UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

Review of the costs associated with the promotion of solar photovoltaic plants in Spain

Author: Javier Santiago Lara
Supervisor: M. Inmaculada Blázquez García

Madrid, July 2019

Master’s Thesis Presentation Authorization

THE STUDENT

JAVIER SANTIAGO LARA

THE SUPERVISOR

M. INMACULADA BLÁZQUEZ GARCÍA

BLAZQUEZ GARCIA MARIA INMACULADA - 46885278P

Firmado digitalmente por BLAZQUEZ GARCIA MARIA INMACULADA - 46885278P
Fecha: 2019.07.03 13:06:44 +02'00'

Authorization of the Master’s Thesis Coordinator

Dr. Luis Olmos Camacho

Signed: …………………… Date: ……/ ……/ ……

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Summary

The world is changing. The growth in the global population has increased the energy consumption, and as a direct consequence, the fossil fuels, which are the most commonly used energy resources, are shrinking. Besides, when these resources are burnt in order to produce energy, they emit CO_2 particles into the atmosphere which are damaging our planet. However, the development of the renewable technologies is changing the paradigm and allows us to produce electricity with zero emissions and without consuming the fossil resources.

That circumstances are propelling the use of renewable technologies in the world, and our country is not an exception. Spain has some of the best renewable resources in Europe, and in particular the solar resources are rather attractive. Adding to this the decrease in the cost of the technology thanks to the newest developments and the support given by the state through regulations, it is obvious that solar PV projects in Spain are becoming one of the most lucrative businesses.

Therefore, companies have to be able to calculate the profitability of these projects. But they cannot calculate that profitability if they do not know the costs of these kind of projects. The intuition would tell us that the cost of solar PV projects should be very easy to calculate, however, it turns out to be the opposite. Due to the high levels of competition the companies do not share their cost structures and the suppliers hide their prices until the last moment. Hence, this project aims to gather in the most accurate way the costs of these kind of projects in order to develop a standard cost structure that should be apply to any solar PV project (except for residential or small projects).

The way used to develop the cost structure has been through researching past projects and asking for quotation to the main suppliers. After pooling all the information, a robust structure has been obtained, able to quickly asses the cost of a project as a function of its installed capacity. As a remarkable point, it is important to say that the cost of the PV panels amount to almost the 50% of the cost of the project, but the rest of costs must not be ignored.

As a conclusion, the structure is able to calculate the cost in an accurate way and asses the profitability of the project. Nevertheless, the model must not be static, the technology is continuously evolving, and it must be updated. Furthermore, it is crucial that the national and European regulation follows the same path towards the energy transition and the promotion of renewable energy sources.

Aknowledgements

Firstly, I would like to express my most sincere gratitude to my supervisor in this thesis, Macu, for her guidance, warmth and expertise during the development of the project and all my internships. Also, I would like to say thank you to all my fellow workers in Osprel, who have eased and cheered my stay in the company.

I would also like to say thanks to ICAI and all its professors because they have contributed to build a better engineer and person, sharing with me their values and knowledge in the sincerest way.

I must follow saying thank you to all my friends and especially those who have been "suffering" alongside me, I have no words to describe the tremendous support they have been for me.

Finally, I will be always thankful to my family, and in particular to my parents, that have made all this possible and always support me.

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1. Introduction and state of the art

The world is evolving. New technologies are barging in all economic sectors and markets, which is changing the traditional way of thinking. Furthermore, estimations made by United Nations' Department of Economic and Social Affairs state that world's population by year 2050 will be higher than 9.5 billion people, which means a growth of 25% [1]. All these things together, are forcing us to adapt ourselves to the changing world.

Moving forward to the topic under study, the electricity demand in the world is steady, but due to the new technological developments and the social growth of some developing countries, there is a reason to believe that this demand is going to increase in the following years. These technological changes are affecting both sides of the sector, in one side, there are new technologies able to generate electricity in a more efficient, cheaper, and cleaner way. In the other side, the automatization of industrial processes and the increasingly active participation of consumers in the energy market are enhancing the total energy demand.

Most of the latest changes and trends in the energy sector are oriented to a most sustainable environment, trying to reduce emissions by taking measures such as the development of renewable generation, the inclusion of the electric vehicle or the aim to approach the demand to the electricity market. Besides, the introduction of distributed generation will be a crucial point, making easier and sometimes cheaper the supply of energy to new customers but also will imply a change in the distribution grid that will be accompanied with an urgent necessity of investments. On top of that, it is remarkable the fact that the fossil fuels used by electricity generation are limited. If we continue with the current rate of consumption of these fuels, the reserves (amount of these fuels able to be extracted with current technologies) of coal, natural gas or oil would last 150, 60 and 45 years respectively.

That is why, the alternative ways of generation, and in particular renewable generation is experiencing an outstanding growth. These sources of generation are quite scalable, and they can supply the growing demand in a sustainable and efficient way. Because of that, there are actions trying to increase the share of that technologies in the energy mix, such as the Winter Package in the European Union (UE), which aims to increase to 32% the energy consumption from these sources by increasing also the energy efficiency and reducing emissions [2]. Nowadays, the world population is highly concerned about the high levels of emissions, and they are willing to participate in the energy transition. Hence, most people are willing to contribute to that change by constructing renewable power plants and trying to increase the share of this technologies in the global energy mix.

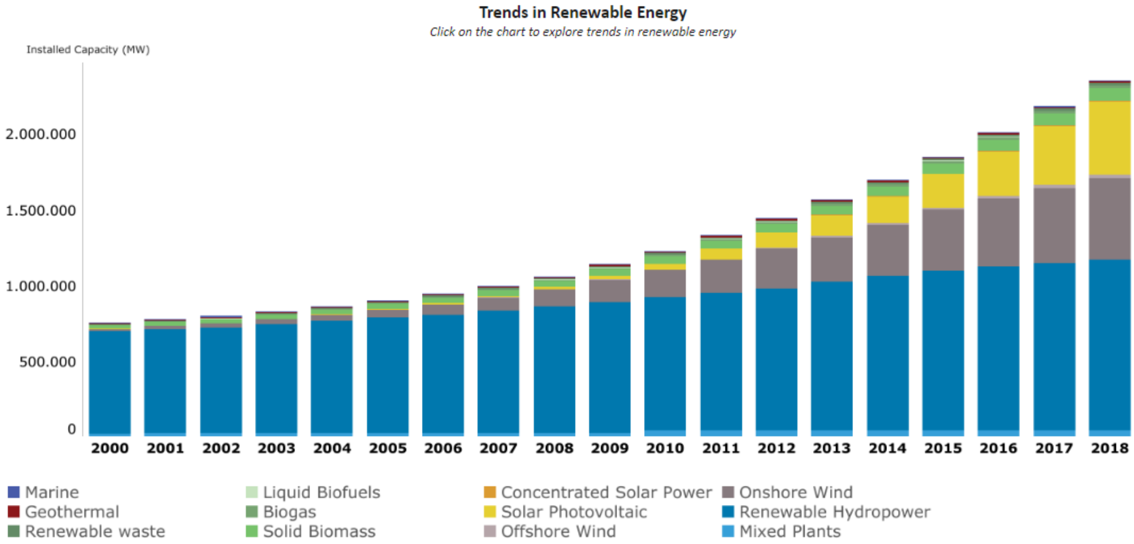


Figure 1. Renewable Installed Capacity in the World (MW). Source: IRENA.

In the case of Spain, it has always been highly dependent on foreign fossil fuels due to the lack of natural resources, and the quality of the existing ones is very poor. However, the geographical situation of the country makes the installation of renewable generation units attractive, and by 2020 more than 20% of electricity consumption must be "clean" (from renewable resources). Especially, the photovoltaic generation is one of the most extended thanks to the high solar irradiance incident in the country, nevertheless, there is a huge amount of solar capacity yet to be installed [3].

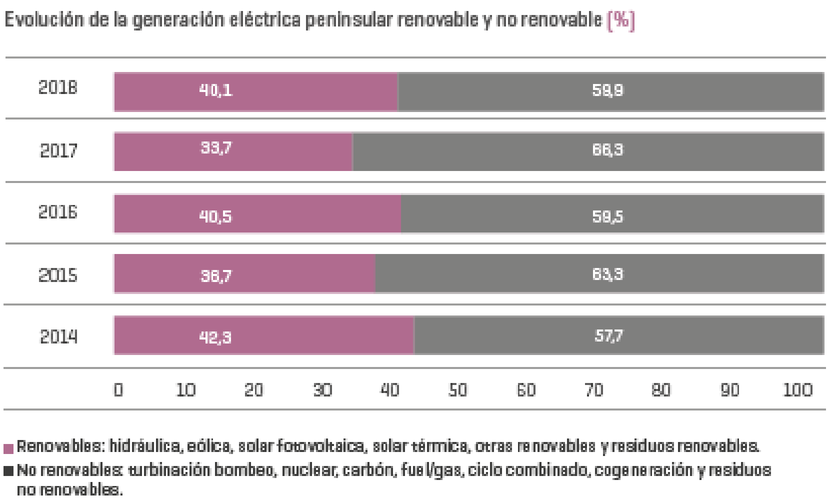


Figure 2. Evolution of the share of renewable energy in Spain. Source: REE.

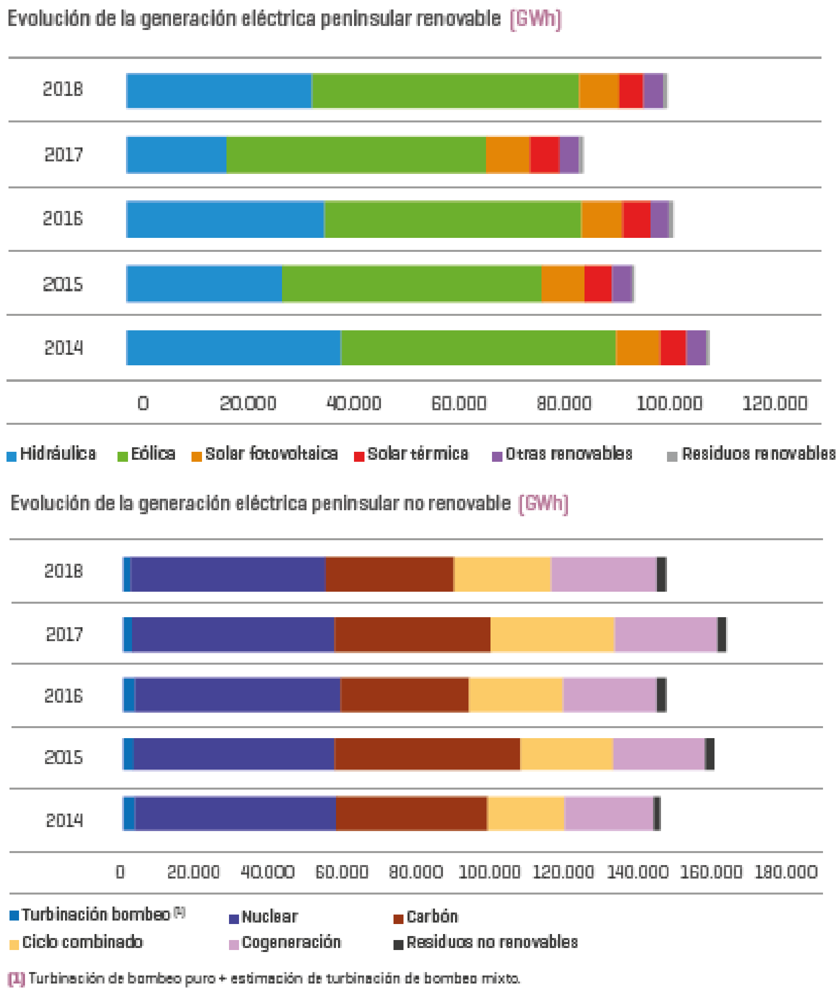


Figure 3. Evolution of electricity generation by technology in Spain (GWh). Source: REE

From above, it can be inferred that renewable generation has been increasing in the last years and conventional generation has decreased its production. Besides, the trend of renewable energy is almost exponential compared to conventional generation.

As it has been mentioned in this section before, renewable energy sources are the ones which are experiencing a more remarkable growth. Specifically, the most used are those technologies able to extract energy from the wind and from the sun. The wind power is the most extended worldwide, but thanks to the high increase in the efficiency of the solar technology, this is the one with the steepest rise in terms of installed capacity. In fact, as shown in Figure 4, in the last 4 years the solar installed capacity has doubled its numbers worldwide, and it is estimated that this growing trend will keep on in that direction.

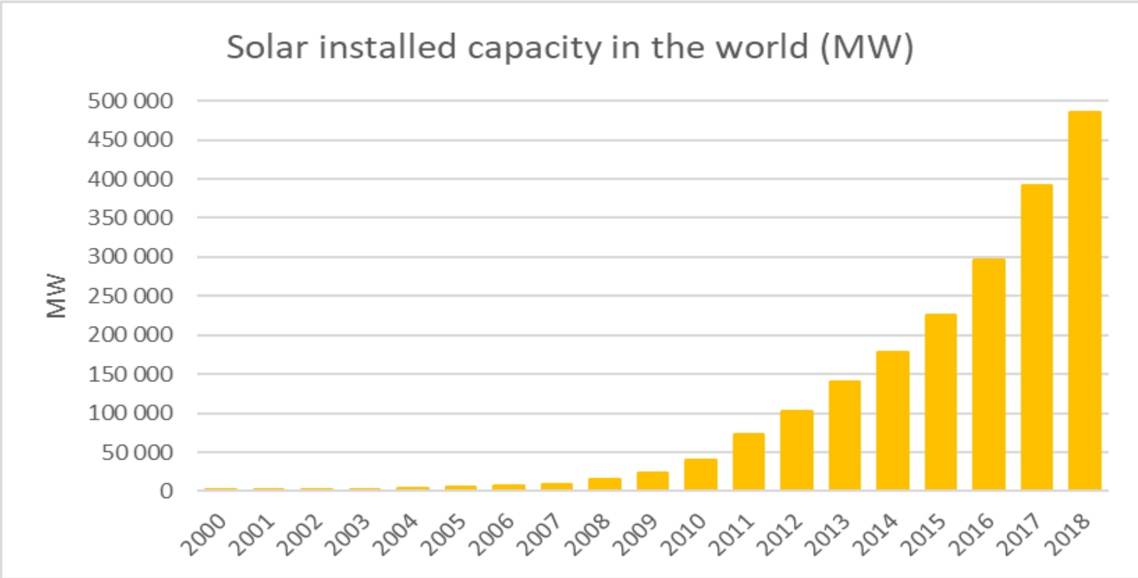


Figure 4. Evolution of solar installed capacity in the world. Source: IRENA

Focusing in Spain, the Figure 5 shows the evolution of the installed solar capacity in our country. It is remarkable that the highest increase happened as a consequence of the Renewable Energy Plan (explained in 3.9).

