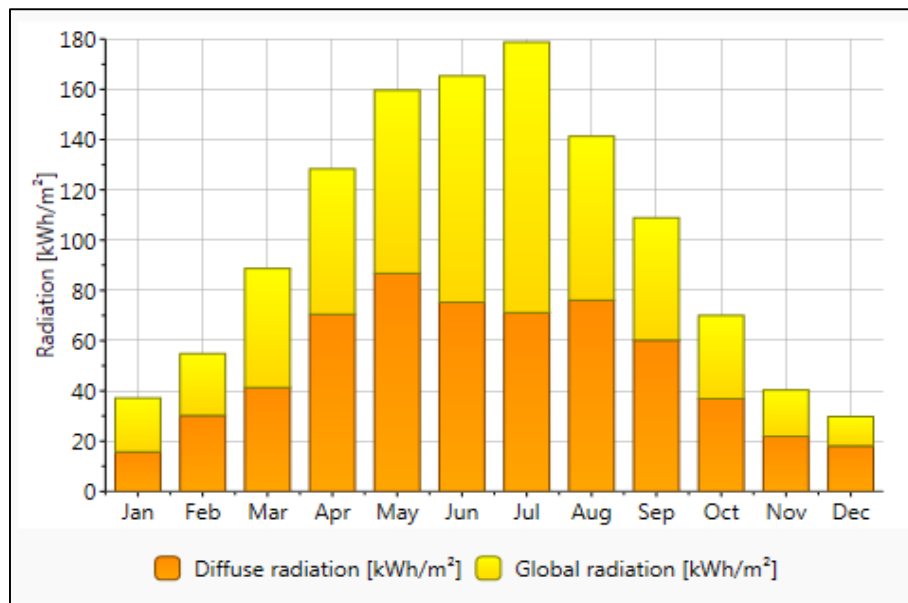


Figure 12. Maribor Solar Radiation.

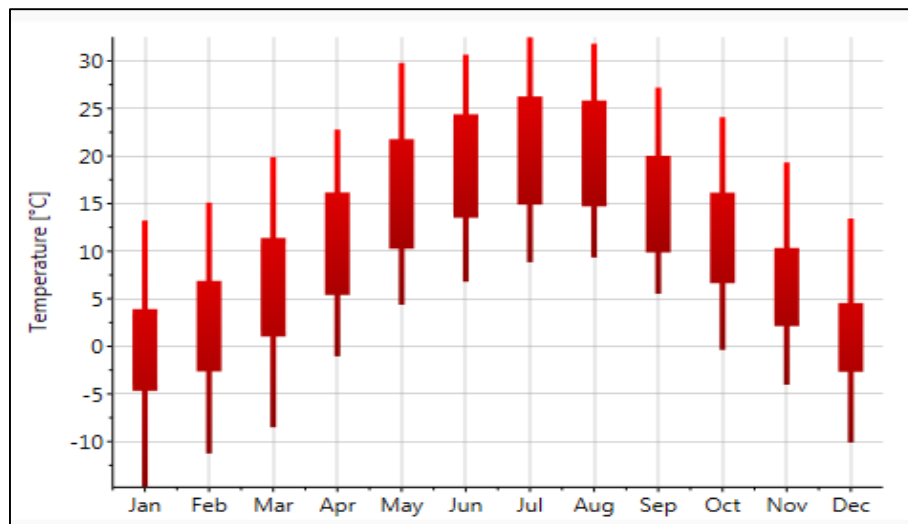


Figure 13. Maribor Temperature.

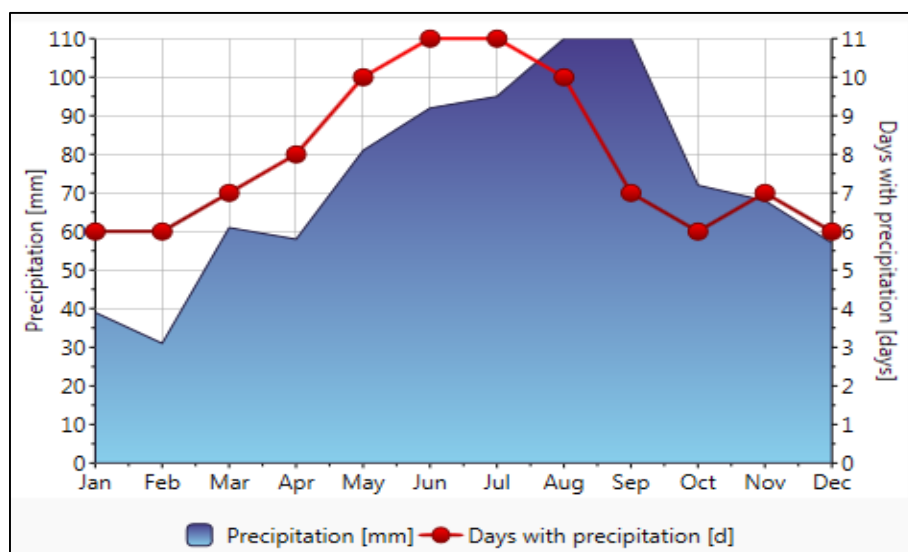


Figure 14. Maribor precipitation.

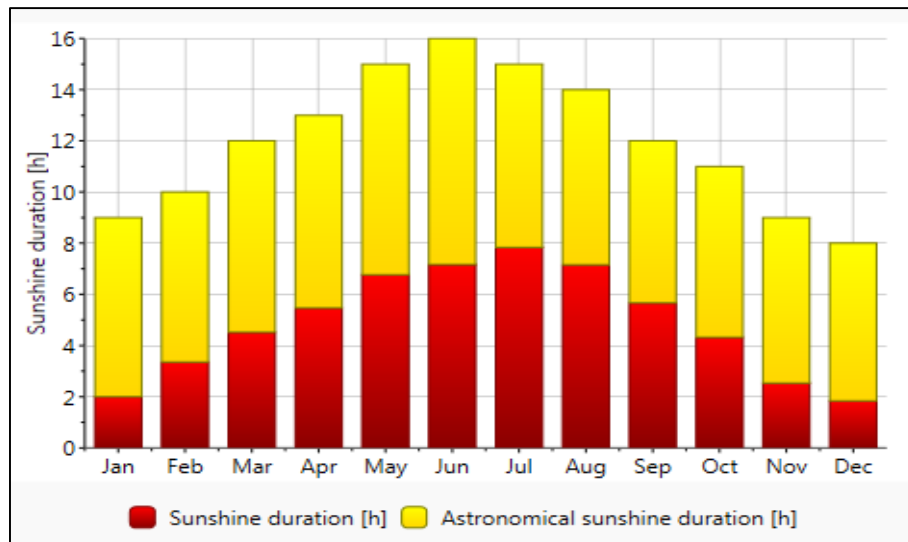


Figure 15. Maribor Sunshine duration.

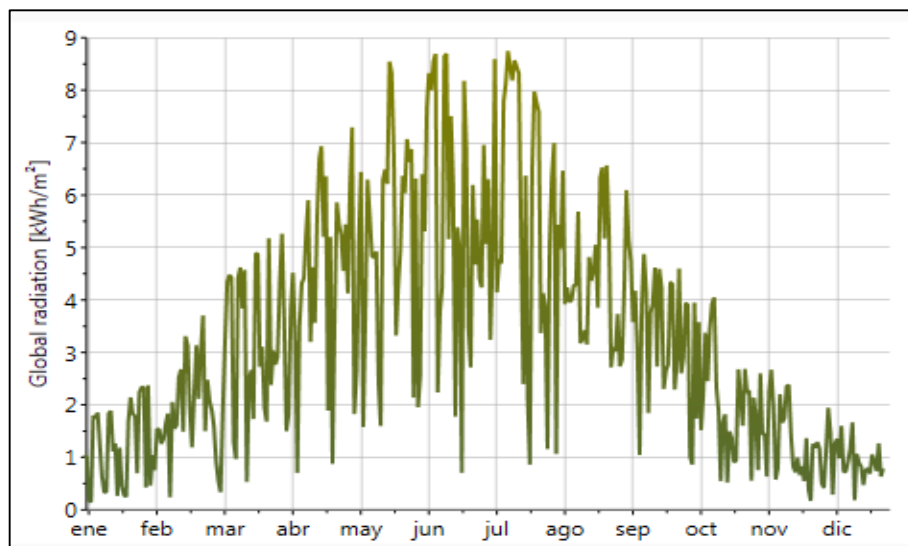


Figure 16. Maribor daily global radiation.

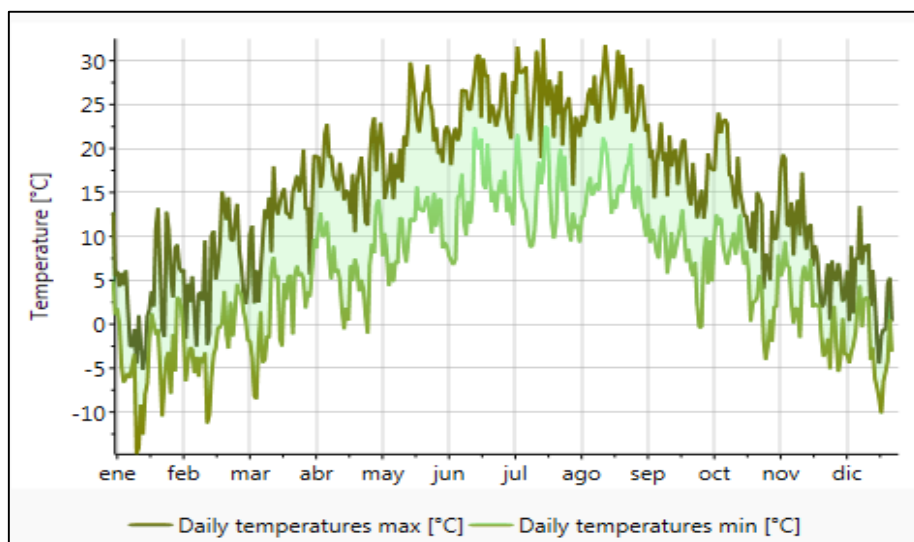


Figure 17. Maribor Daily temperature.

5.2.2. Murcia

Murcia has a hot subtropical semi-arid climate with Mediterranean influence. Given its proximity to the Mediterranean Sea. It has mild winters and hot summers.

It averages more than 320 days of sun per year. Occasionally, Murcia has heavy rains where the precipitation for the entire year will fall over the course of a few days.

In the coldest month, January, the average temperature range is maximum of 16.6 °C (62 °F) during the day and a minimum of 4.7 °C at night. In the warmest month, August, the range goes from 34.2°C during the day to 20.9°C at night. Temperatures almost always reach or exceed 40°C on at least one or two days per year.

Table 2 and figures 18 to 23 show the irradiation and temperature data for this city [8]:

Table 2. Murcia Solar Radiation and Temperature.

