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MASTER THESIS

DISRUPTIVE FACTORS IN THE ELECTRIC SECTOR: CHALLENGES AND OPPORTUNITIES

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Executive summary

European countries, and Spain in particular, have historically had a great degree of dependency on fossil fuels. In 2013, **72% of the Spanish energy consumption** was covered by fossil fuels. In order to reduce this dependence of foreign energy and decrease the impact of energy consumption on the environment, European countries focused on the environmental sustainability target of the energy policy trilemma. Green energy policies gave place to the first disruption of the electric system. In Spain, renewable generation (excluding hydro) grew **from** less than **3%** of the electricity mix in 2000 **to over 26%** in 2014. Accordingly, power prices for domestic consumers increased form below **11 ct€/kWh** in 2003 **to almost 23ct€/kWh** in 2013. As a consequence, affordability of renewable support was increasingly called into question which marked the beginning of the end of this first disruption, as European countries started to reduce renewable subsidies.

Currently, the second disruption is about to come. This time, it will not only be driven by green energy policies but also by several technological and social drivers:

- *Green energy policies:* they have been traditionally the main driver for renewable energy expansion, but **affordability is increasingly questioned** and they are being reduced. Nevertheless, they are still in place to meet with the **20-20-20 European targets**
- *Competitiveness of renewable technologies:* solar **PV´s LCOE** is already in the range of **0.08-0.14 €/kWh** and grid parity is already being reached in the south of Spain. **Onshore wind** is already competitive with conventional generation in locations with good wind characteristics, with LCOE is in the range of **0.05-0.11 €/kWh**. There are other less mature technologies that are gradually reducing their LCOE, such as offshore wind, CSP and ocean energy
- *Competitiveness of storage technologies:* there is abundant innovation in this field and some promising technologies are appearing which could solve the main inconvenient of renewable technologies: intermittency. For instance, EOS energy storage has developed a **zinc hybrid cathode battery** with a LCOE of **$0.12/kWh** and Isentropic offers a **PHES solution** with a LCOE of **$0.05/kWh**

- *Other technology development:* smart grids, HVDC grids and more efficient technology, combined with increasing environmental consciousness, are giving place to **electrification** of the energy consumption and the adoption of additional **energy efficiency measures**

This disruption will affect the business model and revenues of electric utilities. For instance, renewable generation expansion could reduce the **utilization factors of CCGT** power plants below **7.7%** by 2030; **distributed generation** could decrease system electricity demand in **1,900 million €;** energy **efficiency measures** could reduce energy generation in **2,350 million €**; and **electrification** has the potential to increase consumed electricity in **1,630 million €** if leveraged correctly. As a consequence, utilities will need to adapt to change, in order to reduce its impact on their P&L.

Finally, two cases have been analyzed. First, the increasing dilemma of renewable affordability and technology progress has been studied, based on **UK´s offshore wind recent bids**. The UK has moved to a competitive allocation process which is forcing to deploy best practices and techniques in the renewable industry. This way, they have managed to reduce the economic impact of renewable support and it is a good reference for other countries of **how renewables should be subsidized**. Second, the impact of **distributed generation deployment** on Spanish utilities has been modelled. Grid parity will be gradually reached in increasingly more Spanish regions, but there are some barriers that will slow down a rapid expansion. It has the potential to cover up to a **6% of total electricity** consumption by 2020.

Acknowledgements

The concern to forget any name drives me to express collectively my gratitude to all the people that have made this project possible.

First of all, I would like to thank Jorge Solaun. He deserves my especial gratitude and admiration. His continual passion for renewable energy and his large expertise in the electric sector have made him a fantastic supervisor and a good wisdom source during the elaboration of this project. I want to extend these acknowledgements to A.T. Kearney and the great people working here for the opportunity of doing this project and the pleasant treatment received during these months. I also want to thank the Scottish project team for their advices and support during these months in A.T. Kearney.

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Contents

Index of figures

Index of tables

Chapter 1

Introduction

1.1 Motivation

I have always felt a passion for how technology could transform the world we live in, and this enthusiasm was the inspiration on my decision to study engineering. Now, five years later, I find myself at the end of my university formation and keep that passion as fervent as in the beginning of this journey. Working on this project was very appealing for me, as the energy sector has solid fundamentals in technology.

As stated by the United Nations in the World Energy Assessment [1], *"energy is central to achieving the interrelated economic, social and environmental aims of sustainable human development"*. It is an essential resource for a developed society as it is required to cover the basic needs of citizens and to carry out sort of any economic activity.

Traditionally, the electricity activity has been a rigid sector. It was comprehensively regulated and dominated by a unique (or just a few) player(s). In the last decades however, the energy landscape has been subjected to several alterations. There is an increasing environmental consciousness which is leading to "greener" energy policies (e.g. 20-20-20 European targets, the Kyoto Protocol). Innovation in technology is enabling new business models and new methods of generating electricity are emerging (e.g. the final consumer generating its energy for self-consumption). In this context, the energy sector faces an amazing and uncertain future.

A.T. Kearney offered me the possibility to work on this topic, and leverage their industry expertise to further investigate on the potential innovations that could disrupt the power sector.

To sum up, the motivation for the development of this project is based on my passion for technology, the possibility to work with an experienced company and the willingness to shed light to some of the uncertainties that will be faced by the energy sector: which generation sources will dominate? Will the current system remain sustainable as we know it? Will consumers like myself generate their own electricity? What will the impact be on electric utilities P&L?

1.2 Objectives

This project has two main objectives:

- Understand the disruptive factors that can drive to a comprehensive transformation of the system and analyze the potential impact on the electric system and traditional electric utilities
- Apply disruptive factors to real case scenarios

In order to reach those objectives, the following milestones are going to be followed:

- Identify promising and innovative technologies on the electric sector
- Identify the main drivers for system´s disruption and model their impact on the system, building on three possible scenarios
- Analyze and quantify the impact of each scenario on electric utility companies
- Analyze the RES support mechanism transition in the UK and identify shareable learnings
- Identify the main barriers for distributed generation deployment in Spain and quantify its adoption and impact on electric utility companies

Chapter 2

Overall energy landscape

World´s energy demand is increasing at very fast rates. During the last 50 years, the energy consumption has more than tripled from 3,765 Mtoe to 12,730 Mtoe (see Figure 2.1). In non-OECD countries the consumption has increased more than six times driven by rapid economic growth (i.e. from 1,121 Mtoe to 7,197 Mtoe); while in OECD countries it has just doubled (i.e. from 2,643 Mtoe to 5,533 Mtoe).

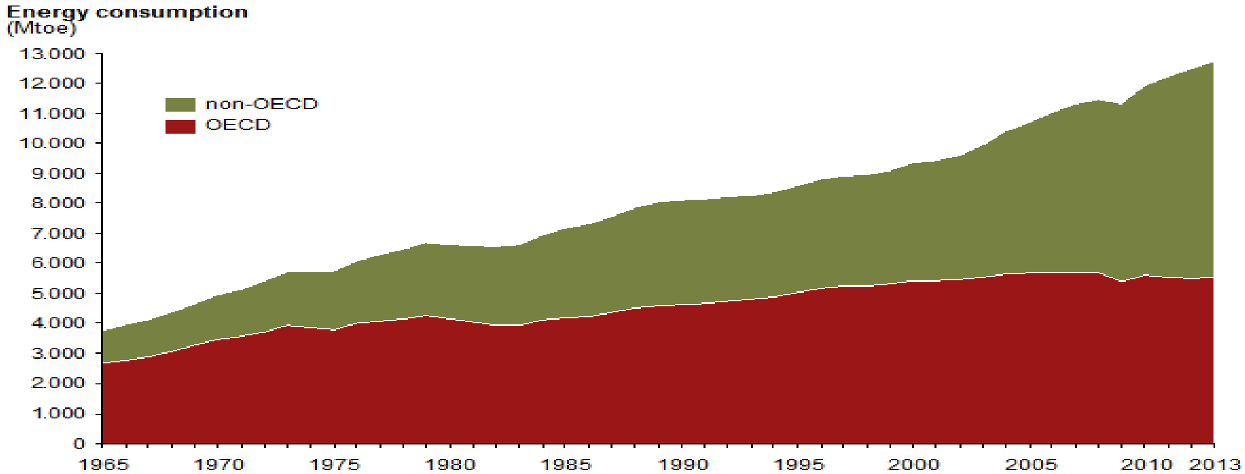

Figure 2.1: Energy consumption by countries *[BP statistical review 2014]*

Predictions are that world´s energy demand will continue growing. IEA predicts that primary energy consumption would increase over 17,000 Mtoe by 2035 in their New Policies Scenario [2]. This growth will be led by non-OECD countries, which will increase consumption from the current 7,197 Mtoe to over 11,000 Mtoe. Energy consumption in OECD countries, on the contrary, has stabilized around 5,500 Mtoe since 2006 and is predicted to maintain around this number. This stabilization of OECD countries´ energy consumption may have its origin in two reasons: energy intensity reduction and moderation of GDP growth. From one side, energy intensity is a measure of the energy efficiency of a country. It is calculated as units of energy per unit of GDP. More developed countries usually have lower energy intensities as efficiency measures have deeper penetration. The trend is that energy intensity will continue decreasing (see Figure 2.2). From the other side, the growing rate of OECD countries has slowed down and figures below 5% of GDP growth are considered good figures (e.g. Spanish economy has grown below 2% in 2014 and it is considered an excellent growth). Non-OECD countries, on the contrary, are having faster growing rates (e.g. China has grown over 7% in 2014 and it is considered a low number). This is reflected in the concept of device saturation. This expression refers to the fact that the market has reached the maximum density for a certain device. It is mainly happening in developed countries with different items, e.g. cars per 1,000 habitants, cell phones per person and number of electro-domestics at houses. Countries in ways of development, however, are rapidly increasing those ratios nowadays. For example, the case of vehicles: in Spain there were 433 vehicles per 1,000 habitants in year 2000, increased to 485 in 2007 and has maintain around this number since then. In the case of UK, the situation is similar to the Spanish one. China, however, has not reached the saturation limit and the number of vehicles per 1,000 habitants will continue increasing (see Figure 2.3).

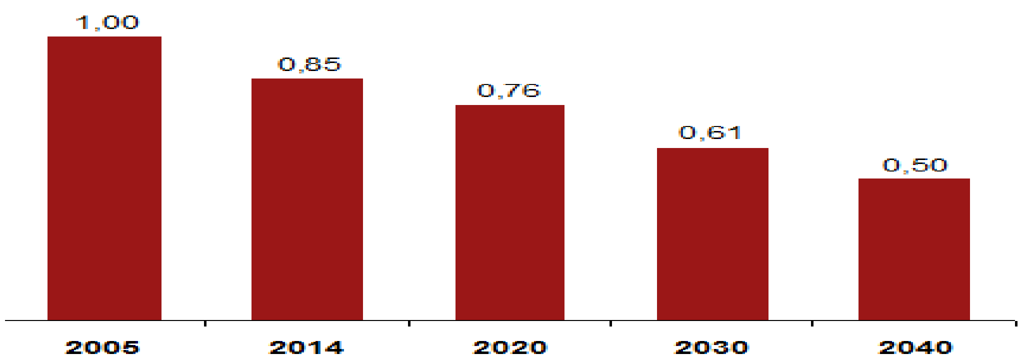

Figure 2.2: Energy intensity in the United States (Energy use per dollar of GDP, reference 2005) *["Annual Energy Outlook 2014 with projections to 2040", EIA - 2014]*

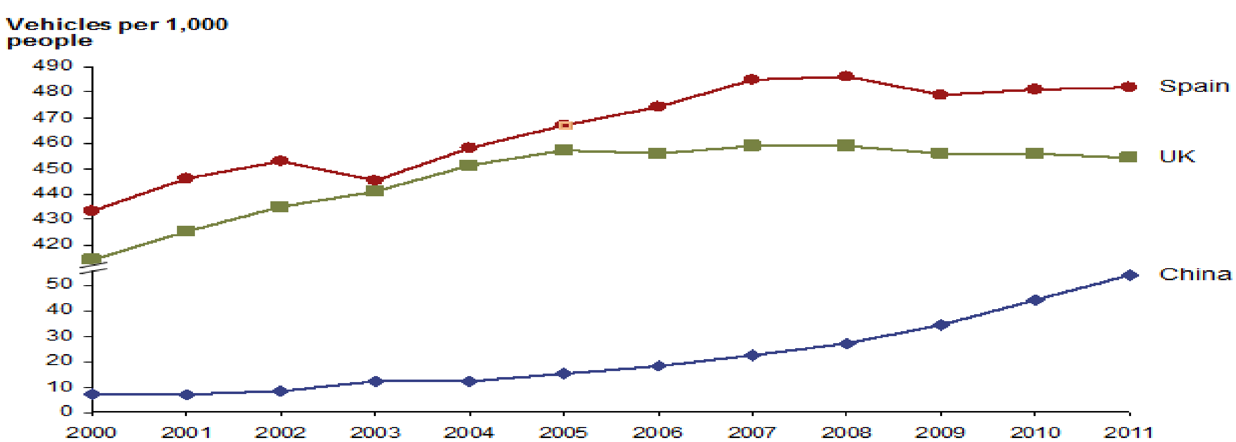

Figure 2.3: vehicles per 1,000 habitants *[The World Bank]*

The International Energy Agency (IEA) clssifies the final uses of energy intro four main goups: industry, transport, others (basically, commerce and residential) and non-energy uses. Coal is mainly used for power generation (60%), oil in transport (55%) and gas in heating both, industry and residential (57%). Around half of the power generated is lost and the rest is consumed mainly by industry (30%) and commerce and residential (40%). There is a small percentage that is used in transport (~1%), barely insignificant if compared to oil (see Figure 2.7).

The world is highly dependent on fossil fuels, accounting more than 85% of primary energy consumption. As fossil fuels generate CO_2 during their combustion, this dependency is creating a strong increase of CO_2 levels in air (i.e. 398.78 ppm in December 2014 [3]), leading to the Greenhouse effect. In addition, dependency on fossil fuels gives place to geopolitical issues between countries. The larger proved reserves lay in Venezuela, Saudi Arabia, Canada, Iraq, Iran, UAE and Russia (see Figure 2.4). So, other countries (e.g. Europe and China) depend on them and have to spend large amounts of money annually (e.g. EU´s trade balance deficit in 2011 of 185 billion € [4]).

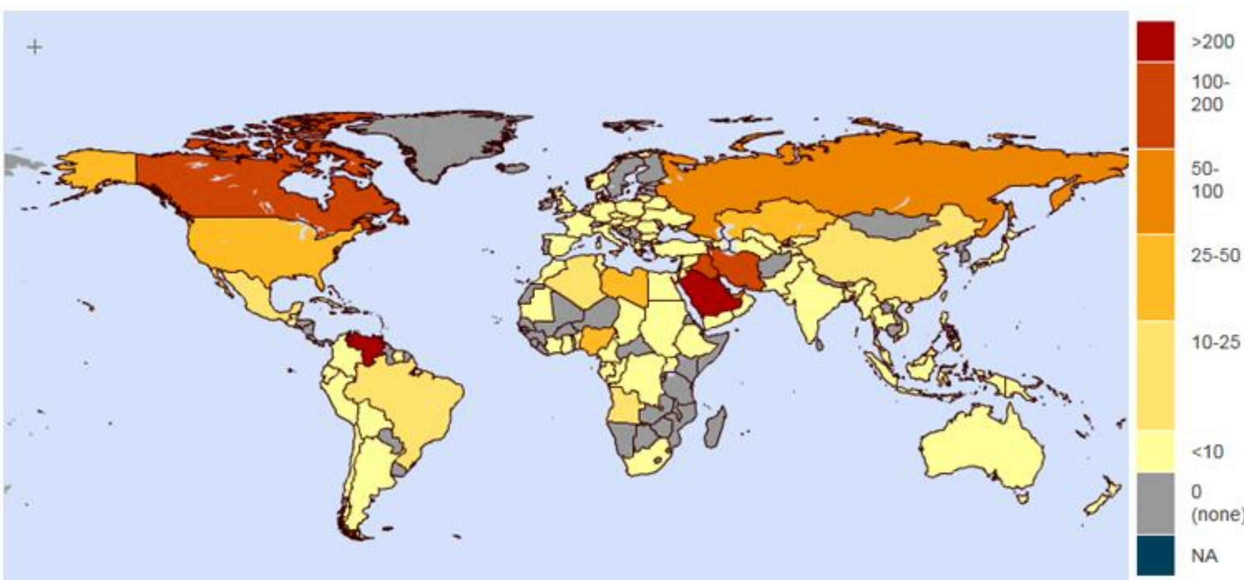

Figure 2.4: 2010 World Proved Reserves (billions of barrels) *[EIA]*

As a consequence, world is moving towards a greener way of generating energy, renewable energy. This trend has special strength in OECD countries. These countries are usually net importers of fossil fuels and have a greater consciousness of the greenhouse effect. Non-OECD countries, however, are in a process of fast economic growth, which results in higher energy needs every short time. The solution to cover these demand increases in a fast and economic way is fossil fuels. Consequently, the fossil fuel consumption share is larger in non-OECD countries and OECD countries are moving quickly towards renewable generation (see Figure 2.5). For instance, in Spain, renewable energy generation, excluding hydroelectric energy, has increased from 8% of total primary energy consumption to 13% in a three year gap. The result of this trend is that the ratio between CO_2 emissions and energy consumption is being reduced in OECD countries, while it seems to be stabilized in non-OECD countries (see Figure 2.6).

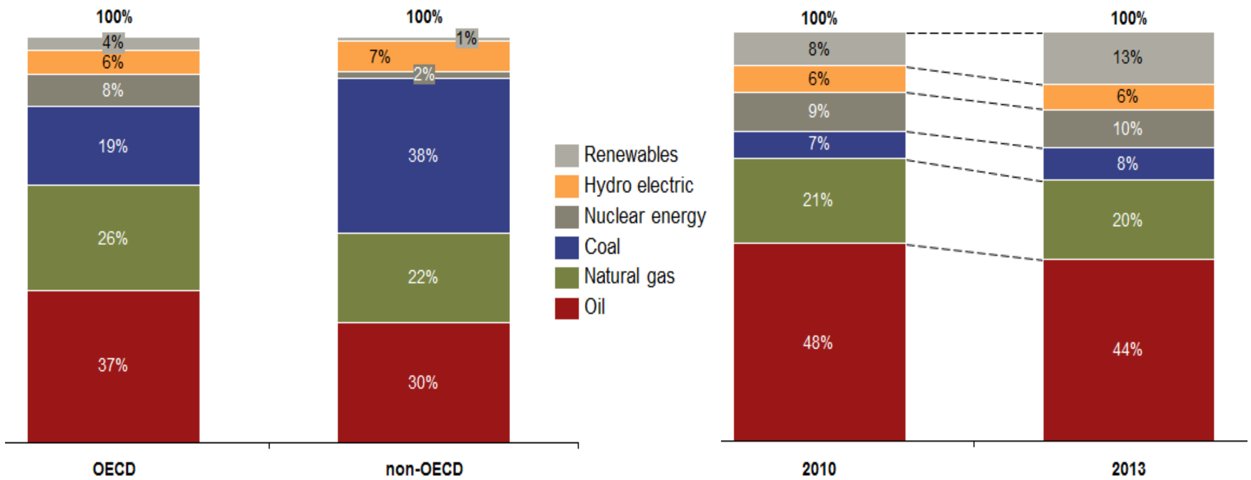

Figure 2.5: Primary energy consumption by fuel (World left, Spain right) *[BP statistical review 2014]*

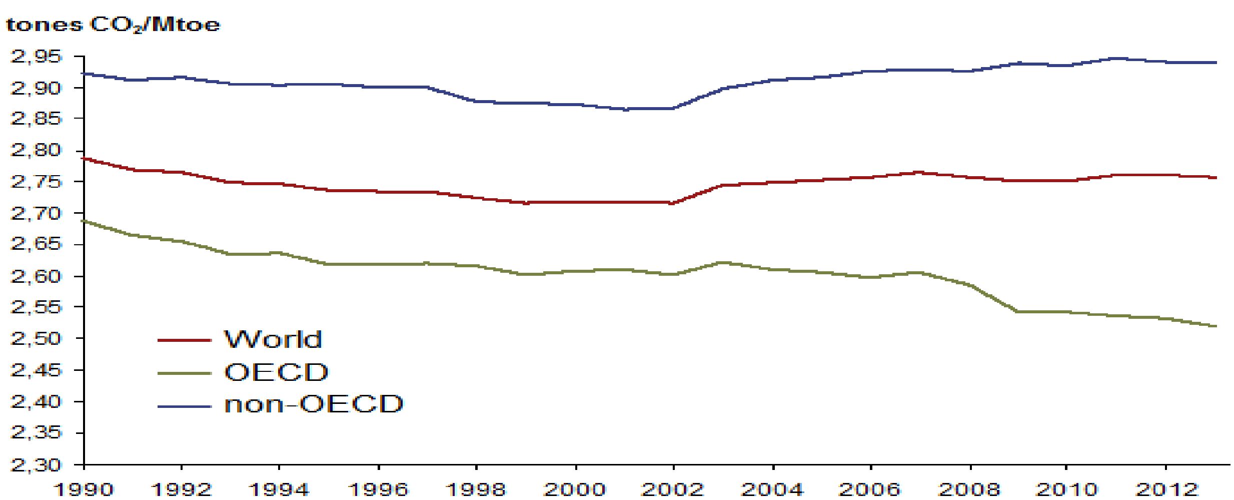

Figure 2.6: CO_2 emissions and energy generation ratio *[BP statistical review 2014]*

Once having seen the energy landscape in the world, the rest of the work is going to be focused in the electric sector, mainly in Spain, from power generation to its commercialization and consumption. New technology is appearing and it seems to be able to originate considerable changes in the way electricity is generated and in the way it is distributed. Moreover, as explained later in point 3.2, everything tends to go electric: from heating to transport. Overall, the electric sector is likely to face several changes in the next years and numerous challenges and opportunities will appear.

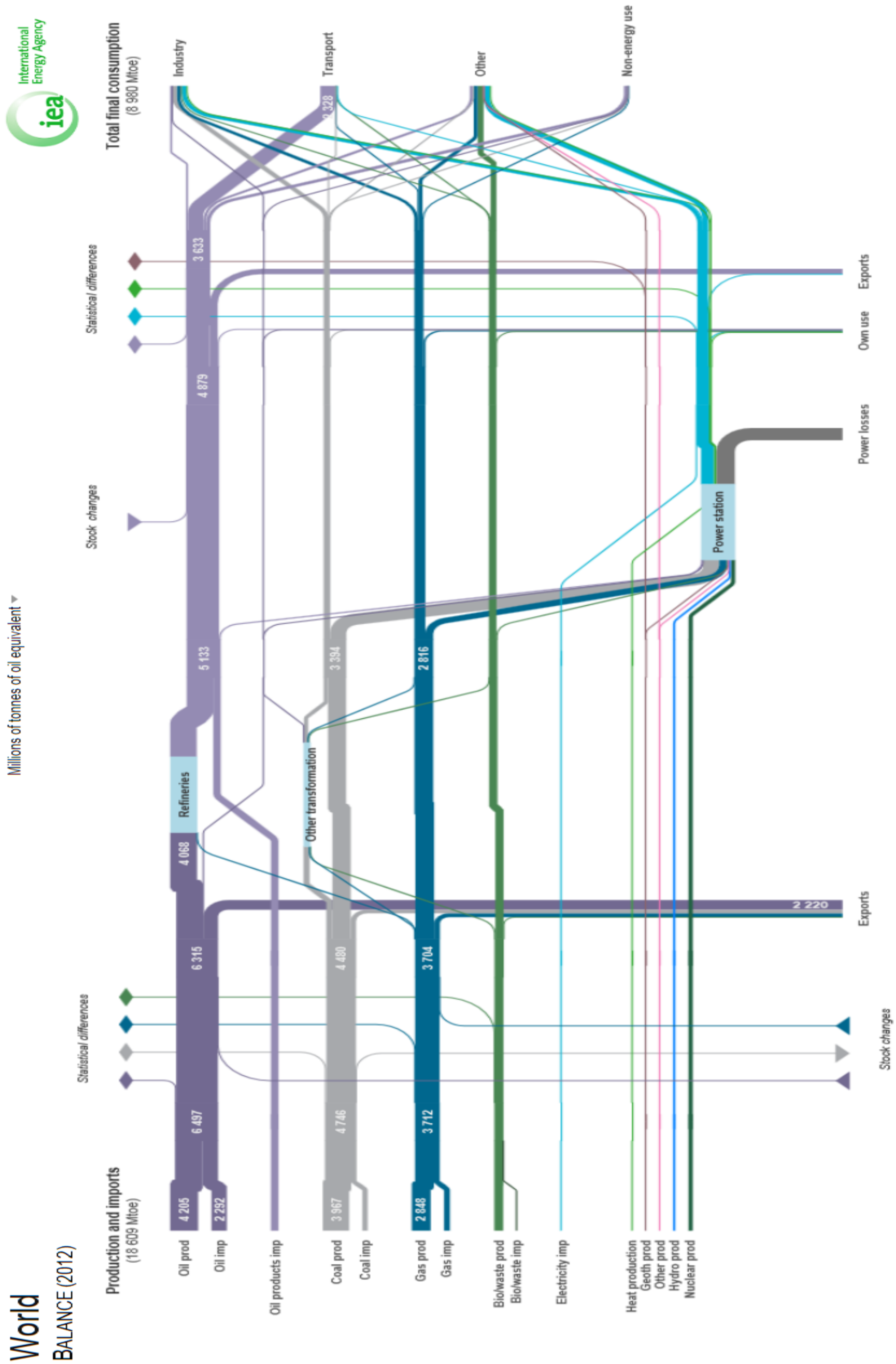

Figure 2.7: World energy generation and consumption balance *[IEA]*

Chapter 3

Overview of the Spanish electric sector

This chapter will focus on the Spanish electric sector. It will first describe how the electric system works in Spain and assess its current situation. Then, the process and events that have led to the current situation will be analyzed.

