UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

ASSESSMENT OF THE IMPACT OF FUTURE PRICES ON THE DESIGN OF A PHOTOVOLTAIC PLANT

Student:
Amable Matus Carrasco

Supervisor:
Luis Martín Blázquez

Company: Iberdrola S.A

Madrid, 2019

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Executive Summary

In Europe the strong growth of renewable energies is high, nowadays there are new investments in plants that are accompanied by great research efforts that lead to improved system solutions along with higher degrees of efficiency, lower production and operating costs. The ambitious goal of penetration of renewables by 2030, have posed a scenario in Spain where photovoltaic energy has a leading role.

Within this framework, photovoltaic technology could become a determining variable within the pool market in Spain and affect its revenues and profitability in projects that depend exclusively on the market, that is, outside the regulated context, since it could charge a lower price per MWh which it enjoys today.

This risk is currently becoming one of the main concerns of both the financiers and the promoters of these plants, since it largely determines the profitability of these assets in the medium and long term.

For this reason, for this work, the profitability of two types of designs to be employed is evaluated for a photovoltaic plant in Talavera de la Reina, Toledo, taking into account the uncertainty of future prices that would affect the profitability of said project, concluding with an investment suggestion that can bring greater benefits in the future.

Acknowledgements

There have been many people who have contributed their support throughout this master's degree. The people that I will mention below are the things that have encouraged me when I needed the most, when I no longer had the strength and wanted to abandon everything

First of all, I thank God for allowing me to complete this stage in my life, your love has been the one that has lifted me, thank you for not leaving me alone, for not letting me fall, and always see your grace work in my life, without your inexhaustible love I would never have achieved anything.

As the commutative property says, "The order of the factors does not alter the product". So, I will start by thanking, on a personal level, my parents. Mom, thanks for pulling my ears when I need it, thanks for sending me love from afar, I'll never stop saying you're the best mom in the world. Papa thank you for always talking to me and never making me feel that I am alone, your motivational images every morning gave me my second breath to move forward.

To my boyfriend, for believing more in me than myself, for trusting in me every day and being a support throughout this year. Thank you for appearing in the last and making me finish the master as you do in the "At zero hour" games. To my sisters, for helping me to make the decision to come to study this master's degree and send me those songs that motivated me every day.

To my friends from MEPI. Thanks for this year, I will never forget our first outings and the last ones, our study hours, and the meetings in my apartment, are the most incredible people I have come to know, and I hope that our friendship lasts despite the distance.

At a professional level, my tutor Luis Martin Blazquez, who always had the time and dedication to teach me when I had no idea what he was doing. Placido Ostos is a great professional that I have learned and admire. Placido, I hope to become like you and be able to return the favor in the same way that you did with me, to my professor of the master, José Pablo Chávez, who opened the door even though I did not have time to eat and I was enlightened a little with this work, and especially my director Luis Olmos, who had the patience throughout the year to cheer me up, give me feedback, give me advice on the subjects, thanks Luis for your time.

To my teacher and friend Fabio, you are an amazing person, without you, I literally could not have done this, my title is also yours.

To finish, I want to thank Iberdrola Mexico for believing in me giving me the opportunity to come and study this master's degree, and also this work, is dedicated to all those people who have been with me since my childhood until now, all have collaborated with me sharing their anecdotes, dreams, happiness that have influenced the person I am now.

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Introduction

The energy coming from the sun is the main source of energy; it directs the chemical, biophysical and geophysical cycles that maintain life on the planet (the cycles of oxygen, carbon, water and climate). Solar energy is what induces the movement of water and wind, so is the origin of the most renewable energy, wind, hydro, biomass etc.

Renewable energies produced in a continuous and inexhaustible on a human scale, have the additional advantage of being able to complement each other that favoring the integration between them. In recent years, renewable energies have increased considerably in the European Union specifically, the percentage of energy from renewable sources in the final gross consumption of energy has almost doubled in recent years, from 8.5% in 2004 to 17.0% in 2016. (Eurostat,2017)

In recent years, solar energy has been experiencing development and expectations for the future, for example, in Spain, the solar potential is the highest in all of Europe. According to statistical data of the European Union, currently, Spain has the fourth place in the world in the manufacture of cells and photovoltaic panels. Summarizing, the photovoltaic systems consist of a set of elements, called solar cells or photovoltaic cells, arranged in panels, which directly transform solar energy into electrical energy.

This energy produced can be transmitted to satisfy energy needs to those who demand this commodity. Thanks to its flexibility in energy production, the growing demand for the manufacture of solar cells and photovoltaic installations has advanced considerably in recent years, which means that within a few years it will become the cheapest source of electricity in many parts of the world.

Motivation

The purpose of the master thesis is to give a conclusion to the Official Master's degree in the Electric Power Industry at University of Comillas taught in Madrid during the academic year 2018-2019. The Master thesis is supervised by Luis Martin Blazquez that is in charge of solar photovoltaic energy in Iberdrola.

As I mentioned before, the photovoltaic system has been increasing, advance in the last years being more competitive at lower costs, with the advances in the innovation of the photovoltaic cells being more attractive for the investors. With the importance that we have today against the struggle of climate change , the reduction of greenhouse gas emissions, the use of renewable

energy this can lead to efficiency, less expensive energy supplies, greater diversity, less air pollution and the possibility of creating new jobs in renewable energies sectors and the environment.
That is why I decided to do my master's thesis in a photovoltaic project, where I could contribute the knowledge acquired throughout the master and the new knowledge acquired through the internship.

Objectives

The objectives that are addressed within this project are:

- Examine the current situation of photovoltaic energy production in Spain.
- Research the solar radiation at the site where the project is developed.
- Apply the regulatory context necessary to develop the project.
- The photovoltaic project design within the available area.
- Calculation of annual hourly solar radiation from a model in Excel.
- Calculate the expected average annual profile of energy injected into the network.
- Calculate the photovoltaic modules needed to reach the maximum allowable power.
- Calculate the effective angle of inclination to maximize production.
- Develop a homogenization of photovoltaic modules.
- Select the models of photovoltaic panels to apply.
- Estimate future market prices from the two selected proposals.
- Estimate the CAPEX and OPEX of the two selected proposals.
- Calculate the cash flows of the two selected proposals.
- Give a selection proposal for a better investment in the future.

Methodology

The development of the project will start in the solar radiation of the site. The hourly solar radiation will be investigated in Talavera de la Reina, Toledo and with this data an Excel model will be developed with dynamic tables that can facilitate the information of the hourly irradiation within the site. This can be achieved based on the solar radiation data provided by the SolarGis tool.

Once the hourly profiles curves have been obtained, a base design model of the site will be developed within the PvDesign tool, which will help us calculate the maximum power of the project. This base model will consist of photovoltaic modules previously used in past projects. Once having the data of the maximum achievable power. The maximum available capacity of the transport network closest to the site will be consulted with the system operator, in order to know the maximum power to be developed.

Once the maximum power to reach the site has been obtained, the maximum number of modules per String will be calculated (based on formulas based on photovoltaic projects), this will be used to compare the software to be used with the previously calculated. Within these calculations, you will also find the calculation for the optimum angle of inclination that maximizes the production of each photovoltaic module.

Based on these basic data, the four different design models will be developed within the PvDesign platform, and starting with the data provided as the maximum allowable power of the site, a homogenization of the annual achieved production will be carried out, this is for the purposes of ease in the choice of the two photovoltaic designs to be compared.

Once the two models to be compared have been selected, the production data for the first year, the 6th year, the 11th year and the last year will be taken into account, in order that they may coincide with the future price data provided by the *Research Institute (IIT) of the Technological University of Comillas*[1]. Once having these two data (of each of the modules). The future market price will be calculated, this in order to calculate the expected income of the project with the two different panel designs.

At the end, the Capital Expenditure (CAPEX) and Operational Expenses (OPEX) of each of the projects will be calculated with the expected income, this with the purpose of calculating the cash flows of each of the projects, with their respective LCOe and At the end, grant a recommendation of the best investment.

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[1] *Análisis de escenarios futuros para el sector eléctrico en España para el período 2025-2050: Carry out a quantitative evaluation of the technical-economic impact that would result from the closure of nuclear power plants at the end of their life of commercial exploitation of design (40 years), and the second corresponds to a progressive and orderly closure of plants.*

Background of Solar Energy

Photovoltaic Solar Energy

Electricity is the most versatile form of energy that we have, it allows the world population to access basic resources that have become indispensable for today, such as light, refrigeration, access to communication media, etc. (Harish,2017)

Photovoltaic solar energy is a technology that generates direct current by means of semiconductors, taking advantage of solar radiation transforming it directly into electrical energy. The conversion of solar energy to electrical energy is generated from a semiconductor element called a photovoltaic cell. Once sunlight hits a photovoltaic cell, the photons in sunlight transmit their energy to the semiconductor electrons so that they can circulate inside the solid (Wang, 2016).

Photovoltaic technology allows part of these electrons to leave the semiconductor material, thus generating an electric current capable of circulating through an external circuit.

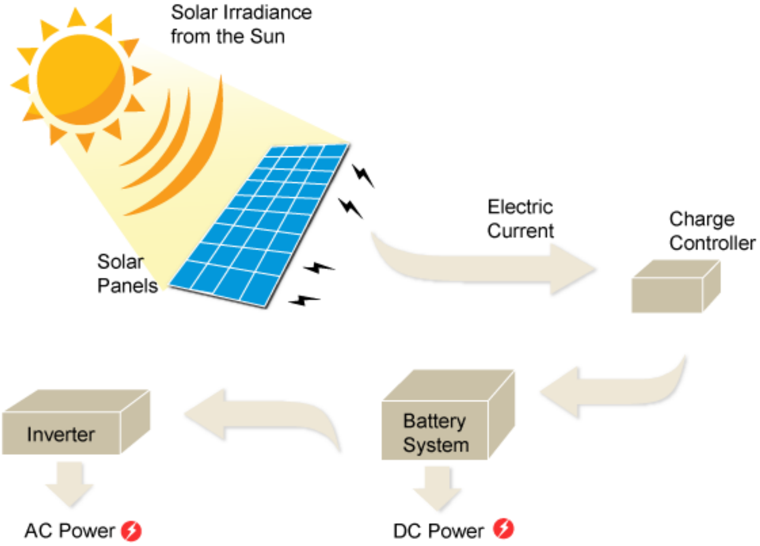

Figure 1. Solar Power

This type of energy is used mainly to generate electricity through distribution networks, but also allows to feed countless applications and autonomous devices, as well as to supply mountain shelters or isolated homes from the electricity grid. Photovoltaic energy does not emit any type of pollution during its operation, contributing to avoid the emission of greenhouse gases (Boxwell, 2019).

Photovoltaic Panel

The photovoltaic module is the device where the photovoltaic cells are located which are physically protected from the weather and electrically insulates the exterior. The photovoltaic module follows a configuration both in series and parallel prepared for its associated installation also to obtain the desired power for the type of application to which it is going to be used. The cell association is encapsulated in two layers of Ethylene-vinyl acetate between a glass front sheet and a back layer of a thermoplastic polymer or another glass sheet when it is desired to obtain modules with some degree of transparency (Perpiñan, 2018).

In the majority the compound is framed by an anodized aluminum structure, this to increase the mechanical strength of the assembly and facilitate the anchoring of the module to the support structures. The front glass must have a good resistance to impact and maintain a high transmissivity in the spectral band in which the solar cells work, its surface must have a shape that helps the anti-reflective behavior with the absence of edges and unevenness that facilitate the dirt accumulation.

Over the years the configuration of modules was used with 36 cells in series to obtain modules with power in ranges of 50Wp - 100Wp. These modules were suitable for batteries with nominal voltage 12V in rural electrification systems. With the prominence of photovoltaic systems connected to the grid, modules with power over 200Wp and voltages in the range of 30V - 50V are now common (Perpiñan, 2018).

Figure 2. Photovoltaic Panel

Components

Generally, it can be said that the modules are made up of the following components (DOE, 1997):

External cover: This made of glass to facilitate the maximum transmission of solar radiation, is characterized by high transmissivity and low iron content, its function is to protect the panel from all atmospheric phenomena.

Encapsulant: It is made of silicone or frequently of EVA (ethylene-vinyl-acetate). Its main function is to adhere the covers and cushion possible vibrations.

Posterior protection: Its main function is to provide rigidity and protection against atmospheric agents. Commonly used sheets formed by different layers of materials of different characteristics.

Metal Frame: Its function is to support the whole set and as an element of mechanical connection between modules, it is composed of stainless steel or anodized aluminum.

Wiring and connection terminals: These are cables made of copper that allow the energy of the module to be collected and located in the back of the module in a box that is protected from humidity.

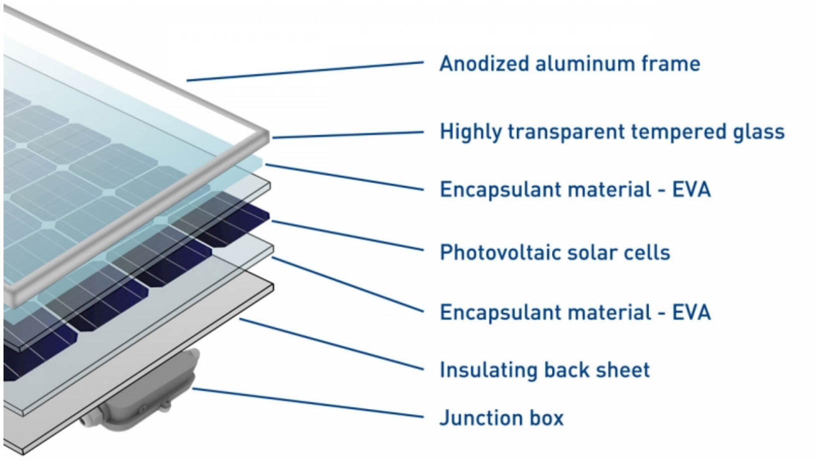

Figure 3. Photovoltaic Components

Current Situation of Photovoltaic Energy

When we talk about emissions, we have always imagined the plastic, steel, metal and glass producing industries. But two of the third parts of CO2 emissions come from electricity generation, heating and transportation. The solar resource is huge and growing which is causing an impact in the electricity production.

In the last few years, more than half of Solar PV's operating capacity has been added, and 98% has been installed since 2014. As mentioned above, the penetration of solar energy is increasing, and causes the average value of solar electricity decrease, since in the market prices are minimum when there are hours of sun since solar production is higher. This means that its cost has to decrease in a way that production and price are competitive against fossil fuels.

As we can see in the Figure 4, the capacity of renewable energy sources has been growing, until reaching a report of 2000GW capacity, where solar positioning and from 2014 to 2017 has been great. (REN21, 2018)

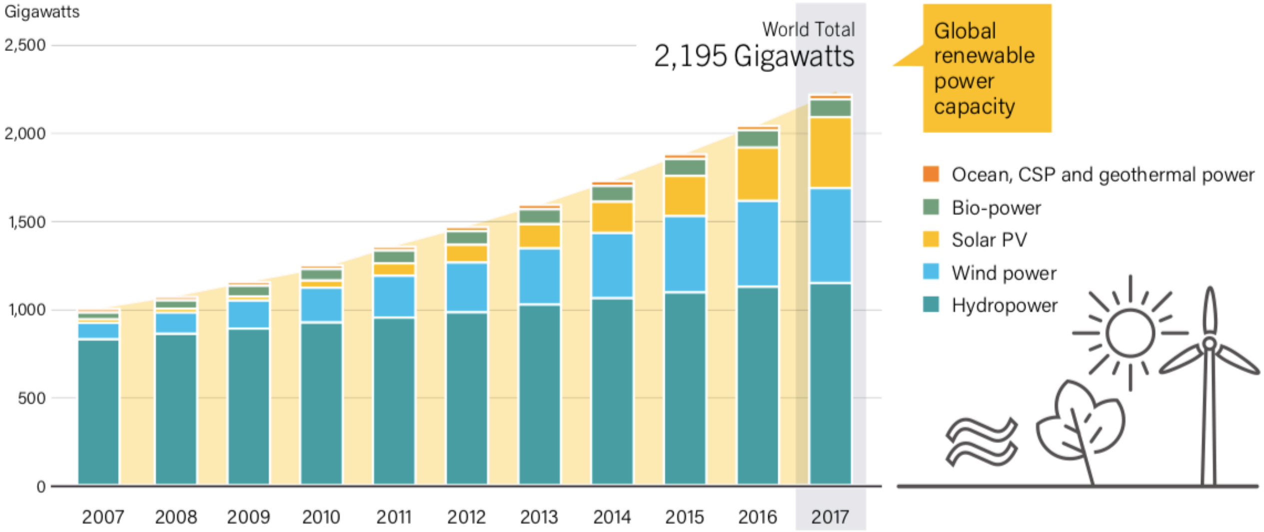

Figure 4. Global Renewable Power Capacity, 2007-2017

If we talk about a key point for the world of solar energy, we could say that 2017 was. Worldwide, more solar photovoltaic capacity was installed than any other technology, including fossil fuels and nuclear energy combined. In 2017, solar energy was the maximum resource of new power capacity in many markets, including the United States, China, Japan and India.

According to data from the Renewable Energy Policy Networks *"For the 21st Century Globally, at least 98 GW of solar PV capacity was installed (on- and off-grid), increasing total capacity by* *nearly one third, for a cumulative total of approximately 402 GW. On average, the equivalent of 40,000 solar panels was installed each hour of the year"* (REN21,2018).

