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UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

Smart Solutions for self-consumption customers: Regulatory framework for users and market

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Summary

The duck curve illustrates the challenges that occur during intermittent integration of renewable sources into the electrical grid. Despite being clean and sustainable energy sources, solar and wind energy's instability can lead to imbalances in the supply and demand for energy. To solve these problems and successfully make the switch to a more renewable and resilient energy system, solutions for energy storage, generation flexibility, and smart grid management are required.

Principled outcomes include developing a regulatory plan that promotes the use of energy storage using batteries, Adopt the self-consumption regulatory framework by creating RD 244/2019. Encourage the low- and medium-voltage networks to be digitalized; monitor the adoption of self-consumption; modify the tariff structure to ensure the long-term viability of the electrical system; and make investments in energy storage. This is effective since neither the customer nor the generator's interests are protected by the regulator. The regulator makes sure the system is secure.

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1. Chapter 1

1.1. Introduction

Renewable energy is energy that comes from a source that won't run out. Most people think that renewable energy is energy produced form sources that come from the nature, which in fact they are not wrong. Sources like the sun, wind, water won't ever run out, but there is a big difference between being renewable and being clean. For example, biomass, burning biomass release CO_2 emissions into the atmosphere, a greenhouse gas. The main advantage of renewable energy is that energy is available in the natural environment, even though renewable energy technologies can cause some emissions, these ones are less than producing energy of a non-renewable energy, such as coal and natural gas.

Smart Solutions are nowadays something to look forward to promoting efficiency, energy saving and care for the environment. These solutions can be for electric vehicles including a management of the infrastructure, services aimed at improving energy efficiency and cost savings, heating, and cooling solutions through different systems. There are other technologies such as green hydrogen that aims for industrial uses and sectors such as aviation, high temperature industry and others, that are difficult to decarbonize.

The term self-consumption is the consumption by one or several consumers of electrical energy from production facilities close to and associated with those of consumption. One type of self-consumption is photovoltaic self-consumption, which requires an installation based on solar panels since it uses solar radiation to produce electricity. Photovoltaic panels became very popular because of the technological advances, the average cost of photovoltaic generation became very competitive, that meant great savings on the monthly electricity bill, improvement in demand management, reduction in CO_2 footprint in the consumers.

Because of the trend of self-consumption, there were some set of rules to manage that issue across history. A deep comparison between different regulatory framework in Spain is worth to look as well as an economic analysis.

1.2. Motivation

The main purpose of this master thesis is to apply all the knowledge acquired during the Official Master's degree in the Electric Power Industry at University of Comillas resided in Madrid, Spain with a whole duration of an academic year 2022-2023.

With collaboration of IBERDROLA S.A., this Master thesis is supervised by Luis Gutiérrez Ochoa, actual head of the Smart Solar department.

Self-consumption is having a significant rise since the installation of green technologies. I have decided to focus my thesis on self-consumption for domestic and industrial customers with the technology of photovoltaic systems.

As I stated above, the rise of the technologies of self-consumption is currently happening, seeing that in a regulatory perspective is quite more interesting because of all the history that self-consumption with photovoltaic systems happened in Spain and proposing a new regulatory scheme would be intriguing by analyzing different factors.

I have acquired some knowledge during my master and in my internship with Iberdrola so that is why I have decided to see the self-consumption in a regulatory perspective.

1.3. Objectives of the Master Thesis

The objectives addressed in this master thesis are:

- Examinate the situation of self-consumption in Spain
- Understand the concept of distributed generation
- Understand the legal situation of self-consumption in Spain
- Comparison between the different regulatory schemes in time in Spain
- Understand the California's duck curve
- Build a market analysis
- Examinate the regulatory context in Spain
- Propose a regulatory scheme for self-consumption
- Examinate the quantified results obtained

1.4. Methodology

The master thesis will start by giving a background in self-consumption, which this background contains the concept of distributed generation, that is important to understand because the technology used for self-consumption, one the most common are photovoltaic systems.

Once this concept is understood, we proceed to search and analyze the Royal Decree 661/2007, which is about the regulation of electrical energy production under the special regime and the Royal Decree 900/2015, that is the regulation of the administrative, technical, and economic conditions of the modalities of supply of electrical energy with self-consumption and of production with self-consumption.

Then, we proceed to analyze the current situation of self-consumption in Spain with the latest Royal Decree 244/2019, which states the regulation of the administrative, technical, and economic conditions of self-consumption of electrical energy.

Once knowing the legal background of the regulation of self-consumption we will proceed to analyze the regulatory framework in Spain and compare between the past Royal Decree, discuss about the actions that could be done better. In addition, a market analysis will be made because it is worth mentioning how the market acts within the concept of self-consumption.

Based on all the readings and the understanding of the same, I will propose a regulatory scheme of self-consumption with improvements and some modifications of the actual one.

Finally, we will get the quantified results and they will be discussed

2. Chapter 2: State of the art

2.1. Introduction of solar photovoltaic energy

As it is well known, solar photovoltaic energy is a process that consists in converting the electrons into voltage, so it generates direct current through semiconductors. Electrons absorb the photons to become energized, only when exposed to daylight.

In simple words, solar photovoltaic energy is a process of converting light to electric power. There are several fundamental components, the main one: the panel, which absorbs the energy coming from the sun in order to convert it in electrical current.

A photovoltaic panel is a group of photovoltaic cells that produce electric power from the sun light that is falling on them. This technology is important because the installation is required for photovoltaic self-consumption and it was mass-produced until the 1990s. A semiconductor discovered previously called photovoltaic cell made of monocrystalline, which is obtained from a crystal composed of pure silicon, this type of silicon achieves maximum efficiency on average of 19% polycrystalline or amorphous silicon. There are cells made of polycrystalline silicon, which are cheap, and their average efficiency is around 16% and the amorphous silicon which tends to have an average efficiency of 8%. These silicon semiconductors with certain impurities were hypersensitive to light.

Figure 1: Solar self-consumption installation in a rooftop of a household

Around the world, solar panels have become so common to see in urban and rural areas because of economy of scales, the cost of photovoltaic generation has become more competitive against conventional energy sources.

In a residential area, a photovoltaic self-consumption system connected to the grid is made of four main elements, which are the photovoltaic panel, the monitoring system, the accumulator, and the inverter.

Figure 2: Installation of photovoltaic and wind energy self-consumption

As already mentioned, the photovoltaic panel is a set of photovoltaic cells that produce electric power from the sunlight falling.

The monitoring system is mainly used in residential areas but in some of them they use a controller which main function is to control the power generation and to prevent overcharging and discharging.

When there is a lot of solar radiation, an accumulator is needed to store energy in order to use it.

An electronic device that converts the direct current from the photovoltaic panel into alternate current, this is called an inverter.

2.2. Background of Self-Consumption

Renewable energy, as its name states, is energy from resources that can be renew naturally on a human time scale. Most of renewable energy are sustainable, that includes the movement of a hydro body, wind, and sunlight, however there are some renewable energy sources that are not considered sustainable. Sustainability is a concept that it is stated as fulfilling our own needs as human beings but without compromising the needs of future generations. Renewable energy is often used for electricity generation, heating and cooling, energy projects are mandatory in order to satisfy people's needs and these projects tend to be typically at large-scale, this is a problem for rural communities or nations in which the use of energy is mandatory in order to satisfy basic necessities.

Having said that, a new way of consuming electrical power has arisen, which is self-consumption of electricity. This happen because the installation of the technologies is making it possible because of the fewer administrative procedures, which depend entirely on the country the user is residing in, and the installation of the technologies, which now a days people can afford them.

Self-consumption gives the possibility of generating our own energy, that means there is an increase in autonomy, we do not depend on the supply of third parties and the cost in the electricity bill is reduced, the distributed generation, will help the user to improve the demand management and will reduce consumers' CO_2 footprint.

In this context, self-consumption happens when the user consume energy produced by installations of production are associated with the consume ones such as photovoltaic panels.

Global PV installed capacity has been increasing at an average 46% yearly during the last decade with modules being the component with faster cost decrease: 24% down every time cumulative capacity doubles.

This greater module learning rate has made them cease to be the most expensive part in terms of $/W, making other components like BoS increase their share of the total power plant Capex.

In this scenario, innovation towards high efficiency cells is a key factor to drive costs down, since higher rated modules occupy the same space, making BoS cheaper in terms of $/W.

More than half of the world´s main countries have a capacity factor greater than 20%, therefore better solar resource exploitation will be also relevant to reduce per MWh costs, being bifacial cells one of the most promising innovations. Solar costs will relentlessly continue to go down, with expectations of around 30% Capex reduction in 2030.

2.3. The concept of Distributed generation

Distributed generation is the generation of electrical energy and the storage of this energy in small devices such as grid-connected devices stated as distributed energy resources. This concept refers to a vast of technologies that can produce electricity near where it will be used.

As already mentioned, distribution generation can be part of a smaller grid that it is tied into a larger electricity system, in some cases that could be an industrial facility, a household or a business. One advantage of distributed generation, or also called on-site generation is that it can support delivery of clean, reliable electric power to consumers and in a technical way, it is viewed that distributed generation help to reduce electricity losses in the transmission and distribution lines.