3.1 System structure

The electric system is a complex system where there is a need to generate what is going to be consumed in each moment, real-time generation. This is done by using a complicated structure in which the consumers have to be constantly connected to the energy generation sources. Consumers and producers of electricity are always in contact and every time there is a change of the demand of a consumer, the supply has to adapt to this change.

In Spain, the involved agents are given by the electric sector law [5] and are the following:

- *Electric power producers*: are those who have the function of generating electric power, as well as construct, operate and maintain generation facilities
- *Market operator*: assumes the management of the supply and demand offers of electric energy in the daily market of electric energy
- *System operator*: its main responsibility is to guarantee the continuity and reliability of the electric supply and the correct coordination between production and transmission systems. The system operator will be the manager of the transmission grid. The law assigns this function to Red Eléctrica de España
- *Transmission grid operator:* has the function of transporting electric energy, as well as constructing, maintaining and operating the transmission facilities. It is responsible for the development and extension of the transmission grid so that it guarantees the maintenance and improvement of a grid designed under homogeneous and coherent criteria. The law assigns this function to Red Eléctrica de España.

- *Distribution grid operator*: has the function of distributing electric energy, as well as constructing, maintaining and operating the distribution facilities that are used to bring electricity to consumption points
- *Commercializers*: are those who, having access to the transmission or distribution grids, acquire energy for selling it to consumers or other system agents
- *Consumers*: are those who acquire energy for its own consumption. Those consumers that acquire energy directly from the production market will be denominated Market Direct Consumers
- *System load managers*: are those that, being consumers, are authorized to resell energy for energy recharge services

Each of these agents is linked to one of the five activities of the electric sector: generation (electric power producers), transmission (transmission grid operator), distribution (distribution grid operator), commercialization (commercializers and consumers) and system management (market and system operators). Finally, law leaves the door open for a sixth activity with the new figure of system load managers. Generation and commercialization are liberalized activities where the first one is responsible for producing electric energy and the last one for selling it to the final consumer. Transmission and distribution are regulated activities that carry the electricity from the power plants to the consumers.

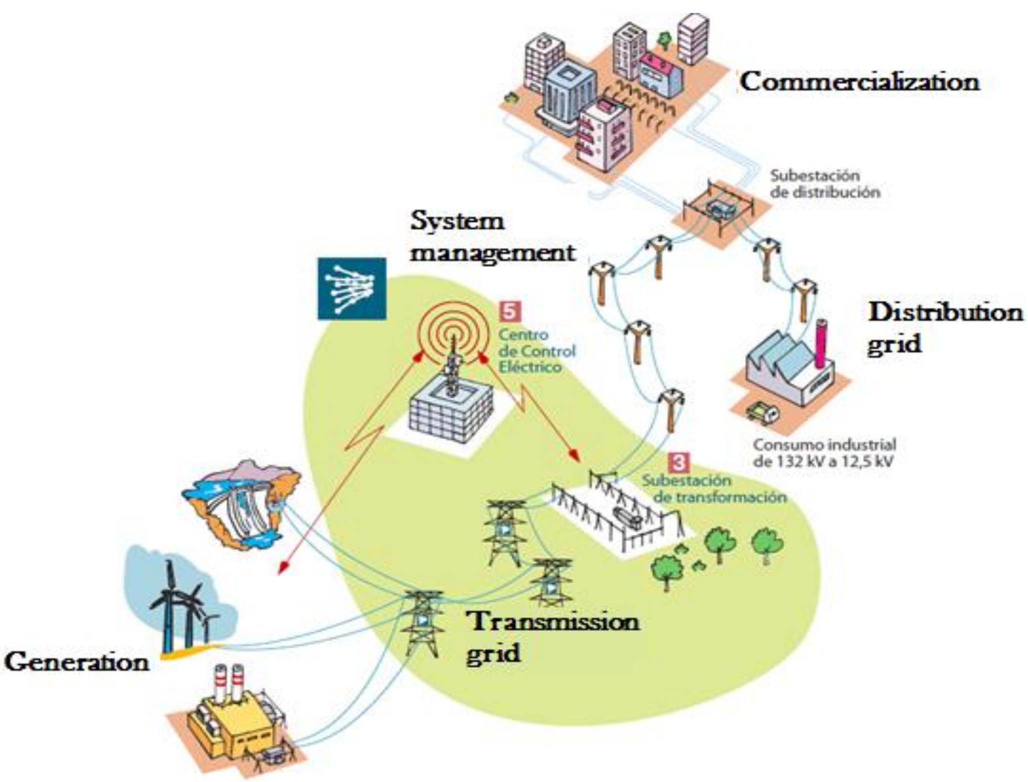

Figure 3.1: System structure *[REE]*

3.1.1 Generation

The generation activity consists on transforming a primary energy (e.g. nuclear, solar, chemical, thermal, and wind) into electric energy. Generation technologies can be classified in three main groups depending on the primary energy used: fossil fuels, nuclear power and renewables. In a generation mix, all of them need to be present due to the different characteristics that make each of them necessary in order to have a reliable system with a good quality of service.

- *Fossil fuels:* coal, oil and natural gas (Combined Cycled Gas Turbines). Fuels are burned to generate heat. Thermal power is then converted into electricity
- *Nuclear power:* fission and fusion. Currently just fission is used, fusion is under development. Nuclear reaction happens and the heat generated is converted into electricity
- *Renewables:* wind, solar, geothermal, biomass, hydroelectric and others. Each technology has its own method of generating electricity depending on the primary energy

Energy demand in Spain[1] during 2013 was 246.3 TWh and was covered by the following technologies [6]:

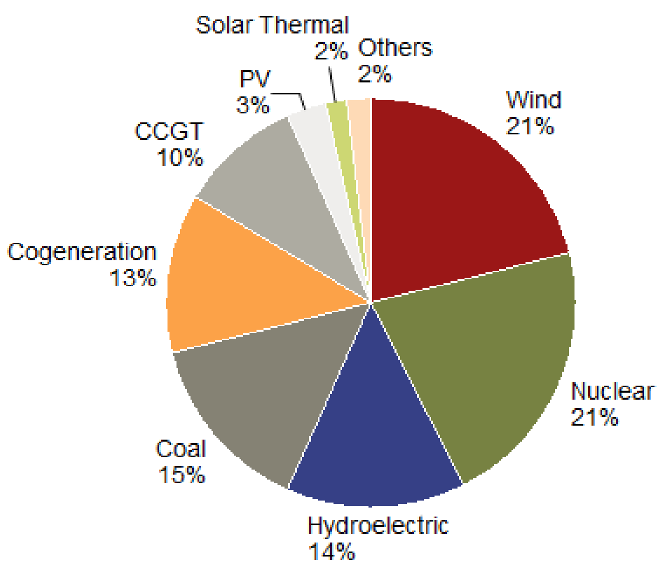

Figure 3.2: Energy generation mix Spain 2013 *[REE]*

From the operational point of view of the electric system, the generation sources are classified in three categories: base load, intermediate and peak units.

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[1] This and all the following references to Spanish electricity consumption will refer to Spanish peninsula

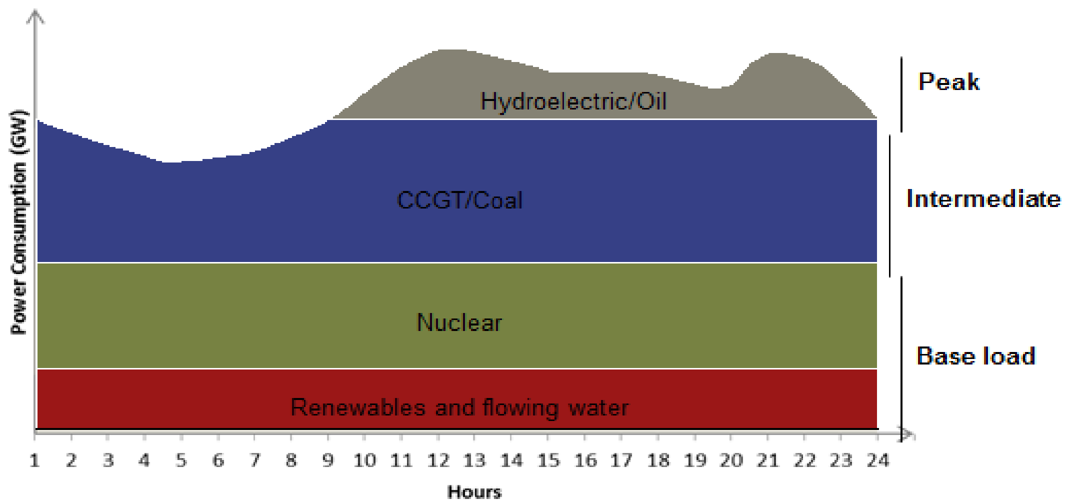


Figure 3.3: Daily electricity demand profile

Base load units are used to satisfy the needs of constant or base power. They work constantly along the year, except when they have to be stopped for maintenance. So, they have to be reliable and have small operating costs. Usually, nuclear plants or flowing water plants are used as base generations due to the low cost of fuel. These plants usually have low ramp rates; it takes long time to change the output power (around hours or days).

Intermediate units, also called cycling units, operate during long periods of time, but unlike base load units, they do not work always at the same power. They have the capacity to change the generated power rapidly. Combined cycle gas turbines and coal plants are usually used as intermediate units.

Peak units only work when the power demand is near to its maximum. They have the ability to switch on and off quickly and operate just for a few hours each year. Oil plants and pumped storage hydroelectric plants are the most commonly used.

Each generation technology has its own structure of costs and technical characteristics. The different power plants are complementary to each other and all of them are necessary in order to have a good quality of service.

- *Costs:* initial investment and operating costs (fixed and variable operating costs). Usually, those having low initial investments have high operating costs, and the other way round
- *Technical characteristics:* time to switch on/off or change the amount of power generated; energy availability

The next table shows a quick insight of the main characteristic of each technology:

Technology		Features	Advantages	Disadvantages	Variants	Maturi-ty	Installed power (GW)	Trends
Fossil fuels	Coal	• Intermediate unit • Big capital investment • Medium fixed costs • Medium variable costs • Medium opportunity costs	• Supply reliability • Medium flexibility • Very low LCOE	• High levels of pollutant gases • CO_2 penalties • Low efficiencies: 40%-45%	• CCS	Mature	10.9	• Being displaced by renewable s
Fossil fuels	Oil	• Peak unit • Medium capital investment • Low fixed costs • Medium variable costs • Very high opportunity costs	• Supply reliability • Flexibility	• High levels of pollutant gases • CO_2 penalties		Mature	0.5	• Not used any more
Fossil fuels	CCGT	• Intermediate unit • Medium capital investment • Low fixed costs • Medium variable costs • High opportunity costs	• Very high flexibility • High efficiencies: 60%-65% • High reliability • Low LCOE	• Moderate levels of pollutant gases • CO_2 penalties	• CCS	Mature	25.3	• Being displaced by renewables
Fossil fuels	Cogene-ration	• Produce electricity and heat • Distributed generation usually	• High efficiencies: 80%-90% • Supply reliability • Flexible	• Emit pollutant gases		Mature	7	
Nuclear power (fission)		• Base load unit • Very big capital investment • High fixed costs • Small variable costs • Low opportunity costs	• Do not emit pollutant gases • High energy density • No CO_2 penalties • Supply reliability • Low LCOE	• Radioactive waste • Strict security measures • Very rigid		Mature	7.9	• Nuclear moratorium
Renewables	Hydroelectric	• Peak unit (except flowing water, base load) • Very big capital investment • Medium fixed costs • Small variable costs • Very high opportunity costs (except flowing water, null opportunity costs)	• Clean energy • No CO_2 penalties • Supply reliability • Flexible (except flowing water, rigid) • Low LCOE	• Dependent on precipitations • Location dependent	• Conventio-nal dams • Pumped storage • Flowing water	Mature	19.9	• Maintain capacity
Renewables	Wind – Onshore	• Big capital investment • Low fixed costs • Null variable costs • Null opportunity costs	• Clean energy • No CO_2 penalties • Scalable • Low LCOE	• Intermittency • Visual and acoustic impact • Location dependent		Mature	22.8	• Increase capacity

		Offshore	• Very big capital investment • Medium fixed costs • Null variable costs • Sea location • Null opportunity costs	• Clean energy • No CO_2 penalties • Reduced visual and acoustic impact • Good wind conditions	• Intermittency • Location dependent • Very high LCOE		Growth	0	• Increase capacity • Reduce costs
	Solar	Photovoltaic	• Big capital investment • Low fixed costs • Null variable costs • Null opportunity costs	• Clean energy • No CO_2 penalties • Cheaper than solar thermal • Scalable • Appropriate for DG	• Intermittency • High LCOE • Location dependent	• c-Si • Thin film • CPV	Growth	4.4	• Increase capacity • DG • Reduce costs
	Solar	Solar thermal	• Big capital investment • Low fixed costs • Null variable costs • Null opportunity costs	• Clean energy • No CO_2 penalties • Molten-salt storage, reducing intermittency	• Intermittency • Needs high solar irradiation • Location dependent • Very high LCOE	• Parabolic trough • Fresnel collectors • Solar tower • Dish stirling	Growth	2.3	• Increase capacity
	Biomass		• Intermediate unit • Big capital investment • Medium fixed costs • Medium variable costs • Medium opportunity costs	• Clean energy • Supply reliability • Flexibility	• Location dependent • High LCOE		Mature	<1	• Increase capacity
	Ocean		• Very big capital investment • Medium fixed costs • Null variable costs • Null opportunity costs	• Clean energy • Scalable	• Very high LCOE	• Tidal • Marine currents • Thermal • Wave • Osmotic	Emer-ging	0	• Develo-ment and testing
	Geothermal		• Very big capital investment • Medium fixed costs • Low variable costs • Medium opportunity costs	• Clean energy	• Location dependent • Very high LCOE		Mature	<1	

Table 3.1: Overview of generation technologies *[REE and own research]*

In Spain, generation is a liberalized activity since 1997. So, there is competence between electric energy producers, potentially reducing electricity prices. Power prices are usually fixed by auctions, known as energy markets. These markets follow a *Merit of Order* mechanism. Different supply offers are placed from the lowest opportunity cost to the highest opportunity cost. Opportunity cost is defined as the price in which the used resource could be sold in other time period. The market mechanism can be graphically seen as in Figure 3.4, where one axis is the number of MWh offered and the other one the price. Lowest opportunity cost supplies are usually renewable technologies (wind, solar, ocean, geothermal and flowing water) that have almost null opportunity costs because if the resource is not used when it appears, it will be wasted. Base load units go next, commonly nuclear plants. Intermediate opportunity costs technologies as coal plants or CCGT come then. Finally, the most expensive supply comes from gas turbines or hydroelectric plants.

The energy buyers place their demand offers with the price they are willing to pay. All the demand offers are ordered forming the demand curve. Commercializers usually place offers at the maximum price to guarantee that they buy the energy needed to supply their customers.

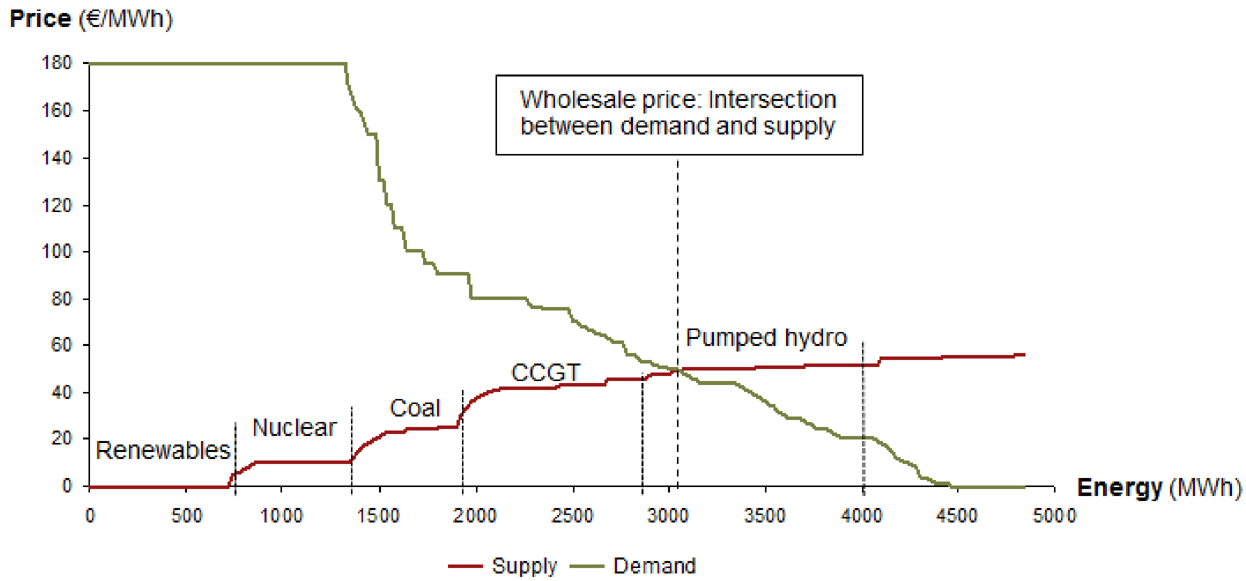


Figure 3.4: Example of energy auction with Merit of Order mechanism

The price is given by the intersection point between the supply and demand curves. All the MWh sold (those to the left of the intersection point) will have the price fixed by the intersection point.

The Merit of Order mechanism was designed so that base load units had the priority, in order to ensure reliable and economic energy, followed by intermediate and peak units. Renewable energy was a minority. In the last years, the exception has become the rule and it has some effects. First, it has a consequence on the market price. Renewable energy has almost null opportunity costs, entering the auction at the first positions and moving the supply curve to the right. So, the intersection between the supply and demand curves is given at lower prices. Moreover, as the offer curve is moved to the right, technologies with higher opportunity costs, as coal or CCGT, may not be necessary to fulfill the demand, reducing their annual utilization factors. These effects will be discussed in greater depth in chapter 6.

3.1.2 Transmission and distribution

Transmission and distribution grids are the responsible for carrying electric energy from the generation point to the consumer. They are both regulated activities. Physical grid development and exploitation is attached to significant scale economies, becoming them a natural monopoly. So, utilities cannot compete with each other avoiding unnecessary duplications of the grid, which would mean an unjustified increase of costs.

Transmission

Most transmission lines can be classified into two groups depending on the technology used: high-voltage three-phase AC and HVDC (High Voltage Direct Current). The first one is the most commonly used, while HVDC is used for higher efficiencies at very long distances or in submarine interconnections.

In Spain, the company responsible for transmission is Red Eléctrica de España (REE). The transmission grid is composed by transmission lines, transformers and others components with voltages over 220 kV and by the international connections lines. There are more than 41,200 km of lines, more than 5,000 substations and a transformation capacity higher than 78,000 MVA. The transmission activity has the following objectives:

- Minimize transmission losses
- Transfer energy between different substations in the grid
- Guarantee the balance and security of the electric system
- Maintain basic parameters (frequency and voltage) inside the required levels in every point of the grid
- Adapt the resources used depending on the demand

The retribution to the transmission activity is regulated and calculated as the sum of three terms:

- Remuneration linked to the present value of the investment
- A term that permits to recover operating and maintaining costs
- Incentives to the availability and efficiency of the infrastructure

Distribution

The distribution grid is responsible for carrying electric energy from the end of the transmission grid to the consumers. There are usually three voltage ranges in the distribution grid, known as subnets: high voltage, medium voltage and low voltage subnets.

High voltage subnets are connected to the transmission grid in the substations. These subnets distribute electricity around big consumption centers forming rings. Voltages from 50 kV to 132 kV are used. These subnets are connected to distribution transformation stations where power is transformed into medium voltage.

Medium voltage subnets distribute electric energy across consumption centers radially. They carry the electricity from the distribution transformation stations to the transformation centers. Medium voltage subnets contain voltages from 5 kV to 24 kV.

Finally, low voltage subnets connect the transformation centers with the end costumers. They usually use 220/380 V.

Distribution covers a series of obligations:

- Measuring the consumption of the end consumer
- Operating and maintaining the electrical grid that goes from the transmission grid to the consumer
- Planning and building new installations to meet the new supply demands
- Ensuring the required quality and supply guarantee
- Applying the consumers the access tariffs
- Informing the regulator and other competent authorities

In Spain, there are five big distribution companies that cover almost the 100% of the grid (see Figure 3.5): Iberdrola, Endesa, Gas Natural Fenosa, EDP and E.ON Spain (Sold to Macquaire in December 2014).

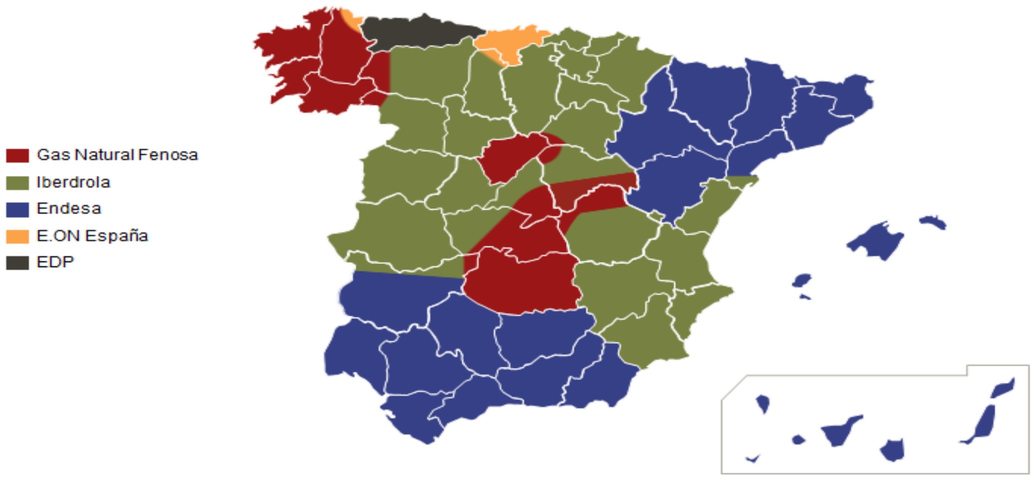


Figure 3.5: Geographical footprint of Spanish distribution utilities

3.1.3 Commercialization

Commercialization consists on delivering electric energy to the final consumer, having an economic compensation for it. Commercializers buy electricity in the energy market and supply it to consumers. These companies have to make an estimation of which the demand of its clients is going to be and plan how much to buy. In order to bring electricity to the consumer, they make use of the transmission and distribution grids, paying a price fixed by the government.

Since 1997, commercialization is a liberalized activity in Spain. However, it is not a completely free market. In 2009, TUR (Tarifa Último Recurso[1]) was introduced. It is a regulated tariff with the purpose of guaranteeing affordable energy for domestic consumers. In the new law of the electric sector in 2013, it was substituted by the PVPC (Precio Voluntario para el Pequeño Consumidor[2]). PVPC is the maximum reference price for costumers of <10 kW contracted power. It is calculated as the sum of: the hourly price of energy in the daily market, the access tariff and a fixed margin for the commercializer. In 2013, the 57% of the access points had the PVPC tariff, while they only accounted for the 17% of the consumed energy.

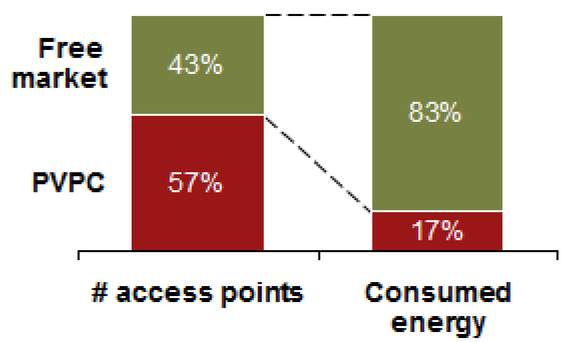


Figure 3.6: Free and regulated market comparison *["Análisis del mecanismo de facturación del PVPC", Ciudadanía y Valores – May 2014]*

Companies offering the PVPC are called reference commercializers. There are five of them [7]: Endesa Energía XXI, Iberdrola Comercialización de Último Recurso, Gas Natural S.U.R., EDP Comercializadora de Último Recurso and E.ON Comercializadora de Último Recurso. As it can be seen, reference commercializers and distribution companies belong to same corporates. As a consequence, they have traditionally dominated the commercialization in the regions they had the distribution grids. It is a barrier for new entrants or the entrance of other reference

[1] Last Resource Tariff

[2] Voluntary Price for the Small Consumer

commercializers in their non-traditional regions. The following table shows the consumer share of each of the commercializers in their traditional regions. All of them dominate their traditional regions in the free market and have shares over 90% in the case of the regulated tariff.

	Iberdrola	Endesa	Gas Natural Fenosa	EDP	E.ON
Free market	79.81%	67.1%	56.46%	87.98%	55.19%
PVPC	99.79%	99.947%	98.7%	99.84%	91.54%

Table 3.2: Market share of main utilities in their traditional region *["Boletín estadístico sobre la evolución del mercado minorista de electricidad", CNMC - Feb. 2104]*

Additionally, there are some new players entering to the commercialization activity. They can be classified into two groups: low-cost and green players. Aura Energía and Alcanzia are some examples of low-cost commercializer, while Fenienergía and Zencer are some of the green commercializers.

An important concept in the commercialization activity is the switching rate. It can be used as the measure of the existing competence. The Spanish switching rate in 2012 was 11.6%.

3.2 Key milestones and current market trends

Spanish generation mix has had lot of changes from the beginning of the 21st century until now. First, coal and nuclear energy dominated the mix with more than 73% of the share and renewable energy was just below 3%. By 2008, combined cycles were the main source of generation (~32%) and renewables reached the 13%. Coal and nuclear production had decreased from the 73% to a 37%. In 2013, renewable energy was the main primary energy with a share of 27% while combined cycles have reduced their production to a 9%.