If we have to do the top 5 of national markets of Solar PV. We can start mainly by China, United States, India, Japan and Turkey, which are responsible for nearly 84% of new installed capacity, and if we want to add another 5 would be Germany, Australia, the Republic of Korea, the United Kingdom and Brazil.

Several countries are successfully integrating increasingly larger shares of variable solar PV into electricity systems by improving regulations and market design to reward flexibility, and by improving transmission and interconnection so as to broaden balancing areas (REN21, 2018)

Asia: China has been one of the countries with the most notorious growth. The significant market increases relative to 2016 was due to China, where new installations were up more than 50%. China has become one of the largest producers and leader in capacity in hydropower, onshore wind power and solar PV. India elsewhere is close to doubling its installed capacity of solar PV.

Europe: Has had a very slow growth in many countries, but in 2017, for the first time, the generation of electricity has come from renewable sources mainly wind solar and biomass. Solar and wind energy take three quarters of the annual growth of power renewable capacity.

North America: In the United States, 18% of total electricity generation comes from renewable sources, but it is true that unlike 2016, 2017 has had a slow growth, but speaking in terms of installed capacity of continuous solar energy increasing up to 26% in 2017. In Canada, on the other hand, the growth of non-hydropower renewable capacity significantly, from nearly 30% in 2014 to around 4% in 2017.

Latin America and the Caribbean: In Latin America, the growth of non-hydropower renewables continued to grow strongly in 2017, and the solar energy and wind power markets are appearing in many countries in the region. Brazil continues to have the largest market for solar energy and energy in the last few years followed by Chile that exceeds an installed capacity of solar energy of 1GW.

Africa: The situation in Africa is that all the growth of installed capacity in renewable energy is limited to only a few countries. South Africa was the only country worldwide to bring CSP capacity online in 2017, leading the global market for the second year running. But in some parts of Africa they are interested in diversifying their energy mix and provide energy access, increasing the production of solar PV.[2]

Oceania: Australia generates around 17% of its electricity from renewable energies, is one of the countries in the top 10 with the highest installed capacity of solar PV, and the country ranked fifth globally for total capacity per inhabitant. New Zealand generates 85% of its electricity from renewable sources, with a higher percentage in hydropower and geothermal power.

Middle East: Middle East markets renewable energy production is very low about 2.5%, with non-hydropower renewables providing less as 0.6%. But despite this, in Saudi Arabia, it launched tenders for solar energy and wind energy to increase its ambitious objectives in renewable production.

The following Figure 5 shows the total solar energy production by country, where as mentioned above, China occupies the first position followed by United States and then Japan.

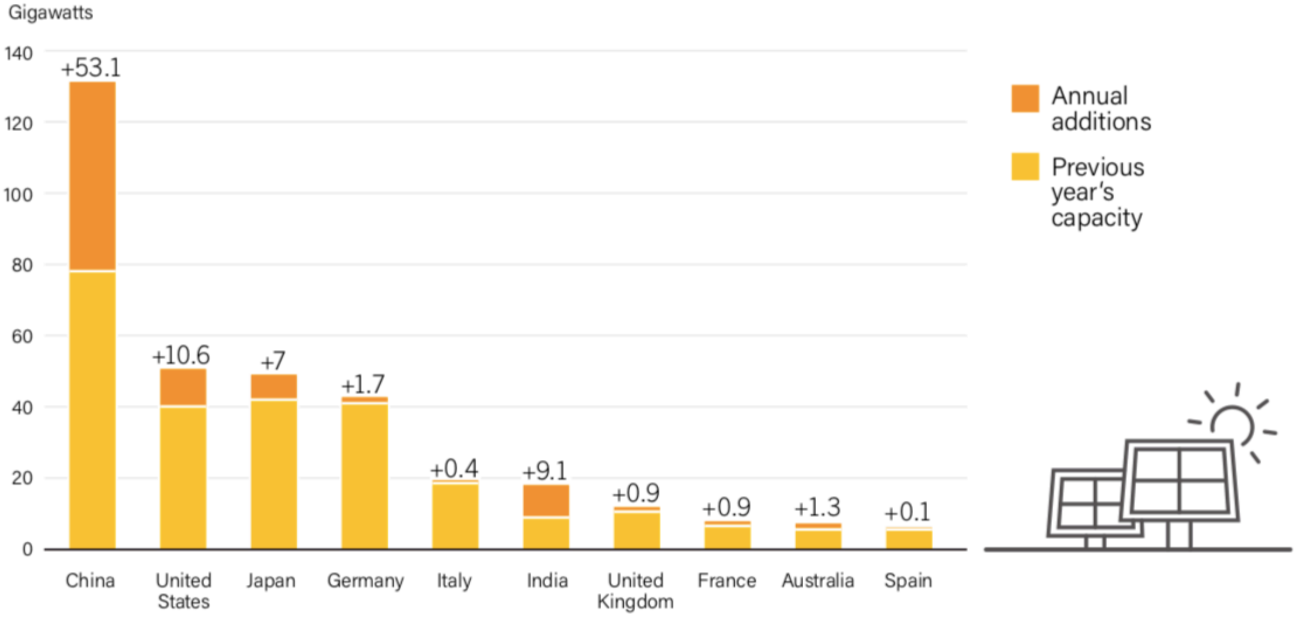

Figure 5. Solar PV Capacity and Additions, Top 10 countries, 2017

Having said that, renewable energies (especially photovoltaic energy) are gaining globally, there is a rapid expansion in capacity, but even fossil fuels continue to be the largest part of the final global energy consumption, that is why it should be to continue with this growth, so that we can continue the fight against climate change.

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[2] *All the data mentioned by country were obtained from the report "Renewables 2018 Global Status Report"*

Photovoltaic development in Spain

Spain takes place in Europe as the fourth country with total capacity cumulated in photovoltaic solar energy, mostly installed in 2008 when the country was a long market around 3.3GW. But it happened that a series of regulations was introduced to limit the growth of this sector and suspend the pre-assigned remuneration of the renewable energy concerns in 2012. "*The justification given for this move was that, until then, Spain's energy system had amassed a EUR 24 billion power tariff deficit “*(IEA, 2017).

The government's argument about this was that a new regime was needed for renewable energies. Which caused a deficit around 9 billion EUR in 2008, a time when payments under the special regime for renewable energy were still limited. But for 2017, new photovoltaic systems were installed with a capacity of roughly 150MW, also contributed 8.4 TWh (3.2%) the electricity generated connected to the grid in the generation of electricity in Spain (Commission, 2017).

As you can see in the following graph. The biggest growth was in 2008, continuing with 2012, and until now it has been increasing but in a slower way.

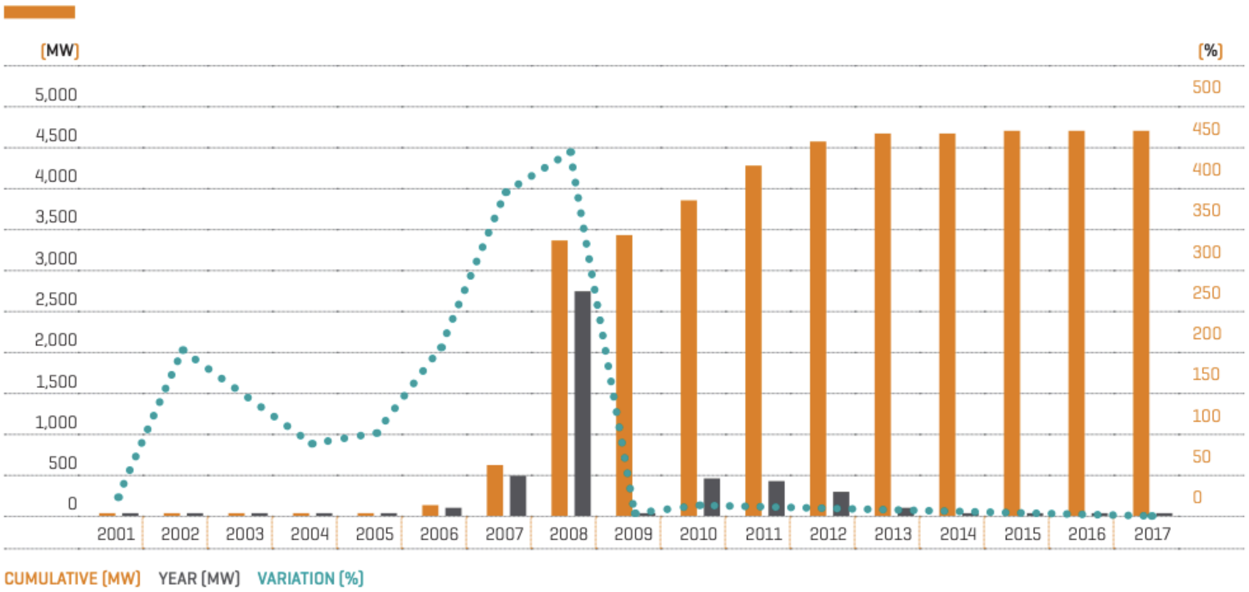

Figure 6. Installed Solar Photovoltaic (PV) Power Capacity. National electricity system

Within Spain, national production is divided into different regions. Where is the installation of solar photovoltaic power capacity is in the Castilla-La Mancha region with 20% of the total national production, below is Andalusia and then Extremadura and Castilla y León with a very small difference. Together these four autonomous regions represent 61% of the installed solar capacity in Spain (REE, 2017).

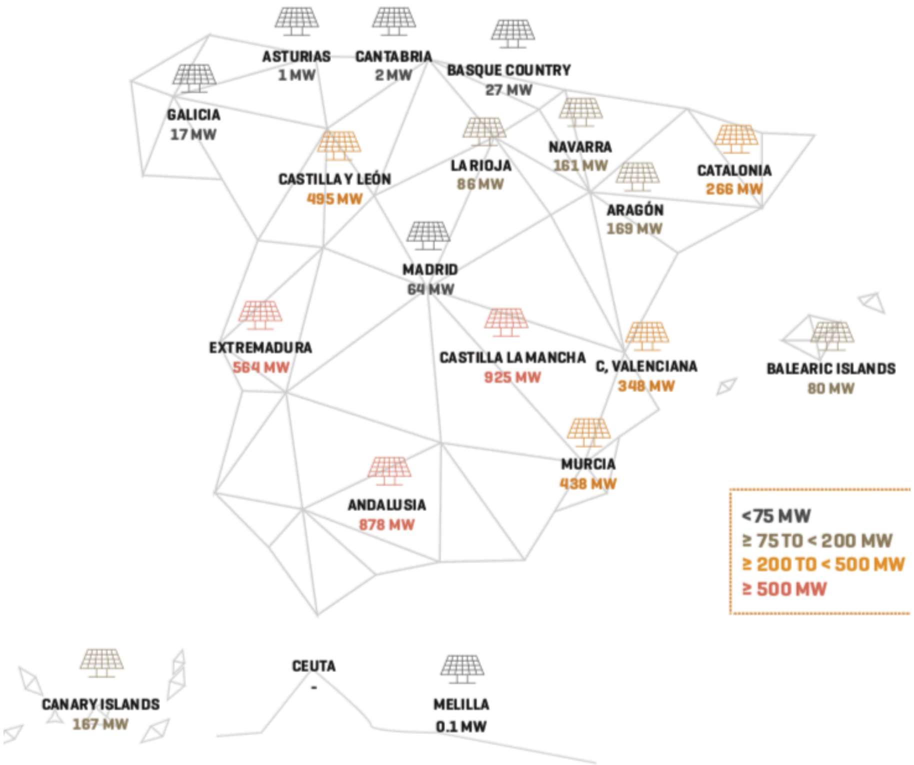

Figure 7.Installed solar photovoltaic (PV) power capacity as at 31.12.2017. National electricity system per autonomous community (MW)

PV MARKET

The solar market had a historic year in 2017, which was installed more than technology that never more than double the capacity of other renewable energies, as can be seen in the following figure, the net energy added in 2017 for each technology.

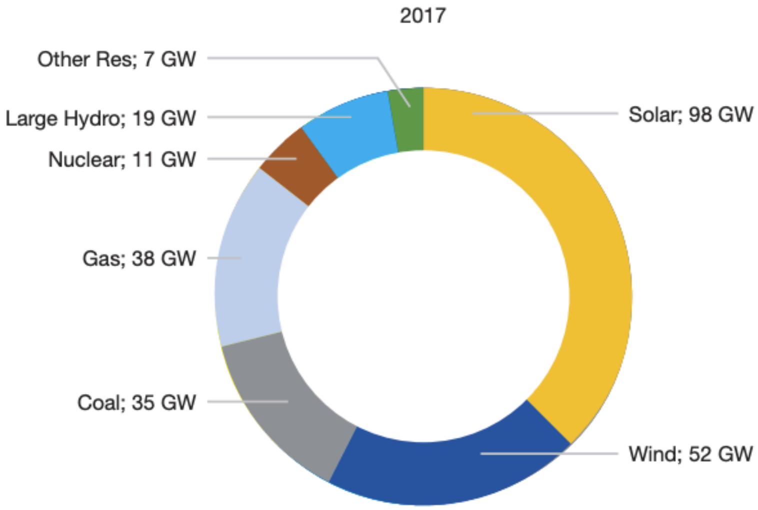

Figure 8. Net Power Generating Capacity Added in 2017 By Main Technology

One of the main causes of this increase in solar energy is the result of cost development (Figure 9). The low prices of solar energy made record in 2016 that even surprised the energy experts since the bids were under 3 US cents per kWh. For example, in Saudi Arabia in 2018, it won a license from the local company ACWA with a world price record of 2.34 cents per kW, while the first seven pre-selected offers were all below 2.90 cents of dollar per kW, here you can clearly see that the price for producing these photovoltaic modules has had a relevant drop, which in turn many companies are taking advantage of to build photovoltaic plants. (RECP, 2018)

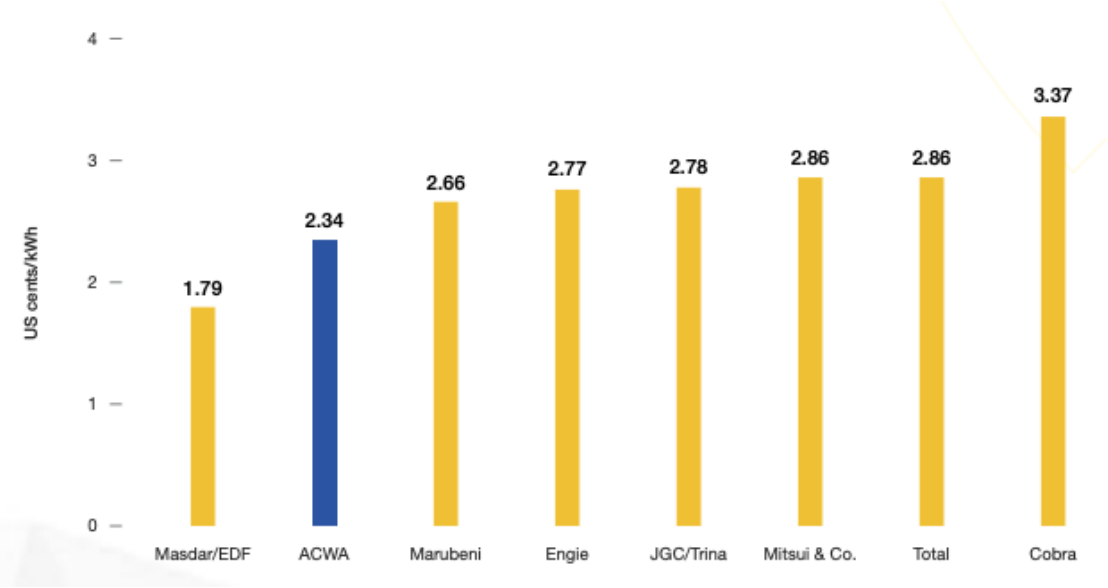

Figure 9. Top 8 Technical Bids For 300 MW SAKAKA PV Project In Saudi Arabia

This decrease is mainly due to technical improvements, the cost of solar energy and the price and in a clear and continuous manner. According to studies conducted at the American investment bank Lazard, solar energy and the escalation of public services in comparison with nuclear energy, coal and new combined cycle gas turbines. The lower the cost of capital, the greater the cost advantage of solar energy. (RECP, 2018)

For 2017 a total of 99.1 GW installed connected to the network is almost 30% annual growth, but it is still lower than the rate of 2016 with 49%, which for analysts was an amazement for that there were no expectations of this growth exponentially. Of course, these price drops lead to a consequence and the market becomes more competitive, in this case China was one of the countries that took advantage. (RECP, 2018)

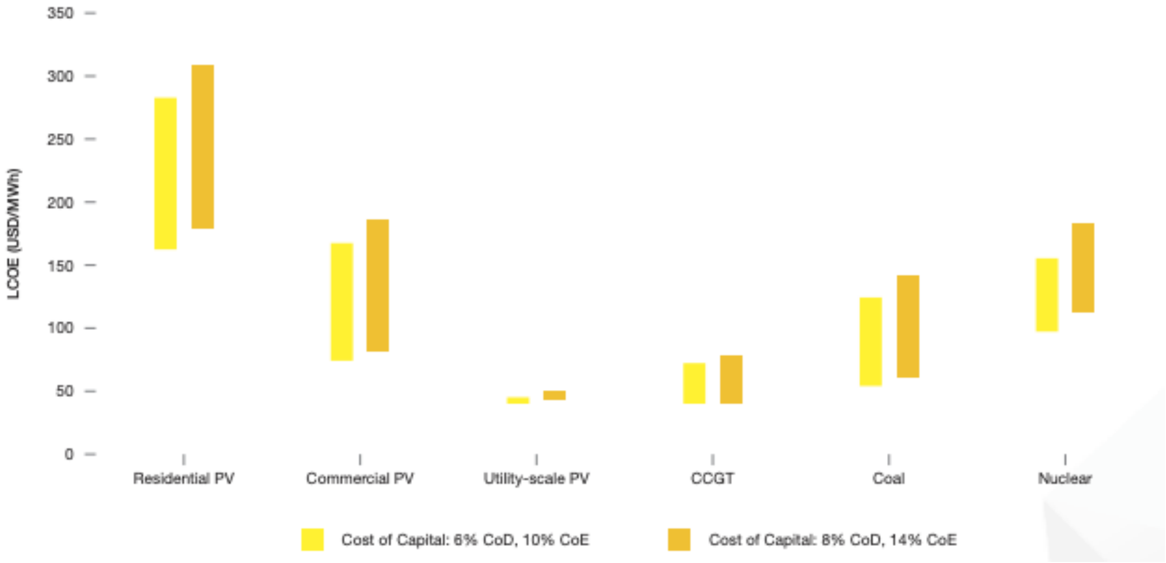

Figure 10. Solar Electricity Generation Cost in Comparison with Other Power Sources

For the first time, it installed more than half of the world's solar capacity in a year with 53.3%. And this was because thanks to the tariff-feeding program, the tariff levels for solar power plants were higher than in most other places in the world, and companies wanted to overcome the upcoming cuts in programmed subsidies, and The Chinese producers of modules once again prioritized the domestic market over the demand from abroad (RECP, 2018)

Another point in favor is that photovoltaic energy is also managing to satisfy the growing interest in some countries to produce electricity at the local level, however, part of the world demand is driven largely by incentives and government regulations. These challenges must be addressed before photovoltaic solar energy can become an important source of electricity worldwide, since countries such as Germany, Greece, and Honduras already satisfy an important part of their electricity demand with photovoltaic solar energy.