On-site systems are not only solar photovoltaic panels, but they can also be small wind turbines, emergency backup generators in the domestic sector. On the other hand, in the industrial sector distributed generation can be combined heat power systems, backup generators, solar photovoltaic panels and more.

Distribution generation can benefit the environment when the use of this systems helps to reduce the electricity generated at power plants that are conventional or centralized. However, on-site generation can have a negative environmental impact because these types of systems have some visual impact, in some cases, this technology involved burning fossil fuels and that lead to CO_2 emissions, it is true that because of the size of these systems is small, the impact is not comparable with a power plant facility.

Despite the disadvantages, which are mainly of the type of technology used for on-site generation, consumers should invest in self-consumptions facilities nowadays. In solar photovoltaic panels, demand management is a challenge because generation in demand is at its peak during daytime and therefore the consumer demand is at its highest during the day. Even though it is needed a storage technology to adjust the generation curve of the system.

2.4. Regulatory Frameworks since 1997 in Spain

For the functioning of society is essential the electricity sector because the price of electricity influences the competitiveness of the economy. Storing electricity is hard nowadays due to the technology available at this time so that means that demand and supply must be coordinated all time. Due to that fact, the electric power industry needs regulation to guarantee, the quality of electricity, affordable cost, and supply.

2.4.1. Regulatory framework under the new model established in the Electricity Sector Law

In Figure 3 is shown a segment of a timeline from 1997 to 2004 of the main regulatory frameworks in the Electricity Sector.

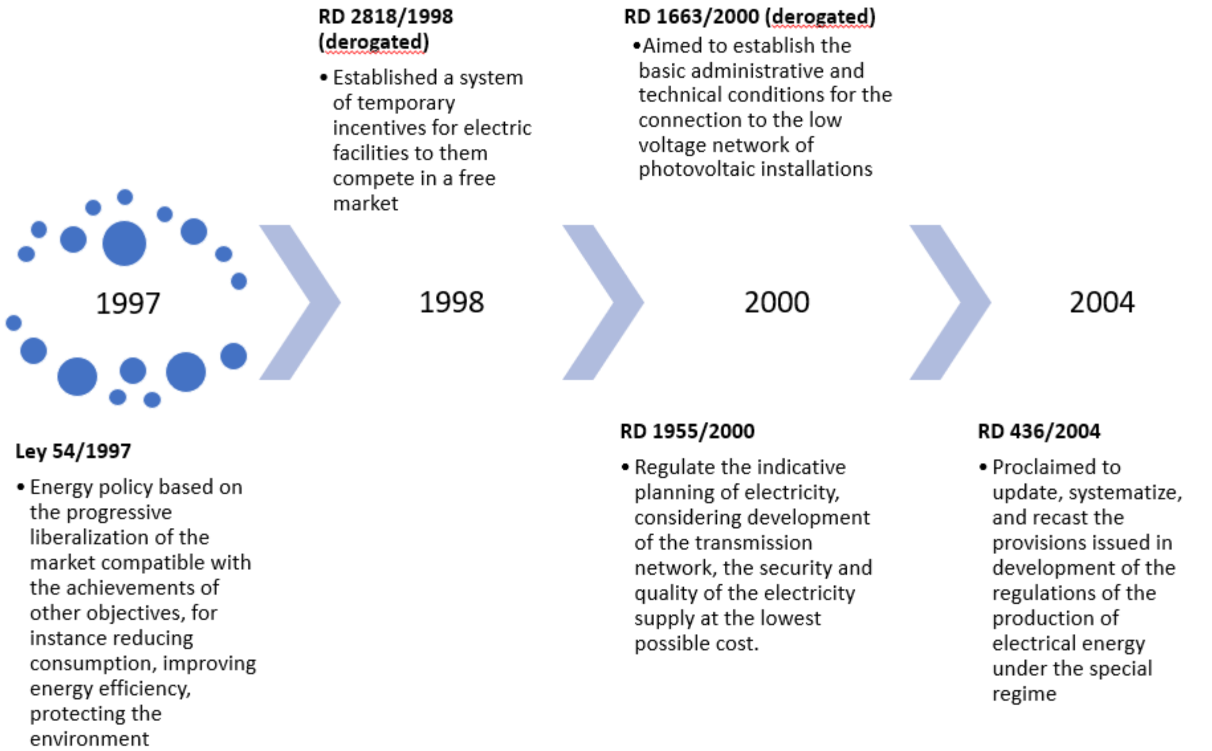

Figure 3: Regulatory Framework from 1997 to 2004

Between 1997 and 2004, Spain's regulatory system for the power industry experienced several significant changes.

Spain's legal foundation for the electrical industry was established by the Electricity Sector Law 54/1997. It sought to advance competition, boost effectiveness, and safeguard consumer rights. To oversee the industry, it established the National Energy Commission (CNE). The following topics are crucial in this period because they underwent major modifications with an emphasis on fostering competition, raising efficiency, and supporting renewable energy sources.

- Electricity Market establishment
- Development of renewable energy
- Regulation of power tariffs
- Market Liberalization

In the first topic, Spain's electricity market was established in 1998. It was intended to be a liberalized, competitive market that welcomed participation from various electricity firms.

With the passing of the Renewable Energy Plan in 2000, Spain started to push renewable energy sources in the early 2000s. This plan provided financial incentives for businesses to invest in renewable energy and set goals for the volume of renewable energy that should be produced in Spain.

Back in 2003, the Spanish government changed the power tariff structure. The goal of this approach was to improve transparency and lower consumer electricity rates.

In 2004, a new electrical law was introduced, which completely liberalized the Spanish power market. This legislation aims to safeguard consumer rights while advancing market efficiency and competitiveness.

2.4.2. Promotion of renewable energy sources, competition, and new technologies

Figure 4 shows the years from 2007 to 2010 the main Royal-Decrees that influenced the promotion of renewable energy sources and competition. The Spanish regulatory environment for the power industry continued to change between 2007 and 2010.

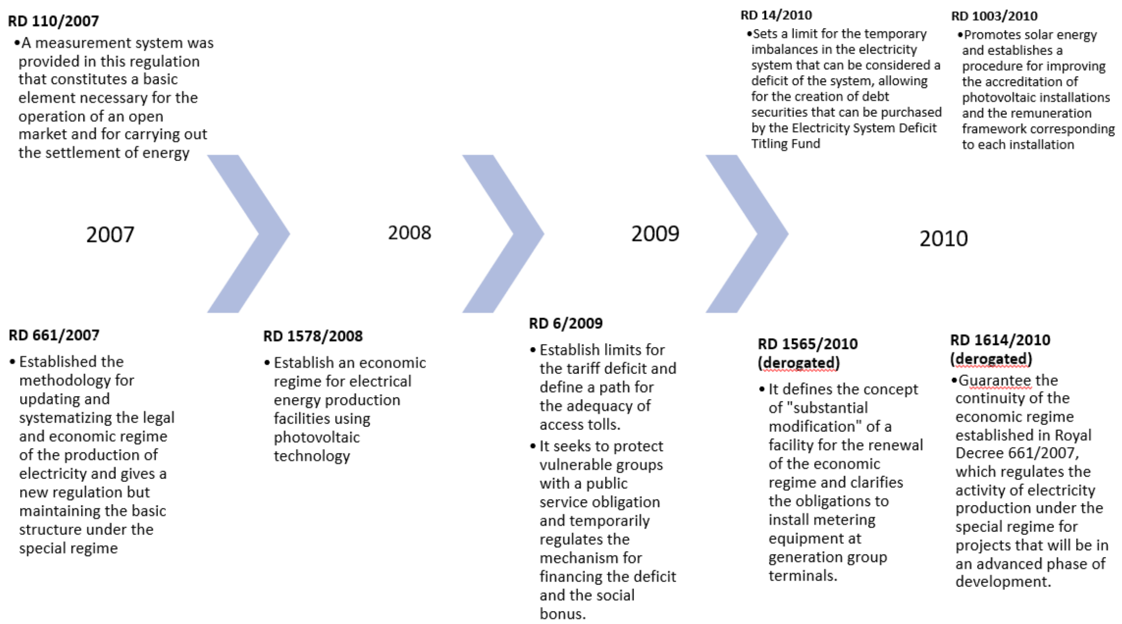

Figure 4: Regulatory Framework from 2007 to 2010

Spain's new renewable energy regulatory framework was established by Royal Decree 661/2007. For example, feed-in tariffs, which ensured a fixed price for power produced from renewable sources, were one of the financial incentives it offered for renewable energy projects.

The National Commission of Energy (CNE) was established in 1997 to oversee Spain's power industry. But in 2007, it had more authority and began to oversee the gas industry as well.

In 2009, Spain started putting the Third Energy Package into practice. This package was designed to encourage competition in the EU's energy market. This package comprised steps to decouple production from supply, improve pricing transparency, and establish independent regulatory bodies.

Spain started promoting the creation of smart grids during this time. Digital technologies are used by smart grids to monitor and control the electrical network, making the distribution of electricity more effective and dependable.

During this time, the Spanish government implemented laws to encourage the usage of electric vehicles. This involved building a charging infrastructure and providing incentives for the purchase of electric automobiles.

2.4.3. Promoting competition and reducing costs in the Electricity Sector

The regulatory framework for the electricity sector in Spain continued to evolve between 2011 and 2013.