	Gh kWh/m ²	Dh kWh/m ²	Bn kWh/m ²	Ta °C	Td °C	FF m/s
January	76	32	111	10,8	4,1	1,9
February	93	39	110	12,2	5,4	2
March	141	53	156	15,1	6,3	2,5
April	177	61	182	17,3	7,8	2,5
May	206	75	194	20,9	11	2,5
June	223	75	216	25,6	14,3	2,7
July	231	71	232	28	17,3	2,8
August	202	70	196	27,9	17,9	2,6
September	151	59	156	24,3	16,3	2,1
October	114	44	136	20,3	13,3	1,9
November	81	35	109	14,4	7,5	1,7
December	66	28	98	11,5	5,1	1,8
Year	1757	644	1895	19	10,5	2,2

Where:

- *Gh*: Horizontal Global Irradiation (kWh/m²)
- *Dh*: Horizontal Diffuse Irradiation (kWh/m²)
- *Bn*: Irradiation of the Normal Direct Radiation (kWh/m²)
- *Ta*: Ambient Temperature (°C)
- *Td*: Temperature Difference (max-min) (°C)

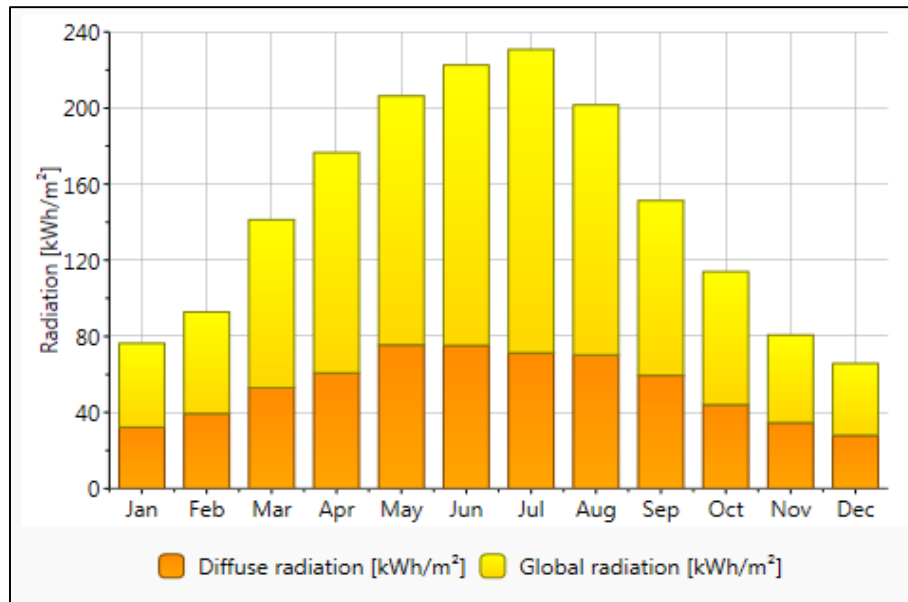


Figure 18. Murcia Solar Radiation.

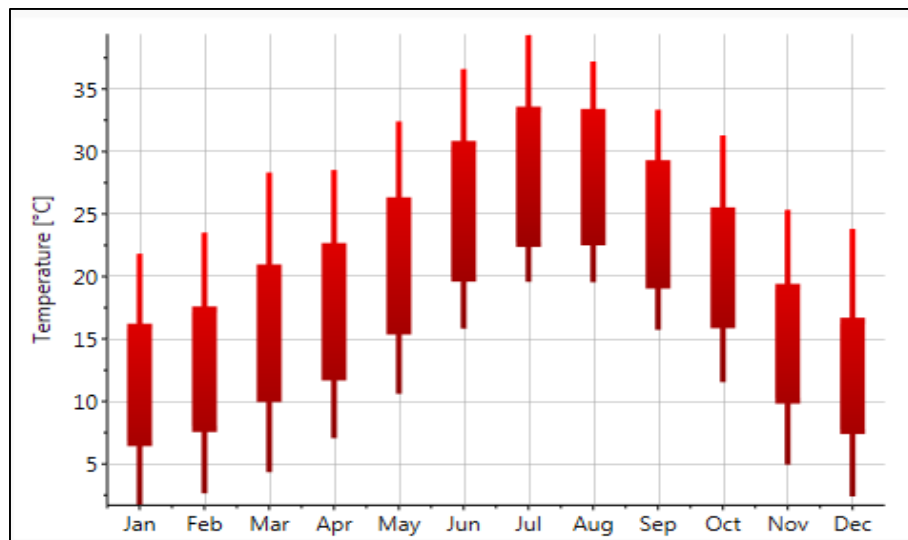


Figure 19. Murcia Temperature.

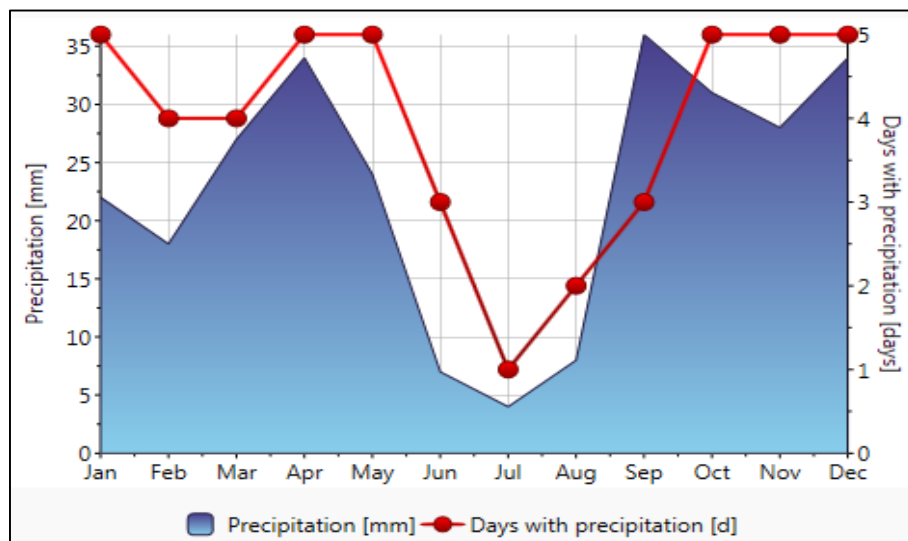


Figure 20. Murcia Precipitation.

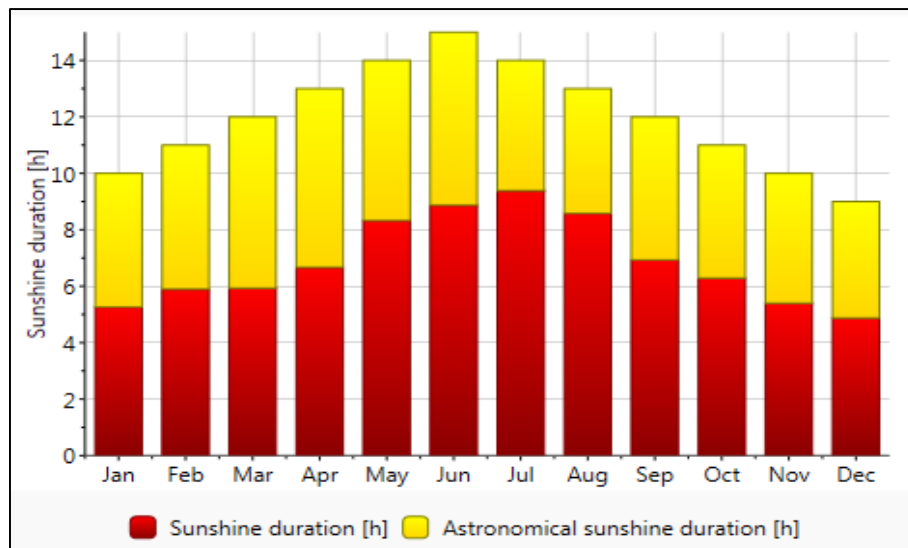


Figure 21. Murcia Sunshine duration.

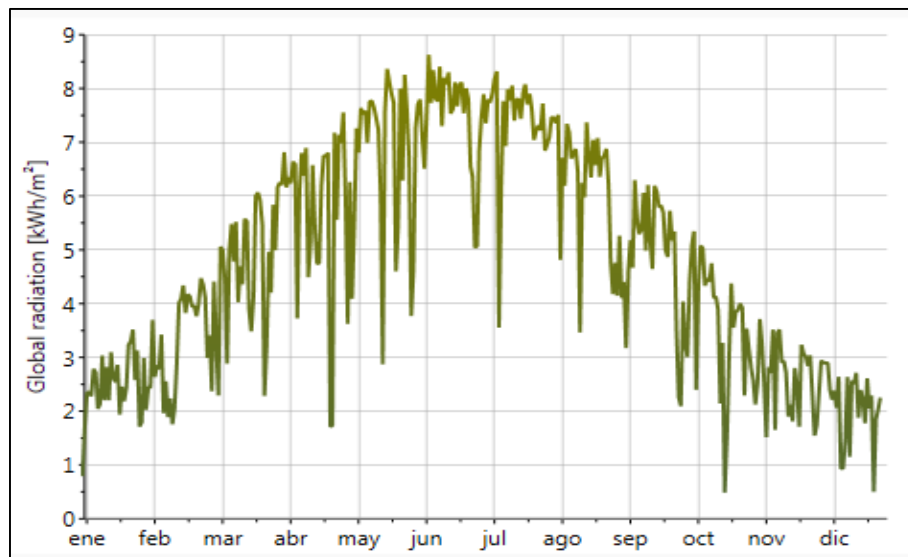


Figure 22. Murcia daily global radiation.

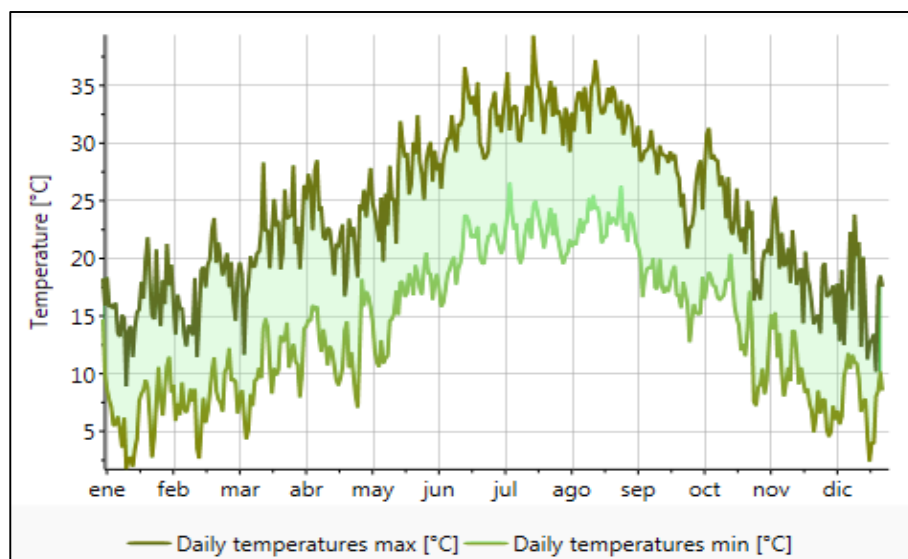


Figure 23. Murcia daily temperature.

5.3. Input data

As already explained in previous sections of this thesis, the main objective is to study and compare two PV plants located at two places, where the weather conditions and solar irradiation are completely different: one location is Maribor, in Slovenia, and the other is Murcia, in the south of Spain.

The total energy to be generated in both locations is 5.000 kWh/year; with this parameter, with the weather conditions and irradiation parameters obtained from reputable sources as Meteonorm data base, and with the simulations done with PVSyst software, each power plant can be sized accordingly.

Firstly, we are going to size each power plant without the software, as it takes into account a series of losses, so we can then compare both results.

5.3.1. Maribor PV plant

In order to calculate the power of the photovoltaic generator (kW) we use the following equation, which is the proposal by I.D.A.E. in its Technical Specifications.

$$P_{mp} = \frac{E_p \cdot G_{cem}}{G_{dm}(\alpha, \beta) \cdot PR}$$

Where:

- E_p : Energy fed into the grid (kWh/day).
- G_{cem} : Constant radiation having a value of 1(kW/m²).
- $G_{dm}(\alpha, \beta)$: annual average value of daily irradiation (Kwh/m²·day), α being the azimuth of the installation, in our case is 0 °, and β the tilt of the panels in our case is 36 °. According to Table 1 is 1201 kWh/m² = 3,3 kWh/m²·day.
- PR : "performance ratio" of the system, which takes into account all efficiency losses resulting from current module temperature, module mismatch, varying irradiance conditions, dirt, line resistance and conversion losses in the inverter. Well-designed PV plants achieve average PR of 80% to 90% throughout the year. According to International Energy Agency we take a PR value of 85% [9].
- P_{mp} : photovoltaic power generation (kW).
- N_p : number of needed modules.

$$E_p = \frac{5000 \text{ kWh/ anual}}{365 \text{ day}} = 13,699 \text{ kWh/ day}$$

$$P_{mp} = \frac{13,699 \text{ kWh/ day} \times 1 \text{ kW/ m}^2}{3,3 \text{ kWh/ m}^2 \cdot \text{day} \times 0,85} = 4,884 \text{ kW}$$

$$N_p = \frac{4884 \text{ W}}{270 \text{ W}} = 18,08 \rightarrow 19$$

To reach the energy objective of the Maribor PV Plant, it will be necessary to install 4,884 kW.

