UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER´S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master´s thesis

Estimation of maximum solar photovoltaic potential for self-consumption and its economic implications in Spain by 2030

Author: Ignacio Porto Olivares

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Madrid, July 2015

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ABSTRACT

COMILLAS PONTIFICAL UNIVERSITY
Official master´s degree in the electric power industry
PORTO OLIVARES, IGNACIO: Estimation of maximum solar photovoltaic potential for self-consumption and its economic implications in Spain by 2030
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In this master thesis, the futures of photovoltaic potential for self-consumption and economic consequences for the system in Spain have been estimated. The aim was to investigate the maximum potential of solar photovoltaic in Spain in the following years, specifically by 2030 considering that the energy produced by new installations will be self-consumed. The research was carried out taking into account that the regulation will support and incentivize self-consumption in the future, for that reason, the economic implications that self-consumption will have if the electricity tariff is not designed properly have been assessed.

Different scenarios subject to the solar radiation have been analyzed in order to estimate different situations of PV penetration levels. In addition, various sectors have been studied to identify the ones with the highest photovoltaic potential in the future. The photovoltaic geographical system (PVGIS) has been the tool used to calculate the photovoltaic potential of the capacity installed along the different regions.

The results obtained have identified the domestic sector as the one with the highest photovoltaic potential and the regions located in the south and east of the peninsula the ones that present the best balance between solar irradiance and feasibility to install a solar photovoltaic system. The scenarios proposed have demonstrated that the solar target regard capacity installed and energy produced can be met in the future. An analysis of the costs recovered though the access tariff has been carried out concluding that under the actual tariff and under the recently one proposed by the government the system will not be sustainable in the event of self-consumption penetration.

RESUMEN

UNIVERSIDAD PONTIFICIA COMILLAS
Máster universitario en el sector eléctrico
PORTO OLIVARES, IGNACIO: Estimación del potencial solar fotovoltaico para auto-consumo y sus implicaciones económicas en España en el año 2030
Julio 2015
Tema principal: tecnología solar fotovoltaica
Palabras clave: Generación distribuida, auto-consumo, paridad de red, potencial fotovoltaico.

En esta tesis, se ha estimado el futuro del potencial solar fotovoltaico para auto-consumo y las implicaciones económicas para el sistema eléctrico en España. El objetivo ha sido investigar el máximo potencial solar fotovoltaico en los próximos años, en particular en el año 2030 considerando que la energía producida por las nuevas instalaciones fotovoltaicas será auto-consumida. La investigación ha sido llevada a cabo bajo el supuesto de una regulación que apoye e incentiva el auto-consumo, por ello, se han valorado las implicaciones económicas que el auto-consumo tendrá en el futuro si la tarifa eléctrica no es diseñada apropiadamente.

Diferentes escenarios sujetos a la radiación solar han sido analizados con el objetivo de estimar varias situaciones en el los que los niveles de penetración fotovoltaica sean diferentes. Además, varios sectores han sido estudiados para identificar cuál de ellos presentarán los mayores niveles de potencial fotovoltaico en el futuro. El sistema de información geográfica fotovoltaica (PVGIS) ha calculado la energía producida en las diferentes regiones del país donde se instalaría la capacidad fotovoltaica.

Con los resultados obtenidos ha sido posible identificar el sector doméstico como aquel con el mayor potencial fotovoltaico y las comunidades situadas en el sur y este del país las que presentan mejor balance entre irradiación solar y posibilidad de instalar un sistema fotovoltaico. Los escenarios propuestos han demostrado que los objetivos establecidos para el futuro respecto a capacidad y energía fotovoltaica pueden ser cumplidos. Finalmente, se ha llevado a cabo un análisis exhaustivo de la tarifa de acceso mediante la cual se recuperan los costes regulados del sistema, concluyendo que ni con la tarifa actual ni con la propuesta recientemente por el gobierno, el sistema sería sostenible en el caso de una alta actividad de auto-consumo.

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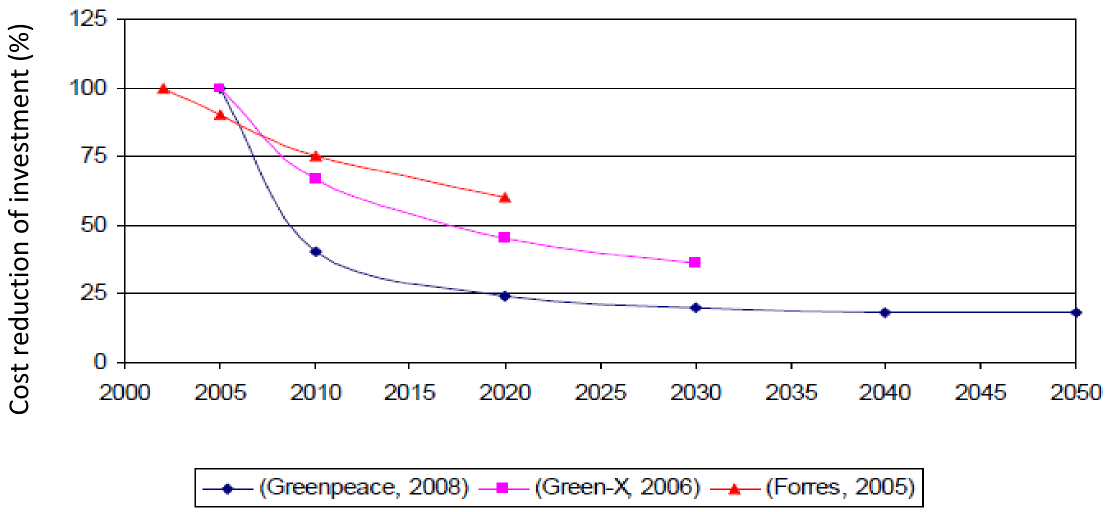
1. Introduction

In the last years there has been a high penetration of renewable sources all around the world. Renewable sources are becoming very relevant in the total energy production of most of the countries. Many European members have decided to invest in renewable sources in order to meet some targets as 20/20/20[1]. Yet, Renewable technologies were neither economically nor technologically mature to enter in the market by their own. In this line, some technologies policies to support RES have been set in order to attract investors.

Feed-in tariff, Feed-in premium and green certificates are the most common mechanisms applied. Few countries like Germany, USA and recently UK are a good example of how PV technology is penetrating especially at domestic levels thanks to support mechanisms. In the case of Spain, FIT and FIP have been applied since 2000 and the incentives were so attractive that Spain became the largest solar market for solar power installation in 2008. However, due to the financial difficulties experienced in the last years, in 2012 Spain was the first European country to absolutely suspend FIT and market premium incentives for new renewable generation. In addition, Spain has made retroactive cuts to FIT and FIP.

Besides the situation previously mentioned, Spain is one of the countries with the highest solar irradiance in Europe, it is for that reason that new solar capacity is expected to come in the following years. In addition, within the wide range of RES, photovoltaic technology is the one that has more room to continue evolving not only technically but also economically as the Figure 1 shows

Figure 1: Cost reduction of investment on PV (*source: Technology policies*)

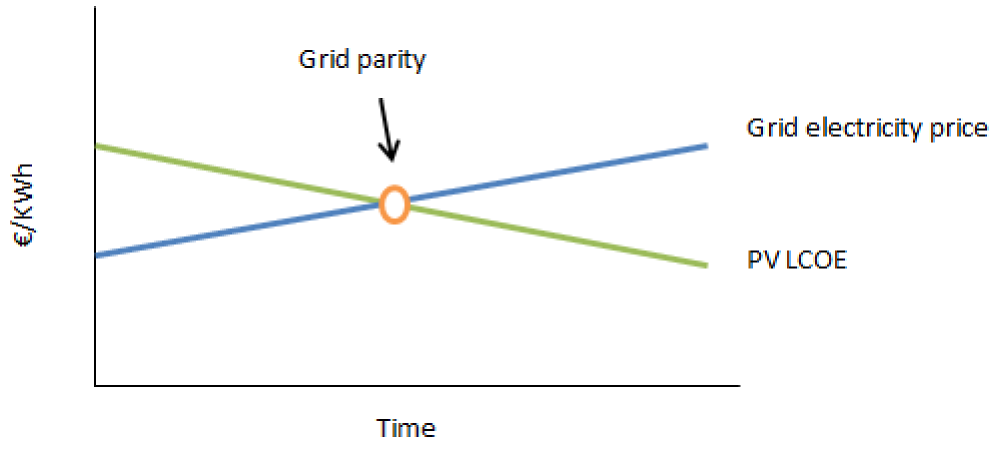


[1] By 2020 the European country must reduce in 20% the carbon emissions, 20% of the energy must be produced by renewable sources and 20% increase in energy efficiency

As it can be seen in the figure above, it is expected that photovoltaic investment cost decreases dramatically in the next years. In fact, it has already gone down in the previous years. This makes this technology the most promising with RES.

Another point to take into account is the “grid parity” which is a term that has arisen as a consequence of the decrease in RES costs. If we focus on photovoltaic technology, PV grid parity PV is defined as the moment in time when the cost of producing energy with a PV panel is equal or lower than the cost of buying the energy from the grid. The next figure shows the moment in which grid parity is reached.

Figure 2: Representation of grid parity (*source: own elaboration*)



This situation is very encouraging for the PV industry: The energy produced by small-scale PV systems is already profitable without supporting mechanism. This new paradigm will open the door to new business and new regulation.

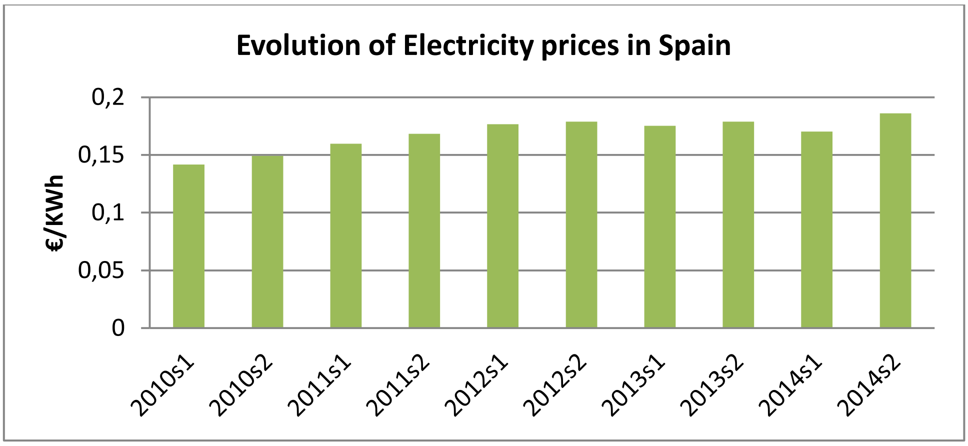
With the situation previously commented, the future of solar photovoltaic seems to be promising, especially in countries with high solar potential. Nevertheless, the regulation in place has to be designed very carefully in order to send the right economic signals to consumers and guarantee the sustainability of the system. Moreover, regulation should be coherent with the tariff or otherwise it may provoke overcapacity and problems to recover system investment.

1.1. Motivation

Starting from the point that grid parity respect photovoltaic technology has been reached in Spain, it is expected that the level of electricity self-consumption rise dramatically during the next years. In addition, Spain is one of the countries with the highest solar irradiance in Europe which makes this country a very profitable one for PV market.

Moreover, electricity prices have been going up during the previous years. In the last 5 years the price of the electricity has risen around 30% as the Figure 3 shows. This is another reason why consumers will decide to produce their own energy instead of buying it in the market.

Figure 3: Evolution of electricity prices in Spain during the last 4 years (*Source: own elaboration via Eurelectric*)



According to this situation and bearing in mind the importance that grid parity will have for the PV industry, the thesis pretend to estimate how this situation is going to impact the Spanish electricity system. Some regulatory measures have been recently approved that may decelerate coming installations.

Nevertheless, these measures are expected to change in the following years as they have been very controversial and are against the trend that other countries are following respect PV penetration. At this moment, we are in a situation of uncertainty, but these regulatory barriers will not be taken into account in this thesis. In fact, a regulation that support and incentivizes self-consumption is going to be considered.

The motivation is to investigate how much photovoltaic potential Spain will have in the future and what would be the economic implication in the event of PV penetration for self-consumption.

1.2. Objectives

This thesis pretends to estimate the potential of PV technology in Spain in the future, specifically by 2030 and calculate the money the system will not recover through the access tariff due to a penetration of PV for self-consumption. To do so, it is necessary to achieve some objectives:

- Find the sectors where the penetration of PV will be feasible.
    - Obtain data from the domestic, commercial and industrial sector.

- Asses the geographical situation of Spain and the region where it is more profitable the installation of PV.

    - It will be identified the region with the highest solar radiation and the ones with lower radiation. Done so, three scenarios will be created to assess different situation in which each region will have different level of penetration depending on the level of solar radiation.

- Quantitative analysis of the potential energy produced by different regions and different sectors
    - The software PVGIS will be the one chosen for calculating the energy produced.

- Identify the amount of money the system will not receive due to self-consumption.
    - The Spanish electricity tariff will be analyzed, identifying the main characteristics of the tariff

- Calculation of money the system will not receive.

1.3. Structure

In order to achieve the objectives, the thesis will be structured as follows:

1. Study and research
    - Study of the photovoltaic market
    - Distributed generation in Spain
    - Grid parity
    - Self-consumption
    - RES energy policies

2. Obtain data

- Acquire data regarding number of houses, buildings, commercial center and small and medium companies as well as big companies per region
- Study of the solar radiation per region

3. Study and analysis
- Different PV panel technologies and selection of the most suitable
- Software PVGIS and methodology applied
- Electricity tariff
- Analysis of the different scenarios proposed

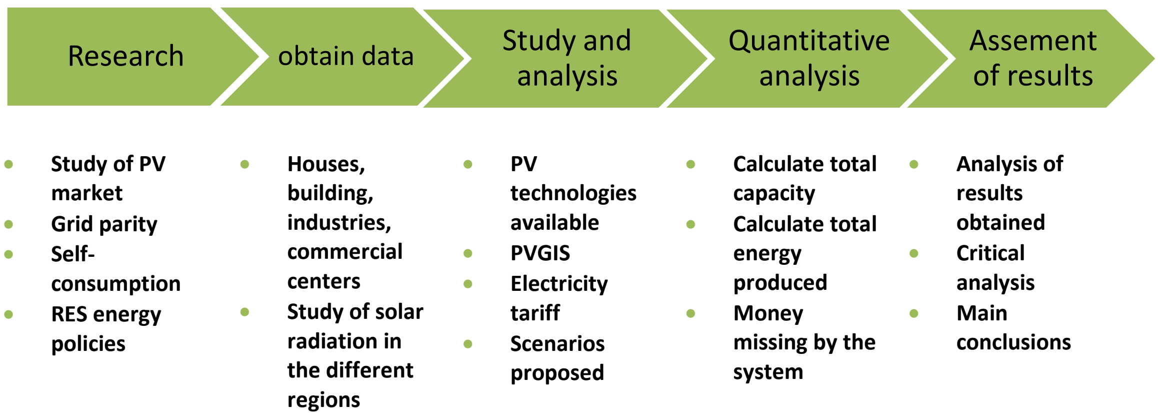
4. Quantitative analysis

- Calculate the total capacity to be installed by 2030 per region and sector
- Calculate the total energy produced by 2030 per region and sector
- Calculate the money the system will not receive due to self-consumption

5. Assessment of results
6. Final conclusions

The figure 3 summarizes the different structures of the thesis:

Figure 4: Structure of the thesis (*source: own elaboration*)



2. State of the art

In this section the photovoltaic state of the art will be studied. The chapter will be structured as follows:

- The main renewable support mechanisms will be studied in order to understand how renewable energy sources have evolved. A section regarding the renewable policy in Spain will be studied
- The next section will be devoted to study the main concepts regarding distributed generation and its state in Spain
- The photovoltaic market as well as the grid parity will be analyzed in the last part of the chapter

2.1. RES support mechanisms

To understand the high penetration of Photovoltaic installations in many countries around the world, it is reasonable to have a look at the policies that have supported these technologies.

During the last years, there has been an enormous increment in the capacity installed of RES all around the world. Some targets set as 20/20/20 have the aim to decrease the level of CO2 emission. These targets have resulted in a lot of investment in different renewable technologies that assure the production of energy without releasing directly[2] co2 emission.

In 2013, electricity generation from renewable sources, with necessary adjustments for wind power and hydro power, contributed 25.4 % to total EU-28 electricity consumption. There is a huge variation between EU Member States: for Malta the level is very low (1.6 %), while for Austria it is 68.1 % followed by Sweden (61.8 %) (Eurostat, 2015)

In addition, the expectation of some government in different countries around Europe is to increase even more the capacity installed to have a production of electricity mainly coming from renewable sources. For instance, Danish government announced that at least 60% of the electricity production in 2020 will be produced by renewable technologies.

In the case of Spain, which is the country that this thesis is focused on, around 40% of the electricity consumption in 2020 will have renewable origin. (CNE, 2010)

Renewable technologies present two main problems: The first one is the dispatchability. Having renewable installed in a system does not assure the production of electricity with these technologies as they depend on sources which are uncertain as it can be wind or sun. The

[2] The process of manufacturing, transporting and installing the plant implies co2 emissions.

second problem is the production cost, they are still very high. Although variable cost are very low, investment cost remain very large.

This makes that the market does not bring by its own this technology. The innovation market does not respond properly to the policies signal we are sending, therefore, technology policies have to be adopted in order to incentive the investment on these sources because otherwise investors will not incur the risk.

In order to bring these technologies to the market, two kinds of technologies policies can be adopted:

- Technology push: The technology is not developed sufficiently to bring it into the market so investment in R&D is made in order to make it more competitive. For those technologies that are not ready to compete in the market.
- Market pull: a market is created for those technologies that are not economically competitive but they are technically competitive. The aim is to produce the technology at mass scale so they may be economically competitive in the long term.

Within both technologies policies there are different types. This thesis will be focus on market pull and more specifically on price instruments and quantity instruments which is called direct methods[3] as they are the ones that have been applied in Spain.

Before entering in any classification, it is worth saying that there is no single technology policy for all technologies. This is a mistake that has been made during the last years, which is set the same technology policy for all renewable technologies.

Each technology should have its own policy. One of the important things to take into account when approving a policy is how well developed is the technology. Although this may seem something obvious, many countries have developed a single renewable policy for all RES technologies.

2.1.1. Price instruments

Feed-in tariff

It is an energy supply policy focused on supporting the development of new renewable energy projects by offering long-term purchase agreement for the energy produced by the technology. So, it guarantees the RES generators to receive a certain price per every MWh produced.

[3] These methods refer to investment support, such as capital grants, tax exemptions or reduction on the purcharse of good. For instance, price subsidies, obligations and so on.

The purchase agreement is a contract which last between 10-25 years. The payment offered for each KWh produced may be differentiated by technology type, project size, resource quality and project location. In order to attract new RES capacity, FIT must be high enough to ensure long-term recovery of costs. In addition, policy maker can also adjust the payment levels to decline for installations in subsequent years, which will both track and encourage technological change.

Successful feed-in tariff policies typically include three key provisions: (1) guaranteed access to the grid; (2) stable, long-term purchase agreements (typically, 15-20 years); and (3) payment levels based on the costs of RE generation.

The key point when designing a FIT is to calculate how much money RES generator is going to receive. If the payment set is too low, no investor will be interested in investing in the technology. On the contrary, if the payment is too high, too many investors will be encouraged to invest and therefore this will result in an overcapacity as well as overpayment which are what has happened in Spain.

If we have a look at the main approaches that have been used around the world, there are four that are the most usual:

1. Based on the actual levelized cost[4] of renewable energy generation. This is the approach that has been mainly used in Europe and it can be said that it is the most successful.
2. Based on the value of renewable energy generation either to society or to the utility. This approach has been used in California.
3. Offered as a fixed-price incentive without regard to levelized RE generation cost or avoided cost. It has been used by some utilities in the U.S.
4. Based on the results of an auction or bidding process which can help to inform price discovery by appealing to the market directly. An auction-based mechanism can be applied and differentiated based on different technologies, project sizes, etc. and is a variant on the cost-based approach. (Williams, Cory, & kreycik, 2010)

When we talk about photovoltaic, FIT has probably been the main cause of the high penetration at household level. If we have a look at some countries like Germany or the UK, FIT has encouraged consumer to install PV panels.

ADVANTAGES

FIT secures a stable market for investors as guarantees a long-term remuneration and investors are not exposed to the volatility of market prices. It also enhances the market access for new comers, which is something that should be beneficial for the system as it should result in a more efficient and flexible system.

[4] It is an economic assessment of the average total cost to build and operate a power-generating asset over its lifetime divided by the total power output of the asset over that lifetime

FIT is a great support for those technologies that have moved beyond R&D but are not sufficiently mature, although this should be beneficial for these technologies, it may happen that high FIT might stop the R&D as there is no incentive to develop the technology, this is something that has happened with PV. FIT decrease considerably the administrative procedures for regulators and for investors as the former and the latter did not need to find any buyer of the energy, for instance.

DISADVANTAGES

As it has been mentioned before, the main disadvantage of this policy is when setting the remuneration. It is so difficult for the policy maker to come up with the right remuneration; there is a lot of information asymmetry which will clearly benefit investors.

A low remuneration will not attract investors and a too high remuneration will attract too many investors which will result in an overcapacity and a lack of R&D investment to continue improving the technology.

Another disadvantage that FIT presents is that they are not “market-oriented”, they are frequently independent from market price signals and therefore generators under this policy do not have any incentive to adjust their production depending on energy prices neither to demand-consume balance.

One thing that it is quite important to bear in mind is that FIT contrary to what it is often assumed are subject to the customary regulatory risks, since they are just a regulatory instrument that is backed-up by a regulatory commitment.

FIT are embodied in special decrees or in electricity acts and require the government to allocate the incurred additional costs to electricity consumers or to taxpayers. Yet, as governments and politic preferences change, so the regulations that govern FIT might also change (Batlle, Perez-Arriga, & Zambrano-Barragán, 2011). A similar case has happened in Spain which will be studied in following chapters.

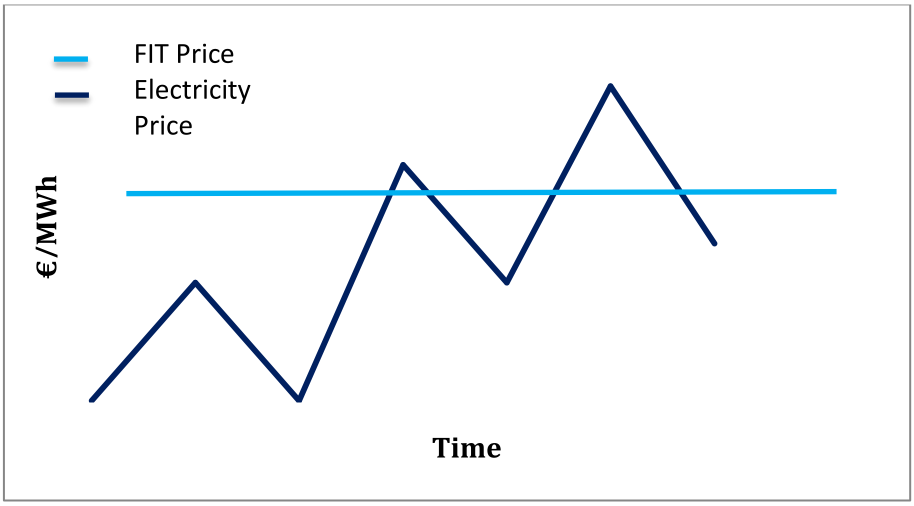
FIT payment structure can be designed in different ways. At the beginning FIT payments in Europe were designed as a percentage of prevailing retail prices; however both fixes price and premium policies structures are the most common today and therefore I will focus on them.

Fixed -price FIT

The majority of countries have chosen the market-independent FIT which is that the payment remains independent from the market price. This policy guarantees a fixed payment for a certain period of time.

Some adjustment can be made in the fixed payment in order to address other factors. the Figure 5 shows a graphical example of this policy. This policy has been widely implemented in around 50 countries as Greece, Germany, France or Switzerland. (Williams, Cory, & kreycik, 2010)

Figure 5: Fixed FIT (*Source: own elaboration*)



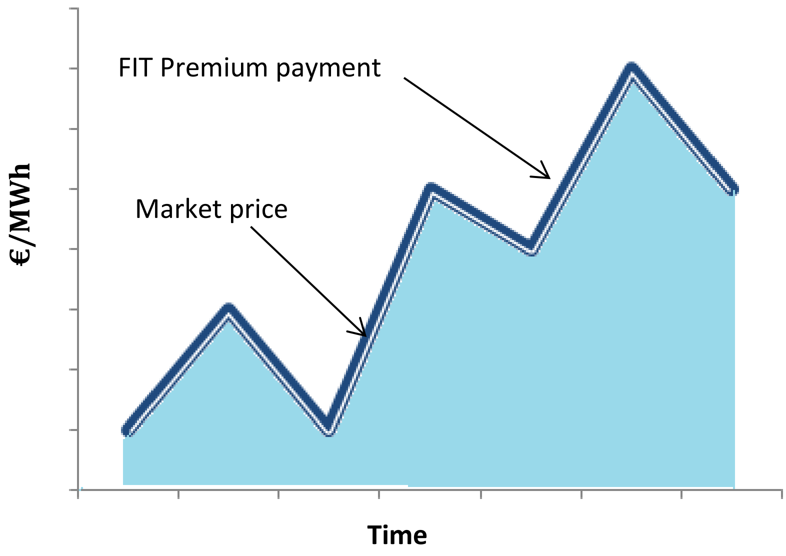
Premium-price FIT

The feed-in premium option offers a premium on top of the spot market. This policy is called market-dependent model as the payment level is totally subject to the electricity market price. Thus, developers under this design will be rewarded when spot price are very high and will penalized when prices decrease.

It is important to mention that this approach is in contrast to the fixed-price approach in the sense that the electricity generated in the former is typically sold in the sport market whereas in the latter, a purchase guarantee is fixed and then the generation is separated from sport market dynamics.

Premium Feed-in tariff has been offered in many countries, one of them is Spain in which I will focus on following chapters. However, the majority of European countries chose the fixed-price policies over premium FIT. The Figure 6: Premium price FIT (*Source: Own elaboration*)Figure 6 shows this FIT premium.

Figure 6: Premium price FIT (*Source: Own elaboration*)



Within the premium Feed-in tariff it exits a sliding premium-price FIT, as this has been applied in Spain. As the chapter 2.2 covers the Spanish case, this variety will be explained in this chapter.

ADVANTAGES

As it has been mentioned before, this policy is "market-oriented" as it depends on sport market prices, for this reason the generators under this policy may be interested in producing in peak hours when the electricity price are higher and therefore could receive larger remuneration. In addition, it may send economic signal to generators to be installed in places where the locational prices are high. Since they have to sell their electricity in the sport market, another advantage this design has is that it may encourage the competition among electricity producers, both renewable and conventional.

DISADVANTAGES

Generators under this policy may have an incentive to avoid generators to predict the load curve which could lead to an inefficient electricity dispatch and therefore higher prices and higher premiums. Premium FIT policies have demonstrated a lower degree of cost efficiency than fixed-price FIT, which results in higher average payments per KWh. (Williams, Cory, & kreycik, 2010)

Investors see as a risk the fact that premium does not imply a guarantee payment as they are subject to spot market. So, maybe a guarantee will increase the investment and the security in the return of the investment. In the case of wind and solar plants, they cannot really decide the hour at which they produce. For this reason they are less benefited from a premium FIT than biogas, hydropower for instance.