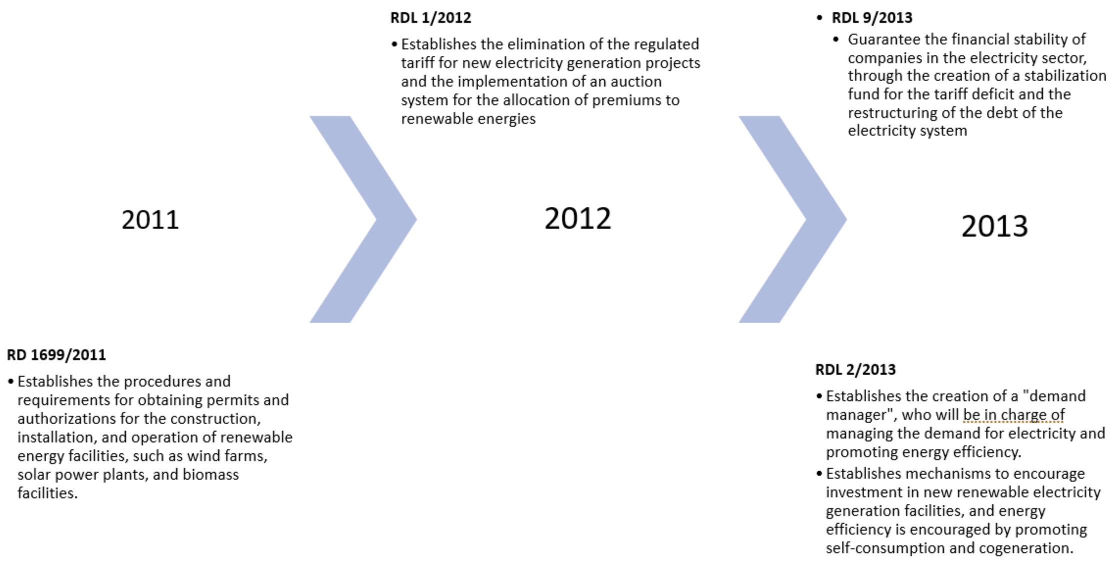

Figure 5: Regulatory Framework from 2011 to 2013

Royal Decree-Law 1/2012 introduced a series of measures to reduce the tariff deficit, which was the difference between the cost of producing electricity and the revenue generated from selling it. The measures included a reduction in feed-in tariffs for renewable energy, as well as the introduction of a tax on electricity production.

In 2013, the Spanish government announced a major energy sector reform, which aimed to increase competition and reduce costs in the sector. The reform included measures to reduce the tariff deficit, promote energy efficiency, and increase transparency in pricing.

The CNMC was created in 2013 to replace several regulatory bodies, including the CNE. The CNMC's role is to promote competition and regulate the electricity and gas sectors in Spain.

As part of the energy sector reform, the Spanish government reduced incentives for renewable energy. This led to a decrease in investment in renewable energy projects in Spain.

The Spanish government introduced several policies to promote energy efficiency during this period. This included the development of a national energy efficiency plan, which aimed to reduce energy consumption and greenhouse gas emissions.

2.4.4. The sun tax

The regulatory framework for Spain's energy industry continued to change between 2014 and 2018.

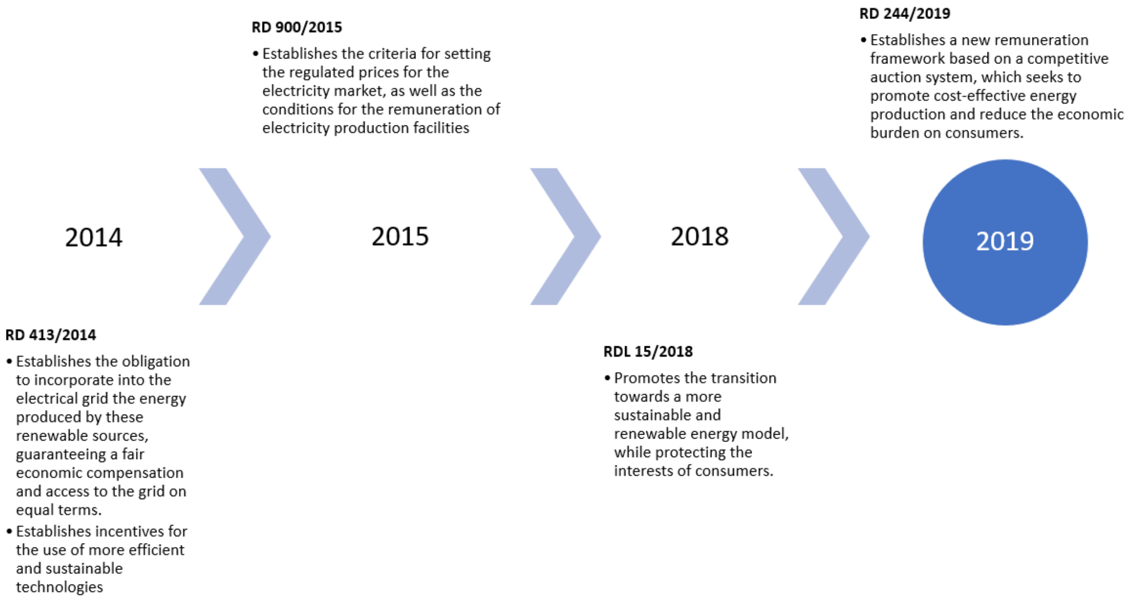

Figure 6: Regulatory Framework from 2014 to 2019

In order to decrease the tariff deficit and boost competition in the renewable energy sector, Spain's Royal Decree 413/2014 developed a new regulatory framework. It created new methods for the selling of renewable energy and contained new regulations for the distribution of subsidies for renewable energy.

The Spanish government launched a significant energy market reform in 2015 with the goal of boosting competition and lowering costs in the industry. The reform included initiatives to ease the regulatory burden on energy companies and enhance the efficiency of the electricity market.

During this time, the Spanish government implemented a number of policies to encourage the usage of electric vehicles. This included financial aid for the purchase of electric cars, the construction of charging stations, and the drafting of rules governing their usage in public transportation.

During this time, Spain's capability for renewable energy increased. By 2020, the Spanish government hopes to have 20% of its energy come from renewable sources.

In 2018, the Spanish government implemented policies to lower energy prices for consumers. Among other things, the value-added tax on gas and electricity bills was decreased.

2.5. Current situation of self-consumption

2.5.1. RD 244/2019

The Royal Decree 244/2019's major goal is to encourage self-consumption in Spain by promoting distributed renewable generating, cogeneration, and waste management. That being said, Spain has regulations governing the administrative, technical, and economic aspects of self-consumption.

Modality of self-consumption without surpluses is a self-consumption-based supply system that doesn't produce surpluses. For these methods to operate, an anti-discharge device must be installed in order to prevent an excessive amount of energy from being added to the transmission or distribution network. There will only be one kind of topic in this instance, the customer.

The modality of self-consumption with surpluses is the supply strategy that makes advantage of surpluses and self-consumption. In this method, the production sources that are near and connected to the consumption sources will have the ability to produce energy for self-consumption as well as load surplus energy into the transmission and distribution networks. The two categories of subjects in these circumstances are the consumer and the producer.

In self-consumption supply situations when the producer and consumer freely choose to apply a surplus compensation mechanism, the surpluses subject to compensation modality is applicable. You can use this option only if all of the requirements below are satisfied.

- Renewable energy sources must be the primary energy source.
- The combined power of associated manufacturing facilities cannot exceed 100 kW.
- If it becomes essential to employ a supply contract for auxiliary production services, the consumer shall sign a single supply contract with a marketing firm for both related consumption and auxiliary production consumption.
- A contract for self-consumption excess compensation has been made between the consumer and the associated producer.

- No supplementary or particular remuneration system has been developed by the producing site.

The excess strategy that is not compensated: This modality shall apply to all instances of self-consumption with surpluses that do not comply with any of the criteria for membership in the modality with surpluses covered by compensation or that freely choose not to take advantage of said modality.

The real question here is how excesses are paid for. Using solar systems for self-consumption is one strategy to combat rising power bill costs. Additionally, you will be able to consume at the most costly periods of time when your photovoltaic system is operating at its peak efficiency. If you choose the self-consumption with surpluses modality, your retailer will give you a discount on the consumption portion of your payment. Consequently, you will receive a discount in addition to the one offered by self-consumption.

The idea of "production facility close to and associated with consumption facilities" is applied to both individual and group customers and specifies the kinds of facilities that can be established:

- Installations connected to the internal network or via direct lines.
- Installations that are linked to the shared transformer-powered low-voltage network.
- Installations where the distance between the generation and consumption of electricity is less than 2 km.
- Installations where the cadastral references for generating and consumption are the same.

The installed power will be the inverter's maximum power or, if applicable, the total of the inverters' maximum powers.

There are two main types of self-consumption which are individual self-consumption and collective self-consumption.

The “Individual self-consumption” when you are free to use any self-consumption technique, discharge or not. Self-consumption through a network will invariably be seen as "self-consumption with surpluses" regardless of the mode.

The “Collective self-consumption” when the modes of self-consumption can only be utilized with surpluses. The same self-consumption modality must be shared by all self-consumers connected to the same generating facility. The owner of the installation will be regarded as a consumer with reference to its supplementary consumption when surpluses are sold.