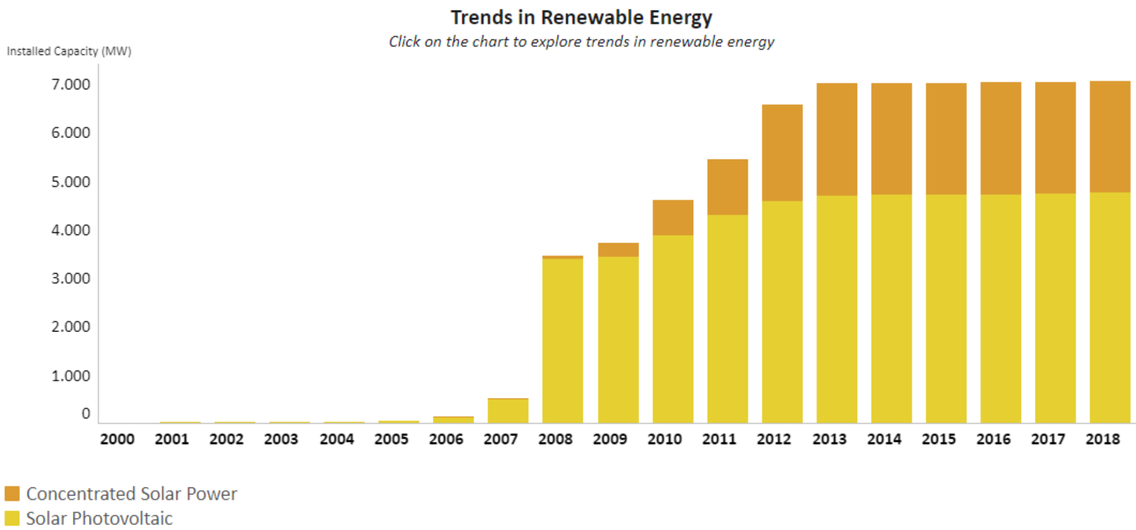


Figure 5. Evolution of solar installed capacity in Spain. Source: IRENA

Furthermore, it is also interesting to talk about distributed generation because it is going to be a very important point in the development of renewable energy. In the recent years the trend of distributed generation is growing thanks to the emergence of self-consumption or the inclusion of the electric vehicle. The distributed generation roughly consists on approaching the generation and the demand, by allowing the latter to produce electricity with small scale generation units. This definition implies that the sources of generation must be available for all the demand and also the technologies must be scalable and handy. For that reasons, renewable energy and in particular solar PV installations have been chosen as the perfect solution. Solar PV installations are enough scalable, and the sizes of these installations can vary from 1 kW to several megawatts. Besides, they fulfill the main requirement requested by most consumers that is the no-emission of CO_2, which turns this technology into a clean and green technology.

Finally, it turns essential to develop some regulations that try to organize this sector. These pieces of regulation have existed in our country since the very beginning of the renewable sources in Spain, but they have been changing and evolving in order to be adapted to the latest trends and insights of the sector. In any case, regulation must be a support for the sector, and it should incentivize good practices and be prepared for future changes.

2. Motivation and objectives

The aim of this project is to discuss the economic viability of a solar PV installation and to study all the costs incurred since the project proposal until it is finally completed. One of the main points of this project is the use of clean and more efficient technologies to get an economic and social benefit, in particular solar photovoltaic installations.

This Project will focus all its efforts in the region of the Iberian Peninsula, that due to its geographical position has a huge amount of renewable resources that may be exploited. In this particular case, the sun irradiation hitting the ground, makes Spain one of the countries in Europe with more solar resources which implies that solar PV is one of the most suitable renewable technologies for the purpose of generating electricity. Thus, the project is focused on this technology. Furthermore, in this document the evolution of the Spanish regulation about renewable energy is reviewed.

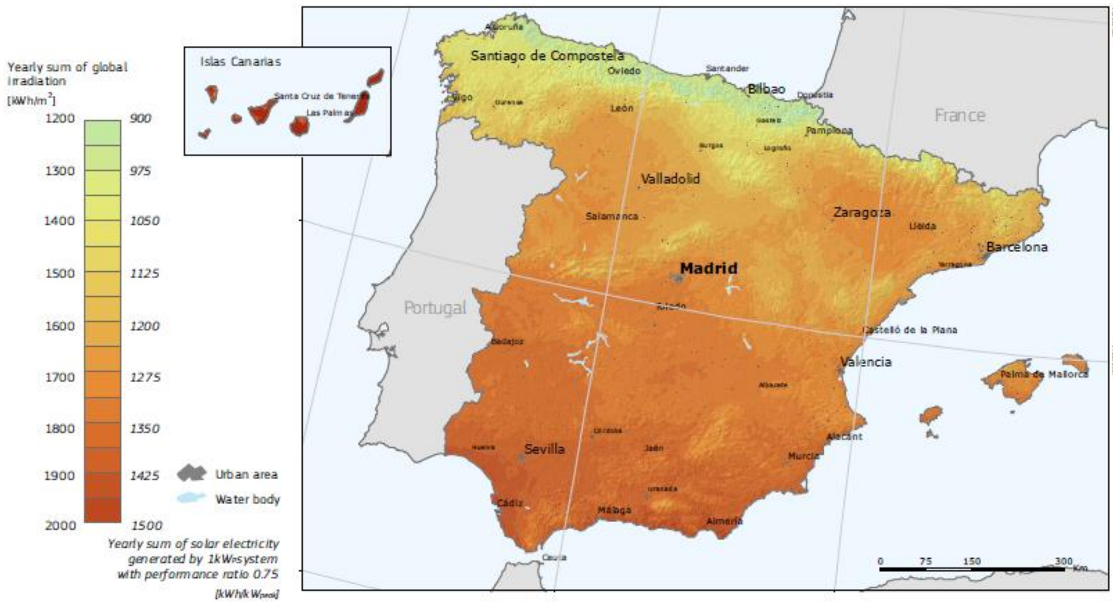


Figure 6. Solar irradiation in Spain.

Some factors that are activating the installation of this technology are economic benefits, the increase of clean generation, the development of these technologies, the pursuit of energy independence, the increase of distributed generation or legal issues.

Talking about economic benefits, there are those related with the sale of electricity to the grid that would turn the installation in a generation unit, or those related with the savings that a self-consumption installation can generate on the owner´s electricity bill. Both situations are induced by the high prices of the electricity that are, among other reasons, caused by the increase in the cost of fossil fuels. So, it is obvious that a solar PV plant would report benefits to its owner.

That bring us the second factor, which is the increase of clean generation. Due to the limited amount of fossil resources in the world, it is crucial to find a way of generating electricity alternative ways that do not need that resources. Besides, the use of those is damaging for the environment because of the emissions they produce. Hence, the public opinion has shown more awareness about this issue, and the society is asking for more renewable generation. This has been traduced in some regulations and directives stablished by the European Union (EU) and the regional governments that aim to increase the share of renewables in the years to come such as the Clean Energy Package [2].

Furthermore, the continuous development of these technologies is making them more efficient and cheaper as we can see in Figure 7. As an example, the current investigations on bifacial PV panels are trying to get more irradiance at a similar price. Also, for big installations, economies of scale have a really important role because of the cost reduction.

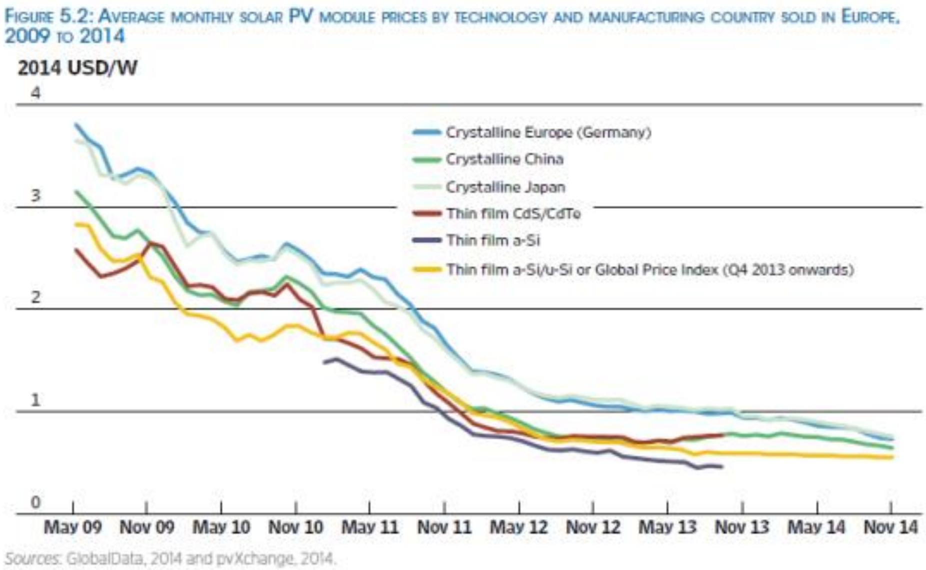


Figure 7. Variación en el precio de los paneles entre 2009-2014.

Other important factor that differentiate this technology from other renewable alternatives is the fact that the size of the installations is not a problem, the panels can be mounted in the roof of a regular house or they can cover thousands of square meters as in the big solar PV installations. The wind turbines, for example, need a huge amount of terrain to be built.

Other important factor has been the distributed generation, that as it was explained in the previous section, has contributed to approach demand and generation. Due to that, some consumers are starting to install small generating units in order to gain independence with respect to the grid. This kind of consumers receive the name of "prosumers" and are enhancing the use of clean energy.

Finally, as it was mentioned before, some consumers are looking for energy independence because of the high prices of electricity and their willingness to contribute with cleaner energy. Henceforth, and helped by some regulation changes (i.e. "sun tax" removal), the self-consumption is increasing both for industrial clients but also for households.

For all these factors, it is essential to know and be able to study the economic viability of installing this technology as well as the social impact that it can generate. The cost structure of this kind of installations is not a public piece of information and requires a lot of work of investigation. Each company has its own structure and belongs to its know-how, that is why this project is confidential.

For all that reasons, the main objectives of the thesis are:

- Develop a simple model that takes into account all the costs incurred during the progress of a solar PV project and is able to assess its profitability.

- Study real cases in order to decompose all the costs and figure out the weights of each one. In the end, a base cost structure will be developed, and it will be valid for all kind of PV projects.

- Get familiar with all the regulation and its evolution regarding renewable energy.

3. Regulation of the sector

For the correct development of the subject, it is crucial to study the evolution and the existing regulation regarding renewable energy. The main sources of information are the BOE (Boletín Oficial del Estado) and the International Energy Agency (IEA). In particular, it is especially important to focus our efforts in all the norms that regulate solar PV energy. It is also remarkable that the topic is under continuous changes, and consequently the regulation has experimented a lot of transformations. In this part, we are going to explain briefly the main pieces of regulation regarding renewable energy.

3.1. Law 82/1980

There is not so much information about the real causes of the development of this law, but it is thought that due to the oil crisis that was hitting Spain in that years, the government decided to impulse the mini-hydro plants in order to be more energy independent from other countries.

This was the first law aiming the increase of energy production from renewable resources in our country [4].

3.2. National Energy Plan 1991/2000

Some years later, the government decided to release a plan to promote the use of renewable resources. The main pieces of regulation in this plan were the RD 2366/1994 and the Law 40/1994.

These regulations set the beginning of the special regime and included solar PV as one of the selected technologies to be part of that regime. They try to protect the use of renewable resources by setting a remuneration plan [5]. Besides, the distribution companies were obliged to buy the energy surpluses as long as it was technically feasible, and the network could handle it. The price for these surpluses was the one fixed by the market.

3.3. Law 54/1997

The Law 54/1997 [6] of the electric sector tried to guarantee to all the consumers the electricity supply at the lowest possible cost. This law differentiated between two types of energy production which are regular regime and special regime. The latter modality implied a generation with renewable sources and with an installed capacity below 50 MW and those with cogeneration units with high efficiency levels. This law also tried to set the remuneration for these generation modalities and stablished a premium so that the price of the energy sold under that regime was around 85% of the average price of the final price paid by consumers. Furthermore, it promoted the increase of renewable energy installations with the goal of 12% by 2010.
After this law, it was necessary some regulation in order to consolidate all the proposals made, so the RD 2818/1998 tried to fix that issue.

3.4. Royal Decree 2818/1998 "Special Regime"

This Royal Decree 2818/1998 [7] (derogated by RD 436/2004), as it has been mentioned before was intended to consolidate the reforms proposed in the Law 54/1997. More specifically it tried to promote the generation with renewable energy resources and stablished the special regime tariffs and premiums that should be reviewed every 4 years.

3.5. National Plan for Renewable Energy

The National Plan for Renewable Energy was launched by the Spanish government in 1999, but it started functioning the next year. Its main goal was the promotion of renewable energy, but also tried to incentivize the use of cleaner infrastructures, the development of technologies such as storage or the substitution of fossil fuels in the transport sector, the more efficient use of the grid or the nuclear safety among others.

During the life of this plan it existed a financing line for renewable and efficient projects with a maximum loan of 70% of the investment. In the end it achieved a huge increase in renewable technologies. The most important ones were solar, hydropower, wind and biomass.

3.5.1. Royal Decree 6/2000

The Royal Decree 6/2000 [8] of urgent measures to the intensification of the competence in good and services' markets, tries to incentivize the participation of the special regime units in the wholesale electricity market and helping them to negotiate contracts with energy suppliers.

3.5.2. Royal Decree 1663/2000

This piece of regulation [9] aimed to simplify the connection to the grid conditions for solar PV installations. And in this case, it released the standard steps that a solar PV installation with a nominal power lower that 100 kW and connected to the low voltage grid must follow.
Besides, for solar PV installations, if they have a nominal power higher than 5 kW the must be connected to the distribution grid in a triphasic way.

3.6. Law 24/2001, Law on Fiscal, Administrative and Social Measures

In a similar way as previous mentioned laws, this one tried to promote the installation of renewable installations [10]. Thus it, offered tax deductions when investing in that kind of projects, in particular, if someone invested in solar, biomass or waste power, a 10% tax deduction was possible. For this regulation wind power was not included.
This measure was thought to be in the RD 1663/2000, but it was finally implemented through this RD a year later.

3.7. Royal Decree 841/2002

The Royal Decree 841/2002 [11] has as a main objective the participation of special regime installations in the electricity market. It also motivates that installations to inform about their estimated productions and tries to guarantee them the sale of their electricity to the supply companies. This RD is a follow-up of the before mentioned RD 6/2000, and for those installations with a nominal power higher than 50 MW it is mandatory their participation in the market. In addition, it allows contracts between generation plants and supply companies for the produced energy.

3.8. Royal Decree 436/2004

This RD aimed to establish the economic and regulatory framework for the generation of electricity by special regime installations [12]. It takes as a reference the law of the electricity sector mentioned above, and it could be understood as the redevelopment of the RD 2818/1998. This regulation defines two options for the owner of the installation:

1. Selling the electricity directly to the distribution company at a regulated tariff. The price would be fixed and will depend on the installed capacity as well as the maturity of the installation and the type of technology.
2. Selling the electricity to the free market at a contracted price. It could be done by a bilateral contract with the supply company or by participating in the wholesale market. Those who participate in the market obtain the market price plus a premium and an incentive for participating (Feed-in Premium).