In a series of analyses, researchers in the EU demonstrated that premium-price FITs tend to provide higher total payments than fixed-price FITs. Spain and the Czech Republic offered a choice between fixed and premium policy options. In these countries, the expected profits were incrementally higher for the premium option than the fixed-price FIT structure, ranging from and additional premium of 0.01 €/KWh to 0.03 €/KWh. The greater investor risk, compounded by the greater uncertainty over the policy costs for society, are likely to make premium FIT policies a costlier policy design. (Williams, Cory, & kreycik, 2010)

2.2. Renewable policy in Spain

In this chapter I am going to assess the main renewable support mechanisms in Spain, give my opinion about them and try to recommend some measures that may have been applied in the past and others that may be applied in the future. In order to do so, it is convenient to have a look at the national policy evolution to identify the weaknesses and strengths of the policy applied.

Spain has supported renewable since early 80s with the passage of the Law for Energy Conservation. Since then, Spain has encouraged renewable generation with a wide range of policies such as grid access, specific tariff for renewable electricity and market premium options for certain renewable generators.

Feed-in tariff and market premium incentives for solar PV were firstly established in 2000. The incentives were so attractive that Spain became the largest solar market for solar power installations in 2008. However, due to the financial difficulties Spain had and the arrival of the crisis, in 2012 Spain was the first European country to absolutely suspend FIT and market premium incentives for new renewable generation. In addition, Spain has made retroactive cuts to FIT and market premium.

If we come back to 1997 a law called General Electricity Law for the deployment of renewable capacity was established. This law created a “special regime” for certain power generators to receive special tariff and guarantee grid access. Those generators under the Special regime used to be compensated through fixed tariff or market premium. Generators under this regime were renewable and combined heat and power (cogenerator). Aspects about the special regime were modified from time to time through the passage of Royal Decrees.

Until 2004 RE developers could choose either a long term fixed FIT payment or a constant premium FIT payment. From 2004, Spain discontinued this option to establish in the Royal Decree 436/2004 a new option in which both payments were defined as a percentage of market prices. For solar thermal power projects the premium was established at 300% of the sport price during the course of 25 year contract. (CNE, Legislation development of the Spanish electric power act, 2006)

Spain abandoned this policy in 2006 and in the Royal Decree 661/2007 introduced a sliding premium option that included a payment cap and payment floor on the premium amount. This policy tried to avoid the problems that the former policy had arisen when FIT where subject to spot market prices as this approach increased policy costs when marginal electricity generation costs increased. This policy was applied to all technologies except solar PV which had a fixed-price option. As it can be seen Spanish government has made a lot of modification to incentive renewable, especially wind and solar. At the end in 2012 all incentives were suspended as a result of a deficit.

Finally, the Royal Decree 413/2014 removed the differentiated concepts of ordinary regime and special regime. According to this new framework the installations producing energy through renewable sources, cogeneration and wastes will receive a specific retribution along their lifespan besides the remuneration they receive for the energy sold in the market. This specific retribution is composed by two elements:

- A capacity term for the power installed that will cover when necessary, the investment cost that has not been recovered by the energy sold in the market. This is denominated retribution to the investment.
- An Operation term that will cover when necessary, the difference between the operation costs and the remuneration received for the participation on the market. It is called retribution for the operation.

For the calculation of the retribution, the standard incomes for the energy sold in the market, the standard operations costs of the plant to carry out the activity and the initial investment cost of the plant will be considered. (Ministry of industry energy and tourism, 2014)

CONCLUSIONS

Spain is a good example to show that setting a policy for renewable support is not easy at all. As I have mentioned in other chapter, when setting a FIT is very important to set a payment which is not too high because it will attract a lot of investment. In the case of Spain, it was so high that it became the largest solar market for solar power installations in 2008. In fact, in 2007 solar installations had already exceeded the country´s planned capacity limit.

It is possible that when Spain started to support the policy for supporting renewable did not take into account two important things, which are the uncertainty and how the technology is going to evolve. If we have a look at the learning curve for PV, we note that since 2000 when Spain started to support it, the technology has evolved dramatically. If the payment is not properly set as it is the case of Spain, these results in a clear overpayment.

But the problem started earlier because beside the high payment that Spain set for FIT at that time, Spain already experienced a deficit. Therefore, it is not reasonable to make a huge investment to support renewable when you experience a deficit. I am not saying that the cause of this deficit it is the policy designed for renewable but inevitably this policy has contributed to increase the deficit. The consequences that this deficit provoked was a set of measures that will contribute that Spain have a lot of difficulties to attract investors in the future:

- Spain suspended all the incentives for renewable in 2012. It is the first country in Europe to do so.
- Spain implemented retroactive policies that affect existing projects which were developed and financed based on prior policies, for instance:

  - Limitations on the number of operating hours eligible for FIT or market premium incentives. This essentially reduces the amount of revenue that can be generated by certain projects.

  - Grid access fee of 0.5 €cent per kWh for all generators (conventional and renewable).

  - A 7% tax on the production value of electricity produced from all fuel sources, effective January 1, 2013. This measure effectively reduces revenue and cash flow for power projects.

  - Change of the inflation adjustment for FIT and market premiums to lower levels; inflation adjustment now excludes food and energy prices.

  - As of February 2013, certain renewable electricity projects (i.e., wind) are no longer eligible for the market premium option. Projects can choose either a fixed tariff or the market price.

  - No project lifetime incentive support for existing renewable electricity projects. Support for each technology is limited to a certain number of years.

  - In July 2013 the government approved Royal Decree RDL 9/2013, which indicates that investment returns for renewable projects will be set at around 7.5%. For some projects, this return level is much lower than the returns which finance and investment decisions were based. (Brown, 2013)

Thus, investors who are willing to put money in a country, when they have a look at the Spanish regulation and the main policies applied, they would probably reject to invest a euro in Spain. The regulation has changed many times. This is a signal that things have not been done properly.

It is true that investors are looking for countries where they can get a good return as it was the case of Spain but the first thing that they look at is if the country has a stable regulation. In the case of Spain as we have seen, the regulation has changed many times, this will inevitable have bad consequences in the deployment of new capacity in the future.

Many of the measures mentioned above are illegal and go against the guidance that European Commission is developing. Sector as wind has taken the government to court which is something totally understandable. Furthermore, I can say that Spain is going backwards. We were a pioneer establishing a system of premiums for renewables and now when other member states are moving towards premium, the government decided to cut the incentives.

Spain has wasted 10 years of effort by the renewable sector and the grid operator to make wind and solar a mainstream technology and it is destroying value each time it approves a Royal Decree that affects investment already made.

The European Commission should take a look at these measures that Spain has adopted. Not only because these measures will affect the European Electricity Market but also because other countries that may present similar difficulties, could take the example of Spain to solve it.

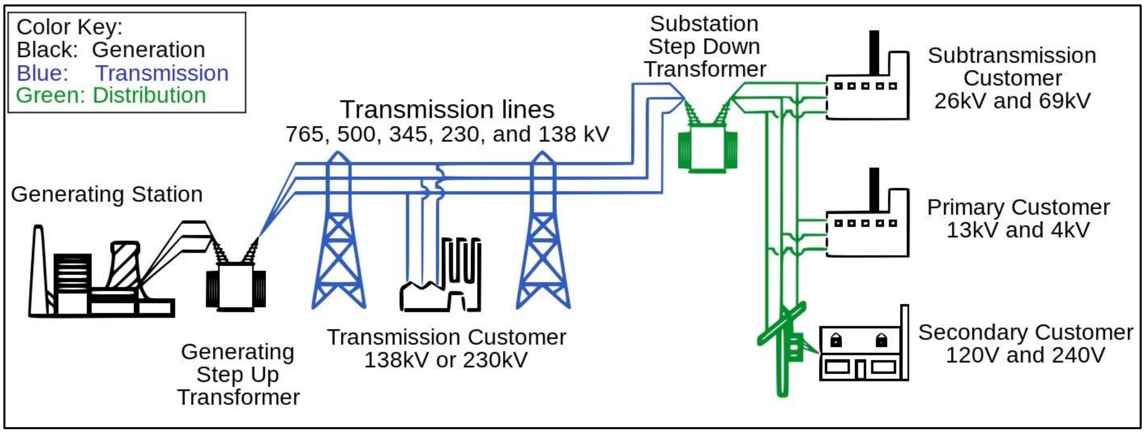
LESSON LEARNT FROM SPAIN

- FITs are a powerful mechanism to attract investment and to accelerate the deployment of cleaner technologies as they offer long term contracts. Nevertheless, the framework applied should have the broad support of citizens and it should be robust to changes in governments and overall economic conditions.
- The policy applied should introduce credible mechanism to ensure that the investment will be paid for in time.
- Avoid changes in regulation every time a Royal Decree is approved. In addition, avoid retroactive regulation.
- Introduce auctions for new capacity. Renewable technologies have evolved dramatically and we can say now that they are mature and in condition to compete with the traditional technologies.
- Do not implement a single policy for all renewable technologies. Rather, design a policy for each technology since each technology evolution is different and it has different learning curve.
- Do not change the policy whenever is convenient for the government as this will result in lack of investment in the future.

2.3. Distributed generation

A new approach in which renewable generation (i.e. wind and photovoltaic) and cogeneration are being installed close to the consumption points or in the same installation where the consumer is located, are becoming very relevant.

Figure 7: Traditional electric power system *(source: imgbduddy)*

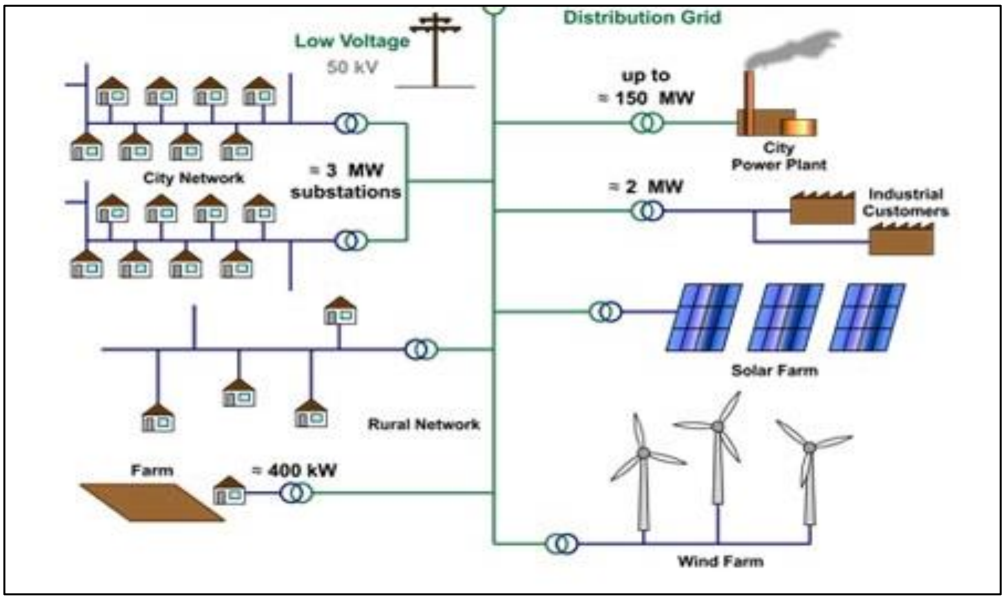


From this new approach the concept "distributed generation" appears. Although there are few definitions of distributed generation, the one most used is the electricity produced by generators which are located close to the consumption point and are directly connected to the distribution network.

The European Union directive defines distributed generation as "generation plants connected to the distribution system" (European Union, 2009).

The Figure 8 represents how the distribution networks looks like nowadays. Different generation energy sources are directly connected to the distribution network, especially RES.

Figure 8: New distribution power system (*source: condiutnw)*



The problem when using the definition that the European commission provides is that distribution system is not equally defined in each country. Depending on the European country the definition of distribution system may depend. This is because almost all the countries in

Europe have different level of voltage to differentiate between transmission line and distribution line as it is shown in the Figure 9.

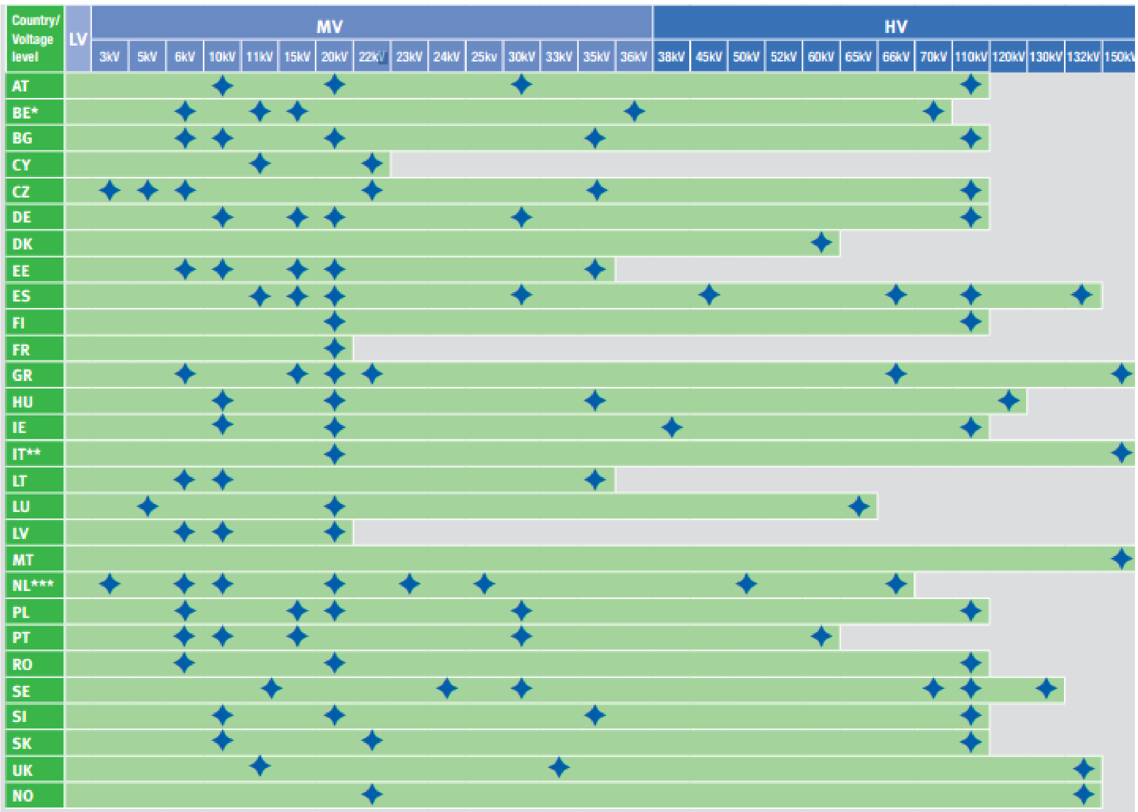
Therefore, if some European Countries were picked up, for instance, Cyprus, France and Spain, it can be seen that in the formers, the DSO only operates the low voltage and medium voltage, whereas in Spain the DSO operates up to the subtransmission grid[5].

This is important to bear in mind because when we are speaking about distributed generation, it may create some confusion between different countries as DSO in certain countries may claim that it is not under its responsibility.

Another issue that arises when we are speaking about distributed generation is if RES are connected to the distribution grid.

If we have a look at some countries´ distribution and transmission network, it can be seen that although it is true that mainly RES are the ones who are connected to the distribution grid, some of them are also connected to the transmission grid. This is what happens in Spain, mainly with wind. In any case, this will be mentioned and analyzed in the following chapter about distributed generation in Spain.

Figure 9: Distribution voltage level in Europe ***(Source: Eurelectric)***



[5] It is the high voltage distribution line, usually up to 150 KV

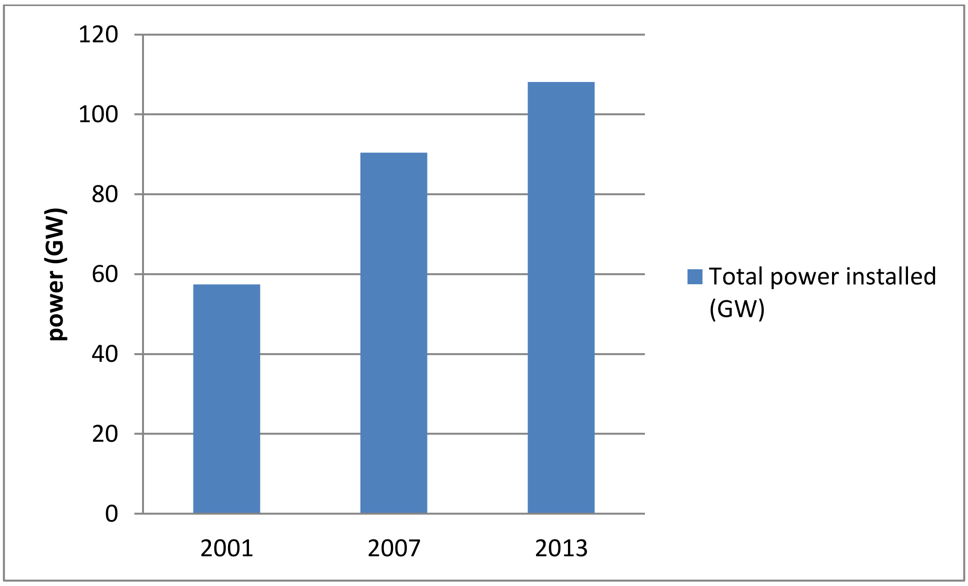
2.2.1. Distributed generation in Spain

The traditional generation approach[6] is changing in Spain as time goes by. Nowadays, both models, traditional and distributed have to be complementary and they will probably be the base for the future development of the electric system.

If we have a look at the past, from 2004 to 2011, the number of installation points for generating energy has gone up from 5.175 to 60.000 (Álvarez Pelegry & Castro Legarza, 2014). Obviously, not all of them are connected to the distribution grid but it gives an idea of how the generation capacity has increased in the last decade.

This high proliferation of generations installed capacity was mainly provoked by the “special regime” (see 2.2. Renewable policy in Spain). In the Figure 10 we can see the capacity installed during the special regime. As it can be observed from 2001 to 2013 the capacity installed was duplicated. Nowadays, the capacity installed from renewable sources, cogeneration and wasted (previously called special regime) account for 39% of the 108 GW installed in Spain.

Figure 10: Evolution of total installed capacity in the Special regime (*own elaboration*)

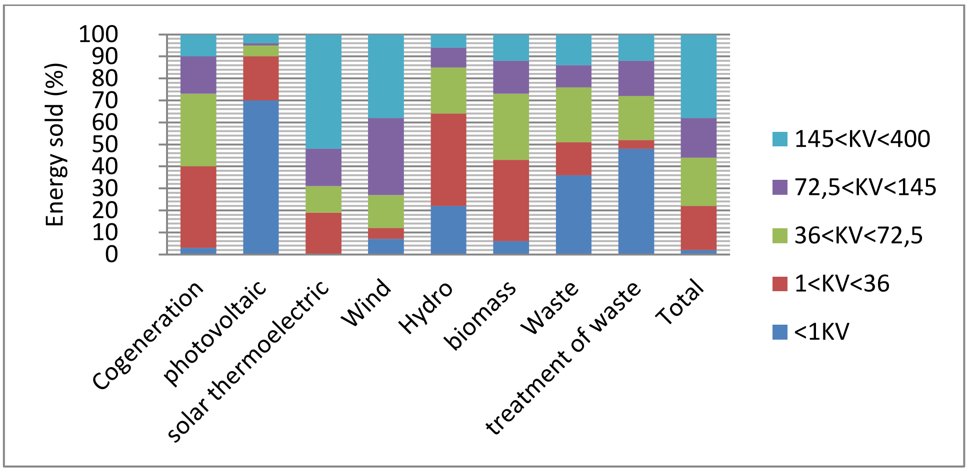


Focusing in photovoltaic technology, from 2006 to 2013 the number of photovoltaic plants in operation was multiplied by 6 times and around 310 times compared 2001. This made that the power installed was multiplied by 30 times and more than 1150 times compared 2001.

Yet, to call distributed generation plants to those generators that were installed in the special regime, we have to take a look at the energy sold in Spain and differentiate by level of voltage they were connected and energy source.

[6] In the traditional approach the power plants are located far away from the consumption points and normally connected to the transmission grid.

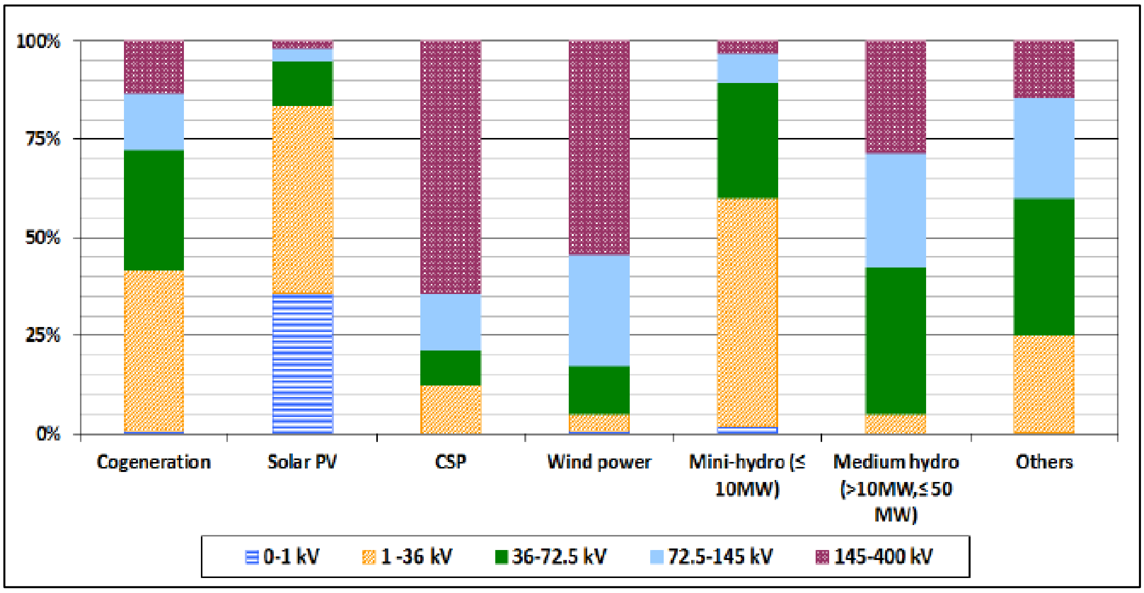
Figure 11: Energy sold in special regime in 2013 (*own elaboration via CNE)*



According to the Figure 11, more than half of the energy consumption in 2013 was produced in power plants connected to the distribution grid; this large amount has to certainly do with the high penetration mainly provoked by the special regime. This data is very relevant to take into account that distributed generation in Spain is becoming very important.

Regarding the installed capacity in Spain, it is usually assumed that RES are connected to the distribution network. However, if we have a look at the Figure 12, it can be seen that more than half of wind capacity is actually connected to the transmission grid.

Figure 12: Installed capacity by energy source and voltage level *(source: CNE and Coussent)*



The same happens with concentrated solar power. Regarding hydro, it is mainly distributed among medium and high voltage. In the case of solar PV, it is worth highlighting the large amount that is connected to the low voltage, more than 30%. This amount is expected to increase dramatically with the installation of PV panel at household level in the near future.

2.3. Self-consumption

"Self-consumption" is a concept that has become very relevant in the last years. In general terms self-consumption is defined as the energy consumed by the same person who is generating it. Some countries define self-consumption as the electricity consumed coming from generators which are directly connected within the consumer´s network or through a direct line.

It is important to distinguish between distributed generation and self-consumption, they are different concepts and that is why all countries have a specific regulation for each one. The distributed generation is subject and controlled by the operator whereas in self-consumption the limitation to control it arises from the limited capacity connected to the grid.

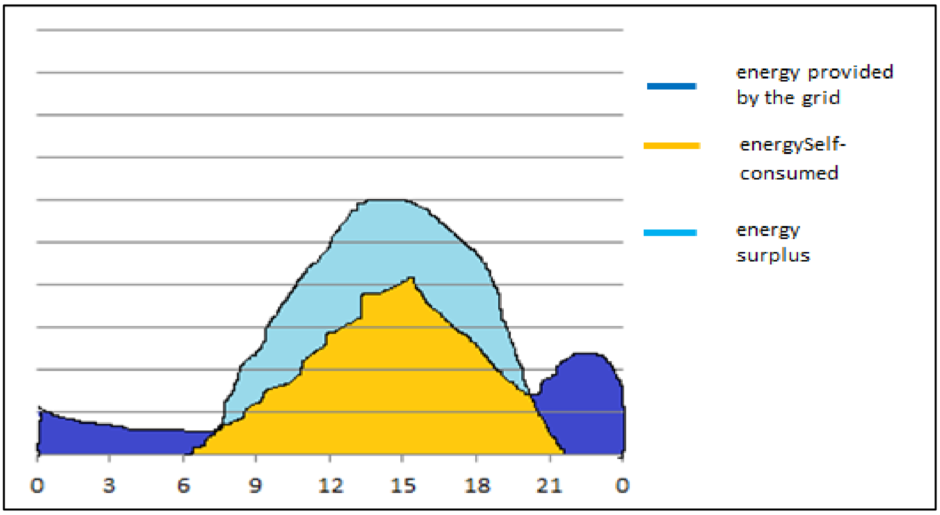
During the last years the technology and knowledge about the distribution system have evolved dramatically. This has made the connection to the distribution grid become feasible and does incur neither high cost nor long time to install the facility.

Therefore, a lot of consumers have decided to install their own PV generators in order to produce part of the energy they consume. Consumers that also generate their own electricity are called prosumer.

The fact that Photovoltaic technology presents very competitive prices has determined that this technology has the greatest potential to be used for self-consumption. In fact, self-consumption is sometimes called photovoltaic self-consumption.

The Figure 13 shows a PV installation that supplies energy for self-consumption in the hours where it is possible to produce. The rest of the demand is covered through the distribution grid. In the event that there is energy surplus and this energy can be injected into the grid being economically compensated, the self-consumer will receive an income which is the result of multiplying the energy transferred by the price stipulated by the energy company and the client. In any case, the self-consumer would pay the energy consumed through the network.

Figure 13: Self-consumption (Source: own elaboration)

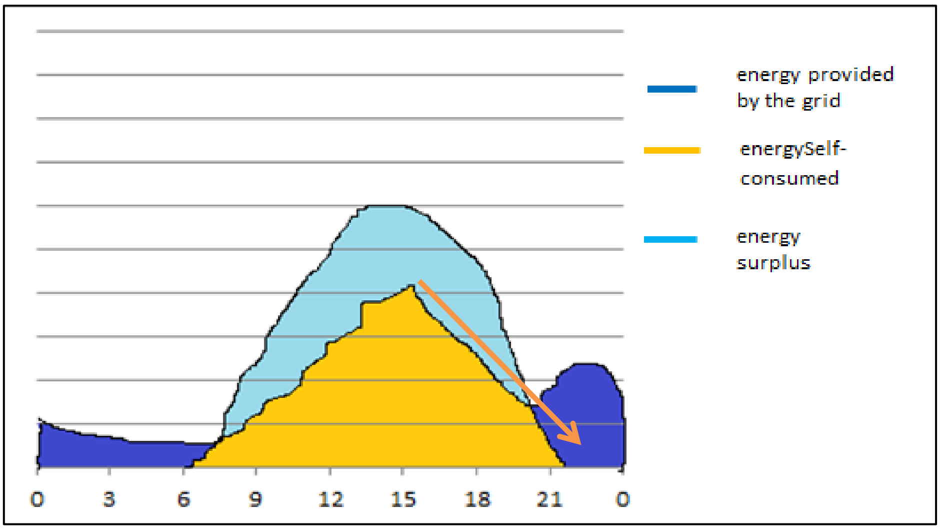


It is important to distinguish between self-consumption and self-consumption trough net metering. Self-consumer under net metering can cover part of their consumption trough auto-production and injection into the grid the excess of energy produced to be consumed in other moments.