There may be differences between the customer and the facility owner. The owner of the supply point and the installation will be the same, with the exception of the self-consumption mode without surpluses.

Provisions for the promotion of energy storage are also included in RD 244/2019. The legislation acknowledges the significance of energy storage technologies for incorporating renewable energy into the grid and guaranteeing its stability, such as batteries and pumped hydro. The legislation sets a regulatory framework, including the permission procedure and the technical and financial criteria, for the construction of energy storage facilities.

It is important to remember that RD 244/2019 is a component of a larger initiative by Spain to support renewable energy and battle climate change. The administration has established a goal of being carbon neutral by 2050 in addition to the above indicated objectives for the production of renewable energy. Spain is spending a lot of money on energy efficiency improvements including building renovations and infrastructure for electric vehicles in order to meet these objectives.

To sum up, the comprehensive piece of law known as RD 244/2019 lays out the guidelines and specifications for the growth of renewable energy in Spain. In addition to protecting the reliability and security of the electrical system, the legislation encourages the development, use, and storage of renewable energy. Spain is taking the lead in the worldwide fight against climate change by encouraging renewable energy and lowering greenhouse gas emissions.

3. Chapter 3: Problem setting, description.

3.1. California's Duck Curve

A typical load curve shows some demand spikes in the morning and in the evening, as shown in the figure below.

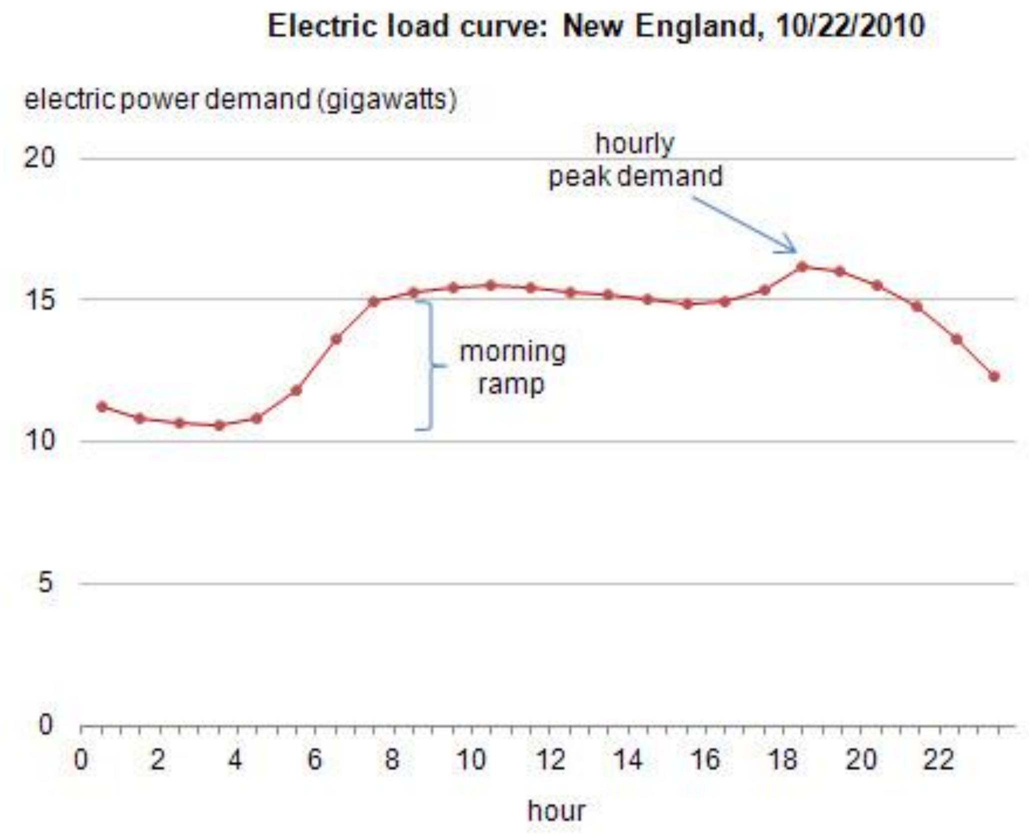

Figure 7: Example of an electric load curve

It is worth to mention that this curve could be different in some regions and in different seasons of year. You could have different ramps in spring than in winter or maybe you could have different size peaks in summer than in fall.

Setting into some context, in 2013 the California Independent System Operator (CAISO) analyzed the deployment of solar photovoltaic power. The behavior that was analyzed showed the difference in electricity demand and the amount of available solar energy throughout the day. This behavior curve is called the Duck Curve.

It is worth to mention that when the sun is not shining in the evening solar drop off as a form of demand peaks in the other way around, when the sun is shining as its best, solar energy floods the market. CAISO analyzed this in a timeframe of 24 hour in California during spring, which is an interesting season because the behavior of the curve is very extreme due to solar radiation. In addition, as stated before spring is not warmer than summer in California, the demand of electricity is low because people are not using electricity as much as they would use it in warmer months.

Seeing that in a point of view from the operator of the grid if you integrate a considerably high amount of solar power intro the grid, as you can see in Figure X that it is going to repress the total net load during the middle of the day. Now reaching the middle of the day the load curve will sink and when sun sets, the load curve will ramp up.

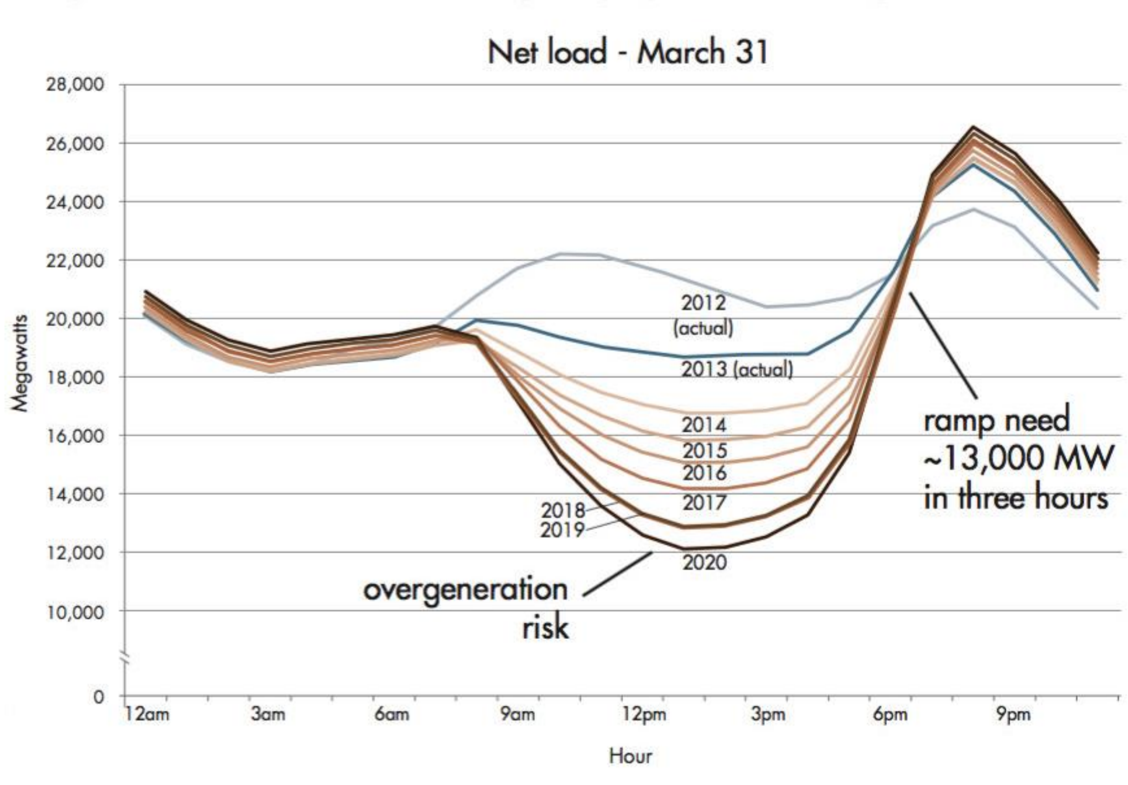

Figure 8: The Duck Curve

Because of this behavior, utilities need to establish a plan derived for the increasing amount of solar energy, even in places that the solar radiation is high, for example California.

The problem here is the challenge for electrical utilizes to balance the supply and the demand on the grid. Systems operators also have a problem with the curtail of photovoltaic generation because of the high radiation to produce more energy, this is called overgeneration.

If this problem doesn't get solved, users that have a self-consumption scheme will get affected in a severe way. Electrical utilities could regularly be forced to ramp up their dispatchable plants when a peak in the morning occurs following that while the sun is out then shut down all the dispatchable plants and finally when the sun sets, start those plants in a faster way.

Since then, the industry has been striving to enhance how the grid handles the duck curve since the neck may make it more challenging for the resource fleet to be flexible enough to ramp up and the belly can lead to both over-generation concerns and renewable curtailment. The ability to be flexible is essential to overcoming these obstacles.

Recently, the net load for CAISO has either hit zero or become negative. As the canyon deepens, dispatchable resources are drastically reduced during the day and the requirement for flexibility is subsequently increased as dusk falls. Here is an illustration of a canyon curve.