3.9. Renewable Energy Plan

The Renewable Energy Plan (REP) for 2005-2010 raised as a redevelopment of the Spanish Renewable Energy Plan for 2000-2010 that was not as successful as it was expected. The REP set the energy target for every renewable technology and tries to put into practice the needed measures to achieve those targets. The targets included financing structures, innovation and physical implementation. The Spanish government's focus on renewable energy sources was also intended to reduce Spain's dependence on oil imports, to further efforts to fulfill the country's Kyoto Protocol commitments and to contribute to the phase-out of the use of nuclear energy.

The main objective was to meet the 12% requirement of total energy consumption from special regime installations set by the previous plan. But this was not the only objective because the REP aimed to get a 29.4% of energy production with renewable sources and almost a 6% of energy transport necessities with biofuels by 2010.

In the particular case that concerns this project that is the solar power, the plan was to have at least 400 MW of solar PV installed capacity by the end of 2010. During that years the results were better than expected and in 2007 almost 90% of the required capacity had been installed, so the target was increased to 1200 MW by 2010.

In terms of financing, it was estimated that the industry would be able to provide a 75% percent while the rest was going to be private investments. All that sources of capital had tax incentives in order to reduce the barriers.

3.10. Royal Decree 661/2007

The Royal Decree 661/2007 [13] regulates the activity of energy production under special regime, and in particular the renewable energy. It was launched as a correction of the RD 436/2004, but it still keeps its main points. With the new RD the owners may either sell the electricity at a regulated price or to the free market, but this new piece of regulation changed the tariffs and the premiums given to each kind of facility. The RD also introduces limits in the prices (floor and cap) and all the costs are held by the network operator (Red Eléctrica) that in the end are passed to the consumers. The modification of the remuneration formula seeks the decrease of the tariff deficit and thus the reduction of tariff prices to consumers.

According to this new regulation, the Autonomous Regions’ institutions are the ones in charge of conceding the condition of special regime to each installation. After that they will register that installations in the administrative record for this kind of installations.

The scheme proposed by the RD is applied to all technologies but with some different specifications depending on the technology and with combined feed-in and feed-in premium tariffs that will vary among the years. In the case of renewable energy, if they have a nominal capacity smaller than 100 MW, the enter in the special regime, and in for those with less than 50 MW installed they can choose between feed-in tariffs or a premium over the wholesale price. The retributive scheme was the following:

$$Floor < (Reference\ market\ price + reference\ premium) < Cap \rightarrow Premium = Ref.Premium$$

$$(Ref.market\ price + reference\ premium) \leq Floor \rightarrow Premium = Floor - Ref.Market\ price$$

$$Reference\ Market\ Price \geq Cap \rightarrow Premium = 0$$

For the case of PV solar installations, they opt to a guaranteed feed-in tariff that are adjusted every quarter of the year. At the end of the next year, the premium and the tariff values changed to a range of 23-44 EUR cents/kWh. In this RD it is also introduced the payment of a guarantee for new facilities that in the case of PV solar is of 500 EUR/kW.

Finally, this RD seeks to contribute to Spain's efforts to achieve its 2010 national target for the promotion of electricity from renewable energy and special regime under the EC Directive 2001/77/CE.

3.11. Royal Decree 1578/2008

This RD modifies the economic retribution method established in the RD 661/2007 for the solar PV installations [14]. It differentiates between those who are installed in the ground and those installed in rooftops. The retributes is adjusted depending on the learning curve of each technology that is specified before every yearly convening. This methodology means a reduction in the price of electricity and puts limits to the previous RD.

3.12. Royal Decree 6/2009

Due to the high impact that the electricity tariffs have over the renewable energy sector, the government decided to launch the Royal Decree 6/2009 [15] in order to change the regulation in the remuneration method for the special regime installations aiming to build a more sustainable system. This RD do not apply to the PV solar installations, that kept regulated as stated in RD 1578/2008.

The solution that the government took was the creation of a Pre-assignment Registry that would be used for the special regime units. With this registry the government tried to stablish a schedule in order to plan and control the commissioning of the renewable power plants whose nominal installed capacity had overtaken the objectives set in the REP (2005-2010). The Registry implies that all the new renewable power plants must be registered before opting to the Feed-in Tariff.

The register process consists on a group of administrative requirements that all the installations must deliver. These documents are building permits, grid access, adequate funding of at least half of the investment costs and provisions for transmission and distribution. Apart from that documents, as it was stated in the previous RD, the installations must also pay for a guarantee that will vary depending on the type of technology.

Thanks to that piece of regulation the costs incurred because of the renewable subsidies can be better distributed among the consumers and the prices would reflect a most accurate transposition of regulated activities. Also, it facilitates the integrations of renewable installations into the grid, contributing to a more reliable system. At the same time, the RD reduces the uncertainty to investors and hence the risk, motivating them to invest in more projects. Finally, it was a huge step for our country in order to achieve the targets set by the European Parliament in the Renewable Energy Directive 2009/28/EC.

3.13. Renewable Energy Action Plan

After the releasing of the European Directive 2009/28/EC [16] of April 23rd, 2009 for the promotion of the use of renewable energy in the European Union, all the member states must transpose that directive into national regulation. The targets set by the EU were a 20% share of energy consumed from renewable resources and an increase in the use of renewable resources in the transportation sector to a 10%. The National Energy Action Plan (NREAP) set a template for all the member states in terms of renewable development. The Plan suffered a change at the end of 2011, that was the starting point that our country took for the development of the Renewable Energy Plan (REP) 2011-2020.

In Spain, the main objectives set for 2020 were 20.8% of renewable energy produced for final energy consumption, 17.3% of heat consumption met with renewable resources, 39% of electricity demand met with renewable energy sources (RES) and 11.3% of energy demand of the transport sector met with RES. In order to monitor that targets, the Institute for Energy Diversification and Saving (IDAE) attached to the Secretariat of State for Energy was appointed as the Office for the REP.

In addition, the REP had to include a Strategic Environmental Assessment in order to fulfill the Spanish requirements. This assessment is included in one of the cornerstones in the development of renewable energy in our country, the Sustainable Economy Act, which main objectives are apart from environmental sustainability, the security of supply and the economic efficiency of the electricity sector. One of the measures of this act was to increase the tax deduction for innovative activities related with this sector.

3.14. Royal Decree 14/2010

This Royal Decree 14/2010 raised as an emergency measure to reduce the tariff deficit that was burdening the sector in Spain [17]. In order to do that, the main measure taken by the government were:

- Since the beginning of 2011 the payment of a fee of 0.50 EUR/MWh for all the energy injected into the grid by the generators operating in either ordinary or special regime.
- The government stablished a limit to support the hours produced with solar PV installations. Once the limit is reached, the energy would be sold directly to the wholesale market without any kind of support.

3.15. Royal Decree 1565/2010

The main objective of the RD 1565/2010 was to modify the support framework set for the renewable installations by reducing the financial support, and the most affected technology was the solar photovoltaic. This regulation also tried to improve the technical integration of all renewable technologies as well as the simplification of all the administrative procedures required.

The specific measures were limiting the number of years with support to solar PV installations to 25 years and reducing the feed-in tariffs to this technology depending on the size of the installation (- 5% for small-size roof installations. - 25% for medium-size (21 to 100 kW) roof installation. - 45% for ground installations) [18]. In order to ease the administrative procedures, this RD Promoted the use of electronic communication tools that would expedite all the formalities.

3.16. Royal Decree 1544/2011

The Royal Decree 1544/2011 was the one in charge of setting the tolls and tariffs that the generating units should pay in order to being able to access to the transmission and distribution networks [19].

It also consolidated the rule set in the RD 14/2010 that said that all the generating units should pay an extra toll of 0.5 E/MWh just because being generating electricity.

3.17. Royal Decree 1/2012

Due to all the measures taken to promote the introduction of renewable generation in our country such as the REP 2005-2010, by 2012 the capacity installed was way bigger than expected. As a consequence, the costs of all the financial support required were significantly higher than anticipated and the value of the tariff deficit kept on growing. Together with this, the country was not going through a good economic situation, so the government decided to take quick measures by abolishing the economic incentives for these installations on a temporary basis. This measure would help to reduce the tariff deficit that is the difference between the money collected from regulated activities and their costs. The RD also suspends the proceedings of the Pre-assignation Register stablished in the RD 6/2009. However, the regulation would not affect the installations currently working or those with an authorized feed-in tariff, it will only be applied to those which are new.

In any case, the measure should not affect neither the security of supply nor the achievement of the renewable targets sets in the National Renewable Energy Action Plan.

3.18. Law 15/2012

After the RD 1/2012, it was necessary a law to regulate the tax measures for energy sustainability. This law included a tax on electricity generation called "IVPEE" for all generators with a value of 7% which objective was purely the collection on funds for the deficit [20].

The law also included a clause that eliminated the right of fossil fuel generators to be remunerated with premium based tariffs.

3.19. Royal Decree 2/2013

After the urgent measures taken in the law 15/2012 it was necessary to keep on reforming the electricity sector, in particular, it was still needed a stronger regulation to reduce the differences between costs and revenues from regulated tariffs and the tariff deficit. As a result, the RD 2/2013 changed the indexing of the remunerated activities, that at this moment were linked to the consumer price index (CPI). After this regulation the remuneration would be indexed to the harmonized IPC with constant rates.

Furthermore, in this regulation there was a modification of the RD 661/2007 because it eliminates the premium for the special regime generation units that sell their electricity in the free market. Hence, the renewable installations could sell their energy at a regulated tariff, or they can go directly to the free market and sell their production but now without the right to get a premium. The default tariff for the generation units will be the regulated one, but they will be able to sell their electricity to the market if they notify that change. In this latter case, they would not be able to come back to the regulated tariff again.

3.20. Royal Decree 9/2013

Due to the same reasons mentioned in previous sections that can be summed up as the promotion of technologies with environmental but also economic benefits, in 2013 it was approved a piece of regulation of urgent measures seeking the stability of the electric sector. The new RD 9/2013 [21] aimed easier bills for the consumers, more competitive electricity tariffs and the final elimination of the tariff deficit.

The model proposed stated that the special regime should disappear, being all the generation units regulated by the same obligations. The incomes will be dependent on the market participation, and based on:

- A capacity term (EUR/MW) thought to cover the investments costs that may not be recovered with the sole sell of electricity in the electricity market. This term allows better profitability for certain installations, and in the case of renewable plants, they will always receive it whenever they have not reached their expected profits.
- An operating term (EUR/MWh) that was designed to cover the differences between the operating costs of the units with the actual revenues obtained of the sale of electricity in the market. With this term, the units should not have losses during the electricity generation. In the case of renewables, which do not have operating costs (or are negligible), this term will be null as long as their revenues from the sale of electricity are higher that the costs.

3.21. Law 24/2013

This law raised as the new reference for the remuneration methods [22]. The law 24/2013 substituted the Law 54/1997, and its main function was to achieve economic sustainability, which means that the revenues should be equal than the costs. As it was set in the RD 9/2013, the special regime is not in practice anymore, but the renewable power plants must receive a remuneration to cover their costs.

As it was mentioned in the previous section, the remuneration depends on the participation in the electricity market. However, renewable power plants would be able to opt to a subsidy that allows them to compete in the market with conventional plants. This subsidy will be calculated in order to allow renewable participants to recover their investment costs as well as enough return. The value of the subsidy will depend on the specific technology (costs and estimated revenues along the lifetime of the unit), the economic situation or the structure of the sector. In a similar way as explained in RD 9/2013, the subsidies would have a capacity term in order to make renewable installations more competitive and allowing them to recover investment costs; and an operative term to cover the differences between revenues and costs. Besides, the electricity produced by these facilities will have preference as long as the economic conditions are balanced, and it does not distort the market.

The granting procedure of the subsidies will depend on competitive basis among the participants.

3.22. Royal Decree 413/2014

After the law 24/2013, it was released the RD 413/2014 where the remuneration scheme is defined. The main goal of this piece of regulation if to offer a good rate of return to the investors, that would be paid on top of the money obtained from the sale of electricity in the market. The remuneration will be available for all kinds of generation, and the rates will be calculated as the average of ten-year Spanish bonds plus a differential.

The regulatory periods are stablished in 6 years, but they are divided in semi-periods of 3 years. Furthermore, for the calculation of the remuneration they are also used the revenues of the unit, the standard operating costs and the initial investment, assuming that the installation is efficient, and the management is the optimal.

The mentioned remunerations will consist on the so-called retribution for investment, that depends on the installed capacity and its main objective is to cover all the costs that cannot be recovered in the market; and the pay for operation that as it was explained in 3.21 aims to compensate the difference between costs and revenues from the market.

3.23. Royal Decree 110/2015

Although this is not a technical regulation, it is really important because in this RD it is established, they way to classify, treat and remove the different kind of materials that compose the solar photovoltaic plant. The main objective is the reduction of the generated impact of their disposal in the environment and most important in human health. This RD introduces the concept of recycling in this sector, seeking a more sustainable environment and promoting the installation of green generation.

3.24. Royal Decree 900/2015

As the solar PV projects and other renewable technologies started to be more and more profitable, the concept of self-consumption entered into play and it was crucial to regulate that activity. In order to solve that the government developed the RD 900/2015 to regulate the administrative and technical conditions of self-consumption in Spain [23].

This RD affects to any renewable generation unit that produces electricity for self-consumption and is connected to the Spanish network, so the islanded installations are not regulated by this Royal Decree.

The RD 900/2015 set two types or self-consumption models where all the participants should be included:

- Type 1: These are the subjects with installed capacity lower than 100 kW, that must be in any case lower than their contracted capacity. All the energy produced should be self-consumed by the same person who produces, and the surpluses injected to the grid are not remunerated.
- Type 2: These are the subject with an installed capacity higher than 100 kW, that must be in any case lower than their contracted capacity. The consumer may be connected to several produces, and the surpluses could be injected into the grid in exchange of a compensation.

Apart from that, the consumers of any modality should pay the access fees to the distribution and transmission grids in order to ensure economic viability on the network. Furthermore, they will have to pay the so-called "tax on sun" that is composed by a capacity term and an energy term.

3.25. Renewable Auctions

Due to the lack of incentives in the regulatory framework or in the electricity market the reliability of the system and the price signals were not the appropriate one in order to promote investments in the renewable sector. Besides, the continuous changes in the regulatory framework lead to bewilderment in the sector and in the end, it caused a stagnation in the investments. However, it was crucial to fulfill the requirements stablished by the European Union about renewables for 2020 and 2030, so the government launched three renewable capacity auctions trying to clear up this matter.

The first auction was celebrated in 2016 and under the umbrella of the RD 947/2016. It was just for wind and biomass capacity, and the auctioned capacity was 700 MW, 500 MW and 200 MW respectively. Nevertheless, the success of this auction was dubious, because all the capacity was awarded without premiums, which means that it was going to be remunerated at the wholesale price. So, years later, it was decided to develop a more complex auctions where the projects could ensure a minimum return during their lifetime. The projects bet discounts over a nominal CAPEX stablished in the BOE (Boletín Oficial del Estado), so the ones with a higher discount are the ones winning the auction.

The results obtained of this auction were not as good as expected and they were even worse than the ones obtained in the market. 3000 MW were awarded and mostly (2979 MW) to wind. The rest of capacity was awarded to biomass and Solar PV (1 MW).