Considering that the power of selected panels (shown in following sections) is 270 W, the PV plant will have 19 modules.

5.3.2. Murcia PV plant

In order to calculate the power of the photovoltaic generator (kW) we use the following equation, which is the proposal by I.D.A.E. in its Technical Specifications.

$$P_{mp} = \frac{E_p \cdot G_{cem}}{G_{dm}(\alpha, \beta) \cdot PR}$$

Where:

- E_p : Energy fed into the grid (kWh/day).
- G_{cem} : Constant radiation having a value of 1(kW/m²).
- $G_{dm}(\alpha, \beta)$: annual average value of daily irradiation (Kwh/m²·day), α being the azimuth of the installation, in our case is 0 °, and β the tilt of the panels in our case is 30 °. According to Table 2 is 1757 kWh/m² = 4,82 kWh/m²·day.
- PR : "performance ratio" of the system, which takes into account all efficiency losses resulting from current module temperature, module mismatch, varying irradiance conditions, dirt, line resistance and conversion losses in the inverter. Well-designed PV plants achieve average PR of 80% to 90% throughout the year. According to International Energy Agency we take a PR value of 85% [9]
- P_{mp} : photovoltaic power generation (kW).
- N_p : number of needed modules.

$$E_p = \frac{5000 \text{ kWh/ anual}}{365 \text{ day}} = 13,699 \text{ kWh/ day}$$

$$P_{mp} = \frac{13,699 \text{ kWh/ day} \times 1 \text{ kW/ m}^2}{4,82 \text{ kWh/ m}^2 \cdot \text{day} \times 0,85} = 3,344 \text{ kW}$$

$$N_p = \frac{3344 \text{ W}}{270 \text{ W}} = 12,39 \rightarrow 13$$

To reach the energy objective of the Murcia PV Plant, it will be necessary to install 3,344 kW.

Considering that the power of selected panels (shown in following sections) is 270 W, the PV plant will have 13 modules.

5.4. Preliminary calculations

The first step in the photovoltaic plant design is to determine the total power to install.

It has been used a specific software for photovoltaic systems called PVsyst, which is able to import meteorological data from different sources, and calculate the energy generation [10].

To reach the energy objective of 5.000 kWh, a preliminary analysis has been done with a prototype PV plant of 99,4 kWp, with a generic PV module. The rest of configuration parameters of this simulation has been automatically selected by the software.

It is necessary to clarify that this preliminary analysis has been done with PV module Bisol 270 Wp polycrystalline, to find out the efficiency of each one of the solar plants, calculating the “equivalent hours”; the final configuration will also be done with this PV module.

The main parameters are the following:

Total power:	99,4 kWp
PV Module:	BMU-270
Nº modules in serie:	23
Nº parallel strings:	16
Inverter:	Sunny Tripower 60-10

It should be clarified that that potential pre dimensioning of equipment and total power, leads to the same value of operating hours for any installed power of 10, 100 or 10,000 kW. So after choosing the panel (BMU-270) and the inverter (Sunny Tripower 60-10), we got into the program 100 kW. The point is that to function properly an inverter from the electrical point of view, it is necessary to set the voltage and current input by grouping the panels in series to form what are called strings, and then connecting these strings in parallel before connecting them to the inverter. What happened was that when selecting random inverter and 100 kWp, the program automatically modified these values so that they were electrically correct, and created an installation with parallel of a total of 16 strings, each with 23 panels series. That is why dropped the power to the 99.4 kWp.

With the first analysis, based on the calculation with Suntech panel, we tried to determine the solar potential of each discussed site. To do this, any panel and any inverter could be used, since what is sought is to get the equivalent number of hours. Obviously each set of modules and inverters has its own characteristics and efficiency values and the obtained equivalent hours vary slightly among individual sets. But, all we are looking for, is the evaluation of PV potential.

5.4.1. Tilt and Orientation

Among the most important parameters in a photovoltaic plant are the tilt and orientation of the solar modules, which determinate the capability of the module to maximize the captured solar radiation during the year.

In this way the modules will be South oriented (Azimuth 0), and the suitable tilt angle is calculated with the next equation [10]:

$$\beta = 3.64 + 0.69 \cdot \text{Latitude}$$

Taking into account the coordinates of both PV plants the obtained angles are:

a. Maribor:

- Latitude: 46,534789°S
- Longitude: 15,640048° W

The obtained tilt angle is 35,75°.

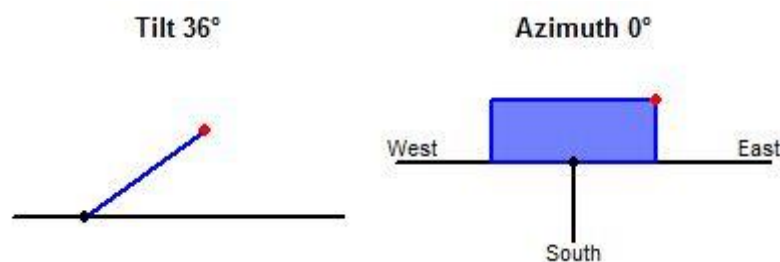


Figure 24. Maribor Tilt and Azimut [10].

b. Murcia:

- Latitude: 37,997166° S
- Longitude: 1,110117° W

The obtained tilt angle is 29,85°.

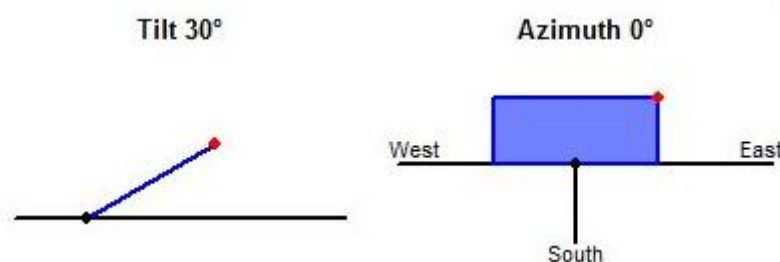
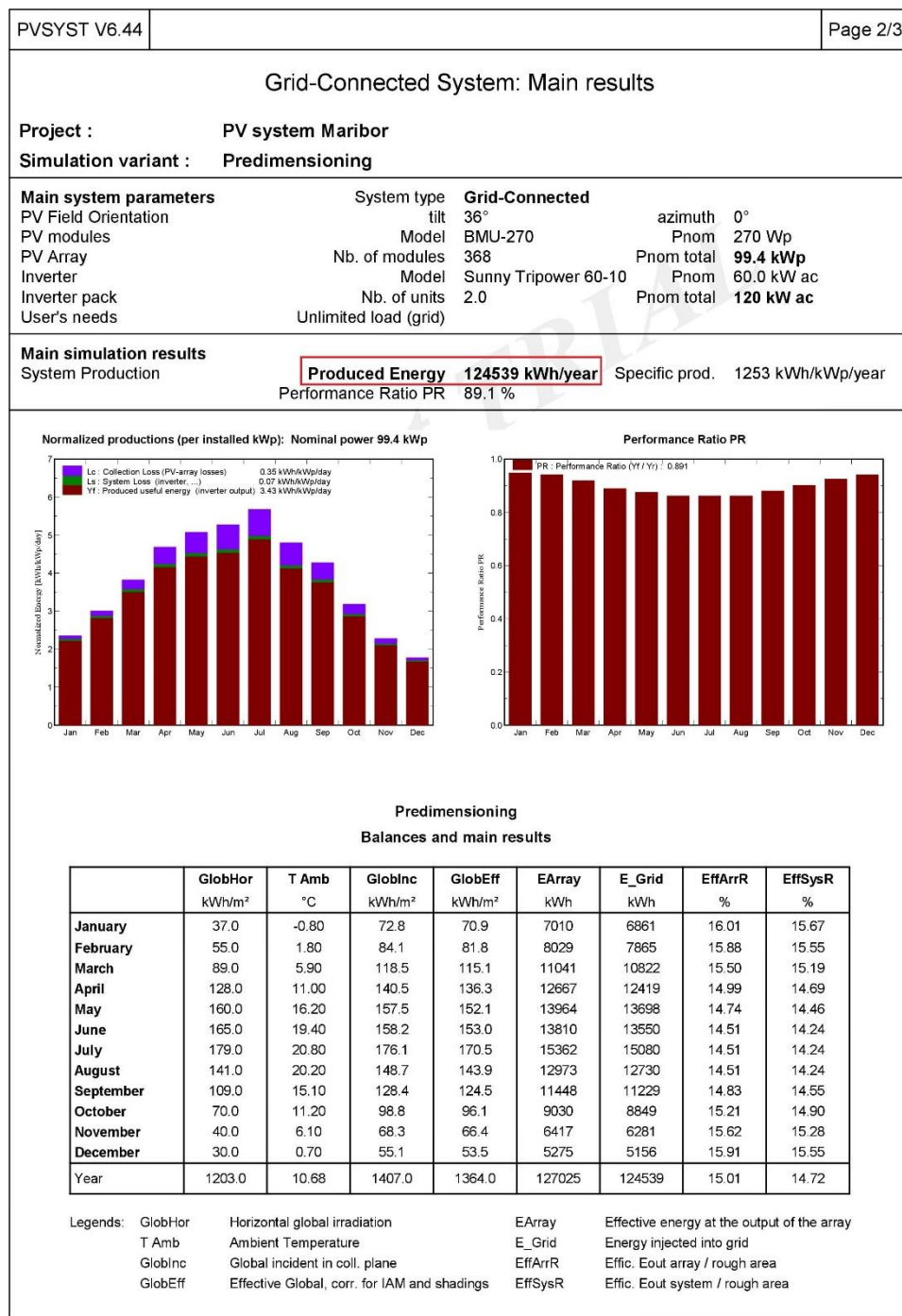