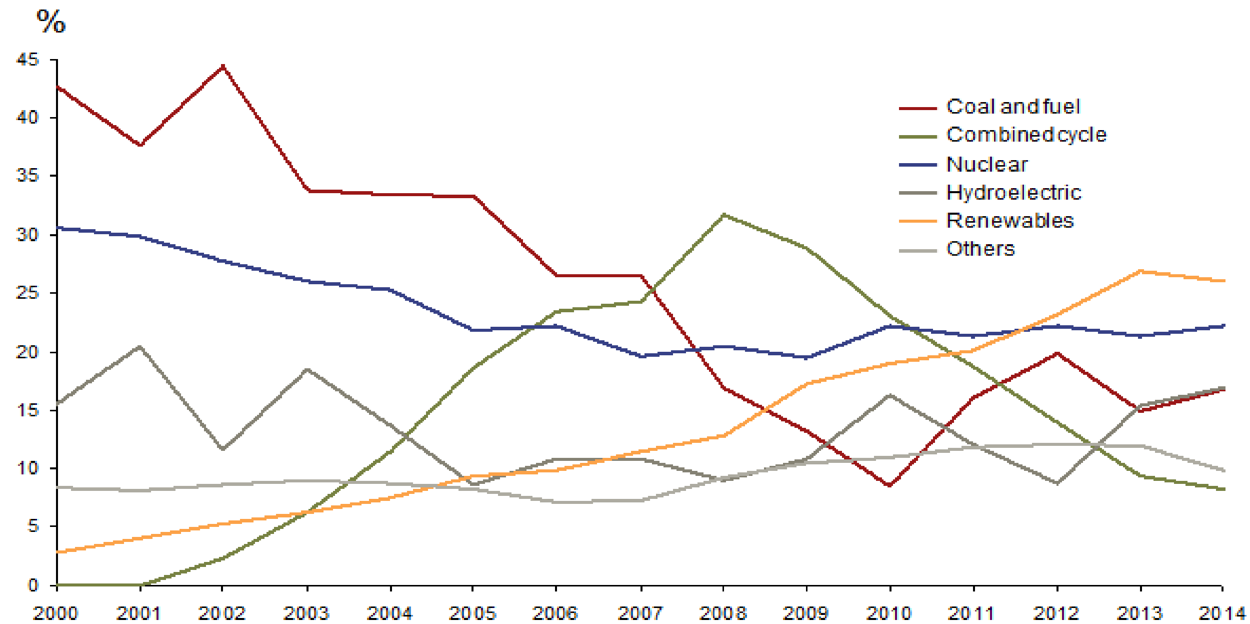


Figure 3.7: Spanish generation mix evolution *[based on REE´s annual publications]*

In the meantime, in 2006, power prices start increasing rapidly with an annual average growth of 10%, from 11.5ct€/kWh in 2006 to 22.7ct€/kWh in 2013 (see Figure 3.8). This increase has mainly its origin in the access cost increase, happening from 2004 (see Figure 3.9).

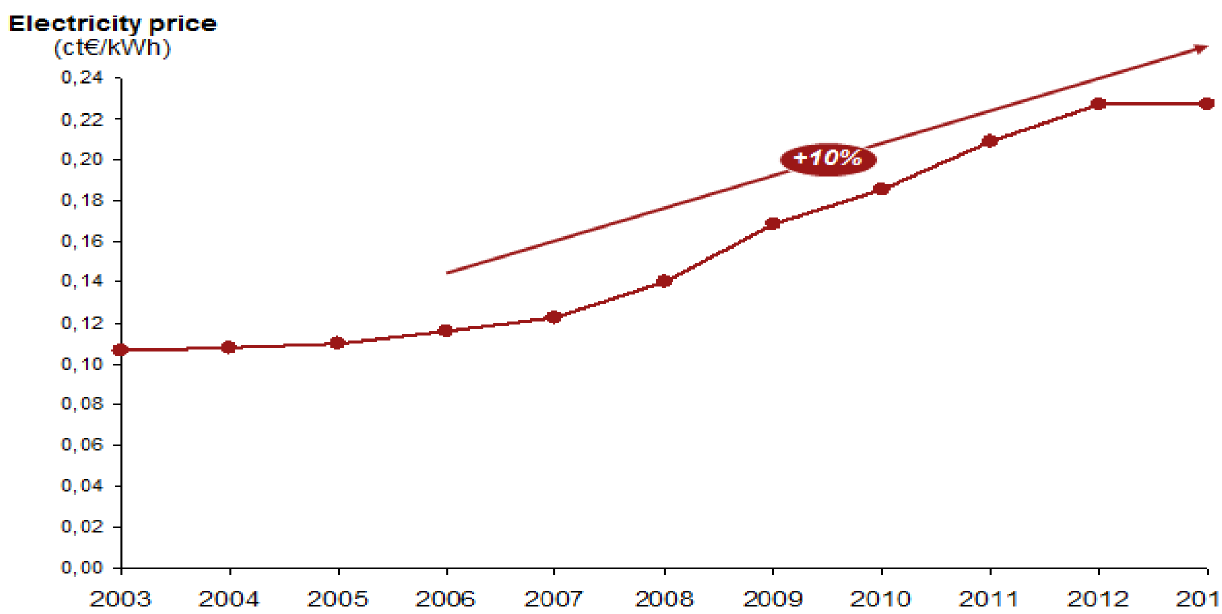


Figure 3.8: Electricity price evolution (Domestic consumers, 2,500 kWh < Consumption < 5,000 kWh) *[Eurostat]*

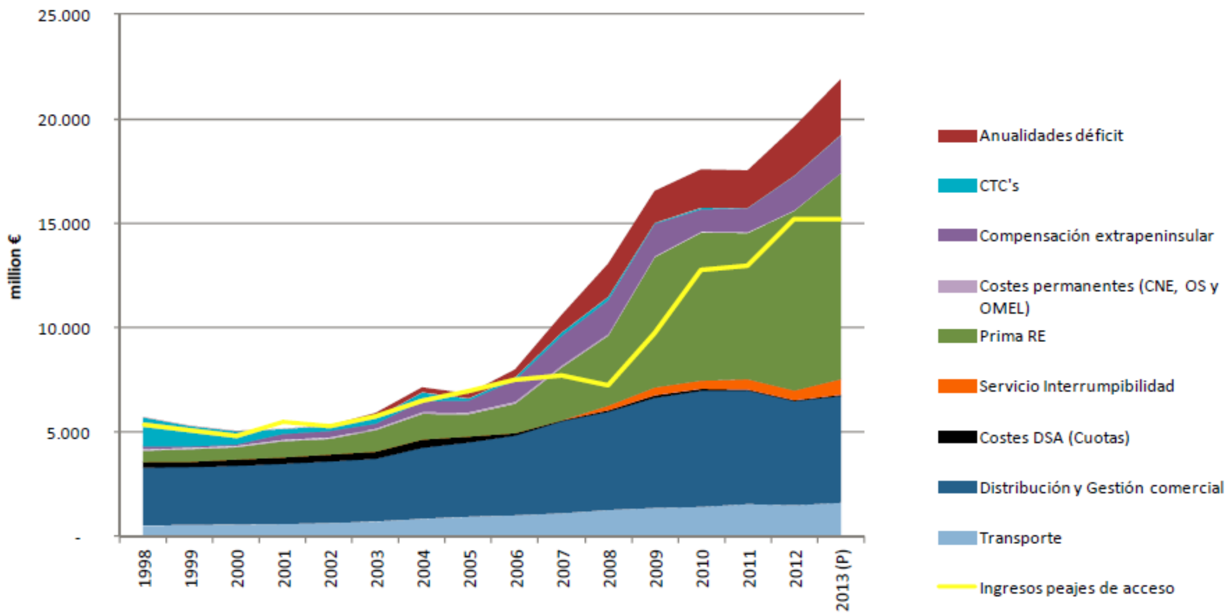


Figure 3.9: System cost evolution *[Symposium Burgos, CNMC]*

Do these two events have relation between them? What has originated such a change in one decade? There are three types of reasons underlying to these evolutions: energy policy, technology enablers and effect of economic cycles.

3.2.1 Energy Policy

Before digging deeper on which the policies have been, it is important to explain the paradigm that rules the energy sector. A country´s energy system is always a trilemma between energy security, energy equity and environmental sustainability [8]. It is a balance in which if a lot of weight is given to one of those, the others lose power. For instance, a country that wants to guarantee supply the 100% of the time whatever the situation is, will have to neglect competitiveness and have a more expensive energy. Spanish situation in year 2000 was close to the energy equity. During the last decade it moved towards environmental sustainability, sacrificing competitiveness as it can be seen on power prices evolution. Finally, it seems that in the last years it is again moving back to affordability.

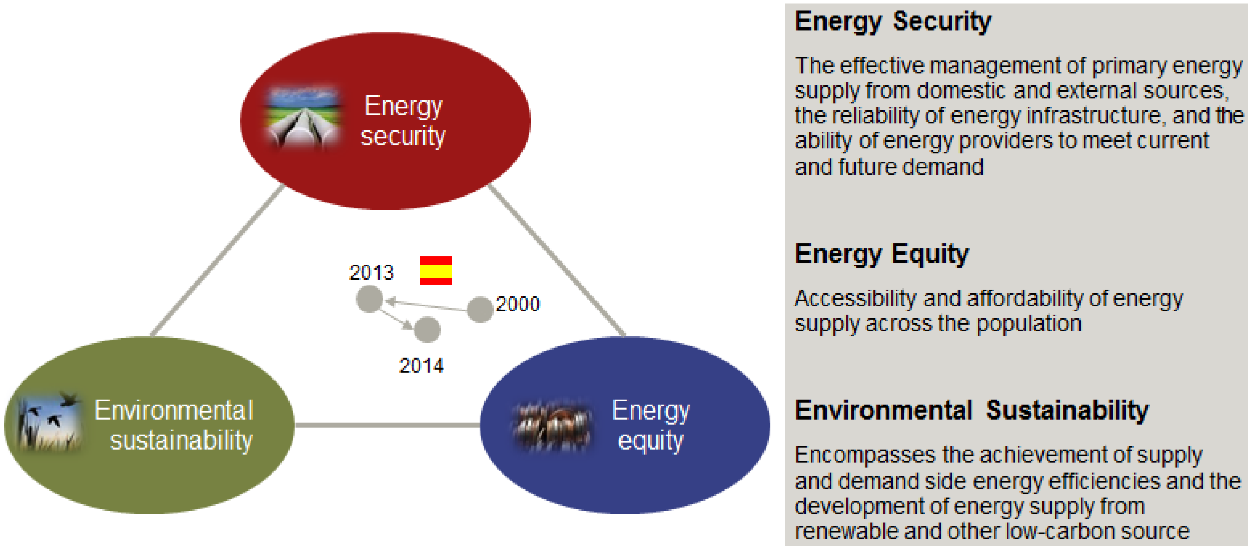


Figure 3.10: Energy Policy trilemma *[based on "World Energy Trilemma", World Energy Council – 2013]*

However, in the last years, there is a fourth factor that seems to be trying to enter into this trilemma, becoming an energy policy square (see Figure 3.11): social acceptance. It is becoming increasingly important what people think about each generation technology. Nowadays, it is not enough having a green, economic and reliable source of energy, it has to go through people´s approval. A good example could be the situation of wind energy. It is a renewable technology that does not emit greenhouse gases, it is competitive in locations with good wind characteristics but some people do not like it because their blades kill birds or wildlife in mountains is destroyed during their construction. More examples of this phenomenon are mentioned in point 5.2 talking about the barriers that the system has to change.

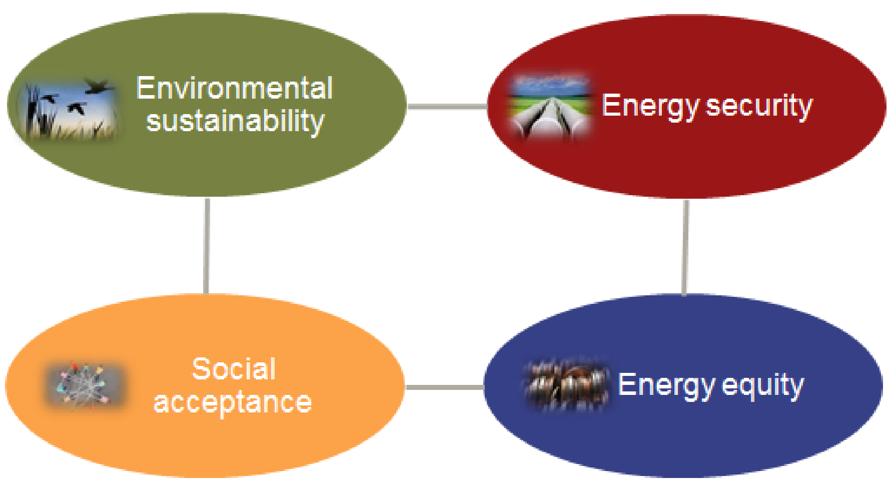


Figure 3.11: The energy policy "square"

There are two types of policies affecting the Spanish electric sector: international and national policies.

International policy:

- *Kyoto Protocol [9]:* it is an international agreement linked to the United Nations Framework Convention on Climate Change which commits its Parties by setting internationally bidding emission reduction targets. It was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. The first commitment period started in 2008 and ended in 2012. The protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities". In the Spanish case, the commitment was to reduce the emissions to a 92% of the base year
- *Doha amendment to the Kyoto Protocol [10]:* it took place in Qatar on 8 December 2012. New commitments were agreed to take in a second commitment period from 1 January 2013 to 31 December 2020. During the first commitment period, 37 industrialized countries and the European Community committed to reduce GHG emissions to an average of five percent against 1990 levels. During the second commitment period, Parties committed to reduce GHG emissions by at least 18 percent below 1990 levels in the eight-year period from 2013 to 2020
- *20-20-20 European targets [11]:* in 2007 the EU made a unilateral commitment to reduce its greenhouse gas emissions. This commitment sets three key objectives for 2020:
    - A 20% reduction in EU greenhouse gas emissions from 1990 levels
    - Raising the share of EU energy consumption produced form renewable resources to 20%
    - A 20% improvement in the EU´s energy efficiency

As these measures show, during the end of the 20th and the 21st century, the international context was moving towards environmental sustainability. This had an impact on the Spanish energy system, increasing the power generated by renewables.

These policies set the targets that each country has to fulfill, but each government has the freedom to use the desired mechanism and policies. In the Spanish case, the followings are the measures taken to reach international objectives.

National policy:

There have been lots of changes in the law since 1997 and just the most relevant ones are going to be exposed next:

- *Ley 54/1997:* liberalization of the generation and commercialization activities in Spain

- *Ley 34/1998:* established the legal framework to the activities of transportation, distribution, storage, regasification and supply of the agents that take part in the gas sector
- *RD 661/2007:* subsidies for especial regime are fixed. The support follows a Feed-In Tariff method, this is, generators are paid an extra amount of money over the market price for each kWh
- *RD 1/2012:* especial regime subsidies are suspended for already installed and new power plants
- *RD 9/2013:* especial regime, transmission and distribution retribution is fixed as the interest of Spanish 10 year's debt plus an additional interest
- *Draft RD for self-consumption, July 2013:* it fixes a limit of 100 kW and introduces the back-up toll*,* which is a tariff that a distributed generator has to pay for each kWh it generates, not taking into account if it is introduced to the grid or self-consumed
- *Ley 24/2013:* new electric sector law that replaces the 54/1997 law

The law 54/1997 makes a movement towards competitiveness by liberalizing generation and commercialization activities. The Spanish electric sector was close to the energy equity and had low power prices.

The law 34/1998 tries to impulse the natural gas consumption for heating purposes in Spain. Natural gas has some important benefits: it is a green source of energy compared to coal and oil with low pollutant emissions; it relatively easy to transport and distribute using pipelines; and it is economic in comparison to other fossil fuels. Combined cycles took advantage of this regasification process in Spain and expanded rapidly, as Figure 3.7 shows.

An important proportion of the access cost increase comes from the tariff deficit. It has its origin in year 2000 and it is a debt that the system/consumers owe to electric utilities. It is originated by the difference between the system costs and incomes and reached an amount of 30 billion € in 2014 [12]. It can have two origins: estimation errors or governments´ political objectives. The last one seems to be the one that has been actually happening. Governments have constantly underestimate system costs in order to reduce the effect of the electric bill increase for political purposes. Nowadays, it has become the third main expense of the access costs (see Figure 3.9).

With the RD in 2007, Spain makes a change towards environmental sustainability by supporting heavily renewable generation. This increases the adoption of renewable energy (see Figure 3.7). However, it also raises considerably power prices (see Figure 3.8). Renewable expansion also meant that other generation technologies with higher opportunity costs were less used, such as coal and combined cycles.

At the end of 2011, a new government comes into power and, as a consequence of the deep economic crisis that Spain was submerged in, it tried to move towards energy equity again by suspending the especial regime support scheme. In the RD 9/2013, renewable generation and T&D activities are considered low risks activities and their profitability is linked to country´s 10 year´s interest, which means considerable reductions compared with the RD 661/2007. Moreover, the draft RD indicates the probable intention of the government to penalize distributed generation with a tariff for each kWh generated. Although it was just a draft RD and it has not gone on for the moment, it generated fear and distrust among those aiming to install their self-consumption plant and obtained the slowing down of distributed generation [13]. As a result of these last measures, renewable energy production is affected and almost frozen.

Other relevant events

Nuclear catastrophes, like Chernobyl in 1986 or Fukushima in 2011, have impact on the social acceptance and make people change of opinion about nuclear energy. This effect is clear in Germany. Statements, before and after Fukushima, of some German politicians are an evidence of this (see Table 3.3):

	Before Fukushima	**After Fukushima**
Angela Merkel, Chancellor	*"Seeing how many power plants are being built worldwide, it would be a pity, if Germany would close down nuclear power plants."* *(06/2009)*	*"The faster we can exit, the better. But it has to be an exit with good judgment."* *(03/2011)*
Günther Oettinger, EU energy Commissioner	*"Nuclear energy is an indispensable part of the energy mix."* *(06/2008)*	*"Japan is a hubris and asks for a new evaluation, a balanced argument in terms of chances and risks of nuclear power. This has to happen in the coming weeks and months."* *(03/2011)*
Markus Söder, Environment Minister Bavaria	*"Isar 1 is safe. A Bavarian nuclear power plant is checked three times a day – more than a thousand times per year."* *(08/2010)*	*"I believe, we should leave those reactors shut down because experts cannot recommend a technical solution for managing the risk of an airliner crashing into one of the reactors."* *(03/2011)*
Guido Westerwelle, Minister of Foreign Affairs	*"It would not make sense, if Germany shuts down nuclear power plants for ideological reasons even if they are the most safe ones world wide."* *(05/2009)*	*"We have an option to go for a certain amount of time on using nuclear plants – but we have no guarantee to go on operating each single nuclear reactor."* *(03/2011)*

Table 3.3: German politician statements about nuclear energy

Although in the Spanish case it is not as clear as in Germany, disasters as those make people change of opinion and create a movement in the energy policies square towards social acceptance.

3.2.2 Technology enablers

- *Electrification:* it means that things start working with electricity instead of other energy sources. The electric consumption per capita and the grade of electrification are clear measures of country´s well-being. So, as a country develops and new technologies are adopted, the electrification levels will grow. As a consequence, the need of electricity has grown and will grow, while the use of other primary energies will reduce. Heating, cooking and vehicles are some good examples of electrification
- *Renewable LCOE reduction:* great amounts of money are being invested in R&D and renewable energy reduces its costs progressively, improving LCOE. It is the key for renewable energy generation expansion
- *Capacity to manage more complex grids:* the entrance of renewable energy brings with it the necessity of a more complex grid. This implies the usage of new technology that permitted to manage grids better (e.g. smart grids, smart meters), translating in higher power prices, as happened from 2007
- *Unconventional oil/gas:* this is a huge revolution that happened during the end of the last decade. A new way of extracting oil and gas is discovered, fracking. Suddenly, USA passes from being an oil and gas importer to be self-sufficient and produce its own resources. One consequence of this is that they increase their generation of power using their gas, and the coal consumption decreases. They start exporting coal and its price is reduced, leading an increase on the coal consumption for power generation in Europe, as it can be seen in Figure 3.7 that happens from 2010 onwards

3.2.3 Effect of economic cycles

Economic prosperity brings with it more electricity consumption: businesses are created, people buy houses in different places… which means that the grid has to be scaled to those necessities. This effect was especially big in Spain, where new urbanizations were built anywhere. Each new house in each new urbanization needed a new connection to the grid. So, the distribution grid was made bigger and lots of new connections were installed. The problem comes when things do not go so good. The economic crisis that Spain has gone through since 2008 brought two imbalances:

- *Unoccupied houses*: plenty of those new houses constructed resulted being unoccupied. Spain ended having a lot of new unoccupied houses with their own grid connection point. The new grid section has to be maintained, incurring in costs. However, as houses are not occupied, there are not revenues generate by them. So, those costs are distributed across all the consumer´s bills, leading to power price increases

- *Demand decrease (i.e. from 265 TWh in 2008 to 246 TWh in 2013)*: as less energy was sold, incomes were lower and grid O&M costs remain equal or larger (the grid is the same or bigger than it was in the previous years). So, the proportion of each kWh price destined to pay the grids had to increase

Figure 3.12 shows the relevant events that have influenced the Spanish electricity sector ordered chronologically.

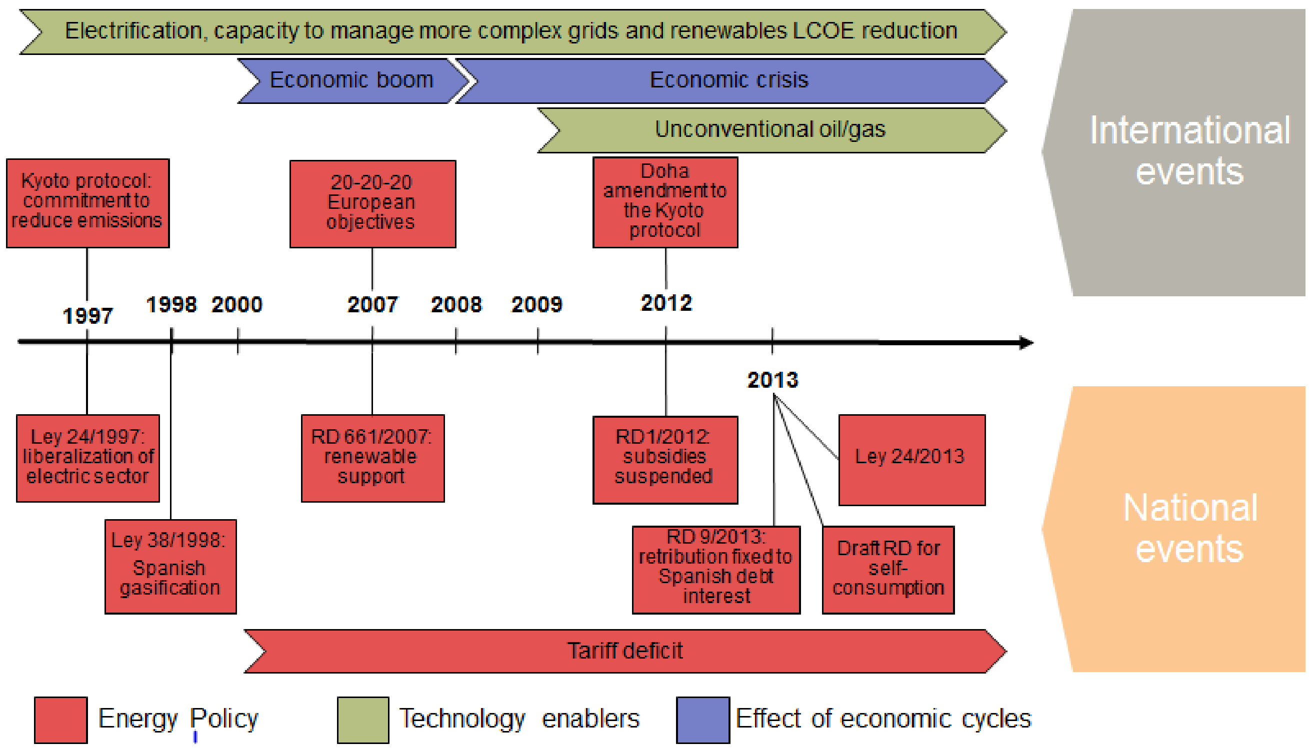


Figure 3.12: Timeline of relevant events in the Spanish electric system

3.3 Key strengths and weaknesses

Before going on with the work, it is important to make especial emphasis on the strengths and weaknesses of the current electric system. Overall, it is a reliable, high quality and diversified system. The liberalization of generation and commercialization activities increased competence and companies of the energy industry with international presence guarantee the latest and most sophisticated technology in generation and grids.

There are several weaknesses too. Having a reliable supply and diversified generation mix has resulted in expensive electricity. Furthermore, planning of new power plants was done with the belief of low renewable penetration. The actual penetration, however, was considerable and resulted in overcapacity of generation and problems in the integration of this new renewable capacity. Finally, regulation has been biased by the political opinions of the different governments. This has led to several changes in energy policies (see Point 3.2.1) and has created a large tariff deficit and legal distrust between investors.

Strengths

- Reliable and high quality supply
- Diversified generation mix
- Efficient and competitive energy markets
- Liberalized generation and commercialization
- Few generation investment needed in the short run
- System operator independent to other system players
- High quality grids and efficiently operated
- Energy and technological companies of relevance internationally

Weaknesses

- Expensive electricity
- Overcapacity in generation resulting in unprofitable power plants
- Massive penetration of renewable energy and problems with its integration
- Tariff deficit
- Energy islands, not properly connected to other European countries
- Dependence on fossil fuel imports
- Biased political management -> several changes of regulation over the last decade

Chapter 4

Energy innovation

The results of the great efforts done in energy innovation are the creation of many new technologies and the development, cost reduction and efficiency improvement of the existing ones. Overall, the focus goes in greener technologies and there are some that could be competitive with conventional techniques in the short run. The possible electric system disruption is going to have innovative technologies as one of the main pillars.