Finally, in the third and last auction, the winning technology was solar PV with 3900 MW of the total 5000 MW awarded. In fact, the total value had to be increased due to the high demand.

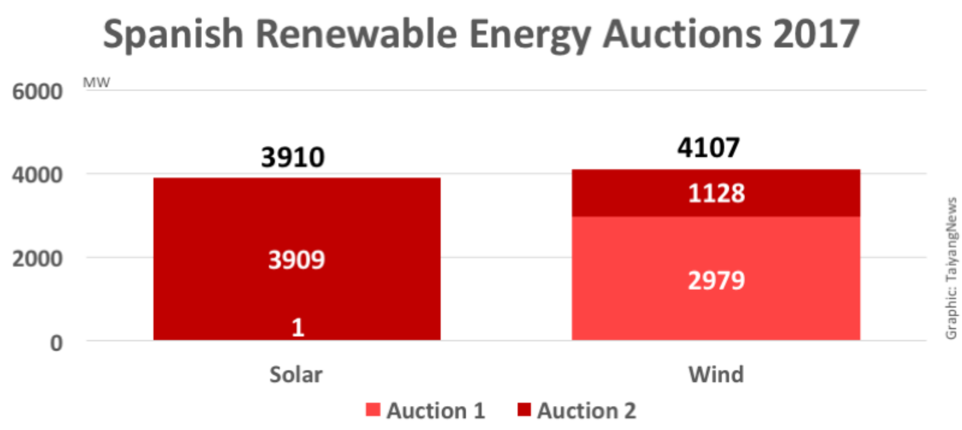


Figure 8. Capaicty awarded in renewable auction. Source: Tayiyang News about solar energy in Spain

The main characteristics of the auctions carried out in our country are:

- The capacity auctioned does not distinguish among technology. All the participants must pay a guarantee of 60 €/MW in order to incentivize a competitive auction and avoid speculative participants.
- The companies are paid for the installed or granted capacity but not for their energy produced. This is a point of differentiation with other auctions.

- The auction is marginalist. The bets are about the discount you are willing to accept to build your plant. In case of a tie, the awarded bet is the one with a technology with more equivalent hours.
- The government has established a floor in the wholesale prices in order to secure some return to the investors.
- In order to follow up the projects, all the awarded projects must provide a site of construction, administrative authorization and they must be registered in the RAIPRE before one year after the auction.

All this awarded renewable capacity is pavement the way towards the fulfillment of the EU's requirements on renewable energy.

3.26. Royal Decree 15/2018

The RD 15/2018 raises due to the urgent need of measures to move towards the energy transition and the protection of the consumers. Thus, most of the measures taken in favor of the energy transition are based on the development of renewable energy.

One of the most important points of the regulation is the elimination of the "tax on sun" introduced in the RD 900/2015. This measure reduces the barriers for the consumers and incentivizes them to install self-consumption facilities in their homes. The introduction of self-consumption allows consumers to be more participative in the electricity sector, introducing cleaner electricity into the system and reducing the cost of their bills. In this case, solar PV installations are being the most used because of their scalability and competitive costs.

Other measures have been the promotion of the electric vehicle (EV) or the elimination of the 7% tax on generation. In the case of the EV, the RD tries to reduce the obstacles that a regular consumer can find when trying to acquire an electric vehicle. In the other hand, the temporal elimination of the 7% tax on generation was intended to incentivize the self-consumption, because the cash flows for the owners would experiment an increase.

Furthermore, the RD also abolishes regulatory barriers for connection that will allow 9000 MW of awarded renewable capacity to be constructed. It also introduced some measures to reduce speculation by increasing the required guarantees for the construction of a renewable power plant to 40 €/MW.

Finally, in order to protect consumers, the RD 15/2018 extend the coverage of the social bond, what will allow more families to be able to access to electricity.

3.27. Royal Decree 244/2019

As I mentioned in a previous report [24], after the proposal sent by the government in the RD 15/2018, it was necessary a new regulation regarding self-consumption with the new changes updated and seeking the energy transition and the electrification of the economy. That is why the RD 244/2019 was developed, aiming to gather all the technical and administrative specifications for a self-consumption installation.

The main points introduced by this RD are:

1. Promote self-consumption in Spain, especially with renewable sources.
2. Define and regulate the shared self-consumption.
3. Redefine the concept of close self-consumption.
4. Define the concept of simplified compensation.
5. Simplify all the technical and administrative requirements.
6. Stablish a tracking of the implantation of the process.

4. Costs strucuture - Methodology

In this section, a standard cost structure is going to be developed. In order to do that, the methodology followed has mainly been in first place, an exhaustive gather of past and ongoing projects with varied capacity installed and structures that have been used to construct the mentioned structure in such a way that any of project could fit in it. As it may be thought, there are some common parts and others that are exclusive of certain projects. Once the structure has been developed, it is time to determine the specific numbers (quantity and cost) for all the components. That part has been carried out by using projects already developed as well as contacting the main component suppliers in order to get the current prices in the market, also it has been done a market research. After this step, the structure is finished.

The main components of that cost structure are described in the following sections.

4.1. Cost of Project Site

There are only two alternatives for this point, and they will depend on the choice of the project owner. These alternatives are the rent of the land or the purchase of the land.

In the first case, the alternative chosen would be to pay a regular rent to the landowner in exchange of the use of the land. It is used in that cases where the project developer does not have land in property. This rent would be implemented in the economic study as part of the variable costs, following the formula below:

$$C_{land_{yx}} = Capacity_{installed}(MWp) \cdot 1250\,\frac{€}{ha} \cdot 1.6\,\frac{ha}{MWp}$$

As it can be seen in the formula, the yearly cost of the land would depend on the installed capacity, which is transformed thanks to a conversion factor in hectares of land required for that capacity. The factor used is 1.6 hectares for each MWp of capacity installed. Finally, after carrying out a market research, the average value of renting 1 hectare of land in Spain is 1250 € per year, so the actual value of renting the required amount of land can be obtained.

In the other hand, it can happen the case where the project owner is also a landowner. This would be the suitable case because in the economic study, the part of the variable costs related with the rent of the land is skipped, so the profitability of the project increases. However, other possible case study is that in which the project owner prefers to pay a mortgage, an acquitting the land, than paying the rent. In this latter case, the mortgage could be included in variable costs in the same way of a regular rent, or it could be assumed as a sunk cost (although this option is more exceptional). Currently, the price of the land in Spain is around 6000 €/ha for dry land and almost twice (12000 €/ha) for irrigated land. Nevertheless, these prices are indicative, and are continuously changing, especially with the huge rise in the demand of solar PV installations.

For the development of our economic model, it has been assumed that the land is rented, which would be the worst case.

4.2. Costs of the grid connection

In order to manage all the formalities required to being able to connect a solar PV installation to the grid, the most common practice conducted by the project owners is to introduce that procedures in the scope of the engineering project. Hence, the cost of that formality would be included in the quotation of the engineering company in charge of the technical design and sometimes construction of the installation.

This process is usually really tedious due to the great amount of documentation and administrative steps that have to be followed. That is why some of the latest pieces of regulation in our country are trying to ease and expedite all these procedures, and in fact a new RD is being developed in order to regulate the access and connection of generation installations to the grid.

There are some occasions, for example when the plant owner is a big utility, that these costs are almost negligible because these companies do that procedures continuously and because of economies of scale.

In any case, the cost of grid connection is not very high compared to the final price of the project. After reviewing several engineering projects, the total cost of engineering and all the required procedures accounts for a 3% of the final cost of the project.

4.3. Costs of the endorsement

An endorsement is an amount of money that the project owner must pay in order to guarantee that the project is going to get ahead. In the renewable sector, the endorsements arose as a measure to fight the people who tried to speculate and asked for some capacity and then they did not use it. So, the endorsement is a way to reduce the risk of people trading with power capacity at certain connection points. Besides, the endorsement would be returned to the project owner at the point when the project starts functioning, so it cannot be understood as a cost to be included in the economic study. In these projects, the endorsement is considered as a sunk cost, and as the project should be developed, there should not be any problem in recovering the amount paid.

The starting value was 10 €/kWp, but in the RD 15/2018, the government decided to increase that value to the current one of 40 €/kWp, because they were not solving the speculation problem. However, that increase has not been welcomed for everyone because has increased the barriers of entry.

Apart from the actual cost of the endorsement, the owner has to pay the cost of constituting it and the costs associated with its maintenance. Those costs usually amount around a 3% of the cost of the endorsement and are paid annually.

4.4. Costs related with regional governments

All the projects must obtain the approval of project execution and the administrative authorization, and these documents are granted by the government of each autonomous region of our country. As a result, the value of this documents will vary among the region where the project is placed.

As an example, in Castilla la-Mancha, the value of these documents is of 6000 €, half for the project approval and half for the administrative authorization. These values have been obtained after researching the appropriate web pages and sources of information.

4.5. Costs related with public Information

After the administrative and technical approval of the project, the project must be published in the ministry of industry and in the Official Gazette of the country and of the specific autonomous region where the installation is located.

The cost is almost negligible compared to the final cost of the project and comprises the administrative procedures of the pushing and the actual cost of the printed version of the final document. That costs are known as the "public information costs" and their value is very close to 500 €.

4.6. Costs of waste treatment and health and security studies

Every construction project must be included a report with the treatment of the wastes produced during the works as well as a report including all the security studies carried out for the project. These reports are often made by the engineering company, and as a result the costs incurred are introduced in the cost of engineering mentioned in the section 4.2.

Then, in this project the assumption made is that the costs of waste treatment and health and security studies are included in the costs of engineering.

4.7. Taxes, tolls and other tariffs

Apart from all the costs mentioned in the previous sections there are other tolls that have not been taken into account. One of these tolls is the one that any project owner must pay in order to acquire the work license. Furthermore, there are other tolls such as the special levy of PV, similar to the IBI, which is the tax on immovable property and accounts approximately for a 2%. This value has been set but the Spanish government.

4.8. Costs Breakdown of the solar PV Installation

These are the key costs for any solar PV project. They are the costs associated with the construction of the actual solar PV plant including purchase of materials and components, all kind of logistics, mounting of all the components, installation of all the systems involved in the functioning of the plant as well as the commissioning of the components with their respective tests. Without all these elements the project could not go ahead, so it is especially important to study which are all these costs just as trying to organize them in a standard cost structure.

In order to develop the mentioned cost structure, the main sources of information are past projects and meetings with suppliers that are willing to give us elaborated quotations about their components. The solar PV sector is very prudent, so all the companies that develop that kind of projects have their own cost structure, which is private, and they are not willing to share with anyone. The cause of this is that most suppliers have contracts with huge utilities, and they are not interested in showing the conditions of the contracts they have agreed with each one of them because that could reduce their market power. That is why there are not public offers and all the companies try to hide their information. As a result, the only way to have an actual cost structure is developing your own power plant and contacting the main suppliers to compare the different offers. The cost structure showed below has a mix between both of them but is mostly based in past projects.

Most of the costs of the projects are sufficient stable during the time so we can assume that are the same that those of other projects, however, there are other costs that may change from one year to another. The latter costs are those related with technology. As technology is evolving so fast, there are a lot of improvements that are reducing the costs of some technologies such as the PV panels.

In the Figure 9 the results obtained after developing the cost structure for an average solar PV project are shown. The different components are studied in the following sections.

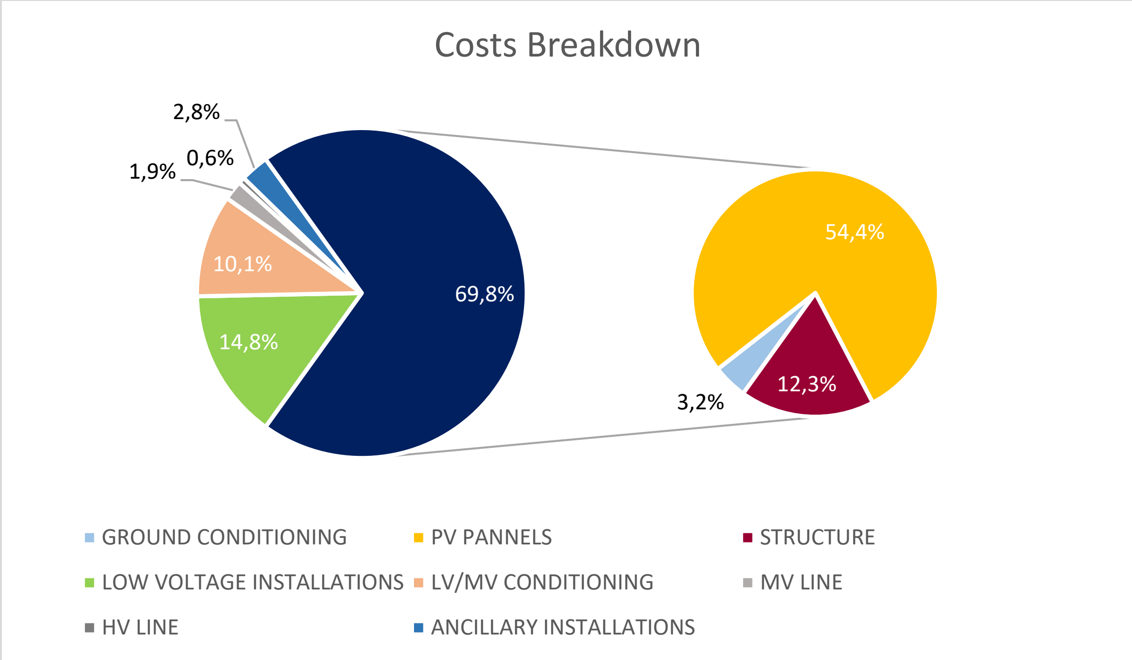


Figure 9. Costs Breakdown of the solar PV installation.

4.8.1. Solar Plant

The solar plant refers to the actual works that should be done in order to construct it. As we can see in the figure above, the costs of the solar plant amount almost to 70% of the total costs of the installation, so it is obvious that this is the most important part when trying to get good prices.

The components of these costs are the ones related with the ground conditioning, the costs of the PV panels and the costs of the supporting structure. The costs of the works and the mounting are included.

The final cost after adding up all the components described below is $0.428\ €/Wp$.

4.8.1.1. Ground conditioning

The ground conditioning is something mandatory for this type of projects. As it can be seen in the figure above, it amounts to the 3.2% of the total costs of the project. It includes the grubbing and cleaning of the ground in order to prepare it for the installation, because most sites are full of weeds that must be removed. There are occasions when it is necessary to move the ground with mechanical means in order to compact it and prepare a uniform topsoil. Besides, in most cases it is necessary to build roads and place fences in the perimeter.