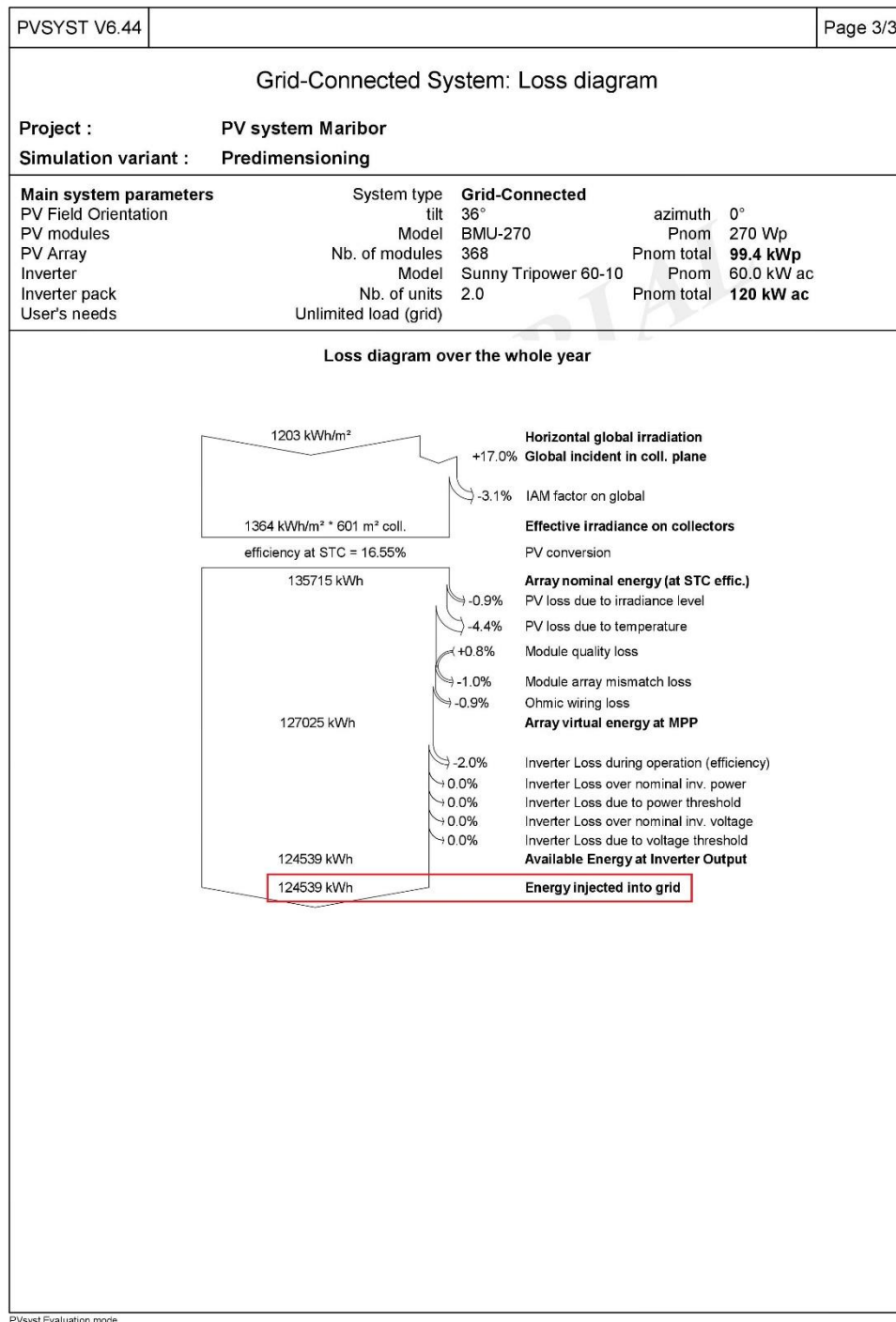
Figure 25. Murcia Tilt and Azimut [10].

5.4.2. Maribor PV plant

The following images show the preliminary simulation for the Maribor plant [10]:

PVSYS V6.44		Page 1/3	
Grid-Connected System: Simulation parameters			
Project : PV system Maribor			
Geographical Site	Maribor	Country	Slovenia
Situation	Latitude 46.5°N	Longitude	15.6°E
Time defined as	Legal Time	Time zone	UT+1
	Albedo	Altitude	272 m
Meteo data:	Maribor	MeteoNorm 7.1 - Synthetic	
Simulation variant : Predimensioning			
Simulation parameters			
Collector Plane Orientation	Tilt 36°	Azimuth 0°	
Models used	Transposition		
Horizon	Free Horizon		
Near Shadings	No Shadings		
PV Array Characteristics			
PV module	Si-poly	Model	BMU-270
Original PVSyst database	Manufacturer		Bisol
Number of PV modules	In series	23 modules	In parallel 16 strings
Total number of PV modules	Nb. modules	368	Unit Nom. Power 270 Wp
Array global power	Nominal (STC)	99.4 kWp	At operating cond. 90.8 kWp (50°C)
Array operating characteristics (50°C)	U mpp	665 V	I mpp 136 A
Total area	Module area	601 m²	Cell area 537 m²
Inverter			
Original PVSyst database	Manufacturer	Sunny Tripower 60-10	
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power 60 kWac
Inverter pack	Nb. of inverters	2 units	Total Power 120 kWac
PV Array loss factors			
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind) 0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	80 mOhm	Loss Fraction 1.5 % at STC
Module Quality Loss			Loss Fraction -0.8 %
Module Mismatch Losses			Loss Fraction 1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param. 0.05
User's needs :	Unlimited load (grid)		





Taking into account the total energy generated and the total installed power in the PV plant, the generation capability in equivalent hours is:

$$\frac{124539 \text{ kWh}}{99,4 \text{ kWp}} = 1253 \text{ h}$$

This value represents the theoretically calculated energy that any solar plant in this location will produce in one year, assuming that it works at nominal power during this time.

Therefore, the total PV power which is necessary to install in this location is:

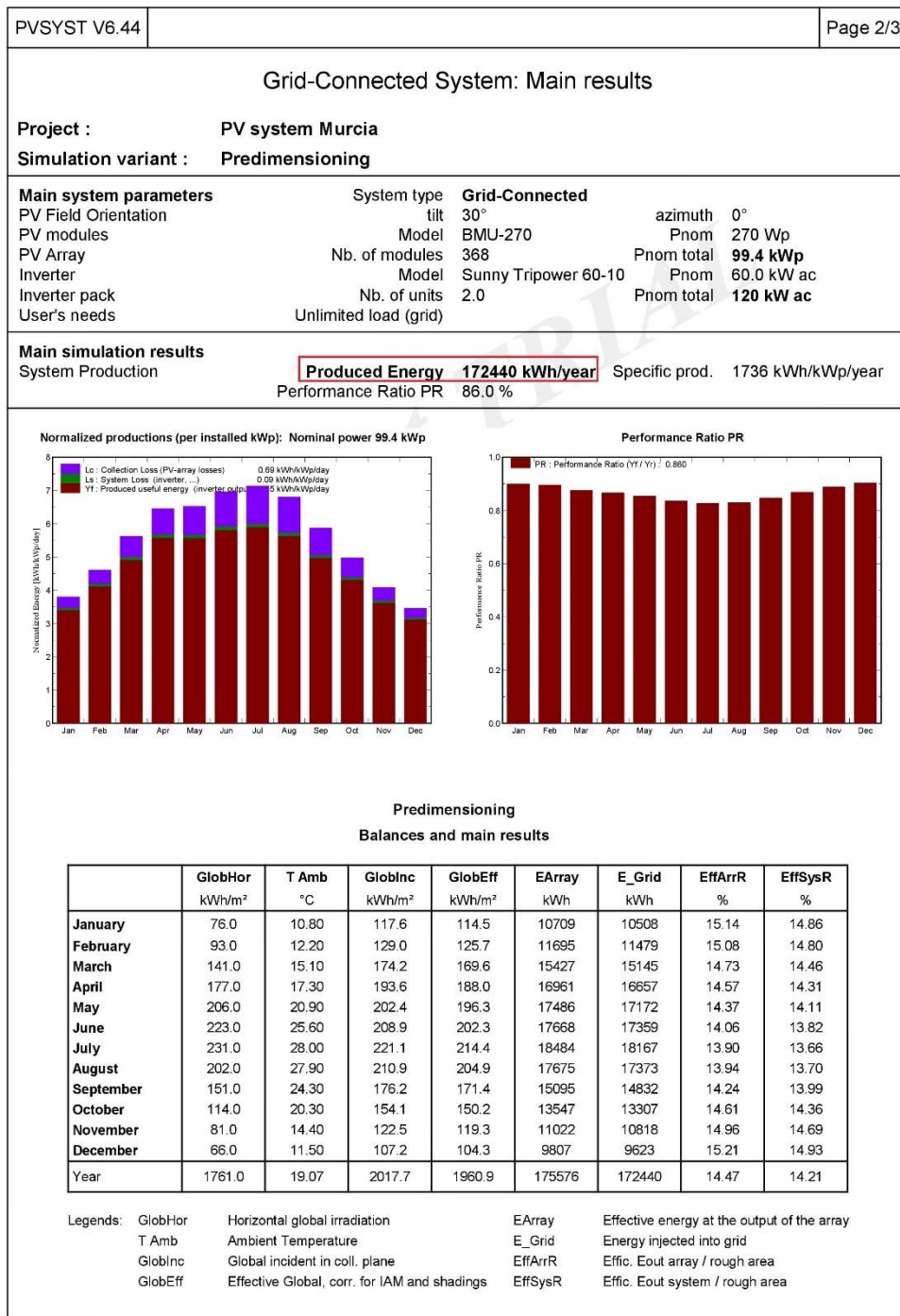
$$\frac{5000 \text{ kWh/ anual}}{1253 \text{ h}} = 3.99 \text{ kW}$$

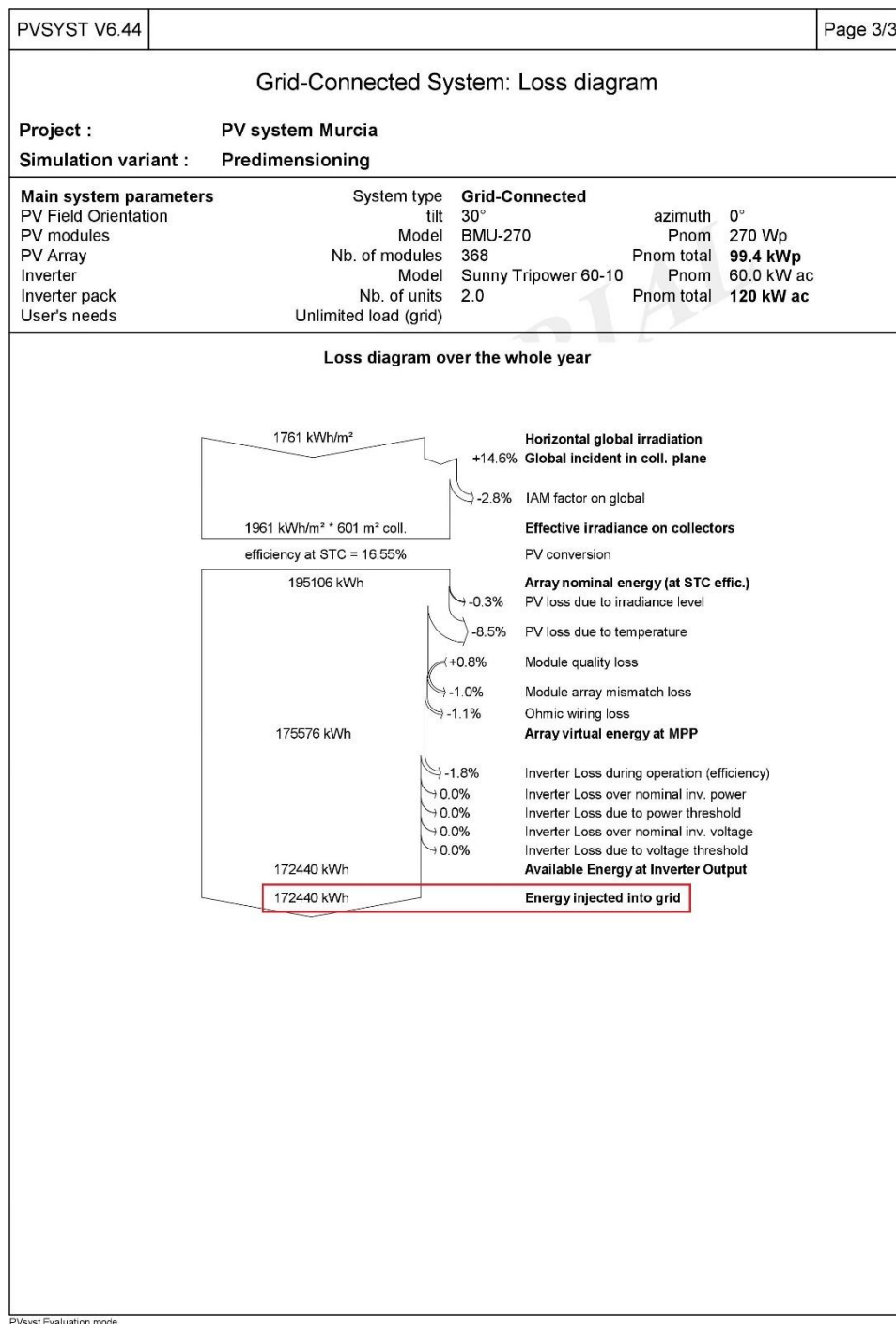
which is less than 4.88 kW calculated in 5.3.1.