In this chapter, motivation for energy innovation is going to be discussed first: what impulses companies, governments and people in general to innovate. Then, innovation origin is going to be explained: how innovation is created and who is doing it. Finally, energy innovation itself: which technologies are being developed, which companies are developing them and trends for each technology.

4.1 Motivation for innovating

Innovation has its origin in two bases: social and economic aspects. Each of them gives place to two purposes; reduce environmental impact of energy consumption and ensure universal access to energy in the case of the social aspect; direct profit and improve brand & corporate image in the economic case.

- *Reduce environmental impact of energy consumption:* conventional fuels emit large quantities of greenhouse and other pollutant gases. Greenhouse gases make the earth´s surface temperature increase, and pollutant gases, as SOx and NOx, create acid rain. The atmospheric abundance of CO_2 has increased a 40% since 1750, reaching an amount of 390.5 ppm in 2011. Atmospheric nitrous oxide (N_2O) was 324.2 ppb in 2011, a 20% increase since 1750 levels. The greenhouse effect is creating a too fast change in the temperature (i.e. 0.72ºC increase over 1951-2012 [14]), extinguishing some species and increasing the sea level due to North and South Pole ice melting. Moreover, fossil fuels will run out sooner or later. So, there are people starting to believe that something has to be done in order to avoid it and who think that the best way is to reduce our dependency to fossil fuels, generate energy in a more friendly way and reduce human´s impact on earth

- *Ensure universal access to energy:* there are nearly 1.3 billion people without access to electricity and 2.7 billion people rely on the traditional use of biomass for cooking [15]. Lack of access to electricity usually happens due to three reasons: 1) energy is too expensive and people cannot afford it (e.g. 16.6% of Spanish citizen were on risk of energetic poverty in 2012 [16]), 2) the lack of sufficient infrastructure in non-developed countries (i.e. 57% of African citizen do not have access to electricity [17]) or 3) the difficulties (high costs) to transport energy to some places of difficult access (e.g. high mountains, islands, poles or low density areas). So there are people motivated to develop energy generation, transmission and distribution techniques to reduce their costs and make them affordable for everyone; or to discover new cheap ways of distributed generation for remote places with difficult access to the grid. In conclusion, making possible that every single human can use energy at an affordable price
- *Direct profit:* world´s biggest 50 utilities have revenues of almost 400 billion$, while this number is around 4,400 billion$ for the biggest 50 O&G companies [18]. The average net profit margins are 11.72% and 10.35% respectively. Profits are used to give returns to shareholders, develop technology or make new investment. These new usages of the profits will give back new profits, repeating the cycle again. These cycles create wealth and jobs, helping to the development of the society. So, companies innovate for two purposes: increase profits (by having bigger margins or increasing activity) and assure future profits by placing on a strategic position. Strategic position in the future: renewable energy is predicted to gain share in the energy mix and is likely to become the main source of energy in the far future. It is a reality that is coming slowly but that will become true earlier or later. Innovation in new energy production techniques brings the opportunity to play an important role in the coming energy future. In the meantime, there are companies developing renewable energy as a defense strategy, in order not to stay out of market in the case of a sudden change of the energy landscape and lose their current revenue sources

On the other hand, national governments invest on energy innovation in order to reduce their country´s dependency to foreign energy. In the case of Europe, big quantities of oil and gas are imported (i.e. over 3,570 million barrels in 2013 [19]). Reducing the dependency to this energy would reduce the vulnerability to an increase of price, give stability to the economy, create jobs and increase wealth (i.e. 388 billion € spent on crude oil imports in 2013 in Europe could have been used in other purposes [20])

- *Improve brand & corporate positioning:* in the recent past, as the environmental consciousness is increasing, it is becoming "cool" to be a green person/company/country. One example could be the case of P&G. Among other environmental sustainability measures, the company has the objective of powering its plant by a 30% of renewable energy by 2020. The use of renewable energy is currently ~7.5% [21]. It gives them the image of a clean and sustainable company. So, there are some companies doing it in order to improve their image and to use this as a marketing tool

The motivation of a company or a government for innovating is not unique. It is usually a combined mix of various reasons. Some reasons have greater relevance than others and have more influence at the time of taking the decision to innovate; these are going to be called "*primary motivations*" and the others, "*secondary motivations*". A real example can be seen in the following table:

	Primary motivation	Secondary motivation
CEIT	• Reduce environmental impact • Ensure universal access to energy	• Direct profit • Improve brand positioning

Figure 4.1: Example of a motivation mix

4.2 Innovation origin

Innovation has its origin in two bases. Both need of each other in order to innovate. The first one is people who has the ability, the infrastructure and willingness (due to the previous mentioned motivation mix) to develop technology and create innovation. These have been called *technology developers*. However, innovation requires money to invest in equipment, people and other kind of resources. Moreover, innovation is an investment that gives its returns in the long-term. So, they have the need of the second base, *funding institutions*. People that have the money to invest in something, but do not have the capacity, ability or willingness (because their business is based in other activities) to develop technology themselves. It may happen that a technology developer is a funding institution at the same time.

Before going on with the technology developers and funding institution, it is important to explain the different stages that technologies go through during their lives. These stages are classified by the grade of maturity, from newly created technologies to obsolete technologies: emerging, growth, maturity and decline.

- *Emerging:* these are newly created technologies, or even technologies that are on ways of being discovered. First, ideas are developed and new technologies, materials… are discovered. Then, they are developed and tested. And finally, small prototypes are made to verify that they work as expected. Many ideas or technologies may not be as good as initially thought and are discarded. Others, even if they work as expected, take a long time to arrive to the next stage because they are very expensive or are not deployable at big scales at that moment. As these technologies are in early stages, they cannot be sold, so there is usually a big need of funding. One example of an emerging technology is the technology being developed by a scientist group of the École Polytechnique Fédérale de Lausanne (EPFL) that transform hydrogen into formic acid
- *Growth:* already small-scale proven technologies that are commercialized to obtain economic revenues. Usually, a real scale prototype is done to show the potential buyers that this new technology is working as expected and it is deployable. The focus on this stage is to build a new product that is price and performance competitive in order to start selling it. There is usually a huge need of funding, especially at the beginning, to build the first units of the product. Moreover, if the product is successful, it has a fast expansion. An example of a technology in the growth stage is thin film PV. It is a technology that is already being commercialized, but it is expected to develop and improve efficiency considerably
- *Maturity:* highly consolidated technologies. Their cost is not going to have significant reduction. This is a stage where companies deploy widely the technology and make profit with it. New technologies start entering into the market and taking their place. Onshore wind is an example of a mature technology. There are already more than 100 GW installed in Europe [22] and very small LCOE reductions are expected (see onshore wind section in point 4.3)
- *Decline*: technologies that start to be obsolete, there are new superior technologies in the market that are cheaper and more efficient. Sales and installed capacity of these technologies decrease. Finally, its use is minimum. The clearest example of a mature technology in the electric sector is oil power plants. In Spain, its use has gone to 0 during the last years

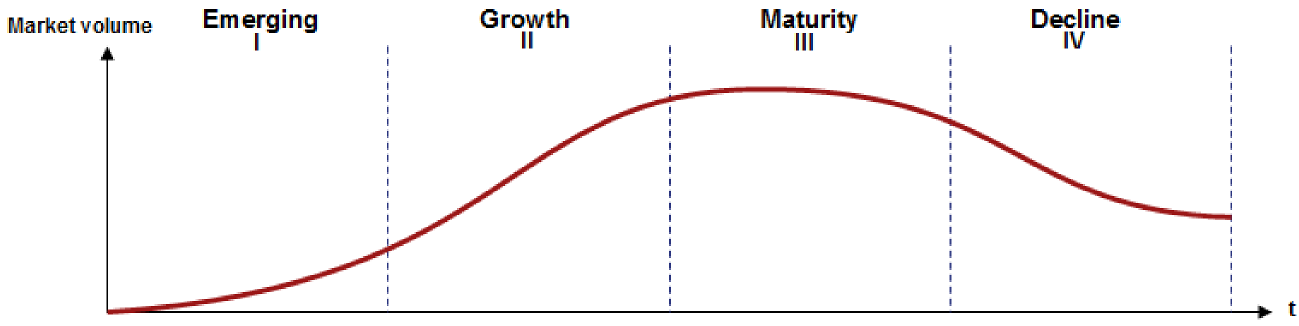


Figure 4.2: technology life-cycle curve

Each funding institution or technology developer is present in certain stages. Motivations are closely related to the stage in which they are present. Emerging technologies are often related to the social purposes, and growth, maturity and decline to the economic purposes.

Technology developers:

There are five main types of technology developers in the energy sector: universities, research centers, start-ups, technological companies and utilities.

- *Universities:* they do basic research in early stages of the technology. It is not innovation itself, it is just the base research from which new technologies, new materials, new techniques are discovered and is the key to then create innovative technologies. It is usually done by professors and students. They usually have limited resources from the university, so have the need of funding. Main institutions for funding are the university itself, government support and utilities. For example, the Altaeros Energy´s high altitude aerostat and Ambri´s liquid metal battery have their origin in the MIT University. Primary motivations: reduce environmental impact and ensure universal access to energy. Secondary motivations: direct profit and improve brand & corporate positioning
- *Research centers:* from basic to applied research (emerging and early growth) is done, and the technologies usually take long time before being widely deployed. They are often associated to a university. There are two kinds of centers depending on the ownership: public property (e.g. Sandia, NREL, CIEMAT and CSIC) and private property (e.g. Fraunhofer Institut, CTAER, and CEIT). However, both types of centers have similar ways of funding: companies and specially, government support. As research centers are usually non-profit organizations, when a potential successful product is discovered, a spin-off company is created to commercialize it. As a consequence, many technological start-ups have their origin as a spin-off of a research center. CPV and organic cells are some examples of technologies that have been developed in research centers. Primary

motivations: reduce environmental impact and ensure universal access to energy. Secondary motivations: direct profit and improve brand & corporate positioning

- *Start-ups:* focused on commercializing already developed technologies that may be successful. They are present in the growth and maturity stages of a technology. Start-ups often have similar development processes: build a commercial, real scale prototype and prove it works; commercialize it; and keep doing research and development in order to improve the product and make it more competitive (i.e. reduce material costs, improve efficiency, reduce manufacturing costs). Start-ups are newly stablished companies that initially do not have enough money, so they have the need of funding until they start selling the product and have revenues. There are plenty of technologies developed by strat-ups. For instance, smart home solutions (e.g. Wattio), high altitude wind solutions (e.g. Makani) or thermal energy storage technologies (e.g. Isentropic). Primary motivations: direct profit. Secondary motivations: reduce environmental impact and ensure universal access to energy
- *Technological companies:* they are present in all the stages of a technology, from emerging (not to stay behind its competitors or to place in a better and more advanced position than competitors) to maturity (have profits from the developed technologies). Apart from doing basic R&D themselves, it is common that they have agreements with universities and research centers, or to have energy venture capitals (this is a good way to become owners of already successful technologies). Technological companies are big businesses that have enough money to fund their R&D activities, so there is commonly no need of external funding. Siemens (HVDC and WTGs[1]) and Abengoa Solar (CSP and thermal storage) are some examples of technological companies innovating in the energy sector. Primary motivations: direct profit. Secondary motivations: improve brand & corporate positioning, reduce environmental impact and ensure universal access to energy
- *Electric utilities:* their business is generation, distribution and commercialization of electricity. They build and operate generation plants and distribution grids. So, their focus is on acquiring already developed and proven technologies to apply them in their projects. They are mainly in the maturity and decline stages. However, there are also some efforts dedicated to do R&D. Most of this R&D is oriented to grids management due to the fear of a probable change in the generation and distribution system. Utilities usually

[1] Wind Turbine Generator

fund projects of universities or start-ups and own energy venture capitals in order to always have the latest technology and be able to use it. They usually have subsidiary companies dedicated to renewable energy. As utilities are commonly big companies, they have enough money for R&D activities without the need of external funding. Nevertheless, they may need external funding to finance big projects (e.g. nuclear power plants construction, offshore wind plant construction). For instance, EDP is developing a floating offshore wind turbine and SaskPower has built the first coal plant with CCS. Primary motivations: direct profit. Secondary motivations: improve brand & corporate positioning, reduce environmental impact and ensure universal access to energy

Funding institutions:

- *Public sector:* supports basic research and start-ups in early phases of development. Governments often support renewable energy plant construction. Public sector plays an important role on the establishment of new technologies, which initially are not competitive against established technologies and need a government subsidy in order to be economically attractive. As those technologies are deployed (subsidized) the sector is learning and reducing their costs, making them more competitive. Worldwide, governments spent 14 billion$ for technology development in 2013 [23]. Primary motivations: reduce environmental impact and direct profit. Secondary motivations: ensure universal access to energy
- *Energy venture capitals/private equities:* they look for start-ups in the growth stage with a very promising and disruptive product. It is a high risk business in which they become owners of a certain percentage of the company. Venture capitals and private equities contributed to funding technology development with 4 billion$ in 2013 [24]. Primary motivations: direct profit. Secondary motivations: reduce environmental impact and ensure universal access to energy
- *Utilities/technological companies:* as stated before, these companies fund projects from universities, have their own energy venture capitals and have cooperation agreements with start-ups. Worldwide, corporation dedicated 15 billion$ to technology development in 2013 [25]. Primary motivations: direct profit. Secondary motivations: improve brand & corporate positioning, reduce environmental impact and ensure universal access to energy
- *Financial institutions:* it is the main way of funding for the great majority of companies. They may not directly fund technology development, but expansion. They usually fund

low risk start-ups in order to grow or big companies to construct new projects. Primary motivations: direct profit. Secondary motivations: improve brand & corporate positioning

- *Crowdfunding:* small and newly created start-ups may use this method to obtain funding (e.g. Wattio). It is a very small amount compared to the others funding methods. Primary motivations: reduce environmental impact and ensure universal access to energy. Secondary motivations: direct profit

Figure 4.3 resumes the presence of technology developers and funding institutions on the technology curve.

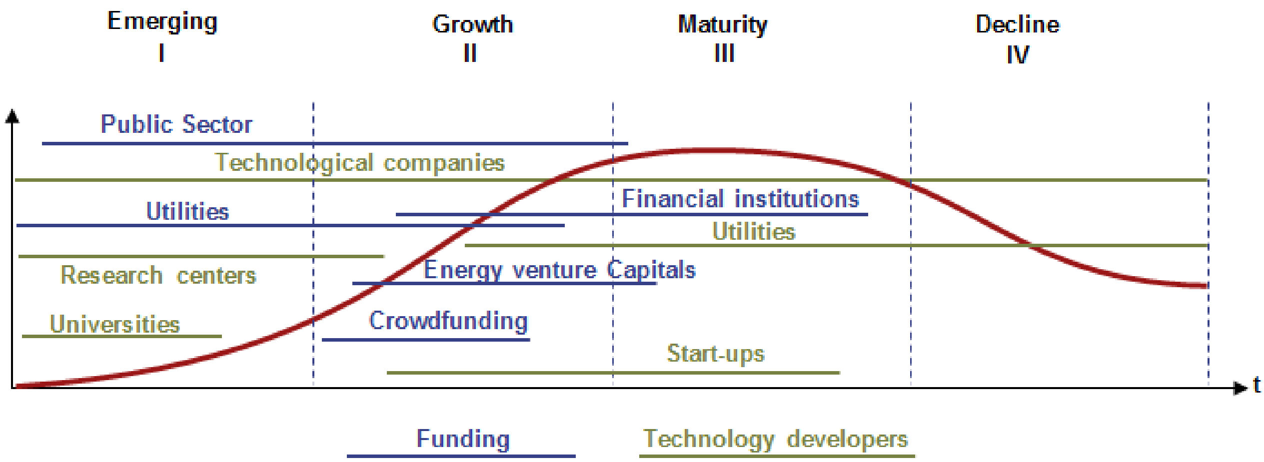


Figure 4.3: Presence of developers and funding institutions in each cycle

4.3 Innovative technologies

Once seen why people/companies are innovating and who is doing it, let´s see which the result of this innovation is. Among all the stages, those technologies in the growth stage have the greatest potential to substitute existing technology and disrupt the electric sector. This is why this point will focus on innovative technologies in the growth stage, mentioning also some technologies in the emerging stage.

Innovative technologies can be classified into four groups depending on its nature: generation, efficiency, infrastructure and storage.

- *Generation:* it is a key activity of the electric sector. Historically, this is where more money has been spent. The other innovative technologies try to make possible, improve or deal with the changes brought by new generation techniques

- *Efficiency:* it includes the technologies that enable consuming less, reducing the demand of energy from the final consumer. So, it is closely related to the commercialization activity of the electric sector
- *Infrastructure:* it comprises all the technologies that improve grids: make them more efficient and have less loses; or help monitoring and managing complex energy grids (due to distributed generation or renewable energy) where energy does not flow in a single direction. It is related to the transmission and distribution activities
- *Storage:* storage units are part of the infrastructure of the electric grid. However, it is going to be analyzed separately for two reasons: first, it is not only linked to transmission and distribution activities, it is also related to generation and commercialization activities; the second reason is the important role storage will play in the coming electric sector

The research of innovative technologies and companies is based on the 2013 and 2014 Global Cleantech 100 lists [26]. Additionally, in order to find disruptive start-ups, the investment portfolio of several energy venture capitals has also been studied (e.g. EnerTech Capital, Innogy Venture Capital or The Westly Group). Some technological companies have also been analyzed (e.g. Siemens, SENER and Abengoa Solar).

4.3.1 Generation

Generation technologies can be classified by their primary energy as seen in Figure 4.4:

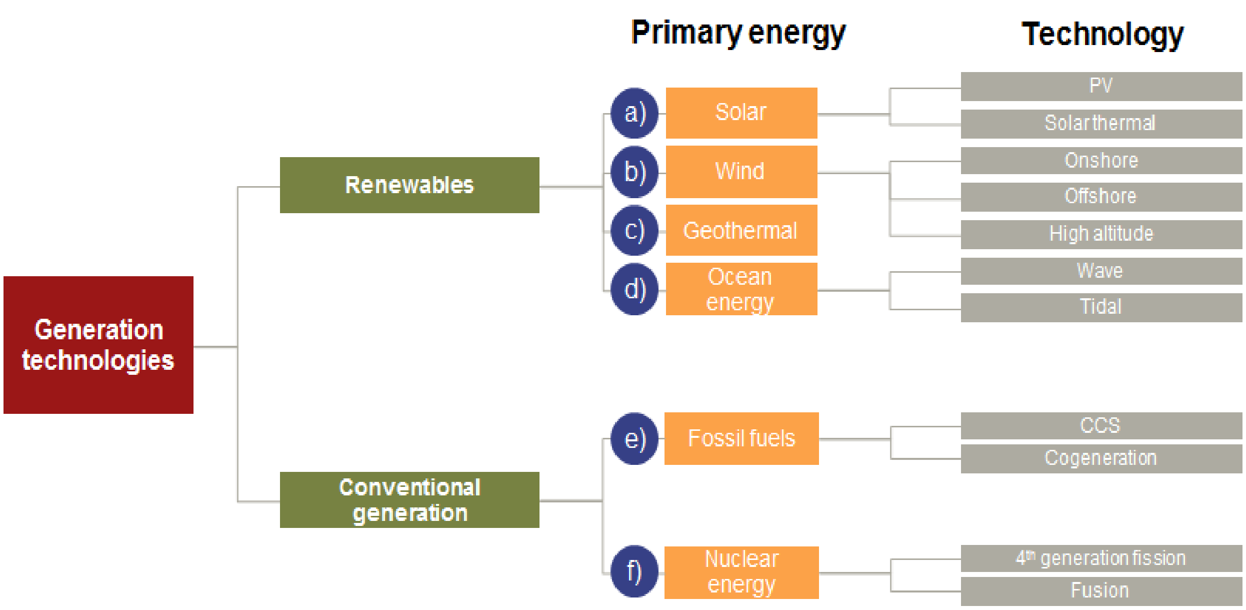


Figure 4.4: Classification of generation technologies

a) Renewables: solar

Photovoltaic (PV):

PV technologies are usually classified into three generations, depending on the material used and the commercial maturity.

First generation includes all the crystalline silicon technologies. It is a mature technology and it is fully commercial nowadays. So, innovation in these technologies focuses on improving competitiveness. These are some examples of companies innovating in this field:

- *Sun Edison:* announced on October 2014 that they are developing a step-change technology that will enable to deliver solar panels at a cost of $0.4 per watt peak by 2016. The technology is called “high-pressure fluidized bed reactor” (HP-FBR) and is able to produce high purity polysilicon ten times more efficiently than non FBR technologies
- *Ever Green Solar:* anti-reflective glass increasing 2-3% electricity produced compared to panels with standard glass. They also have improved performance under hot conditions obtaining a 4% higher output
- *Enphase Energy:* micro inverters that allow each solar module to operate independently for a higher performance. Simple installation so that any individual could install it. Control and monitoring system
- *tenkSolar:* parallel architecture of reflectors capturing the light that normally falls between rows of modules (see Figure 4.5)

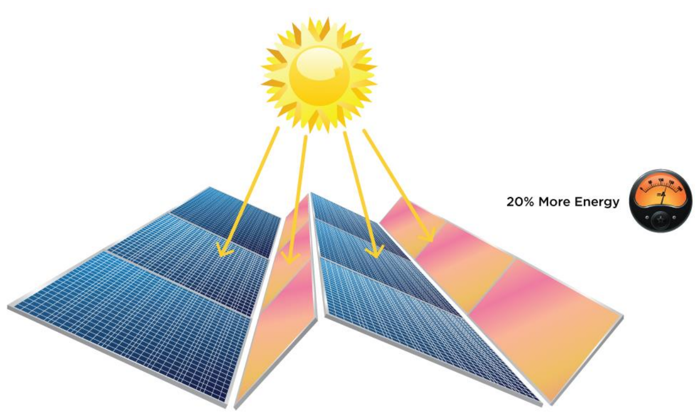


Figure 4.5: Illustration of the parallel architecture *[tenkSolar]*

- *SunPower:* copper foundation adding strength and becoming almost impervious to corrosion

Since the commercial production of Si PV panels began in 1963 [27], several innovations, such as efficiency improvement or lower manufacturing costs, have made the PV prices reduce considerably from over 100 $/Wp to less than 1 $/Wp. This cost reduction has historically followed a logarithmic learning curve depending on the manufactured capacity (see Figure 4.6). In 2009, cost were higher than the theoretical learning curve due to a temporally shortage of silicon. Then, costs came down rapidly because of Chinese dumping. They started selling solar panels at very low prices. In 2013, the European Commission carried an investigation to decide if Chinese PV producers were selling panels below their manufacturing costs in order to eliminate European competitors. The 2nd December 2013, the investigation concluded that China was making dumping and some duties were imposed to those PV panels imported from China [28]. The price increase in 2009 and the next fast price reduction had their origin in events taking place in that moment and did not mean a structural change of the industry. So, in the long term costs will tend to the theoretical curve. Sun Edison´s announcement, however, would mean a structural reduction of costs if it came true, leading to a different learning curve model.

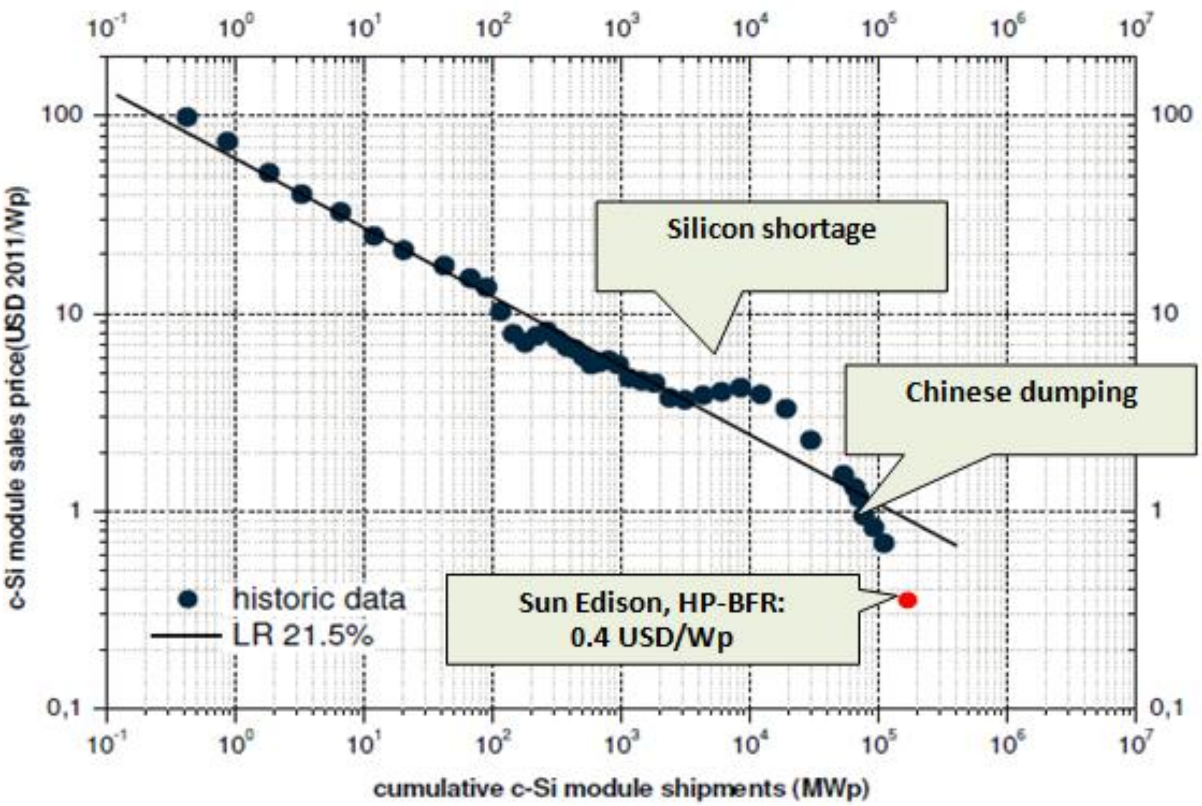


Figure 4.6: Learning curve for module price as function of the cumulative PV module shipments *[based on ITR PV 2013 Results]*

Second generation technologies are mainly thin-films. These technologies are in the transition to be commercial after a long period of development. Thin-films are built by successive thin layers deposited on a glass substrate, requiring lot less semiconductor than Si panels. So, thin-films could potentially provide cheaper electricity than conventional Si modules due to lower cost per kW, but they have lower efficiencies making them lose competitiveness. In addition, they are light and flexible which enables creating new functionalities for solar PV, as building-integrated PV (BIPV). BIPV are used to replace conventional building materials of the outside surface of a building. Thin-films innovation is focused in finding ways of improving cell efficiencies. Historically, this innovation has mainly come by the development of cells with different semiconducting materials. There are mainly three types of thin-film commercially available:

- *Amorphous silicon, a-Si (e.g. Xunlight Corporation, Anwell technologies):* the most developed and known thin-film technology along with Cadmium telluride. It has efficiencies in the range of 4% to 8%. The main disadvantage of this technology is that the sun degrades its performance over time
- *Cadmium Telluride, CdTe (e.g. First Solar):* have lower production costs and higher efficiencies than other thin-film technologies, up to 16.7%. The main disadvantage is that tellurium production in the long-term may be limited
- *Copper-Indium-Selenide/Copper-Indium-Gallium-Diselenide, CIS/CIGS (e.g. Ascent Solar, Solar Frontier):* have the highest efficiencies among all the thin-film technologies. Nowadays, it goes from 7% to 16%. However, efficiencies up to 20% have been achieved in laboratories

Amorphous silicon has historically dominated the thin-film industry, as it was the only technology commercially available. Since 2004, CdTe technology became increasingly important, and it reached market shares around 70% in 2009. Finally, CIGS are gaining market share since 2009, and in 2013, they almost reached CdTe technology (see Figure 4.7).