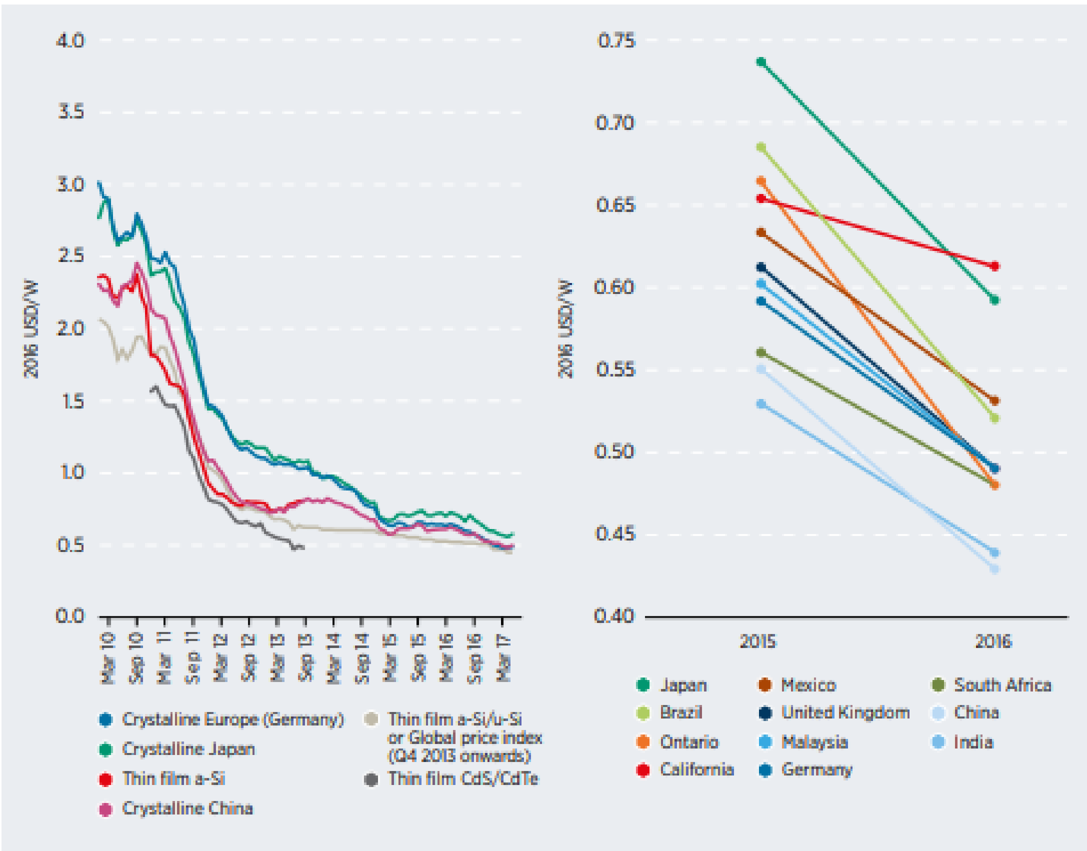
After reviewing several projects, the conclusion is that the average cost of the ground conditioning per MWp is:

$$C_{ground\ conditioning} = 0.0195\ €/Wp$$

4.8.1.2. PV Panels

As it could be expected the PV panels are the most critical part of the project, being their cost 54% of the whole project. Due to that, a small variation in that price could change a lot the whole costs of the project.

As it was stated in the IRENA's report about renewable power generation costs in 2017 [25], in the last 10 years, the price of the PV panels has been sunken thanks to the continuous progresses in the technologies used for their fabrication and the increase of the competition because of the entry of the Chinese manufacturers in the market.



Source: GlobalData, 2017; pvXchange, 2017; Photon Consulting, 2017.

Figure 10. Average monthly European solar PV module prices by module technology and manufacturer, March 2010—May 2017 (left) and average yearly module prices by market in 2015 and 2016 (right)

In order to stablish the costs of PV panels for the cost structure, past projects have been taken, however, there is an evidence that the prices between projects oscillated because of the date of construction and the size of the installation. So, as it was mentioned before, in order to have the most accurate numbers, several requests for quotation were sent to different suppliers and after receiving the offers and standardizing them, the updated prices for the most commonly used panels are:

Table 1. Cost of PV panels.

	EUR/kWp
Monocrystaline Standard 2019	280,0
Monocrystaline Standard 2018	350,0
Split Cell Pannel 2019 <1MW	320,0
Future trends	250,0
Split Cell Pannel 2019 >1MW	305,0

As it can be inferred from the Table 1, and comparing that prices with the ones showed in Figure 10, the values have shrunk almost by half, so owing to the high correlation between the final costs and the costs of the panels, as the latter decrease so does the final cost of the solar PV installation.

Among the different kind of panels showed in the table above, looking at the actual installations, the most used are the polycrystalline ones, so the price used for the standard cost structure is $0.305\ €/Wp$, although that can be change in any moment.

On top of that price, it has to be added the cost of the mounting, that after some contacts with companies in charge of that issue it has been set to $0.028\ €/Wp$. Thus, in the final cost of PV panels, 8.5% will be due to the mounting while the 91.5% remaining will be due to the supply.

4.8.1.3. Supporting structure

The final component of the solar PV plant is the supporting structure. That structure will be responsible for the anchoring of the panels to the ground. Usually, the structure is made of metallic elements and it is fixed, although in some projects it could be interesting to install a tracking structure able to rotate following the sun path.

Despite the rise of tracking systems, currently in Spain the vast majority of solar PV systems have fixed axis structures, so for this project we are going to assume that the structure is fixed in terms of costs.

As we can see in the figure above, the supporting structure amounts to a 12.3% of the total costs of the project, so it is also an important part. In this case, the mounting is more complex so out of the total cost of the structure, 66.5% will be the supply while the 33.5% will be the mounting.

As a final result for the structure, the price for the supply of the structure will be $0.05\ €/Wp$, and the price of the mounting will be very similar to the panel's one, being finally set to $0.025\ €/Wp$.

4.8.2. Low voltage installations

After installing the solar plant, all the energy produced must be evacuated, so the next step is to develop a low voltage system that will lead all the energy to the LV/MV conditioning center (inverter, transformer and isolator). The low voltage installation costs have three main components which are the protection cabinets, the electric conduits and the civil works.

The protection cabinets are located at the output of the PV panels and are in charge of isolating the system in case of a fault upstream. Its cost has remained steady during the last years, so the values taken are those from past projects, in particular, the costs of the cabinets, electric switches and running tests amount to $0.04\ €/Wp$.

The electric conduits have also a steady price. These conduits must connect the panels with the LV/MV conditioning center, and their cost depends mostly on their section and length. Besides, in their price it is included the supporting installation composed by trays, plastic flanges, fuses and connectors. After some research, and doing the weighted average considering the most common lengths and sections of the wires, the cost of the conduits is set at $0.042\ €/Wp$.

Finally, the cabinets and the conduits must be installed, so it is required the addition to that costs of the civil works. That works comprise the installation and the trenches needed for the conduits and amount to $0.0088\ €/Wp$.

In the end, the cost of low voltage installation would be $0.0908\ €/Wp$, that represents a 14.8% of the total costs.

4.8.3. LV/MV conditioning

The LV/MV conditioning center is the place where the energy produced by the plant is transformed in order to be transferred to the grid. First of all, the energy produced in direct current (DC) must be transformed into alternating current (AC), and that is the mission of the inverter. Once the DC flow is converted to AC, the low voltage must be elevated to the same voltage of the MV grid, for that purpose it is crucial to have a transformer installed. Finally, it is also really important to install a sectioning center able to disconnect the solar PV plant from the grid in case some fault happens.

The prices of all these three components have not changed in the last years, the prices taken may be those from past projects.

First of all, the inverter. It can be central, which means just one inverter collecting the energy from all the panels, or string inverter, which requires the reorganization of the panels in strings (groups of panels) and each inverter collects the energy of its string. In the second case we need a higher number of inverters, however these are smaller and cheaper. The conclusion is that either way, the price per watt installed is similar, so in order to develop a standard structure we are going to set a single price. After researching some projects, the price set is $0.032\ €/Wp$.

The transformers price is stable, so the prices taken are extracted from past projects. In a similar way to inverters, there is a choice to be made between a big transformer collecting all the outputs of the inverters or several transformers in the case of the string distribution. The price per watt would be similar, however, the cost of all the MV wires in the second case would increase, so the assumption made is that the most economic price is the one selected, so the chosen transformer will be the central one. Its reference price will be $0.016\ €/Wp$.

The case of the sectioning center is analogous to the one described in the transformer. One of them must be installed, and it will include the protection and measure cabinets. The price set will be $0.012\ €/Wp$.

Apart from that cost, the controller costs and the civil works and tests musts be included. Hence, the final cost for the LV/MV conditioning center will be $0.062\frac{€}{Wp}$, that represent a 10% of the total costs of the project.

4.8.4. Medium voltage installations

The MV installations are those connecting the LV/MV conditioning part (output of the sectioning center) with the grid. The costs of these installations are usually low because the length of these lines is normally really small (depends on the distance between the solar plant and the closest element of the network).

The main components are the grounding system, the wires and the connectors. The cost of that components is $0.0083\ €/Wp$, and on top of that it has to be added the cost of the mounting and the civil works, being the final cost $0.0118\ €/Wp$. This cost represents a 2% of the total costs.

4.8.5. High voltage installations

The high voltage installations are necessary just in those cases where the solar PV plant is connected directly to the HV grid (very rare), so these costs will be introduced as a very low proportion of the total costs.

The structure of that costs is analogous to the one mentioned before in the MV voltage installations, being the final set costs $0.0038\ €/Wp$, that represents 0.6% of the total costs.

4.8.6. Ancillary installations

When talking about ancillary services, the document is refereeing to all the systems that are not properly part of the solar PV plant, but must be done for the better functioning of the plant. They represent a 2.8% of the total costs of the installation, and are composed by the grounding, the lightning system, the security system and the civil works.

The grounding system is a fundamental part of the installation because it helps to reduce the faults as well as to increase the protection of the people working there. The grounding costs are basically the metallic structure and the connections between this, and the rest of elements grounded. The costs of the grounding amount to $0.0143\ €/Wp$.

The lightning system is not crucial for the well-functioning of the plant but is very useful for the people working there. The costs are really low compared with the total costs and are set in $0.00056\ €/Wp$.

The security system is an extra but is really helpful for big installations. The cost of the security system, considering cameras and the communication center, is $0.0017\ €/Wp$.

In the end, the cost of the ancillary installations, taking into account the mounting and civil works is $0.017\ €/Wp$.

4.8.7. Cost summary

In the end, the total costs of the solar PV installation are the following:

Table 2. Summary of costs' breakdown.

		€/Wp
SOLAR PLANT	69,8%	0,4282
GROUND CONDITIONING	3,2%	0,0194
PV PANNELS	54,4%	0,3334
STRUCTURE	12,3%	0,0754
LOW VOLTAGE INSTALLATIONS	14,8%	0,0905
LV/MV CONDITIONING	10,1%	0,0617
INVERTER	5,2%	0,0316
TRANSFORMER	2,6%	0,0161
SECTIONING & CPM	2,0%	0,0120
CONTROLLER	0,2%	0,0011
CIVIL WORKS AND TEST	0,1%	0,0008
MV LINE	1,9%	0,0118
HV LINE	0,6%	0,0038
ANCILLARY INSTALLATIONS	2,8%	0,0171
TOTAL	100,0%	0,6131

As a final result, the cost of the solar PV installation is $0.613\ €/Wp$.

4.9.PRL and Project Management

Apart from all the costs mentioned, in some cases, it is really interesting to have an external party doing the project management. This is especially interesting for big projects which want to reduce the risk of default and can afford paying it. The cost of the project management is usually around 100000€, so it is going to be added in considerably big projects (more than 5 MW), for lower capacities, that costs would be enormous compared with the investment required, then it would not be worthy.

Besides, the PRL, which stands for Labor Risks Prevention, is an independent study that must be done compulsory. The costs of the PRL includes the study and all the measures taken to fulfill all the requirements. Its costs are approximately $0.002\ €/Wp$.

4.10. Studies

In this part, the main points needed to develop a solar PV project are listed. Due to the huge business this is, there is not public information covering this point, and each company has the know-how that has developed after a lot of studies and the development of other projects and cannot be shared with others. This does not mean that the information is private, but it is very spread among a lot of different regulations and papers, so it is very hard to gather. That is why this part shows a very schematic checklist with the main points that must be approved before starting with the construction.

Furthermore, in order to keep on going with the project, all the following studies must be approved:

1. <u>Environmental Study.</u> This study must be done in order to assess if the project is harming the environment at some point. When environment is mentioned, the document refers to any protected species of animals or plants and any ecosystem surrounding them. The project will move forward as long as this study approves it. Its cost rounds 5000 € per project.

2. <u>Cultural Heritage Study.</u> This study is done in order to assess that the location of the project is not harming any cultural asset such as an archeological site. The project will move forward as long as this study approves it. Its cost rounds 2000 € per project.

3. <u>Urban Planning Study.</u> This study is made in order to know if the actual site of the project is prepared for the construction of a solar PV plant. It could happen the case where the floor is planned to be used for buildings so the project would be cancelled. Its cost rounds 500 € per project.

4. <u>Assets and Patrimony Study.</u> This study is made to verify that the project is not affecting any public asset or patrimony such as roads. This study has to be signed by the ministry. Its cost rounds 500 € per project.

5. Hydrological study. This study is made to know if the project location may be damaging any hydrological resource such as an aquifer or a creek. Its cost rounds 1000 € per project.

4.11. Costs of Operation & Maintenance

Finally, all the solar PV projects have a yearly cost because of the operation and maintenance (O&M).

The operation costs are mainly due to the necessity of a market agent responsible of the sale of the electricity produced in the market.

In the other hand, the maintenance costs are caused mostly by the regular cleaning required by the panels in order to keep their efficiency rates. Besides, that costs also include any repair needed in the solar PV installation.

In this project, these costs will be included directly in the economic study as an annual percentage of 8% over the revenues and introduced in the income statement as a fixed cost (Better explanation in 5.2.3).

4.12. Final Cost Structure

If we take the costs obtained in 4 and add them up, we obtain the final cost structure of a standard project:

Table 3. Final Cost Structure.

TOTAL INSTALATION COSTS	4,3%	95,88%	12.261.950,34 €
ENGINEERING		2,88%	367.858,51 €
REGIONAL GOVERNMENT FEES		0,08%	10.000,00 €
PUBLIC INFORMATION		0,00%	500,00 €
PRL		0,31%	40.000,00 €
PROJECT MANAGEMENT		0,78%	100.000,00 €
STUDIES		0,07%	9.000,00 €
TOTAL COSTS		639.465,44 €	12.789.308,85 €

We started this project with the premise that the costs of a solar PV project must be around $0.69\ €/Wp$, and the value obtained is $0.639\ €/Wp$, so we can conclude that the cost structure is valid. Furthermore, this value is not steady. Due to the lumpiness of some cost elements, the higher the installed capacity, the lower its ratio per watt, so when we increase the installed capacity, the unitary cost per watt will be reduced. That explanation is illustrated in the following figure.