5.4.3. Murcia PV plant

The following images show the preliminary simulation for the Murcia plant [10]:

PVSYS V6.44		Page 1/3	
Grid-Connected System: Simulation parameters			
Project :	PV system Murcia		
Geographical Site	Murcia	Country	Spain
Situation	Latitude 38.0°N	Longitude	1.2°W
Time defined as	Legal Time Time zone UT+1	Altitude	49 m
Meteo data:	Murcia	MeteoNorm 7.1 - Synthetic	
Simulation variant : Predimensioning			
Simulation parameters			
Collector Plane Orientation	Tilt 30°	Azimuth 0°	
Models used	Transposition		
Horizon	Free Horizon		
Near Shadings	No Shadings		
PV Array Characteristics			
PV module	Si-poly	Model	BMU-270
Original PVSyst database	Manufacturer Bisol		
Number of PV modules	In series	23 modules	In parallel 16 strings
Total number of PV modules	Nb. modules	368	Unit Nom. Power 270 Wp
Array global power	Nominal (STC)	99.4 kWp	At operating cond. 90.8 kWp (50°C)
Array operating characteristics (50°C)	U mpp	665 V	I mpp 136 A
Total area	Module area	601 m²	Cell area 537 m²
Inverter			
Original PVSyst database	Manufacturer	Sunny Tripower 60-10	
Characteristics	Operating Voltage	570-800 V	Unit Nom. Power 60 kWac
Inverter pack	Nb. of inverters	2 units	Total Power 120 kWac
PV Array loss factors			
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind) 0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	80 mOhm	Loss Fraction 1.5 % at STC
Module Quality Loss			Loss Fraction -0.8 %
Module Mismatch Losses			Loss Fraction 1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param. 0.05
User's needs :	Unlimited load (grid)		





Taking into account the total generated energy and the total installed power in the PV plant, the generation capability in equivalent hours is:

$$\frac{172440 \text{ kWh}}{99,4 \text{ kWp}} = 1735 \text{ h}$$

This value represents the theoretically calculated energy that any solar plant in this location will produce in one year, assuming that it works at nominal power during this time.

Therefore, the total PV power which is necessary to install in this location is:

$$\frac{5000 \text{ kWh/ anual}}{1735 \text{ h}} = 2,882 \text{ kW}$$

which is again which is less than 3.34 kW calculated in 5.3.2.

5.5. Description of the PV plants

5.5.1. Maribor PV Plant

As mentioned in previous sections, to reach the energy objective of the Maribor PV Plant, it will be necessary to install 3,99 kW.

Considering that the power of selected panels (shown in following sections) is 270 W, the PV plant will have 15 modules.

$$N_p = \frac{3990 \text{ W}}{270 \text{ W}} = 14,77 \rightarrow 15$$

These modules will produce the energy in DC, and they will be connected to a central inverter of 4,6 kW to convert it to AC. The AC output of the inverter will be connected to the electrical grid through a protection breaker in the main panel board of the building, and to differentiate the energy supply/consumed to the grid, a two-way meter will be installed.

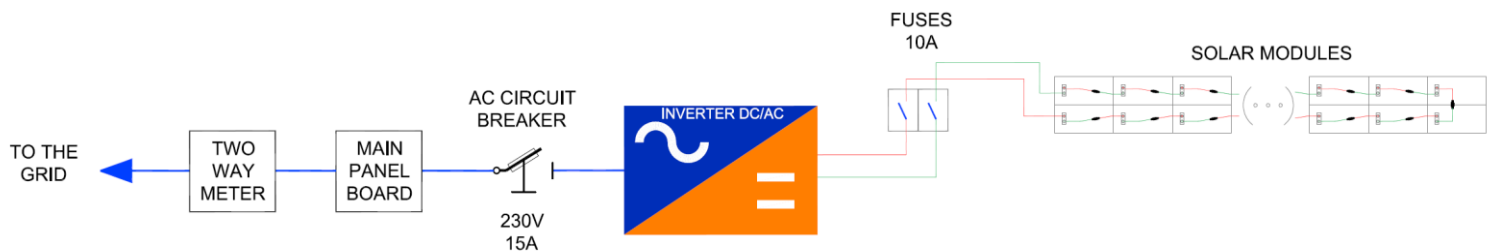


Figure 26. PV plant scheme.

5.5.2. Murcia PV Plant

As mentioned in previous sections, to reach the energy objective of the Murcia PV Plant, it will be necessary to install 2,882 kW.

Considering that the power of selected panels (shown in following sections) is 270 W, the PV plant will have 11 modules.

$$N_p = \frac{2882}{270} = 10,67 \rightarrow 11$$

These modules will produce the energy in DC, and they will be connected to a central inverter of 3,3 kW to convert it to AC. The AC output of the inverter will be connected to the electrical grid through a protection breaker in the main panel board of the building, and to differentiate the energy supply/consumed to the grid, a two-way meter will be installed.

5.5.3. Selected Solar Modules

The solar module selected for both plants is the **BISOL BMU-270**, with a maximum power output of 270 W.

The modules will withstand humidity and salt mist conditions, being also dust and water proof.

(Datasheet can be find in Annex 1)

5.5.4. Selected inverter

The inverter transforms the DC current generated by the PV modules into AC current in low voltage. The selected inverters are the **INGECON SUN 1Play TL M**, which are inverter with an output rated power of 4,6 and 3,3 kW respectively, which features a double MPP tracking system that enables it to harvest the maximum power from the PV plant, even under difficult situations, such as partial shadings, scattered clouds or on-roof installations with different orientations.

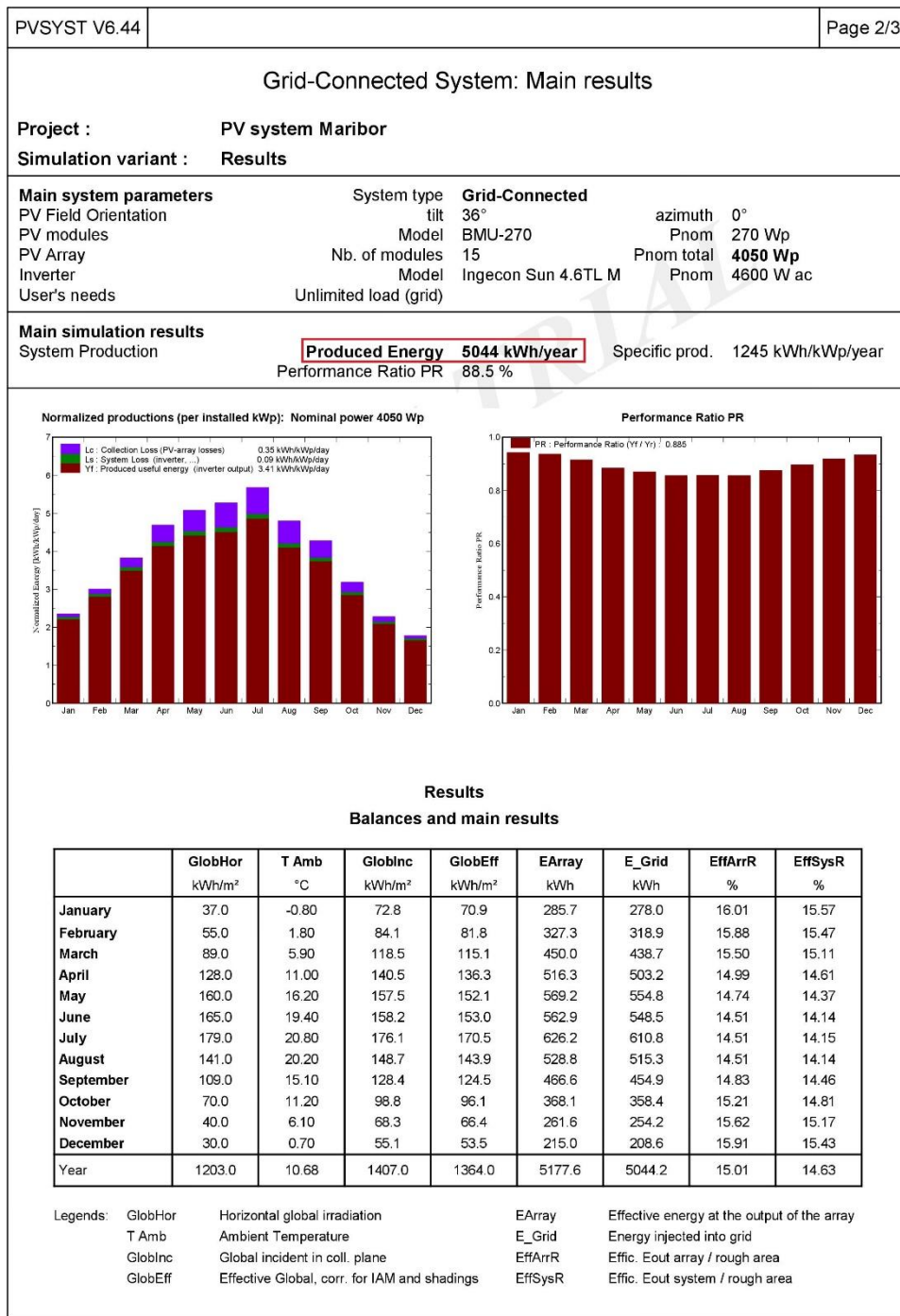
(Datasheet can be find in Annex 2)

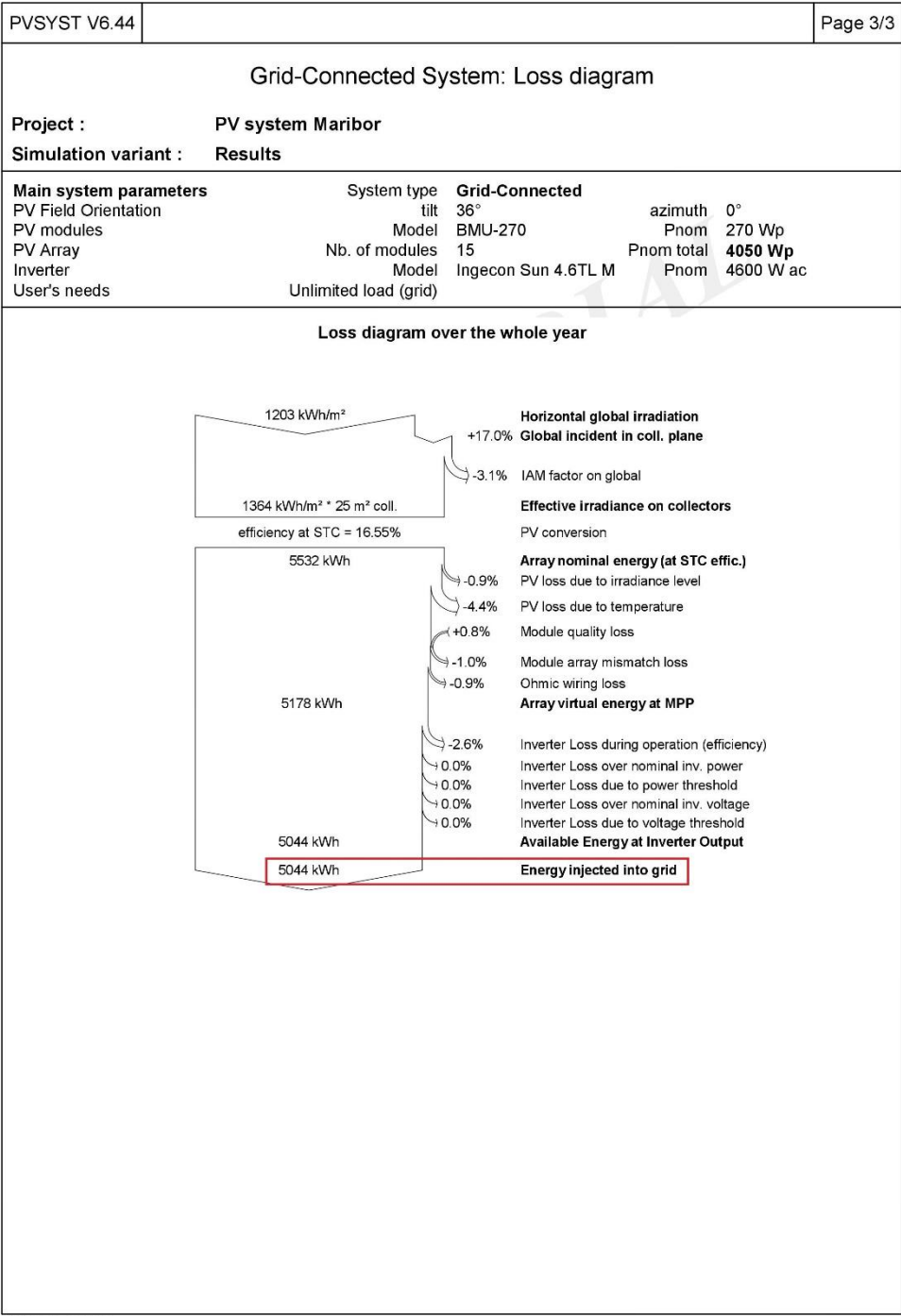
5.6. Final energy generation

In each case, once introduced all the parameters (from the previous subsection) in the PVsyst software, the final results of production are [10]:

5.6.1. Maribor PV plant

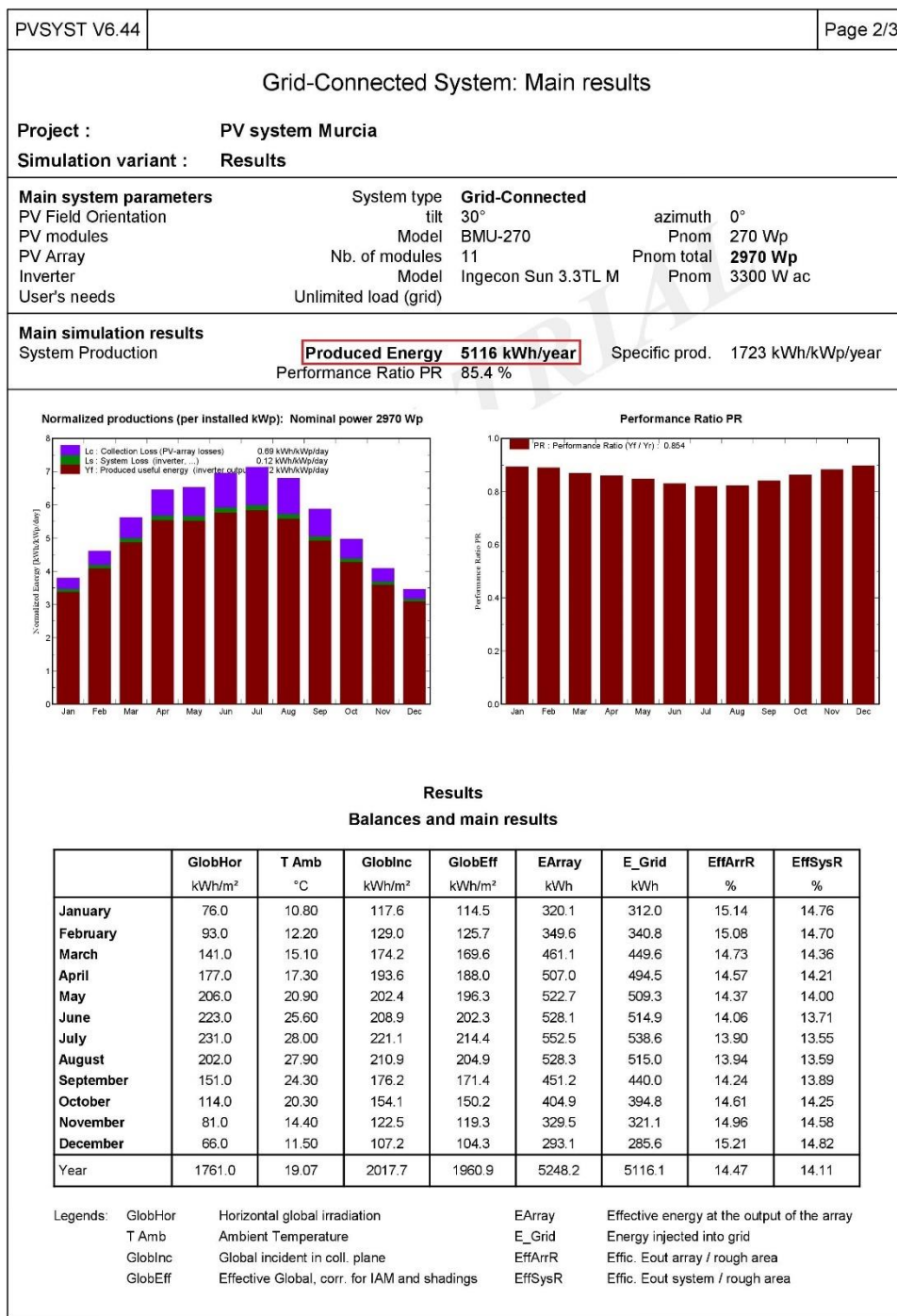
PVSYST V6.44		Page 1/3	
Grid-Connected System: Simulation parameters			
Project :	PV system Maribor		
Geographical Site	Maribor	Country	Slovenia
Situation	Latitude 46.5°N	Longitude	15.6°E
Time defined as	Legal Time	Time zone	UT+1
	Albedo		272 m
Meteo data:	Maribor	MeteoNorm 7.1 - Synthetic	
Simulation variant : Results			
Simulation parameters			
Collector Plane Orientation	Tilt 36°	Azimuth 0°	
Models used	Transposition		
Horizon	Free Horizon		
Near Shadings	No Shadings		
PV Array Characteristics			
PV module	Si-poly	Model	BMU-270
Original PVsyst database	Manufacturer	Bisol	
Number of PV modules	In series	15 modules	In parallel 1 strings
Total number of PV modules	Nb. modules	15	Unit Nom. Power 270 Wp
Array global power	Nominal (STC)	4050 Wp	At operating cond. 3700 Wp (50°C)
Array operating characteristics (50°C)	U mpp	434 V	I mpp 8.5 A
Total area	Module area	24.5 m²	Cell area 21.9 m²
Inverter			
	Model	Ingecon Sun 4.6TL M	
Original PVsyst database	Manufacturer	Ingeteam	
Characteristics	Operating Voltage	125-750 V	Unit Nom. Power 4.60 kWac
Inverter pack	Nb. of inverters	1 units	Total Power 4.6 kWac
PV Array loss factors			
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind) 0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	838 mOhm	Loss Fraction 1.5 % at STC
Module Quality Loss			Loss Fraction -0.8 %
Module Mismatch Losses			Loss Fraction 1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM = 1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :	Unlimited load (grid)		