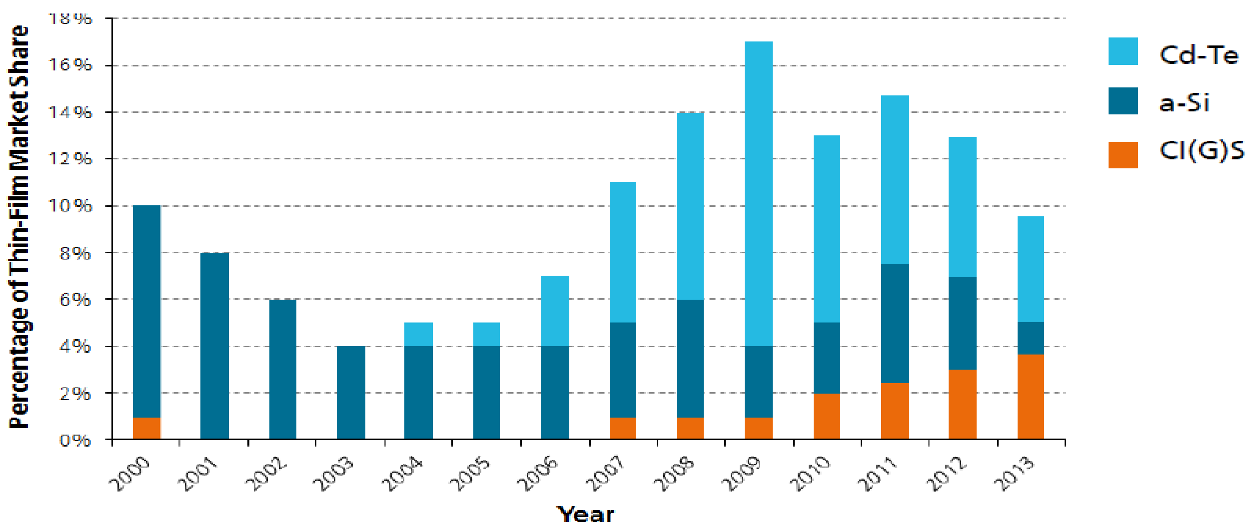


Figure 4.7: Thin-film market share by type *["Photovoltaics Report", Fraunhofer ISE – Oct. 2014]*

Finally, the third generation includes concentrating PV (CPV), organic solar cells, dye-sensitized solar cells (DSSC) and other emerging technologies. Some of these technologies are starting to be commercialized (mainly CPV) and the rest are still in development.

CPV are based in the use of optical devices (i.e. mirror and lenses) to concentrate direct solar radiation into a small solar cell. This cell is composed by a multi-junction which makes it highly efficient. This technology is classified into three groups depending on the solar concentration. First, low concentration PV having concentrations in the range of 2 to 100 suns. Then, medium concentration PV from 100 to 300 suns. And finally, high concentration PV with concentrations up to 1,000 suns. Nowadays, efficiencies are around 35%, but have reached the 40% in some laboratory proves. The main disadvantage is that they work under direct solar irradiance, meaning that the sun has to be directly hitting the panel, not as in the case of silicon PV, where diffuse radiation also generates energy. So, having solar tracking systems is almost necessary for these technologies. Moreover, although the amount of semiconductor material used is reduced considerably, the optical devices are usually expensive, making them more expensive than silicon PV. Big efforts in innovation are being made to reduce the optics costs. Some of the companies innovating and offering CPV technology are Soitec, Suncore Photovoltaic technology, Zytech and Abengoa Solar.

Organic cells are those composed by organic or polymer materials. It is a really young technology. Organic cells are usually cheap, but they have very low efficiencies, in the range of 4% to 5%. Heliatek obtained efficiencies around 10% in 2012 and aims increasing them to almost 14% by 2015. Organic cells are light and flexible. It is a niche technology that could compete in the future with other PV technologies for portable applications (e.g. mobile phones, laptops, toys). Innovation consists mainly on searching new material with higher efficiencies and better properties.

The following table compares some performance characteristics of each of the PV technologies:

	First generation PV	Second generation PV			Third generation PV	
		a-Si	CdTe	CIS/CIGS	CPV	Organic cells
Best research solar cell efficiency	24.7%	13.2%	16.5%	20.3%	43.5%	11.1%
Commercial module efficiency	15-19%	5-8%	8-11%	7-11%	25-30%	1%
2012 PV module cost (USD/W)	<1.4	~0.8	~0.9	~0.9	-	-
Market share in 2010	89%	2%	-	9%	-	-
Area needed per kW	7m^2	15m^2	11m^2	10m^2	-	-

Table 4.1: Characteristic comparison of main PV technologies *[based on "Renewable energy technologies: cost analysis series, Solar Photovoltaics", IRENA – June 2012]*

Among all these technologies, Si PV is nowadays the leading technology (i.e. ~90% of PV market share in 2013) and seems to remain as it is for a long while (i.e. since 1992 silicon technology has accounted of market shares in the range of 80-90%, and has an increasing tendency). They have the better trade between costs and efficiency, making them the most competitive technology. Moreover, if the manufacturing process that Sun Edison has announced becomes true, costs will reduce significantly. Other technologies, like CPV or BIPV, have some drawbacks against silicon PV making them occupy a secondary place in the future. BIPV´s expansion is mostly limited to the construction of new buildings in locations with good sun conditions (i.e. facing south, not being shaded by other buildings). Moreover, BIPV results being quite expensive, it may be cheaper in many cases to construct the building with common materials and then installing the solar panels in the rooftop. CPV technology´s main disadvantage is that they only work over direct normal irradiance (DNI). This means that electricity generation could go to 0 if a cloud is shading the sun. So, they are only competitive in places with high yearly DNI (e.g. Australia, Middle East, Northern and Southern Africa). And as the cost of the optical devices is quite high, they have slightly higher LCOE and could only replace silicon PV in applications with limited space where space has more relevance than economics.

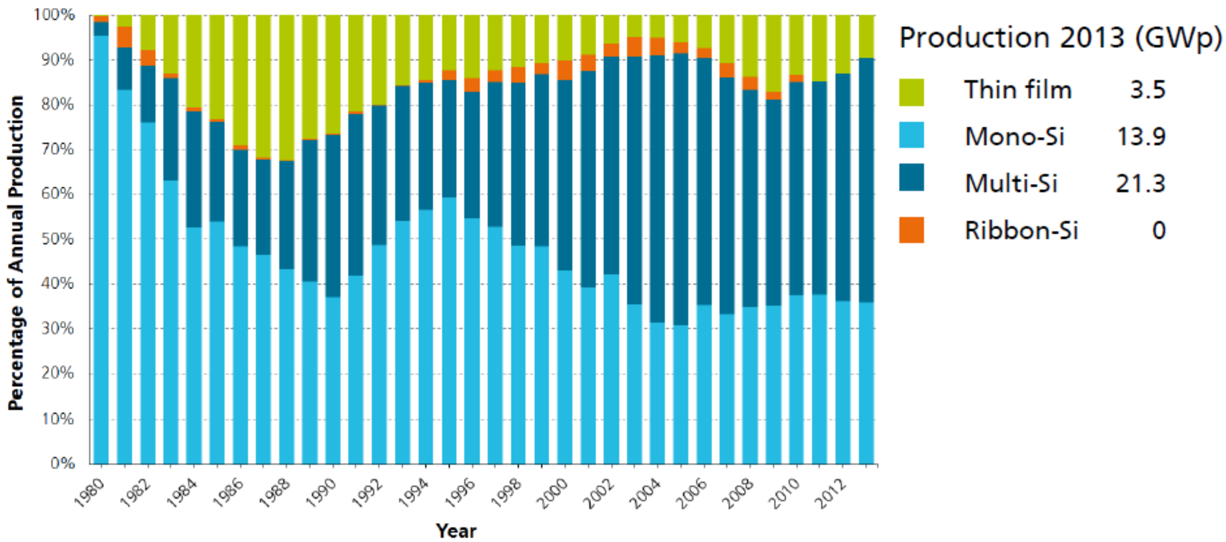


Figure 4.8: Market share by PV technology *["Photovoltaics Report", Fraunhofer ISE – Oct. 2014]*

Concentrated Solar Power (CSP):

There are four main types of CSP technologies. Table 4.2 shows the main characteristics of each technology:

	Parabolic Trough	Solar Tower	Linear fresnel	Dish-Stirling
Typical capacity (MW)	10-300	10-200	10-200	0.01-0.025
Key technology providers	Abengoa Solar, SolarMillenium, Sener Group, Acciona, Siemens, NextEra, ACS, etc.	Abengoa Solar, BrightSource Energy, eSolar, Solarreserve, Torresol	Novatec Solar, Areva	
Operating temperature (ºC)	350-550	250-565	390	550-750
Capacity factor (%)	• 25-28 (without storage) • 29-43 (with 7h storage)	55 (with 10h storage)	22-24	25-28
Plant peak efficiency (%)	14-20	23-35	8	30
Cycle	Superheated Rankine steam cycle	Superheated Rankine steam cycle	Saturated Rankine steam cycle	Stirling

Table 4.2: Comparison of different CSP technologies *[based on "Renewable energy technologies: cost analysis series, Concentrating Solar Power", IRENA – June 2012]]*

Innovation efforts in CSP technologies are mainly done in four fields: solar collection system, thermal generation system, storage system and electrical generation system (see Table 4.3). Thermal generation system is where higher improvements of efficiency and cost can be obtained. As a consequence, the bigger efforts are being done in this field, especially in obtaining higher operating temperatures.

Technology / functionalities	Solar collection system	Thermal generation system	Storage system	Electrical generation system
Parabolic Trough	• Mirror size and accuracy • Optimized support structure design	• HCE[1)] characteristics • Alternative working fluid • Higher operating temperature	• Alternative storage reservoir and storage medium	• Turbine efficiency
Solar Tower	• Field configuration and heliostat size optimization • Optimized tracking system costs	• Alternative working fluid • Higher operating temperature • Improved cycle technology	• Alternative storage reservoir and storage medium	• Turbine efficiency
Dish Stirling	• Optimized support structure design • Optimized mirrors		• Storage development	• Engine efficiency and capacity
Linear Fresnel	• Automatic mirror assembly • Optimized mirrors	• HCE characteristics • Higher operating temperature	• Storage development	• Turbine efficiency

Table 4.3: Innovation focuses by technology and field *[A.T. Kearney experience]*

Between the different companies researching in this field, Abengoa Solar is a good representative as they are trying to solve the temperature limitation with different solutions. Other companies such as Solar Reserve, SENER, Bright Source and Solar Millennium are also developing these technologies, but just the Abengoa´s case is going to be shown in order to avoid repetitions.

Abengoa Solar is developing technologies mainly in two solar thermal technologies: concentrated solar tower and parabolic trough. The developed tower technologies are the followings:

- *Superheated tower:* the company´s biggest efforts in R&D in recent years have focused on designing a new generation of solar tower. They have built a 3 MW prototype at the Solucar platform that has achieved producing superheated steam at high temperatures significantly improving power generation efficiency
- *Salt solar tower:* solar tower where molten salts are used as heat transfer fluid
- *Solugas:* Abengoa has begun the construction of a pilot plant that seeks to validate a new energy generation concept that combines solar energy with a Brayton cycle. This technology uses air as the heat transfer fluid. High cycle temperatures can be reached achieving high power generation efficiency

While the parabolic trough developments are:

- *High temperatures:* advanced heat transfer fluids that operate at a higher temperature than present fluids, increasing the efficiency of the cycle. Certain molten salts are currently being evaluated. They could increase the operation temperature up to 500ºC

- *Direct steam generation:* eliminates the need for an intermediate heat transfer fluid, being water directly going in the troughs. The main advantage of this technology is that eliminates the maximum temperature limitations, thus increasing system efficiency

Solar tower technology seems to be the technology that is likely to dominate the CSP market. The main reason for this is the LCOE comparison between both. As the following table shows, solar tower had lower LCOE in 2011 and predictions are that it will not change for 2020. Parabolic trough LCOE is predicted to be around 0.09 and 0.14 USD/kWh, while solar tower´s LCOE is likely to be slightly lower, 0.07-0.09 USD/kWh.

(2010 USD/kWh)	2011		2020	
	Low estimate	High estimate	Low estimate	High estimate
Parabolic trough				
IEA 2010	0.20	0.295	0.10	0.14
Fitchner 2010	0.22	0.24		
Based on Kutschet et al. 2010	0.22		0.10	0.11
GTM 2010	0.155	0.168	0.09	0.12
Solar tower				
Kollo et al. 2010	0.16	0.17	0.08	0.09
Fitchner 2010	0.185	0.202		
GTM 2010	0.117	0.139	0.07	0.08

Table 4.4: Estimated LCOE for parabolic trough and solar tower technologies *[based on "Renewable energy technologies: cost analysis series, Concentrating Solar Power", IRENA – June 2012]*

Finally, when comparing solar PV technologies with CSP technologies, it seems that PV will have larger expansion in the future due to three main reasons:

- CSP technologies only work under direct normal irradiation, while PV technologies also produce energy with diffuse radiation. So, concentrated solar thermal technologies are mainly limited to location with high DNI
- PV has the characteristic of modularity and scalability, allowing it to distributed generation. Solar thermal technologies, however, are limited to utility scale generation
- PV has lower LCOE predictions (see Figure 4.9)

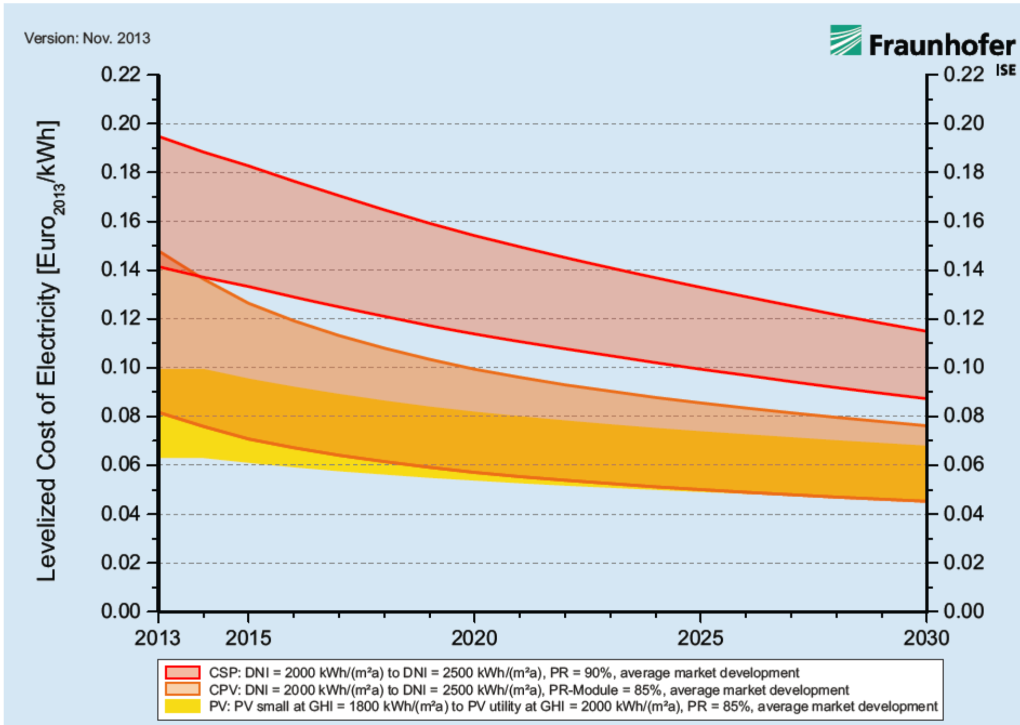


Figure 4.9: LCOE evolution for solar technologies *["Levelized cost of electricity renewable energy technologies", Fraunhofer ISE – Nov. 2013]*

b) Renewables: Wind

Wind energy technologies have traditionally been classified into two groups: onshore and offshore wind. However, there is an additional emerging group: high altitude wind power. Onshore wind is a mature and widely deployed technology (i.e. ~110 GW capacity in Europe by 2013 [29]). Offshore wind is an emerging technology of which there are already some projects being carried out (i.e. almost 7 GW of cumulative capacity in Europe by 2013). High altitude wind power, on the contrary, is an industry that has just emerged and is on early phases of development, with no commercial solutions already installed. This maturity difference between the three technologies leads to different types of innovation. While onshore wind main developments are in the field of improving efficiency, high altitude wind power´s innovations are new and creative ways of generating electricity.

<u>Onshore</u>

Innovation in the onshore wind industry has taken two main directions. On one hand, making the turbines bigger and more powerful. The first wind turbine was made by Bonus Energy and had a capacity of 22 kW. Nowadays, biggest onshore wind turbines have capacities around 3 MW and offshore turbines reach the 8 MW. Nevertheless, the use of big turbines in onshore wind farms is limited by logistics. As the turbine has larger capacities, its size increases (e.g. Siemens´s larger onshore turbine has a capacity of 3.3 MW and a blade length of 63 m). They are reaching some dimensions that it is becoming increasingly difficult to transport turbines to the site (e.g. large trucks with extensions or necessity to build extra-wide roads). There are innovative solutions appearing to deal with these installation problems. Skyacht Aircraft Inc. is developing a tethered aerostat crane that would end with those difficulties and enable the deployment of bigger turbines.

On the other hand, improving reliability and efficiency is the second direction of innovation. The followings are some examples:

- *Direct drive (Enercon):* this technology is based on a simple principle: fewer rotating components reduce mechanical stress allowing an increasing of the equipment´s technical life. One large O&M cost of a wind farm is caused by gearbox failures. The gearbox is the element connecting the rotor with the generator. Usually, the rotor and the generator work at different rotation frequencies. The rotor rotation speed is given by wind and it is usually of a few Hz. The generator frequency, on the contrary, is given by the electrical frequency of the grid, 50Hz or 60Hz depending on the continent. So, gears are the responsible for converting the low frequency of the rotor to the required one by the generator. In direct drive systems, the rotor and the generator are directly interconnected to form one gearless unit. However, the frequency of the generated electricity has then to be adapted to grid frequency by power electronics
- *Superconductivity (AML):* it is based on generators having superconductive wires. These generators are 75% lighter, 50% smaller, more efficient and more reliable than current generators
- *Air core generators (Boulder Wind Power):* the air core generators developed by this company are lighter, cost less and deliver more electricity
- *Variable speed control (Atlantic Bearing Services, ChapDrive*…): originally, wind turbines were fixed speed turbines, this is, the rotor frequency was the same for all wind speeds. This meant that the wind turbine was not working at peak efficiency across all wind speeds. This mechanism allows the rotor moving at different frequencies depending on the wind speed, increasing the efficiency and the output energy

Onshore wind is a mature technology, already competitive with conventional generation technologies (see Figure 4.10) but not further significant cost improvements are expected. The Fraunhofer´s study in November 2013 stated that the LCOE of offshore wind was in the range of

0.045 €/kWh to 0.11 €/kWh, while 2030 predictions are between 0.04 €/kWh to 0.10 €/kWh. Moreover, best wind locations are already being used. So, onshore wind expansion has to be done in locations with worse wind conditions. Another option that some wind farm operators are taking into account is rebuilding the old wind farms (those with best wind conditions, as these were the first to be used) and replace the old small turbine for some current larger turbines.

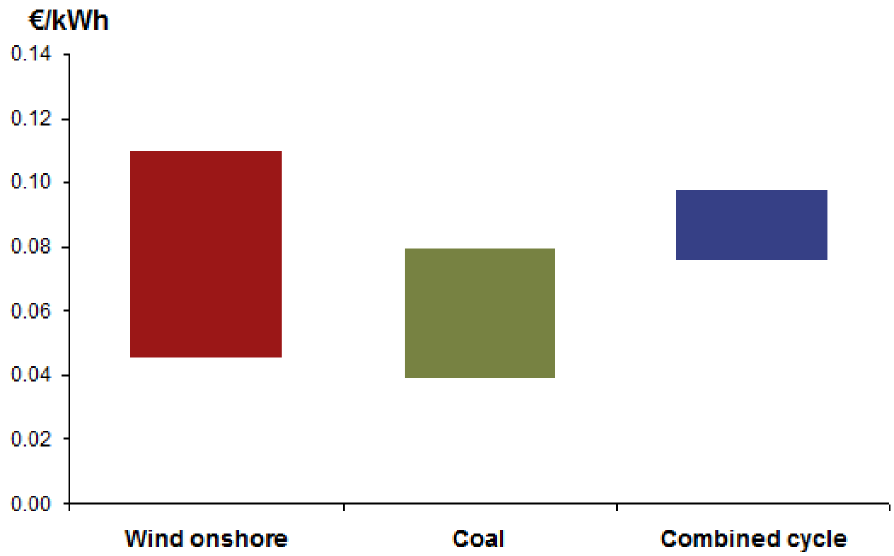


Figure 4.10: Wind, Coal and CCGT LCOE comparison *[based on "Levelized cost of electricity renewable energy technologies", Fraunhofer ISE – Nov. 2013]*

Offshore

Offshore wind industry development has taken two main directions: having larger and powerful turbines and going further from the shore. Larger turbines mainly bring cost reductions, while distancing from shore enables taking advantage of more stable and powerful winds. However, the further from the shore, the deeper the seafloor usually is. Substructures are evolving fast in order to deal with the increasing depth. Industry development is explained in greater depth in point 7.3.

Offshore wind is an industry that is predicted to have relevant cost reduction, leading to an improvement of the LCOE. Fraunhofer´s study in November 2013 calculated that LCOE was in the range of 0.12-0.195 €/kWh in 2013 and the predictions are improvements until 0.095-0.15 €/kWh in 2030.

High altitude wind power

Wind is stronger and has higher speed as the altitude increases. Wind speed can be estimated as a function of the altitude as:

$$\frac{V}{V_r} = \left(\frac{H}{H_r}\right)^{Sf}$$

Where H_r is the reference altitude, V_r is the wind speed at the altitude of reference, H is the new altitude, V the speed at the new altitude and Sf an experimental factor that depends on the type of location. For example, if the wind speed is 4 m/s at 10 m altitude on a location with Sf = 0.31, the wind speed at 50 m can be estimated to be 6.59 m/s.

High altitude wind power technologies try to take advantage of this effect by working at altitudes above 500m. There are two kind of high altitude wind generators in development nowadays: aerostats and gliders.