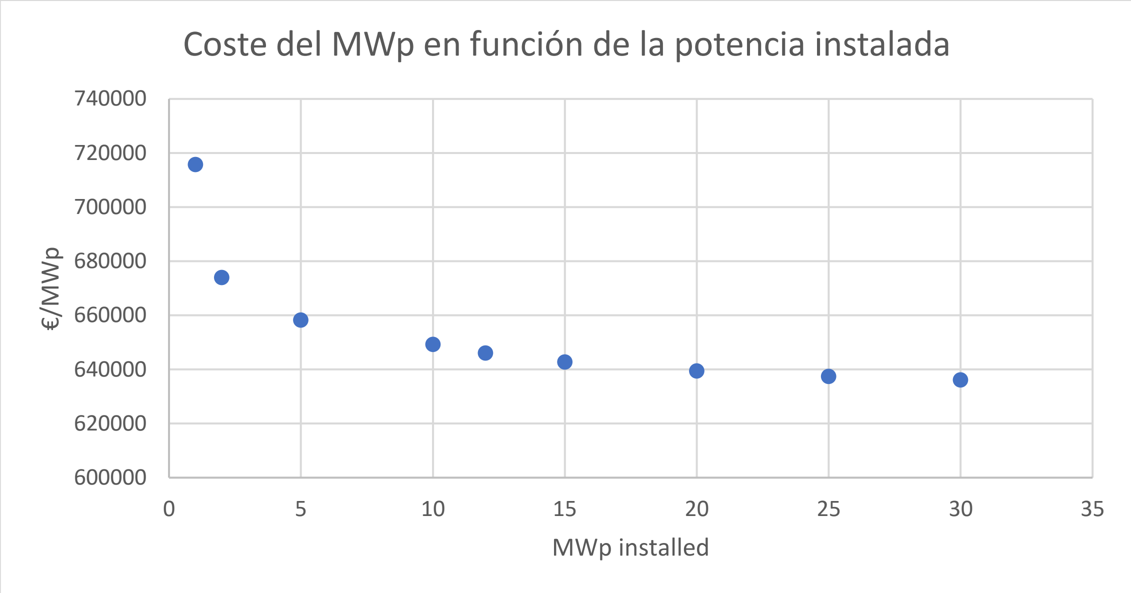


Figure 11. Evolution of the €/MW ratio as a function of the installed capacity.

5. Economic Study

In this part, a simple excel model will be developed in order to calculate the profitability of those projects.

The annual production will be an input extracted form a software able to calculate the solar irradiation and the equivalent energy production depending on the geographical situation, and it will be given in term of hours of production. The income in the model will be the sale of electricity that will be calculated at a fixed price (average price during the year). The market price will be extracted from OMIE's repositories. Thus, the model will return the net present value (NPV), internal rate of return (IRR) and the payback of the project. Also, the model will compare the profitability with and without financing.

5.1. Initial Investment

This is the initial amount of money that the owners of the project must disburse in order to start with it. The value of that investment is the cost of the project that has been elaborately explained in the epigraph 4. It will depend on the size of the project and we will obtain it directly from the cost model developed for this project.

The costs of building the solar photovoltaic plant will depend on several factors but they will approximately be:

$$Cost_{construction} = 613100 \frac{€}{MWp}$$

To that construction cost we will have to add, as explained in the epigraph 4, the cost of the project management, PRL, engineering costs, the costs of all the studies mentioned in 4.1 and other administrative costs, all of them amounting for 4.3% of the investment (see Table 3).

5.2. Income Statement

The key point of the economic analysis is the development of an income statement.

Its main components are:

Revenues
(COGS)
(Fixed Costs)
EBITDA

(Depreciation)
EBIT

(Interests)
EBT

(Taxes)
Net Income

Figure 12. Structure of an income statement.

5.2.1. Revenues

The revenues will be calculated as the product of the annual production (MWh) and the average price of electricity (€/MWh) calculated with OMIP’s repository data. The annual production will be calculated as the product of the installed capacity that will be an input of the model and the hours produced that will be also an input and will depend on the specific location of the project.

We will assume that the hours of production are on average the same for all the years of the lifespan of the project, while the price will increase a 0.5% each year.

This is a positive value in the net income at showed in Figure 12.

5.2.2. *Costs of Goods Sold*

These costs are related with the expenditure made in order to sell the product. In the case of renewable energy, that does not have fuel costs, these costs could be assumed to be just the part corresponding to the rent of the land. As it was mentioned above, in case that the land is owned by the project owner, these costs would be null.

In the case where we have to rent the land, the costs will the ones explained in epigraph 4.1.

As shown in Figure 12, these costs are subtracting in the income statement.

5.2.3. *Fixed Costs*

The fixed costs of this project are stablished as the operation and maintenance costs, that amount for an 8% of the revenues of every year. This value has been obtained after the study of several projects.

As shown in Figure 12, these costs are subtracting in the income statement.

If we subtract to the revenues of every year the COGS and the Fixed Costs, we obtain the EBITDA, that stands for Earnings Before Interests, Taxes, Depreciation and Amortization, and represents the gross profit of the project if we do not take into account the financing activity and the asset depreciation.

5.2.4. *Depreciation*

For calculating the depreciation, we are going to assume that the useful life of the project is of 20 years, and at that point the salvage value is a 90% of the initial one. These values are extracted after analyzing other solar PV projects and the datasheets of the manufacturers of PV modules. Then, every year we will depreciate a twentieth of the 10% of the value of the project.

All that assumptions are corroborated with the chapter 8 of the RD 1777/2004. [26]

After subtracting to the EBITDA the depreciation and amortization, we obtain the EBIT (Earnings Before Interests and Taxes), and represents the gross profit of the project if the financing activity and the asset depreciation are not taken into account.

5.2.5. *Interests*

The interests would be taken into account when there is a part of the project financed. The method used has been French amortization, which uses a constant principal for all the years. That principal is composed by the interests and the amortization of that principal. The interests will be lower each year because they will be calculated over the pending capital, however, the amortization of the principal will be higher in order to compensate the interests' decrease.

The cost of the debt will depend on the size of the project and the percentage financed, but it will be oscillating in a range between 1.5 and 4.5%.

5.2.6. *Taxes*

The taxes used for the economic analysis are those that the generating company has to pay because of the energy production. So, the value of that taxes will be 7% as it was established in the Law 15/2012 (3.18).

After subtracting to the EBIT, the taxes and interests, we will obtain the Net Income from Operating Activities (NOPAT).

5.3. Cash Flows

In order to assess the profitability of the project, we need to calculate the cash flows. In particular, we are going to calculate the Free Cash Flow (FCD) and the Cash Flow to the Bank.

5.3.1. Free Cash Flow

In order to calculate the Free Cash Flow, we use the next formula:

$$FCF_X = OCF_X - \Delta NWC_X - NCS_X$$

Where OCF is the Operating Cash Flow and represents the money obtained yearly thanks to the operating activities of the company.:

$$OCF_X = EBIT_X + Depreciation_X$$

The ΔNWC_X is the change in Net Working Capital between two consecutive years, but for our project and in most renewable projects, it is considered null.

The NCS stands for Net Capital Spending, represents the investments (or divestments) made each year, that in our case will be positive in year zero.

The FCF Will be obtained after doing that process for all the years of the lifespan of the project.

5.3.2. Cash Flow to the Bank

This value is different to zero when there is some part of the project financed. The cash flow that the bank receives is positive during all the years of the lifespan of the project with a value equal to the principal explained in 5.2.5, nevertheless, in the year zero, the bank has a negative cash flow with the value of the initial investment multiplied by the percentage that has been financed.

5.3.3. Cash Flow to the Shareholders

Once the Cash Flow to the bank has been calculated, if we subtract it to the FCF, we obtain the Cash flow to the shareholders, which will consist of a negative cash flow in the year zero with the value of the amount that has not been financed, and positive cashflows during the rest of the years of the project that amount for the difference between the OCF and the principal paid to the bank.

$$FC_{shareholders} = FCF - FC_{bank}$$

5.3.4. Net Present Value (NPV)

The Net Present Value is the indicator we will use to see if the projects are profitable, if the value obtained for the NPV is positive, the project will be considered as profitable. It is calculated by bringing all the future cashflows to the present in order to add them up. To do that, we have to use the proper rate of return that in this case is the WACC (Weighted Average Cost of Capital) as follows:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Being C_0 the value of the cash flow in year zero (normally the initial investment), and C_t the value of the cash flows in the year t. Besides, the rate of return is represented by the r.

5.3.4.1. Rate of return

The rate of return is used to bring future cash flows to the present. As it has been mentioned before, we are going to use the WACC as the rate of return for our project.

It is interesting to use the WACC because it introduces the capital structure of the project in the calculations. The WACC is calculated by considering the amount of debt (D) and equity (E) of our project and their respective costs (k_D and k_E). Besides, it also takes into account the value of the taxes for this sort of projects.

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

As we can see in the figure below, as the leverage increases, both the cost of debt and the cost of equity increase, and as a consequence so does the WACC. This happens because when we increase the leverage of the project, the bank has more stake of the project and as a result, more risk; in the other hand, when the leverage increases, the risk of a bank default increases so the shareholders assume more risk. Thus, when the leverage increases, the value of the WACC approaches the value of the debt, and by definition the cost of debt is always lower than the cost of equity [27].

Furthermore, as we have shown in 5.3.4, the WACC is in the denominator, so the higher the WACC, the lower the NPV. Hence, we have to find the equilibrium between relatively high leverages in order to reduce the amount of capital invested, but without reaching high values of risk.

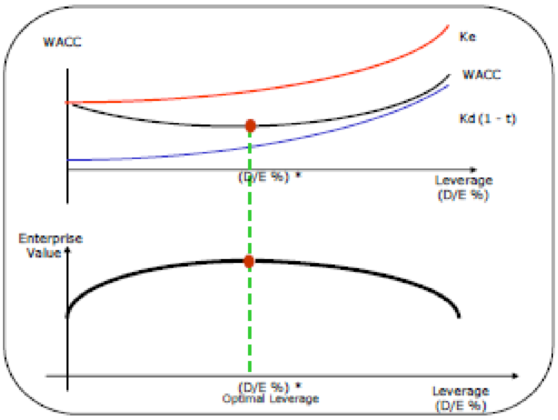


Figure 13. Evolution of the WACC with the leverage.

In addition, the values of the cost of debt and cost of equity have been obtained by reviewing past projects and studying the solar PV market. The cost of debt has been set previously in this project in a range between 1.5 and 4.5 % (5.2.5). Conversely, the cost of equity depends on the project, but after a research in the market the value obtained has been a 12%. With these values we can assure that the value of the WACC will be between them.

The value of the WACC is indicative, in real life the value used ought to be close to the actual rate of return of this kind of projects in order to obtain values of NPV more conservative. For solar PV projects, the value used oscillates between 7 and 10%.

5.3.5. Internal Rate of Return (IRR)

The Internal Rate of Return is the value that sets the limit from which the NPV begins to be negative, that is to say, the rate of return that makes the NPV zero. Values of the rate of return higher than the IRR will make the NPV negative, so the project unprofitable.

$$IRR = NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 = 0$$

The IRR can be used also to measure the profitability of the project, so it can be the substitute of the NPV.

5.3.6. Payback

The payback is another indicator to asses profitability of projects. Is shows the number of years that should be necessary to cover the initial investment with the cashflows but without considering the time value of money. This is a less accurate measure but is rather visual.

6. Case Example

In order to check the correct performance of the project, we are going to compare the obtained results in our model with actual cost ratios obtained in real projects.

6.1. Case A

The client is an industrial company in Almeria, and they are proposing a project of 20 MWp, and in the final project proposal they have estimated a cost of $690000\ €/MWp$. For that geographical location, we can obtain the equivalent hours of production with a specialized software such as PVGIS, and the resulting value is 1850 h. Besides, we are going to be as conservative as possible and we are going to assume that the energy is going to be sell at the prices set by OMIP for the future years.

Year	2019	2020	2021	2022	2023	2024	2025-2044
Price (EUR/MWh)	56,1	51,95	49,5	48,34	47,42	46,92	46,92

If we apply the model, the obtained results are the following:

Table 4. Solar PV plant installation cost breakdown.

		€/Wp	
SOLAR PLANT	69,8%	0,4282	8.563.945,35 €
GROUND CONDITIONING	3,2%	0,0194	388.945,35 €
PV PANNELS	54,4%	0,3334	6.667.500,00 €
STRUCTURE	12,3%	0,0754	1.507.500,00 €
LOW VOLTAGE INSTALLATIONS	14,8%	0,0905	1.810.440,79 €
LV/MV CONDITIONING	10,1%	0,0617	1.233.380,00 €
INVERTER	5,2%	0,0316	632.064,00 €
TRANSFORMER	2,6%	0,0161	322.152,00 €
SECTIONING & CPM	2,0%	0,0120	240.000,00 €
CONTROLLER	0,2%	0,0011	22.264,00 €
CIVIL WORKS AND TEST	0,1%	0,0008	16.900,00 €
MV LINE	1,9%	0,0118	235.730,40 €
HV LINE	0,6%	0,0038	76.000,00 €
ELECTRIC EQUIPMENT	0,4%	0,0027	53.523,28 €
MOUNTING	0,2%	0,0011	22.476,72 €
ANCILLARY INSTALLATIONS	2,8%	0,0171	342.453,80 €
TOTAL INSTALLATION COSTS	100,0%	0,6131	12.261.950,34 €

Table 5. Final investment costs breakdown with standard costs.

TOTAL INSTALATION COSTS	4,3%	95,88%	12.261.950,34 €
ENGINEERING		2,88%	367.858,51 €
REGIONAL GOVERNMENT FEES		0,08%	10.000,00 €
PUBLIC INFORMATION		0,00%	500,00 €
PRL		0,31%	40.000,00 €
PROJECT MANAGEMENT		0,78%	100.000,00 €
STUDIES		0,07%	9.000,00 €
TOTAL COSTS		639.465,44 €	12.789.308,85 €

As we can see, the final value obtained is $639465\ €/MWp$, that is lower than the $690000\ €/MWp$ that they calculated as final cost. However, reviewing the final project of the client, we have realized that the unitary cost per panel they have used is way bigger than the one used in the structure of the project, and that is because the project was closed at the beginning of the previous year and the price of panels have decreased a lot since then. In fact, if we put the cost of the panels they get for their project in our model, the value obtained is $685815\ €/MWp$, which is very similar to the theoretical price we should have obtained (Table 6).

Table 6. Final investment costs breakdown with actual costs.

TOTAL INSTALATION COSTS	4,2%	95,96%	13.161.950,34 €
ENGINEERING		2,88%	394.858,51 €
REGIONAL GOVERNMENT FEES		0,07%	10.000,00 €
PUBLIC INFORMATION		0,00%	500,00 €
PRL		0,29%	40.000,00 €
PROJECT MANAGEMENT		0,73%	100.000,00 €
STUDIES		0,07%	9.000,00 €
TOTAL COSTS		685.815,44 €	13.716.308,85 €

Thus, we can conclude that the cost structure is reliable and works as expected. Besides, it is very remarkable the huge differences obtained in the final investment costs depending on the price of panels, although that should not be a surprise, because as we saw in 4.8, the cost of panels is around 50% of the total costs of the project, so the final investment costs are very sensitive to the changes in solar PV panels.