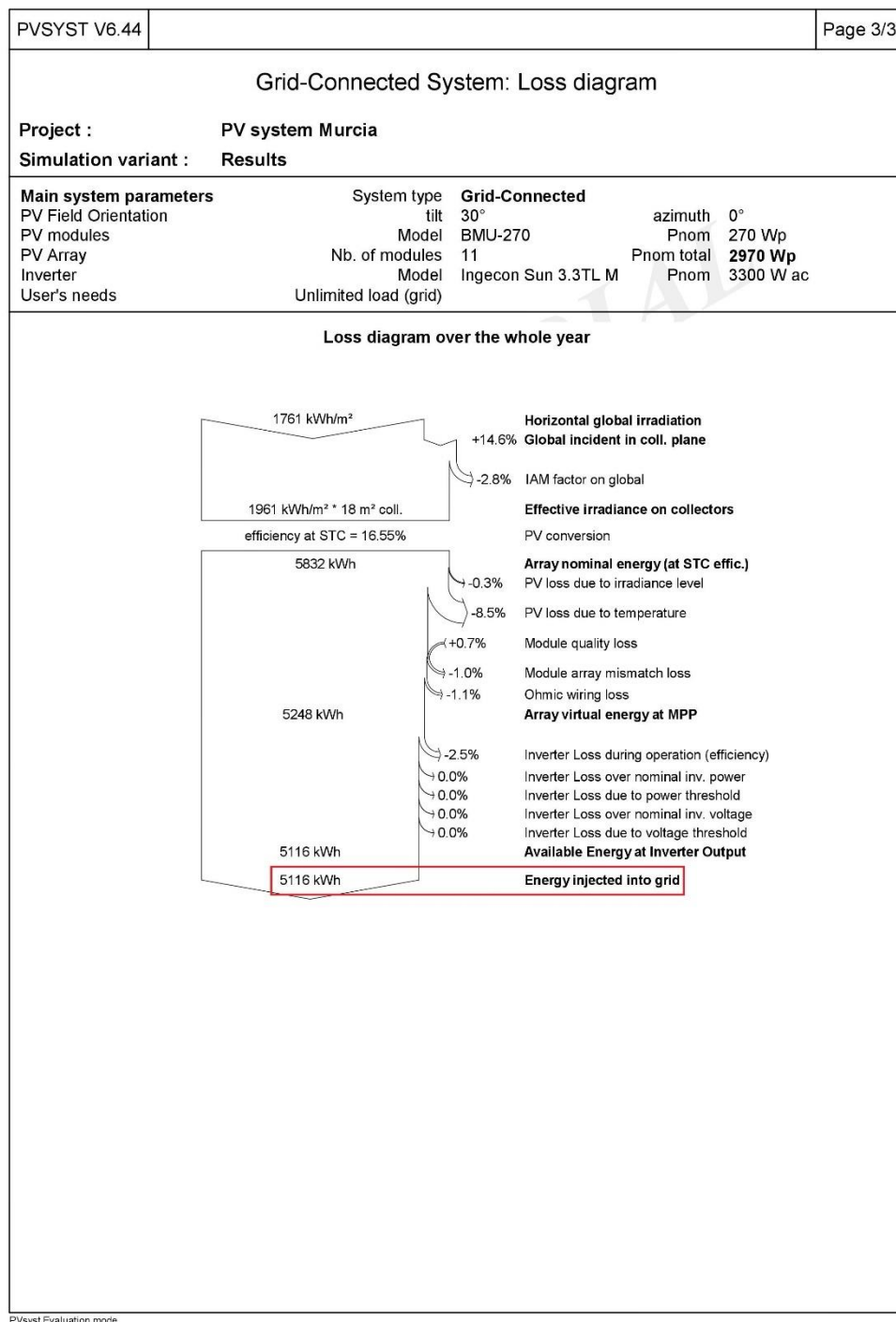




5.6.2. Murcia PV plant

PVSYST V6.44				Page 1/3																																																																																
Grid-Connected System: Simulation parameters																																																																																				
Project : PV system Murcia																																																																																				
Geographical Site	Murcia	Country	Spain																																																																																	
Situation	Latitude 38.0°N	Longitude	1.2°W																																																																																	
Time defined as	Legal Time	Time zone	UT+1																																																																																	
	Albedo 0.20	Altitude	49 m																																																																																	
Meteo data:	Murcia	MeteoNorm 7.1 - Synthetic																																																																																		
Simulation variant : Results																																																																																				
Simulation parameters Collector Plane Orientation <div style="display: flex; justify-content: space-around; margin-top: 5px;"> Tilt 30° Azimuth 0° </div> Models used Transposition Horizon Free Horizon Near Shadings No Shadings PV Array Characteristics <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%;">PV module</td> <td style="width: 20%;">Si-poly</td> <td style="width: 20%;">Model</td> <td colspan="2">BMU-270</td> </tr> <tr> <td>Original PVsyst database</td> <td></td> <td>Manufacturer</td> <td colspan="2">Bisol</td> </tr> <tr> <td>Number of PV modules</td> <td>In series</td> <td>11 modules</td> <td>In parallel</td> <td>1 strings</td> </tr> <tr> <td>Total number of PV modules</td> <td>Nb. modules</td> <td>11</td> <td>Unit Nom. Power</td> <td>270 Wp</td> </tr> <tr> <td>Array global power</td> <td>Nominal (STC)</td> <td>2970 Wp</td> <td>At operating cond.</td> <td>2713 Wp (50°C)</td> </tr> <tr> <td>Array operating characteristics (50°C)</td> <td>U mpp</td> <td>318 V</td> <td>I mpp</td> <td>8.5 A</td> </tr> <tr> <td>Total area</td> <td>Module area</td> <td>18.0 m²</td> <td>Cell area</td> <td>16.1 m²</td> </tr> </table> Inverter <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%;"></td> <td style="width: 20%;">Model</td> <td colspan="3">Ingecon Sun 3.3TL M</td> </tr> <tr> <td>Original PVsyst database</td> <td>Manufacturer</td> <td colspan="3">Ingeteam</td> </tr> <tr> <td>Characteristics</td> <td>Operating Voltage</td> <td>125-750 V</td> <td>Unit Nom. Power</td> <td>3.30 kWac</td> </tr> <tr> <td>Inverter pack</td> <td>Nb. of inverters</td> <td>1 units</td> <td>Total Power</td> <td>3.3 kWac</td> </tr> </table> PV Array loss factors <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 30%;">Thermal Loss factor</td> <td style="width: 20%;">Uc (const)</td> <td style="width: 20%;">20.0 W/m²K</td> <td style="width: 20%;">Uv (wind)</td> <td style="width: 10%;">0.0 W/m²K / m/s</td> </tr> <tr> <td>Wiring Ohmic Loss</td> <td>Global array res.</td> <td>614 mOhm</td> <td>Loss Fraction</td> <td>1.5 % at STC</td> </tr> <tr> <td>Module Quality Loss</td> <td></td> <td></td> <td>Loss Fraction</td> <td>-0.8 %</td> </tr> <tr> <td>Module Mismatch Losses</td> <td></td> <td></td> <td>Loss Fraction</td> <td>1.0 % at MPP</td> </tr> <tr> <td>Incidence effect, ASHRAE parametrization</td> <td>IAM =</td> <td>1 - bo (1/cos i - 1)</td> <td>bo Param.</td> <td>0.05</td> </tr> </table> User's needs : Unlimited load (grid)					PV module	Si-poly	Model	BMU-270		Original PVsyst database		Manufacturer	Bisol		Number of PV modules	In series	11 modules	In parallel	1 strings	Total number of PV modules	Nb. modules	11	Unit Nom. Power	270 Wp	Array global power	Nominal (STC)	2970 Wp	At operating cond.	2713 Wp (50°C)	Array operating characteristics (50°C)	U mpp	318 V	I mpp	8.5 A	Total area	Module area	18.0 m²	Cell area	16.1 m²		Model	Ingecon Sun 3.3TL M			Original PVsyst database	Manufacturer	Ingeteam			Characteristics	Operating Voltage	125-750 V	Unit Nom. Power	3.30 kWac	Inverter pack	Nb. of inverters	1 units	Total Power	3.3 kWac	Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s	Wiring Ohmic Loss	Global array res.	614 mOhm	Loss Fraction	1.5 % at STC	Module Quality Loss			Loss Fraction	-0.8 %	Module Mismatch Losses			Loss Fraction	1.0 % at MPP	Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
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5.7. Comments

Based on the data obtained from the Micro solar power plant of the UM Feri in 2015, we are going to determine the time of operation with a power installed of 7,5 kWp. Then, we are going to sized a power plant with this data knowing that the total energy to be generated is 5000 kWh/year.

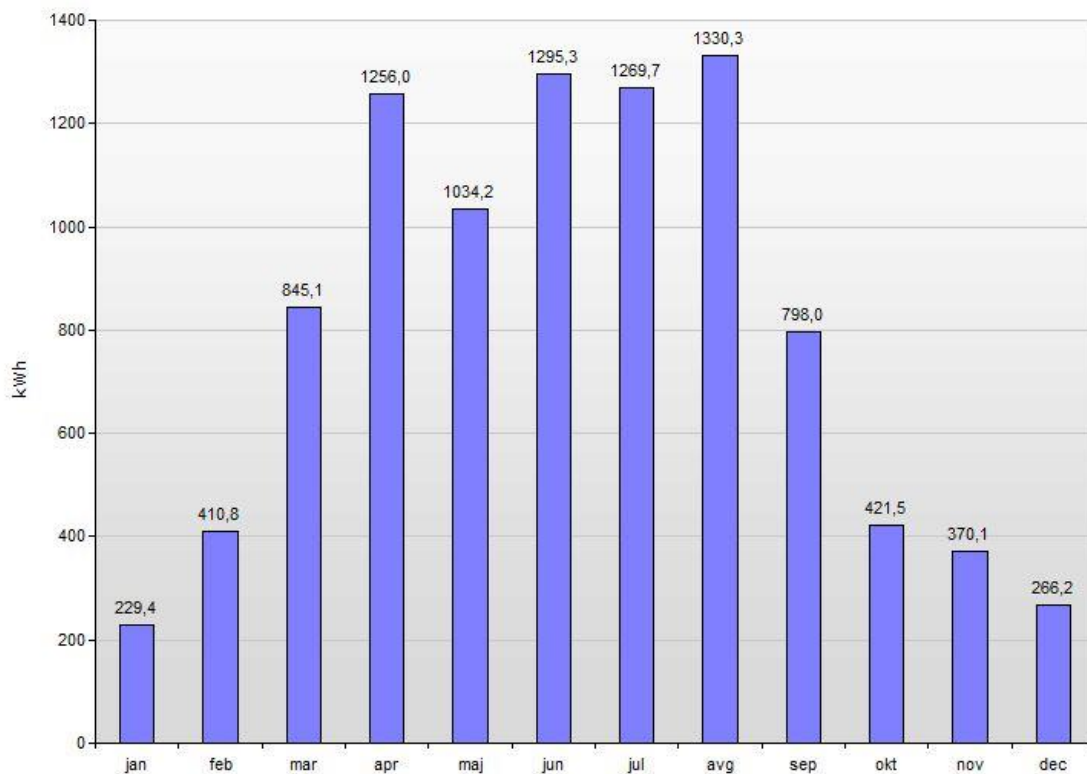


Figure 27. Total energy power plant UM Feri (2015) [15]

Using the data from Figure 24, we calculate total energy generated:

$$W_T = 229,4 + 410,8 + 845,1 + 1256 + 1034,2 + 1295,3 + 1269,7 + 1330,3 + 798 + 421,5 + 370,1 + 266,2 = 9526,6 \text{ kWh}$$

Taking into account the total energy generated and the total installed power in the PV plant, the generation capability in equivalent hours is:

$$\frac{9526,6 \text{ kWh}}{7,5 \text{ kWp}} = 1270 \text{ h}$$

Therefore, the total PV power which is necessary to install in this location is:

$$\frac{5000 \text{ kWh/year}}{1270 \text{ h}} = 3,94 \text{ kW}$$

To reach the energy objective of the Maribor PV Plant, it will be necessary to install 3,94 kW.

Considering that the power of selected panels (shown in following sections) is 270 W, the PV plant will have 15 modules.

$$N_p = \frac{3937 \text{ W}}{270 \text{ W}} = 14,58 \rightarrow 15$$

From the Micro Solar Power Plant of UM Feri in 2015, we determine that it had 1270 hours of operation. Normally, in Maribor the time of operation is between 900 and 1000 but that year was a year with a lot of hours of sun. We obtained the same number of panels with BMU-270 characteristics as the PV plant calculated with PVsyst.

6. Conclusion

The aim of the project was to study and compare two photovoltaic plants that could provide yearly net self-sufficient energy supply of a house with an average consumption of 5000 kWh per year. The house is connected to the grid (so it was not necessary to use batteries).

From a daily consumption of 5000KWh/365 and irradiation data (Table 1 and 2), the size of the installation and the number of modules required was designed. The energy produced by the photovoltaic system was also obtained.

If we make a first analysis comparing the data obtained by PVSYST and without software, we can observe that in the case of Maribor we obtained a power of 4,884 kW and 19 modules without using the software and 3.99 kW and 15 modules by PVSYST. In the case of Murcia 3,344 kW and 13 modules were obtained without using the program and 2,882 kW and 11 modules by PVSYST. The number of modules required at both installations is reduced when using PVSYST and this is because the program in the power calculation takes into account a series of losses that we do not have.

The results obtained by the program seems to be overestimated for 20% or more.

If we now compare both installations (Maribor and Murcia), the installation in Murcia will have a lower cost, needing fewer panels and less input power to the inverter. In addition, will also have a higher efficiency due to fewer hours of sunshine in Maribor. Of the latest results obtained with PVSYST we can get that Maribor will have a production energy of 5044 kWh/year and Murcia 5116 kWh/year.

We can say that both PV plants designed fulfill the parameters required for installation and operation, referring to the energy supply of housing.

At the end of the lifespan of the installations discussed in this project, they could be replaced with further developed and more efficient technologies, and thus continue the advantage of discussed installations.

As prospects, is proposed the ability to supply and sell excess energy to the electrical grid making profits and with the advantage of supplying possible peak consumption, ie, give the house the ability to work not only as a load but also as a generator.

ANNEX 1

BISOL Premium Series

Multicrystalline PV Modules / BMU 250-270 Wp



Solar company!





Made in EU



Strictly positive power output tolerances



PID free



All relevant certificates



Module presorting for a more profitable investment



Extremely low degradation



Module efficiency up to 16.5%



13% higher real-life performance



Excellent performance in low light conditions

Warranties:



The graph shows the power output percentage over a 25-year period. The BISOL Linear Warranty (orange line) starts at 97% and decreases linearly to 85% at year 25. The Standard Industry Linear Warranty (light orange area) starts at 97% and decreases to 80% at year 25. The Standard Industry Tiered Warranty (grey area) starts at 97% and remains constant at 80% from year 10 to year 25.

Year	BISOL Linear Warranty (%)	Standard Industry Linear Warranty (%)	Standard Industry Tiered Warranty (%)
1	97.0	97.0	97.0
5	94.0	94.0	94.0
10	91.0	91.0	91.0
15	88.0	88.0	80.0
20	85.0	85.0	80.0
25	85.0	80.0	80.0



Linear warranty
85% power output in 25th year



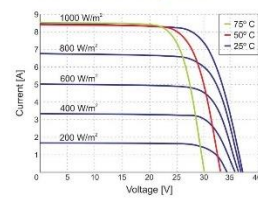
Product warranty
10 years

Certificates:

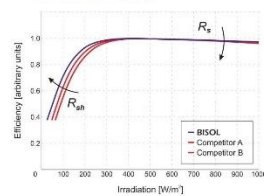


A collection of certification logos for BISOL PV modules, including IEC 61730 Ed.1, IEC 61215 Ed.2, CE, PV CYCLE, MCS, AS5033 compliant, Salt water mist resistance certificate, ISO 9001, ISO 14001, BUREAU VERITAS Certification, and ISTITUTO GIORDANO.