Basically the difference between self-consumption and net metering resides in how the excess of energy is treated, in other words, the difference between the net energy produced and the energy consumed.

When we talk about net metering, the excess of energy produced can be injected into the grid and be consumed in other period of times when the installation is not able to generate energy. However, self-consumer consumes instantly the energy produced by the installation. In fact, the regulation treats the excess of energy in a different way depending on the country.

Figure 14: Net metering (*source: own elaboration*)



Regarding pros from self-consumption, There are many advantages resulted from it. From the system point of view, payment for carbon emission and energy losses will be reduced. It lowers the cost of the transmission network and may also reduce distribution network cost. From the consumer point of view, it will provide the consumer with energy independency and will avoid him/her to buy part of the energy consumed to the retailer.

Nevertheless, not all are advantages. Firstly, this generation will be in many cases out of the control of the system operator which makes the operation of the system even more difficult. The unitary cost of the installation is still very high as it does not take advantage of the economics of scale.

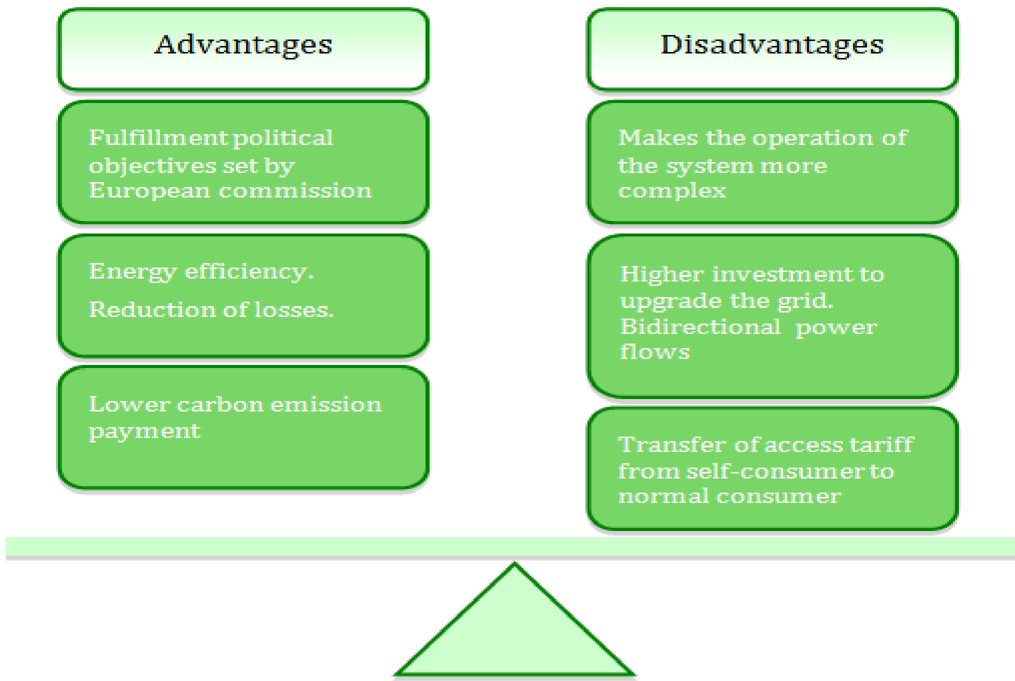
In addition, PV installations have a lack of dispatchability. PV installations do not allow the consumer to produce and consume whenever necessary but it is subject to the sun radiation.

Therefore, the consumer will depend on the weather as well as on the time when the sun is shining.

Probably the most important inconvenient that PV self-consumption presents is the transfer of access tariff from those who are self-consumer to those who are not. This may happen when the fixed cost that the self-consumer avoids is greater than the cost that the system saves.

Chapter 3 of this thesis will study this problem and will analyze what would be the implications for the system when large amounts of self-consumers are producing energy for self-consumption.

Figure 15: Pros and cons from self-consumption (*Source: own elaboration*)



2.3.1 Self-consumption in Spain

Regarding self-consumption in Spain, it has been proposed a Royal Decree where the technical and economic conditions are established. There is a wide range of possibilities regarding the different charges that a consumer under the self-consumer regime has to face.

The Royal Decree regulates the hourly energy consumption coming from generation installations that are connected to the consumer network or through a direct line. It can be distinguished two forms of consumption:

1. Consumers with an installation lower than 100 KW who are not registered as generators. The consumer under this form will need two devices in order to

measure the energy produced and consume. In addition, they are subject to the following conditions:

- For the energy auto-consumed, the consumer will pay a fee called "transitory charge for energy auto-consumed". The charge will be paid in €/KWh and it will be divided in three components: charges associated to the cost of the system, capacity payment and balancing services.
- In the component related to the cost of the system, the cost associated to the network will be discounted since the self-consumer is not using the network when is auto-consuming.
- If there is an excess of energy production and it is injected into the grid, this energy will not be economically compensated.

2. Consumers with generation installations registered and directly connected to their network or through a direct line. It will be a consumer and a producer. In this form, there is no capacity limitation but they need to have devices to measure the energy produced in excess. In addition, they are subject to the following conditions:

    - The producer under self-consumption regime could inject the excess of energy into the grid. The energy injected may be economically compensated.
    - The energy acquired from the retailer is calculated from the hourly difference between production and consumption and the price will be the one accorded with the retailer.
    - The self-consumer will pay the transitory charge for energy auto-consumed and access tariff for the energy injected into the grid.
    - In the current situation, there is no economic incentive for the energy injected by new installations, only for the ones already in place.

The most controversial aspect of the Royal Decree is the mentioned transitory charge for energy auto-consumed. It will be calculated taken into account:

- Variable term of the access tariff
- Price of the payment for capacity
- Price of the balancing services

It is worth highlighting that the last Royal Decree proposed (June 2015) differs from the one proposed in 2013 in some aspects. For instance: the variable term of the access tariff, in the one recently proposed and pending of approval, the access tariff from the distribution and transmission network is discounted from the variable access tariff. With this measure, the self-consumer will not have to pay the grid when is self-consuming as he/she is not actually making use of the network. This has resulted in a reduction on the charge from 70€/MWh in the first proposal to 49€/MWh in the recent one.

However, when the self-consumer is injecting energy into the grid or receiving energy from the grid, the part regarding network will be included in the access tariff.

The new Royal decree also introduces a new charge that will disincentive the use of batteries since the regulation will not only allow to use batteries as the recent one launched by Tesla but self-consumer will be penalized for the storage system that panels nowadays provide.

2.3.2 International experiences

In this section, net metering in some countries is going to be reviewed in order to assess if some of the measures that have been taken can be applied in Spain.

Netherlands

In the Holland system there is a subsidy for PV investment. It consists a 15% of the investment costs with a maximum set at 650 euros per installation and just if the installation capacity is between 0.6 and 15 KW.

Therefore, the grid parity has been reached in the residential sector. The budget for subsidies in 2012 was about 22 million euros and 30 million euros in 2013. Such budget produced an increase in the PV installed capacity which already is about 175 MW.

Italy

Italy started to promote net metering in the beginning of 2001 and the regulation has suffered some changes.

In a first stage it was limited to small installations lower than 20 KW which received a feed in tariff for the energy injected into the grid. After some changes, in 2013 the “on-the-sport-trading” was approved for big installations up to 200 KW.

The energy injected and consumed is compensated in annual based with a bidirectional mechanism, in other words, generation and consumption. All consumers pay the energy consumed at the diary market price and the energy injected into the network is compensated as zonal price at the end of the year.

The compensation paid by the GSE (the Italian energy agency) is paid as an annual subsidy. The compensation is independently calculated for each consumer.

Denmark

The mechanism for self-consumption is based on Feed in tariffs received for the energy injected into the grid. It has a benefit which is that there is no imposition of consuming that energy. In addition, all the energy delivered into the grid is exempt of electric tariff and the high Danish taxes.

From 2012, the subsidy program compensates the consumption with the generation by hour's bases instead of annual as it was before. With this system, the number of hours in which the energy produced can be compensated by energy consumed is reduced.

The objective set for the photovoltaic technology in term of capacity was at 200 MW by 2020. Nowadays the PV installed capacity is more than double.

Germany

It began in 2009 for installation lower than 500 KW. Net metering is a generalized practice in Germany and in 2010 there were 860.000 installations on rooftop, industries and rural houses.

They count with two devices to measure energy, one device for generation and the other one for consumption. The final bill will be a result of the net energy consumed. The energy surplus is compensated and distributors are obliged to buy such energy at a special tariff for a 20 years period.

Regarding self-consumed electricity, there is an incentive for it but lower than the Feed in tariff. Nevertheless, it has been published a new regulation in which self-consumer must consume at least 20% of the energy produced, otherwise they will just be remunerated for the 80% of the energy injected.

California

Net metering has been established in California since 1996. They just need a device to measure the retrieved energy and the injected energy. The self-consumer pays for the difference between the energy injected and consumed.

The value of the energy injected into the grid generates a credit which value is the price of electricity at the retail level and the self-consumer can use those credits until the end of the year. If they are not used, there is compensation.

Japan

In 2009, the government established a tariff for the energy surplus through a net metering system. This led a great increase in the PV installations, being the total capacity double in 2010.

Residential consumers have a subsidy for the installation. Moreover, electric companies must purchase the excess of electricity generated by the PV installations for a 10 years period. Net metering is applied for residential houses lower than 10KW as well as no residential buildings.

From July 2012 there is a new tariff for the energy injected into the grid which is greater for non-residential building than for residential ones.

Portugal

Net metering is allowed in Portugal. The self-consumer can make a contract to sell the excess of energy produced to the supplier Company. Bilateral contracts are also allowed. The price of the energy sold will be the price of market less 10%. Additionally, self-consumption installation will receive a subsidy for the investment which will be by KW installed and will last for 10 years. (Abad Santiago, 2014)

2.4. PV market

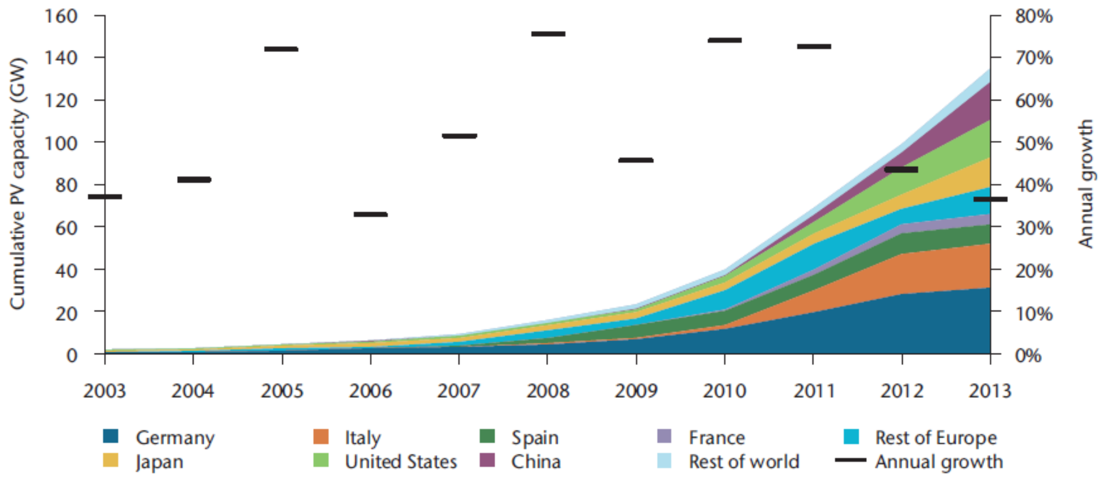
Photovoltaic industry is evolving drastically since 2009. The manufacturing capacities have increased considerably and many European and American manufacturers have decided to move their factories to Asian countries where the prices of producing PVs are lower. Market prices have dropped dramatically. For instance, the price of modules has decreased by a factor of five and the whole system by almost three. (Agency, 2014)

The global rate of annual new-built capacities was 7 GW in 2009 whereas in 2013 was five times higher. As the Figure 16 shows, the cumulative installed capacity has grown in the last ten year as a reason of 49% per year. A relevant data to take into account is that 100 MW of PV were installed per day in 2013. A consequence of this is that the total capacity installed in 2013 was 135 GW.

This trend has not only taken place in Europe or US but Asians have behaved very actively since 2004. In fact, in this year and for the first time, more new capacity was installed in Asia than in Europe. Indeed, only China installed 11GW which is higher capacity than the one installed in Europe in that year.

Japan is also becoming a relevant actor in PV industry and it was the second country to install more capacity with around 7 GW followed by United stated which installed over 4 GW. Therefore, a lot of money has been invested on PV. Indeed, it is calculated that only in 2013 over 96 billion dollars were invested in PV capacity.

Figure 16: Global cumulative growth of PV capacity (*Source: EIA*)



PV installations are being installed of very small capacity, to provide a high valued energy to off-grid system and of medium and massive capacity as it is the case of China and US where there are some plants over 100 MW of capacity.

Table 1: Solar PV market and installation since 2009 (*source: own elaboration*)

	End of 2009	End 2013
Total installed capacity	23 GW	135 GW
Annual installed capacity	7 GW	37 GW
Annual investment	USD 48 billion	USD 96 Billion
Number of countries with > 1 GW installed	5	17
Number of countries with > 100 MW yearly market	9	23
PV electricity generated during the year	20 TWh	139 TWh
PV penetration levels	**% of electricity consumption**	
Germany		5.3%
Italy		7%
Europe		2.6%

The high capacity installed has made that solar energy becomes very relevant in the share of electricity production. In Germany, 1.3 million solar power plants generated over 30 TWh in 2013 which is equivalent to 5% of German electricity consumption (Burger, 2014) and Italy PV systems generated around 22 TWh in 2013. In Spain PV generations has exceeded 3% of electricity demand. (Agency, 2014)

A lot of effort has been put in R&D in order to improve the efficiency of panels and development of new systems. However, crystalline silicon modules continue dominating the market with around 90% of share. Thin films represents about 10% of the market and concentrating photovoltaic is increasing but it only represents 1%.

The efficiency of the modules has improved in the last ten years. Regarding commercial silicon modules which are the most installed nowadays, the efficiency has improved about 0.3 % per year and nowadays its efficiency varies from 16% to 20%. Other modules based on heterojunction and interdigitated back contact present efficiencies of 20%.

This high improvement has led PV levelized cost of energy in some countries to levels equal or lower than the retail electricity price. What is called “grid parity” has been reached in countries like Spain. The next chapter explains in more details what the LCOE and grid parity are and how the situation is in Spain.

2.4.1. PV grid parity

The remarkable growth of PV market as well as the constant technological improvement over the last few years has led to a notorious decline in costs of this technology. In addition, electricity prices are increasing year by year; these two factors have been pushing the arrival of PV “grid parity”: The moment in which the cost of producing energy with a PV installation is less or equal than the cost of purchasing the energy from the electricity grid.

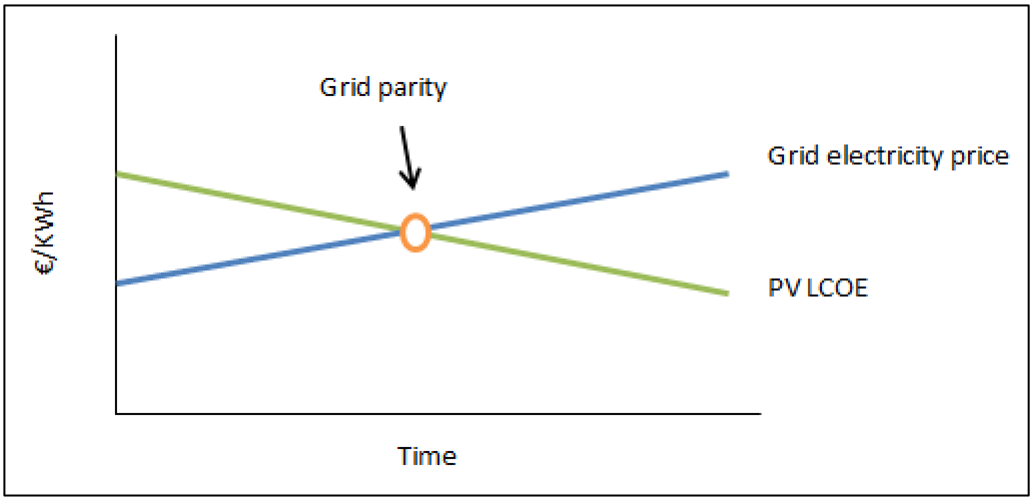
Some assumptions for grid parity definition must be taken into account:

It may happen that not all the energy produced by the PV generator is consumed. Therefore, the surplus will be fed into the electric grid. Depending on the country´s regulation, this excess of electricity produced will have different value:

- In those countries where self-consumption is not regulated, the prosumer will not be remunerated for the excess of electricity injected into the grid.
- If there is a self-consumption regulation adopted, the owner of the installation is remunerated either monetary or by KWh (in exchange of the energy fed into the grid you can consume the same amount of energy from the grid) for the energy surplus injected into the grid. Depending on the country this compensation can be equivalent to the retail prices or lower.

Thus, Once PV grid parity is reached, it would be attractive from the economic point of view to own a PV panel installation and produce the energy with it instead of purchasing electricity from the network. The graph below shows in a simple way the grid parity in which PV electricity cost (LCOE) and grid electricity price are compared. In the moment in which both lines cross the grid parity is reached.

Figure 17: Grid parity (*Source: Own elaboration*)



In order to assess the grid parity, the costs of generating electricity by PV installations have to be analyzed to be compared with the retail prices.

The cost of PV-generated electricity is expressed as the **Levelized Cost of Electricity (LCOE)**, defined as the constant and theoretical cost of generating a kWh of PV electricity that incorporates all the costs associated with the PV system over its lifetime.

To properly study the levelized cost of electricity many variable must be taken into account, for instance: initial investment, O&M costs, discount rate, average PV system lifespan and so on.

Equation 1: LCOE calculation

$$LCOE = \frac{I + \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}$$

- Average PV system lifespan (T)
- Initial investment (I)
- O&M cost (C_t)
- PV- generated electricity over the system´s lifespan (E_t)
- Discount rate (r)

2.4.2. PV grid parity in Spain

Grid parity has been reached in Spain, both in continental Spain and in the Canary Islands. The main reasons why this has occurred are:

- The PV LCOE has experienced a decrease in the last few years (an average annual decrease of 5.5% in Madrid and in the Canary Islands from 2009 to 2014).
- An increase of standard electricity prices.

The Figure 18 shows the Past evolution of retail electricity price and PV LCOE in Madrid and in the canary Island Spain (including taxes).

Figure 18: Madrid´s grid parity proximity (*source: grid parity monitor*)

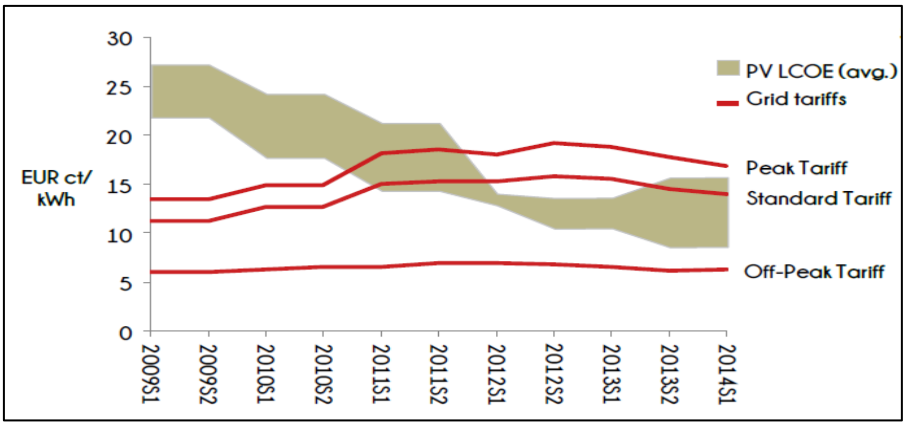
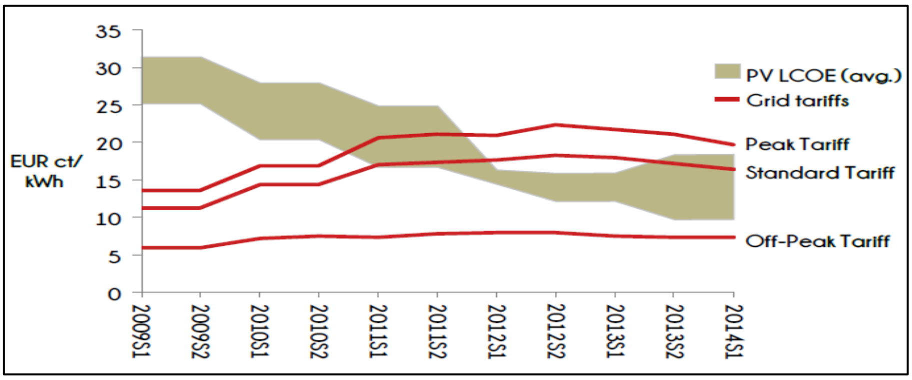


Figure 19: Las palmas´ grid parity proximity *(source: grid parity monitor)*

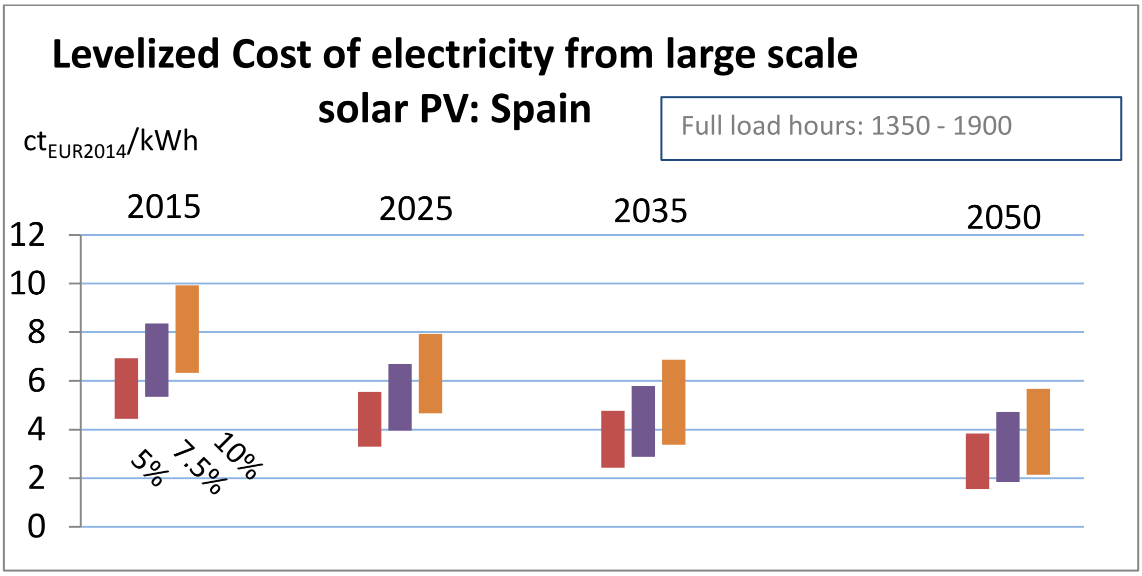


From 2012 the LCOE average has usually been below the peak and standard tariff. From that point it is economically efficient to start producing energy by your own PV panel instead of buying the energy to the retail company.

But this trend is just the beginning. Some surveys as the one carried out by Agora energie wende have forecasted the LCOE with a horizon of 35 years. If we have a look at Spain, the levelized cost is expected to decrease dramatically in the next years; this is going to make PV investment even more profitable.

For instance, in 2035 which approximately is the year in which the estimation of PV installed capacity will be calculated, with a WACC of 10% the LCOE is expected to be around 0.07 €/KWh (Mayer, 2015). If we think that the price of electricity in Spain is around 0.12 €/KWh nowadays and it is expected to rise in the next years, it is very reasonable that by 2030 there will be an enormous penetration of PV in Spain.

Figure 20: Forecast of levelized cost of capital in Spain (*Source: own elaboration via Agoraenergiewende*)



CONCLUSIONS FROM GRID PARITY:

- Grid parity represents a very good opportunity to create a cost-effective PV market based on self-consumption in Spain. For that reason, the regulation must be reviewed in order to incentivize this activity.
- A compensation for the excess electricity produced by PV installations and feed it into the grid must be adopted by the government.
- It is not probably to have 100% self-consumption for a residential consumer, Therefore the excess of energy has to be evaluated in each consumer.

3. Introduction of the problem: PV potential and economic implications in Spain

3.1. Estimation of PV potential for self-consumption by 2030

Currently there are a lot of companies are trying to forecast the future of the photovoltaic sector. Every month new reports are issued by specialist companies in the sector that conclude that PV technology has a brilliant future.

If we have a look at the report recently issued by Mercom capital, the PV market will grow around 57.4 GW in 2015 (Mercom capital group, 2015). The markets that will continue growing steeply will be China, Japan and the US. They will install around 60% of the total new installed capacity in the world.

It is not only Mercom Capital which estimates a great future for the PV but GTM Research has also published a forecast for the year 2015. GTM states that the photovoltaic market will approximately grow 55 GW in this year, which is not far away from the estimation that Mercom has published.

As it has been mentioned in the chapter 2.4. PV market, the general reduction of costs in all the segments in the photovoltaic industry, not only in the photovoltaic panels but also in the inverters and storage batteries as well as the improvement in efficiency are going to make that this and coming years are expected to be very promising for the photovoltaic technology.

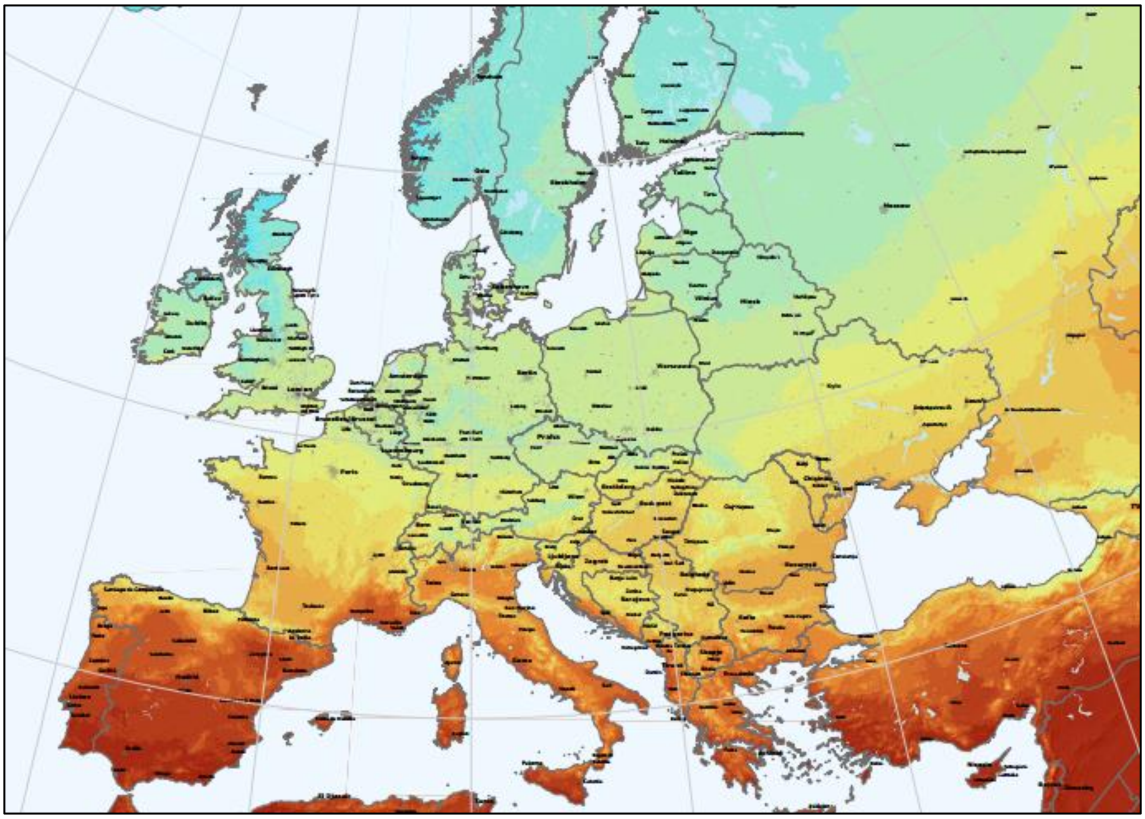
From 2009 the cost of photovoltaic has decreased up to 75% and the electricity produced by big projects cost around five times less than five years ago. This trend is expected to continue evolving and lower prices will make PV the most competitive technology in the future.