With this, it can be concluded, that the market expansion was caused by the increasing energy of photovoltaic energy and the growing demand of the countries in the development paths, together with the objectives of sustainable development in countries such as Spain, France, Germany They are committed, for example, to the continued reduction of CO2 emissions and access to energy for marginalized countries. (RECP, 2018)

Solar Resource

The sun as an energy source

Solar energy is the most abundant energy resource on earth and has two components of use (direct and indirect radiation). Direct radiation comes from solar radiation and indirect radiation has its form in wind, biomass, oceanic etc. Irradiation is the amount of radiant solar energy that affects one unit of area per unit of time.

The density of flow at an average distance between the sun and the normal earth is known as the solar constant, which has an approximate value of 1366.1 W / m² (according to the most recent estimate). When this density is averaged with the surface of the earth it suffers from losses in the passage through the earth's atmosphere. Therefore, the annual average of horizontal surface irradiance is approximately 170 W / m². (SolarGis, 2019)

Figure 11 and Figure 12 show the monthly solar energy that falls on the earth, these two months were selected, since as can be seen at first glance in the image (Figure 11) in Europe the colors are more red in comparison to the month of December, this at first sight shows us that the solar radiation in the month of July is stronger than in December.

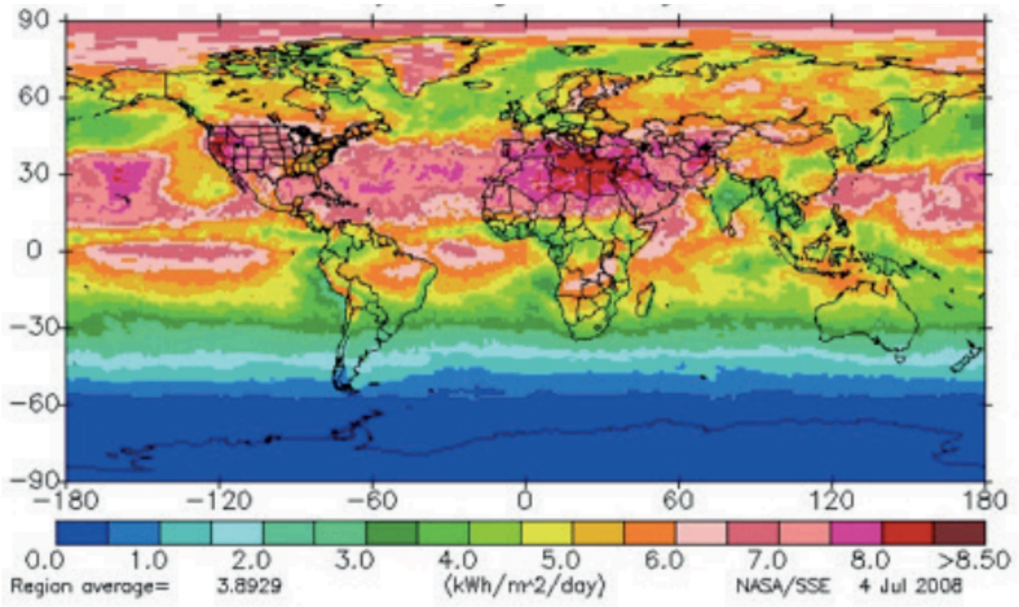

Figure 11. Average Daily Solar Radiation for July

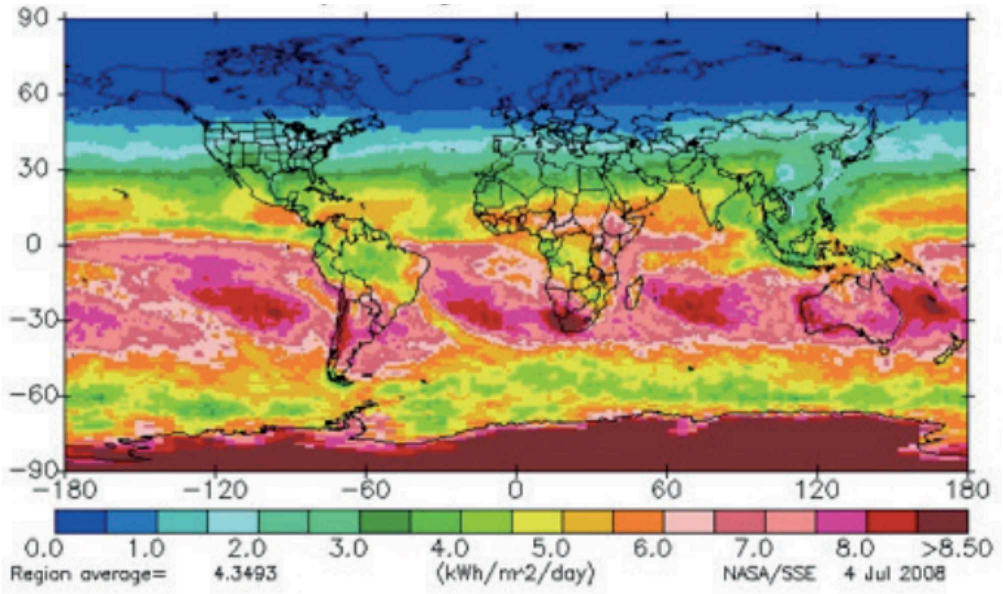

Figure 12. Average Daily Solar Radiation for December

Solar energy has parameters of solar resources and its specialty in space time, depend on their applications (solar collector, photovoltaic plant, thermal plant, etc.). They can differ a lot and in turn are not available for many locations, since the weather stations do not have enough geographical coverage of time / specific site of irradiation.

These coverages are important since you can evaluate sites dependent on their geographical area and the energy demand they have. Therefore, they allow a better evaluation of the feasibility of a solar energy application and its value. There are public data measured of solar radiation around the world, where it can be accessed from websites of government agencies in most countries of the world. Therefore, for the purposes of this project, this information is used and, based on what has been previously estimated, the specific radiation data for the Talavera de la Reina site is calculated. (SolarGis, 2019)

Regulatory Context

Applicable Regulations

The regulation that regulates the operation of a photovoltaic plant connected to the network is studied, mainly we have to distinguish between a regulation and a recommendation. The regulations are dictated through different legal mechanisms, while the recommendations act as criteria for good practices. (BOE, 2014)

The main regulations that are applied for this project with respect to electrical installations are[3]:

- **Law 1/2007 of February 15.** Promotion of Renewable Energies and incentivization of Energy Saving and Efficiency in Castilla La Mancha
- **Royal Decree 299/2003 of November 4.** Regulates the procedure of the condition of installation of electric power production in special regime and the creation of the Autonomic Registry of the installations under said regime.
- **Royal Decree 80/2007 of June 19**. Regulates the procedures for authorization of electric energy inhalations to be processed by the community board of Castilla La Mancha and its review and inspection regime.
- **Law 7/2008.** Regulation of fees in matters of Industry, Energy and Mines of Castilla de La Mancha.
- **Royal Decree 1995/2000 of December** 1. It regulates the activities of transportation, distribution, marketing, supplies and authorization procedures for electric power installations.
- **Royal Decree 337/2014 of May 9**. It approves technical conditions and safety guarantees in high voltage electrical installations and their complementary instructions ITC-RAT 01 A 23.
- **Royal Decree 413/2014 of June 6**. It regulates the activities of production of electrical energy from renewable energy sources, cogeneration and waste.
- **Royal Decree 842/2002 of August 2**. In which the Electrotechnical Regulations for Low Voltage and complementary technical instructions are approved.
- **Instruction of January 21, 2004**. Of the General Directorate of Industry, Energy and Mines, on the procedure of commissioning of the photovoltaic installations connected to the network.
- Regulation of Electrical Verifications and Regularity in the Supply of Electric Power.
- UNE Standards and UNESA Recommendations that are applicable.
- Conditions and Municipal Ordinances imposed by the affected public entities.

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[3] *All the regulations applied were obtained from the "Boletin Oficinal del Estado"*

- **Law 54/1997 of November 27.** Of the Electricity Sector (BOE number 285 of November 28, 1997).

The main regulations that apply to the project with respect to the prevention of occupational risks:

- **Law 31/1995 of November 8**. Prevention of occupational hazards.
- **Law 54/2003 December 1**. Reform of the normative frame of prevention of labor risks.
- **Royal Decree 486/1997 of April 14**. Minimal safety and health provisions in workplaces.
- **Royal Decree 664/1997**. Protection of workers exposed to biological agents.
- **Royal Decree 1215/1997**. Minimum provisions of work teams.
- **Royal decree 614/2001**. Minimum provisions against electrical risk.

The main regulations that apply to the project with respect to the environment are:

- **Law 4/2007 of March 8**. Application of environmental assessment procedures of Castilla - La Mancha.
- **Royal Decree 178/2002 of December 17.** Approval of the General Regulations for the Development of Law 5/1999 of April. Environmental Impact Assessment of Castilla - The stain and adapt its annexes, would continue in force in what does not oppose the same.
- **Law 27/2006 of July 18.** Regulates the rights of access to information, public participation and access to justice in environmental matters.

Grid Connection

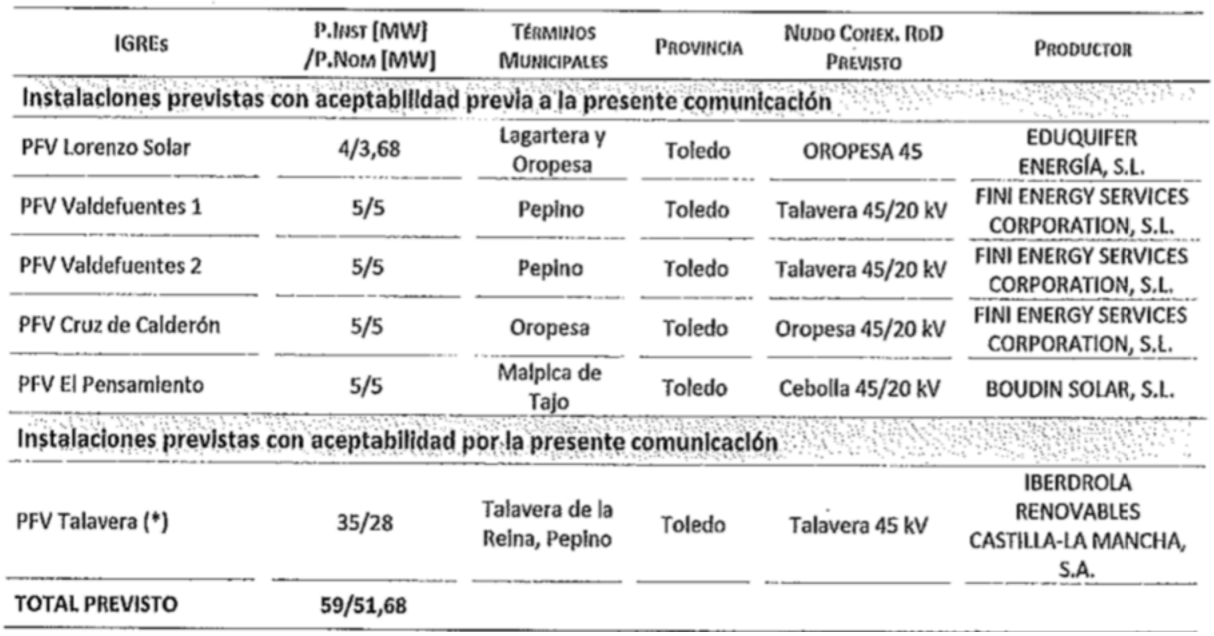
In order to proceed with a connection and access to the network, and the operation conditions from renewable energy sources, they are resolved as established in Royal Decree 1955/200 mentioned above. At the same time, the criteria must be observed in relation to the maximum admissible power in the production interconnection or set of facilities that share a point of connection to the network.

From the start of the request for the connection network point, a maximum amount of power is requested according to the available site. In the case of Talavera de la Reina, the site has an installation capacity of 50 MW. Therefore, a proposal for the access and connection point is requested from the owner company, for this specific case an application was filed with Iberdrola Distribution where the result was non-acceptance as it does not have availability for that capacity.

The node closest to the implementation has capacity 97.73 MWn of which 46.05 MWn are currently in service, that is why another application with less capacity to the access point starts.

After the first connection rejection, another request was made with a maximum peak power of 35MW where the result was acceptability from the transport perspective. This installation would be part of a grouping of IGREs (Installation of renewable generation) to the underlying distribution network of Talavera 220 KV, as indicated in the table

Table 1.Generation Facilities Planned in the Distribution Network, with Impact on the Transport Network in Talavera 200kv node, with Accessibility Accepted by the System Operator.



IGREs	P.Inst [MW] /P.Nom [MW]	Términos Municipales	Provincia	Nudo Conex. RdD Previsto	Productor
Instalaciones previstas con aceptabilidad previa a la presente comunicación					
PFV Lorenzo Solar	4/3,68	Lagartera y Oropesa	Toledo	OROPESA 45	EDUQUIFER ENERGÍA, S.L.
PFV Valdefuentes 1	5/5	Pepino	Toledo	Talavera 45/20 kV	FINI ENERGY SERVICES CORPORATION, S.L.
PFV Valdefuentes 2	5/5	Pepino	Toledo	Talavera 45/20 kV	FINI ENERGY SERVICES CORPORATION, S.L.
PFV Cruz de Calderón	5/5	Oropesa	Toledo	Oropesa 45/20 kV	FINI ENERGY SERVICES CORPORATION, S.L.
PFV El Pensamiento	5/5	Malpica de Tajo	Toledo	Cebolla 45/20 kV	BOUDIN SOLAR, S.L.
Instalaciones previstas con aceptabilidad por la presente comunicación					
PFV Talavera (*)	35/28	Talavera de la Reina, Pepino	Toledo	Talavera 45 kV	IBERDROLA RENOVABLES CASTILLA-LA MANCHA, S.A.
TOTAL PREVISTO	59/51,68				

With this response to the request, the design of the plant with the maximum capacity restriction to the connection point will begin.

Project General Description

Object

The following sections are aimed at describing the technical and economic characteristics of the design of the Talavera de la Reina solar power plant, Toledo with a peak power of 35 MW connected to the distribution network.

Site

The present work is developed on the study area of Talavera de la Reina, Toledo. Talavera de la Reina is a city in Spain belonging to the province of Toledo, autonomous community of Castilla de la Mancha. It has 83,009 inhabitants, is the second most populated municipality in the province and the fourth in the community. Keep in mind that the region is the leading Spanish producer of photovoltaic energy with 1,622 GWh in 2016, ahead of Andalusia and Extremadura (Ayuntamiento de Talavera de la Reina, s.f.)

In the following figure the location of the project is shown:

Figure 13. Location of Talavera de la Reina

Figure 14. Location of the project in Talavera de la Reina

The choice of plots where the photovoltaic plant is located has been made taking into account the following main criteria.

1. Solar Radiation
2. Proximity to the point of connection to the network with available capacity
3. Land lease
4. Compliance with environmental and urban regulations
5. Technological development and existing infrastructures, which facilitate transport and installation work.

With all these points taken into account, the installation allows to ensure high yields of energy production in relation to the investment made.

Sizing of the project

The proposed land for the site consists of 1 available area with a total area of 76.4 ha. The size of each area and the total area available for installation are shown in the following table:

Table 2. Available area of the project

Area Name	*Surface*
Available area	
Area 1	76.4 ha
Area of the substation	
Area 1	1.2 ha
Total area available	75.2 ha

Figure 15. Area of the PV Plant in Talavera

Topography

For the preliminary estimation of the topography to be studied, an analysis was made of the availability of suitable land for the construction. The North - South and East - West slopes were calculated (These data have been provided by google earth SRTM30).