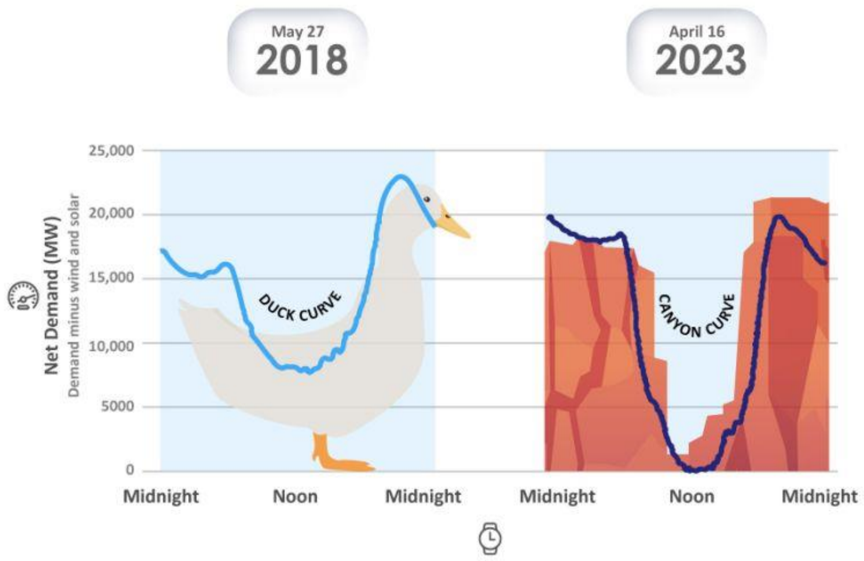

Figure 9: The Duck Curve that looks like a Canyon

As a result, energy firms will have to shut down any resources that can't start up quickly enough to cross the canyon before sundown, or else they'll have to reduce solar output, squandering free, clean energy. Energy businesses require greater flexibility from the little remaining resources as the canyon walls become steeper.

Today, the process of descending into the canyon is mostly accomplished by lowering the amount of gas produced, switching from importing to exporting electricity, and charging batteries. Even at the canyon floor, some gas production must continue to run in order to scale the walls. The whole ascent calls for increasing gas production as the sun sets, moving from exporting to importing power, releasing extra hydroelectric generating from reservoirs, and fully discharging batteries utilizing the energy they stored on the canyon bottom.

Future filling of the canyon and scaling of the cliffs may need further resources. Additional forms of energy storage (thermal, mechanical, chemical, etc.) that can transfer energy to when it is needed; new technologies like hydrogen with adaptable new electrolyzers; and time-of-use rates and other programs that promote electricity use from the evening to midday are some examples of these tools.

Doing that ramping and staring in economic terms is expensive and highly inefficient, in a hypothetically way if the voltage rises extremely high, the solar expansion could be handicap. Therefore, a regulatory framework is going to be proposed in order to address the upcoming problem.

3.2. The Spanish Duck Curve

The duck curve is happening right now in Spain, the question to answer about the demand in Spain and the introduction of renewable energy sources is quite challenging topic. Using ESIOS data from April 4th 2023, it is stated that:

- With the large introduction of renewables, demand ramps are getting progressively exaggerated, especially the second. Meeting these demand spikes is one of the most crucial challenges, along with surpluses.
- Programs for solar or wind adjustments start to be adjusted more often.
- The connections may begin to saturate.
- Generation on demand starts to have an hourly average excess of significance.

Without going into many details, the objective is to reveal the photo of a typical day, and it is not representative, a seasonal analysis must be made with a sufficient sample, but it does give an idea of what can, or rather is going to happen without a doubt in my opinion. Congestion, saturation

and increased restrictions.

Undoubtedly, energy storage can be one of the solutions to solve these problems that are beginning to appear consistently. Likewise, the improvement of interconnections is relevant, in addition to designing the generation mix of the future in a sustained energy transition in a reasonable manner.

This behavior is generally analogous in energy markets with a massive entry of renewables in one way or another, depending to a large extent on the type of network, generation mix, and distribution of demand. It is not a particular case of Spain, but the solutions have to be taken in a customized way for each country.

As stated before, in Spain, the duck curve is already something that occurs nearly daily. From 9:00 a.m. to 5:00 p.m. today, the cost of energy will be €0, which implies that no power producer will be paid a single euro for the energy it produces and sells on the wholesale market.

It is a pattern that has started to repeat itself consistently on the weekends, which has made it feasible to cut the average monthly price of power, which has increased so dramatically over the last two years. Despite being true, there is a growing gap between the hours with renewable energy penetration (particularly solar) and the hours without it.

In fact, the price of electricity will soar after these hours, at 10:00 p.m. tonight, to €100/MW, an exorbitant price compared to what we had a few years ago.

Authorities that can handle the current situation urgently need to act since there is a steady rise in solar self-consumption (sometimes rationally, sometimes not), and there will be 40 GW of solar installations erected over the next three years that already have an environmental impact statement.

Along with the requirement to expand our storage capacity at a reasonable cost, we also require measures that improve the flexibility of consumption by businesses and households. Both the electric vehicle and the charging stations are important factors.

4. Chapter 4: Proposed Method

4.1. Extent of utility regulatory models

In order to propose a method to solve the California duck curve, it should be first answered the question of to what extent utility regulatory models are a barrier to solving the problem stated.

4.1.1. Ramping Flexibility

Flexibility supply curve is a concept often referred to as a responsive or elastic supply curve, depicts the link between the quantity of an item or service supplied and its price, with the quantity supplied significantly changing as the price varies.

Learning how to ramp coal and gas power plants better is the real issue because of the impact that could have either technically or economically speaking.

Consider an industrial client that has coal or gas plants that were built as base or intermediate loads with minimal capacity for load following, and whose operators aren't accustomed to moving these units across a wide range.

Technically, it would be feasible for the plants to expand their range by more than 50% thanks to the technical sheets. Nevertheless, due to the global corporate analysis, this was not feasible because of the higher cost. Nowadays, there is a lot less pushback because these utilities are communicating with one another to discover what they can accomplish and what the difficulties are.

4.1.2. Utility Regulatory Models

Numerous advantages to system operation have resulted from the expansion of deregulated ISO/RTO marketplaces. The system's economic dispatch is more effective, and there is considerably more openness.

Vertically integrated utilities do, however, have a modest edge in this particular scenario. They may consider the entire system, not just one single power plant, but several power plants in addition to their fleet of wind and solar generators. They can assess the overall cost of this. There are difficulties when there is only one plant owner.

4.1.3. Reducing inflexible baseload capacity to make more room for renewables

We need to "flatten the duck". It seems bizarre to go back and expand solar power if you're talking about other type of energy source, for example nuclear facilities, which some of them are already in operation since you're exchanging one carbon-free resource for another.

In order to absorb part of that power, it is vital to consider if we can transfer a lot of demand beneath the duck's belly while establishing a regulatory framework.

Therefore, it is necessary to plan accordingly and provide socially acceptable ways for people to consume electricity in the most cost-effective manner.

4.1.4. The impact of Smart Solutions to overcome the problem

Given that it is predicted that electric cars might have a massive and distributed fleet of batteries, providing Smart Solutions could be very helpful in absorbing renewable energy in times of surplus.

To encourage individuals to charge correctly, it is crucial to understand how the right pricing signals are transmitted.

Returning to the smart electric vehicle solution, the basic premise is that as soon as you plug your car in at home, your smart car will begin to transmit signals. In essence, you will be choosing times when the battery charge will be at its best.

For example, consider that the worst time to load is at 5 or 6 p.m. Therefore, the car will wait until midnight to charge, presumably mainly or entirely out of peak hours, as it will be aware that your person typically won't require the car until 6am.

The proper economic signals are sent by EVs, which charge at different rates throughout the day.

Figure 10: Charging point of an electric vehicle

4.1.5. Solar Power excedents

Rooftop solar alone would be a major issue because the ISO has no control on that. Fortunately, a sizable enough portion of solar energy is used for utilities, allowing the ISO to eventually switch it off.

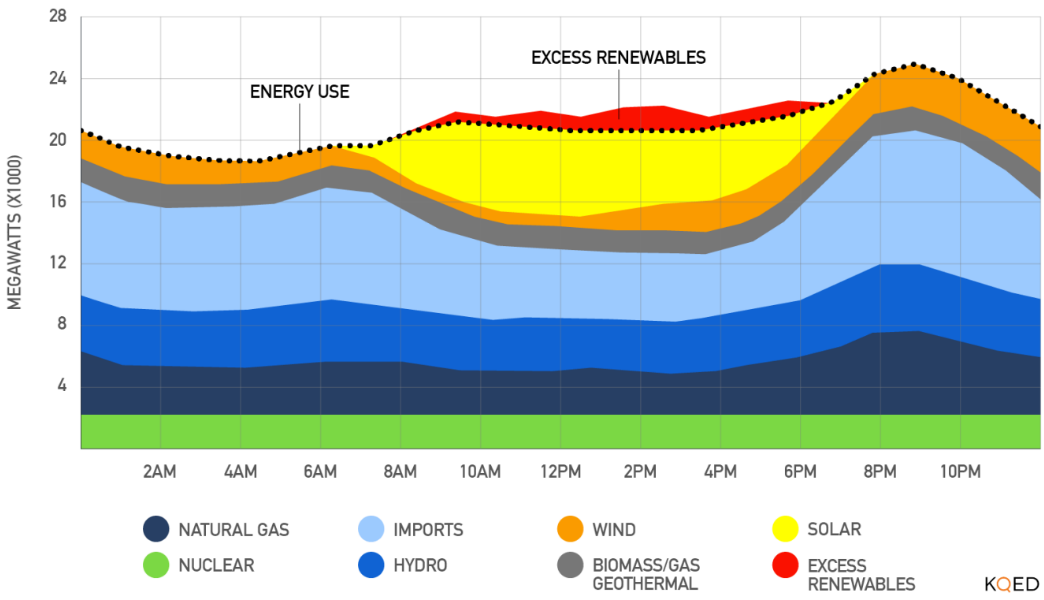

Figure 11: Excess in renewables by type

Due to the expansion of the market for energy imbalance solutions and the increase on the flexibility side, the cost of energy storage is big area of opportunity.