Spain has one of the highest photovoltaic potential in Europe. However, it is not working properly in deploying an amount of photovoltaic technology that will be beneficial for the country. On the other hand, other countries within Europe have acted very actively in the last years, especially Germany and the UK.

Just to have a clear idea of the potential that Spain has regarding photovoltaic, it is only necessary to have a look at the photovoltaic solar electricity potential in the European countries. PVGIS[7] offers an assessment of the electricity generation from photovoltaic systems in Europe. From the Figure 21 it can be seen that obviously southern countries have greater potential than Nordic countries.

[7] Photovoltaic Geographical Information System provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa and South-West Asia

Figure 21: Photovoltaic solar electricity potential in European countries (*source: PVGIS*)



PVGIS calculates the potential for the optimal inclined photovoltaic modules. In any case, countries with very high potential in Europe like Spain are not behaving in line with the possibilities that the weather provides in such countries.

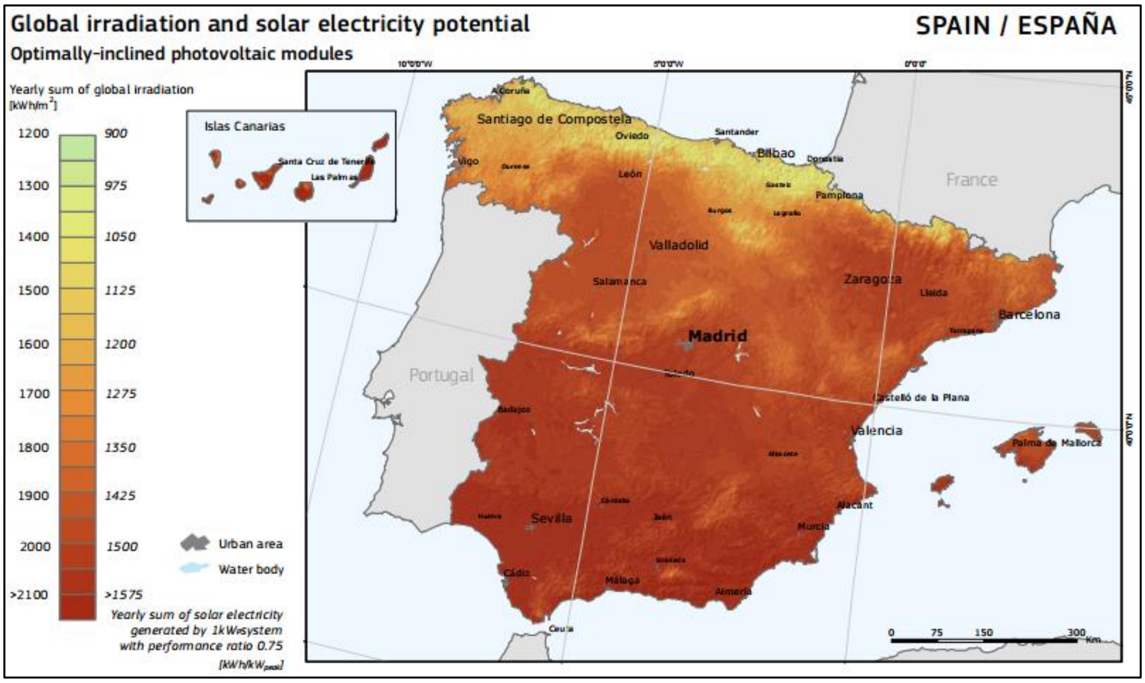
Nevertheless, other countries like Germany and the UK with much lower PV potential have experienced an enormous photovoltaic penetration in the recent years. For instance, The UK has reached 5000 MW installed and Germany over 38000 MW (UK government, 2014) (Greenteachmedia, 2014)

In the contrary, Spain who became the largest solar market for solar power installations in 2008 stopped this trend and nowadays only few MW are installed every year. The photovoltaic capacity installed in Spain is 4.428 MW (Red Electrica España, 2015) which is considerably less than Germany and the UK.

Taking into account the great possibilities that the weather offers to the Spanish country, it is reasonable to think that Spain may be one of the countries in Europe with the highest growth regarding photovoltaic installed capacity in the future.

To assess the potential that Spain has regarding photovoltaic, the Figure 22 shows the map of Spain with the global solar irradiation. From this map it can be concluded that the resources that Spain counts on are not being exploited properly.

Figure 22: Global irradiation and solar electricity potential in Spain (*Source: PVGIS*)



In order to compare Spain with the two countries mentioned before, the global irradiation and solar electricity potential is going to be assessed. In the UK, the places with the highest solar irradiation are in the south. These areas have a maximum global irradiation of around 1300 KWh/m2 a year

In the case of Germany, the areas with highest potential are in the south-west. These areas have a global irradiation that fluctuates from 1000 to 1400 KWh/m2 a year.

Looking at the map of Spain provided by PVGIS with the global irradiation and solar electricity potential, some conclusions can be made. For instance, if the northern areas of Spain are assessed, they have the lowest potential within the country, the potential those areas have is between 1300 and 1500 KWh/m2 a year. Even though, this potential is higher than the maximum potential areas in Germany and The UK have.

Furthermore, some areas in the south and the south-east in Spain have almost double potential than the areas with highest potential in the UK or Germany. In general terms, whole Spain has a very large PV potential, especially from the middle to the south and the islands.

In terms of number of hours of solar radiation, the average for the whole country is around 2588 hours a year (AEMET, 2012). In the north, regions like Cantabria or Basque Country present the lowest number of hours with around 1600 hours of sun radiation a year.

In the south and east-south, regions like Andalucia and Murcia have the highest potential and the highest number of hours of sun radiation with around 3200 hours a year. Other regions like Castilla La Mancha, Extremadura, Aragon and Valencia are good candidates to install photovoltaic panels since they account for around 3000 hours of sun a year.

Spain seems to start recovering from the financial crisis that has frustrated the country in the last 7 years and new investments are expected to come in the coming years. In addition, target set by the European Commission regarding the environment and specifically carbon emissions will impulse the country to a generation mix mainly composed by renewable sources.

All these facts make think that Spain may install a large amount of PV capacity in the near future. This will not be possible without a regulation that supports self-consumption. For this reason, the objective of the chapter 4 will be estimate the maximum capacity that could be installed for self-consumption in the medium-term, more specifically in 2030, taking into account that the regulation in place will support and incentivize the practice of self-consumption.

3.2. Economic implications of self-consumption in Spain

3.2.1 Spanish electricity tariff

As it has been mentioned in the chapter 2.3. Self-consumption and in the Figure 15 , self-consumption has many advantages, not only for the self-consumer but also for the system. Nevertheless, it has also some drawbacks; probably the most important one from the economic point of view is the transfer of access tariff from self-consumers to normal consumers.

To understand why self-consumption will imply the transfer mentioned, it is essential to have a look at the Spanish electricity tariff in order to understand how it is structured and which are the parts that a self-consumer would pay and the ones that would not pay.

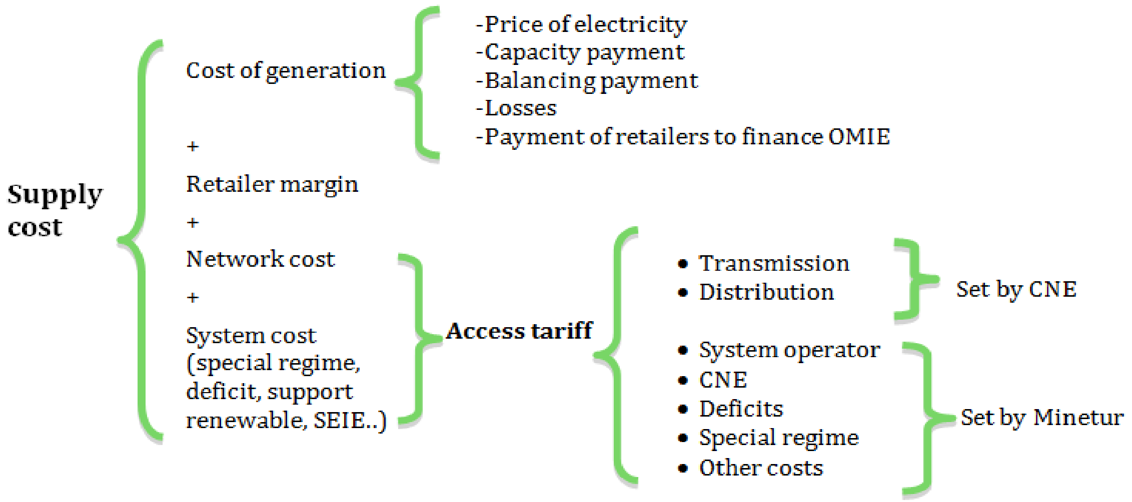
The Spanish electricity tariff is composed by two parts; one part is subject to the capacity contracted and other part to the energy consumed. The electricity bill is completed with a fee for the rent of equipment and the corresponding taxes.

The supply cost is composed by the cost of generating the energy and the regulated costs. The cost of generation is subject to the spot market, capacity payment, balancing payment and losses between others. The regulated costs include the network costs and system costs which are mainly political costs as deficit, primes to the special regime, CNE and so on.

It is important to distinguish between the costs of generating the energy and the regulated cost because as it will be explained in the following pages, the regulated costs will be included in the access tariff whereas the generation costs will be independent of the access tariff.

To have a clear idea of the total costs of the system, the Figure 23 Shows the different costs the system incurs when supplying energy:

Figure 23: Cost of the electric system (*source: own elaboration)*



The aim of the access tariff is to pay all the regulated costs of the system, which can be classified in two. The first ones are the network costs which are the ones incurred when building the lines that will transport the energy from the generation plants to final consumers. These costs are calculated following the methodology established by the CNE[8], they are computed taking into account the peak capacity.

The second part of the system costs are the political costs, in other words, regulated cost not related to the network costs as it can be the special regime or the deficit. It is important to mention that these costs do no depend on the capacity contracted or the energy consumed; therefore they should not be included in the access tariff. In addition, there is no methodology to calculate those costs not related to the network. Minetur sets that costs.

As it has been previously mentioned, the access tariff formula is composed by a term related to the capacity contracted, a term for the energy consumed and if it were the case, a term for the reactive energy. So, the capacity term depend on the power contracted whereas the energy term depends on the consumption. In general terms the access tariff will be:

Equation 2: Access tariff

$$\text{Access tariff} = Pt\ (€/KW) + Et\ (€/KWh)$$

During the last years, the weighted average for the variable access tariff (MWh) and the fixed access tariff (MW) has changed. In the order IET/107/2014 and 1491/2013 in which the access tariff were reviewed, the part related to the power was increased. The Table 2 shows the changes applied in the weighted average between the fixed term and the variable term since 2013.

[8] CNE is the energy regulator in Spain

Table 2: weighted average (%) for the fixed and variable access tariff (*source: own elaboration*)

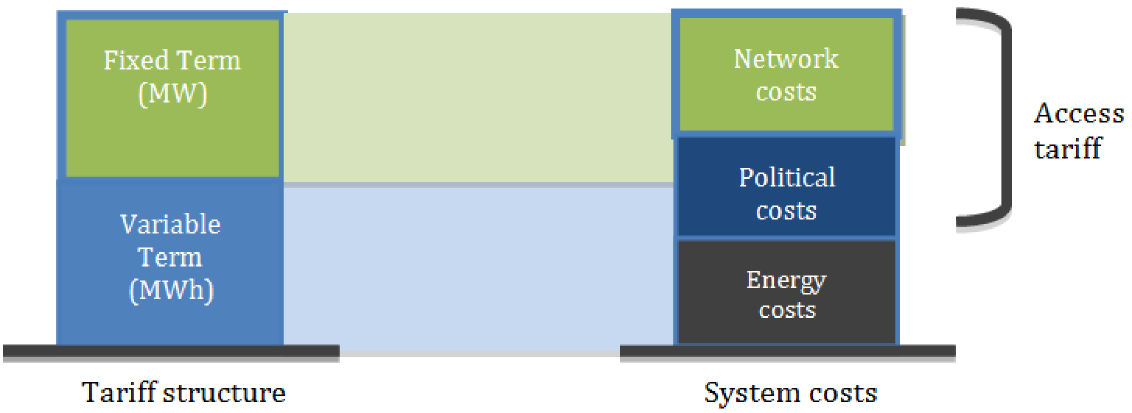
Access tariff	January 2013	December 2013	February 2014
Fixed term	35	50	60
Variable term	65	50	40

The variable part of the access tariff did not cover the recognized costs. Until July 2013 when the 1491/2013 entered into force, the energy term accounted significantly more than the power term. However, the balance has been shifted in the last years. The possible arrival of self-consumption and the deficit are the main reasons to shift the balance.

Since August 2013 the capacity term increased and the energy term decreased and lately, since 2014 the fixed term accounts for more than the energy term. This structure is not sending the right economic signal to consumers since consumers will not reduce significantly the final bill even consuming efficiently. This has resulted in many consumers reducing the capacity installed in order to decrease the final price of the bill.

To understand the relationship between the costs of the system and the tariff structure, the Figure 24 represents graphically this relation.

Figure 24: Relation between system costs and tariff structure (*source: own elaboration*)



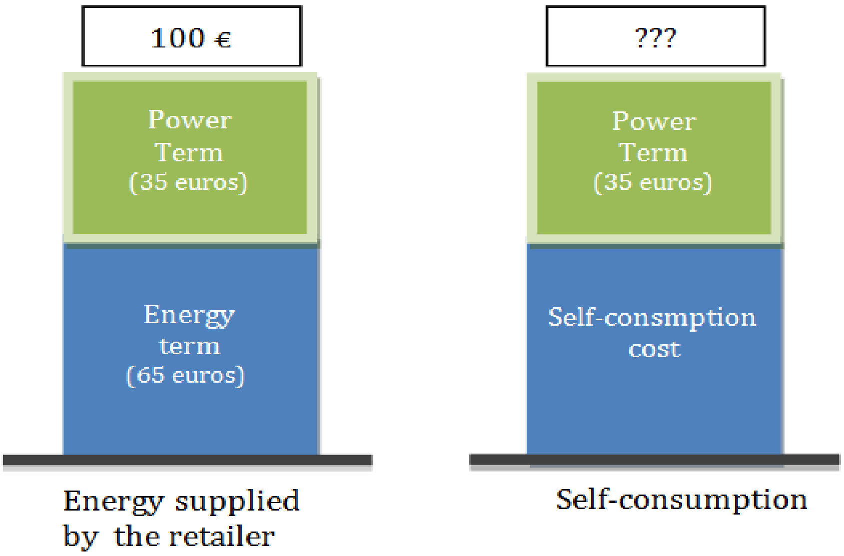
It can be seen that part of the regulated costs are paid by the variable term. This is the reason why self-consumer will not pay part of the regulated costs. The tariff should not be designed in that way; regulated costs should be entirely paid by the fixed term and the variable term should only be paid through energy costs. The following chapter is devoted to explain the economic implications of an inefficient tariff when a large penetration of self-consumption is in place which is the case that this thesis is focused on.

3.2.2. Economic implications of self-consumption

To properly assess the economic implications of self-consumption it is reasonable to analyze both the self-consumer and the system. As it has been mentioned in the chapter 2.4.1. PV grid parity, a normal consumer will decide to begin producing his/her own energy when the price of producing with the PV system is lower or equal than the price of buying the energy to the retailer.

If a consumer is supplied by the system, he/she will pay the fixed term for the power contracted[9] (€/KW) and the variable term (€/KWh) for the energy consumed. A consumer with a capacity installed of 4.6 KW and energy consumption of 500 KWh will pay around 100 euros every 2 months[10] (65€ for the energy and 35€ for the power contracted)

Figure 25: Comparison of payment between self-consumer and energy consumer (*source: own elaboration)*



However, if the same consumer had a PV installation for self-consumption, he/she would pay the same amount of money for the power contracted but he/she would save part or whole of the energy term[11]. Therefore, the money to be paid would be 35 euros for the capacity contracted and the price of producing with the PV installation.

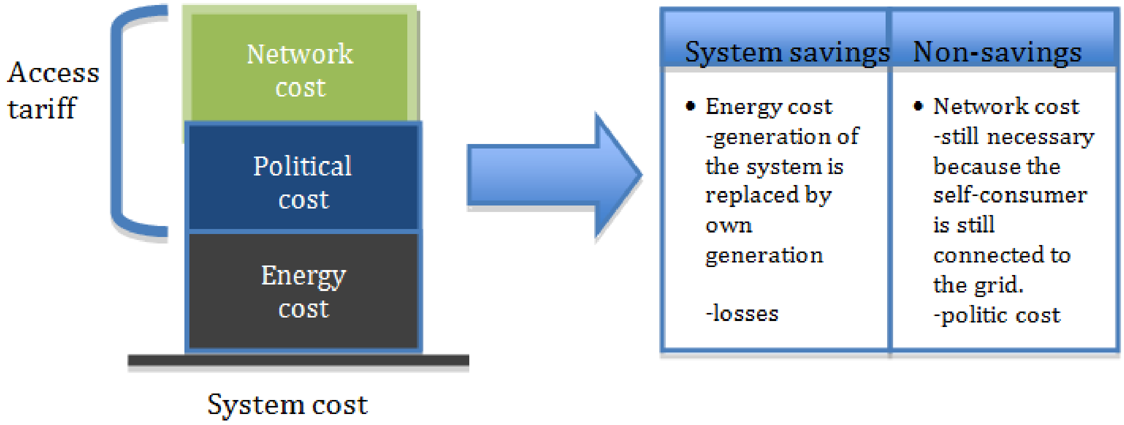
Obviously, if the cost of producing energy with the PV is lower than buying it in the market, it will worth it generating the energy with the PV installation. Therefore, from the self-consumer point of view this action will be profitable.

[9] The average power contracted is around 3 and 4 KW in Spain
[10] Considering the he/she is under PVPC, the price of the energy is 0.13 €/KWh and the price of the power contracted is 0.12 €/KW/day
[11] It is not likely that the PV installation can supply all the energy consumed since in the night and early in the morning the PV will not produce energy. This would be possible with a battery.

Nevertheless, it is important to analyze self-consumption from the view of normal consumer and the system.

When the self-consumer is producing his/her own energy, the system will save the cost of producing that energy. However, the system still has to pay the regulated costs, in other words, the network and political costs. The Figure 26 shows the costs that the system avoids when the self-consumer is producing his/her own energy.

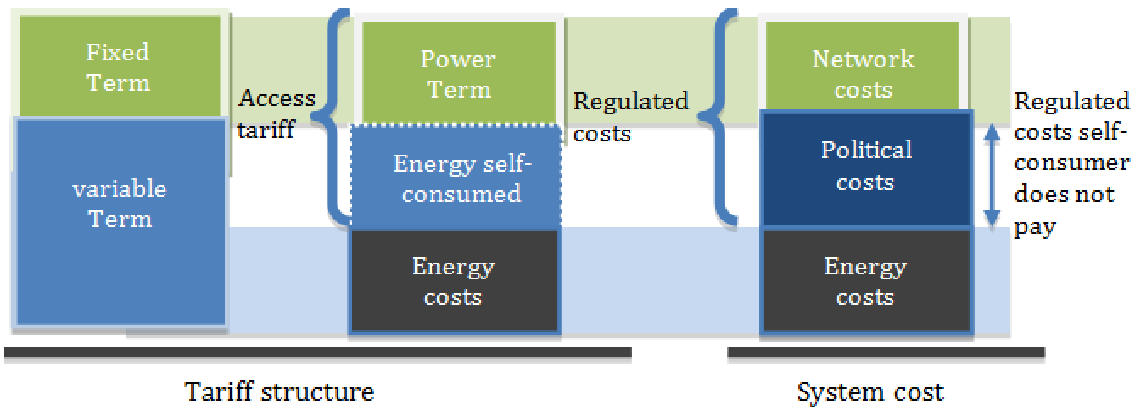
Figure 26: System savings due to self-consumption *(Source: own elaboration)*



Then, the self-consumer will not pay the part of the regulated costs that are within the variable term that he/she was paying when was supplied by the retailer. This happens due to the inefficiency in the tariff; the variable term is not only used to pay the energy consumed but also to pay part of the regulated costs.

To sum up, the self-consumer is not paying part of the regulated costs recovered by the energy consumption since the energy consumed is now provided by the photovoltaic panel. At the end, self-consumers are receiving an implicit subsidy. The Figure 27 shows in a graphical way the economic implications of the self-consumption.

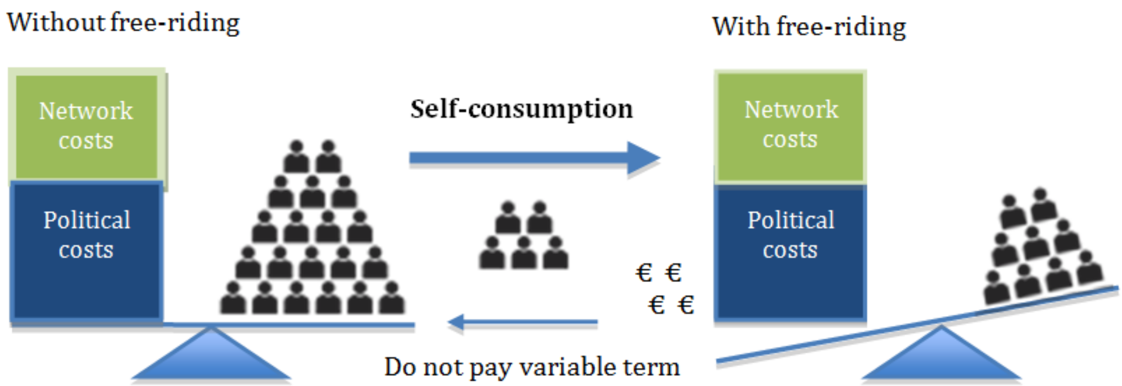
Figure 27: Regulated costs avoided by self-consumer (*source: own elaboration*)



These regulated costs that the self-consumer is not paying do not disappear but they still have to be paid. Therefore, these costs would be transferred to the rest of consumers; this would imply an increase of the tariff since there are fewer consumers to pay the same costs.

Consequently, if the tariff rises, the price of self-consumption is more competitive, then it is reasonable to think that more consumers will decide to self-consume and this will result in a vicious cycle in which at the end only few consumers will cover the regulated costs.

Figure 28: Free riding due to self-consumption (*source: own elaboration*)

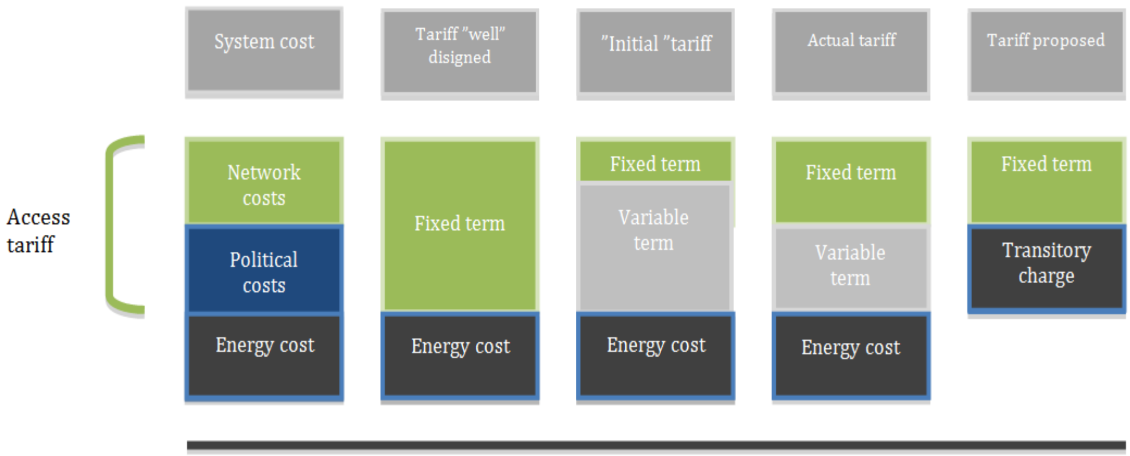


Therefore, It has been demonstrated that with the current tariff the system would not be sustainable if there is a high penetration of self-consumption. The electricity tariff should be modified: the regulated costs of the system should be paid through the fixed part (power term) and the variable cost of the system should be recovered though the variable part (energy term).

As commented in Table 2, since February 2014 the weighted average of the access tariff is 60% the fixed term and 40% the variable term. According to this, self-consumers with a PV installation capable to supply all the energy required will not pay 40% of the regulated costs.

To avoid this situation, it has been proposed a Royal Decree for self-consumption (see 2.3.1 Self-consumption in Spain) in which a transitory charge must be paid for the energy self-consumed in order to recover the regulated costs not paid by self-consumers.

Figure 29 Tariff structure and self-consumption (*source: own elaboration*)



What it seems reasonable is to remove from the variable term of the access tariff all the political costs because they are not related to the consumption. In any case, they should be included in the fixed part of the access tariff.

Due to those facts, it is interesting to estimate the economic implications that a high PV penetration in Spain by 2030 will have. At the end, the purpose is to calculate what would be the maximum PV capacity installed for self-consumption and the money that the system will not receive due to such penetration in the medium-term.

This thesis will be focused on the money not received from consumers connected to the low voltage <1KV, with and installed capacity <10KW that in the case they did not self-consume, they would be under the PVPC tariff.

4. Methodology applied to calculate the maximum PV potential and money not recovered by the system due to self-consumption

This chapter is devoted to explain the methodology applied to estimate the PV capacity installed for self-consumption by 2030, the energy produced by the panels installed and the economic implications that such penetration may have. The chapter will be structured as follows:

- The first part will make an analysis of the different PV panels that nowadays exist and the one to be used in this thesis is chosen
- In the second part of the chapter the sectors where the PV capacity will be installed are identified
- The third part explains the scenarios created to estimate the capacity installed
- The fourth part is devoted to PVGIS, the software used to calculate the energy produced by the panels
- In the last part the methodology to calculate the economic implications of self-consumption is presented

4.1. Selection of PV panel

The first part of the process consists in choosing the PV panel to be installed. The selection of the right panel will have relevant consequences in the production of energy and in the cost incurred. For that reason, it is important to analyze the different technologies in place to have an idea of the most economic and efficient ones.