The results of the analysis show three differentiated zones:

- Areas where the slope is less than 5%
- Areas where the slope is between 5% and 10%
- Areas where the slope is greater than 10%

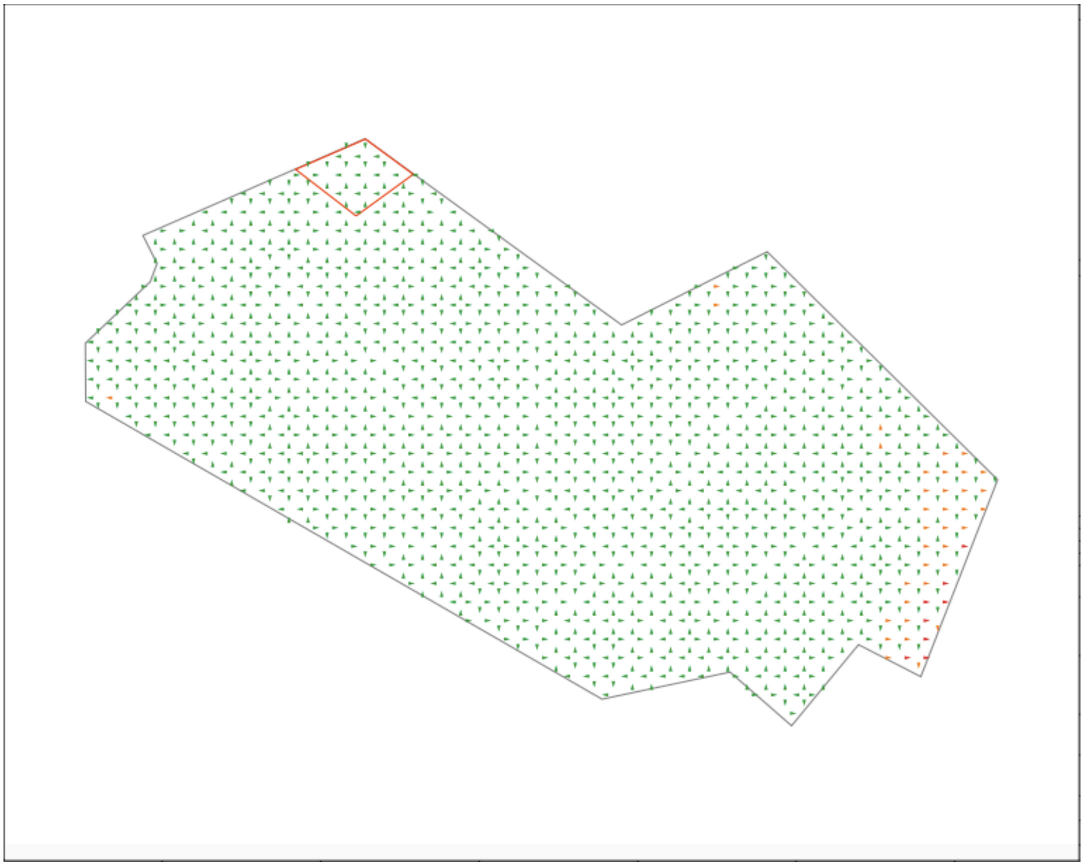


Figure 16. Inclination of the Land

The map shown in Figure 16 represents the slopes of the terrain, with the following colors:

Pendientes < 5%
Pendientes >5% y <10%
Pendientes > 10%

Solar Radiation

The solar resource is usually given as a series of values per hour of irradiance and temperature, for a period of a year. This series is called the Typical Meteorological Year (TMY). The source used to generate the TMY was the PVGIS database and the uncertainty of the PVGIS data is between ± 3% to ± 10%, depending on the location.

Average Radiation

To determine the expected annual production, start by creating a model in Excel based on the site data, taking into account the factors of direct solar radiation, diffuse radiation, temperature and wind, which are provided from the measurements made previously in the place.

Initially the information is collected for each hour to create an average time profile of the solar radiation, based on this, the data is entered in the model created in Excel, where it automatically calculates the monthly and annual hourly average profile curves. This information helps us to know the impact of the expected energy and decide if it is viable to make the investment.

The following below shows the total average of global radiation emitted in the area:

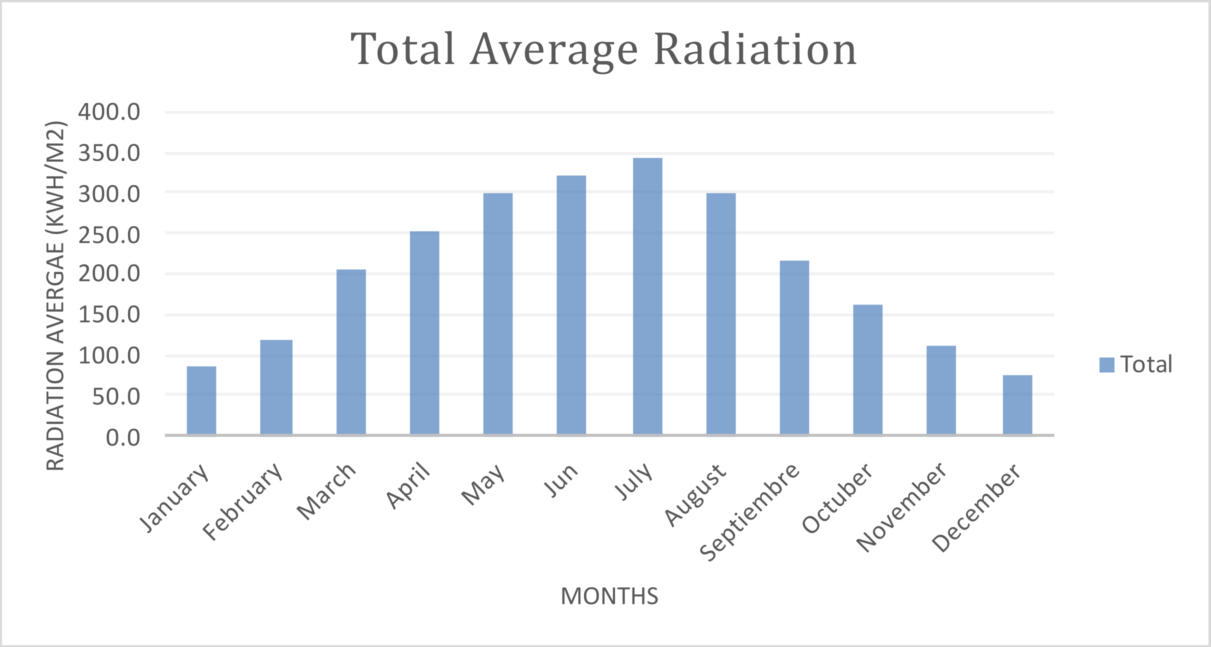


Figure 17. Total Average Radiation

As can be seen in the table above, the month with the highest solar radiation is July followed by June, May and August. With these results, we proceeded to obtain the hourly radiation curves per month, so that in the end we can see how the following graph turns out to be able to have the monthly comparison of radiation projection.

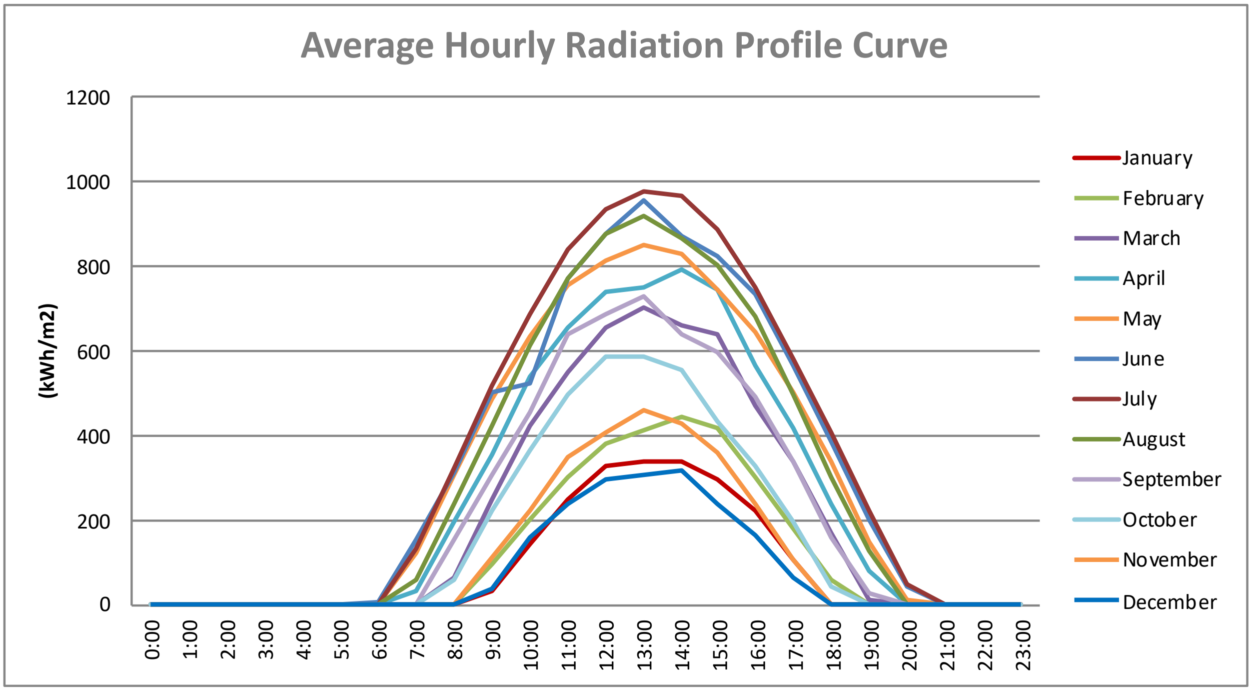


Figure 18. Average Hourly Radiation Profile Curve

Average Grid Energy

To proceed with the calculation of hourly production, the data that were taken into account were the time, temperature, month, global horizontal irradiation and the estimated energy that enters the network. To obtain the result, a model was made in Excel with the help of dynamic tables, where the monthly produced energy of the year was added in a column, with the factors described above, and based on this you get two estimation tables as you can see in the following figures.

The following table shows the average energy delivered (MWh) in the network per month:

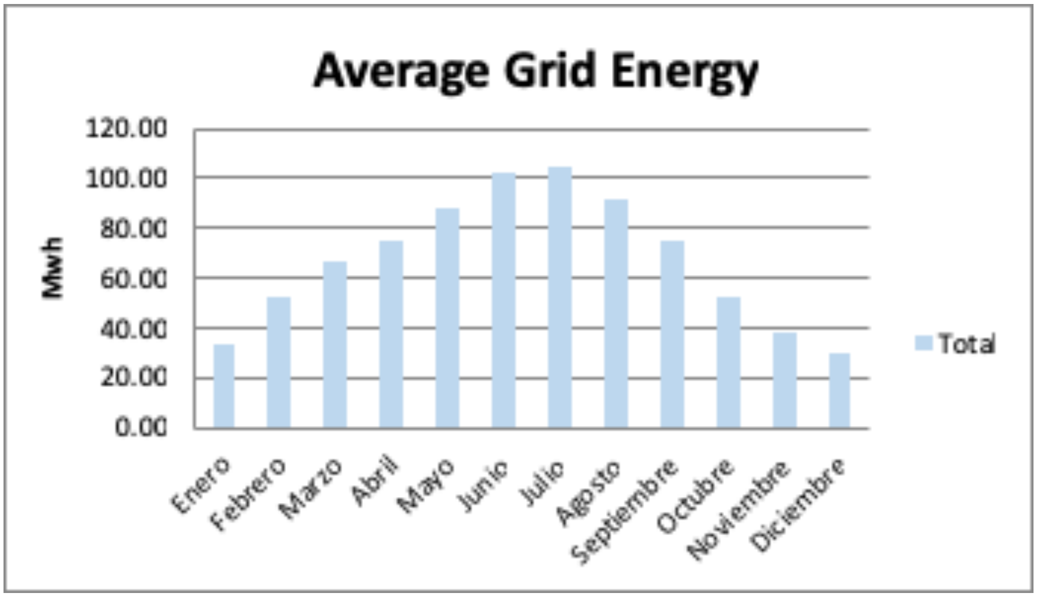


Figure 19. Average Grid Energy

As can be seen in the above table, the results coincide in the months when there is more solar radiation, there is more energy delivered to the network, such as the months of July, June, May and August. Apart from this, the model automatically shows you the production average for each hour of the year, this data helps to question the profitability of installing a battery, because knowing the maximum production hours can optimize the control of the dispatch of the stored energy coming from the sun.

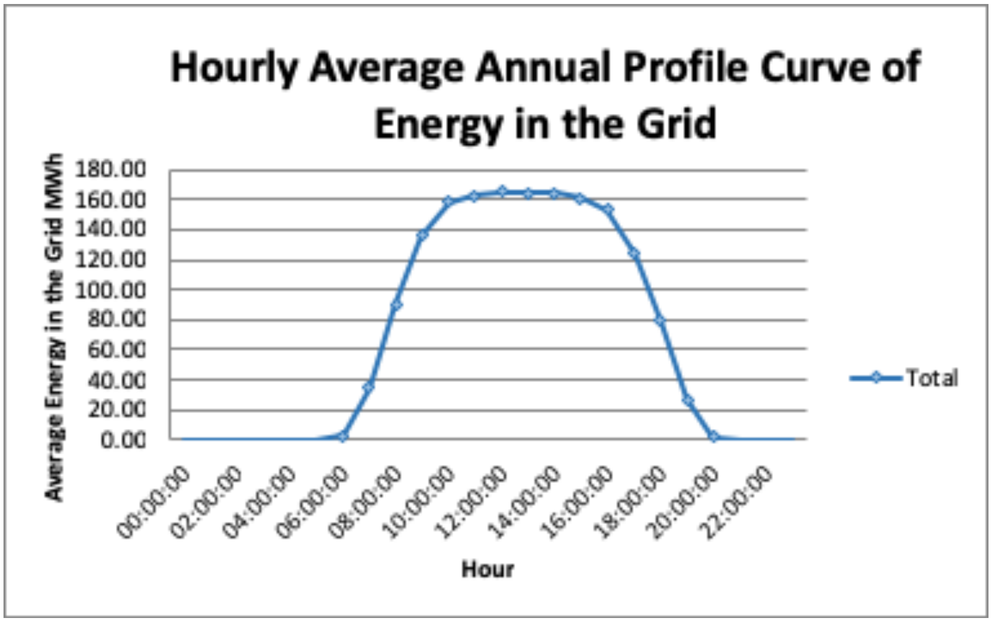


Figure 20. Hourly Average Annual Profile Curve of Energy in the Grid

According to the above figure, you can see the interval of hours with more solar radiation, which coincide between 09:00 am to 16:00 pm.

Sizing of the photovoltaic generator

Maximum number of modules per series (string)

To determine the dimensioning that optimizes the capture of energy from the sun, the electrical characteristics of the selected inverter input have been considered, as well as the possible energy losses that may appear in the section between the photovoltaic generator and the inverter.

To delimit the number of modules connected in series, it is delimited by the maximum voltage in vacuum of the inverter. This corresponds to the open circuit voltage of the PV generator when the module temperature is minimal, that is, in low irradiation conditions (50W / m²) and the minimum historical ambient temperature is -3.4°C.

$$N_{min} = \frac{U_{max,inv}}{U_{ca}(-15\ °\mathrm{C}\,)} = \frac{1500\ V}{U_{ca}\ (\,-3.4\ °\mathrm{C})}$$

Equation 1. Number of modules

Where U_{ca} (-3.4 °C) is calculated as the cell voltage at ambient conditions of 15°C. Under these conditions we assume irradiance conditions of 50 W / m°, so that the temperature of the cell under these conditions of ambient temperature and irradiance will have a higher temperature corresponding to the next value.

$$T_{cel} = T_{amb} + \frac{TONC - 20}{800} * Irradiance = -3{,}4\ °C + \frac{45\ °C - 20}{800} * 50 = -1{,}83$$

Equation 2. Cell Temperature

The voltage therefore at ambient temperature of -10 °C will be.

$$U_{ca}(-15\ °C) = U_{0C} + Coef\,U_{0C} * (T_{cel} - 25) = 47{,}24 - 0{,}142 * (-1{,}83 - 25) = 51{,}90V$$

Equation 3. Voltage with Ambient Temperature

$$N_{max} = \frac{U_{max,inv}}{U_{ca}(-15\ °\mathrm{C})} = \frac{1500V}{51{,}90} = 28{,}90\ \approx 29$$

Equation 4. Maximum Number of Modules in Series

Therefore, under these conditions, it is possible to configure a maximum of 29 modules in series and for comfort and design it is recommended to use a total of 30 modules.