In most of California, four-hour batteries ought to be competitive with peaking resources. Then you may have a sink with a capacity of several megawatts or perhaps several gigawatts for at least some of this reduced solar energy.

4.1.6. Affordable energy storage

Research on the Renewable Electricity Future claims that by combining geographical variety with short-lived storage, we can create 80% of renewable energy.

We can also manage day shifts despite our limited storage. According to the aforementioned analysis, up to 80% of the energy might be obtained from renewable sources with just 100 GW more storage.

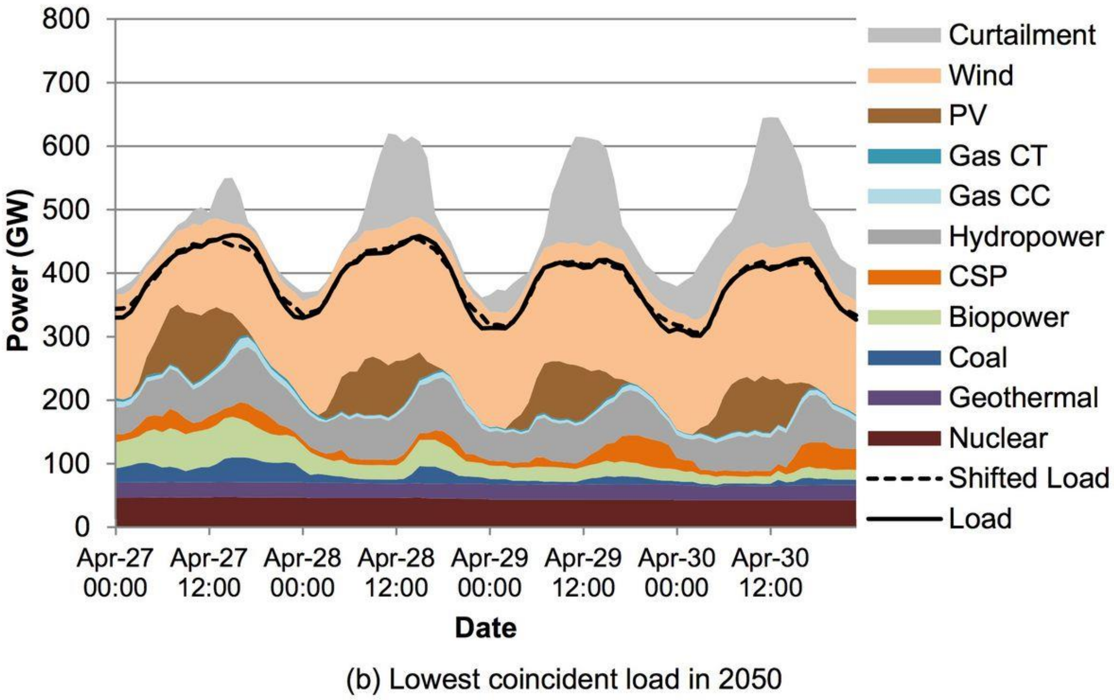

Figure 12: Lowest coincident load in 2050

For example, the transport fleet has been electrified, and the power sector has been decarbonized to an extent of eighty percent of renewable energy and twenty percent gas. The big task today is to continue toward the objective of a fully decarbonized electrical sector.

4.2. Analysis of the solar self-consumption market in Spain

First of all, for the market analysis of solar self-consumption, it is necessary to establish certain essential points such as: energy demand, price of energy discharged into the network, energy distribution channels, legislation, and regulation of renewable energies.

The current situation and the exponential growth that is happening with renewable energies today makes an in-depth analysis of the market necessary. In this case, as the focus is only directed towards solar self-consumption, it is necessary to look for new opportunities for development throughout the world.

Spain experiences solar radiation levels of 1,600 kW/m2 to 1,950 kW/m2, making it the European nation with the greatest potential for photovoltaic energy harvesting. In terms of competition, the Mediterranean nations top the list, but they lack the vast plains and pastures needed to support panels and gather all of this energy. The region that records the greatest radiation is specifically the Community of Aragon.

In Spain there are 247k solar self-consumption installations: 21k more than last month and triple that of the same month of the previous year as you can see in the previous graph.

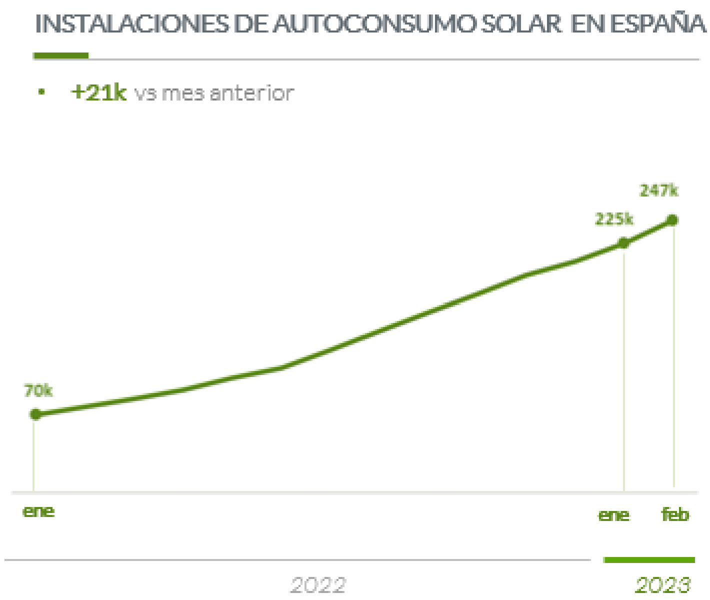

Figure 13: Self-consumption solar facilities in Spain

The market is expected to grow to 400k solar self-consumption users by the end of 2023. To reach this result, the metric of users or solar self-consumption contracts was used instead of installations, since self-consumption in buildings is becoming more and more important. of homes (66% of homes in Spain are vertical homes).

It is also estimated that the installed capacity is 3 GW. This is an estimate based on reasonable assumptions. There are clear discrepancies between different sources in the sector (REE vs UNEF).

The fragmentation of the market continues to increase: 68% of solar installations carried out by small installers.

On the part of collective self-consumption, there is an incipient market with high potential in the medium/long term, as well as leadership opportunity. This installation market is more concentrated than the single-family segment. Competitors offer models with different commercial approaches.

The market is very fragmented with no barriers to entry. There is price competition. In the following Figures can be seen the main actors.

Figure 14: Principal players and other retailers

Figure 15: Specialists in self-consumption and other actors

Now, it is important to mention the keys of the collective self-consumption market in Spain.

Analyzing the collective market, we can observe an immature market, less than 5% of the total number of installations in the market.

On the other hand, the incipient market with high potential has been analyzed and 240k potential roofs suitable for the development of solar communities have been identified.

Growth is expected from 2023 with massive development thanks to favorable regulation (expansion from 0.5km to 2km). This implies a leadership opportunity.

It is important to mention the different models on the market that have had and will have a huge impact in the coming years, such as the installation in communities of owners' investment client (CCPP), solar communities' investment company (CCSS), distributed generation investment client, subscription to the solar service, energy communities and others.

Likewise, a more concentrated market analysis was observed than the single-family segment. And it was analyzed that the main brakes are, terms of complexity in the operation, slowness due to collective decisions. Delays in administrative procedures that slow down the start-up of collective facilities. Complexity and immaturity of the product. Delay in the collection of subsidies by the client. Lack of skilled labor in the installation process. The business investment model is very little developed and concentrated in few competitors because it requires a financial investment that small competitors cannot bear.

Now, making a comparison of solar self-consumption at a global level where the focus is on the countries of Spain, Portugal, the United Kingdom, Brazil, France, Italy, and Mexico as you can see in Figure 16

Instalaciones (crecimiento anual)	225k (+221%)	129k (+84%)	1,2M (+12%)	1,5M (+133%)	233k (+57%)	1M (+12%)	300k (+25%)
Potencia instaladas	3 GW	0,7 GW	7,6 GW	16,3 GW	1 GW	12 GW	2,7GW
Hogares con autoconsumo	1%	1,7%	4%	2%	1%	3,2%	0,1%
Recurso Solar Solar kWh/kWp	1.475	1.420	869	1.460	995	1.277	1.640
Principales competidores	edp, SOLARPROFIT, galp, SOLAR360, holaluz, Naturgy, AutoSolar, OTOVO	edp, galp, solar, GreenVolt, sunenergy	Project Solar UK, e.on, eco,solar	edp, enel x, OTOVO	OTOVO, EDF, COMWATT	enel x, e.on, plenitude	-
Segmentos objetivo							

Figure 16: Comparison between different countries in self-consumption

In Spain, the increase in self-consumption facilities has increased by 221% compared to the year 20222 and this may be due to economic competitiveness in the main segments such as: single-family, block of flats, services, irrigators and industry depending on the solar radiation.