First of all, it is important to know which the components of a PV system are. A Photovoltaic system can be classified into three subsystems: PV modules, power electronics and BOS.

PV modules are composed by interconnected PV cells. The cells are the most important part of the modules since they are the responsible of converting the sunlight into electricity. The electricity produced by the PV system is in the form of direct current (DC) but the majority of the devices and equipment final users use need alternating current (AC).

Therefore, an electronic device is needed in order to convert direct current into alternating current. This will be possible thanks to an electronic device called inverter. BOC comprises the remaining components and procedures required to complete a PV system, including mounting and wiring hardware, land, installations and permitting fees. (SunShot, 2012)

4.1.1 PV module technologies

There are several module technologies that have been demonstrated commercially. Other technologies have been investigated and may be relevant in the future. This part of the chapter is going analyze the most common module technologies in order to have enough information to make the right decision regarding the cell to be installed.

SILICON CELLS

The first group of cells is the so called crystalline silicon cells. There are also called first-generation solar cells or traditional solar cells. These kinds of semiconductor dominate the world PV market with around 90% of the share (Fraunhofer institute, 2014). Within this variety, there a few types of silicon PV technologies on the market today; single crystalline silicon (c-Si), multicrystalline (mc-Si) and silicon heterostructures.

Crystalline silicon cell provides the highest energy conversion efficiency of all commercial cells and modules. Monocrystalline semiconductor wafers are cut from single-crystal silicon ingots. Multicrystalline semiconductor wafers are cut from directionally solidified blocks or grown in thin sheets. Monocrystalline ingots are more difficult, energy intensive and expensive to grow that simple block of multicrystalline silicon.

However, monocrystalline silicon produces higher-efficiency cells. The rated DC efficiencies of standard c-Si PV modules are about 14%–16%. A number of new or non-standard cell architectures—such as back-contact cells—are growing in importance because they offer the potential for significantly higher efficiency. Non-standard cell architectures tend to use high-quality monocrystalline wafers and more sophisticated processing to achieve module efficiencies of about 17%–21%. (SunShot, 2012)

THIN FILM

Thin-film PV cells consist of a semiconductor layer a few microns (µm) thick, which is about 100 times thinner than current c-Si cells. The most common ones are morphous silicon, CdTe, and CIG/CIGS. Most thin films are direct bandgap semiconductors, which mean they are able to absorb the energy contained in sunlight with a much thinner layer than indirect bandgap semiconductors such as traditional c-Si PV.

The most common thin-film semiconductor materials are cadmium telluride (CdTe), amorphous silicon (a-Si), and alloys of copper indium gallium diselenide (CIGS). Thin films are very sensitive to water vapor and thus have traditionally been encapsulated behind glass to maintain performance. Eliminating the need for glass through the use of “ultra barrier” flexible glass replacement materials is an important next step in thin film development.

Thin-film modules have lower DC efficiencies than c-Si modules: about 9%–12% for CdTe, 6%–9% for a-Si, and 8%–14% for CIGS. CdTe-based PV has experienced significantly higher market growth during the last decade than the other thin-film PV technologies primarily due to the success of First Solar, which utilizes CdTe technology. (SunShot, 2012)

MULTIJUNCTION CELLS

Multijunction cells utilize light at different wavelengths more efficiently than crystalline silicon cells through multiple stacked layers of semiconductors. Although more efficient at converting sunlight into electricity, they are currently less efficient economically due to their complexity and resulting manufacturing costs. This price premium has limited their application mainly to the aerospace industry, which is uniquely willing to pay more for their higher efficiencies. (GW solar institute, 2014)

THIN FILMS CELLS VS CRYSTALLINE CELLS

Then, the selection will be between thin film cells and silicon cell. Multijunction cells are not included in the selection because as we have seen, they are currently too expensive and the application they mainly have is for the aerospace industry.

Focusing on both alternatives chosen, besides the appearance of the modules, the relevant differences between them is their sunlight to electricity conversion efficiencies and power densities. For the same amount of power, crystalline modules require less space than thin-film modules and furthermore the latter presents lower efficiency conversion.

Single and multicrystalline modules typically have conversion efficiencies between 14% and 21% whereas thin film can have half of this between 8% and 14%. Thin film modules approximately need double space than crystalline modules to generate the same amount of energy.

Another advantage that crystalline modules have respect thin film modules is that they immediately stabilize the rated output power whereas thin film takes from 6 to 12 months to reach their stable rated output.

Not all are advantages for crystalline modules; they present higher reduction in power when cell temperature increases. For high temperature the crystalline module will produce around 5% less power than its nominal power whereas in the case of thin film, it would produce only 2% less power.

To have a clear idea of the main advantages and disadvantages that both technologies presents, the Table 3 makes a comparison between both that will very useful to make the final decision.

Table 3: Pros and cons of crystalline silicon and thin-film cells (*source: own elaboration via homepower*)

Advantages

Crystalline silicon	Thin-film
Highest power per area	Output less affected by temperature
Requires less racking & support material	Less manufacturing used
Fewer modules means lower shipping costs	Lower cost/watt
large number of module choices	Faster energy payback
Greatest inverter flexibility	More shade tolerant

Disadvantages

Crystalline silicon	Thin-film
Higher cost/watt	lower power/area
high temperatures affect out more	takes months to stabilize output
Low shade tolerance	twice as much rack material required
individual cell visibility	Higher shipping costs
	Lower series-string capacity
	limited inverter flexibility
	more combiner boxes

This analysis has been very helpful to choose the technology. Finally and after analyzing all the pros and cons the crystalline silicon has been chosen; the technology has been widely used and the performance is already known. In addition, although it is more costly than thin-film, some of the sectors where it will be installed may present lack of space. In line with this, crystalline silicon will allow us to install the same capacity in lower space.

It is also reasonable to think that consumer will go for the technology with higher efficiency because even if the prices are higher at the end it will pay off. (homepower, 2008)

4.2. Identification of the sectors to install photovoltaic technology

The second step is to identify the sectors where the PV panels will be installed. It is essential to analyze and assess which sectors will be the most accessible to install photovoltaic panels.

The sector where probably will be easier to install a PV panel is the domestic one: houses, single family houses and apartment houses.

4.2.1 Domestic sector

Within the domestic sector, the single family houses and houses are the most accessible. Therefore, they are a very good opportunity to install PV panels. To know in details what is the number of single family houses and houses in Spain, we have had to investigate through the different statistics published in the literature.

Probably the most reliable one is the National Institute of Statistics (INE).[12] According to the survey published by the INE in 2013 regarding houses, there are 5.8 million of single family houses and houses in Spain. (INE, 2013)

There is a high concentration of houses and single family houses in Andalucia, Cataluña and Valencia. This distribution is very relevant because Andalucia and Valencia are the regions with high solar irradiance, approximately from 1400 to 2000 KWh/m2 (see Figure 22) and more than 3000 hours of sun radiation a year (AEMET, 2012).

The Table 4 shows how houses and nº of hours of sun are distributed along the Spanish country:

Table 4: Distribution of number of houses and number of hours of sun along Spain (Source: own elaboration via INE)

Region	nº of hours of sun	nº of houses (x1000)
Cantabria	1541	87,1
Pais Vasco	1760	60,1
Asturias	1925	102,3
Galicia	2191	472,4
Navarra	2278	77,4
Rioja	2586	25,1
Cataluña	2678	656,7
Madrid	2700	337,8
Castilla Leon	2714	435,2
Baleares	2800	168,1
Castilla Mancha	3027	443,9
Aragon	3063	138,7
C. Valenciana	3068	599,6
Extremadura	3099	238,3
Canarias	3111	344,9
Andalucia	3173	1415,5
Murcia	3255	233,2
Total	44969	5836,3

[12] INE elaborates and distributes Statistics about different sectors in Spain

The other kinds of houses which are good candidates to install PV panels are the apartment buildings. Through the statistics published by the INE we have found out that there are 12.3 million of houses distributed along apartment buildings.

The regions where there is more concentration of building blocks are Cataluña with 2.3 million, Madrid 2.16 million and Andalucia and Valencia with 1 million each one. The Table 5 shows how building blocks are distributed along Spain and the nº of hours.

Table 5: Distribution of houses in building blocks along Spain (source: own elaboration via INE)

Region	nº of hours of sun	nº of houses (x1000)
Cantabria	1541	150,7
Pais Vasco	1760	830,7
Asturias	1925	357,2
Galicia	2191	598,1
Navarra	2278	172,8
Rioja	2586	104,3
Cataluña	2678	2289,6
Madrid	2700	2159,1
Castilla Leon	2714	596,1
Baleares	2800	271,1
Castilla Mancha	3027	341,1
Aragon	3063	399,8
C. Valenciana	3068	1396,4
Extremadura	3099	190,6
Canarias	3111	459,8
Andalucia	3173	1719,5
Murcia	3255	293,7
Total	2645	12330,6

4.2.2 Industrial sector

The industrial sector is the second sector in which PV panels will be installed. In Spain, there a lot of warehouses, small, medium and big companies. They could use part or whole of their rooftop to install PV installation. We believe that this sector presents a good opportunity to self-consume.

According to the industrial survey carried out by the INE in 2013, there are 191.075 companies in Spain. 175.977 of them are small and medium companies with less than 20 employees. Those companies in which the installation of a PV panel would result very difficult have been removed from the list. These companies refer as ones like coal, oil, wood and so on.

Thus, after that removal, there are 130.147 small and medium companies and 12.055 big companies. Unfortunately, the geographical situation of the companies is not available.

4.2.3 Commercial centers

Commercial centers also have a high photovoltaic potential. They usually are very big building with a lot space on the rooftop to install PV panels. The installation would be rather easy, so these centers would be included in the calculation to estimate the capacity installed by 2030. According to the statistics published by La Caixa[13], there are 655 commercial centers distributed along the Spanish country. They are distributed as shown in the Table 6

Table 6 Commercial centers distributed along Spain

Region	nº of commercial centers
Cantabria	6
Pais Vasco	31
Asturias	18
Galicia	42
Navarra	8
Rioja	4
Cataluña	55
Madrid	132
Castilla y Leon	31
Baleares	9
Castilla la Mancha	26
Aragon	14
C. Valenciana	63
Extremadura	19
Canarias	48
Andalucia	125
Murcia	24
Total	655

[13] La Caixa is a Spanish bank

4.3. Scenarios proposed

Once we have identified the sectors where the PV panels will be installed, it is necessary to proposed different scenarios in order to estimate the penetration; a low, medium and high penetration scenario.

Obviously, depending on the sector, the scenarios will be different since there is no the same expectation of PV penetration in the domestic sector than in the industrial sector, for instance.

4.3.1 Scenarios for the domestic sector: houses and single family houses

It is reasonable to suppose that in the regions with high solar radiation the penetration of photovoltaic panels will be larger than in regions with low radiation. Therefore, the penetration will be subject to the number of solar radiation.

According to this, Murcia which is the region with the highest number of sun radiation will be the one to set the maximum penetration for the different scenarios. The penetration will decrease proportionally to the number of hours of sun radiation.

The average capacity installed at houses in Spain is around 4 KW; therefore it has been decided to install 4 KW in this sector. Taking into account that the regulation will incentive self-consumption, the houses will be able to consume whole the energy produced. In the event that part of the energy is not consumed, that energy may be injected into the grid, getting some prime or it may be used in other hours through net metering.

In line with the capacity installed, it is worth mentioning that the scenarios proposed will not be subject to the installed capacity but to the solar radiation. Thus, in all scenarios the capacity installed per house will be 4 KW for this sector; however the number of houses to install a PV panel will be different depending on the penetration set in each scenario. Therefore, the total capacity installed for all the houses will be different for each scenario.

It has been studied 3 scenarios, in the first one the maximum penetration has been set to 30%, the second to 50% and the third to 80%. The Annex 1 shows the tables with the different scenarios, in which the regions, number of hours, penetration and number of houses to install PV panels is shown.

4.3.2. Scenarios for the domestic sector: Houses in building blocks

For the building block the scenarios studied will include a lower penetration than in houses. When installing a PV installation in a building block there many people involved. Some people may claim that they do not want to install it due to economic reasons or other they just do not want. At the end, the decision to install it or not will depend on many people; this makes us think that the penetration in building will not be as high as in houses.

The Table 5 shows the number of houses distributed in building blocks. However, the number of building blocks in Spain is not available. At the end what we want to know is the number of building to install the PV panels, thus, they have to be calculated.

According to the survey carried out by the INE in 2011 the number of floors per building in average in Spain is 4. In some cities like Madrid the average is 5.3 and in the Basque country 6. The region with the shorter buildings is Extremadura with 2.6.

To find out how many houses are per building, it has been estimated that in average there are 2.5 houses per floor. With this assumption, we come up that Spanish buildings have an average of 10 apartments per building.

As we know that there are 12.3 million of houses distributed along building, it is possible to estimate how many building there are dividing the total number of houses by the number of houses per building. This results in 1.2 million of buildings.

This capacity has been estimated through the space needed to install a PV panel. According to some manufacturers PV seller like solarmania[14], the efficiency that monocrystalline panel has is around 14% and 15%. Therefore it is necessary around 1 m2 to install 142 W. So it would be necessary around 29m2 to install 28KW which is reasonable taking into account the dimension of the buildings.

The scenarios considered for building blocks have been a minimum scenario of 13%, a medium of 25% and a maximum of 50%. In all scenarios the capacity installed per building will be 28 KW. The Table 25, Table 26 and Table 27 in the Annex 1 show with the results obtained for these scenarios.

4.3.2. Scenarios for the industrial sector

Big companies as well as small and medium present a good opportunity to install PV modules. For the industrial sector there is no availability regarding the geographical situation of the companies. For this sector in the low penetration scenario we have supposed a penetration of 5% for small and medium companies and 10% for big companies.

[14] Company dedicated to sell PV panels

In the second scenario, there will be a 15% penetration for small and medium companies and 20% for big companies. In the high penetration scenario 25% of small and medium companies will install PV panel and 50% the big companies

The capacity installed for small and medium companies will be 42 KW. Following the explanation of the chapter 4.3.2. Scenarios for the domestic sector: Houses in building blocks , it would be needed 300 m2. In the case of big companies there will be more space to install panels; therefore the capacity installed will be 84 KW. For this capacity it is necessary 600 m2.

In the Annex 1 the Table 28 Table 29 Table 30 represent the result obtained from this sector for the different scenarios considered.

4.3.3. Scenarios for commercial centers

There are 655 commercial centers in Spain (see 4.2.3 Commercial centers). All of them together have a total surface of 15.5 million of m2. This means that in average each shopping center will have 24200 m2. Commercial centers usually have more than one floor. We will consider they have an average of 2.5 floors.

In the low penetration scenario, the penetration will be 25% for the regions with maximum solar radiation. With this information it has been calculated that it will be a total surface available for the installation of PV panel of 1.3 million m2. Considering that 1m2 is needed to install 0.14 KW the power install for this penetration will be 187 MW.

In the medium penetration scenario, 50% of the available capacity will be used to install photovoltaic panels. This results in 2.7 millions of m2. For this surface it will be possible to install 375 MW.

The high penetration scenario will consider a penetration of 80%. Therefore, 4.3 million m2 will be available for PV panels. This will results in a capacity installed of 599 MW.

The annex 1 shows the graphs with the results obtained for the different scenarios.

4.4. PVGIS: Software used to calculate the potential of PV panels installed

The last step is to calculate the potential of the different sectors where the PV panels have been installed. There are different softwares available to calculate the photovoltaic potential, some of them are free and others need a fee to be used.

Within the wide range of software available, we have opted to use the photovoltaic geographical information system (PVGIS). It is a research, demonstration and policy-support instrument for geographical assessment of the solar energy resource in the context of integrated management of distributed energy generation. PVGIS combines a team expertise from laboratory research, monitoring and testing with geographical knowledge to analyze technical, environmental and socio-economic factors of solar electricity generation. (Dr Huld & Dr Dunlop, 2007)

PVGIS has been developed by the European Commission at the joint research center for renewable energy. The software provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia.

This software has been used as it provides quite complete information about the potential in any area of Spain and it is very reliable according to many papers published, for instance (Abdelfettah & Mouncef, 2007).

4.4.1. Methodology applied by PVGIS

The methodology applied by PVGIS is the geographical information system (GIS) GRASS. It combines geospatial data with known correlations for estimation of the performance of different kind of photovoltaic cells like crystalline/thin film silicon modules under varying irradiance and temperature along a wide range of areas.

This method has been used in Europe, Africa, and Mediterranean basin as well as in the South-West of Asia. Applying this methodology it can be assessed the PV performance of any geographical location in the areas already mentioned.

The software is able to calculate the potential of an area just entering the Peak power and the technology required. It is not necessary to introduce the nominal efficiency, this is only necessary to calculate the surface of the modules. This is one the drawback found on this software.

The nominal peak power is measured as the power output of the module under standard test conditions (STC) which are 25° C, 1000W/m2 and a solar spectrum corresponding to an air mass of 1.5. Therefore, if the modules were 100% efficiency, the energy output would be 1000W per 1m2. But PV modules are far from being 100% efficient; in fact, the one we have considered to calculate the space needed has an efficiency of 14%.

The efficiency under standard condition will be called eff_{nom}. So, if the P_{pk} is the nominal peak power and *A* is the area of the modules, the formula to calculate the peak power is

Equation 3: Peak power (*source: own elaboration via PVGIS*)

$$P_{pk} = A * eff_{nom}$$

Since the software does not have access to the area and nominal efficiency, to calculate the power output is necessary to know the irradiance *G* and the real module efficiency, this one is a function of the module temperature T_m and the irridance. The actual power is calculated as:

Equation 4: Actual power (*source: own elaboration via PVGIS)*

$$P = G/1000 * A * eff(G, T_m) = G/1000 * A * eff_{nom} * eff_{rel}(G, T_m).$$

The actual efficiency is calculated putting together the nominal efficiency and the relative efficiency. If the formula 3 and the formula 4 are combined, we get:

Equation 5: Calculation of final power (*source: own elaboration via PVGIS)*

$$P = G/1000 * P_{pk} * eff_{rel}(G, T_m).$$

Then if the relative efficiency and the nominal peak power are known, there is no necessity to provide the nominal efficiency or the area to calculate the actual power. So, the software actually does not need the nominal efficiency. However this would be useful to know the area needed.

Yet, the program still needs the relative efficiency. The method that PVGIS applies to calculate the PV output is based on a mathematical formula that takes into account the following effects:

- The temperature of the module, which directly affect the efficiency of the PV
- The light intensity, almost all the modules decreases its efficiency with low light intensity.
- The reflection of the light from the modules´ surface. So the angle at which the light reaches the module is very relevant.

To have access to the solar radiation, the software used a computational approach that is based on a solar radiation model called r.sun and a spline interpolation techniques s.surf.rst and s.vol.rst which are implemented within GIS software GRASS which is completely free. The rsun model estimates direct, diffuse and reflected components of the clear-sky and real-sky global irradiance and irradiation for horizontal or inclined surfaces.

Regarding the temperature used by the software, it is provided by 800 ground stations over the period 1995-2003. The stations measure the temperature at 6, 9, 12, 18 GMT. For each station the monthly and yearly averages of the temperature are calculated.

The software does not take into account the solar spectrum; therefore this method could not be used for those technologies that strongly depend on the solar spectrum as it the case of amorphous silicon modules.

The formula that the software uses to calculate the relative efficiency used in the formula 5 is the following one:

Equation 6: Relative efficiency (*source: own elaboration via PVGIS)*

$$eff_{rel}(G^{'},T^{'}_{m}) = l + k_1 \ln(G^{'}) + k_2 \ln(G^{'})^2 + k_3 T^{'}_{m}$$
$$+ k_4 T^{'}_{m} \ln(G^{'}) + k_5 T^{'}_{m} \ln(G^{'})^2 + k_0 T^{'}_{m}{}^2$$

The coefficients K_n depend on the technology installed. To estimate those values, there has been made a comparison for each of the different technologies. For the case of crystalline silicon which the cells we are interested in, a number of calculation have been made on different PV modules. All the data have been combined to make an estimate for an average crystalline module.

The temperature of the module $T_m$is calculated as:

Equation 7: Temperature of the module (*source: own elaboration via PVGIS)*

$$T_m = T_{amb} + k_t G$$

In which the K_t will depend on the mounting used. As we have considered a free-standing the value for K_t is estimated as 0.035 °C/(W/m2) which have been based on measurements at the laboratory.

As all models, PVGIS may be affected by uncertainties and the chain of measurement. For instance, the ground station measurement may be miss some data and the not be interpreted it. The pyranometer may be dirty, covered with snow or frost. There may be some uncertainty regarding the diffuse irradiation. In addition, the software estimates the performance of PV as a function of instantaneous value of solar irradiance and air temperature.

Therefore, it there is no instantaneous data but only long-run average values, it is probable to make a mistake. The developers of the software have estimated that using average data will make that PVGIS overestimate the output power in approximately 1%. This is mainly provoked because when using averaged data and extra loss in module efficiency is not taking into account.

At the end we have concluded that although the software may present some uncertainties, for the purpose of the thesis is sufficiently reliable. PVGIS prediction is valid for a long period of time as one year; nevertheless it is not that valid if the periods of time considered are short like one month because of some discrepancies between estimated and expected values. (Abdelfettah & Mouncef, 2007)

PVGIS INTERFACE

PVGIS´ interface is very simple for any user with reasonable knowledge about the subject. Although there are some things that could be improved as the presentation of tables and graphs obtained, in general terms it is very handy.

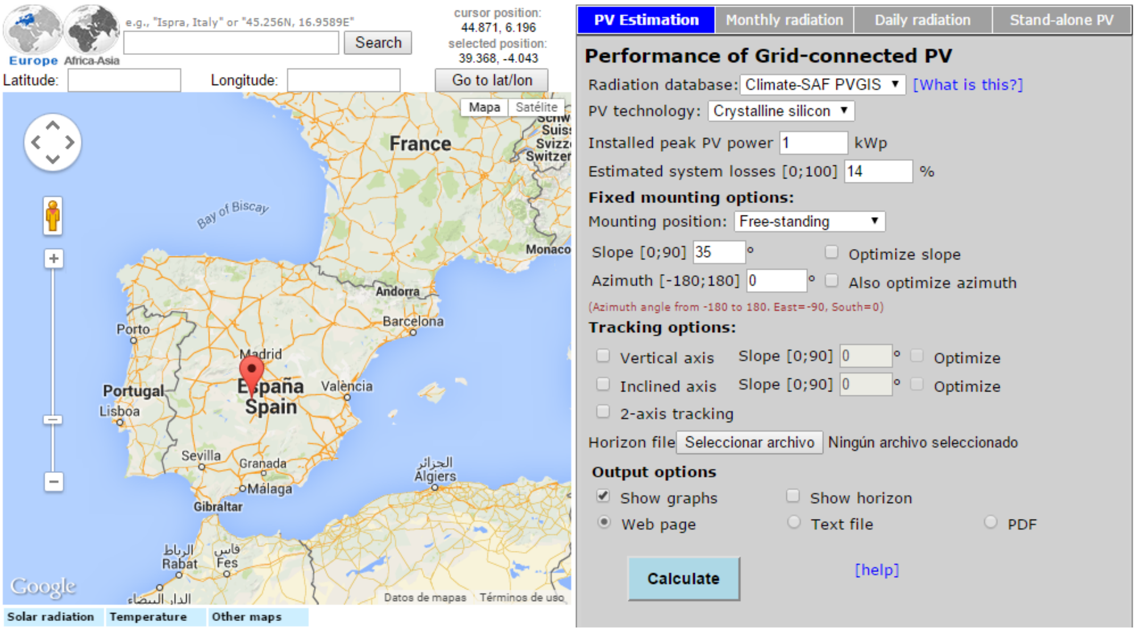
The first input to provide is the PV technology, at the moment PVGIS is able to estimate losses due to temperature and irradiance effects for crystalline silicon cells, thin film made from CIS or CIGS and thin film from cadmium telluride (CdTE). As it has been explained in the chapter 4.1. Selection of PV panel , we have opted to install crystalline silicon cells.

The next input to introduce is the peak power, we have estimated different peak power for the different sectors (see section 4.3. Scenarios proposed). PVGIS can also be provided by the estimated system losses as it may be lower power injected into the grid than the produced by PV panels. This is due to losses in the cables, power inverters, and dirt. As we cannot measure those losses we have applied the one suggested by PVGIS which is 14%.

The mounting position selected has been free-standing. So, the modules are mounted on a small rack and the air can flow behind the modules which makes that the efficiency is not very affected. The inclination of the angle can also be chosen, however we have allow the software to provide the optimal inclination as well as the orientation angle.

For those systems that can track the movement of the sun, it is possible to choose among different options like vertical axis, inclined axis or two-axis tracker. In our case, we are not interested in this input so we will not fill it.

Figure 30: PVGIS´ interface (source: PVGIS)

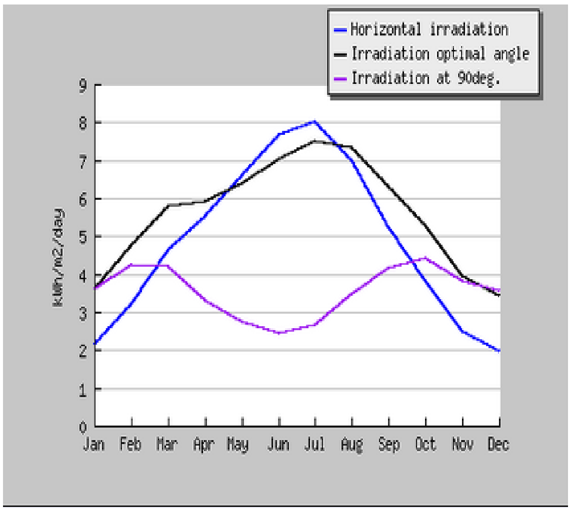


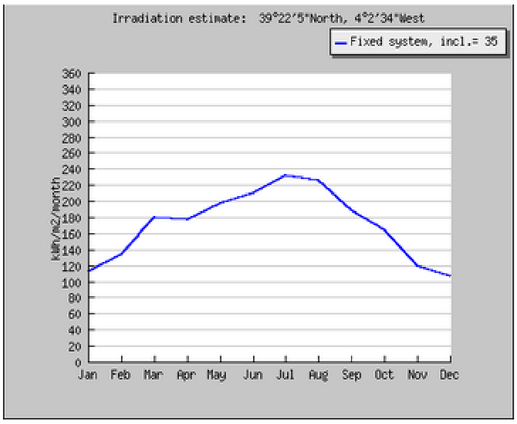
PVGIS gives the possibility to introduce a give horizon. The software uses as a horizon information of 3 arc-seconds (approximately 90m) therefore, there may be some things that are not included like houses or trees. We have opted to trust on the horizon provided by PVGIS.

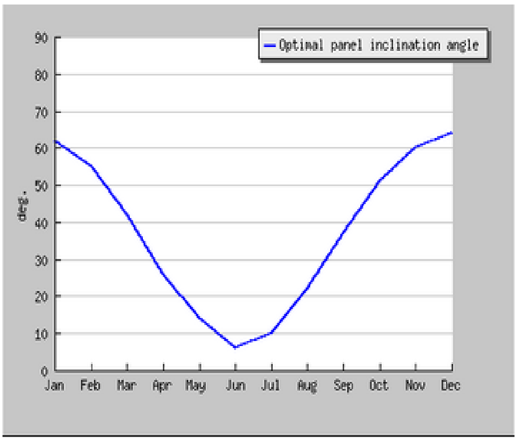
Once the model is run, the software provide a wide range of data as daily average electricity production, monthly average electricity production, daily average sum of global irradiation per square meter, irradiation on horizontal plane and optimal inclined plane, global irradiance of a fixed plane, diffuse irradiance on a fixed plane, global clear-sky optimal angle inclination, average of temperature and number of heating degree days.