Minimum number of modules per series (parallel)

To delimit the number of minimum modules in series is given by the minimum input voltage the inverter in which the maximum power follows. The minimum value must be less than or equal to the maximum voltage minimum power of the photovoltaic generator: which corresponds when the maximum ambient temperature is 37.5 °C and high irradiance (1000 W / m²).

$$N_{min} = \frac{U_{mp,inv}}{U_{mp}(49{,}7\ ℃)} = \frac{913V}{U_{mp}(37{,}5)}$$

Equation 5. Number of modules in parallel

Under these conditions we assume an irradiation of 1000 W / m² so that the temperature of the module under these conditions of ambient temperature and irradiation will have a higher temperature corresponding to the following value:

$$T_{cel} = T_{amb} + \frac{TONC - 20}{800} * Irradiancia = 37{,}5℃ + \frac{45℃ - 20}{800} * 1000 = 68{,}75$$

Equation 6. Cell Temperature

The voltage therefore at ambient temperature of 49.7 ℃ will be:

$$U_{mp}(68{,}75) = U_{mp} + CoefUmp * (T_{cel} - 25) = 38{,}58 - 0{,}166(68{,}75 - 25) = 31{,}31$$

Equation 7. Voltage with Ambient Temperature

$$N_{min} = \frac{U_{mp,inv}}{U_{mp}(49{,}7℃)} = \frac{913V}{31{,}31V} = 29{,}16$$

Equation 8. Number of Modules in Parallel

In this way, it is obtained that each series has to have a minimum of 29 modules, but as mentioned above, 30 modules will be used. Within these calculations it can be said that the number of optimal modules in the site is 29, this could be deduced in that if fewer modules are implanted it could not optimize the use of the energy produced by the sun, and more modules would affect the operation of the selected inverter.

Inclination Angle

To calculate the optimal angle of a photovoltaic implementation there are several methods. The one that will be used in this work is from the latitude of the place. The following equation expresses the optimum annual inclination to achieve the highest possible annual solar radiation, is based on the statistical analysis of the annual solar radiation on surfaces with different inclinations located in places of different latitudes, so it provides the optimum inclination in function of the latitude of the place.

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

Equation 9.Optimum angle

Where:
β: It is the optimum angle of inclination in degrees
$|\phi|$: It is the latitude of the place in absolute value degrees.

In this case we will use the latitude of Talavera de la Reina, Toledo which is +39.95 °, resulting in the following:

$$\beta_{opt} = 3{,}7 + 0{,}69 \cdot |+39.95\,°|$$
$$\beta_{opt} = 30{,}47$$

Module Selection

In order to select the best investment option in terms of the materials needed in the construction of the photovoltaic plant, a homogenization of photovoltaic modules was carried out, which according to quoted contributions were selected two types to choose from, in this case coming from the Trina Solar company. Trina Solar is a Chinese developer of solar modules where in recent years it has become one of the most developed companies according to Fortune magazine.

Within this homogenization will be considered the production of power both in fixed configuration and in follower with two types of panels monocrystalline and multicrystalline or better known polycrystalline. The two modules to consider are:

Table 3.Characteristics photovoltaics modules

Characteristics photovoltaics modules

Manufacturer	Technology	Model	Power Offered (W)
Trina Solar	Monocrystalline	TSM-DE15H (II)	385
Trina Solar	Multicrystalline	TSM-PE15H	340

Inverter Selection

For the assembly of a photovoltaic plant it is necessary to install an inverter. The inverter is the device responsible for converting direct current into alternating current at effective value and with the same frequency as in the case of Europe is 50 Hz. The operation of the inverter is automatic, from a sufficient input power value, the Power electronics implemented in the inverter monitor the voltage and frequency of the network and from there the power conditioning process begins (Solar, 2019).

To guarantee the quality of the energy discharged in the electrical installation of the house, it is necessary to synchronize the frequency of the injected current with that of the network, adapting it to the required conditions according to the type of load and this synchronization is carried out by the inverter.

The inverters work to take the maximum possible power from the solar modules. When the solar radiation that hits the panels is not enough to supply power to the network, the inverter stops working. Since the energy consumed in operation by the electronic devices of the equipment comes from the production of the photovoltaic generator itself, at night the investor will only consume a small amount of energy from the company's distribution network (Solar, 2019). In this case, the inverter described in the following table was selected, since it complies with the technical characteristics for the installation.

It should be noted that the inverter complies with the EMC directives EN-6100-6-1, EN-61000-6-2, EN-6100-6-4, EN61000-3-11, EN-61000-3-12, EN62109, EN6219-2, IEC62103, The directive of Low Voltage EN 50178 (Asociación Española de Normalización , 2019).

Table 4. Characteristic of Inverter

Inverter

Manufacturer	Model	Efficiency	Maximum output voltage
Power Electronics	FS3225K_645V_20180207	98,7%	1500 V

Homogenization Photovoltaic Modules

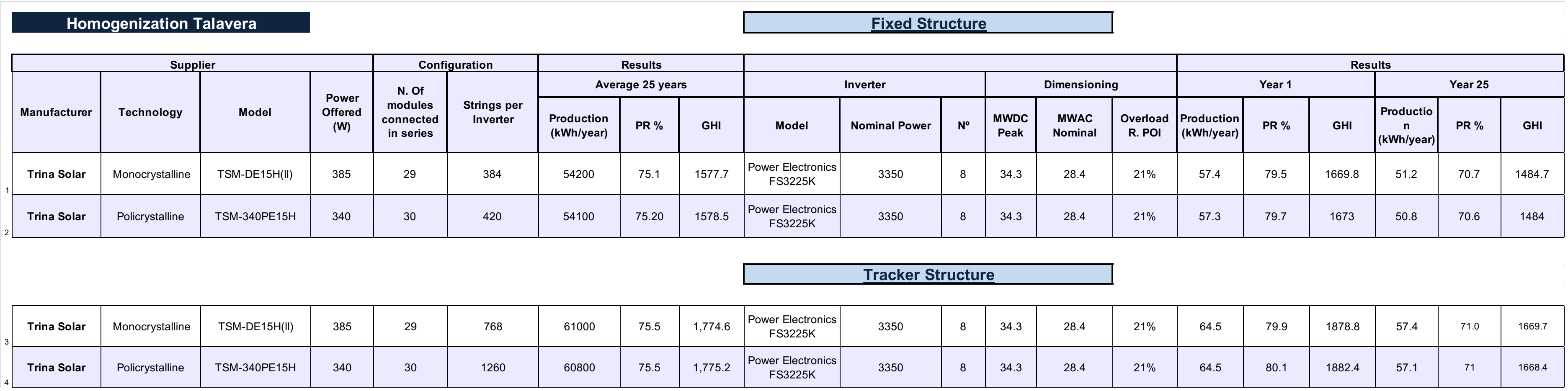
To begin with the selection of the two final designs to be compared, a homogenization of photovoltaic modules is carried out. This homogenization consists in collecting the data of each of the modules to be compared, the type of structure in which it is going to be compared, the energy production that they have at year 1 and at the end of their useful life. With these data an average of production is obtained and according to the results the two best possible ones are chosen. The design of each of the modules is made specifically at the site to be compared, in which for this project is Talavera de la Reina. This is so that the values are as similar as possible.

Within this homogenization, the four types of photovoltaic panel design are implemented in the implementation. This is done with the finality of having a better image of how land use can be better exploited, since the future has to be taken into account. For example, in this case the distribution company limited to a specific power available, but if in the future this availability grows by a new line, it would be necessary to add more photovoltaic modules in the implementation and have a greater production power.

The results obtained from this model with fixed configuration, the monocrystalline structure according to the specific power that is needed shows us an optimal number of panels of 29 modules that in counterpart to the polycrystalline is 30. In turn, it approximates us to have an average production during 25 years of 54200, the degradation does not vary much against part to the polycrystalline in fixed, but in the field of strings per inverter if less is needed for the power module of 385 W compared to 340W.

On the other hand, with the follower configuration, we have a better capture of solar irradiation, and consequently the production is higher than in fixed configuration. Within the point of comparison with follower, modules with power of 340W need more strings per inverter than the other three configurations. The total power produced varies approximately 10% more than the fixed configuration. So far, the module selection recommendation can be thought to be with a monocrystalline of 385 W.

Table 5. Homogenization with fixed tilt and single axis tracker



Homogenization Talavera

Fixed Structure

	Supplier				Configuration		Results									Results					
							Average 25 years			Inverter			Dimensioning			Year 1			Year 25		
	Manufacturer	Technology	Model	Power Offered (W)	N. Of modules connected in series	Strings per Inverter	Production (kWh/year)	PR %	GHI	Model	Nominal Power	Nº	MWDC Peak	MWAC Nominal	Overload R. POI	Production (kWh/year)	PR %	GHI	Productio n (kWh/year)	PR %	GHI
1	**Trina Solar**	Monocrystalline	TSM-DE15H(II)	385	29	384	54200	75.1	1577.7	Power Electronics FS3225K	3350	8	34.3	28.4	21%	57.4	79.5	1669.8	51.2	70.7	1484.7
2	**Trina Solar**	Policrystalline	TSM-340PE15H	340	30	420	54100	75.20	1578.5	Power Electronics FS3225K	3350	8	34.3	28.4	21%	57.3	79.7	1673	50.8	70.6	1484
										Tracker Structure											
3	**Trina Solar**	Monocrystalline	TSM-DE15H(II)	385	29	768	61000	75.5	1,774.6	Power Electronics FS3225K	3350	8	34.3	28.4	21%	64.5	79.9	1878.8	57.4	71.0	1669.7
4	**Trina Solar**	Policrystalline	TSM-340PE15H	340	30	1260	60800	75.5	1,775.2	Power Electronics FS3225K	3350	8	34.3	28.4	21%	64.5	80.1	1882.4	57.1	71	1668.4

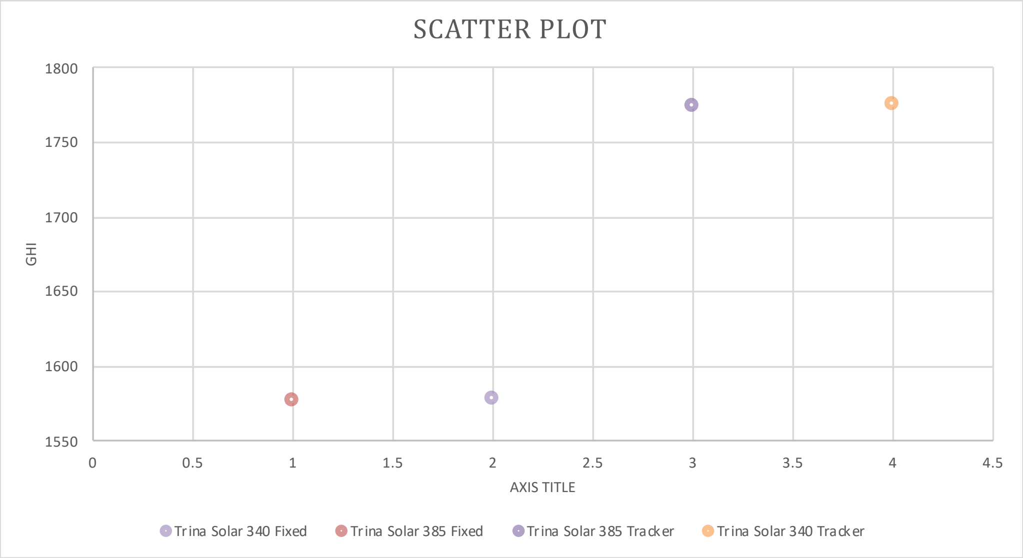


Figure 21. Scatter Plot from the Homogenization

General layout

To design the two different modules to be compared, the input power, the specific power, the number of photovoltaic modules to be implanted, the angle of inclination, the structure (fixed or tracker), the life time of the plant, the investor, type of module and the results were the following:

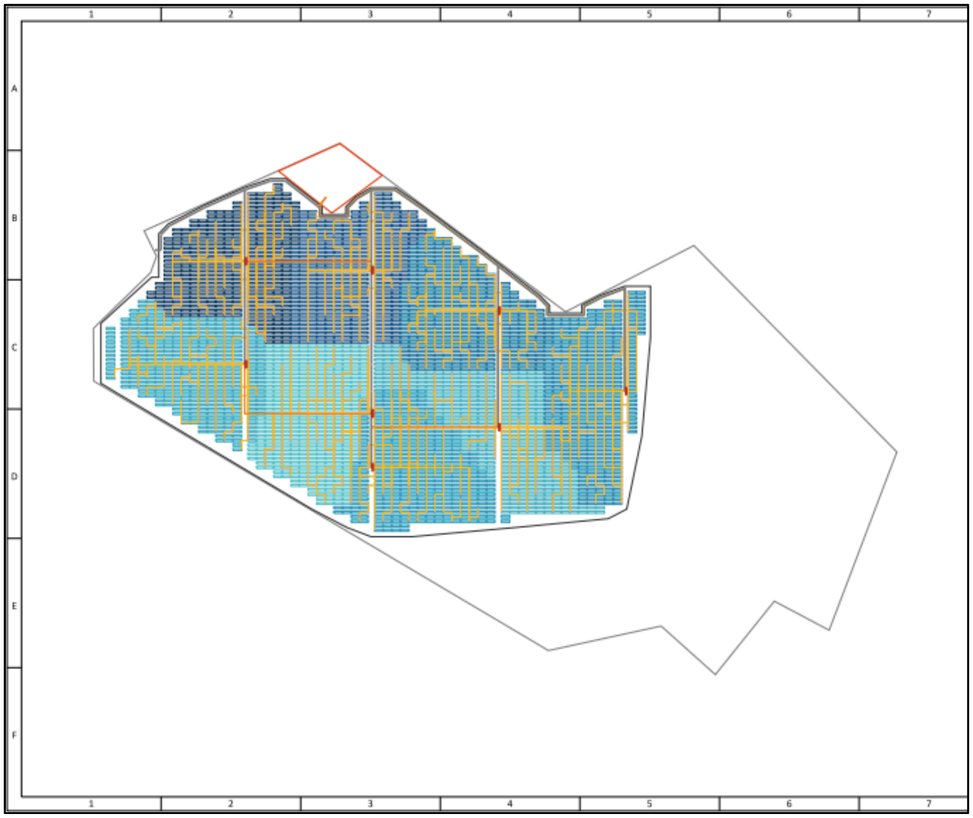


Figure 22. Layout with fixed tilt

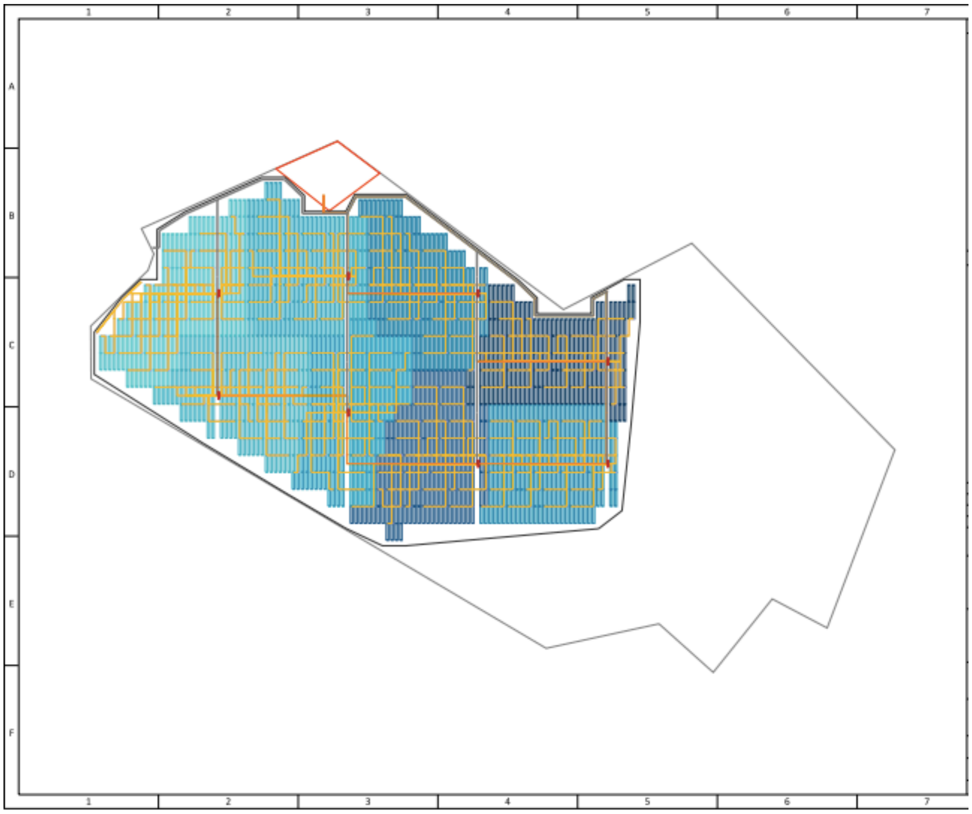


Figure 23. Layout with single axis tracker

Previous designs were made in the PvDesign software. This software allows you to design any type of implementation around the world, it facilitates the user (in a quick way) to design all types of terrains with the necessary restrictions so that it resembles reality as well as possible.

As can be seen in Figure 22, the implementation made with this configuration has a better use of land use, where it translates to less space occupied on the site, it may have an advantage compared to Figure 23, because if in the future there is a greater availability of network connection, within the terrain you can take better advantage of the spaces and increase the power of the place.

Since from this we can have a broader vision on which module to choose for the project, our decision does not have to be based on the module that produces the most, but we have to take into account other variables that affect the project. As they are the costs, the future prices in the market, and the operation and maintenance of the project, this is why later we will have a comparison of the two final models, which in this case are Trina Solar 385W in fixed structure and Solar Trina 385W in follower.

Cost Estimate

The main objective in project planning is to provide a framework for rational estimates of resources, costs and time. Companies today have the need not only to know in what time they recover their investment and obtain profits if they do not know the market in which they face.