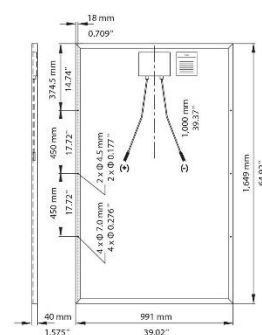
I-V Curve at Various Irradiation Levels and Various Cell Temperatures



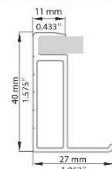
Effective Efficiency



Dimensions



Frame cross section



Electrical Specifications @ STC (AM1.5, 1,000 W/m², 25 °C):

Module Type		BMU-250	BMU-255	BMU-260	BMU-265	BMU-270
Nominal Power	P_{MPP} [W]	250	255	260	265	270
Short Circuit Current	I_{SC} [A]	8.75	8.85	8.90	9.00	9.10
Open Circuit Voltage	V_{OC} [V]	38.4	38.7	39.0	39.3	39.6
MPP Current	I_{MPP} [A]	8.25	8.35	8.40	8.50	8.60
MPP Voltage	V_{MPP} [V]	30.3	30.5	30.9	31.2	31.4
Solar Cell Efficiency	η_{c} [%]	17.1	17.5	17.8	18.1	18.5
Module Efficiency	η_M [%]	15.3	15.6	15.9	16.2	16.5
Power Output Tolerance		0/+ 5 W				
Maximum Reverse Current		18 A				
Maximum System Voltage		1,000 V (Application Class A)				

Additional power classes available upon request. Efficiency at irradiation 200 W/m² decreases to 95.7 % of efficiency at STC.

Electrical Specifications @ NOCT (AM1.5, 800 W/m², Cell Temperature 44 °C):

Module Type		BMU-250	BMU-255	BMU-260	BMU-265	BMU-270
Nominal Power	P_{MPP} [W]	185	189	192	196	200
Short Circuit Current	I_{SC} [A]	7.08	7.15	7.20	7.28	7.36
Open Circuit Voltage	V_{OC} [V]	35.1	35.3	35.6	35.9	36.1
MPP Current	I_{MPP} [A]	6.68	6.76	6.81	6.88	6.96
MPP Voltage	V_{MPP} [V]	27.7	27.9	28.2	28.5	28.7

Thermal Specifications:

Current Temperature Coefficient	α	+ 4.9 mA/°C
Voltage Temperature Coefficient	β	- 121 mV/°C
Power Temperature Coefficient	γ	- 0.35 %/°C
NOCT		44 °C
Temperature range		- 40 °C to + 85 °C

Mechanical Specifications:

Length x Width x Thickness	1,649 mm x 991 mm x 40 mm (64.92" x 39.02" x 1.575")
Weight	18.5 kg (40.79 lbs)
Solar Cells	60 multi c-Si in series / 156 mm x 156 mm (6+)
Junction Box / Connectors	Three bypass diodes / MC4 compatible / IP 67
Frame	Anodized AL with drainage holes / rigid anchored corners
Glass	3.2 mm tempered glass / high-transparency / low-iron content
Packaging	16 or 25 modules per pallet / stackable 3 pallets high
Certified Nominal Load	5,400 Pa
Impact resistance	Hailstone / Ø 25 mm / 83 km/h (51 mph)



Dealer Information

www.bisol.com | www.bisol.co.uk

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ANNEX 2

INGECON
SUN

 1Play
TL M Series

SINGLE-PHASE TL INVERTER WITH A DOUBLE MPPT SYSTEM

**2.5TL M / 3TL M / 3.3TL M / 3.68TL M / 4.6TL M /
5TL M / 6TL M**

The INGECON®SUN 1Play TL M inverters have been designed to maximize the power generation and also to facilitate user access to the PV plant. This solar inverter family is valid for low kilowatt residential applications, and also for decentralized commercial and industrial systems rated up to several hundred kilowatts.

In domestic installations, these inverters present the great advantage of being compatible with 30 mA RCDs, the most commonly used to protect the people against electric discharges.

High efficiency system

Ingeteam has developed its own technology to maximize the efficiency rates of the INGECON®SUN 1Play TL M inverter family.

Thanks to this *High efficiency system* and to the use of innovative electronic conversion topologies, values of up to 98% can be achieved. Furthermore, an advanced double-MPPT algorithm makes it possible to harness the maximum energy from the PV array at all times, even in difficult situations, such as scattered clouds and partial shadings.

Easy to install

The INGECON®SUN 1Play TL M inverters feature fast-on connectors on the DC side (type 4) and the AC side for a fast and easy connection to the system. Every country-specific configuration and language can be easily selected from the inverter screen. Moreover, the INGECON®SUN 1Play TL M inverters are compatible with all the PV module technologies on the market.

Simple operation and maintenance

Ingeteam is at the forefront of innovative firm-ware. As a result, the INGECON®SUN 1Play TL M inverters are extremely easy to operate. The menu displayed on the LCD screen has been designed so that it is simple and easy to use. These inverters feature an internal datalogger for several months data storage, accessible from a PC.

Every inverter can be accessed from either a remote PC or onsite from the inverter front touch key-pad through its LCD screen. The display also features a number of LEDs to indicate the inverter operating status.

These LED indicators light up whenever any incident is detected, thereby simplifying and facilitating equipment maintenance tasks.



www.ingeteam.com
solar.energy@ingeteam.com

Ingeteam

INGECON

SUN

1Play TL M Series

2.5TL M / 3TL M / 3.3TL M / 3.68TL M / 4.6TL M / 5TL M / 6TL M

Firmware updating

The INGECON® SUN 1Play TL M inverters allow the user to perform the firmware (FW) updating himself. It is as easy as to download the latest version of the firmware from the Ingeteam website: **www.ingeteam.com**, and update it using a simple SD memory card.

Monitoring and communication

The internal operating variables and the internal datalogger can be monitored through a number of media such as USB communications, supplied as standard. Also, RS-485, Ethernet, Wi-Fi, and 3G communications are available upon demand.

Included at no extra cost are the INGECON® SUN Manager, INGECON® SUN Monitor and its Smartphone version iSun Monitor -available on the App Store- for monitoring and recording the inverter data over the Internet.

Able to withstand extreme conditions

The INGECON® SUN 1Play TL M inverter housing is suitable for outdoor use (IP65 protection rating). Likewise, it can be used under extreme atmospheric conditions with temperature ranges from -25 °C to +65 °C, although its main cooling system is air convection.

SiC technology

This solar inverter presents silicon carbide (SiC) components. SiC technology allows higher efficiency levels and also a more reliable, light and compact equipment.

Long life expectancy

Ingeteam takes every care in the selection and sizing of the electronic components used for its inverters. The 1Play inverters have been designed to guarantee a long life expectancy, as demonstrated as demonstrated by the stress tests they are subjected to.

Standard 5 year warranty, extendable for up to 25 years

OPTIONAL ACCESSORIES

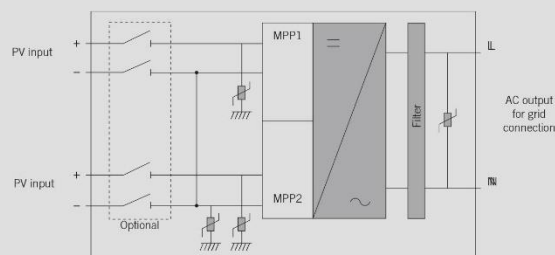
- Inverter communication via RS-485, Ethernet, Wi-Fi or 3G.
- DC switch.
- INGECON® SUN WeatherBox for meteorological values measurement and registration.
- Four additional digital inputs.
- Self-consumption kit.

PROTECTIONS

- Reverse polarity.
- Input and output overvoltages with type 3 surge arresters.
- Output shortcircuits and overloads.
- Anti-islanding with automatic disconnection.
- Insulation failures.

MAIN FEATURES

- Compatible with 30 mA RCDs.
- Double-MPPT system.
- Available from 2.5 up to 6 kW.
- 98% maximum efficiency.
- SiC Technology inside.
- Inverter updating by the user through a SD memory card.
- USB communications supplied as standard.
- Two digital inputs as standard.
- Software INGECON® SUN Manager for PV plant access and data registration.
- Software INGECON® SUN Monitor for PV plant monitoring.
- LCD Display.
- Easy maintenance.
- Suitable for indoor and outdoor installations (IP65).
- Display-configurable potential free contact, to indicate insulation fault or grid connection.
- Compact design.
- Language and Country Code, rated voltage configurable by display.

1Play TL M**Ingeteam**

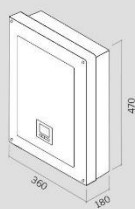
INGECON		SUN		1Play TL M Series			
	2.5TL M	3TL M	3.3TL M	3.68TL M	4.6TL M	5TL M	6TL M
Input (DC)							
Recommended PV array power range ⁽²⁾	2.8 - 3.3 kWp	3.2 - 4 kWp	3.8 - 4.4 kWp	3.9 - 4.8 kWp	5.2 - 6 kWp	5.7 - 6.5 kWp	6.3 - 7 kWp
Voltage range MPP1 ⁽³⁾				125 - 750 V			
Voltage range MPP2 ⁽³⁾				90 - 750 V			
Maximum voltage ⁽⁴⁾				850 V			
Maximum current (Input 1 / Input 2)				11 / 11 A			
Inputs (Input 1 / Input 2) ⁽⁵⁾				1 / 1			
MPPT				2			
Output (AC)							
Rated power	2.5 kW	3 kW	3.3 kW	3.68 kW	4.6 kW	5 kW	6 kW
Max. temperature at rated power ⁽⁶⁾	60 °C	55 °C	52 °C	50 °C	58 °C	55 °C	45 °C
Maximum current	16 A	16 A	16 A	16 A	26.2 A	26.2 A	26.2 A
Rated voltage				230 V			
Voltage range				122 - 265 V			
Frequency				50 / 60 Hz			
Power Factor				1			
Power Factor adjustable	Yes. Smax=2.5 kVA	Yes. Smax=3 kVA	Yes. Smax=3.3 kVA	Yes. Smax=3.68 kVA	Yes. Smax=4.6 kVA	Yes. Smax=5 kVA	Yes. Smax=6 kVA
THD				<3%			
Efficiency							
Maximum efficiency	97.6%	97.7%	97.7%	97.8%	97.9%	98%	98%
Euroefficiency	97.3%	97.4%	97.4%	97.5%	97.5%	97.6%	97.6%
General Information							
Refrigeration system				Air convection			
Stand-by consumption ⁽⁷⁾				<10 W			
Consumption at night				0 W			
Ambient temperature				-25 °C to +65 °C			
Relative humidity (non-condensing)				0 - 100%			
Protection class				IP65			
Marking				CE			
EMC & Security standards	EN 61000-6-1, EN 61000-6-2, EN 61000-6-3, EN 61000-6-4, EN 61000-3-11, EN 61000-3-12, EN 62109-1, EN 62109-2, IEC62103, EN 50178, FCC Part 15, AS3100						
Grid connection standards	RD1699/2011, DIN V VDE V 0126-1-1, EN 50438, CEI 0-21, VDE-AR-N 4105:2011-08, G59/2, G83/2 ⁽⁸⁾ , P.O.12.3, AS4777.2, AS4777.3, IEC 62116, IEC 61727, UNE 206007-1, ABNT NBR 16149, SABS NBR 16150, South African Grid code, Chilean Grid Code, Romanian Grid Code, Ecuadorian Grid Code, Peruvian Grid code, IEEE 929, Thailand MEA & PEA requirements, DEWA (Dubai) Grid Code, Jordan Grid Code						

Notes: ⁽¹⁾ Depending on the type of installation and geographical location. ⁽²⁾ The output power will be conditioned by the voltage and current configuration selected at each input. ⁽³⁾ To drop to 90 V, the other input must be at least at 125 V. ⁽⁴⁾ Must not be exceeded under any circumstances. Consider the voltage increase of the "Voc" at low temperatures. ⁽⁵⁾ Optionally, the DC inputs could be duplicated. ⁽⁶⁾ For each °C of increase, the output power will be reduced at the rate of 1.8%. ⁽⁷⁾ Consumption from PV field. ⁽⁸⁾ Related only inverters up to 16 A.

Efficiency INGECON® SUN 5TL M V_{dc} = 680 V



Size and weight (mm)



2.5TL M / 3TL M / 3.3TL M / 3.68TL M
20 kg.

4.6TL M / 5TL M / 5.5TL M / 6TL M
21 kg.

LIST OF REFERENCES

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