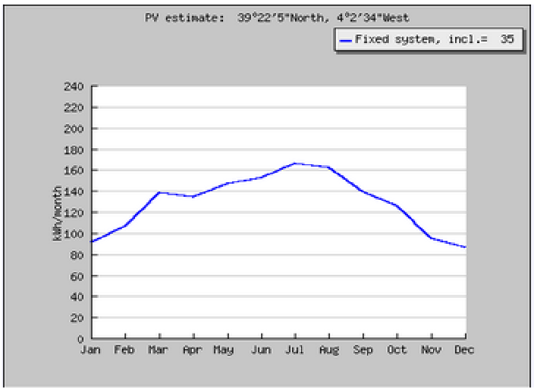
Furthermore, it also provides with graphs where irradiation is compared, the optimal angles, and the electricity production per months. So in general it provides the necessary data to have a clear idea of the performance of the PV panel.

Some of the output data provided by the software is shown in the following pages. It is important to mention that although the software displayed the most important graphs regarding the performance of the PV module, it is possible to have access to numerical data to build your own graph or tables.





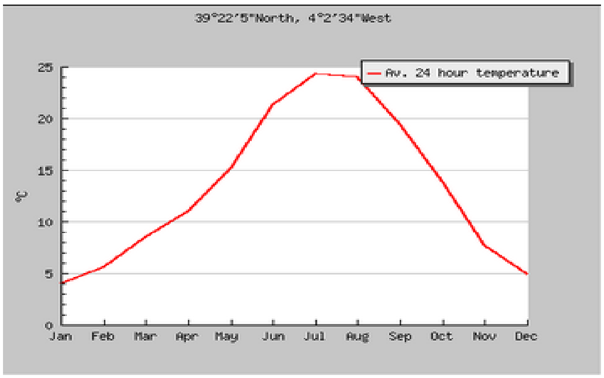




Solar radiation database used: PVGIS-CMSAF

Nominal power of the PV system: 1.0 kW (crystalline silicon)
Estimated losses due to temperature and low irradiance: 9.8% (using local ambient temperature)
Estimated loss due to angular reflectance effects: 2.5%
Other losses (cables, inverter etc.): 14.0%
Combined PV system losses: 24.4%

Fixed system: inclination=35°, orientation=0°				
Month	E_d	E_m	H_d	H_m
Jan	2.93	90.8	3.61	112
Feb	3.81	107	4.79	134
Mar	4.47	138	5.79	180
Apr	4.49	135	5.92	178
May	4.74	147	6.37	197
Jun	5.08	152	7.01	210
Jul	5.35	166	7.47	232
Aug	5.23	162	7.29	226
Sep	4.64	139	6.31	189
Oct	4.06	126	5.31	165
Nov	3.18	95.3	3.99	120
Dec	2.80	86.7	3.45	107
Yearly average	**4.23**	**129**	**5.61**	**171**
Total for year		**1540**		**2050**



4.4.2 Calculation of the PV potential

Once it is known the type of module to be used, the sectors where the module is going to be installed, the scenarios considered for each sector and the software for calculating the PV potential, it can be estimated such PV potential.

The methodology applied has been running the software for each region in order to get an average electricity production according to the installed capacity considered for each sector. This has been done for the sectors where the geographical data was available which are domestic and commercial centers (see 4.2. Identification of the sectors to install photovoltaic technology).

For the industrial sector where there is no availability regarding the geographical situation of the companies, an average of the energy produced by the modules in Spain has been applied. The next pages explain in more details how the potential has been calculated for each sector and region.

ENERGY PRODUCED AT HOUSES AND SINGLE FAMILY HOUSES

As it has been explained in the section 4.3.1 Scenarios for the domestic sector: houses and single family houses, the peak power to be installed per house has been 4 KW. Since we have the geographical situation of the houses, the software has calculated the PV potential that each house has in the different regions.

Then, a weighted average of the electricity production of the different cities within each region has been calculated. Since we have the number of houses per region that are going to install a PV module, it is possible to calculate the total energy production per region. To do so, it is only necessary to multiply the average electricity production per region by the total number of houses in each region.

For the different scenarios considered the capacity installed and the energy production will be different. To really understand how the energy electricity production has been calculated an example of Andalucia region is going to be explained:

If we have a look at the Table 25, the total installed capacity for Andalucia in the low penetration scenario has been 1656 MW (see 4.2.1 Domestic sector further information). The number of houses that are going to install PV modules according to this scenario is 414004. Then, we need to know how much energy is going to be produced.

To do so, the software has been run for each city of the region to estimate how much energy will be produced in each city. The Table 7 shows the total electricity production/year for each of the cities in the Andalucia region as well as the average electricity production. The average electricity production which for the case of Andalucia is 6461 KWh/year has been multiplied by the total number of houses that are going to install PV for the low penetration scenario.

Table 7: Total electricity production/year per city in Andalucia for single family houses in the low scenario (*Source: own elaboration via PVGIS*)

City	KWh produced/year (4KW)
Cadiz	6530
Sevilla	6390
Huelva	6530
Cordoba	6240
Jaen	6330
Almeria	6680
Malaga	6520
Granada	6470
Average	**6461**

The result obtained is 2674 GWh a year will be produced in the Andalucia region. The same methodology has been applied for the other two scenarios (medium and high penetration scenarios). For a medium penetration the energy production is 4458 GWh and for the high penetration 7133 GWh. The Table 38 shows the results obtained for the other regions.

ENERGY PRODUCED AT BUILDING BLOCKS

The methodology applied for building blocks has been the same than in houses. As it has been done in the houses, an example of how the energy production has been calculated for building blocks in Andalucia region is going to be explained:

The medium penetration scenario is going to be considered for this case. Having a look at the Table 29 , it can be seen that 46620 buildings are going to install PV modules in this scenario in Andalucia. As mentioned in the chapter 4.3.2. Scenarios for the domestic sector: Houses in building blocks, the peak capacity installed per building is 28 kW.

To calculate the energy produced by each city within the Andalucia region, the software has been run for each of them. The Table 40 shows the results obtained, the average production is 45228 KWh/year. If this value is multiplied by the total number of buildings that are going to installed PV modules, we come up with 2108 GWh. For the low and high penetration scenario the results obtained are 1096 GWh and 4217 GWh respectively. In the Annex 2 it is possible to see further details.

Table 8: Total electricity production/year per city in Andalucia for building blocks in the medium scenario (*Source: own elaboration via PVGIS)*

City	KWh produced/year (28KW)
Cadiz	45700
Sevilla	44700
Huelva	45700
Cordoba	43700
Jaen	44300
Almeria	46800
Malaga	45700
Granada	45220
Average	**45228**

ENERGY PRODUCED AT INDUSTRIAL SECTOR

As previously mentioned, we do not have information available regarding the geographical situation of the companies. For this reason, it has not been possible to apply the same methodology than in previous cases.

In this case, a weighted average of the energy production for the whole country has been applied. An example for one of the scenarios is going to be explained:

If we have a look at the Table 31 , the number of small and medium companies that are going to installed PV panels for the high scenario is 32537. As it has been explained in the section 4.3.2. Scenarios for the industrial sector the capacity installed per company will be 42 kW. If the software is run for each city of the Spanish country, the average energy produced for this peak power considered is 60650 kWh. If this value is multiplied by the number of companies that are going to install PV modules under the high penetration scenario, the value obtained for medium and small companies is 1973 GWh.

The same method has been applied for big companies, the only difference applied is the capacity installed, which has been 84 kW per company as explained in the section 4.3.2. Scenarios for the industrial sector.

ENERGY PRODUCED AT COMMERCIAL CENTERS

Fortunately, we have found geographical situation of the commercial centers along the Spanish country. To see how the capacity installed has been calculated see section 4.2.3 Commercial centers.

The methodology applied for this sector is going to be explained with an example of the Andalucia region:

Having a look at the Table 34, the power installed for the Andalucia region is 37.3 MW in the low penetration scenario. In order to calculate the energy produced by each city of the region, this capacity has been introduced in the software. A weighted average of the total electricity production of all the cities has been 59 GWh/year. The same method has been applied to calculate the other two scenarios.

City	MWh produced/year (37,25 MW)
Cadiz	58500
Sevilla	59500
Huelva	58500
Cordoba	58200
Jaen	59000
Almeria	62200
Malaga	60700
Granada	60300
Average	**59612,5**

As for the other sectors, in the annex 2 there is more information available regarding the energy production for this sector.

4.5. Calculation of money not received by the system due to self-consumption at domestic sector

The estimation of the PV potential for the domestic sector has been calculated in previous sections (see 4.4.2 Calculation of the PV potential). The energy produced by this sector for the different scenarios proposed is already available. Thus, it is possible to estimate what would be the money that the system will not receive due to self-consumption.

As it has been widely explained in the section 3.2.2. Economic implications of self-consumption, the Spanish electricity tariff is inefficient since in the event of a penetration of self-consumption, part of the total costs of the system will not be recovered though the access tariff.

To estimate what would be the costs that self-consumers would not pay, it is necessary to have a look at the payment made by any consumer in the access tariff. An assumption has to be made in order to simplify the calculation; the consumers considered will be under PVPC tariff if they were not self-consumers.

The first step is to find out how much every consumer under regulated tariff pays for the access tariff. According to the IET/107/2014 where the access tariffs are reviewed, the values are the following ones (Ministry of industry energy and tourism, 2014):

Table 9: Price of the access tariff for PVPC (Source: own elaboration)

PVPC Access tariff	
Energy term (€/kWh)	capacity term (€/kW)
0,044027	38,043426

This means that for every kWh that the self-consumer produces with the PV module, the system will miss 0.044027€. The capacity term is paid by self-consumers independently if they produce with the photovoltaic panel or not, it depends on the power contracted but not on the energy consumed.

However, when every consumer is paying the electricity bill, there are other two payments that are included in the final price of the energy, which are the capacity payment and the balancing payment. These payments have also to be paid by self-consumers. So at the end, self-consumers do not pay the variable term of the access tariff, the capacity payment and the balancing payment. The value for the two last ones are 0.009812 €/kWh and 0.00569 €/kWh respectively.

If we have a look at the Table 38, Table 37, it can be seen the total energy produced by the domestic sector for the 3 scenarios chosen. Thus, by multiplying the energy by the variable term of the access tariff, capacity payment and balancing payment, we come up with the money that the system is not receiving by self-consumers.

The following table shows the money not received in the different scenarios:

Table 10: Total money not received by the system due to self-consumption at domestic sector (*Source: own elaboration)*

	Total energy produced self-consumers GWh	Total missing money M€
High penetration scenario	52926	3.150,62
Medium penetration Scenario	26241	1.562,10
Low penetration Scenario	15562	926,39

To reduce the money missed by the system, the government has proposed a new Royal Decree which applies a transitory charge for the energy auto-consumed in order to make self-consumers assume the cost of the system that they have also incurred. According to the proposal, the transitory charge will be divided as follows:

Table 11: Structure of the transitory charge (source: own elaboration)

Component	€/kWh
Variable charge	0,033367
Capacity payment	0,009812
Balancing payment	0,00569
Total	0,048869

If the self-consumers had to pay the transitory charge for the scenarios we have proposed, the final payment for each scenario would be as follows:

Table 12: Total money paid by self-consumers at domestic sector if the transitory charge is applied (*source: own elaboration)*

	Total energy produced self-consumers GWh	Total money paid M€
Maximum scenario	52926	2.586,43
Medium Scenario	26241	1.282,37
Minimum Scenario	15562	760,50

It can be seen that with the transitory charge proposed by the government not all the costs will be paid, this is because the network part has been discounted from the variable access tariff in the transitory charge.

Table 13: Missing money due to self-consumption at domestic sector after the application of the transitory charge (Source: own elaboration)

	Total energy produced self-consumers GWh	Total money missing after transitory charge M€
Maximum scenario	52926	564,19
Medium Scenario	26241	279,73
Minimum Scenario	15562	165,89

5. Analysis of the results

In this chapter the results obtained are going to be analyzed. In order to do so, the chapter is divided in the following parts:

- Analysis of the results obtained from the domestic sector
- Analysis of the results obtained from the industrial sector
- Analysis of the results from the commercial centers
- Analysis of the results as a whole
- Analysis of the results obtained from the economic implications of self-consumption at the domestic sector

5.1. Analysis of the results obtained from the domestic sector

The domestic sector has been found as the sector with the largest photovoltaic potential. In fact, for the study we have carried out, houses have been where more capacity has been installed.

Firstly, single family houses are going to be analyzed: To have a picture of the total capacity installed at household, the Table 14 shows the number of houses to install panel, the peak power installed, the total energy produced and the average energy produced per house.

In Spain there are 5.8 million of single family houses and houses. Under the scenarios that we have proposed, there will be more than one million and a half of houses for the low penetration scenario, 2.5 million for the medium penetration scenario and more than 4 million for the high penetration scenario.

The high scenario may seem very optimistic, but it is just a scenario in which we want to know what would be the maximum potential of photovoltaic, for that reason it is necessary to study a very high penetration.

Regarding the energy produced, every house will produce in average 6087 KWh/year. If all houses are put together, the energy obtained a year will be around 9244 GWh in the case of a low penetration of 24% in average, 15820 GWh for an average penetration of 41% and 25316 GWh for a very high penetration of 65% in average.

If we have a look at the settlement from the year 2014, the total energy consumed by consumers under the tariff 2.0 and 2.0 DHA[15] was 63091 GWh (CNE, 2010). Consumers living at single family houses and houses are usually under this tariff. With the scenario proposed, 14% of the energy consumed will be self-produced for the low scenario, 25% for the medium scenario and 40% for the high penetration.

[15] Consumers with a power contracted under 10 KW and connected to < 1KV

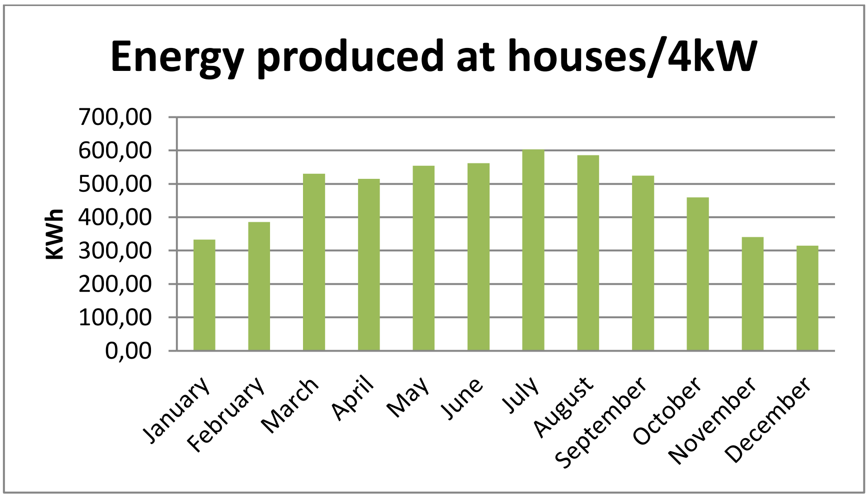
Table 14: Total capacity installed at houses and energy produced for the different scenarios (*Source: own elaboration*)

Low penetration scenario (24%)			
Average KWh/year	Total kWh/year	MW installed	nº houses
6087	9244000	6159	1.539.761
GWh	9244		
Medium penetration scenario (41%)			
Average KWh/year	Total kWh/year	MW installed	nº houses
6087	15820000	10265	2.566.268
GWh	15820		
High penetration scenario (65%)			
Average KWh/year	Total kWh/year	MW installed	nº houses
6087	25316488	16424	4.106.029
GWh	25316		

We have analyzed what would be the panel´ s performance for the capacity chosen. Although the energy produced in each region may be different, especially if northern regions and southern regions are compared, the Figure 31 shows in average the performance of the panel for the different months of the year.

As it is expected, in the summer is when the panel produces the largest amount of electricity. July is the month with highest production with more than 600KWh produced. On the contrary, the month with the lower production is December with a little more than 300 KWh.

Figure 31: Monthly electricity produced by 4KW PV system installed (*source: own elaboration*)



The capacity installed has not been equally distributed from the geographic point of view. This is basically because there are few regions that present high concentrations of single family houses as Andalucia, Valencia, Cataluña and Galicia.

Table 15: Capacity installed at houses by region *(Source: own elaboration*)

Region	High penetration	Medium penetration	Low penetration
Cantabria	132	82	49
Pais Vasco	104	65	39
Asturias	194	121	73
Galicia	1018	636	382
Navarra	173	108	65
Rioja	64	40	24
Cataluña	1729	1081	648
Madrid	897	560	336
Castilla Leon	1161	726	435
Baleares	463	289	174
Castilla Mancha	1321	826	495
Aragon	418	261	157
C. Valenciana	1808	1130	678
Extremadura	726	454	272
Canarias	1055	659	396
Andalucia	4416	2760	1656
Murcia	746	466	280
Total	16424	10265	6159

The region with the maximum capacity installed is Andalucia. In this region there are 1.4 million of houses and furthermore it is the second region with the highest sun radiation of the country. This fact makes that Andalucia accounts for 25% of the total capacity installed in the country for the three different scenarios.

The second country with the highest capacity installed is Valencia closely followed by Cataluña with approximately 10.5% of the total capacity. If Andalucia, Valencia and Cataluña were gathered, they would account for almost half of the total power installed. In the contrary, small regions with low sun radiation show the smallest power installed; La rioja and Navarra are the places with lowest photovoltaic potential.

It is reasonable that those regions with very high capacity installed are the ones with the highest energy production. In the case of Andalucia, the region where the largest amount of capacity has been installed, the electricity production would be 7133 GWh in the high scenario. This means that Andalucia could produce 11% of the total energy consumed in the country.

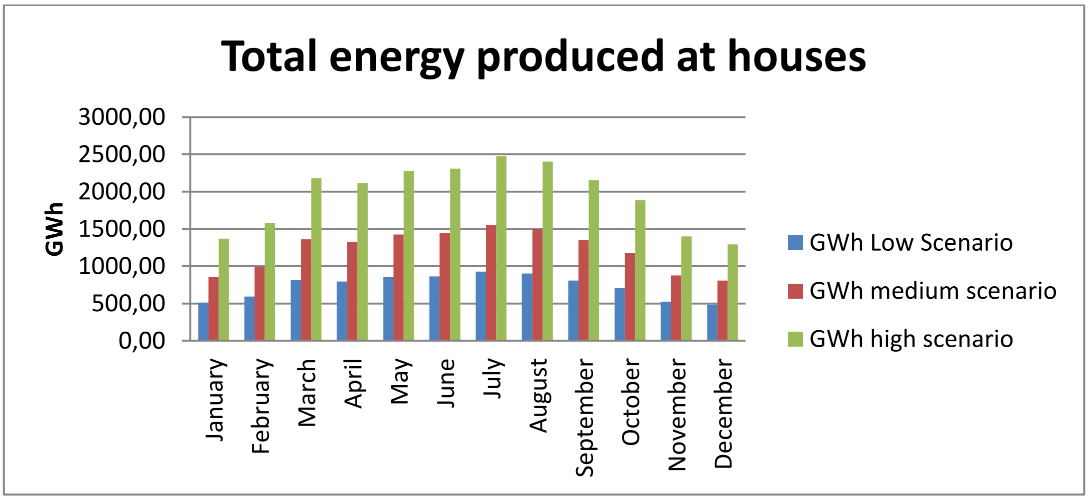
Valencia is the second region with the largest electricity production followed by Cataluña, Canary Island and Castilla la Mancha. It is worth mentioning that regions like Galicia that present a large number of houses do not produce very much energy. This is because they are situated in the north of Spain where the sun radiation is the lowest in the country. Therefore, the penetration estimated for these regions has been very little.

Table 16: Electricity production at houses GWh for the different regions in the three scenarios (*Source: own elaboration)*

Region	Low penetration	Medium penetration	High penetration	optimal angle
Andalucia	2.675	4.458	7.133	33
Aragon	237	394	631	37
Asturias	88	147	235	38
Baleares	272	453	725	35
C. Valenciana	1.088	1.814	2.902	36
Canarias	661	1.099	1.763	27
Cantabria	54	89	143	35
Castilla Leon	632	1.053	1.685	35
Castilla Mancha	751	1.252	2.004	34
Cataluña	812	1.624	2.598	37
Extremadura	425	709	1.134	34
Galicia	509	848	1.357	35
Madrid	436	873	1.397	35
Murcia	439	732	1.172	35
Navarra	90	150	239	36
Pais Vasco	43	72	115	33
Rioja	32	53	84	35
Total	**9244**	**15820**	**25316**	

Regarding the monthly energy produced, July and August have been the months with the highest electricity production and January, November and December when the lowest production have been found . In average, the total production has been 731 GWh/year for the low scenario, 1220 GWh/year for the medium scenario and 1952 GWh/year for the highest scenario.

Figure 32: Total energy produced at houses for the different scenarios (*Source: own elaboration*)



Regarding building blocks, the scenarios considered has been lower than at single family houses. For the lowest scenario, the penetration in average has been 11% whereas in the medium and in the high scenario the penetration in average has been 20% and 40% respectively. Murcia presents the highest penetration and Cantabria the lowest one.

In Spain there are 12.3 million of houses distributed in building blocks. We have calculated that there are 1.2 million of building blocks along the Spanish country (see 4.3.2. Scenarios for the domestic sector: Houses in building blocks). For the scenarios proposed, in the low scenario 27 thousand of building would install photovoltaic panel, 245 thousand in the medium penetration and 491 thousand in the high penetration scenario.

In total terms, the capacity installed for the different scenarios has been very reasonable although lower than in the single family house sector. The capacity installed for building blocks has been 28 KW per building. With this peak power capacity the average production for the whole country has been 40 MWh/year.

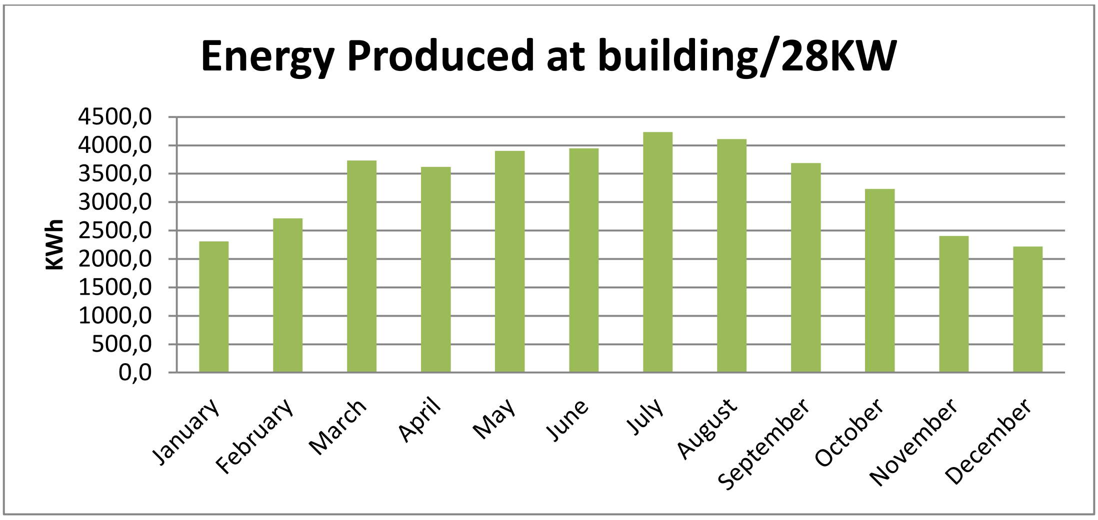
However, regions like Murcia with the highest solar radiation in the country has an average production of 44 MWh/year for the capacity proposed. In the contrary, Cantabria produces 30.3 MWh/year which is considerable less.

Table 17: Total energy production and capacity installed at building blocks *(Source: own elaboration)*

Minimum scenario penetration (11%)			
Average production KWh/year	nº buildings	total production MWh	Total capacity installed MW
40433	127761	5419091	3577
GWh		5419	
Medium penetration scenario (20%)			
Average production KWh/year	nº building	total production MWh	Total capacity installed MW
40433	245694	10421355	6879
GWh		10421	
High penetration scenario (41%)			
Average production KWh/year	nº building	total production MWh	Total capacity installed MW
40433	491391	20842801	13759
GWh		20843	

The photovoltaic array´s performance has been analyzed. As it has been mentioned before, the capacity installed has been 28 kW per building. If we have a look at the Figure 33, the electricity production has been monthly analyzed. As the same than in houses, the months with the highest electricity production are the ones distributed in the summer.

Figure 33: Monthly electricity production at building blocks by 28 KW PV systems installed (*Source: own elaboration)*



The highest electricity production is found in July with a total production over 3500 KWh/month whereas the lowest is again during the winter, specifically in December when the total monthly production is 2100 kWh/month. The monthly average production has been 3456 KWh/month.

Figure 34: Capacity installed at building blocks per region (*Source: own elaboration*)

Region	High penetration (MW)	Medium penetration (MW)	Low penetration (MW)
Cantabria	194	45	23
Pais Vasco	438	219	114
Asturias	240	120	62
Galicia	564	282	147
Navarra	150	75	39
Rioja	103	51	27
Cataluña	2270	1135	590
Madrid	1889	945	491
Castilla Leon	762	381	198
Baleares	365	182	95
Castilla Mancha	636	318	165
Aragon	458	229	119
C. Valenciana	1594	797	414
Extremadura	385	192	100
Canarias	716	358	186
Andalucia	2611	1305	679
Murcia	490	245	127
Total	13863	6879	3577

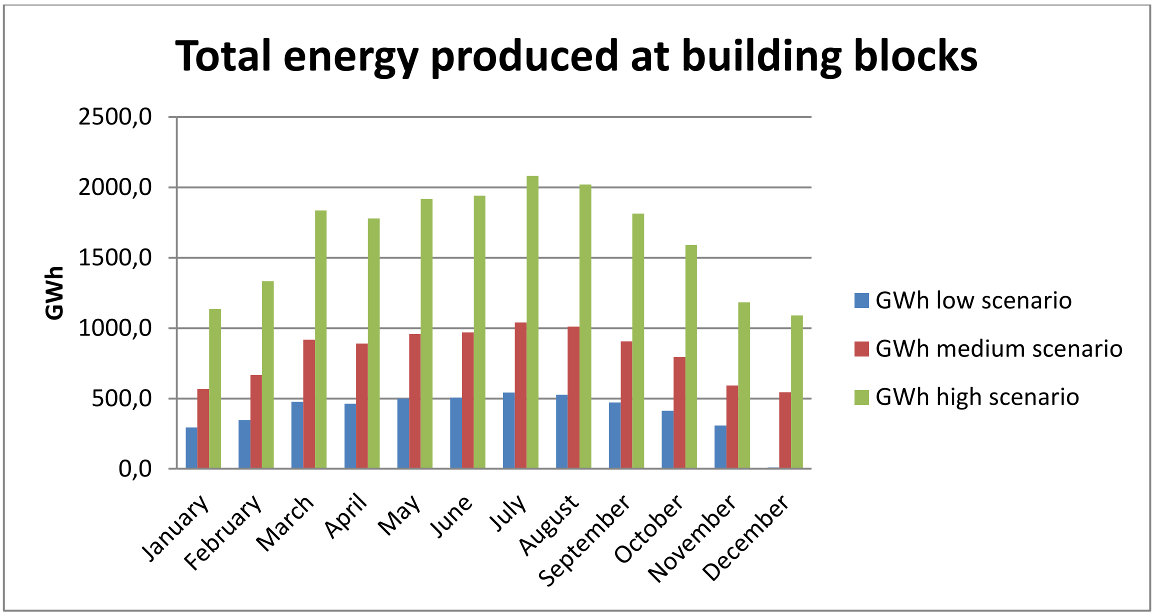
Regarding the geographical situation of the capacity installed, Andalucia is again the region where the highest capacity has been installed. Nevertheless and contrary what happened at house sector, Barcelona is very close to Andalucia regarding capacity installed.