- *Aerostat:* Altaeros energy is the company developing this solution. It consists on placing a wind turbine in the middle of an aerostat. The aerostat flies at hundreds of meters of altitude and is connected to ground by some tethers. When meteorological conditions are not good enough, the aerostat is taken to ground. It can be easily moved from one site to another as the ground station consists on a truck

Figure 4.11: Picture of the aerostat of Altaeros Energy

  The main advantage of this aerostat is its flexibility, mobility and rapid deployment. It eliminates the logistical challenge of installing traditional renewables in remote areas. In this case, the truck has to go to the desired location and then the aerostat is released, reducing considerably the cost of energy in remote areas

- Gliders: it consists on kites or airplanes gliding at high altitudes. There are two types of gliders: those with wind turbine generators and those that generate energy unrolling a cable. Makani power builds a solution of the first kind. It consists on an airplane that has some turbines on it. As it glides at high altitude winds, energy is generated and transmitted through the cable that joins the ground station and the plane. The other types of gliders generate power by unrolling a cable. There is a kite or an airplane connected to a turbine in ground. Wind pushes them to higher altitudes, making the turbine rotate as the cable unrolls. Once the cable is totally unrolled, the kite is placed in a special position to reduce the energy spend during the recovery process. Skysails Power, KiteGen and Ampyx Power are some companies offering these solutions

Figure 4.12: Illustration of Makani´s plane (left) and picture of KiteGen´s kite (right)

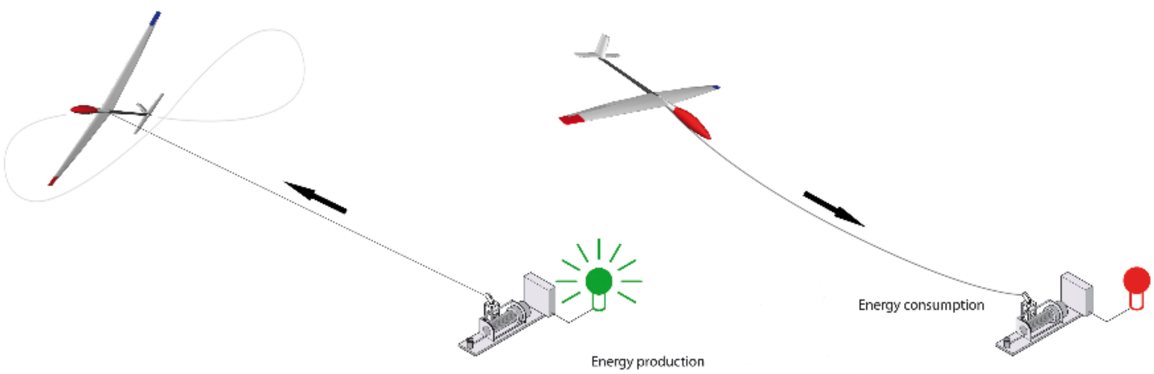


Figure 4.13: Illustration of the working principle of Ampyx Power´s technology

Figure 4.14: Illustration of a wind farm with Skysails technology

Overall, high altitude wind solutions are in early stages of development and their expansion will depend on their reliability and cost evolution. However, there is one thing that seems to be already clear: they are the fastest way to build a power generation plant. It makes them adequate for some niche application. For example, if an earthquake leaved the electric system of a region inoperable, aerostats would be easily installed and power supply would be recovered quickly. Another example could be the case of an oil well. These technologies could easily replace the diesel generators used to produce the required power.

c) Renewables: Geothermal

In the geothermal industry, innovation goes on the direction of modularity and being able to produce energy without the need of special geological conditions. In this field, there are two companies with innovative solutions:

- *Green Energy Group:* they have created a modular solution of 6.4 MW with the size of a 40 foot ISO container. The aim of this solution is to end with the prohibited investment cost associated with the deployment of traditional geothermal power plants. It is based in the standardization of key components for obtaining cost reductions. Moreover, these power plants are designed to be decommissioned, transported and redeployed in a second well, optimizing their profitability
- *Ecoforest:* this Spanish company offers a solution that can be installed anywhere without the need of specific geological conditions. The idea is that below 20m of depth, temperature keeps almost constant all over the year. This solution has a reverse heat pump that uses the constant temperature to heat water independently of the season. It is oriented to replace heating systems in locations without access to natural gas, where heating is done by diesel generators or using electricity

Geothermal energy is likely to have little expansion in the future. Although they could reduce their cost and become highly competitive against other technologies, they are limited to those places with the required geothermal characteristics. And solutions that do not have this limitation, as the offered by Ecoforest, are usually niche technologies.

d) Renewables: Ocean energy

It is an emerging technology, so innovation consists on finding creative and efficient ways of harvesting ocean energy. These are some of the innovative solutions developed:

- *Wave Dragon:* it is a floating energy converter of the overtopping type that can be deployed in a single unit or in arrays. It basically consists of two wave reflectors focusing waves towards a ramp. Behind the ramp there is a large reservoir where the water is stored temporarily. This water is evacuated through hydro turbines that use the difference of the potential energy between the reservoir and the sea level

- *Pelamis:* the solution offered by this company uses the wave motion to generate electricity. It is formed by five semi-submerged tube sections that are facing into the direction of the waves. As the waves pass through, it bends converting this movement into electricity

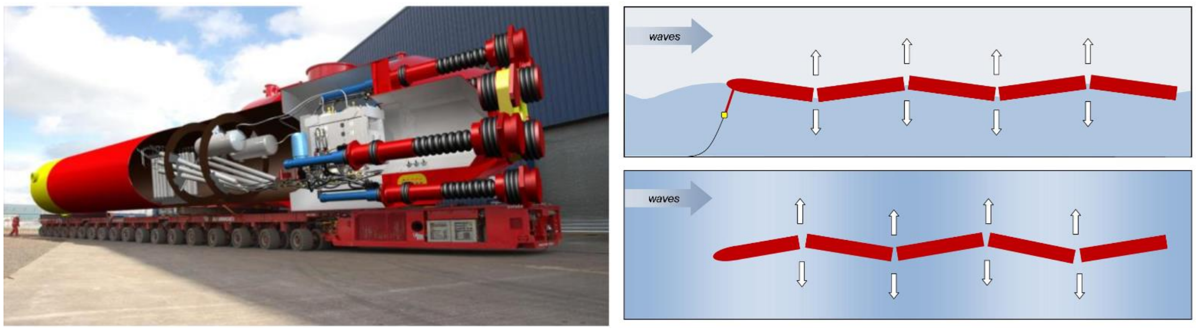


Figure 4.15: Illustration of Pelamis´ wave motion generator

- *AWS and Oceanlinx:* these two companies offer similar solution based in wave generated air compression. The solution offered has three main components. First, an oscillating water column. It is a simple construction that works as a piston and a cylinder as waves pass through. Second, a bidirectional reaction turbine that generates electricity regardless the direction the wind is flowing. So, electricity is generated during both steps of the cycle: compression and decompression. And finally, the generator that converts the rotation of the turbine into electricity

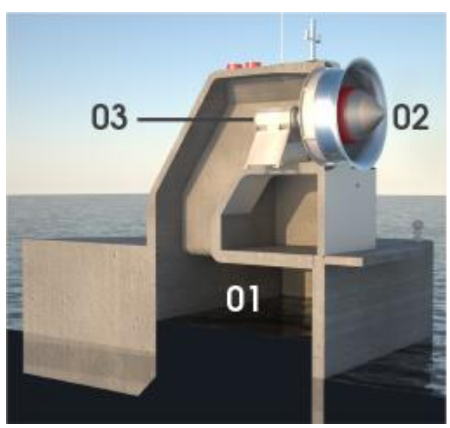


Figure 4.16: Structure of wave generated air compression

- *Ocean Power Technologies:* this solution consists on a buoy that converts wave energy into electricity. This buoy is anchored to the seafloor. As waves pass through, a piston inside the buoy bobs. This movement drives a generator producing electricity

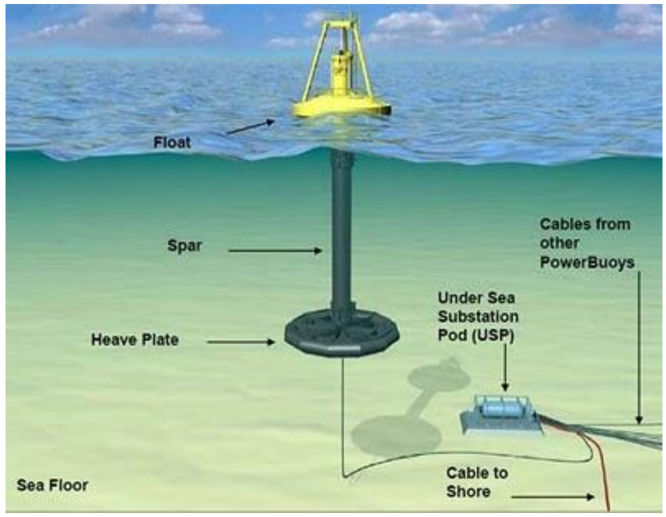


Figure 4.17: Illustration of a buoy generator

Ocean energy is an emerging industry in early phases of development. The firsts real scale prototypes are being build and tested currently. Technologies are usually not price competitive. The LCOE estimated by the UK government in 2014 (see chapter 7) is £305/MWh, significantly higher than other renewable technologies as onshore or offshore wind, £90/MWh and £140/MWh respectively. The LCOE is likely to improve as technology develops, but is unlikely that in the mid-term they reduce the large gap they have with other more mature generation techniques.

e) Conventional generation: Fossil fuels

Fossil fuels are a relevant part of the generation mix because they allow balancing the intermittency of renewable energy and the inflexibility of base load units. As a consequence, current projections for global energy demand still point to fossil fuels being used in quantities incompatible with level required to stabilize greenhouse emissions. In 2011, worldwide fossil fuel consumption was 10,668 Mtoe emitting 31.2 Gt of CO_2. Predictions for 2035 in the New Policies Scenario [30] are 13,208 Mtoe and 37.2 Gt of CO_2 emissions. Carbon Capture and Storage (CCS) is the only way to reduce CO_2 emissions while keeping fossil fuels in the generation mix.

CCS is a family of technologies and techniques that enable the capture of CO_2 from fuel combustion or industrial processes, the transport of CO_2 via ships or pipelines, and its underground storage in depleted oil and gas fields and deep saline formations [31].

In October 2014, the first commercial power plant with CCS was launched [32]. It is a coal plant, called Boundary Dam, located in Saskatchewan, Canada. Right now only two other CCS power plant projects are under construction, both in the USA. CCS is still a very costly technology. The company operating the Boundary Dam coal plant, SaskPower, invested $1 billion to equip one of the four generators of the coal plant with CCS. Moreover, the output capacity was reduced about a 20% from the original 160 MW. Nevertheless, CCS should get more competitive over time. The Intergovernmental Panel on Climate Change projects that the price of adding CCS to coal plants should reduce to one-third of what SaskPower spent at Boundary Dam. Additionally, SaskPower states that with the lessons learned so far, it could now build a similar CCS project for $200 million less.

Nowadays, adding CCS is not profitable and it needs from government support in order to be deployed.

f) Conventional generation: Nuclear energy

Development in nuclear fission energy is coming from the Generation IV International Forum (GIF) [33]. It is an international collective representing governments of 13 countries and it was initiated in year 2000. They are developing six nuclear reactor technologies for deployment between 2020 and 2030. Four of them are fast neutron reactors and all operate at higher temperatures than today´s reactors. The six technologies are: gas-cooled fast reactors, lead-cooled fast reactors, molten salt reactors (there are two variants), sodium-cooled fast reactors, supercritical water-cooled reactors and very high-temperature gas reactors. Table 4.5 shows the main characteristics of each of the technologies.

	neutron spectrum (fast/ thermal)	coolant	temperature (°C)	pressure*	fuel	fuel cycle	size(s) (MWe)	uses
Gas-cooled fast reactors	fast	helium	850	high	U-238 +	closed, on site	1200	electricity & hydrogen
Lead-cooled fast reactors	fast	lead or Pb-Bi	480-800	low	U-238 +	closed, regional	20-180** 300-1200 600-1000	electricity & hydrogen
Molten salt fast reactors	fast	fluoride salts	700-800	low	UF in salt	closed	1000	electricity & hydrogen
Molten salt reactor - Advanced High-temperature reactors	thermal	fluoride salts	750-1000		UO_2 particles in prism	open	1000-1500	hydrogen
Sodium-cooled fast reactors	fast	sodium	550	low	U-238 & MOX	closed	30-150 300-1500 1000-2000	electricity
Supercritical water-cooled reactors	thermal or fast	water	510-625	very high	UO_2	open (thermal) closed (fast)	300-700 1000-1500	electricity
Very high temperature gas reactors	thermal	helium	700-950 (1000 later)	high	UO_2 prism or pebbles	open	250-300	hydrogen & electricity

* high = 7-15 Mpa
\+ = with some U-235 or Pu-239
** 'battery' model with long cassette core life (15-20 yr) or replaceable reactor module.

Table 4.5 : Characteristics of the six nuclear reactor technologies *[GIF]*

Apart from nuclear fission development, there are also some R&D efforts focused on nuclear fusion. ITER is a large-scale scientific experiment that aims to demonstrate the technological and scientific feasibility of fusion energy. It aims to be the first of all fusion experiments to produce more energy than the one consumed, having an input power of 50 MW and a production of 500 MW. The ITER project is being developed by seven international agencies: China, European Union, India, Japan, Korea, Russia and United States. The construction works began in 2010 near Marseille, France. Plans are to end construction by 2019 and start producing energy by the end of 2020s.

In October 2014, the aerospace company Lockheed Martin claimed to be developing a compact fusion reactor [34]. The first reactor prototype will be designed to generate around 100 MW and fit into transportable unit measuring 23x43 ft (e.g. a truck).

4.3.2 Storage

The performance of a storage device can be defined by the following parameters:

- *Rated power (kW):* the maximum power that a storage system is able to give
- *Energy capacity (kWh):* the amount of energy that can be stored
- *Discharge time (seconds, minutes, hours…):* how long the storage device is able to supply the rated power. Energy capacity can be calculated as the product of the rated power and discharge time
- *Response time (seconds, minutes, hours…):* the time needed to start providing the demanded energy
- *Roundtrip efficiency (%):* the ratio between the energy discharged and the energy needed to charge it. It is a measure of the energy losses for each cycle
- *Lifetime (years, cycles):* how long the storage device will work without significant performance degradation
- *Energy density (kWh/kg) and power density (kW/kg):* relation between storage and physical characteristics

Energy storage devices have plenty of uses, from reliability purposes (e.g. back-up power generation in case of grid failure) to renewable integration. Each of these applications has its own requirements of power and energy. For instance, a back-up storage device needs a few kW in order to maintain the supply of a house or an office, and energy should last from some minutes to a few hours. Renewable integration, in the contrary, needs power capacities in the order of the MW and last for some hours. Figure 4.18 shows the power and energy requirements for some of the most common storage applications. It also shows to which segment of the electric sector the application corresponds.

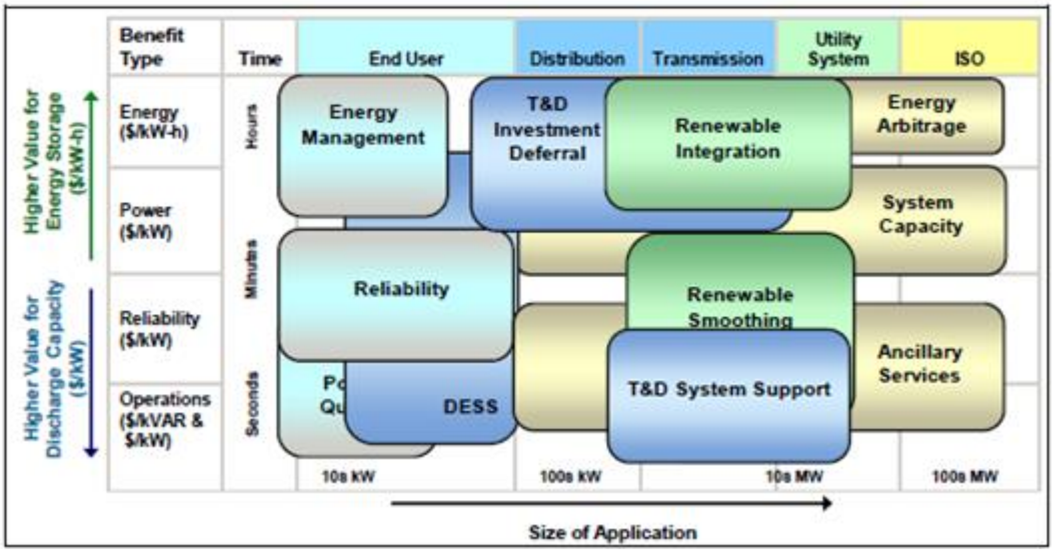


Figure 4.18: Requirements of each storage application *["Electricity Energy Storage Technology Options", EPRI – Dec. 2010]*

Energy is not usually stored as electricity; it is first transformed into another energy form and then stored. Storage devices can be classified depending on the form in which energy is stored: chemical, electrochemical, mechanical and thermal storage. Pumped hydro storage (a type of mechanical storage) is the most mature and expanded technology between storage devices, around the 95% of current storage capacity [35]. As it is a very mature technology, there are not many innovative solutions for it and it is not going to be analyzed in this chapter.

a) Chemical energy storage

Hydrogen is the main technology of chemical storage. It follows a three step process:

- *Production:* there are different ways of generating hydrogen molecules, but water electrolysis is the one using electricity. It consists on splitting the water molecule to separate hydrogen from oxygen ($2H_2O$ + electricity -> $2H_2 + O_2$)
- *Storage:* as Figure 4.19 shows, hydrogen has good energy properties by mass compared to other fuels, but it has poor volumetric properties. At standard conditions, hydrogen is in the gaseous state and is the gas with the lowest density. So, one of the main problem of hydrogen is the space that it takes to be stored, needing high pressures to reach reasonable volumes (e.g. density of 42 kgH_2/m^3 at 700 bar). Moreover, strong safety measures have to been taken due to hydrogen´s inflammability in the gaseous state

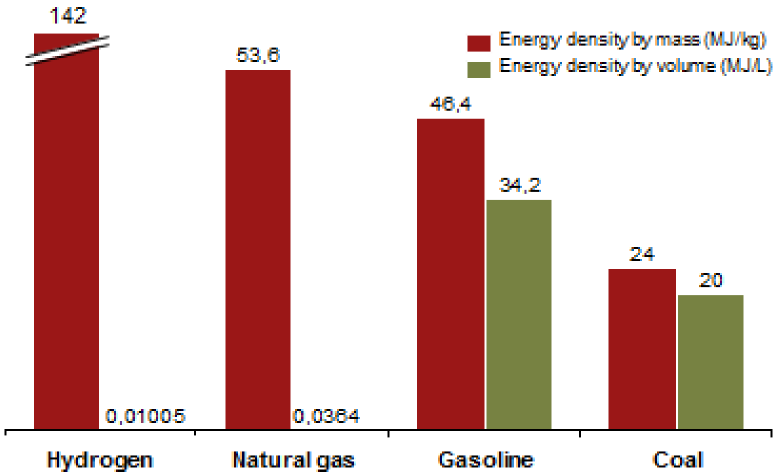


Figure 4.19: Energy densities for different fuels

- *Electricity generation:* done by fuel cells. It is the opposite chemical process to electrolysis in which hydrogen and oxygen are joined together forming water again, generating electricity in this process

There are many companies that, believing hydrogen will be the main storage method in the future, are developing innovative hydrogen technologies. These are some of those companies and their solutions:

- *McPhy energy*: they have developed a solid state hydrogen storage. Some metals or alloys have the property of forming reversible bonds with hydrogen atoms leading to the formation of metal hydride. By using different temperatures and low pressures, hydrogen is either absorbed or desorbed by the metal. McPhy has selected magnesium hydrides (MgH_2) for mass storage. Solid state storage main advantage is the higher volume density than compressed gas or liquid hydrogen (see Figure 4.20). This technology also reduces drastically the risk of inflammation

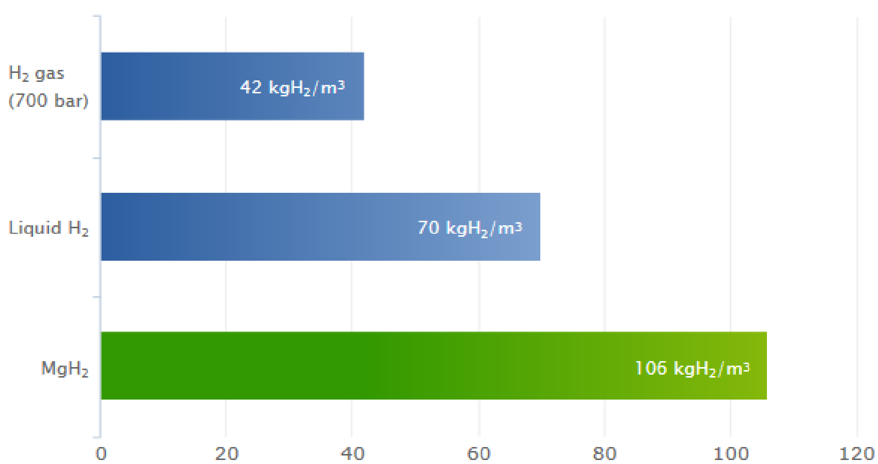


Figure 4.20: Energy density of hydrogen in different states *[McPhy energy]*

- *Hydrexia*: this company offers a similar solution to McPhy energy, a solid state hydrogen storage using magnesium hydrides
- *Areva*: it has developed the Greenergy Box. It is a device consisting of an electrolyzer and a fuel cell. It stores hydrogen and oxygen generated by water electrolysis and then recombines them to generate electricity. This solution is already being implemented in different locations, Corsica and the French city of La Croix Valmer between them
- *École Polytechnique Fédérale de Lausanne (EPFL)*: a scientist group of this university has created a solution for transforming hydrogen in a less flammable liquid fuel, formic acid. It is yet a technology in early developments. It uses CO_2 to create formic acid by its hydrogenation

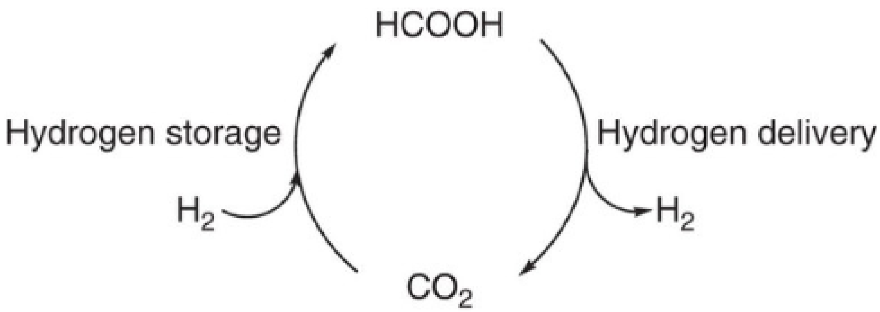


Figure 4.21: Cycle of hydrogen storage as formic acid *[EPFL]*

Hydrogen has some very good properties: it has a good energy density compared to other fuels; it can be generated in one site and transported to another; it can be used as a transport fuel; it is an endless and environmental friendly resource and the cost of the hydrogen is very low due to its abundance. However, there are some features that slow down its expansion. It has very low roundtrip efficiencies (20-50%) as each of the stages has energy losses. Efficiency of water electrolysis is in the range of 60-80%, while fuel cells have efficiencies around 50%. Moreover, as it has to be stored under high pressure, large quantities of energy have to be used, losing efficiency in storage.

In the case of transport, hydrogen vehicles sound as possible substitutes of combustion engines. But, they will be competing with electric vehicles and these last seem to be currently in a better position. Electric vehicles´ price is going down fast carried by batteries´ cost reduction. Moreover, the energy cycle has better efficiencies and they are easier to charge nowadays.

Nevertheless, some think that this will be the main storage method in the future. The property of easy transportation makes it have different applications, such as, cars functioning with hydrogen and emitting water instead of CO_2 or each household being supplied hydrogen at home by using the current gas distribution grid and generating electricity with a fuel cell. The large power and energy capacities make hydrogen a good solution for renewable integration too. Hydrogen could have many new applications if roundtrip efficiencies were improved and its storage was simplified. Among those who think in a hydrogen future, Shell, Siemens and The Linde Group are some of the remarkable companies.

b) Electrochemical energy storage

There are two main types of electrochemical energy storage technologies: batteries and ultra-capacitors.

Batteries

They can be classified into two groups depending on how energy is stored. Solid state batteries are the first type. These are the batteries that have been used historically and store the energy in the electrodes, while the electrolyte allows the ions move between electrodes. There are many types of solid state batteries: Pb acid and Nickel-Cadmium (NiCd) batteries are the conventional technologies; and lithium ion (Li-ion), sodium sulfur (NaS), NaNiCl and lead batteries are the most common new technologies.

The second group is formed by flow batteries. They store the energy in the electrolyte, having as one of the biggest advantages that they can be almost instantly recharged by replacing the electrolyte liquid. Redox, Iron-Chromium, Vanadium Redox and Zinc-Bromine are the main flow battery technologies.

The followings are some examples of companies developing some innovative technologies in the world of batteries:

- *Ambri*: the solution offered by this company, liquid metal battery, is the only battery where all three active components are in liquid form when the battery operates. The two liquid electrodes are separated by a molten salt electrolyte, and these liquid layers float on top of each other based on density differences and immiscibility. The main advantage is the low cost, obtained by the use of inexpensive, earth-abundant materials and the design that takes advantage of the economies of scale inherent to electro-metallurgy and conventional manufacturing. Their actual prototype is a 17.5 kW / 35 kWh battery and they intend building systems of 1 MW / 2MWh
- *Aquion energy:* this company has developed the Aqueous Hybrid Ion battery, a saltwater electrolyte technology. It uses abundant and nontoxic materials. This technology was

developed with one clear idea: a large-scale energy storage system that is high performance, safe, sustainable and cost-effective. They offer modules with output powers from the few kilowatts to multi-MW. The batteries are large and operate slowly, but they are manufactured economically

- *EOS energy storage:* they offer a zinc hybrid cathode battery. It has a cost of $160/kWh, lifetime over 30 years and 75% round-trip efficiency. Moreover, it has an energy capacity of 6 MWh housed in a 40 feet ISO container. The company claims it can offer a LCOE of $0.12/kWh [36]

Batteries main advantages are modularity and high efficiency (70-100% in advanced batteries). Nowadays, the main application areas are portable devices and electric vehicles. It is also used as back-up storage for households or offices. However, their high costs make them unprofitable in utility scale deployment for the moment.

Batteries outlook seems promising. Tesla is building a giga factory of batteries in Nevada. The predictions are that it will produce batteries for 500,000 vehicles by 2020, reducing the kWh price of batteries by 30% [37]. This will mean a step forward for batteries expansion in many aspects. First, electric vehicles prices would reduce significantly as batteries are their main cost. It will also launch the distributed generation expansion. Economic batteries will increase profitability of these installations by allowing storage during day and consumption at evening and night. For instance, the LCOE for residential solar-plus-battery installations is already better than retail energy prices in Hawaii and it is likely to be the case in New York from 2025 and California from 2031 [38]. In addition, the deployment at utility scale could become profitable, helping to deal with renewables intermittency and their integration.