Now, we are going to calculate the income statement and the cash flows of the project in order to see if it is profitable. As we said, the revenues are calculated with the equivalent hours of production and the costs of the futures established by OMIE. The COGS will be obtained with the cost of land set in 4.1, and the fixed costs will represent the O&M and will be calculated as an 8% of the revenues. Other issue is that when calculating the NCS, the value of the endorsement is subtracted in year 0 and recovered in year 1. With all that information we obtain the following:

	Year	0	1	2	3	4	5	6	7	8	9	10
	Growth		*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	
			56,1	51,95	49,5	48,34	47,42	46,92	46,92	46,92	46,92	46,92
1	Revenues		2.075.700,00	1.922.150,00	1.831.500,00	1.788.580,00	1.754.540,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00
	(COGS)		(40.000,00)	(40.040,00)	(40.080,04)	(40.120,12)	(40.160,24)	(40.200,40)	(40.240,60)	(40.280,84)	(40.321,12)	(40.361,44)
	(Fixed Costs)		(166.056,00)	(153.772,00)	(146.520,00)	(143.086,40)	(140.363,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)
	EBITDA		**1.869.644,00**	**1.728.338,00**	**1.644.899,96**	**1.605.373,48**	**1.574.016,56**	**1.556.956,40**	**1.556.916,20**	**1.556.875,96**	**1.556.835,68**	**1.556.795,36**
	(Depreciation)		(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)
	EBIT		**1.805.697,46**	**1.664.391,46**	**1.580.953,42**	**1.541.426,94**	**1.510.070,02**	**1.493.009,86**	**1.492.969,65**	**1.492.929,41**	**1.492.889,13**	**1.492.848,81**
	(Interests)		(306.943,41)	(280.168,58)	(252.590,51)	(224.185,09)	(194.927,51)	(164.792,21)	(133.752,84)	(101.782,30)	(68.852,63)	(34.935,08)
	EBT		**1.498.754,04**	**1.384.222,87**	**1.328.362,91**	**1.317.241,84**	**1.315.142,50**	**1.328.217,65**	**1.359.216,81**	**1.391.147,12**	**1.424.036,50**	**1.457.913,73**
	(Taxes)	1,00	(104.912,78)	(96.895,60)	(92.985,40)	(92.206,93)	(92.059,98)	(92.975,24)	(95.145,18)	(97.380,30)	(99.682,56)	(102.053,96)
	Net Income		**1.393.841,26**	**1.287.327,27**	**1.235.377,50**	**1.225.034,91**	**1.223.082,53**	**1.235.242,41**	**1.264.071,64**	**1.293.766,82**	**1.324.353,95**	**1.355.859,77**
	OCF		1.869.644,00	1.728.338,00	1.644.899,96	1.605.373,48	1.574.016,56	1.556.956,40	1.556.916,20	1.556.875,96	1.556.835,68	1.556.795,36
	Book Value	12.789.308,85	12.725.362,31	12.661.415,76	12.597.469,22	12.533.522,67	12.469.576,13	12.405.629,59	12.341.683,04	12.277.736,50	12.213.789,95	12.149.843,41
2	Initial Investment	(13.589.308,85)	800.000,00									
	Taxes for OCF		(126.398,82)	(116.507,40)	(110.666,74)	(107.899,89)	(105.704,90)	(104.510,69)	(104.507,88)	(104.505,06)	(104.502,24)	(104.499,42)
	- NCS-taxes	**(13.589.308,85)**	**673.601,18**	**(116.507,40)**	**(110.666,74)**	**(107.899,89)**	**(105.704,90)**	**(104.510,69)**	**(104.507,88)**	**(104.505,06)**	**(104.502,24)**	**(104.499,42)**
1	OCF		1.869.644,00	1.728.338,00	1.644.899,96	1.605.373,48	1.574.016,56	1.556.956,40	1.556.916,20	1.556.875,96	1.556.835,68	1.556.795,36
2	- NCS-taxes	(13.589.308,85)	673.601,18	(116.507,40)	(110.666,74)	(107.899,89)	(105.704,90)	(104.510,69)	(104.507,88)	(104.505,06)	(104.502,24)	(104.499,42)
3	- ΔNWC											
	Free Cash Flow	**(13.589.308,85)**	**2.543.245,18**	**1.611.830,60**	**1.534.233,22**	**1.497.473,59**	**1.468.311,66**	**1.452.445,71**	**1.452.408,32**	**1.452.370,90**	**1.452.333,44**	**1.452.295,94**
	CFFA	**(13.589.308,85)**	**2.543.245,18**	**1.611.830,60**	**1.534.233,22**	**1.497.473,59**	**1.468.311,66**	**1.452.445,71**	**1.452.408,32**	**1.452.370,90**	**1.452.333,44**	**1.452.295,94**
	Capital Cash Flow	**(13.589.309,85)**	**2.564.731,22**	**1.631.442,40**	**1.551.914,56**	**1.513.166,55**	**1.481.956,58**	**1.463.981,16**	**1.461.771,02**	**1.459.495,66**	**1.457.153,12**	**1.454.741,40**

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0,1%	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*
46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92
1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00	1.736.040,00
(40.401,80)	(40.442,21)	(40.482,65)	(40.523,13)	(40.563,65)	(40.604,22)	(40.644,82)	(40.685,47)	(40.726,15)	(40.766,88)	(40.807,65)	(40.848,45)	(40.889,30)	(40.930,19)	(40.971,12)
(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)	(138.883,20)
1.556.755,00	**1.556.714,59**	**1.556.674,15**	**1.556.633,67**	**1.556.593,15**	**1.556.552,58**	**1.556.511,98**	**1.556.471,33**	**1.556.430,65**	**1.556.389,92**	**1.556.349,15**	**1.556.308,35**	**1.556.267,50**	**1.556.226,61**	**1.556.185,68**
(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)	(63.946,54)					
1.492.808,45	**1.492.768,05**	**1.492.727,61**	**1.492.687,12**	**1.492.646,60**	**1.492.606,04**	**1.492.565,43**	**1.492.524,79**	**1.492.484,10**	**1.492.443,38**	**1.556.349,15**	**1.556.308,35**	**1.556.267,50**	**1.556.226,61**	**1.556.185,68**
1.492.808,45	**1.492.768,05**	**1.492.727,61**	**1.492.687,12**	**1.492.646,60**	**1.492.606,04**	**1.492.565,43**	**1.492.524,79**	**1.492.484,10**	**1.492.443,38**	**1.556.349,15**	**1.556.308,35**	**1.556.267,50**	**1.556.226,61**	**1.556.185,68**
(104.496,59)	(104.493,76)	(104.490,93)	(104.488,10)	(104.485,26)	(104.482,42)	(104.479,58)	(104.476,74)	(104.473,89)	(104.471,04)	(108.944,44)	(108.941,58)	(108.938,72)	(108.935,86)	(108.933,00)
1.388.311,86	**1.388.274,29**	**1.388.236,67**	**1.388.199,03**	**1.388.161,34**	**1.388.123,61**	**1.388.085,85**	**1.388.048,05**	**1.388.010,22**	**1.387.972,34**	**1.447.404,71**	**1.447.366,76**	**1.447.328,77**	**1.447.290,75**	**1.447.252,68**
1.556.755,00	1.556.714,59	1.556.674,15	1.556.633,67	1.556.593,15	1.556.552,58	1.556.511,98	1.556.471,33	1.556.430,65	1.556.389,92	1.556.349,15	1.556.308,35	1.556.267,50	1.556.226,61	1.556.185,68
12.085.896,86	12.021.950,32	11.958.003,78	11.894.057,23	11.830.110,69	11.766.164,14	11.702.217,60	11.638.271,05	11.574.324,51	11.510.377,97	11.510.377,97	11.510.377,97	11.510.377,97	11.510.377,97	11.510.377,97
(104.496,59)	(104.493,76)	(104.490,93)	(104.488,10)	(104.485,26)	(104.482,42)	(104.479,58)	(104.476,74)	(104.473,89)	(104.471,04)	(108.944,44)	(108.941,58)	(108.938,72)	(108.935,86)	(108.933,00)
(104.496,59)	**(104.493,76)**	**(104.490,93)**	**(104.488,10)**	**(104.485,26)**	**(104.482,42)**	**(104.479,58)**	**(104.476,74)**	**(104.473,89)**	**(104.471,04)**	**(108.944,44)**	**(108.941,58)**	**(108.938,72)**	**(108.935,86)**	**(108.933,00)**
1.556.755,00	1.556.714,59	1.556.674,15	1.556.633,67	1.556.593,15	1.556.552,58	1.556.511,98	1.556.471,33	1.556.430,65	1.556.389,92	1.556.349,15	1.556.308,35	1.556.267,50	1.556.226,61	1.556.185,68
(104.496,59)	(104.493,76)	(104.490,93)	(104.488,10)	(104.485,26)	(104.482,42)	(104.479,58)	(104.476,74)	(104.473,89)	(104.471,04)	(108.944,44)	(108.941,58)	(108.938,72)	(108.935,86)	(108.933,00)
1.452.258,40	**1.452.220,83**	**1.452.183,22**	**1.452.145,57**	**1.452.107,88**	**1.452.070,16**	**1.452.032,40**	**1.451.994,60**	**1.451.956,76**	**1.451.918,88**	**1.447.404,71**	**1.447.366,76**	**1.447.328,77**	**1.447.290,75**	**1.447.252,68**
1.452.258,40	**1.452.220,83**	**1.452.183,22**	**1.452.145,57**	**1.452.107,88**	**1.452.070,16**	**1.452.032,40**	**1.451.994,60**	**1.451.956,76**	**1.451.918,88**	**1.447.404,71**	**1.447.366,76**	**1.447.328,77**	**1.447.290,75**	**1.447.252,68**
1.452.258,40	**1.452.220,83**	**1.452.183,22**	**1.452.145,57**	**1.452.107,88**	**1.452.070,16**	**1.452.032,40**	**1.451.994,60**	**1.451.956,76**	**1.451.918,88**	**1.447.404,71**	**1.447.366,76**	**1.447.328,77**	**1.447.290,75**	**1.447.252,68**

If there is not financing in the project, the results are the following:

Table 7. Profitability indexes without financing.

Present Value	17.447.377,71 €	
Rate of return	8%	WACC
Net Present Value	3.858.068,86 €	
IRR	11%	
Payback	8,39728526	años

However, with an 80% financed, the obtained results are:

Table 8. Profitability indexes with 80% financed.

Present Value	9.307.599,18 €	
Rate of return	8%	Ke
Net Present Value	5.949.736,41 €	
IRR	20%	
Payback	7,326709306	años

As it was expected, with financing, the ratios are better because the amount to recover is smaller. Furthermore, when the financed period concludes, all the cash flows go to the shareholders, so the IRR is bigger. In any case, due to the price of the energy and the current efficiency of the panels, the cash flows are rather high compared to the investment cost, so the project is profitable and very liquid.

To sum up, the model has returned a value in $€/MWp$ very similar to the one we were expecting, and also it is able to asses quick profitability. It is also remarkable that the effect of the price of PV panels on the costs is very high. Besides, we have discovered that as far as the costs of the project are reasonable, most solar PV projects will be profitable, because the current prices of electricity give a really high return.

6.2. Case B

Now the client is an industrial company in Ciudad Real, and they are proposing a project of 3.5 MWp, and in the final project proposal they have estimated a cost of $597000\ €/MWp$. For that geographical location, we can obtain the equivalent hours of production with a specialized software such as PVGIS, and the resulting value is 1850 h. Besides, we are going to be as conservative as possible and we are going to assume that the energy is going to be sell at the prices set by OMIP for the future years (Same as case A).

Year	2019	2020	2021	2022	2023	2024	2025-2044
Price (EUR/MWh)	56,1	51,95	49,5	48,34	47,42	46,92	46,92

If we apply the model, the obtained results are the following:

Table 9. Solar PV plant installation cost breakdown.

		€/Wp	
SOLAR PLANT	66,1%	0,3796	1.328.476,11 €
GROUND CONDITIONING	3,9%	0,0223	77.976,11 €
PV PANNELS	48,8%	0,2801	980.500,00 €
STRUCTURE	13,4%	0,0771	270.000,00 €
LOW VOLTAGE INSTALLATIONS	15,8%	0,0908	317.817,14 €
LV/MV CONDITIONING	10,8%	0,0620	217.079,00 €
INVERTER	5,5%	0,0316	110.611,20 €
TRANSFORMER	2,8%	0,0161	56.376,60 €
SECTIONING & CPM	2,1%	0,0120	42.000,00 €
CONTROLLER	0,2%	0,0011	3.896,20 €
CIVIL WORKS AND TEST	0,2%	0,0012	4.195,00 €
MV LINE	3,7%	0,0210	73.375,35 €
HV LINE	0,7%	0,0038	13.300,00 €
ELECTRIC EQUIPMENT	0,3%	0,0015	5.266,04 €
MOUNTING	0,4%	0,0023	8.033,96 €
ANCILLARY INSTALLATIONS	3,0%	0,0171	59.929,42 €
TOTAL INSTALLATION COSTS	100,0%	0,5743	2.009.977,01 €

Table 10. Final investment costs breakdown.

TOTAL INSTALATION COSTS	4,3%	95,86%	2.009.977,01 €
ENGINEERING		2,88%	60.299,31 €
REGIONAL GOVERNMENT FEES		0,48%	10.000,00 €
PUBLIC INFORMATION		0,02%	500,00 €
PRL		0,33%	7.000,00 €
PROJECT MANAGEMENT		0,00%	- €
STUDIES		0,43%	9.000,00 €
TOTAL COSTS		599.078,95 €	2.096.776,32 €

As we can see, the final value obtained is $599079\ €/MWp$, that is pretty similar to the value of $597000\ €/MWp$ that they calculated as final cost. It is important to say that the low ratio is because the price used for the panels is really low, $0.25\ €/Wp$ that are the costs of the newest ones for this year.

Thus, we can conclude that the cost structure is reliable and works as expected also for this case. Besides, it is remarkable that for this size that is considerably smaller that in Case A, the model works also perfectly.