Electric networks will have to face 3 main challenges for the integration of distributed resources in low voltage and medium voltage:

- The networks will have to integrate a high volume of distributed resources over a million of points by 2030

- Self-consumption could give rise to two-way discharges/flows, which would imply new requirements for the network (eg, new protection systems and voltage regulators) to maintain a high level of security of supply.
- Investments will be necessary in modernization and digitization of networks to guarantee the quality of supply and optimize the integration of renewable generation in the system

Recommendations for networks to facilitate the development and integration of self-consumption

It is necessary to develop 5 axes to facilitate the promotion of self-consumption

1. Adopt the regulatory framework for self-consumption, developing RD 244/2019
2. Encourage the digitization of the low voltage and medium voltage network, defining an attractive remuneration scheme adapted to the new type of investment
3. Monitor the deployment of self-consumption, notifying the distributor of all the facilities connected to its network and reviewing the degree of compliance with the 2030 environmental objectives established by the EU
4. Adapt the tariff framework to guarantee the sustainability of the electricity system
5. Invest in energy storage

4.3. Regulatory Framework Proposal

4.3.1. Adapt the existing self-consumption regulatory framework

The goal of the proposed regulatory framework is to create suggestions along five axes that will make it easier to implement self-consumption facilities and guarantee system sustainability.

The regulatory framework for self-consumption must first be modified. It is worth to mention that a regulatory framework must be defined to ensure that self-consumption develops effectively for both the system and the electrical customer.

This is why the new legal framework has to include language about managing surpluses that enables all traders to act as representatives.

The idea must be established with regard to facilities close to consumption, specifying the measurement dissemination system, expenses, and maximum sizes.

The proposed legislation must be implemented in accordance with the Grid Codes of the European Union while taking self-consumption facilities into consideration.

Similarly, the measuring apparatus must be set up in accordance with the equipment's proper setup for each scenario.

4.3.2. Encourage investments for the digitization of the low voltage network

The absence of LV network digitalization in light of the energy revolution and the penetration of dispersed resources (EV and self-consumption) is the problem that this new regulatory framework must overcome.

This new regulatory framework should promote the modernization and digitalization of the low-voltage and medium-voltage network by: Introducing new technology, for instance, sensors, that enable network monitoring and management in both directions

For this kind of investment, it should also have an alluring compensation plan; examples include acknowledgment of the novel investment kind and alluring cash compensation.

4.3.3. Track the deployment of self-consumption

The poor visibility of already operational self-consumption facilities and the requirement for distributors to confirm compliance with technical rules are two additional extremely significant problems that the proposed regulatory framework must address.

The new regulatory framework should suggest keeping an eye on operational self-consumption facilities to assess compliance with the European Union's 2030 renewable energy objectives. Also, it must provide the distributor of the facilities linked to its network with the information that is essential.

Figure 17: Solar photovoltaic panels

4.3.4. Adapt the tariff framework

It is vital to modify the existing tariff framework in order to provide effective pricing signals and to prevent the system's income and cost imbalance in the future.

Redesign the tariff structure to provide an effective price signal for self-consumption, considering, for instance, the penetration of dispersed resources and the rise in the number of prosumers.

It is essential to maintain the system's income and expense balance.

4.3.5. Invest in energy storage

As I indicated above, energy storage is a fantastic answer to the duck curve issue. If you invest in solar batteries, installing them for self-consumption has several advantages.

Greater energy independence is achieved; it has been established that energy use is 90% and 70% in solar self-consumption scenarios, respectively. These are fairly impressive and alluring figures in the client's eyes.

Greater energy independence is attained by having the ability to store the energy produced by solar panels, which reduces dependency on the traditional electrical grid.

Figure 18: Energy storage

Purchasing self-consumption batteries gives you financial security because you won't notice price fluctuations, which means that the bills are affordable.

Solar batteries for self-consumption enable you to maximize the energy produced by solar panels, reducing the need to draw power from the traditional electrical grid and, as a result, potentially lowering your electricity cost. It's also crucial to emphasize that storage means savings, maximizing your savings.

Solar batteries for self-consumption can have a backup power source in case the traditional network's electricity supply is interrupted, which improves the dependability of the electricity supply. To put it another way, there will be more price variation on the day, lower compensation pricing, and storage for the present and the future. And yet another benefit is that there is supply security and you do not disconnect from the network.

5. Chapter 5: Results

5.1. Economic analysis of a solar farm and a solar rooftop installation of a hotel

Going back to the previous market analysis stated, now it is proceeded to develop an economic analysis of a solar farm and a solar rooftop installation of a hotel. In the following figure it may be able to see.

This economic analysis was carried out with the purpose of emphasizing the importance of investing in self-consumption facilities and encouraging industrial and domestic clients, as indicated by the proposed regulation.

In Figure 19, the peak power, nominal power of a solar farm and a photovoltaic installation of a hotel in the region of Cáceres, Spain, with a predicted radiation of 1585 kWh/kWp, were analyzed.

	Solar Farm	Self-consumption roof hotel	Units
Peak Power	105.000	54	kWp
Rated Power	100.000	50	kWn
Panels	228.261	117	460 W monocrystalline panels
Location	Cáceres (España)	Cáceres (España)	-
Predicted radiation	1.585	1.585	kWh/kWp
Structure	Fixed axis tracker	Fixed structure facing south 25° inclined	-

Figure 19: Data obtained from the solar farm and solar rooftop hotel in Cáceres

Several measurements were made in terms of solar production and an apportionment was made to calculate the annual production and with this the expected radiation was multiplied by the nominal power. And the results were reached in the following figure

	Solar Farm	Self-consumption roof hotel	Units
Annual Solar Production	158.500.000	79.250	kWh
	158.500	79	MWh
Previous network client consumption		450.000	kWh
Self-consumption ratio		45	%
Self-consumed energy		35.663	kWh
Energy to be exported to the grid		43.588	kWh

Figure 20: Calculation of Annual Solar Production

In the following Figures 21, 22, 23 are the data taken into consideration to know the payback of a solar self-consumption rooftop of a hotel and that of a solar farm. As you can see in Figure 22, the cost of installation is the product of the Peak Power times the ratio.

	Solar Farm	Self-consumption roof hotel	Units
Grid electricity supply Price		150	€/MWh
Market pool Price	80		-
Surplus simple compensation Price		100	€/MWh

Figure 21: Description of market pool price.

	Solar Farm	Self-consumption roof hotel	Units
Ratio €/Wp	0,48	1	€/Wp
Installation cost	50.400.000	54.000	€
O&M	650.000	2.000	€/year

Figure 22: Ratio, installation cost and O&M.

In the analysis, to get the annual incomes the product of the solar annual production times the market pool price times the representation of the market minus the O&M and the results were the following.

	Solar Farm	Self-consumption roof hotel	Units
Representation in the market	5		%
Annual incomes	11.396.000	7.708	€
Simple Pay Back	4,4	7,0	years

Figure 23: Annual incomes and simple pay back comparison

Finally, you could see in the Figure 23 that the Simple Pay Back calculated as the Cost of installation over the annual incomes.

Investing in solar panel purchases might offer protection against rising power rates. Producing your own energy protects you against price increases and stabilizes your energy expenditures, which are prone to rising over time. Given that solar panels have a lifespan of at least 25 years, during which time you may benefit from constant, affordable electricity, this is especially beneficial in the long run.

6. Chapter 6: Conclusions

In conclusion, in the field of energy, the term "Duck curve" is used to describe how electricity supply and demand are related in an electrical system with a high penetration of intermittent renewables, such as solar and wind. The Duck curve graphically shows how power generation changes throughout the day. During the hours of greatest solar or wind production, there are high levels and low levels.

The “duck crest" refers to how big it looks like a duck. The cat's "head" is a metaphor for the need for energy both during the day and at night, when the sun is not shining, and the wind's intensity might change. To fulfill demand at this time, additional electricity must be produced using traditional fuels like coal or natural gas.

The body of the duck depicts the middle of the day when solar output is at its highest. Currently, there may be extra electricity in the grid if renewable energy output exceeds demand. To prevent stability issues and provide a steady and dependable supply, the electrical network has to be balanced.

The duck's "tail" represents the shift from day to night when solar output declines and energy consumption starts to rise once more. Rapid generation adaptation is necessary to satisfy rising demand and keep the system stable throughout this period, either by using energy storage or flexible power sources.

This phenomenon is currently happening in Spain, managing surpluses and addressing demand surges is getting harder as renewable energy sources gain popularity. Additional modifications are being made to the solar and wind programs in order to overcome these problems. Additionally, the links between the grid and renewable energy sources could have capacity restrictions. As a result, during certain times a growing amount of generation is produced, which needs to be carefully handled.