Ultra-capacitors/supercapacitors

They are high capacitance electrochemical condensers based on a thin, layered solid/liquid interface created by special, high-surface (1000 m^2/g) carbon electrodes and electrolytes. The main characteristics of ultra-capacitors are the high power density (up to 6 kW/kg), a low specific energy (30 Wh/kg) and fast response time [39]. Moreover, high power density and low specific energy result on fast charging and discharging rates.

One of the main uses for ultra-capacitors is transport. Their high power density and fast response time characteristics make them ideal for supplying power during the acceleration of electric vehicles. These are some examples of ultra-capacitors being used in transport applications:

- *Electric bus:* the first electric bus in Spain, developed and fabricated by Irizar, started working in the summer of 2014 in San Sebastian [40]
- *Supercapacitor tram:* the Chinese city of Guangzhou is the first city in the world to have a tram powered solely by supercapacitors, without the need of overhead wires. The tram is charged as needed at stops. This process takes between 10 and 30 seconds and the trams are able to run for up to about two and a half miles between charges [41]

They could also be used in applications with high power and low energy requirement, such as grid frequency regulation.

c) Mechanical energy storage

There are two main storage mechanisms apart from pumped hydro storage: Compressed Air Energy Storage (CAES) and flywheels.

<u>CAES</u>

It consists on using off-peak electricity to compress and store air into underground caverns or mines. Pressurized air is then used in a gas turbine when it is required. Common gas turbines usually use 2/3 of the input fuel to compress air before combustion. So, using already compressed and stored air, input fuel can be reduced by a 40%. Efficiencies in the range of 42% to 55% are obtained [42].

The preferable locations are salt caverns. They have several positive characteristic for storing compressed air (e.g. high flexibility, no pressure losses within storage no reaction with the oxygen in the air). However, in the case of no suitable salt formations, natural aquifers or depleted natural gas fields could be used.

The main problem of CAES is that during compression air is heated up strongly and the energy needed for compression increases with air temperature. So, air has to be cooled during the compression process and then heated again before the combustion in the gas turbine. Efficiency could be improved storing the thermal energy obtained during the air cooling and using it during the re-heating. Efficiencies up to 70% can be achieved. This technology is called adiabatic method. It is under development, mainly driven by an international consortium headed by the company RWE. A pilot plant is scheduled to start working by 2018. There are two other companies that are also developing adiabatic solutions:

- *Airlight Energy:* they use a thermal energy storage that they had already developed for CSP. Instead of using underground salt caverns, they use mountains which enable easy access in order to construct inside the air storage reservoir. Furthermore, equipment such as the turbo machinery is also placed inside the mountain, reducing dramatically the visibility and environmental footprint of the plant. This solution obtains round-trip efficiencies of >72%

- *LightSail Energy:* they are developing a flexible and modular energy storage solution. Air is stored in tanks and each of the modules has a 250 kW output power and 750 kWh storage capacity. Roundtrip efficiencies are around 90%

The potential use of compressed air is similar to the one of pumped hydro storage due to the similar characteristics of output power and energy storage capacity; applications that require high power and large amounts of energy, such as, renewable integration.

Liquid Air Energy Storage (LAES) works similar to CAES, but in this case, instead of compressing the air, it is refrigerated to temperatures around -200ºC and turns liquid. In the liquid state, air can be stored in standard insulated, but unpressurised vessels at very large scale. Highview Power offers a LAES storage solution. They are developing systems of 50 MW output power and 200 MWh of energy, having efficiencies around 70%.

Flywheel

It works by accelerating a rotor. The rotor spins in a nearly frictionless enclosure and operates in vacuum in order to reduce drag and maintain efficiency. Low-speed flywheels rotate at rates up to 10,000 RPM and more advanced ones can reach a rotational frequency of 100,000 RPM [43].

The main characteristics of flywheels are the high power density and fast response time (see Table 4.6). Moreover, they have good round-trip efficiencies, but usually have low energy density. As a consequence, flywheels are increasingly important to high power and low energy applications. They are especially appropriate for applications of power quality and reliability, being the responsible for frequency regulation. When there is a relatively big change in energy demand or supply in a short period of time (a power plant is switched on/off), the frequency of the grid is slightly changed from 50 Hz. Flywheels are a good option to absorb the excess power or supply the lack of power in this short periods, maintaining grid frequency close to 50 Hz. This is especially important in small electric systems (e.g. Canarias islands), where a power plant produces a higher proportion of the total power than in a bigger system (e.g. Iberian peninsula).

Electric vehicles could be another application of flywheels. During acceleration, these vehicles need high powers during short periods of time. A fast response time is also essential. However, space is usually reduced in vehicles, becoming the main limitation for flywheels. Ultra-capacitors seem to be winning in this application.

The biggest company offering flywheels is Beacon Power. They produce carbon fiber flywheels of powers going from 100 kW to multi-MW.

d) Thermal energy storage

It allows storing energy in the form of heat or cold. Molten salts are the main current commercial technology. These salts have the property to absorb and store heat energy with very few losses. The use of this storage technology has almost exclusively been by CSP power plants, as these power plants first produce heat to then generate electricity. So, they can directly store the thermal energy before its transformation to electricity. The largest efforts on developing thermal storage come then from CSP developers and operators. For instance, this is one of the four main focuses of Abengoa Solar R&D efforts.

There is a thermal storage technology that allows converting electricity to thermal energy and stored it, Pumped Heat Electrical Storage (PHES). Electricity is used to drive a storage engine connected to two large thermal stores. In the energy storing step, electrical energy drives a heat pump, which moves heat from the cold store to the hot store. To generate electricity back, the heat pump is reversed and becomes a heat engine. It takes heat from the hot store, delivers waste to the cold store and produces mechanical work [44]. One company offering this solution is Isentropic, which has a PHES solution with round-trip efficiencies around 70-75% and a lifetime over 25 years [45]. Tthey calculate to have a levelized cost of storage of $50/MWh [46].

To sum up, Table 4.6 resumes the main characteristics of the different storage technologies:

		Rated power (MW)	Discharge rates	Response time	Roundtrip efficiency (%)	Lifetime (years)	Energy density (Wh/kg)	Power density (W/kg)	Power cost (€/kW)	Energy cost (€/kWh)
Pumped hydro		100-5000	1-24h+	s-min	75-85	50-100	0.5-1.5	-	500-3600	60-150
Hydrogen		0.001-50	s-24h+	min	20-50	20-50	800-10^4	500+	550-1600	1-15
CAES		100-300	1-24h+	5-15min	42-54	25-40	30-60	-	400-1150	10-120
Flywheel		0.002-20	15s-15min	s	85-95	20+	5-130	400-1600	100-300	1000-3500
Batteries	**Conventional (NiCd)**	0.001-40	s-h	-	60-91	15-20	40-60	150-300	350-1000	200-1000
	Lithium-ion	0.001-0.1	min-h	-	85-100	5-15	75-250	150-315	700-3000	200-1800
	Zinc Hybrid	0.05-2	s-10h	ms	70-75	5-10	60-80	50-150	500-1800	100-700
Ultra-capacitors		0.01-1	ms-1h	ms	85-98	20+	0.1-30	1000+	100-400	300-4000

Table 4.6: Overview of main characteristics by storage technology *[based on "The future role and challenges of Energy Storage ", European Commission]*

4.3.3 Efficiency

Efficiency technologies can be classified into three groups depending on its functionality: performance efficiency, monitoring and management and building materials.

- *Performance efficiency:* It comprises all the technologies, which having similar characteristics and performance, need less power to work
- *Monitoring and management:* technologies that help tracking the consumption in a house and consequently, allow changing habits to reduce consumption
- *Building materials:* those technologies that allow constructing more efficient buildings, reducing the energy requirements

Company	Technology description	Functionality
Bridgelux	• Advance LEDs of GaN-on-Si offering high light-extraction efficiency, low thermal resistance and excellent reliability	Performance efficiency
Cooltech	• A magnetic refrigeration system that reduces energy consumption up to 50%	
Novaled	• High-performance Organic LED (OLED)	
Nualight	• Tailored LED lighting products and control solutions for grocery and specialty retailers, high-rise offices, high-end industrial buildings and transport	
Phoebus energy	• A hybrid water heating solution that selects the way of heating/cooling more efficient in each moment: traditional heating (boilers) or heating pumps	
Phononic	• A compact heat pump of lower size than traditional compressors • It uses no toxic chemicals and is highly energy efficient	
SorTech	• Adsorption chiller aggregates (a refrigerator) that uses excess waste heat for intelligent cooling of processes and buildings	
Digital Lumens	• Intelligent lighting to all types of commercial, retail and industrial environments for maximum efficiency, visibility and control	Monitoring and management
Enlighted	• Smart technology that sees and responds automatically to environmental factors such as ambient light, room temperature occupancy and occupant motion, and tasks • Significantly reduces light energy consumption without compromising lighting quality	
First Fuel	• A solution designed for utilities and governments in order to offer efficiency measures to their consumers • It consists on a platform that uses data analytics to implement efficiency measures	
Nest	• An intelligent thermostat that learns your schedule, programs itself and can be controlled from the phone	
Opower	• For utilities to help costumers understand their energy use and better manage it • Utility-integrated intelligent thermostat	
Tendril	• Help utilities offering an energy efficiency solution to their costumer and increase their engagement • Manage peak demand, reduce costs by control devices that help delivering relevant information	
Wattio	• Series of devices for data collection, which you can manage from a home automation touch screen or simply console accessing the implementation of Wattio from a computer with internet connection, or your mobile device	

Next step living	• Air sealing, insulation and energy-efficient window solutions to reduce the energy spend in cooling and heating	Building materials
Project frog	• A company that builds energy-efficient buildings that are 40-50% more efficient that traditional ones • Oriented mainly for education and healthcare. They also offer solutions for individuals	
Sefaira	• A software platform for performance-based building design	
SageGlass	• A glass that reduces energy consumption by letting sunlight in on cool days and blocking it in hot days	

Table 4.7: Sample of relevant energy efficiency start-ups

Regulation plays an important role in this industry. As technology develops, governments introduce the new efficiency solutions into regulation. For instance, the RD 235/2013 introduced in Spain the minimum requirements of energy efficiency for buildings, or the electro-domestics´ energy certification introduced by the European Union. So, there is no doubt that efficiency technologies will be adopted progressively at a relative high speed.

In the case of performance efficiency technologies, the absorption pace will be mostly determined by the average life of lighting and electro-domestics. Although there are currently more efficient technologies being commercialized, the change will mainly happen when the need of buying new one comes. A similar thing happens with building materials, the change will mostly come from new buildings, which are forced by law fulfilling some efficiency requirements. These obligations of efficiency are less strict to already existing buildings. So, even if they will also gradually adopt these technologies, pace will be slower. Finally, monitoring and management technologies are likely to have a slower adoption as they usually imply habits changes in people.

Efficiency has mainly two effects in the power sector. First, it seems obvious that energy consumption is reduced. Although this being true, efficiency can change people´s habits leading to greater energy consumption. For instance, as heating or lighting are more efficient than previous technologies, people may use them for longer time without worrying of an expensive bill. In the meantime, a management application, as the one offered by Wattio, that lets you control lighting and electro-domestic from the mobile phone creates new possibilities that may increase consumption. For example, someone could switch on the heating remotely from the office to have a warm arrival to home or switch on lights and the music player while he is on holidays to simulate life and chased robbers away. So, the energy consumption reduction may not be proportional to the efficiency improvement.

The other effect is load shift. Home monitoring and management devices make easier to adapt some consumption habits to periods were electricity is cheaper. For example, in the case of electricity price being the half at night that during the day, someone could program an application (e.g. Wattio) to switch on the dish washer or the washing machine at night. Or in the case of having a self-consumption PV module, electro-domestics could be activated during the mid-day, maximizing the consumption of the energy generated.

4.3.4 Infrastructure

Innovations in infrastructure can be classified into two groups: grid management and transmission and distribution grids.

- *Grid management:* technologies oriented to operate more complex grids
- *Transmission and distribution grid:* solutions that increase efficiency of the grids, mainly by reducing losses

Company	Technology description	Functionality
Autogrid	• A predictive model of the grid to shift loads at peak periods using Big Data	Grid management
Gridco Systems	• Active grid infrastructure that enables utilities to more cost-effectively and reliably integrate distributed renewable generation, improve Conservation Voltage reduction and Volt-VA Optimization for greater energy efficiency and peak demand reduction…	
Intel	• Integrated, scalable hardware and software solutions that integrate into existing energy infrastructure to bridge traditional IT and operations, turning data into knowledge and integrating intelligence across the grid to help solve the industry´s greatest challenge	
On-Ramp Wireless	• A network that has the range, capacity and security necessary to address the growing demand for smart grid	
Trilliant	• Smart distribution: a broadband mesh network built specially for utilities that provides the reliability, bandwidth and low-latency needed. It connects substations and distribution grid devices to the utility´s head-end	
Amantys	• A technology that reduces switching losses of power electronics	T&D grids
Siemens	• Efficient power transmission: Flexible AC Transmission Systems (FACTS), High Voltage DC systems (HVDC) and Gas-Insulated Transmission Lines	
Transphorm	• A technology that reduces transformation losses by using Gallium Nitride (GaN) material	

Table 4.8: Sample of relevant infrastructure developers

Besides the companies in Table 4.8, there are other organisms that are also developing and researching in this field. Utilities are some of those as it is crucial to improve on their businesses. For example, over 25 projects related to grids and grid management were developed by Iberdrola during 2011-2013 [47]. CIGRE is another example. It is *"an international non-profit Association for promoting collaboration with experts all around the world by sharing knowledge and joining forces to improve electric power systems of today and tomorrow"* [48]. They organize different events and meetings where they gather several experts in the matter. The last event in Spain was held in Madrid on the 25th and 26th of November 2014. The main subjects of the meeting were active management (i.e. new equipment, O&M and supply reliability) and future networks (i.e. sustainability, smart grids and storage&electric vehicle).

These technologies will be adopted rapidly for two reasons. First, regulation, as in the case of efficiency technologies, adapts as technology develops and goes making obligatory new solutions. In Spain, by the end of 2016 all the meters in each access point have to be smart meters. And second, the complexity brought by renewables to grids operation makes them necessary in the future. The evolution of the grid is a necessary requirement in order to be able to deal with the changes happening currently in the electric sector. Grid management has been the field in which system operators have focused their efforts on.

The main disadvantage of HVDC grid is the high cost of the AC/DC and DC/AC converting substations. Nowadays, the savings obtained by the reduction of losses only compensate the expensive costs in long distances. As substations develop, they get more economical and the distance gets shorter. It is likely that in the future HVDC grids will tend to substitute current HVAC grids.

Chapter 5

Changing electric sector

In the previous chapter the status of energy innovation has been presented. This chapter will consist on analyzing how this innovation can change the electric sector. First, the discussion will focus on which drivers can lead to a substantial change or prevent it from happening, disruptive factors and barriers respectively. Finally, taking into account both, the innovative technologies explained in the previous chapter and disruptive factors, three possible scenarios of the 2020 and 2030 generation mix will be presented.

5.1 Disruptive factors

Disruptive factors have been classified into two groups depending on the probability to occur they have: on-going drivers and wildcards. On-going drivers are those factors that are very likely to happen. They usually have an evolution over time and are currently going on. Their effect can be somehow predicted and measures can be taken to adapt to the change. Wildcards however, are those elements that are unlikely or less probable to happen. Moreover, they could happen in a short period of time, in a long period or never happen; and are usually unpredictable, so it is difficult to take preventive measures.

a) On-going drivers

The first to be considered is **energy policy and governments**. While renewable technologies are not competitive by themselves, this is the driver that has the greater relevance and impact. In a study developed by the World Energy Council in collaboration with A.T. Kearney [49], the main driver of the change in all the analyzed countries was green energy policy. As a consequence, the coming electric sector will be greatly shaped by the governments measures and policies. In the last decades, since the Kyoto Protocol and the European 20-20-20 targets, countries have gone towards the environmental sustainability in the trilemma. However, it seems that some countries are trying to get back to energy equity (see the Spanish case in chapter 3 or the British case in chapter 7). There are two ways in which governments can affect disruptively the electric sector:

- *Direct support (i.e. subsidies):* it is a driver with large relevance. Greater subsidies can increase the learning and deployment pace of a technology. However, when talking about the effect of government subsidies on renewables, it is important to take into account that it is just a measure to give the initial impulse to a non-established technology, carry out projects that without support would not be competitive and reduce costs in the meantime. These subsidies will not last forever and there are some countries that start reducing them due to an affordability issue (e.g. Spain, UK and Germany). So, it has to be complemented by technology evolution and LCOE reduction. Wind and PV technologies have been traditionally the more subsidized technologies. By the end of 2013, there were already 117.3 GW [50] of wind capacity installed in Europe and 81.5 GW [51] of solar PV
- *Indirect support (i.e. regulatory framework)*: another way, apart from subsidies, of supporting renewable energy is regulation. It especially affects in the case of distributed generation. The tendency during the last years in more mature electric sectors has been to move towards more liberalized frameworks. For example, a complete liberalization of the commercialization activity would bring competitiveness and would leave place to new entrants, presumably increasing the switching rates and reducing prices in the long term. However, it is difficult that this liberalization happens in the short term in Spain. The current government made the law 24/2013 setting the PVPC. So, it is difficult that they derogate it and make a new one. The main possibilities of changing mainly depend on the entrance of a new government

  In the case of distributed generation, *net metering* would maximize the profitability of self-consumption, while additional taxes to DG would stop its expansion. The Spanish situation is currently closer to the last case after the draft RD of July 2013 that introduced the possibility of the back-up toll

As technology and energy industry evolve, energy policies lose their relevance as disruptive drivers. There are two relevant technology-related drivers that can be disruptive. The first one is the **LCOE reduction of renewable generation technologies**. There are several technologies that are becoming competitive rapidly and will make their space in the coming electric sector. The main current barrier for renewable deployment is that they are expensive in comparison with conventional technologies, but they are developing and quickly reducing LCOEs (see Chapter 4). Moreover, apart from being green ways of generation, renewables have a characteristic that is likely to give them advantage over other technologies: the energy market´s Merit of Order mechanism. In Spain, as long as market rules are not changed, renewables production will have preference over conventional power plants. So, renewables load factor will be exclusively limited by the resource availability, while conventional production will depend on renewable production.

Onshore wind, depending on site´s wind conditions, is already competitive with conventional power plants (see Figure 4.10) and has been the main generation source after nuclear energy in Spain for the last two years. Offshore wind is expected to reduce costs and have a wide deployment (i.e. global offshore wind capacity of 39.9 GW in 2020 [52]). However, the technology that is likely to be the most disruptive among all is solar PV. The expectations are that PV panels costs will decrease following the learning curve shown in Figure 4.6. But, the Sun Edison´s new manufacturing technique would mean a disruptive reduction on PV costs. Additionally, due to its characteristics scalability and easy distributed deployment, solar photovoltaic technology will contribute greatly on distributed generation expansion.

A new concept has been created with the expansion of distributed generation for **self-consumption, *Prosumer*.** It refers to the consumer that at the same time is a producer. It will become increasingly important as PV technology develops. Traditionally, investment decisions have been taken on a "*what is the best for the electric system?"* basis. Distributed generation, however, gives place to *"what is the best for me?"*, which often does not match with the best for the system. This is translated in that competitiveness is not measured against conventional generation technologies, but against electricity price. As electricity prices are constantly increasing and the LCOE of PV is decreasing, there will be a moment in which it will be more economical to produce your own energy than taking it from the grid (see Figure 5.1).

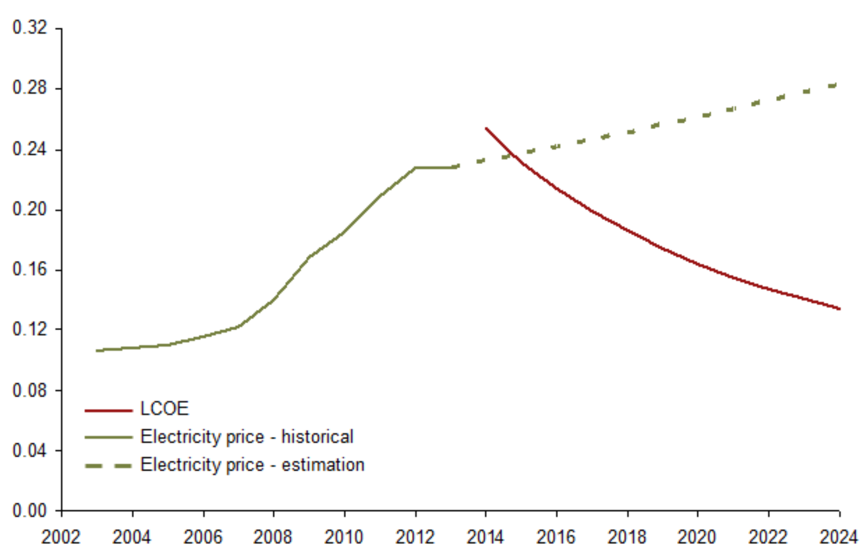


Figure 5.1: Electricity price and PV LCOE comparison *[Eurostat and LCOE model]*

The intersection between the LCOE and the electricity price will not happen at the same time all over the world, it will highly depend on the location. PV competitiveness varies with the location for two reasons: electricity price and the amount of solar irradiance. So, grid parity will happen first in regions with high solar irradiance (lower LCOE) and more expensive electricity.

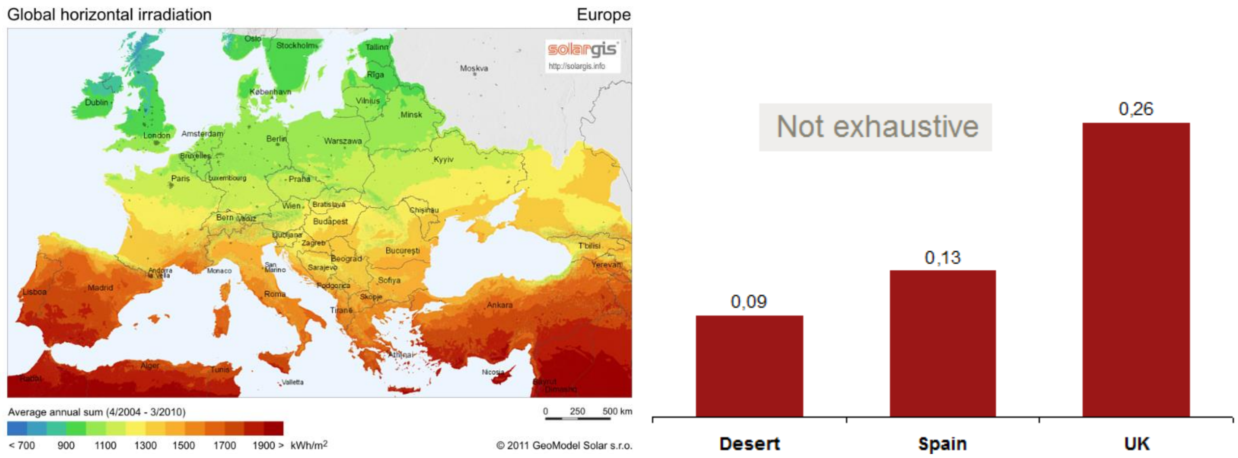


Figure 5.2: Solar irradiation (left) *[Solar GIS]* and example of LCOE for different regions (right)

Price of electricity depends mainly (if it is not subsidized as in the case of Canarias islands) on the accessibility to the grid. This means that places that are not connected to the grid have more expensive electricity. The reason is quite obvious, they have to be energy autonomous, having their own ways of generating energy without benefiting of the scale economies that they may have if they were connected to the grid. These locations are mainly islands and places far from urban areas as deserts or rainforests.

So, it is logical to conclude that distributed generation with PV will start first in islands, and will continue in places with high solar irradiance and it will progressively reach lower irradiance locations.

As clean energy is reducing the LCOE and becoming a reality, **conventional generation** plants are **losing competitiveness**. There are two factors that contribute to it: fossil fuels price increase and CO_2 penalties. Historical data of prices shows that the tendency is to increase (see Figure 5.3). During the second semester of 2014, however, the Brent barrel´s price has decreased more than a 50% due to a supply and demand imbalance. So, there is considerable uncertainty in which direction oil price will go.

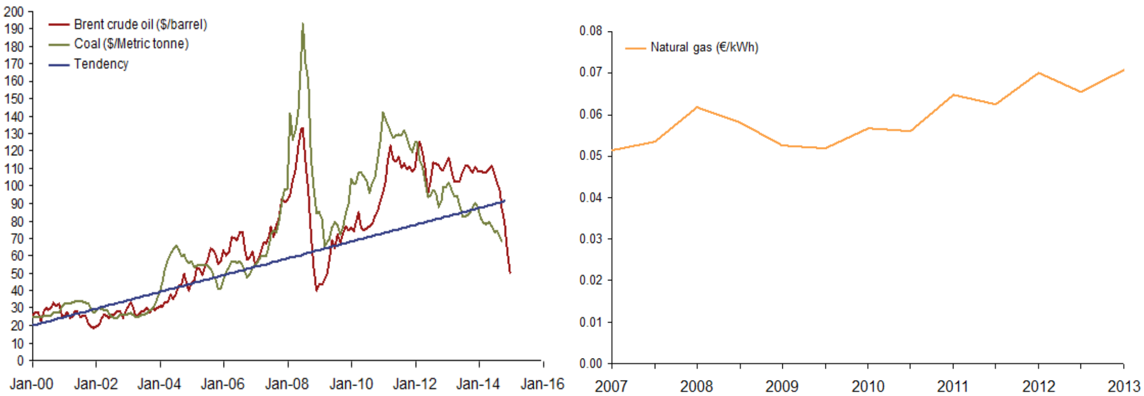


Figure 5.3: Fossil fuels price evolution *[EIA and Eurostat]*

Moreover, as seen in the previous chapter, CCS technology is still too costly and reduces power plant´s output. But, in the meantime, this is the only way of keeping using fossil fuel technologies while reducing CO_2 emissions.