In the low scenario at building blocks, Andalucia would install around 175 MW more than Barcelona. However, if both countries are compared in the low scenario at single houses, the difference is almost 2000 MW. This is due to Barcelona´s population is very concentrated in building blocks. It is the second one in number of buildings in the country and very close to Andalucia.

A similar situation is identified in Basque country. It is the second lowest region regarding solar radiation, however, there a plenty of building in this region. For this reason, a reasonable amount of capacity would be installed. To have an idea of this, Extremadura which has much more photovoltaic potential, would install less capacity than the Basque country.

In average, the monthly electricity production for the high scenario has been 1778 GWh whereas in the medium and lowest scenario the energy produced has been 889 GWh and 439,5 GWh respectively.

Figure 35: Total production at building blocks for the different scenarios (*Source: own elaboration)*



5.2. Analysis of the results obtained from the industrial sector

As it has been previously mentioned, in the industrial sector it has not been possible to find the geographical situation of the companies where the module would be installed.

Inevitably, this situation makes the estimation less accurate. We have opted to calculate the average production for the different regions in Spain in order to know what would be the average production for the capacity installed in the whole country.

Table 18: Energy produced and capacity installed at small and medium companies (*source: own elaboration*)

Low penetration scenario small and medium companies (5%)			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
60650	6507	394650	274
GWh		394	
Medium penetration scenario small and medium companies (15%)			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
60650	19522	1184009	823
GWh		1184	
High penetration scenario small and medium companies (25%)			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
60650	32537	1973369	1372
GWh		1973	

In the case of small and medium companies, the capacity installed has been 42 KW per company. For this peak power installed the average production has been 60650 Kwh/year for the whole country. With this energy production per company, the energy production in the low scenario would be of 394 GWh/year with a total capacity installed of 274 MW.

In the medium scenario the capacity installed rise up to 823 MW and an energy production of 1184 GWh whereas in the high penetration scenario the total capacity would be 1372 MW and the energy production around 1973 GWh.

In the case of big companies the capacity installed has been selected as 84 KW. However, the total capacity finally installed would be lower than for the small and medium companies. This is basically because the number of big companies is lower than small and medium ones.

For the peak power installed at big companies, the electricity production calculated for the whole year has been 121300 KWh/year in average. The energy produced in the highest scenario would be 731 GWh which is even less than the one produced in the medium scenario for the small and medium companies.

Figure 36: Electricity production and capacity installed at big companies for the different scenarios (Source: own elaboration)

Low penetration scenario big companies (10%)			
Average KWh/year	nº Companies	Total production MWh	Total capacity MW
121300	1206	146288	101
GWh		146,2878	
Medium penetration scenario big companies (25%)			
Average KWh/year	nº Companies	Total production MWh	Total capacity MW
121300	2411	292454	203
GWh		292,4543	
High penetration scenario big companies (50%)			
Average KWh/year	nº Companies	Total production MWh	Total capacity MW
121300	6028	731196	508
GWh		731,1964	

5.3. Analysis of the results obtained from commercial centers

Fortunately we have had access to the geographical situation of the commercial centers. Therefore, it has been possible to run the software for the different commercial center locations and come up with results which are highly accurate.

As explained in the section 4.3.3. Scenarios for commercial centers, the scenarios proposed have been subject to the space and not the number of commercial centers. In other words, the capacity installed has not been set for each commercial center but can increase or decrease depending on the level of penetration.

For this sector, we believed that the penetrations would be large. Thus, the penetration considered for the different scenarios has been 25%, 50% and 80%. To have a whole picture of the value obtained, the Table 19 shows the results obtained for the different scenarios. In Spain there are 655 commercial centers, in the low penetration scenario with a 20% of penetration, there would be a total capacity installed of 187 MW and 141 commercial centers would install a photovoltaic array.

In the second scenario the power installed is duplicated and the number of commercial centers to install photovoltaic module are 284. For the very high penetration scenario, the number of commercial centers would increase up to 442 with a total power installed of almost 600 MW.

Table 19: Total nº commercial centers, power installed and energy production for the different scenarios (*Source: own elaboration)*

Low penetration Scenario (20%)		
nº commercial centers	Total production KWh	Total capacity MW
141	247152762	187
GWh	247	
Medium penetration Scenario (41%)		
nº commercial centers	Total production KWh	Total capacity MW
284	494305270	375
GWh	494	
High penetration Scenario (65%)		
nº commercial centers	Total production KWh	Total capacity MW
442	790884660	599
GWh	791	

The Table 20 shows the regions with the number of commercial centers that have PV capacity installed. Andalucia is the region that accounts for more commercial centers in Spain, since this region has one of the highest sun radiation ratio in the country, it is expected that it would be the one with the largest number of commercial centers with photovoltaic arrays installed.

Table 20: Number of commercial centers with PV capacity installed for the different scenarios

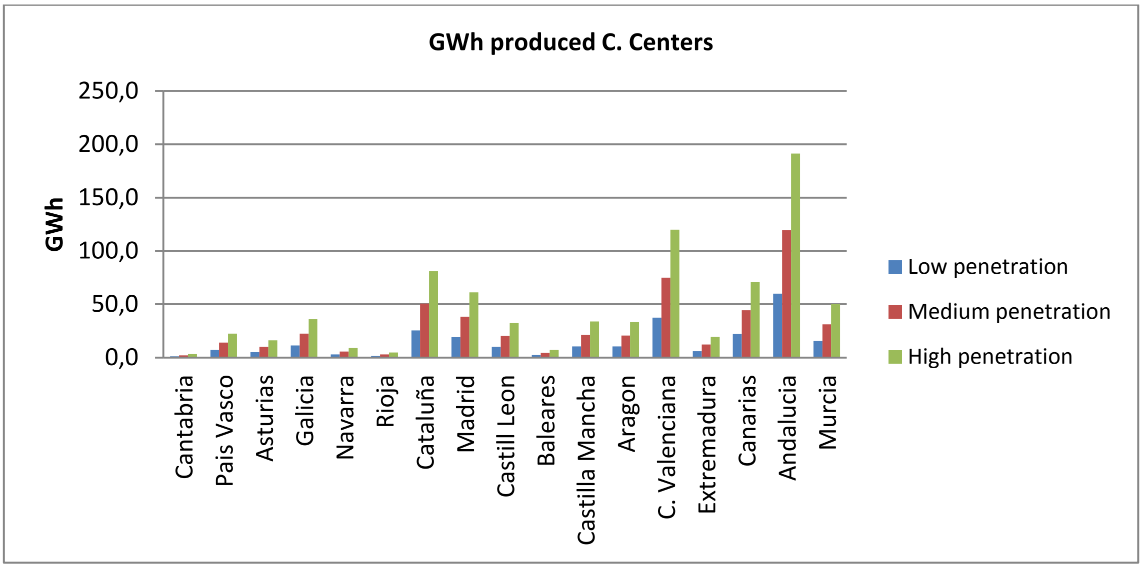
Region	Low penetration	medium penetration	high penetration
Cantabria	1	1	2
Pais Vasco	4	8	13
Asturias	2	5	8
Galicia	7	14	22
Navarra	1	2	4
Rioja	1	1	2
Cataluña	11	22	36
Madrid	27	54	87
Castilla Leon	6	12	20
Baleares	1	1	6
Castilla Mancha	6	12	19
Aragon	3	6	10
C. Valenciana	14	29	47
Extremadura	4	9	14
Canarias	11	11	36
Andalucia	30	60	97
Murcia	12	24	19
Total	141	284	442

Madrid would also have many commercial centers with PV installed as well as Valencia, Cataluña and Murcia. On the contrary, Cantabria, La Rioja and Baleares present the lowest number regarding commercial centers with photovoltaic installations.

In the Table 34,Table 35,Table 36, the total capacity for the different regions and scenarios can be seen. It would be interesting to analyze what would be the production of the different regions.

There is a relevant difference between the energy produced in the regions with the highest capacity installed, like Andalucia or Valencia and the region with the lowest power installed as Cantabria, Navarra, Rioja. Commercial centers located in Andalucia produce approximately 25% of the total energy produced at commercial centers in the whole country and 59 times more than Cantabria which is the region with the lowest production.

Figure 37: Energy produced at commercial centers for the different scenarios (source: own elaboration)



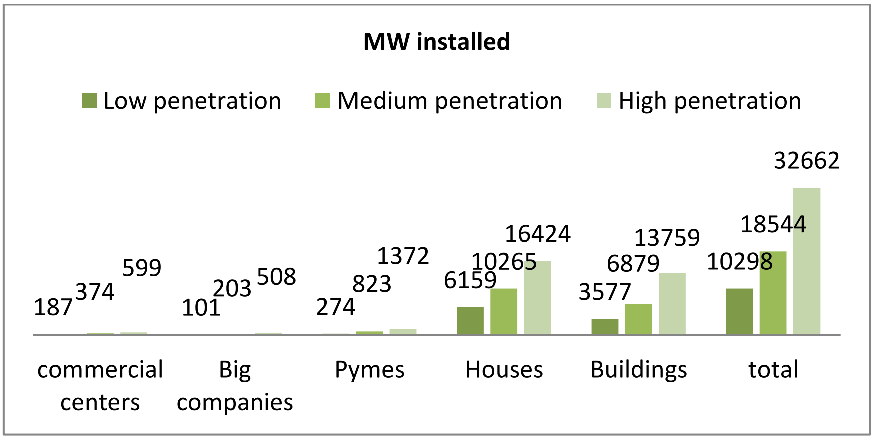
If Andalucia, Valencia, Cataluña and Madrid were gathered, the potential they have is very considerable. All of them together would produce more than half of the total production in the country. Obviously, this is not only because the high sun radiation that this regions have, but also the large number of commercial centers in place in this regions.

5.4. Analysis of the results as a whole

In this chapter the results obtained gathering all the sectors for each scenario are going to be analyzed. If we have a look at the Figure 38 the total capacity installed for the different scenarios and sectors can be seen.

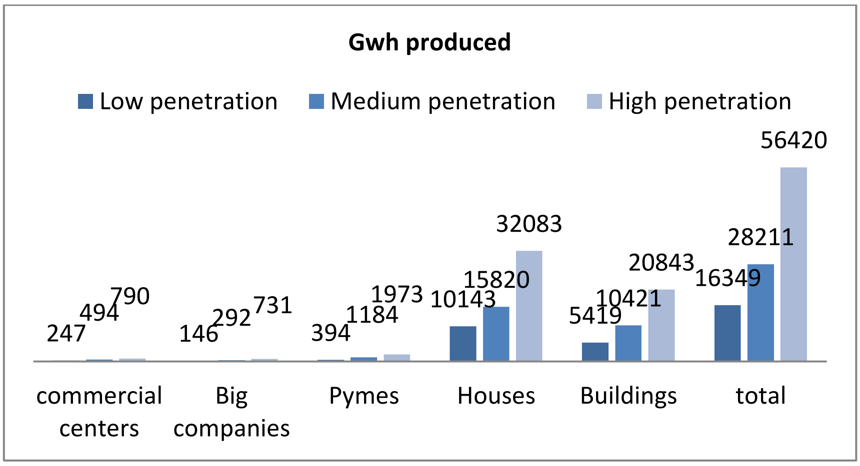
It is quite relevant the total power installed at the domestic sectors which account for majority of the installed capacity. Big companies are the ones with the lowest capacity installed followed by commercial centers and small and medium companies. The largest amount of power would be installed at single family houses closely followed by building blocks.

Figure 38: Total capacity installed by sectors and scenarios (*Source: own elaboration)*



In the lowest scenario proposed, the total capacity installed would be 10 GW. It is worth saying that the photovoltaic capacity currently installed in Spain is 4.4 GW so it is realistic to think that in 15 years the capacity would be a little more than 2 times the capacity already installed. In the case of very high penetration the capacity calculated has been 32.6 GW, which is quite a lot. This is just a very high scenario to know what would be the capacity installed if the regulation highly supported the Photovoltaic technology.

Figure 39: Total energy produced by sectors and scenarios (source: own elaboration)



Regarding the PV energy production, for a low penetration scenario, the results obtained has been over 16 thousand of GWh. The photovoltaic production in Spain in the year 2014 was more than 8 thousand GWh. It is reasonable to think that the production by this technology could be double the produced in 2014. In the case of very high penetration of photovoltaic technology, the production would be 56420 GWh which is around 20% of the total energy generated in the country. It is very optimistic scenario, but as it has been previously mentioned, this scenario would be a scenario to have an idea of what would be the maximum potential of PV if the support from the regulation was extremely high.

In term of market share, the capacity installed for the houses and building blocks account for more than 90% for all scenarios. Small and medium companies are the ones with the higher penetration but in any case more than 5%.

Figure 40: Capacity share by sector in the low penetration scenario (*Source: own elaboration)*

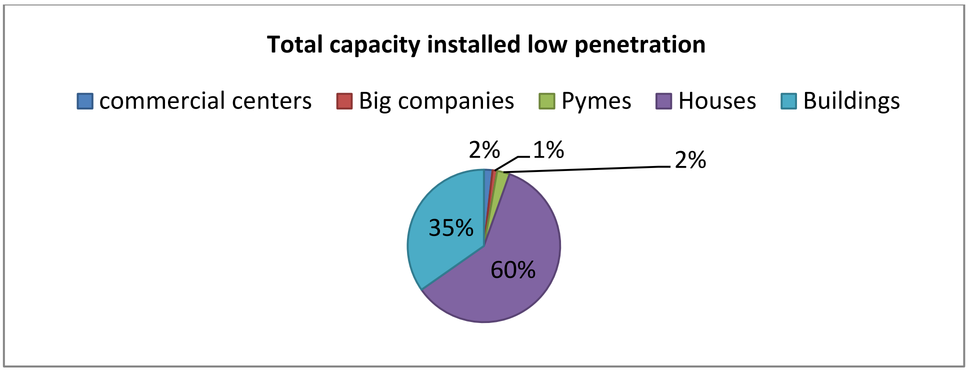


Figure 41: Capacity share by sector in the medium penetration scenario (*source: own elaboration)*

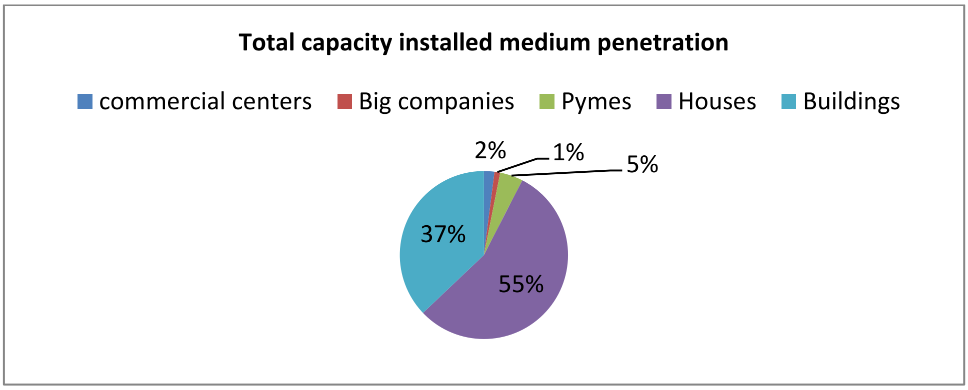
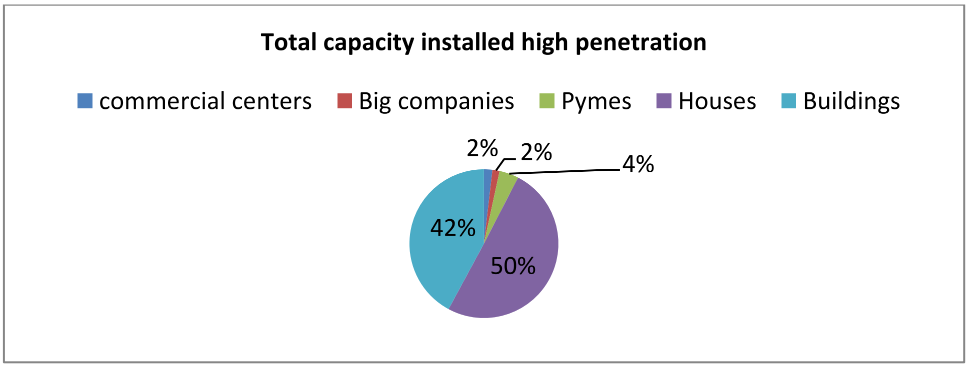
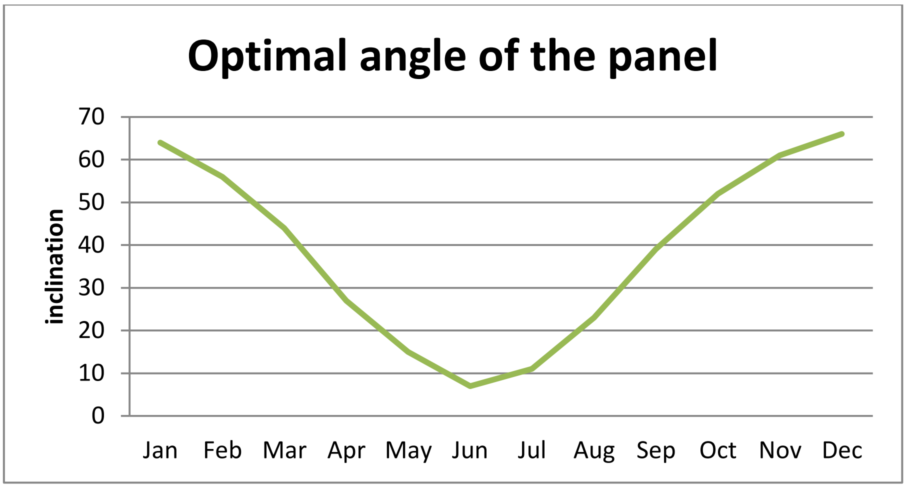


Figure 42: Capacity share by sector in the high penetration scenario (*source: own elaboration)*



The optimal angle of the panel is slightly different in average in the different regions. The average of the whole country and year has been identified at 35 degrees. However, in the Figure 43 , the optimal angle for the different months of the year show that for the different months of the year, the optimal inclination is quite different. In the winter months it is preferable to have higher inclination angles, however during the summer the panel´s angle decrease until less than 10 degrees in the case of June.

Figure 43: Optimal photovoltaic angle in Spain for different months *(source: own elaboration via PVGIS*)



The reason of this high difference between the angles in summer and winter is due to the solar incidence angle. During the summer the sun is higher than in summer, for that reason the optimal angle needed to receive the largest amount of sun irradiation is lower than in winter when the panel would have to be positioned in a higher inclination to receive the highest amount of solar irradiation.

The position of the panel has been always set to south direction, 0 degrees. With such characteristics it is expected to receive the highest amount of sun radiation. We are aware that it is not always possible to install the panel in south direction but in order to estimate the highest potential possible it is a reasonable selection.

In line with this, the monthly average global irradiation has been also calculated. It has been calculated for all the regions. At the end we are interested in the average for the whole country. The data obtained continues proving the high photovoltaic potential that Spain has.

In the summer months, the production per m2 installed of crystalline cells is over 200 Kwh. In the months with the lowest solar radiation as January and December this amount is reduced up to half . For the whole year the average has been found at 174 KWh/m2/month. The Table 21 summarizes the final results obtained and the Table 22 shows the total capacity installed per region for domestic sectors and commercial centers.

Figure 44: Monthly average sum of global irradiation for crystalline cells (*source: own elaboration via PVGIS*)

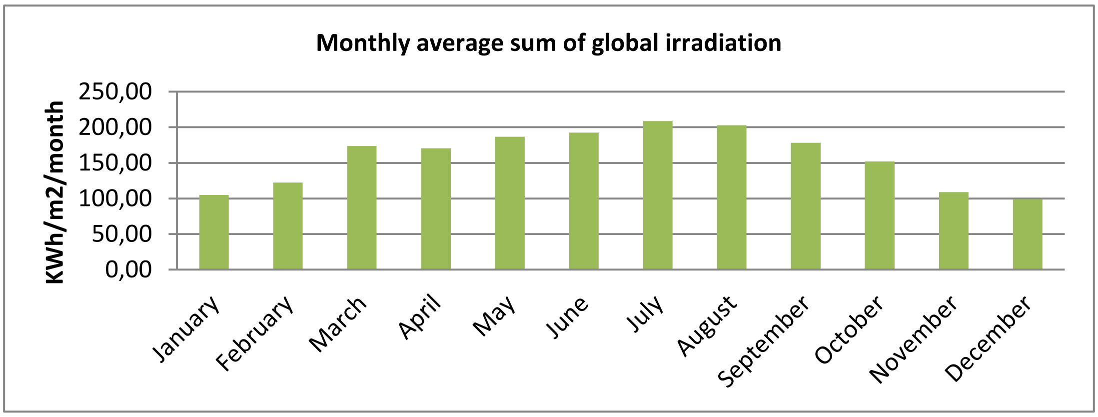


Table 21: Final results obtained for the different scenarios (*source: own elaboration)*

scenario minimum penetration			
Sector	Total production GWh	Total capacity MW	Average penetration (%)
commercial centers	247	187	20
Big companies	146	101	10
Pymes	394	274	5
Houses	10143	6159	24
Buildings	5419	3577	11
Total	16349	10298	14
scenario medium penetration			
Sector	Total production GWh	Total capacity MW	Medium penetration (%)
commercial centers	494	374	41
Big companies	292	203	20
Pymes	1184	823	15
Houses	15820	10265	41
Buildings	10421	6879	20
Total	28211	18544	27,4
scenario maximum penetration			
Sector	Total production GWh	Total capacity MW	Medium penetration (%)
commercial centers	790	599	65
Big companies	731	508	50
Pymes	1973	1372	25
Houses	32083	16424	65
Buildings	20843	13759	41
Total	56420	32662	49,2

Table 22: Total capacity installed at domestic sector and commercial centers per region for the different scenarios (*source: own elaboration*)

Low scenario		Medium scenario		high scenario	
Region	Capacity	Region	Capacity	Region	Capacity
Andalucia	2372	Andalucia	4140	Andalucia	7146
Cataluña	1255	Cataluña	2249	Cataluña	4052
C. Valenciana	1116	C. Valenciana	1974	C. Valenciana	3477
Madrid	864	Madrid	1579	Madrid	2904
Castilla Mancha	668	Castilla Mancha	1158	Castilla Mancha	1979
Castilla Leon	640	Castilla Leon	1121	Castilla Leon	1945
Canarias	595	Canarias	1044	Canarias	1813
Galicia	537	Galicia	935	Galicia	1608
Murcia	417	Murcia	731	Murcia	1268
Extremadura	376	Extremadura	654	Extremadura	1123
Aragon	282	Aragon	504	Aragon	897
Baleares	271	Baleares	476	Baleares	835
Pais Vasco	159	Pais Vasco	297	Pais Vasco	563
Asturias	139	Asturias	249	Asturias	447
Navarra	106	Navarra	187	Navarra	330
cantabria	74	cantabria	129	cantabria	224
rioja	52	rioja	94	rioja	170

5.5. Analysis of economic implications due to self-consumption at domestic sector

The study carried out to estimate the photovoltaic potential of self-consumption in Spain would have many economic implications. The photovoltaic industry would experience an enormous growth and probably a lot of people would be hired to work on this sector.

However, this growth in the PV sector would not be welcomed by the retail companies since they would see how part of the energy that they were providing to final consumers, now they it is self-produced by them.

Generators would not be satisfied either. Generation companies have invested a lot of capital that has to be recovered through selling electricity. If part of the electricity is now produced by self-consumers, it will take longer to recover the money invested.

This situation seems to be “fair” since retailing and generation are currently liberalized business and investors must assume the possible risks of the business. However, the network business is regulated; therefore every consumer has to pay a regulated charge for the use of the network.

Nevertheless, as previously explained it in the section 3.2.2. Economic implications of self-consumption, if finally there was a high penetration of PV at domestic sector, there would be part of the regulated costs that would not be paid by self-consumers.

For the scenarios we have considered, the penetration at domestic sector would be very large. It is that large that in the high scenario, 84% of the total energy consumed by consumers under the tariff 2.0A and 2.0 DHA would be supplied by self-consumers through the PV panels, in the medium scenario 42% and in the low scenario 25%.

With such penetration, self-consumer would not pay the variable part of the access tariff of the energy self-produced which would incur the system a total losses of 3.150 million of euros in the high penetration scenario, 1.562 million of euros in the medium scenario and 926 million of euros in the low scenario. This money results from the multiplications of the total energy produced by the variable access tariff which is shown in the Table 9 and its value is 0,044027 €/KWh

If we have a look at the settlement of the year 2014, the systems received through the access tariff for the tariff 2.0A and 2.0 DHA the following money:

Figure 45: Money recovered through access tariff for different tariffs (*source: own elaboration via CNMC*)

Tariff	Energy GWh	Incomes M€
2.0 A	55908	6369,868
2.0 DHA	7183	424,497
Total	63091	6814,365

If we considered that all self-consumers were under the PVPC tariff the system would not receive 84% of the payment made though the variable part of the access tariff in the high scenario, 42% in the medium scenario and 25% in the low scenario. This would make the system unsustainable.

The government is very concerned about this problem and since the year 2013 is studying the way in which self-consumers that are connected to the grid pay the regulated costs. Firstly, they proposed a very high charge for every KWh produced by self-consumers; it was set around 6 €cents for every KWh.

As mentioned in the section 2.3.1 Self-consumption in Spain, in 2015 a new proposals has been issued in which the charge for self-consumption, now called “transitory charge” is not that high (0,048 €/KWh). We already explained that the transitory charge is composed by: The variable term of the access tariff, price of the payment for capacity and price of the balancing services. However, the part corresponding to the network which is paid through the variable access tariff has been discounted.

It is worth mentioning that the transitory charge is actually lower than the variable access tariff paid by normal consumers; although the variable access tariff is set to 0,044 €/KWh and it is actually cheaper than 0,048 €/KWh paid in the transitory charge, normal consumers also pay the capacity and balancing payment in the final price of the energy. So, if the price of the capacity payment and balancing payment, 0,009812€/KWh and 0,00569€/KWh receptively are added to 0,044€/KWh, the final price paid by normal consumers from the variable access tariff is 0,059537 €/kWh which is around 20% higher than the transitory charge. The difference between the variable access tariff and the transitory charge is due to 0,010€/KWh which is the part corresponding to the network cost that has been discounted in the transitory charge.

To know how much money would be paid if the transitory charge is applied to self-consumers, The Table 24 in which the energy self-produced in the different scenarios and the money paid if the transitory charge is applied to such energy has been created:

Table 23: Total money paid in the different scenarios if the transitory charge is applied (source: own elaboration)

	Total energy produced self-consumers GWh	Total money paid M€
Maximum scenario	52926	2.586,43
Medium Scenario	26241	1.282,37
Minimum Scenario	15562	760,50

If the money paid is discounted from the initial losses the system incurs through self-consumption, the system is not sustainable. The Table 24 shows the money that the system would not receive even applying the transitory charge.