CAPEX

CAPEX, as its name indicates, is Capital Expenditure, it is the investment in fixed capital that a company makes to acquire, maintain or improve its non-current assets. Below is the two CAPEX made for the two types of design that apply to the Project:

Table 6. Capital Expenditure for the Module Trina Solar 385W with fixed tilt

Project	Talavera de la Reina	Bill of Quantities		CAPEX	
	Items	Purchase Value (€)	% VAT	Purchase Value with VAT (€)	VAT on investment (%)
Photovoltaic modules	Trina Solar 385 W	€ 7,175,560.00	10%	€ 7,893,116.00	40%
Structure	Fixed	€ 1,435,112.00	10%	€ 1,578,623.20	8%
Inverter	Power Electronics FS3225K	€ 1,255,723.00	10%	€ 1,381,295.30	7%
Engineering, Procurement, and Construction	Civil Works	€ 4,484,725.00	10%	€ 4,933,197.50	25%
Electricity Grids	Power Station, Cables, etc.	€ 2,690,835.00	10%	€ 2,959,918.50	15%
Others	Internal expenses	€ 896,945.00	10%	€ 986,639.50	5%
	Total	€ 17,938,900.00	-	€ 19,732,790.00	100%

Table 7. Capital Expenditure for the Module Trina Solar 385W with single axis tracker

Project	Talavera de la Reina	Bill of Quantities		CAPEX	
	Items	Purchase Value (€)	% VAT	Purchase Value with VAT (€)	VAT on investment (%)
Photovoltaic modules	Trina Solar 385 W	€ 8,026,200.00	10%	€ 8,828,820.00	40%
Structure	Tracker	€ 1,605,240.00	10%	€ 1,765,764.00	8%
Inverter	Power Electronics FS3225K	€ 1,404,585.00	10%	€ 1,545,043.50	7%
Construction	Civil Works	€ 5,016,375.00	10%	€ 5,518,012.50	25%
Electricity Grids	Power Station, Cables, etc.	€ 3,009,825.00	10%	€ 3,310,807.50	15%
Others	Internal expenses	€ 1,003,275.00	10%	€ 1,103,602.50	5%
	Total	€ 20,065,500.00	-	€ 22,072,050.00	100%

After having completed all the fixed costs that are required for each of the designs, we can see that the most expensive structure is that of the single axis tracker with a cost of € 22,072,050.00 (with VAT included). This is roughly 20% more expensive than the fixed structure.

But this is not only that we need to take into account, also in the total cost of the project there are cost related with operation and maintenance that all photovoltaics plants need to do. So, to extend more specific, each of the cost was developed.

OPEX

Next, we will determine the operating expenses that we anticipate this project will take. These costs are known as OPEX (Operational Expenditures) and are those expenses associated with the operation, maintenance and functionality of the project during its entire useful life (Solar Power Europe, 2017). Next, we describe each of the main compounds that are taken into account:

Monitoring: The monitoring of a photovoltaic plant allows analyzing and solving the usual problems of all kinds that can be found within the project.

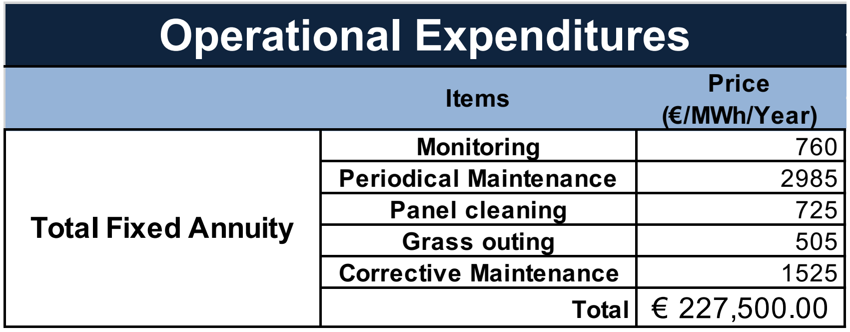
Periodical Maintenance: Consists in carrying out the cleaning of the upper part of the batteries and terminals, as well as the connection terminals.

Panel Cleaning: It consists of carrying out the cleaning of any type of object, dirt, etc. That may affect the correct production of solar panels.

Grass outing: For a correct preventive maintenance of the installation, all the electrical components of the installation must be checked: DC panel, alternating current, inverters, monitoring system.

Corrective Maintenance: This maintenance will only be applied when, due to circumstances that have arisen, due to breakdowns in the installation, it is necessary to correct the defect.

Table 8. Operational Expenditures of the project Talavera de la Reina



Operational Expenditures		
	Items	Price (€/MWh/Year)
Total Fixed Annuity	Monitoring	760
	Periodical Maintenance	2985
	Panel cleaning	725
	Grass outing	505
	Corrective Maintenance	1525
	Total	€ 227,500.00

As we can see in the previous Table, taking into account all the costs described above, we obtain a total of 227500 €/MWh/year.

Production and Income Estimation

To calculate the revenues that our plant will have throughout its useful life, the future prices that the electric market may suffer must be taken into account, since it is planned to take the energy generated from the project to the market.

To get an idea of how the Spanish electricity market works today, two fundamental aspects have to be highlighted. The first is that it is a highly regulated market and the second characteristic aspect is that since it is a highly complex market with great barriers to entry, we find that a few companies are actively involved in almost the entire market (CNMC, 2018).

To prevent an oligopolistic market, where prices were manipulated by the big electricity companies, the Spanish government decided to liberalize the market and seek the same opportunities through electric auctions, with greater competitiveness among companies to achieve a decrease in prices and benefiting the end users.

Today there are two ways to set the electricity price and that end users through marketers can choose, these are:

1. **Free Market:** Within the free market the marketer is the one that sets the prices of their rates. These prices may vary according to the price for which the marketer has purchased the electricity in the wholesale market, which is done through auction.

2. **Regulated market (PVPC):** In the regulated market, the cost comes from the government, where it usually checks annually. Within this category, the reference marketers offer two options: With prices indexed to the hourly market price and fixed price, which maintains the price throughout the year.

Electricity prices in Europe are fixed daily (every day of the year) at 12:00 hours, for the twenty-four hours of the following day, in what we know as the Daily Market. The purpose of the Daily Market is to carry out electricity transactions for the next day by presenting offers to sell and acquire electric energy by market agents.

After the daily market, agents can buy and sell electricity again in the intraday market during different trading sessions a few hours before the real time. There are six trading sessions based on auctions such as those described for the daily market, where the volume of energy and the hourly price determine it by the intersection between supply and demand equally for the daily market (OMIE, 2018).

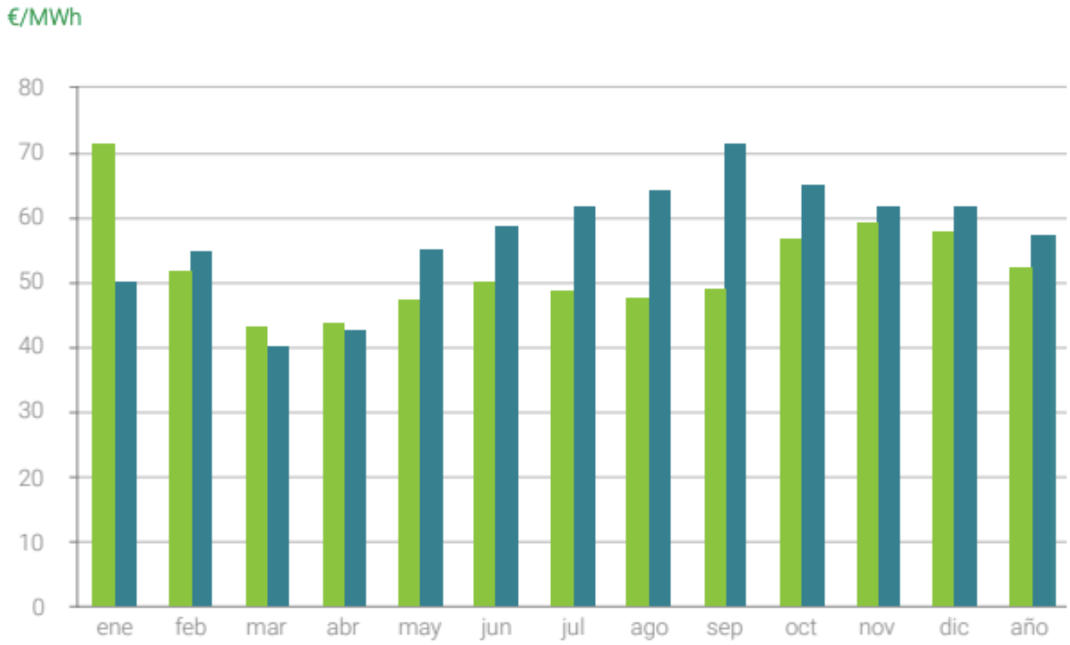


Figure 24.Average price of the daily market

That is why today in the electricity price are influenced by many factors mainly related to supply and demand, for example, in the last year 2018 the share of renewable electricity generation reached 40%, and this mainly affects prices since the generation from renewable energy relatively prices are very low.

In the analysis of this project, this price volatility was considered and how they influence the income of new renewable projects in the future. Based on a study conducted by the research center of the University of Comillas on the *"Analisis de escenarios futuros para el sector eléctrico en España para el periodo 2025 – 2050"*. The objective of which is to evaluate the costs and operation of the Spanish electricity system for a horizon of 2025-2050, considering different possible future scenarios.

This study analyzes how the electrical system is evolving, based on the minimization of system costs, and not taking into account other aspects of a more regulatory nature that could distort the results such as the existence of taxes, fees, tolls or the effect of a specific tariff structure that could condition the deployment of distributed generation.

The costs of electricity networks were not considered within the study, and the impact of the interconnections of the Spanish system is analyzed in a very simplified way, showing in the sensitivity analysis a reduced impact on the results obtained in that study (reaching the 3% cost differential between the proposed scenarios). Without, however, the impact of these interconnections must be considered for a deeper analysis.

To begin to describe the steps that were followed for the income result, the hourly production of each of the designs has to be taken into account, and this is obtained from the PvDesign platform, as described above, a Once the photovoltaic models have been designed, this tool allows you to download the hourly production that the plant will have throughout the life cycle, taking into account all the losses, the degradation of the module and the efficiency of the panel.

Table 9. Comparison between Average total generation 2018 with average generation with fixed and tracker

Fixed		Tracker		Total Generation 2018	
Hour	**Average Generation Fixed (MWh)**	**Hour**	**Average Generation Tracker (MWh)**	**Hour**	**Average Total Generation (MWh)**
0	0.00	0	0.00	0	25,703.76
1	0.00	1	0.00	1	24,253.38
2	0.00	2	0.00	2	23,406.84
3	0.00	3	0.00	3	22,999.13
4	0.00	4	0.00	4	23,013.62
5	0.00	5	0.00	5	23,940.48
6	0.00	6	0.02	6	25,850.12
7	0.66	7	2.00	7	28,202.47
8	3.60	8	7.04	8	30,165.32
9	8.64	9	12.91	9	31,502.40
10	13.67	10	16.05	10	32,340.13
11	18.49	11	18.02	11	32,713.04
12	20.99	12	18.52	12	32,765.47
13	21.61	13	18.84	13	32,415.49
14	21.12	14	19.13	14	31,604.42
15	19.03	15	19.36	15	31,016.53
16	14.79	16	18.43	16	30,691.88
17	9.44	17	14.76	17	30,486.53
18	4.23	18	8.44	18	30,958.67
19	0.73	19	3.02	19	31,897.92
20	0.11	20	0.27	20	32,606.06
21	0.00	21	0.00	21	31,690.06
22	0.00	22	0.00	22	29,592.03
23	0.00	23	0.00	23	27,532.78

Once the production was taken, it was calculated by means of dynamic tables, the average of the hourly production that each of the plants would have during the first year (2019), and to have a better image of how the generation through from time, the information of the generation mix was downloaded from the published OMIE data, to know approximately the production curve that we have today and the results were those described in Figure 25. Where it can clearly be observed the generation supposed for the structure in fixed and in tracker.

When calculating the production, it can be compared that explicitly the production with tracker has a better use throughout the day and this is in hours where the radiation is not as direct as a fixed structure obtains it. This can be a variable cable for the decision of investment since counting the future prices and the generation we can have gains if we produce in more hours of the day than only a lot in a few.

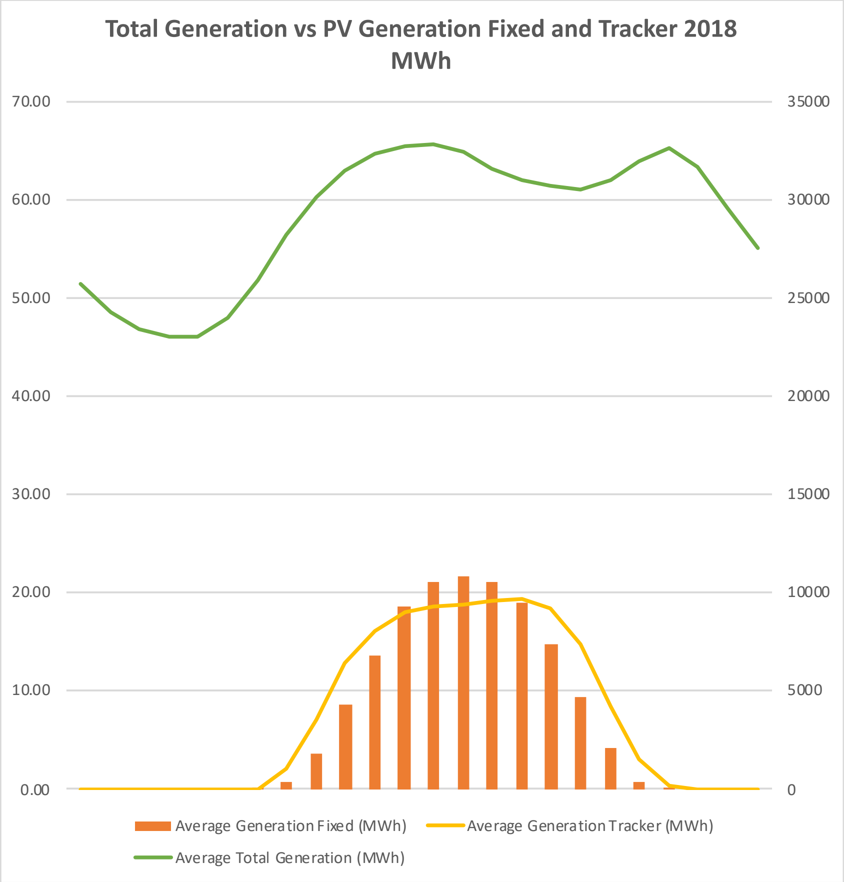


Figure 25. Total Generation vs PV Generation Fixed and Tracker

Once having the production of energy produced every hour and the prices of the future market for the years 2025-2050. A model was started in Excel, taking into account the variables of date, time, production and estimated market price. Since the study does not provide us with the data as of 2025 and our plant would start operating from 2019. We took into account the data provided by the System Operator, which in this case is Red Eléctrica.

With the energy production data and the 2018 prices, the incomes were calculated from the following equation:

$$I = Production(Mwh) \cdot Price\ (\frac{€}{MWh})$$

Equation 10. Income Estimation

This translates to the production generated by each hour for the estimated price in that hour, doing all this for all the hours of all the months of the year. As the life cycle of our plant is 25 years, the year-end of operation is the year 2043, and in the Analysis where this estimate is based only contains data for specific years, an interpolation was made between the years 2040 and 2050 to know an estimate of how much prices would be in 2043. Obtaining the price data for each hour of all the months of that year, the same procedure is performed to calculate the income for that year.

Once having the expected income for each hour, the total sum of income for each year was made, in this case, in the project were taken into account the years 2018, 2025, 2030 and 2043 (which are those that were counted with information). In turn, the sum of the production of each year was made, and with the income and production a Weighted Average Price was obtained.

This weighted average price (WAP) relates production and income and is the valuation price according to your generation over time, to have a point of comparison and see the impact that this analysis tries to tell us, we calculated the Average Arithmetic Price of each year.