In order to overcome this problem, there is an urgent need for authorities who can handle the current scenario to respond since solar self-consumption is steadily increasing, this can actually be achieved by investing in the future in energy storage.

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8. Annexes

8.1. Annex about news about self-consumption in Spain.

Historia de la fotovoltaica en España: desde sus inicios en 1984 a sus objetivos para 2030

16/01/2020 · Aleasoft Energy Forecasting

NATURA

12 de Enero de 2008, número 21

ACTUALIDAD/RENOVABLES

Tras el gran 'boom' de 2007 España es la cuarta potencia solar mundial

La solar fotovoltaica instalada en España se multiplicó por cinco en 2007, pasando de los 100 MW de 2006 a los 500 MW existentes a final de año

JOSÉ LÓPEZ-COZAR

REUTERS

Afinales del año pasado, el presidente del Gobierno, José Luis Rodríguez Zapatero, inauguraba en la Moncloa dos instalaciones solares de última generación. Desde ese momento los tejados de la residencia presidencial cuentan con 50 paneles solares capaces de abastecer parte de la energía eléctrica que se consume en la Moncloa y climatizar todas las estancias durante el invierno y el verano. El proyecto, financiado por el IDAE en colaboración con la empresa Isofotón, pretende ser una prueba más del compromiso del Ejecutivo por reducir las emisiones de CO2, pero también, es un magnífico colofón a un año marcado por el boom de la energía solar.

En un solo ejercicio la potencia instalada ha crecido un 500%, pasando de los 100 MW de 2006 a los 500 instalados a finales de 2007. Con este impulso, España se coloca entre las cuatro potencias solares más importantes del mundo (sólo por detrás de Alemania, Japón y Estados Unidos) y se encuentra ante la oportunidad histórica de situarse en la vanguardia de un sector que cuenta con grandes expectativas de cara al futuro, tal y como ha destacado el Gobierno de Zapatero en varias ocasiones.

El boom solar en nuestro país ha sido tal que, a mediados de agosto, se había alcanzado el techo previsto en el Plan de Energías Renovables 2005-2010, por lo que fue necesario establecer objetivos más ambiciosos para evitar una posible paralización del mercado. Ahora, el nuevo techo solar se ha fijado en 1.200 MW, pero los principales productores de energías renovables señalan que, con el actual ritmo de crecimiento, pronto se llegará a sobrepasar el listón de nuevo, a finales de 2008.

El escenario previsto por la Asociación de la Industria Fotovoltaica (ASIF) preocupa al sector, que ve cómo podría producirse un parón absoluto del mercado dentro de un año, con el consecuente cierre de empresas y pérdida de puestos de trabajo. Y es que el borrador del nuevo Real Decreto no contempla ningún tipo de prima para las instalaciones que se enganchen a red una vez superado el objetivo de los 1.200 MW del vigente Plan.

«Somos conscientes de que no es viable, ni siquiera recomendable, seguir creciendo al ritmo actual, pero no por eso se puede dejar de tener un marco regulatorio que asegure la estabilidad al sector a medio y largo plazo. Sobre todo, porque se trata de una tecnología que depende en gran medida de su grado de desarrollo: cuanto más avance, más barata será», apunta Tomás Díaz, director de Comunicación de ASIF.

Para el director de Comunicación de ASIF, «la energía fotovoltaica puede llegar a competir en precio con la electricidad doméstica, si se garantizan crecimientos sostenidos de al menos un 20%». Ahora sólo falta saber cuál será la respuesta del Ministerio de Industria y cómo quedará el nuevo Real Decreto que regula las tarifas de las energías renovables. Por el momento, la Comisión Nacional de la Energía ya ha advertido del peligro de supeditar la tarifa fotovoltaica a unos objetivos concretos.

ECONOMÍA

La industria fotovoltaica duplica el negocio tras el boom de 2007

- La patronal nacional Asif y 'Alimarket' discrepan sobre el ranking de productores

C. PIZÁ / SEVILLA
11 Marzo, 2008 - 05:02h

1

La industria fotovoltaica española experimentó un fuerte crecimiento en 2007 al calor del boom del sector, que pasó en doce meses de tener instalados 166 megavatios en España a más de 400 a final del pasado año, según estimaciones del sector. Como consecuencia, los productores de paneles fotovoltaicos también duplicaron su negocio hasta los 1.502 millones de euros, según un estudio de la revista *Alimarket*.

A la hora de establecer la clasificación de los principales fabricantes de placas solares en 2007, esa publicación aporta datos que son cuestionados por fuentes de la patronal fotovoltaica española Asif. La revista sitúa como líder a Solaria, con 150 megavatios, seguida de Isofotón, con 85.

DECRETO DEL AUTOCONSUMO >

El Gobierno aprueba el 'impuesto al sol' para el autoconsumo eléctrico

Todos los partidos de la oposición se han comprometido a derogar la norma

el periódico de la energía

NET ZERO POLÍTICA ENERGÉTICA RENOVABLES ALMACENAMIENTO HIDRÓGENO MOVILIDAD OPINIÓN

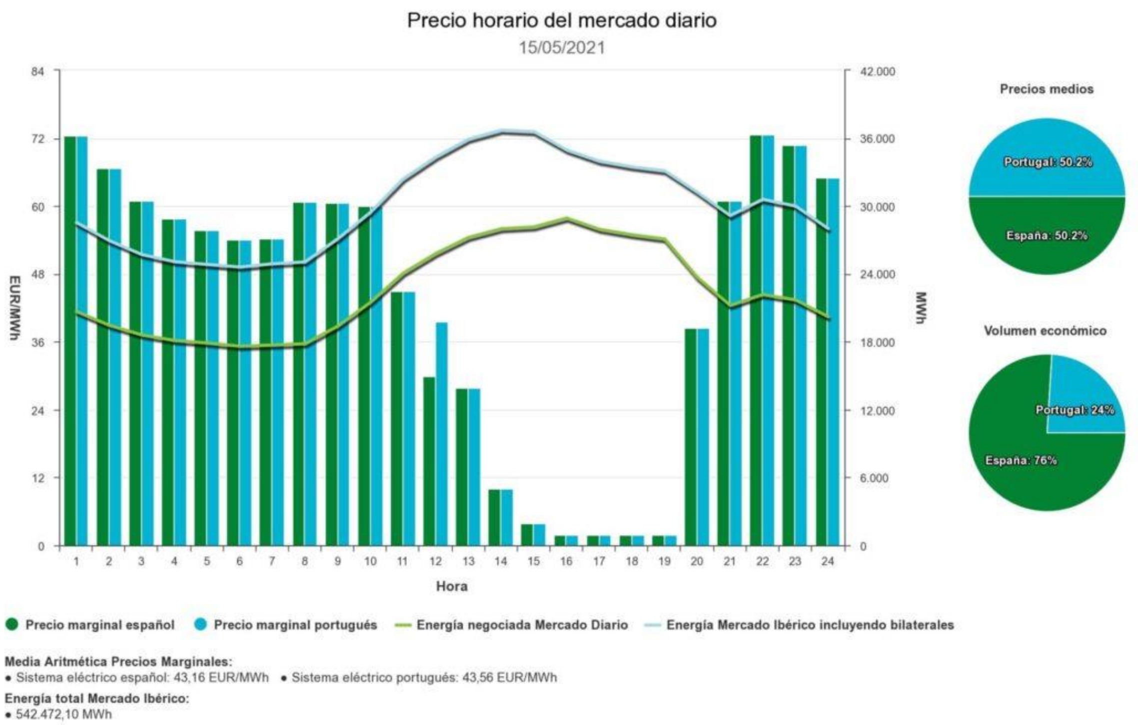
ACTUALIDAD EN PORTADA MERCADOS

La curva de pato ya está aquí: la solar provoca esta temida figura en el ‘pool’ los fines de semana

17/05/2021 · Ramón Roca

La temida curva de pato ya está en el mercado eléctrico español. Era cuestión de que la energía solar comenzara a tomar forma para que fuese una realidad y es por ello que ya se está viendo en la curva de precios del mercado mayorista ibérico.

Ya van dos fines de semana consecutivos en los que la curva de precios de tanto el sábado como el domingo nos muestra claramente esta curva de pato. Vean las siguientes gráficas de este fin de semana.



8.2. Full economic analysis of solar farm vs a self-consumption roof hotel

	Solar Farm	Self-consumption roof hotel	Units
Peak Power	105.000	54	kWp
Rated Power	100.000	50	kWn
Panels	228.261	117	460 W monocrystalline panels
Location	Cáceres (España)	Cáceres (España)	-
Predicted radiation	1.585	1.585	kWh/kWp
Structure	Fixed axis tracker	Fixed structure facing south 25° inclined	-
Annual Solar Production	158.500.000	79.250	kWh
	158.500	79	MWh
Previous network client consumption		450.000	kWh
Self-consumption ratio		45	%
Self-consumed energy		35.663	kWh
Energy to be exported to the grid		43.588	kWh
Grid electricity supply Price		150	€/MWh
Market pool Price	80		-
Surplus simple compensation Price		100	€/MWh
Ratio €/Wp	0,48	1	€/Wp
Installation cost	50.400.000	54.000	€
O&M	650.000	2.000	€/year
Representation in the market	5		%
Annual incomes	11.396.000	7.708	€
Simple Pay Back	4,4	7,0	years