Table 24: Missing money due to self-consumption at domestic sector after the application of the transitory charge (Source: own elaboration)

	Total energy produced self-consumers GWh	Total money missing after transitory charge applied M€
Maximum scenario	52926	564,19
Medium Scenario	26241	279,73
Minimum Scenario	15562	165,89

It can be concluded that more than 15% of the total costs are not paid even applying the transitory charge to self-consumers, for that reason there should be designed another way to charge for the system costs that it would not made the system unsustainable in the case of self-consumption.

6. Conclusions

The significant price depression of photovoltaic modules and the increase in electricity prices in the last years have lead many countries including Spain to reach the photovoltaic grid parity. As a consequence, there has recently been a large deployment of solar photovoltaic capacity in Europe. It is not the case of Spain; since 2012 the photovoltaic market has slowed down significantly due to a regulation which does not incentivize new comers. However, taking into account that Spain has one of the highest solar irradiance in Europe, solar photovoltaic installations are expected to increase in the coming years. In line with the situation previously commented, this thesis has estimated the maximum solar photovoltaic potential for self-consumption and its economic implications in Spain by 2030.

For calculating the photovoltaic potential, various steps were followed: different sectors where a photovoltaic installation is feasible have been analyzed and selected, the geographical situation of Spain and its regions were studied in order to identify the areas of the country that present the highest solar irradiance, three scenarios were proposed to estimate the photovoltaic potential under different penetration levels, the photovoltaic geographical information system (PVGIS) was run to estimate the photovoltaic potential, and finally an assessment of the economic implications that self-consumption may have in the future was presented.

We have identified the domestic sector as the one where the highest photovoltaic capacity would be installed; being single-family houses the ones with the largest potential. Small and medium companies as well as commercial centers have also a large photovoltaic potential not only due to their accessibility but also because of the space they offer for the installation of photovoltaic panels. The total capacity installed has resulted in 10298 MW in the low penetration scenario, 18544 MW in the medium penetration scenario and 32662 MW in the high penetration scenario by 2030.

The domestic sector accounted for 95% or more of the total capacity installed for the different scenarios proposed. Within the domestic sector, single-family houses capacity installed has ranges from 50% in the high penetration scenario to 60% in the low penetration scenario. The rest was installed in building blocks. The 5% remaining has been distributed among commercial centers, big companies and small and medium companies being the latter the one with the highest share.

The regions with the best balance between solar irradiance and feasibility to install photovoltaic modules for self-consumption were found in the south, east and center of the peninsula. Andalucia, Cataluña and Valencia have the highest solar photovoltaic potential in the country. All of them together have accounted for almost half of the total capacity that would be installed by 2030 under the scenarios proposed. Under such scenarios, it has been demonstrated that even taking into account a low photovoltaic penetration, Spain´s national target for solar capacity in the future can be met.

PVGIS has been found as accurate, useful and easy-to-use software. The methodology (GIS) has been successfully applied on the different regions of Spain. Through PVGIS the photovoltaic performance for any geographical location where the modules would be installed has been accurately calculated. The energy produced by PV modules could cover around 25% of the energy consumed at domestic sector under the low-penetration scenario, 42% in the medium-penetration scenario and 84% in a very high-penetration scenario.

In order to assess the sustainability of the system, it was crucial to study the economic implications that photovoltaic penetration for self-consumption have. To do so, the Spanish electricity tariff was intensively analyzed though numerical calculations, concluding that under the tariff already in place the system would not be sustainable in the event of PV penetration for self-consumption. If self-consumers were under PVPC tariff the system would not recover through the variable access tariff 3150 M€ in the high penetration scenario, 1562 M€ in the medium penetration scenario and 926 M€ in the low penetration scenario.

It was also studied the transitory charge for the energy auto-consumed that the Spanish government has recently proposed. The results obtained have demonstrated that network costs would not be totally recovered under this proposal. The system would miss 564 M€ in the high penetration scenario, 279 M€ in the medium penetration scenario and 165 M€ in the low penetration scenario.

For this reason it is especially important that a proper regulation is designed in order to provide customers with economic signals to consume efficiently and at the same time guarantee the sustainability of the system. In line with this, this thesis leave some room to investigate future design of the electricity tariff taking into account that distributed generation is going to gain importance in the coming years. It is essential that regulation will be capable to anticipate the future of the electricity market.

References

Abad Santiago, L. (2014). *Situación del autoconsumo en España y en el mundo.* Madrid.

Abdelfettah, B., & Mouncef, B. (2007). *PVGIS approach for assessing the performances of the first.*

AEMET. (2012). *Calendario meteorológico 2012.*

Agency, I. E. (2014). *Technology Roadmap Solar Photovoltaic Energy.*

Álvarez Pelegry, E., & Castro Legarza, U. (2014). *Generación distribuida y autoconsumo.*

Amatya, R., & Brushett, F. (2015). *The future of solar energy, and interdisciplinary MIT study.*

Batlle, c., Perez-Arriga, I., & Zambrano-Barragán. (2011). *Regulatory Design for RES-E.*

Briano, J. I., Báez, M. J., & Moya, R. (2015). *PV grid parity monitor.* Madrid.

Brown, P. (2013). *European union wind and solar electricity policies: Overview and considerations.*

Burger, B. (2014). *Electricity production from solar and wind in Germany in 2014.*

CNE. (2006). *Legislation development of the Spanish electric power act.*

CNE. (2010). *Informe sobre los resultados de la liquidación.*

CNMC. (2014). *Liquidación provisional nº 14 del 2014.*

Dr Huld, T., & Dr Dunlop, E. (2007). *PVGIS.*

DrJardine, C., & Dr Lane, K. (s.f.). *Photovoltaic pannel assesment.*

Duque, P. (2015). *Photovoltaic energy: Current situation and perspectives.*

European Union. (2009). *EU directive 2009/72/EC.*

Eurostat. (2015). *Energy from renewable sources*. Obtained From Eurostat statistics explained: http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_from_renewable_sources

Fraunhofer institute. (2014). *photovoltaic report .*

Greenteachmedia. (2014). Obtained in May 2015, from http://www.greentechmedia.com/articles/read/germanys-energy-transition-explained-in-6-charts

GW solar institute. (2014). Obtained in May 2015 from http://solar.gwu.edu/q-a/what-types-solar-photovoltaic-technologies-exist-today-and-how-do-they-work

homepower. (2008). Obtained in April 2015, de http://www.homepower.com/articles/solar-electricity/equipment-products/solar-electric-options-crystaline-vs-thin-film

IDAE. (2011). *Análisis del consumo energético del sector residencial en España.*

INE. (2013). *Encuentas continua de hogares 2013.*

IRENA. (2014). *Rethinking energy.*

Jones, B. (2012). *Study on the impact of photovoltaic generation on peak demand.*

Lark, A., Munian, E., & Wilmot, N. (2011). *Photovoltaic forescast.*

Mayer, J. (2015). *Current and future cost of photovoltaics.*

Mercom capital group. (2015). Obtained in June 2015, de http://mercomcapital.com/mercom-capital-group-forecasts-strong-year-ahead-with-global-solar-installations-of-approximately-54.5-gw

Ministry of industry energy and tourism. (2014). *IET/107/214.*

Ministry of industry energy and tourism. (2014). *Real decreto 413/2014.*

Ministry of industry, energy and tourism. (2013). *Real decreto balance neto.*

Ministry of industry, energy and tourism. (2015). *Real decreto de autconsumo .*

Navarro, C., & López Cardenete, J. L. (2015). *Implicaciones del autoconsumo en el sistema eléctrico.*

Pérez-Arriaga, I. (2011). *managing large scale penetration of intermitent renewables.*

Red Electrica España. (2015). *Potencia instalada abril 2015.*

Sancho Ávila, J. M., & Riesco Martín, J. (2006). *Atlas de radiación solar en España.*

SunShot. (2012). *SunShot vision study.*

Sunwiz consulting. (2012). *Solar PV forecast for AEMO 2012-2022.*

Terrer Viñes, h. (2013). *Rentabilidad de las instalaciones fotovoltaicas de autoconsumo: peaje de respaldo y autoconsumo instantáneo.*

UK government. (2014). Obtained in April 2015, de www.gov.uk/government/statistical-data-sets/weekly-solar-pv-installation-and-capacity-based-on-registration-date

Union Española Fotovoltaica. (2014). *La energía fotovoltaica conquista el mercado.*

Williams, E., Cory, K., & kreycik, C. (2010). *A policymaker's guide to Feed-in Tariff policy design.*

World energy council 2013. (2013). *World energy resources: solar.*

Annex 1

Table 25: Installed capacity obtained from low penetration scenario at single houses (Source: own elaboration)

Region	nº of hours	nº of houses(x1000)	Penetration %	nº houses PV installed	Capacity installed (MW)
Cantabria	1541	87	14	12371	49
Pais Vasco	1760	60	16	9746	39
Asturias	1925	102	18	18145	73
Galicia	2191	472	20	95405	382
Navarra	2278	77	21	16250	65
Rioja	2586	25	24	5982	24
Cataluña	2678	657	25	162102	648
Madrid	2700	338	25	84061	336
Castilla y Leon	2714	435	25	108849	435
Baleares	2800	168	26	43381	174
Castilla Mancha	3027	444	28	123856	495
Aragon	3063	139	28	39156	157
C. Valenciana	3068	600	28	169527	678
Extremadura	3099	238	29	68064	272
Canarias	3111	345	29	98902	396
Andalucia	3173	1416	29	414004	1656
Murcia	3255	233	30	69960	280
Total		**5836**		**1539761**	**6159**

Table 26: Installed capacity from the medium penetration scenario at single houses (Source: own elaboration)

Region	nº of hours	nº of houses(x1000)	Penetration %	nº houses PV installed	Capacity installed MW
Cantabria	1541	87	24	20618	82
Pais Vasco	1760	60	27	16244	65
Asturias	1925	102	30	30242	121
Galicia	2191	472	34	159009	636
Navarra	2278	77	35	27084	108
Rioja	2586	25	40	9971	40
Cataluña	2678	657	41	270170	1081
Madrid	2700	338	41	140101	560
Castill Leon	2714	435	42	181415	726
Baleares	2800	168	43	72301	289
Castilla Mancha	3027	444	47	206426	826
Aragon	3063	139	47	65259	261
C. Valenciana	3068	600	47	282546	1130
Extremadura	3099	238	48	113440	454
Canarias	3111	345	48	164837	659
Andalucia	3173	1416	49	690007	2760
Murcia	3255	233	50	116600	466
Total		**5836**		**2566269**	**10265**

Table 27: Installed capacity from the high penetration scenario at single houses (Source: own elaboration)

Region	nº of hours	nº of houses(x1000)	Penetration %	nº houses PV installed	Capacity installed MW
Cantabria	1541	87	38	32988	132
Pais Vasco	1760	60	43	25990	104
Asturias	1925	102	47	48387	194
Galicia	2191	472	54	254414	1018
Navarra	2278	77	56	43334	173
Rioja	2586	25	64	15953	64
Cataluña	2678	657	66	432272	1729
Madrid	2700	338	66	224162	897
Castilla Leon	2714	435	67	290263	1161
Baleares	2800	168	69	115682	463
Castilla Mancha	3027	444	74	330282	1321
Aragon	3063	139	75	104415	418
C. Valenciana	3068	600	75	452073	1808
Extremadura	3099	238	76	181503	726
Canarias	3111	345	76	263739	1055
Andalucia	3173	1416	78	1104012	4416
Murcia	3255	233	80	186560	746
Total		**5836**		**4106030**	**16424**

Table 28: Installed capacity from low penetration scenario for houses in buildings (source: own elaboration)

Region	nº of hours sun	houses (x1000)	Penetration %	Houses PV	Buildings PV	nº floors	houses/building	Installed capacity (MW)
Cantabria	1541	151	6	9275	834	4	11	23
Pais Vasco	1760	831	7	58375	4072	6	14	114
Asturias	1925	357	8	27455	2228	5	12	62
Galicia	2191	598	9	52343	5234	4	10	147
Navarra	2278	173	9	15721	1393	5	11	39
Rioja	2586	104	10	10772	955	5	11	27
Cataluña	2678	2290	11	244908	21075	5	12	590
Madrid	2700	2159	11	232825	17543	5	13	491
Castilla Leon	2714	596	11	64606	7073	4	9	198
Baleares	2800	271	11	30317	3385	4	9	95
Castilla Mancha	3027	341	12	41241	5907	3	7	165
Aragon	3063	400	12	48908	4249	5	12	119
C. Valenciana	3068	1396	12	171084	14799	5	12	414
Extremadura	3099	191	12	23590	3572	3	7	100
Canarias	3111	460	12	57135	6653	3	9	186
Andalucia	3173	1720	13	217931	24242	4	9	679
Murcia	3255	294	13	38181	4547	3	8	127
Average	2645	725	11	79098	7515	4	10	210
Total		**12331**	**100**	**1344669**	**127761**			**3577**

Table 29: Installed capacity from medium penetration scenario for houses in buildings (source: own elaboration)

Region	nº of hours sun	houses (x1000)	Penetration %	Houses PV	Buildings PV	nº floors	houses/building	Installed capacity (MW)
Cantabria	1541	150,7	11,8	17836	1603	4	11	45
Pais Vasco	1760	830,7	13,5	112259	7830	6	14	219
Asturias	1925	357,2	14,8	52798	4284	5	12	120
Galicia	2191	598,1	16,8	100659	10066	4	10	282
Navarra	2278	172,8	17,5	30233	2679	5	11	75
Rioja	2586	104,3	19,9	20716	1837	5	11	51
Cataluña	2678	2289,6	20,6	470977	40529	5	12	1135
Madrid	2700	2159,1	20,7	447740	33737	5	13	945
Castilla Leon	2714	596,1	20,8	124243	13602	4	9	381
Baleares	2800	271,1	21,5	58301	6509	4	9	182
Castilla Mancha	3027	341,1	23,3	79311	11359	3	7	318
Aragon	3063	399,8	23,5	94054	8171	5	12	229
C. Valenciana	3068	1396,4	23,6	329008	28460	5	12	797
Extremadura	3099	190,6	23,8	45366	6869	3	7	192
Canarias	3111	459,8	23,9	109875	12794	3	9	358
Andalucia	3173	1719,5	24,4	419098	46620	4	9	1305
Murcia	3255	293,7	25,0	73425	8745	3	8	245
Average	2645	725,3	20	152112	14453	4	10	405
total	**2645**	**12331**	**100**	**2585902**	**245695**	**4**	**10**	**6879**

Table 30: Installed capacity from high penetration scenario for houses in buildings (source: own elaboration)

Region	nº of hours sun	houses (x1000)	Penetration %	House PV	Buildings PV	nº floors	house/building	Installed capacity (MW)
Cantabria	1541	150,7	23,7	35673	3207	4	11	90
Pais Vasco	1760	830,7	27,0	224519	15660	6	14	438
Asturias	1925	357,2	29,6	105596	8569	5	12	240
Galicia	2191	598,1	33,7	201319	20132	4	10	564
Navarra	2278	172,8	35,0	60467	5359	5	11	150
Rioja	2586	104,3	39,7	41432	3674	5	11	103
Cataluña	2678	2289,6	41,1	941954	81058	5	12	2270
Madrid	2700	2159,1	41,5	895479	67473	5	13	1889
Castilla Leon	2714	596,1	41,7	248486	27205	4	9	762
Baleares	2800	271,1	43,0	116602	13018	4	9	365
Castilla Mancha	3027	341,1	46,5	158621	22719	3	7	636
Aragon	3063	399,8	47,1	188109	16342	5	12	458
C. Valenciana	3068	1396,4	47,1	658017	56921	5	12	1594
Extremadura	3099	190,6	47,6	90733	13738	3	7	385
Canarias	3111	459,8	47,8	219750	25587	3	9	716
Andalucia	3173	1719,5	48,7	838197	93240	4	9	2611
Murcia	3255	293,7	50,0	146850	17489	3	8	490
Average	2645	725	41	304224	28905	4	10	809
total		**12330,6**	**100**	**5171803**	**491389**			**13759**

Table 31: Installed capacity from low penetration scenario for small, medium and big companies Source: own elaboration)

	Small and medium companies	Big companies
nº of companies	130147	12055
Penetration (%)	5	10
Companies PV	6507	1206
Installed capacity per company (KW)	42	84
Total installed capacity (MW)	275	102

Table 32: Installed capacity from medium penetration scenario for small, medium and big companies Source: own elaboration)

	Small and medium companies	Big companies
nº of companies	130147	12055
Penetration (%)	15	20
Companies PV	19522	2411
Installed capacity per company (KW)	42	84
Total installed capacity (MW)	823	203

Table 33: Installed capacity from high penetration scenario for small, medium and big companies Source: own elaboration)

	Small and medium companies	Big companies
nº of companies	130147	12055
Penetration (%)	25	50
Companies PV	32537	6028
Installed capacity per company (KW)	42	84
Total installed capacity (MW)	1372	508

Table 34: Installed capacity from low penetration scenario for commercial centers (Source: own elaboration)

Region	Nº hours of sun	nº of centers	nº center PV	Penetration %	m2	m/center	m/floor	Total m2	Capacity MW
Cantabria	1541	6	1	11,84	127755	21292,5	8517,0	6048,2	0,9
Pais Vasco	1759	31	4	13,51	831880	26834,8	10733,9	44967,5	6,3
Asturias	1924	18	3	14,78	498852	27714,0	11085,6	29494,3	4,1
Galicia	2191	42	7	16,83	889615	21181,3	8472,5	59888,4	8,4
Navarra	2278	8	1	17,50	207141	25892,6	10357,1	14496,7	2,0
Rioja	2586	4	1	19,86	101311	25327,8	10131,1	8048,9	1,1
Cataluña	2678	55	11	20,57	1451401	26389,1	10555,6	119422,9	16,8
Madrid	2700	132	27	20,74	3156252	23911,0	9564,4	261808,9	36,8
Castilla Leon	2713	31	6	20,84	598625	19310,5	7724,2	49907,7	7,0
Baleares	2800	9	2	21,51	197829	21981,0	8792,4	17017,5	2,4
Castilla Mancha	3027	26	6	23,25	531411	20438,9	8175,6	49424,2	7,0
Aragon	3063	14	3	23,53	517025	36930,4	14772,1	48652,8	6,8
C. Valenciana	3067	63	15	23,56	1778446	28229,3	11291,7	167609,2	23,6
Extremadura	3099	19	5	23,80	284441	14970,6	5988,2	27080,9	3,8
Canarias	3111	48	11	23,90	968850	20184,4	8073,8	92607,8	13,0
Andalucia	3173	125	30	24,37	2717184	21737,5	8695,0	264906,7	37,3
Murcia	3255	24	6	25	704573	29357,2	11742,9	70457,3	9,9
Total		**655**	**141**		**15562591**	**24216,6**	**9686,7**	**1331840,0**	**187,3**

Table 35: Installed capacity from medium penetration scenario for commercial centers (Source: own elaboration)

Region	Nº hours of sun	nº of centers	nº center PV	Penetration %	m2	m/center	m/floor	Total m2	Capacity MW
Cantabria	1541	6	1	23,67	127755	21292,5	8517,0	12096	1,7
Pais Vasco	1760	31	8	27,03	831880	26834,8	10733,9	89935	12,6
Asturias	1925	18	5	29,56	498852	27714,0	11085,6	58989	8,3
Galicia	2191	42	14	33,66	889615	21181,3	8472,5	119777	16,8
Navarra	2278	8	3	34,99	207141	25892,6	10357,1	28993	4,1
Rioja	2586	4	2	39,72	101311	25327,8	10131,1	16098	2,3
Cataluña	2678	55	23	41,14	1451401	26389,1	10555,6	238846	33,6
Madrid	2700	132	55	41,47	3156252	23911,0	9564,4	523618	73,6
Castilla Leon	2714	31	13	41,69	598625	19310,5	7724,2	99815	14,0
Baleares	2800	9	4	43,01	197829	21981,0	8792,4	34035	4,8
Castilla Mancha	3027	26	12	46,50	531411	20438,9	8175,6	98848	13,9
Aragon	3063	14	7	47,05	517025	36930,4	14772,1	97306	13,7
C. Valenciana	3068	63	30	47,12	1778446	28229,3	11291,7	335218	47,1
Extremadura	3099	19	9	47,60	284441	14970,6	5988,2	54162	7,6
Canarias	3111	48	23	47,79	968850	20184,4	8073,8	185216	26,0
Andalucia	3173	125	61	48,75	2717184	21737,5	8695,0	529813	74,5
Murcia	3255	24	12	50	704573	29357,2	11742,9	140915	19,8
Total		**655**	**281**		**15562591**	**24216,6**	**9686,7**	**2663680**	**374,6**

Table 36: Installed capacity from high penetration scenario for commercial centers (Source: own elaboration)

Region	Nº hours of sun	nº of centers	nº center PV	Penetration %	m2	m/center	m/floor	Total m2	Capacity MW
Cantabria	1541	6	2	37,87	127755	21292,5	8517,0	19354	2,7
Pais Vasco	1760	31	13	43,24	831880	26834,8	10733,9	143896	20,2
Asturias	1925	18	9	47,30	498852	27714,0	11085,6	94382	13,3
Galicia	2191	42	23	53,86	889615	21181,3	8472,5	191643	26,9
Navarra	2278	8	4	55,99	207141	25892,6	10357,1	46389	6,5
Rioja	2586	4	3	63,56	101311	25327,8	10131,1	25756	3,6
Cataluña	2678	55	36	65,82	1451401	26389,1	10555,6	382153	53,7
Madrid	2700	132	88	66,36	3156252	23911,0	9564,4	837789	117,8
Castilla y Leon	2714	31	21	66,70	598625	19310,5	7724,2	159705	22,5
Baleares	2800	9	6	68,82	197829	21981,0	8792,4	54456	7,7
Castilla Mancha	3027	26	19	74,40	531411	20438,9	8175,6	158157	22,2
Aragon	3063	14	11	75,28	517025	36930,4	14772,1	155689	21,9
C. Valenciana	3068	63	47	75,40	1778446	28229,3	11291,7	536349	75,4
Extremadura	3099	19	14	76,17	284441	14970,6	5988,2	86659	12,2
Canarias	3111	48	37	76,47	968850	20184,4	8073,8	296345	41,7
Andalucia	3173	125	97	77,99	2717184	21737,5	8695,0	847701	119,2
Murcia	3255	24	19	80	704573	29357,2	11742,9	225463	31,7
Total		**655**	**450**		**15562591**	**24216,6**	**9686,7**	**4261888**	**599,3**

Annex 2

Table 37: Monthly Electricity production for different scenarios at house sector (*Source: own elaboration*)

Month	Ed (KWh)	Em (KWh)	Hd KWh/m2	Hm (KWh/m2)	GWh Low Scenario	GWh medium scenario	GWh high scenario
January	12,64	333,14	4,11	104,76	512,96	854,93	1367,88
February	13,76	385,16	4,38	122,64	593,05	988,42	1581,47
March	17,12	530,61	5,60	173,49	817,01	1361,69	2178,70
April	17,17	514,92	5,68	170,45	792,85	1321,41	2114,26
May	17,89	554,50	6,02	186,59	853,80	1423,00	2276,81
June	18,72	561,97	6,43	192,75	865,30	1442,16	2307,45
July	19,46	603,04	6,74	208,95	928,54	1547,56	2476,10
August	18,87	585,41	6,54	202,80	901,39	1502,32	2403,71
September	17,49	524,79	5,94	178,28	808,05	1346,75	2154,80
October	14,82	458,86	4,91	152,11	706,53	1177,55	1884,08
November	11,36	340,84	3,63	108,99	524,81	874,69	1399,51
December	10,14	314,59	3,19	99,10	484,39	807,31	1291,70
Annual average	17,65	514,26	5,91	174,63	731,91	1220,00	1952,50
total/year		**6087,00**		**5725,45**	**9372,53**	**15620,88**	**24993,40**

Table 38: Electricity production at house sector for the different scenarios and different regions (source: own elaboration)

Region	Low penetration (GWh)	Medium penetration (GWh)	High penetration (GWh)	optimal angle
Andalucía	2.675	4.458	7.133	33
Aragon	237	394	631	37
Asturias	88	147	235	38
Baleares	272	453	725	35
C. Valenciana	1.088	1.814	2.902	36
Canarias	661	1.099	1.763	27
Cantabria	54	89	143	35
Castilla Leon	632	1.053	1.685	35
Castilla Mancha	751	1.252	2.004	34
Cataluña	812	1.624	2.598	37
Extremadura	425	709	1.134	34
Galicia	509	848	1.357	35
Madrid	436	873	1.397	35
Murcia	439	732	1.172	35
Navarra	90	150	239	36
Pais Vasco	43	72	115	33
Rioja	32	53	84	35
Total	9373	15621	24993	

Table 39: Monthly electricity production for different scenarios at building blocks (*Source: own elaboration*)

Month	Ed (KWh)	Em (KWh)	Hd KWh/m2	Hm (KWh/m2)	GWh low scenario	GWh medium scenario	GWh high scenario
January	74,5	2309,6	3,3	103,7	295,1	567,5	1134,9
February	96,9	2712,5	4,4	123,6	346,6	666,4	1332,9
March	120,4	3733,7	5,6	174,6	477,0	917,3	1834,7
April	120,6	3619,1	5,7	171,3	462,4	889,2	1778,4
May	125,8	3900,6	6,1	187,6	498,3	958,4	1916,7
June	131,7	3949,3	6,5	193,5	504,6	970,3	1940,7
July	136,6	4235,4	6,8	209,6	541,1	1040,6	2081,2
August	132,7	4111,7	6,6	203,6	525,3	1010,2	2020,5
September	123,0	3688,4	6,0	179,1	471,2	906,2	1812,5
October	104,4	3234,5	4,9	153,3	413,2	794,7	1589,4
November	80,3	2406,8	3,7	110,1	307,5	591,3	1182,7
December	71,6	2219,3	3,2	99,8	9,7	545,3	1090,6
Annual average	113,4	3456,9	5,4	165,6	439,5	889,0	1778,0
total/year	40501,2	40533,0		59120,1	5274,0	10668,0	21314,0

Table 40: Electricity production per region and scenario for building blocks (*source: own elaboration)*

Region	Low penetration (GWh)	Medium penetration (GWh)	High penetration (GWh)	optimal angle
Andalucia	1096	2109	4217	33
Aragon	180	346	691	37
Asturias	76	146	291	38
Baleares	149	286	572	35
C. Valenciana	658	1265	2529	36
Canarias	311	599	1197	27
Cantabria	25	49	97	35
Castilla Leon	255	490	979	35
Castilla Mancha	251	483	966	34
Cataluña	887	1705	3411	37
Extremadura	156	301	602	34
Galicia	195	376	751	35
Madrid	765	1471	2942	35
Murcia	200	385	770	35
Navarra	54	104	207	36
Pais Vasco	126	242	485	33
Rioja	35	68	136	35
Total	5419	10421	20843	

Table 41: Electricity production at small and medium companies for the different scenarios (*Source: Own elaboration*)

Low penetration scenario Small and medium companies			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
60650	6507	394650	274
		394 GWh	
Medium penetration scenario Small and medium companies			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
60650	19522	1184009	823
		1184 GWh	
High penetration scenario Small and medium companies			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
60650	32537	1973369	1372
		1973 GWh	

Table 42: Electricity production at big companies for the different scenarios (*Source: Own elaboration)*

Low penetration scenario big companies			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
121300	1206	146288	101
121,3		146,2878	
Medium penetration scenario big companies			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
121300	2411	292454	203
121,3		292,4543	
High penetration scenario big companies			
Average KWh/year	nº companies	Total production MWh	Total capacity MW
121300	6028	731196	508
121,3		731,1964	