With these two values we obtained the kurtosis or peak factor, which means the ratio between the real price charged by a plant and the average market price, and in this case to know what the percentage of change is between the expected to the real. Therefore, a calculation was made of these variables for the two types of designs and for the sample years described above and the results for the fixed structure were the following:

Table 10. Weighted Average Price 2018

Trina Solar Fixed 385W Weighted Average Price 2018	
Σ Income (€)	3,368,096.11
Σ Production (MWh)	57,350.40
WAP (€/MWh)	58.73
AAP (€/MWh)	57.29
Kurtosis	2.5%

Table 11. Weighted Average Price 2025

Trina Solar Fixed 385W Weighted Average Price 2025	
Σ Income (€)	2,278,713.48
Σ Production (Mwh)	56,073.40
WAP (€/MWh)	40.64
AAP (€/Mwh)	41.00
Kurtosis	-1%

Table 12. Weighted Average Price 2030

Trina Solar Fixed 385W Weighted Average Price 2030	
Σ Income (€)	1,998,497.55
Σ Production (Wh)	54733.1
WAP (€/MWh)	36.51
AAP (€/MWh)	39.32
Kurtosis	-7.1%

Table 13.Weighted Average Price 2043

Trina Solar Fixed 385W Weighted Average Price 2043	
Σ Income (€)	1,249,330.65
Σ Production (Wh)	50994.5
WAP (€/MWh)	24.50
AAP (€/MWh)	31.34
Kurtosis	-22%

After obtaining the results, for each of the years, it can be seen that the prices decrease according to the years. To obtain the kurtosis variable, a fragmentation was made between the Weighted Average Price and the Arithmetic Average Price, which consisted of the following equation:

$$Kurtosis = \frac{PMP}{PMA} - 1$$

Equation 11. Kurtosis calculation

Where we obtained the results as a percentage of the change between the WAP and AAP over time. To have a better visualization of this effect, the year 2018 was considered with the estimated productions for the year 2019 and the market prices in 2018 together with the estimated prices for 2043 with the fixed structure design:

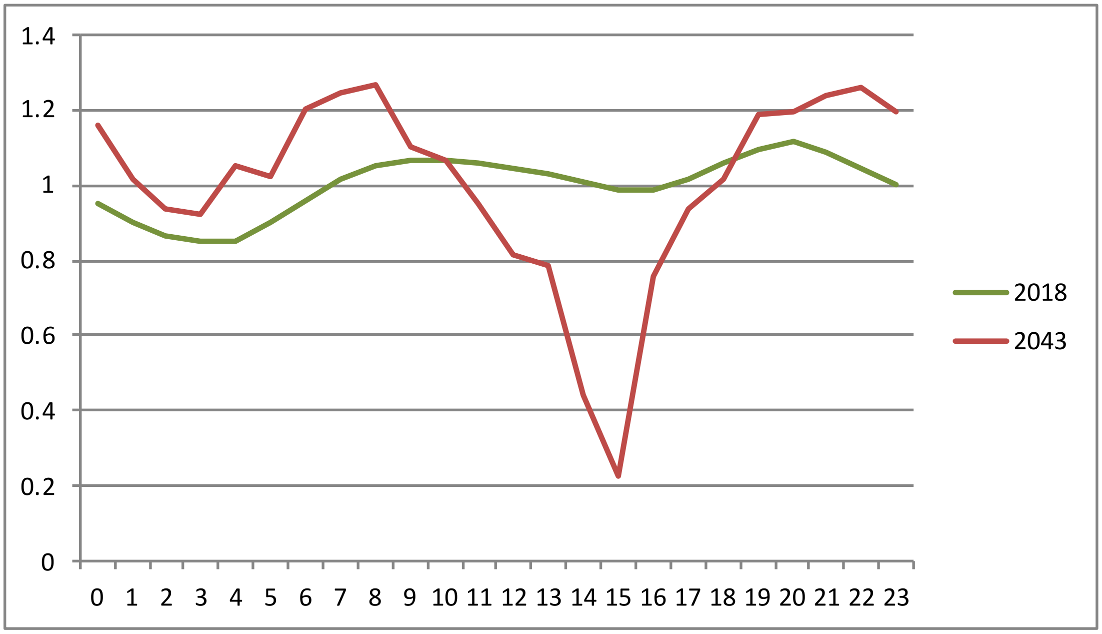


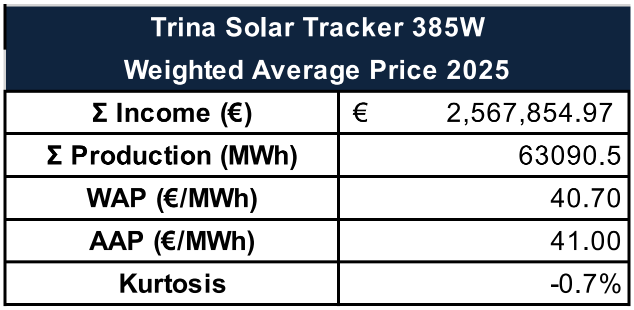
Figure 26. Comparison of the change of kurtosis between 2018 and 2043 with fixed structure

The same procedure described above was performed for the structure with follower and the results were the following:

Table 14. Weighted Average Price 2018

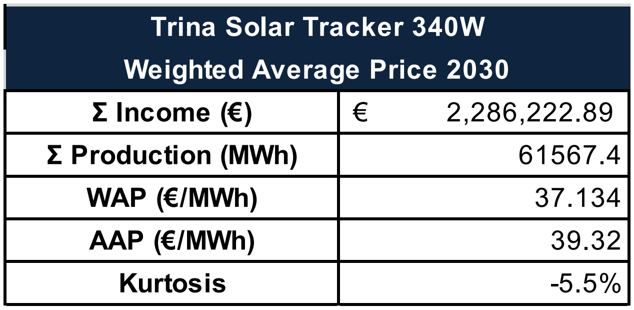
Trina Solar Tracker 385W Weighted Average Price 2018	
Σ Income (€)	€ 3,790,545.91
Σ Production (MWh)	64,533.50
WAP (€/MWh)	58.74
AAP (€/MWh)	57.29
Kurtosis	2.5%

Table 15. Weighted Average Price 2025



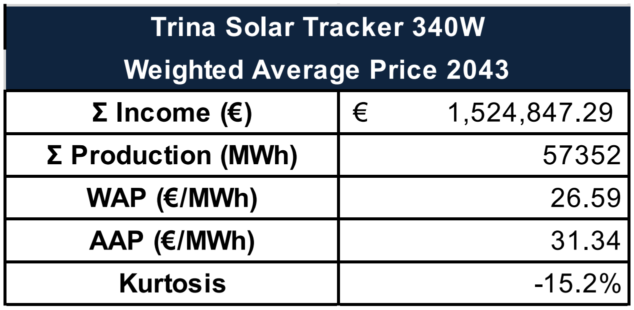
Trina Solar Tracker 385W Weighted Average Price 2025	
Σ Income (€)	€ 2,567,854.97
Σ Production (MWh)	63090.5
WAP (€/MWh)	40.70
AAP (€/MWh)	41.00
Kurtosis	-0.7%

Table 16. Weighted Average Price 2030



Trina Solar Tracker 340W Weighted Average Price 2030	
Σ Income (€)	€ 2,286,222.89
Σ Production (MWh)	61567.4
WAP (€/MWh)	37.134
AAP (€/MWh)	39.32
Kurtosis	-5.5%

Table 17. Weighted Average Price 2043



Trina Solar Tracker 340W Weighted Average Price 2043	
Σ Income (€)	€ 1,524,847.29
Σ Production (MWh)	57352
WAP (€/MWh)	26.59
AAP (€/MWh)	31.34
Kurtosis	-15.2%

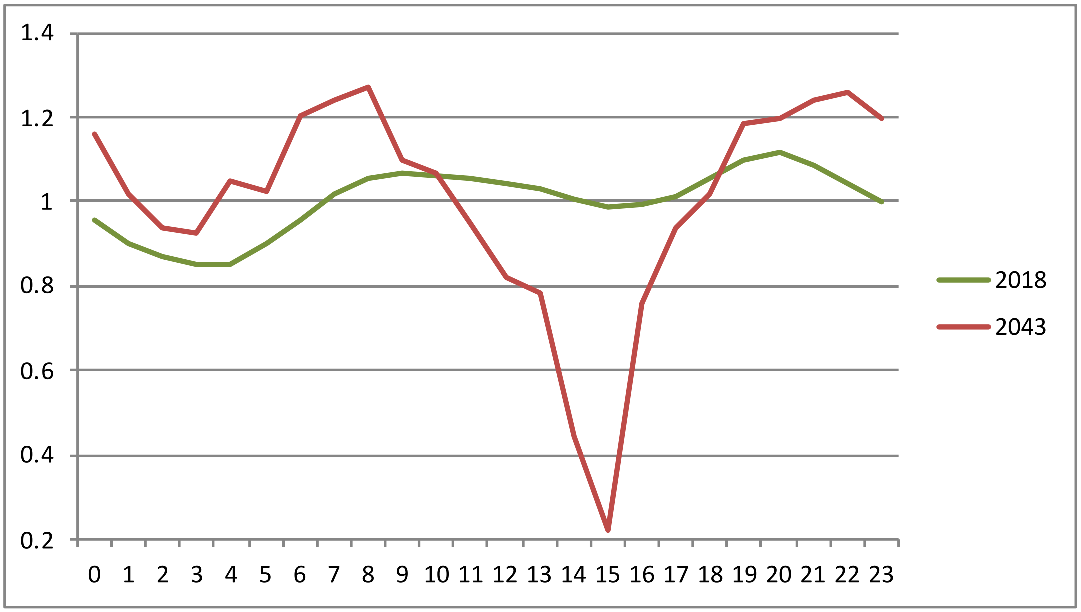


Figure 27. Comparison of the change of kurtosis between 2018 and 2043 with tracker structure

Free Cash Flow

In the financial analysis the funds are equivalent to money; Cash flow is, then, flow of money or cash flow. With money all companies can pay their debts at the time of maturity, remunerations, interest, taxes to the state and dividends to the owners (Finance Institute Corporation, 2019).

When a company does not generate enough money, it causes a restriction when buying inputs or new equipment, which causes a reduction in the magnitude of purchases that it can make and with it the size of its operations and competitiveness in terms of customer relationships and development will decrease.

The generation of money originates in the difference between the price at which the company sells the goods purchased and the price that it must pay for these purchases. This is the cash cycle; money is used to buy and pay for goods, which will be sold, ultimately receiving money, which will be used to pay for other goods, and so on.

For the Talavera project, the main factors that should be considered in a cash flow were taken into account:

Table 18. Cash Flow Statement

EBITDA
Inflow
Outflow
Net income
Depreciation & Amortization (+)
EBIT
Taxes
FREE CASH FLOW
Change in debt
Change in equity
NET CASH FLOW GENERATED IN THE PERIOD
CASH AT THE BEGINING OF THE YEAR
CASH AT THE END OF THE YEAR

With this data, two cash flows were generated for the types of design, (fixed and tracker). By comparing the final results of each of the designs, the final results were as follows:

Table 19. Cash at the end of the year with the two designs

Cash at the end of the year Fixed	*€ 35,882,132.61*
Cash at the end of the year Tracker	€ 44,184,397.32

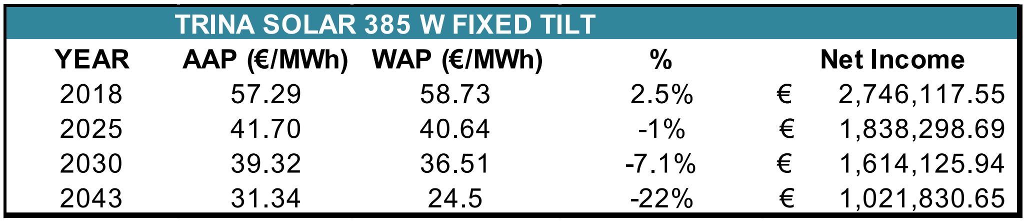
The results obtained show that at the end of the useful life of the projects, the design with structure with tracker has more gains in comparison with the fixed structure, and a factor that influences this is the production, since to calculate the income of each year had to multiply the production by its price in the market and this gave us the annual income for each of the designs.

It is true that for the fixed structure less investment is needed, and it may be beneficial for them to invest in it, but only by comparing these costs can a decision be made that determines the type of investment, which will be compared later on. Results with the levelized cost of energy.

¿How do futures prices affect the Net Income?

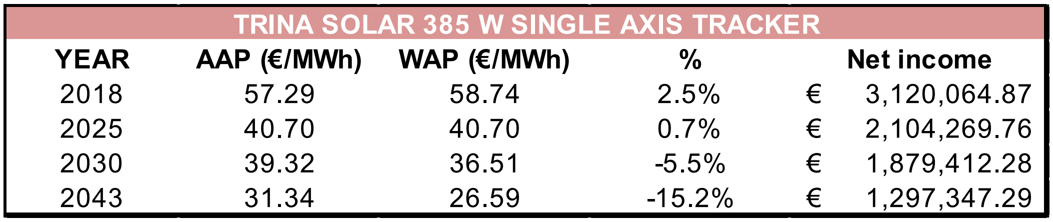
To have a better image of the variables that may affect our investment decision, we made a comparison of the specific years (where the prices are specifically calculated), with the WAP, AAP, the percentage of kurtosis and the net income from of the cash flow previously performed, the following graphs that are shown below show the previously calculated result.

Table 20.Results for the Trina Solar 385W with fixed tilt



TRINA SOLAR 385 W FIXED TILT				
YEAR	AAP (€/MWh)	WAP (€/MWh)	%	Net Income
2018	57.29	58.73	2.5%	€ 2,746,117.55
2025	41.70	40.64	-1%	€ 1,838,298.69
2030	39.32	36.51	-7.1%	€ 1,614,125.94
2043	31.34	24.5	-22%	€ 1,021,830.65

Table 21.Results for the Trina Solar 385W with single axis tracker



TRINA SOLAR 385 W SINGLE AXIS TRACKER				
YEAR	AAP (€/MWh)	WAP (€/MWh)	%	Net income
2018	57.29	58.74	2.5%	€ 3,120,064.87
2025	40.70	40.70	0.7%	€ 2,104,269.76
2030	39.32	36.51	-5.5%	€ 1,879,412.28
2043	31.34	26.59	-15.2%	€ 1,297,347.29

With Table 20 and Table 21 the result of the following graphs was obtained, which basically shows that until the year 2025 WAP and AAP prices both for the fixed structure and tracker maintain a constant but very similar constant , continuing the years until 2043 we see that the separation is a little more noticeable and this is due to the price of energy and the expected income to have, since with our production and the marginal price makes the curve of supply and demand move with the increase in the entrance of renewable energies in the market, and make our profits even lower.

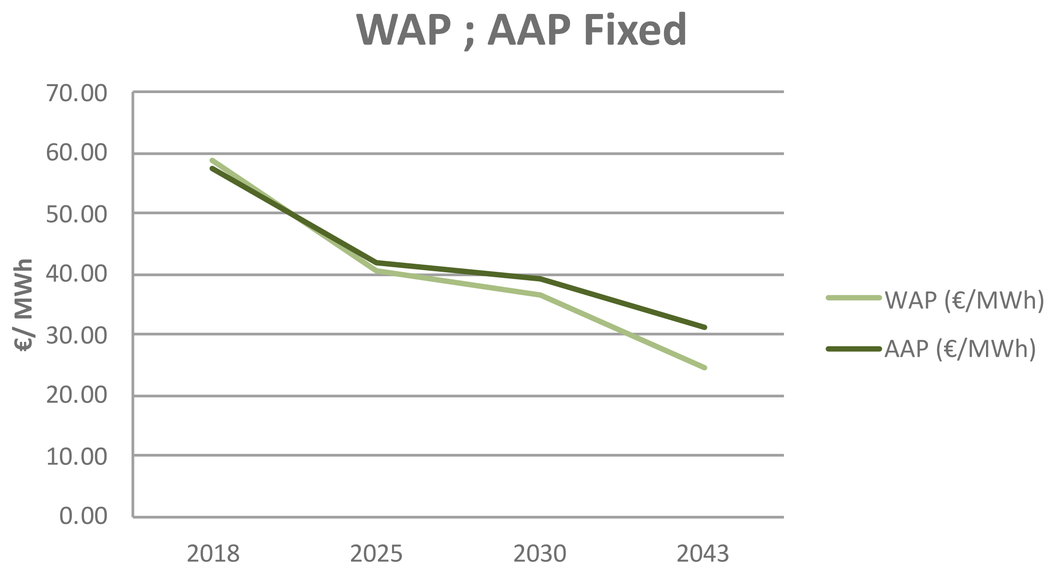


Figure 28. Comparison between WAP y AAP for the fixed tilt

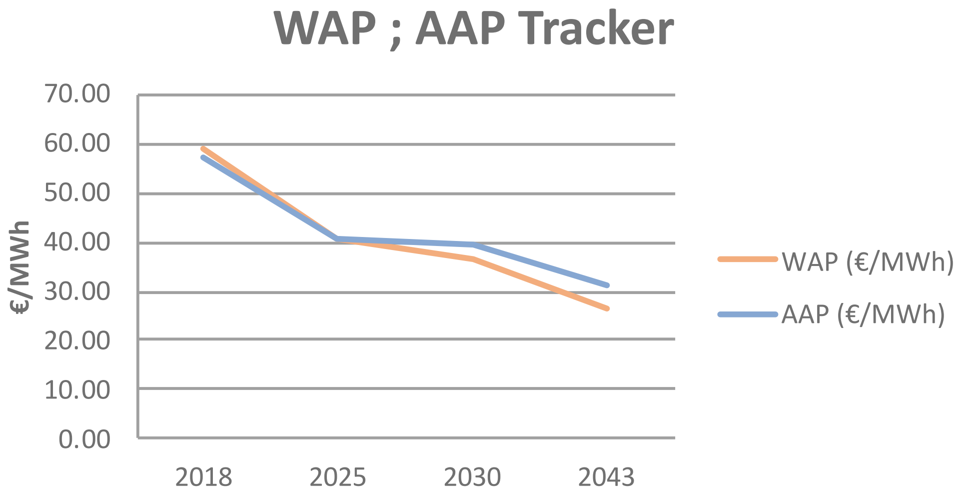


Figure 29. Comparison between WAP y AAP for the single axis tracker

Later, the kurtosis chart began for the years 2018, 2025, 2030 and 2043, both in fixed structure and in Tracker, the results show information on the decline in prices until the year 2043. Where it relates the price of sale of energy from the photovoltaic project to be built, it is observed that with a fixed structure a fall of -22% is foreseen in comparison to the structure with Tracker (-15%). This is because as the production is implicitly related to the price of energy, the percentages are different, and it can also reveal that for the hours when there is greater production there is less demand and the price of energy decreases compared to of the hours in which more energy is needed (commonly they are between 21:00 pm and 8:00 am) and where there is no production from the photovoltaic energy.