Now, we are going to calculate the income statement and the cash flows of the project in order to see if it is profitable. As we said, the revenues are calculated with the equivalent hours of production and the costs of the futures established by OMIP. The COGS will be obtained with the cost of land set in 4.1, and the fixed costs will represent the O&M and will be calculated as an 8% of the revenues. Other issues are that when calculating the NCS, the value of the endorsement is subtracted in year 0 and recovered in year 1. With all that information we obtain the following:

	Year	0	1	2	3	4	5	6	7	8	9	10
	Growth			*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*
	Price (EUR/MWh)		56,1	51,95	49,5	48,34	47,42	46,92	46,92	46,92	46,92	46,92
1	Revenues		363.247,50	336.376,25	320.512,50	313.001,50	307.044,50	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00
	(COGS)		(7.000,00)	(7.007,00)	(7.014,01)	(7.021,02)	(7.028,04)	(7.035,07)	(7.042,11)	(7.049,15)	(7.056,20)	(7.063,25)
	(Fixed Costs)		(29.059,80)	(26.910,10)	(25.641,00)	(25.040,12)	(24.563,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)
	EBITDA		**327.187,70**	**302.459,15**	**287.857,49**	**280.940,36**	**275.452,90**	**272.467,37**	**272.460,33**	**272.453,29**	**272.446,24**	**272.439,19**
	(Depreciation)		(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)
	EBIT		**316.703,82**	**291.975,27**	**277.373,61**	**270.456,48**	**264.969,02**	**261.983,49**	**261.976,45**	**261.969,41**	**261.962,36**	**261.955,31**
	(Interests)		(50.322,63)	(45.932,96)	(41.411,60)	(36.754,60)	(31.957,90)	(27.017,28)	(21.928,46)	(16.686,96)	(11.288,22)	(5.727,52)
	EBT		**266.381,19**	**246.042,31**	**235.962,01**	**233.701,87**	**233.011,12**	**234.966,20**	**240.048,00**	**245.282,45**	**250.674,14**	**256.227,78**
	(Taxes)	1,00	(18.646,68)	(17.222,96)	(16.517,34)	(16.359,13)	(16.310,78)	(16.447,63)	(16.803,36)	(17.169,77)	(17.547,19)	(17.935,94)
	Net Income		**247.734,50**	**228.819,34**	**219.444,67**	**217.342,74**	**216.700,34**	**218.518,57**	**223.244,64**	**228.112,68**	**233.126,95**	**238.291,84**
	OCF		327.187,70	302.459,15	287.857,49	280.940,36	275.452,90	272.467,37	272.460,33	272.453,29	272.446,24	272.439,19
	Book Value	2.096.776,32	2.086.292,44	2.075.808,56	2.065.324,68	2.054.840,80	2.044.356,92	2.033.873,03	2.023.389,15	2.012.905,27	2.002.421,39	1.991.937,51
2	Initial Investment	(2.236.776,32)	140.000,00									
	Taxes for OCF		(22.169,27)	(20.438,27)	(19.416,15)	(18.931,95)	(18.547,83)	(18.338,84)	(18.338,35)	(18.337,86)	(18.337,37)	(18.336,87)
	- NCS-taxes	**(2.236.776,32)**	**117.830,73**	**(20.438,27)**	**(19.416,15)**	**(18.931,95)**	**(18.547,83)**	**(18.338,84)**	**(18.338,35)**	**(18.337,86)**	**(18.337,37)**	**(18.336,87)**
1	OCF		327.187,70	302.459,15	287.857,49	280.940,36	275.452,90	272.467,37	272.460,33	272.453,29	272.446,24	272.439,19
2	- NCS-taxes	(2.236.776,32)	117.830,73	(20.438,27)	(19.416,15)	(18.931,95)	(18.547,83)	(18.338,84)	(18.338,35)	(18.337,86)	(18.337,37)	(18.336,87)
3	- ΔNWC											
	Free Cash Flow	**(2.236.776,32)**	**445.018,43**	**282.020,88**	**268.441,34**	**262.008,41**	**256.905,07**	**254.128,53**	**254.121,98**	**254.115,43**	**254.108,88**	**254.102,32**
	CFFA	**(2.236.776,32)**	**445.018,43**	**282.020,88**	**268.441,34**	**262.008,41**	**256.905,07**	**254.128,53**	**254.121,98**	**254.115,43**	**254.108,88**	**254.102,32**
	Capital Cash Flow	**(2.236.777,32)**	**448.541,02**	**285.236,19**	**271.340,15**	**264.581,23**	**259.142,12**	**256.019,74**	**255.656,98**	**255.283,52**	**254.899,05**	**254.503,24**
	Cash Flow from Bank	**1.677.421,06**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**	**(196.644,92)**
			(146.322,29)	(150.711,96)	(155.233,32)	(159.890,32)	(164.687,03)	(169.627,64)	(174.716,46)	(179.957,96)	(185.356,70)	(190.917,40)
	Net cash Flow for sh.	**(559.356,26)**	**251.896,10**	**88.591,27**	**74.695,23**	**67.936,31**	**62.497,20**	**59.374,82**	**59.012,05**	**58.638,60**	**58.254,13**	**57.858,32**

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0,1%	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*	*0,1%*
46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92	46,92
303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00	303.807,00
(7.070,32)	(7.077,39)	(7.084,46)	(7.091,55)	(7.098,64)	(7.105,74)	(7.112,84)	(7.119,96)	(7.127,08)	(7.134,20)	(7.141,34)	(7.148,48)	(7.155,63)	(7.162,78)	(7.169,95)
(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)	(24.304,56)
272.432,12	**272.425,05**	**272.417,98**	**272.410,89**	**272.403,80**	**272.396,70**	**272.389,60**	**272.382,48**	**272.375,36**	**272.368,24**	**272.361,10**	**272.353,96**	**272.346,81**	**272.339,66**	**272.332,49**
(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)	(10.483,88)					
261.948,24	**261.941,17**	**261.934,09**	**261.927,01**	**261.919,92**	**261.912,82**	**261.905,71**	**261.898,60**	**261.891,48**	**261.884,35**	**272.361,10**	**272.353,96**	**272.346,81**	**272.339,66**	**272.332,49**
261.948,24	**261.941,17**	**261.934,09**	**261.927,01**	**261.919,92**	**261.912,82**	**261.905,71**	**261.898,60**	**261.891,48**	**261.884,35**	**272.361,10**	**272.353,96**	**272.346,81**	**272.339,66**	**272.332,49**
(18.336,38)	(18.335,88)	(18.335,39)	(18.334,89)	(18.334,39)	(18.333,90)	(18.333,40)	(18.332,90)	(18.332,40)	(18.331,90)	(19.065,28)	(19.064,78)	(19.064,28)	(19.063,78)	(19.063,27)
243.611,87	**243.605,29**	**243.598,71**	**243.592,12**	**243.585,52**	**243.578,92**	**243.572,31**	**243.565,70**	**243.559,08**	**243.552,45**	**253.295,82**	**253.289,18**	**253.282,54**	**253.275,88**	**253.269,22**
272.432,12	272.425,05	272.417,98	272.410,89	272.403,80	272.396,70	272.389,60	272.382,48	272.375,36	272.368,24	272.361,10	272.353,96	272.346,81	272.339,66	272.332,49
1.981.453,63	1.970.969,74	1.960.485,86	1.950.001,98	1.939.518,10	1.929.034,22	1.918.550,34	1.908.066,45	1.897.582,57	1.887.098,69	1.887.098,69	1.887.098,69	1.887.098,69	1.887.098,69	1.887.098,69
(18.336,38)	(18.335,88)	(18.335,39)	(18.334,89)	(18.334,39)	(18.333,90)	(18.333,40)	(18.332,90)	(18.332,40)	(18.331,90)	(19.065,28)	(19.064,78)	(19.064,28)	(19.063,78)	(19.063,27)
(18.336,38)	**(18.335,88)**	**(18.335,39)**	**(18.334,89)**	**(18.334,39)**	**(18.333,90)**	**(18.333,40)**	**(18.332,90)**	**(18.332,40)**	**(18.331,90)**	**(19.065,28)**	**(19.064,78)**	**(19.064,28)**	**(19.063,78)**	**(19.063,27)**
272.432,12	272.425,05	272.417,98	272.410,89	272.403,80	272.396,70	272.389,60	272.382,48	272.375,36	272.368,24	272.361,10	272.353,96	272.346,81	272.339,66	272.332,49
(18.336,38)	(18.335,88)	(18.335,39)	(18.334,89)	(18.334,39)	(18.333,90)	(18.333,40)	(18.332,90)	(18.332,40)	(18.331,90)	(19.065,28)	(19.064,78)	(19.064,28)	(19.063,78)	(19.063,27)
254.095,75	**254.089,17**	**254.082,59**	**254.076,00**	**254.069,41**	**254.062,80**	**254.056,20**	**254.049,58**	**254.042,96**	**254.036,33**	**253.295,82**	**253.289,18**	**253.282,54**	**253.275,88**	**253.269,22**
254.095,75	**254.089,17**	**254.082,59**	**254.076,00**	**254.069,41**	**254.062,80**	**254.056,20**	**254.049,58**	**254.042,96**	**254.036,33**	**253.295,82**	**253.289,18**	**253.282,54**	**253.275,88**	**253.269,22**
254.095,75	**254.089,17**	**254.082,59**	**254.076,00**	**254.069,41**	**254.062,80**	**254.056,20**	**254.049,58**	**254.042,96**	**254.036,33**	**253.295,82**	**253.289,18**	**253.282,54**	**253.275,88**	**253.269,22**
254.095,75	**254.089,17**	**254.082,59**	**254.076,00**	**254.069,41**	**254.062,80**	**254.056,20**	**254.049,58**	**254.042,96**	**254.036,33**	**253.295,82**	**253.289,18**	**253.282,54**	**253.275,88**	**253.269,22**

If there is not financing in the project, the results are the following:

Table 11. Profitability indexes without financing.

Present Value	3.052.786,74 €	
Rate of return	8%	WACC
Net Present Value	816.010,42 €	
IRR	12%	
Payback	7,84265912	años

However, with an 80% financed, the obtained results are:

Table 12. Profitability indexes with 80% financed.

Present Value	1.718.289,69 €	
Rate of return	8%	Ke
Net Present Value	1.158.933,43 €	
IRR	23%	
Payback	5,23141397	años

As it was expected, with financing, the ratios are better because the amount to recover is smaller. Furthermore, when the financed period concludes, all the cash flows go to the shareholders, so the IRR is bigger. In any case, due to the price of the energy and the current efficiency of the panels, the cash flows are rather high compared to the investment cost, so the project is profitable and very liquid. Also, it has to be said that the payback ratios can be affected by the payment of the endorsement, so they are not the best indicator of the profitability of the project.

6.3. Cost Analysis as a function of PV panels' cost

As we have seen in the previous examples, the most determinant costs are the ones of the PV panels, so it is interesting to analyze what happens if that costs change. So, taking as a reference the Case A, and running the model for different solar PV prices, the results obtained are:

Table 13. Evolution of NPV and investment cost as a function of PV panels' cost.

	PV panel cost (€/kWp)	Inv. Cost (€/MWp)	NPV (€)
Future trends	250,0	582815,4425	4987026,237
Monocrystaline Standard 2019	280,0	613715,4425	4371231,306
Split Cell Panel 2019 >1MW	305,0	639465,4425	3858068,863
Split Cell Panel 2019 <1MW	320,0	654915,4425	3550171,397
Monocrystaline Standard 2018	350,0	685815,4425	2934376,465

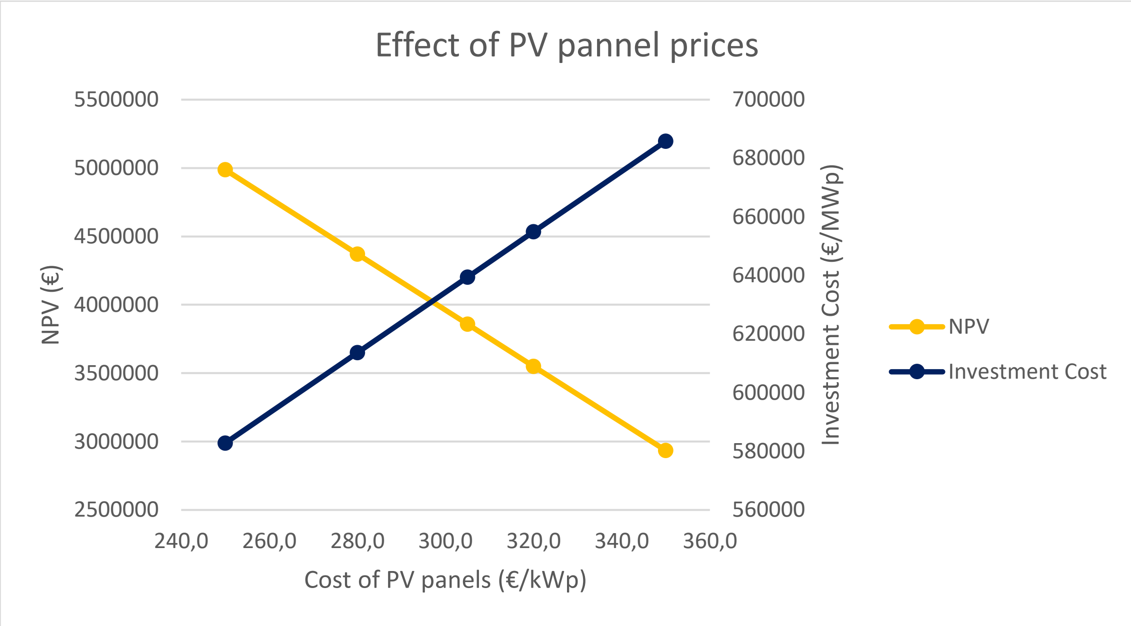


Figure 14. Evolution of NPV and investment cost as a function of PV panels' cost.

As it can be inferred from the figure, the relationship between the cost of the PV panels and both NPV and investment costs is linear, which means that an increase (decrease) in the cost of the PV panels would produce an increase (decrease) in the investment cost, and as a consequence the NPV of the project will suffer a reduction (gain).

If we focus on the numbers, a 20% decrease in solar PV costs would represent a 49% increase in the NPV and a 10.5% decrease in the investment cost. This makes sense because as it was mentioned above (4.8.1.2), the cost of PV panels represents a 49.8% in the total costs, so the increase in the total investment costs will be half of the increase in the cost of panels.

7. Conclusions

After the development of this project, these are the main conclusions drawn:

- The renewable energy sector is evolving continuously, and the latest technology developments are changing the game field. As a consequence, it has to be a regulation to control the introduction of that changes, and it has to be dynamic. However, that regulation must not be an obstacle for the new technologies, but it has to support them. A clear example of this is the release of the new RD 244/2019 that has changed the paradigm of self-consumption in our country.

- There is a lack of public information concerning this issue. It has been very hard to find verified information, because most engineering companies and solar PV promoters do not want to share their analyses in order to keep their market power. Thus, it was necessary the development of this project in order to know which the true prices of a solar PV project are.

- The model is especially useful for projects above 0.5 MW, because this is the order of magnitude of the projects under the scope of the company in charge of this thesis. The model could be applied for smaller projects, but these are usually simpler, and some components of the developed model do not apply to them. Nevertheless, for solar PV projects higher than 0.5 MW, the model has proven to be robust and to work in a very accurate way.

- Solar PV projects could not go ahead without any of its components, but after analyzing the model, it is evident that in terms of costs there are some that affect much more to the final numbers. This is specially the case of the cost of the solar PV panels. As it is showed in Figure 9, the supply and mounting of these amounts to a 54.4% of the total costs of the project, so a change in the prices of the panels could affect considerably the investment costs. Hence, in order to maximize the profitability of the project, we should try to reduce the investment costs as much as possible, and that should be done by means of a reduction in the cost of panels.

- Other components such as the LV installations or the LV/MV conditioning are also crucial in terms on costs, but their costs have been more less steady among the years, so it is more difficult to improve our investment costs by changing these values. In any case, we are assuming that the electric design of the LV and MV installations has been made properly and all the components are well dimensioned.

- The model is also able to assess the profitability of the projects with or without financing. As it was expected, the financing helps to reduce the risk of the project and also gets better values. Besides, we can assure that due to the current prices of electricity and the costs studied in this project, most solar PV projects return a positive profit for their owners. The future trends are a reduction in costs, which would be translated in higher profits. However, the high increase of this type of installations could be a problem because the capture price of this technology could be reduced because of the overcrowding of renewable energies in the wholesale markets during that hours of the day. In any case these problems are above the scope of this project.

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