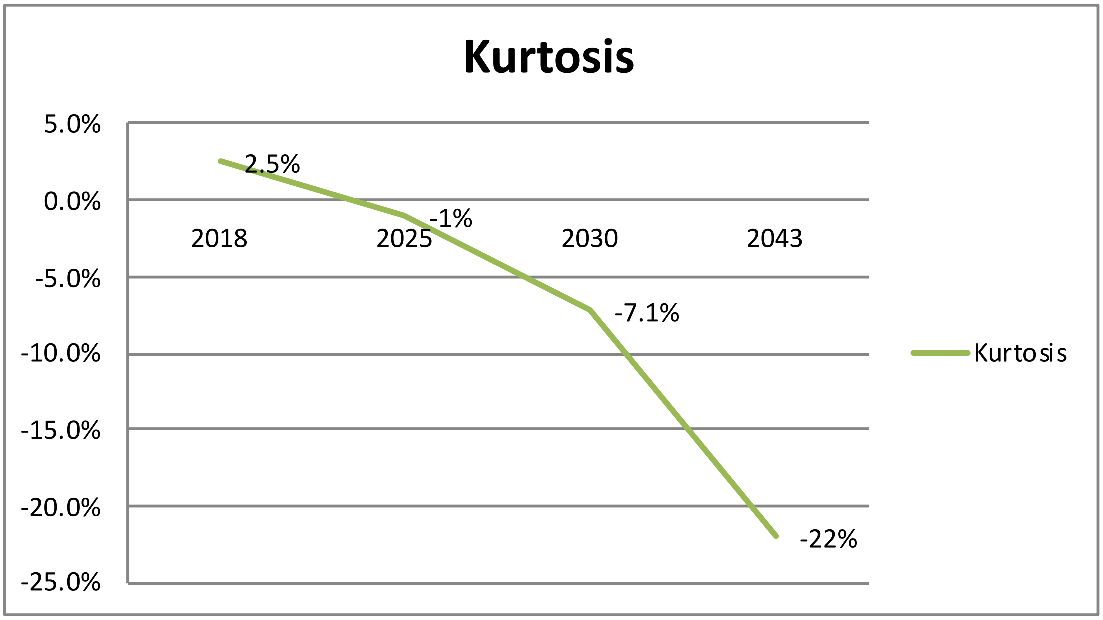


Figure 30.Decrease in kurtosis over time for the fixed tilt structure

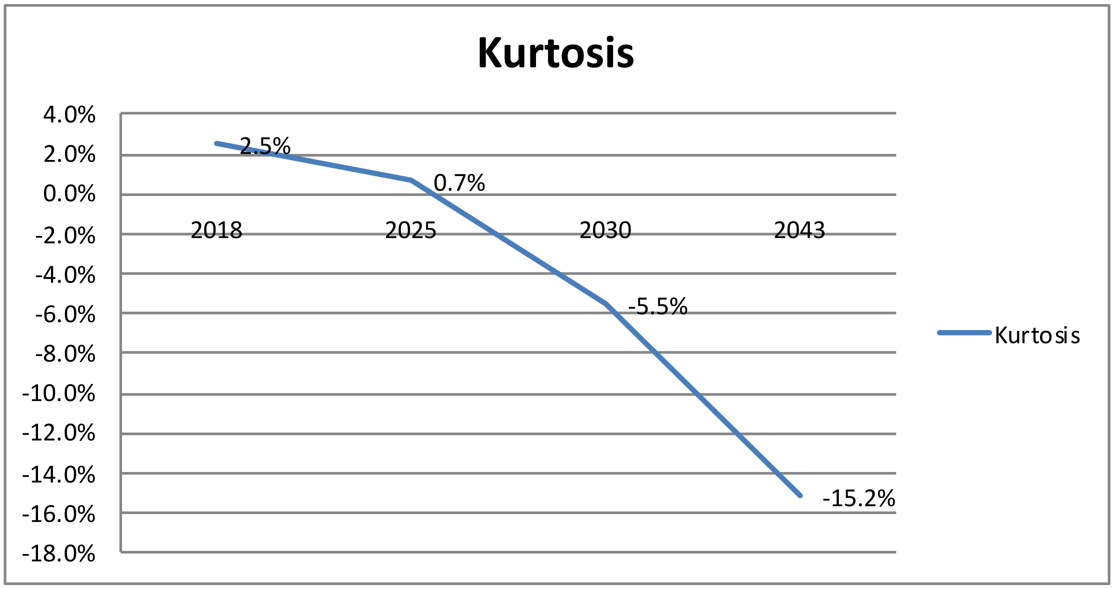


Figure 31. Decrease in kurtosis over time for the single axis tracker structure

Then an analysis of the prices of the two designs for the first year of operation and the last year of operation was made to have a better picture of how the impact of the price decrease in the future is. As you can see in Figure 32. The prices in 2018 are more or less constant during the day, with two notable peaks (between 7:00 am - 9:00 am and 19:00 pm - 23:00 pm). But with the analysis done, there is a noticeable decrease between 11:00 am and 6:00 pm, where in turn, photovoltaic energy has its highest production since as described above, in these hours is when there is more radiation solar, this can be a big problem in terms of the profitability of new projects, since if prices continue to decrease as expected, the electric companies will have less incentives to invest in photovoltaic plants.

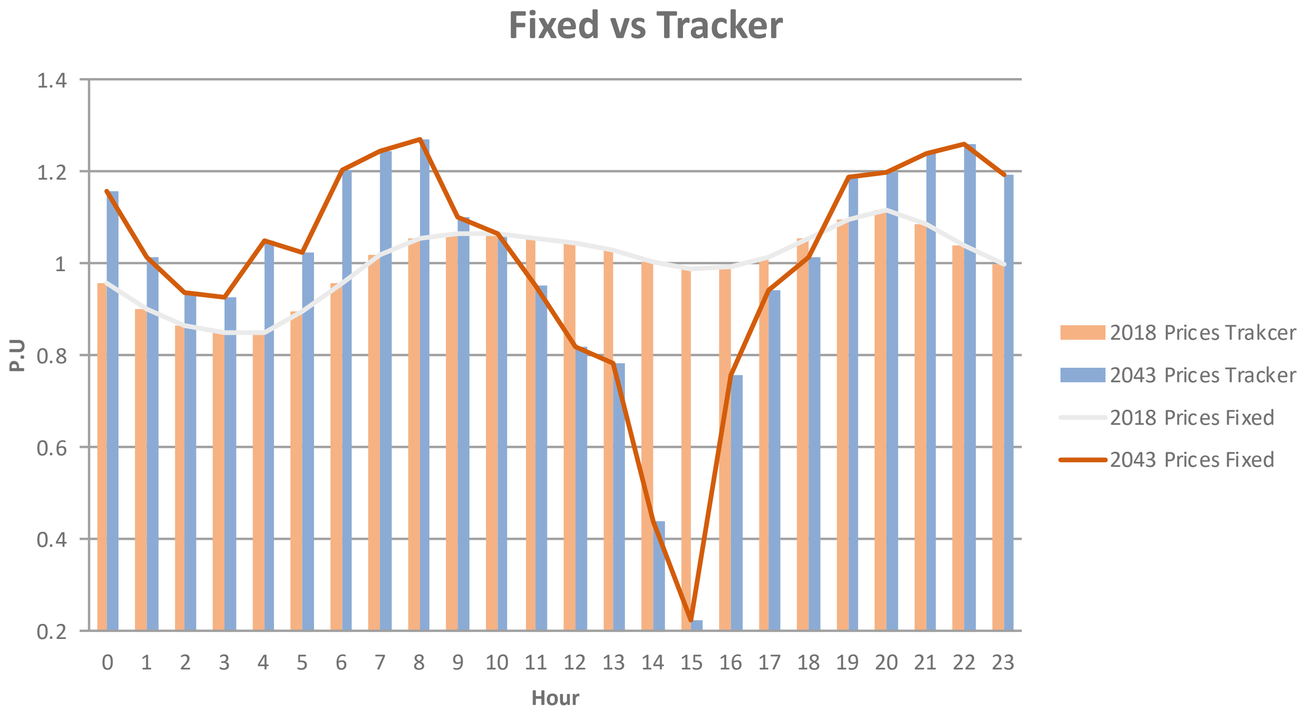
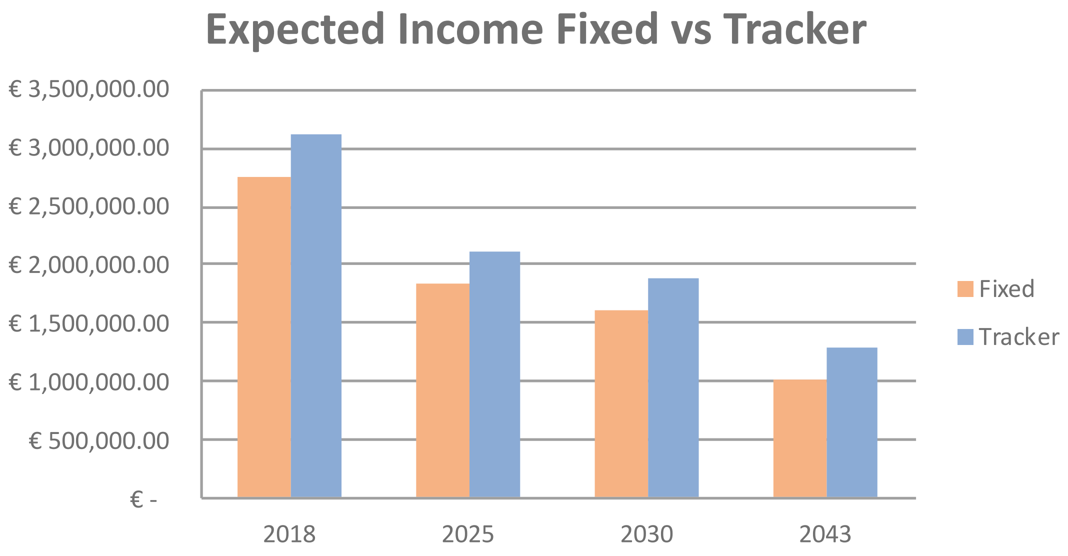


Figure 32. Actual and Future prices for the two designs

The following chart shows the expected future income. As can be seen at the beginning of 2018, revenues are high and continually decreasing, and this is due to the fact that the marginal costs of the generation system would be considerably maintained with slight decreases until the year 2025. The penetration of renewables reduces the average prices to be low variable cost technologies, and this has an impact on our future revenues.



You can come to think that with these results it would not be feasible to continue investing in photovoltaic plants, since the scenarios may turn out not to be optimistic. But based on the aforementioned model about the prediction of future prices, the ways in which the future investments are recovered are taken into account, for each technology by means of three types of income (Rivier, et al., 2018):

1. **Revenue from the energy market:** Consists of the hourly generation by the marginal cost of energy or the market Price
2. **Revenues through mechanisms of retribution of the firm capacity**: It consists of the capacity restriction multiplied by the firm power of the investment for each type of technology
3. **Additional remuneration to renewables:** Consists in the generation of renewable investment by the variable of the restriction of the renewable quota.

In the case of renewables (which is the topic addressed in this work), they manage to recover a significant part of their investment costs with market revenues by marginalizing other technologies such as combined cycles. If we contemplate a growth in zero demand, less investment would be needed and therefore it would not be necessary for open cycles to operate and, consequently, market prices would decrease, but if we were to contemplate growth in demand there would be more investment and the prices could be a little higher.

Therefore, the additional remuneration that will be made for renewable energies is usually higher to counterbalance lower market incomes and represent a greater proportion of renewable revenues compared to cases with growth in demand.

Levelized Cost of Electricity

The various electric generation technologies have different characteristics of yields and costs that can be difficult to compare. For example, plants that use fossil fuels allow them to generate at all times, however, they have the disadvantage that prices are very volatile, high operating costs, energy costs that are unpredictable for repairs, damage to the environment, that on the other hand, renewable technologies do not produce.

However, renewable energies such as photovoltaic plants, the fuel they use is solar energy, which has no price, but the only drawback (explained above), only generate electricity during the day, unless there is storage in its installation that allows to supply the consumption for the rest of the time. The levelized cost of energy (LCOE), explains the differences between the different technologies from the conversion into a standard price figure for energy (MWh). This price would be the amount of money that the consumer pays the electricity generating company, to recover their investment costs and have a profit margin. (Rudnick, s.f.)

The LCOE includes the initial investment, fuel cost (if applicable), fixed and variable operations, operation and maintenance costs, financing costs, etc. It is important to take these factors into account because, depending on the technology, these factors vary. For photovoltaic plants (without fuel costs) and operating and maintenance costs are relatively small, the LCOE changes compared to other technologies. The calculation of LCOE (like any projection) can vary regionally and temporally as prices change and technologies evolve (Rudnick, s.f.)

Today, the constant and rapid decrease in installation costs and the increase in capacity factors improve the economic competitiveness of solar energy in the world. It is estimated that the weighted average LCOE has been reduced by 73% between 2010 and 2017. (IRENA, 2017)

That is why to give a better investment decision we have to take into account the LCOE of each of the projects). As a first instance, the present value of the investment costs was calculated with the following equation:

$$NPV = \frac{FC}{(1+r)^n}$$

Equation 12. Net Present Value

Where:

FC: It is the flow of costs throughout the life cycle of the project

R: Is the weighted average cost of capital of the Project

N: It is the number of years of life cycle in the project.

The Weighted Average Cost of Capital (WACC) is the discount rate used to discount future cash flows when valuing an investment project (Nicolau, 2016) and is calculated as follows:

$$WACC = K_e \frac{E}{E+D} + K_d\,(1-T)\frac{D}{E+D}$$

Equation 13. Calculation of Weighted Average Cost of Capital

A rate of 7.1% was obtained through the WACC methodology, assuming 30% debt at a return of 8%, 70% equity at a cost of 12%. With this and with the cost flows, the calculation of LCOE for each of the different models is put to work and the results were the following:

Table 22. LCOE for the Fixed Tilt

Levelized Cost of Energy Trina Solar 385 Fixed Tilt	
Total Cost (€)	20,877,933.81
Total Energy (MWh)	636,318.38
LCOE (€/MWh)	32.81

Table 23.LCOE for the Single Axis Tracker

Levelized Cost of Energy Trina Solar 385 Single Axis Tracker	
Total Cost (€)	23,062,116.81
Total Energy (MWh)	715,834.16
LCOE (€/MWh)	32.22

Considering the results obtained, we can see that the cost of energy is lower with a tracker structure than with a fixed one, although the results are very similar, that is to say that there is not much difference in price, we can say that a tracker structure could produce more energy, with a lower cost and higher income, that is why we also analyze the cash flow brought to the present value to know which project has more value and the results were the following:

Table 24. Net Present Value for both designs

Net Present Value	
Trina Solar 385W Fixed Tilt (€)	9,736,996.61
Trina Solar 385W Single Axis Tracker (€)	11,836,917.85

Once doing the analysis of the present value we can see that the Tracker has more value around 20% more. Then it can be said, that taking into account the future price variations, the investment cost, the productions to throw throughout the life cycle, the costs for operation and maintenance; For this specific project (thinking about the future) it can be said that the Trina Solar 385W with a Power electronics inverter model FS3225K_645V_20180207 and with the Single Axis Tracker structure is the best investment option.

Conclusions

The photovoltaic sector is growing worldwide, only in the past 2017 it exceeded 100GW of generation from photovoltaic solar energy according to estimates made by the International Energy Agency. Growth is inevitable and it is expected that this path will continue in the coming years. However, to ensure that these projects are profitable, electricity companies nowadays need more precise evaluations of investment in photovoltaic plants to achieve objectives proposed by Spanish policy.

For this reason, this study has presented the analysis and evaluation on the possible investment of a new photovoltaic plant that is expected to be built in the second half of this year 2019, which will sell all its electricity produced through the Spanish electricity market.

The site that was chosen for this photovoltaic plant was in "Talavera de la Reina, Toledo" within the community of Castilla-Mancha, where it was estimated that the solar radiation is 208,700W/m² which makes it an attractive place to invest in photovoltaic projects. With this result of radiation, the average production that would reach this location was estimated, which in total was 67.51 MWh.

For this study the modules of the Trina Solar company were chosen, which is achieving a good positioning in the market thanks to its low prices, and two types of designs were evaluated: fixed tilt and single axis tracker. The investment costs calculated were € 17,938,900 for fixed tilt and € 20,065,500 for single axis tracker. O & M expenditure was included in the costs, which will cost € 227,500 annually.

The total income of the project was estimated taking into account the future prices and the different scenarios considered in the report "*Análisis de escenarios futuros para el sector eléctrico en España para el período 2025-2050*" by the Institute of Technology Research of the University of Comillas. The simulation performed shows a clear trend of decreasing income for both project designs with an approximate reduction of up to € 1,000,000.00 for both projects.

With this characteristic, a levelized cost of electricity (LCOE) was reached for each photovoltaic design to be compared, where it was found that the most profitable design is that which uses photovoltaic modules with a structure with single axis trackers. This is due to the fact that with this type of structures they allow to produce energy during more hours in the day thanks to its design that allows to follow the solar radiation.

This type of analysis offers electricity companies a future vision of the return on investment that new projects will have and allows the evaluation of different technologies that are better adapted to the needs of the project.

It must be said that the evolution of prices can be affected by constraints such as electricity demand, the introduction of the electric vehicle, penetration of self-consumption, contracts in PPA format, oil prices etc., will largely determine the price charged for energy Solar photovoltaic.

The forecasts not only indicate to a photovoltaic market with storage in about 10 years, but to including Battery Electricity Storage into the already existing photovoltaic parks. Adding manageability to renewable energies eliminates the problem of cannibalization, therefore, the electricity sector has no choice but to extend to offer manageability to continue growing.

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