As seen in Figure 5.4, onshore wind is already competitive with fossil fuel technologies, PV will become competitive with CCGT and hard coal by 2020 and offshore wind by 2030. As a consequence, it seems likely that they would gain share in the generation mix. However, it is important to remark that unless storage technologies deploy widely at utility scale, there will always be the need of conventional generation plants to fill the gaps of power created by the renewables intermittency and nuclear energy´s rigidity.

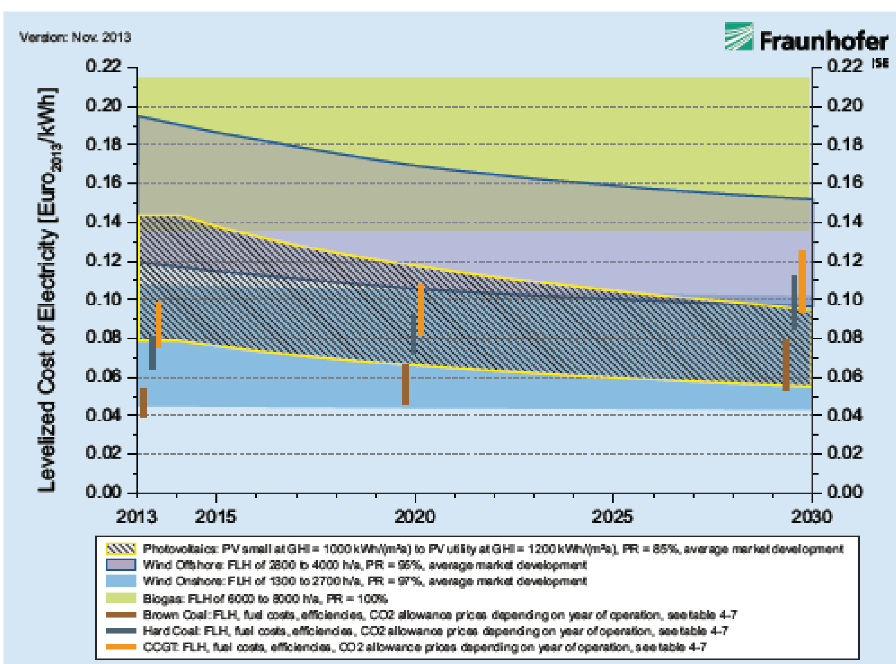


Figure 5.4: LCOE comparison for different generation technologies *["Levelized cost of electricity renewable energy technologies", Fraunhofer ISE – Nov. 2013]*

Energy storage is the other technology development that will make the difference. Renewable generation has always needed from other conventional technologies as back-up capacity due to its intermittency. Storage systems are the method so that renewable technologies become autonomous. Thus, an economic storage system will disruptively affect the electric sector and it has become the R&D focus for many. These R&D efforts have resulted in many new technologies and development, improvement and increasing competitiveness of the existing ones. Tesla´s gigafactory (see chapter 4), for example, is likely to contribute to batteries cost reductions by a 30% and become an important milestone in storage spread.

Energy storage can affect disruptively the electric sector in two main applications. First, renewable integration at utility scale. It would reduce the dependency of fossil fuel as back-up capacity and, theoretically, it would allow covering all the demand with renewable energy if the energy storage capacity was large enough. Moreover, it would permit the energy generation not to be exactly equal to the demand, this is, supply shift. Going to the extreme case, it would be possible to have a system with just base load units, where energy is stored during periods of low demand and released at peak moments. Energy storage used for this finality needs having high power and energy capacities. So, pumped hydro storage, CAES, hydrogen or batteries could be appropriate. According to Scott Van Pelt, director of engineering at Urban Green Energy, *“utilities are the biggest market right now because of their ability to install large amounts of storage in just a few projects”.*

The second application is self-consumption and distributed generation. It would allow prosumers to consume at night energy generated during the day. As these systems are usually small and located in houses, the properties required are mainly modularity, simplicity of usage and low noise generation. Batteries are the most appropriated storage technology in this case.

Overall, disruption will come mainly leaded by **batteries**. A benchmark developed by the U.S. Department of Energy has pointed the following targets for the battery industry: levelized cost of storage under 20 ct$/kWh/cycle for the near-term (2014-2018) and under 10 ct$/kWh/cycle for the long-term (2019-2023) [53]. It means that batteries would be already profitable for DG in Spain by the near-term (as current power price is over 20 ct€/kWh) and profitable at utility scale in the long-term. There is already a company claiming to offer batteries with a LCOE lower than $0.12/kWh (i.e. EOS Energy Storage).

Finally, there are other drivers that, although their impact may be smaller, will also be important in the reshaping of the coming electric sector. **Electric vehicles´ competitiveness** is one of these. Although their deployment is relatively low nowadays (e.g. 50,000 rechargeable vehicles sold in Europe in 2013, 0.4% of total amount [54]), the number of EV sold has doubled each year since 2010 and there is people claiming that in 2030 the 100% of vehicles will be electric [55]. The EV deployment pace will depend mainly in two aspects: EV cost reduction and expansion of electric recharge stations. While the first of these aspects will be mainly given by energy storage evolution, the second one will depend on political and economic interests. Electric vehicles are likely to accentuate the already on-going tendency of electrification.

Smart grids development and optimization is another on-going driver. In this case, they are not a disruptive factor, but a necessary factor for the system´s disruption. The electric sector is changing from a monologue (i.e. the demand speaks and the supply listens and adapts the generation) to a dialogue (i.e. there is communication from both sides optimizing the system). Moreover, the entrance of renewable and distributed generation makes the system more complex and difficult to manage. Smart grids are the technology that is going to allow this concept evolution and make the management of the new complexity of grids possible. The greatest R&D efforts of utilities and grid operators are made in this field of *smart things* (e.g. grids, meters, cities).

The development of smart grids and the expansion of EVs will create a new way of energy storage: **electric vehicles as a storage method**. Due to the mentioned dialogue between demand and supply, the grid operator will be able to know which vehicles are charged and connected to the grid in order to use their batteries as a source of energy. This is a cheap way of increasing the storage capacity.

Finally, **energy efficiency** is having a fast **development** and, combined with the increasing environmental consciousness, the trend is that their adoption will grow at very fast rates in the future. One of the European targets for 2020 year is to improve efficiency by a 20% and the World Energy Outlook 2013 predicts that energy intensity in residential buildings will decrease a 25% and global energy efficiency will improve in >30% by 2035.

b) Wildcards

These are some of the least probable drivers for disruption:

- ***Unconventional oil/gas boom in Europe****:* as occurred in United States during the late 2000s, it would suppose a radical change of the energy system. Europe would decrease their oil and gas imports reducing their dependency to other countries. It could even happen that Europe became energy self-sufficient. It would likely mean a significant reduction on natural gas prices as well as on oil prices. Nevertheless, unconventional oil has several barriers in Europe. One of the most important is the restrictive regulation which makes unconventional fossil fuels production much more expensive than in the USA

- *Fusion becomes possible:* electricity would be very cheap and it would change drastically the electric sector. Generation would be done in a centralized way in a few nuclear fusion power plants of high capacity. There are two kinds of possible fusions: "hot" fusion (commonly known as nuclear fusion) and cold fusion. The **ITER project** and the **compact fusion of Lockheed Martin** are the more developed cases of hot fusion. Cold fusion is a nuclear fusion reaction that happens at room temperature and pressure. So, it would not have the difficulties that hot fusion has, dealing with temperatures of millions of degrees. However, it is thought to be impossible by the great majority of the scientific community
- ***European HVDC super-grid****:* why building a wind plant in Spain, with load factors around 25%, instead of doing it in the north of Europe, with load factors >40%? Why installing PV panels in Germany instead of doing it in the Sahara desert? The reason is that the energy would have to be then transported across long distances and there would be a lot of electrical losses. However, HVDC technology lets transmitting high quantity of power over long distances with very few energy losses, but, constructing these lines would be so expensive that a private entity would have difficulties to finance

  There is already a project going on with this idea: **Desertec project**. The idea is constructing huge plants of solar technology in North Africa and transmitting that power to Europe in a HVDC grid. The project develops slowly due to lack of funding of the required large amount of money
- ***Nuclear disaster****:* Chernobyl and, specially, Fukushima have had a great impact on society´s believing about nuclear energy. A good example of this are the two declarations of Angela Merkel before and after what happened in Fukushima: "*Seeing how many power plants are being built worldwide, it would be a pity, if Germany would close down nuclear power plants*" (06/2009) and "*The faster we can exit, the better. But it has to be an exit with good judgment*" (03/2011). So, if another nuclear disaster happened, many nuclear plants would be questioned and shut down; leaving a big gap of base load units that would have to be replaced quickly and as economically as possible

- ***Other disasters*** *(e.g. war, terrorist attack, epidemic diseases):* it is difficult to know what would happen if any of these disaster happened, but the electric sector would be likely to change somehow

5.2 Barriers to the change

The **regulatory barrier** is one of the most important barriers to take into account. Favorable regulation can launch renewable energy and contrary regulation can become the barrier that prevents renewable technologies from expansion. Regulation varies across countries and may change with new governments, so it can be a factor that freezes or slows down the expansion pace for a while, but not permanently. Moreover, as world tends to a cleaner generation system, regulation will tend not to be a barrier.

One of the clearest examples of regulation being a barrier is the Spanish case. The draft RD announced in July 2013 introduced the concept of back-up toll. Technologies with good characteristics for distributed generation that would have a rapid expansion without any support from government, as solar PV, may be slowed down if this regulation goes on.

As the fourth factor in the energy trilemma, **social acceptance** can affect governments´ decisions and make them change regulation and reduce subsidies. It affects to all types of technologies: conventional and renewables.

- *Fossil fuels:* there are people that oppose this kind of technologies because they are pollutant and are the origin of the global warming. People usually do not like having this type of power plants nearby. In the case of unconventional oil/gas, there is an important concern about pollution and the chemistry used for the drilling and production
- *Nuclear:* people oppose nuclear energy because they think nuclear plants are dangerous and a disaster can happen in anytime, as in Fukushima. Moreover, radioactive waste takes too long to become safe and contaminates the environment. Usually, people do not want to have a nuclear plant in their vicinity
- *Renewables:* a very expanded idea is that renewable energy is expensive. In the last years, there is an arising concern about economic affordability of renewable support (see Spanish case in point 3.2 or British case in point 7.2). In order to fulfil European 20-20-20 objectives, governments have been heavily supporting renewable energy generation. This has led to an increase on electricity price. So, there are people who question if this is sustainable and who ask for subsidy reductions. As a consequence, some

governments are reducing their support to renewables (e.g. Spain, UK and Germany). In addition, people have concerns about some technologies for the environmental impact they may have. Some examples are stated below:

- *Wind energy:* the construction of a wind park destroys the area where it is built and they have a visual and acoustic impact. Moreover, birds are killed by the blades of turbines
- *Hydroelectric:* when a dam is built, the valley disappears under the water, villages have to be evacuated, wild life disappears
- *Solar tower:* thousands of birds are killed by abrasion annually
- *Ocean energy:* marine life is perturbed and destroyed

There is another social barrier that may prevent disruption form happening: **mindset barrier**. New technology means change and change brings distrust and disturbance of habits. So, innovative and disruptive technologies usually have a progressive adoption that takes several years (see Figure 5.5). It took more than 20 years before TV started being adopted and almost 40 years to have penetrations close to 100%. Recently appeared technologies (e.g. PC, internet and mobile phone) have a faster adoption pace. Nevertheless, it took mobile phones more than 10 years to reach penetrations around 20-30%. This barrier has mainly effect on those technologies that affect directly the consumer (e.g. home management products, distributed generation or electric vehicles).

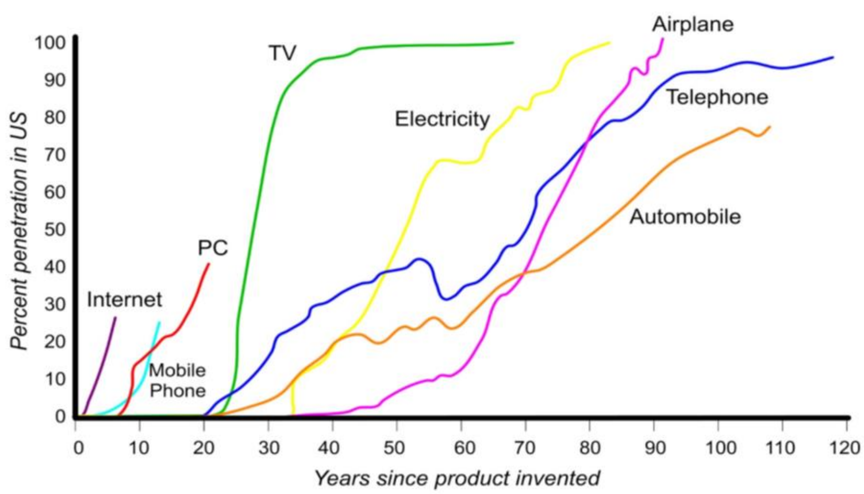


Figure 5.5: Adoption of different technologies *[33rd Square]*

The energy sector has been traditionally dominated by a few established players which are making large profits. The disruption of the system means a threat for their source of revenues. As a consequence, it is likely that these companies will become a barrier to the change by

lobbying and preventing new players from entering the market. A clear example is the case of electric vehicles. EVs suppose a threat to oil companies as they are able to reduce drastically oil consumption. So, they will make large efforts in order to try to slow down or freeze EV expansion.

The last, but not least important, is the **economic barrier**. Two dimensions can be distinguished in this point. First, as clean energy is an emerging industry, technologies are often more expensive and have higher LCOE than conventional technologies. The second dimension is the entrance barriers that the energy sector has: large capital investments are usually needed to take part in the electric sector (e.g. anyone cannot build an offshore wind farm or own a distribution grid). As a consequence, there are a few major players that have a big share of the market, giving them some power to set the direction in which the system will go. Nevertheless, technology development is enabling to overcome this barrier and there are lot of new companies entering into the market, mainly in the field of distributed generation and energy efficiency.

5.3 2020 and 2030 scenarios of the electric sector

In this point, three scenarios are developed and analyzed. They are going to be a valuable tool in chapter 6 in order to quantify the impact on utilities of each of the previously explained drivers. The development and evolution of each scenario is based on different energy policies as they are considered to be the main driver for disruption.

There is considerable uncertainty about which direction energy policies are going to take. Recent events have polarized society. From one side, a segment of the population is concerned about the greenhouse effect and human´s impact on earth. These people claim for greater renewable support, even if it implies slightly more expensive electricity. From the other side, the deep crisis in which Spain has been submerged has helped to realize the effect of renewable support on electricity prices. Some people believe that the priority should be having economic electricity and that renewable generation should not be supported by the government.

In Europe the situation is similar: there is a dilemma between environmental impact and economic affordability. Some countries have started to reduce their support to renewable energy or moving to more effective and efficient support mechanisms.

In this European and Spanish context, the following three scenarios are suggested:

- *Scenario 1 (base case)*: it is the central scenario based on the continuity of existing energy policies. It assumes a tradeoff between environmental sustainability and energy equity
- *Scenario 2 (economic affordability policies)*: regulator´s scope is focused in having a sustainable system at the possible minimum price for the consumer. Energy equity gains strength over environmental sustainability
- *Scenario 3 (green policies)*: it is the most disruptive scenario. Focus goes on environmental sustainability while energy equity plays a secondary role

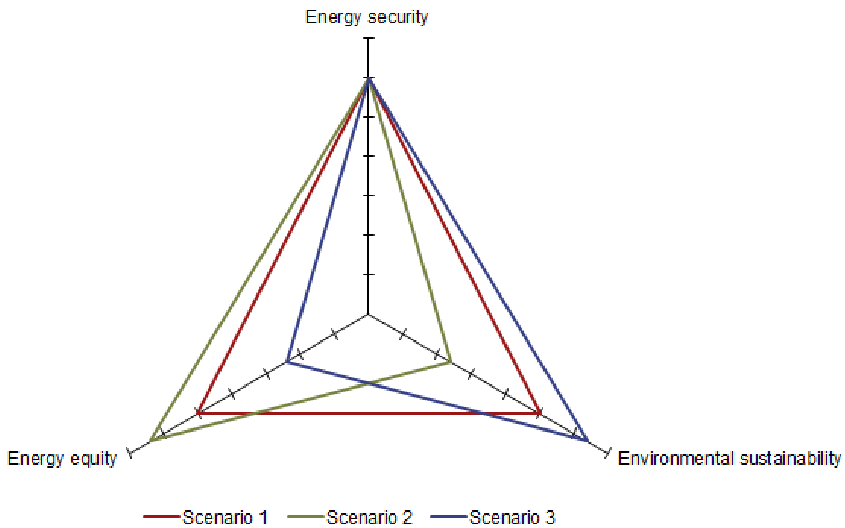


Figure 5.6: Energy trilemma balance by Scenario

The three scenarios will be based on a solid economic growth stage. After the economic crisis in which Spain has been submerged, the economy seems to be recovering in 2014 and further GDP increases are expected for the following years. Electricity demand declined considerably during the crisis (i.e. from 265 TWh in 2008 to 243.5 TWh in 2014 [56]), so it is likely to grow as the GDP does it. Historical data shows that electricity demand seems proportionally linked to GDP growth [57]. So, economic growth of 3% CAGR is assumed in all the scenarios, resulting in electricity demand increase of 30 TWh by 2020 and 70 TWh by 2030, without taking into account efficiency measures.

Finally, each of the scenarios presented here are linked with one of the regulatory cases developed in chapter 8. So, distributed generation policies and adoption figure for 2020 are taken from that chapter. Scenario 1 is linked to the *no regulation case*, scenario 2 to the *back-up toll case* and scenario 3 to the *net-metering case*.

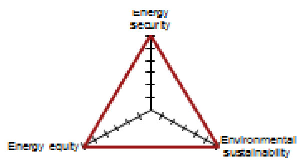
5.3.1 Scenario 1: base case

Assumptions

Energy policy	• Continuity on current energy policy • Back-up toll does not go on
Energy market mechanism	Energy/Power dichotomy by 2030
Electricity demand (CAGR)	~1%
LCOE reduction pace[1]	●
Efficiency	◐
Electrification pace	◐

1. Renewable generation and energy storage

Reduced/Slow ○ – ● Expected/Fast



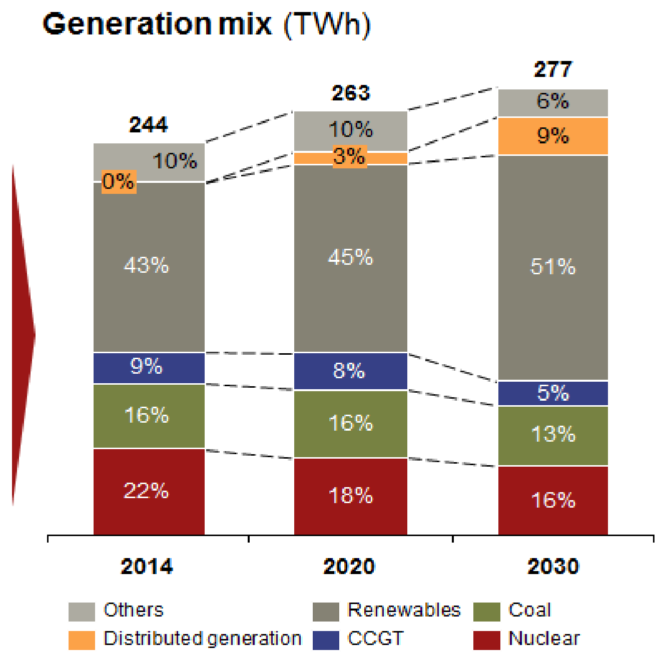


Figure 5.7: Overview of Scenario 1

Spanish energy priority goes to a middle point between environmental sustainability and energy equity in the energy trilemma. No changes are foreseen in the renewable energy support policy, this is, renewable generation profitability remains linked to country´s 10 year´s interest. The draft RD that introduced the back-up toll does not go on due to large opposition, but distributed generation is neither supported.

Electrification has moderate absorption due to a moderate expansion of electric vehicles (2% by 2020 and 20% by 2030). They start being competitive to similar characteristic combustion vehicles by the end of 2010s. However, their initial expansion is reduced due to the lack of recharge infrastructure. In the 2020s, electric recharge stations start appearing as the share of electric vehicles increases.

Efficiency continues improving, especially in residential buildings. However, this efficiency improvement does not translate in a consumption decline because of electrification and economic growth. The economic crisis of the beginning of the 2010s made electricity consumption reduce and a new cycle of economic growth will make electricity demand increase again and have a CAGR from 2014 to 2030 around 1%.

Renewable energy has a little expansion until 2020 (from 43% in 2014 to 45% in 2020) because of the reduced profitability offered by the government subsidies and the higher LCOE than conventional generation technologies (except from wind energy in certain locations with good wind characteristics). By the end of the 2010 decade, wind energy starts being competitive with conventional technologies in more locations and by the middle of the 2020 decade, solar energy becomes competitive without subsidies at utility scale. Moreover, during this decade, energy storage solutions start being profitable and make easier the renewable integration in the electric system. As a consequence, renewable energy obtains shares of 51% by 2030.

Distributed generation has a moderate expansion and reaches the generation of almost 8 TWh by 2020. Launched by affordable energy storage and solar PV LCOE reductions, distributed generation increases its market share to 9% by 2030 and generates 24 TWh annually.

Nuclear moratorium continues and there is no new nuclear power plant development. So, nuclear energy generation steadily declines over the 2020 decade and passes from generating a 22% of the electricity in 2014 to a 16% in 2030. Fossil fuel power plants initially increase slightly their generation due to the demand increase. In the long run, however, their production is conditioned by the renewable energy expansion and is used as back-up capacity.

The renewable energy expansion happening over the 2020 decade creates the need of changing the current energy market mechanism. Technologies are separated into two groups depending in their main characteristic: important for the capacity of supplying energy (e.g. most renewable technologies and nuclear energy) and important for the capacity of assuring the required power levels (e.g. coal plants, CCGT and hydroelectric energy). The first group is remunerated according to the energy generated, while the second one depending on the availability and power capacity.

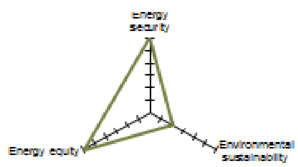
5.3.2 Scenario 2: economic affordability policies

Assumptions

Energy policy	• No renewable support • Back-up toll goes on
Energy market mechanism	Merit of Order
Electricity demand (CAGR)	~0.5%
LCOE reduction pace[1]	◐
Efficiency	◐
Electrification pace	○

1. Renewable generation and energy storage

Reduced/Slow ○ – ● Expected/Fast



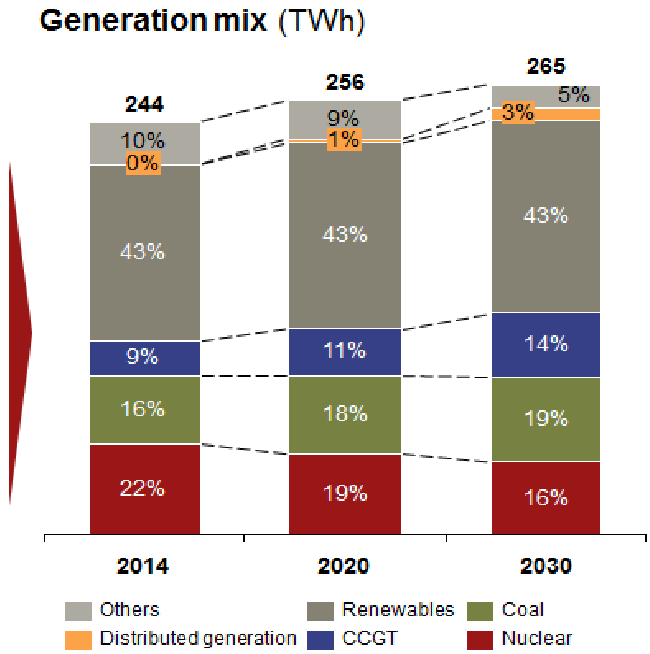


Figure 5.8: Overview of Scenario 2

In this scenario, the regulator opts for the energy equity in the energy trilemma. As special regime support (i.e. renewable generation, cogeneration and waste) accounts for more than a third of the grid access cost, it is suspended for new projects. Furthermore, the back-up toll is established to guarantee the sustainability of grids.

Electrification has a reduced absorption. Expansion of electric vehicles is slowed down (0.5% by 2020 and 5% by 2030). They start being competitive to similar characteristic combustion vehicles by 2020, but the lack of government support, reduced number of recharging stations and strong lobby from O&G companies prevent them from giving the last step towards massive expansion.

Energy efficiency continues improving, especially in residential buildings. However, this efficiency adoption does not translate in a consumption decline due to strong economic growth. Overall, electricity demand will increase again and have a CAGR from 2014 to 2030 under 0.5%

Renewable energy LCOE reduction is not as good as expected. This has its origin in fewer renewable subsidies than expected at European and world level. So, the combination of no support and low LCOE reduction results in almost null renewable expansion (i.e. 43% in 2020 and 2030). In addition, the back-up toll prevents distribution from expansion and it has almost null absorption by 2020. In the 2020 decade, DG starts becoming profitable again and reaches 8 TWh generation by 2030.

Nuclear moratorium continues and there is no new nuclear power plant development. So, nuclear energy generation steadily declines over the 2020 decade and passes from generating a 22% of the electricity in 2014 to a 16% in 2030.

Fossil fuel power plants increase their production to fulfill the gap left by the demand increase, renewables´ weak situation and the nuclear moratorium. CCGT power plants generate ~28 TWh by 2020 and ~37 TWh by 2030, while these figures are ~46 TWh and 50 TWh for coal plants.

The evolution of the generation mix allows the current energy market mechanism to continue being sustainable.

5.3.3 Scenario 3: green policies

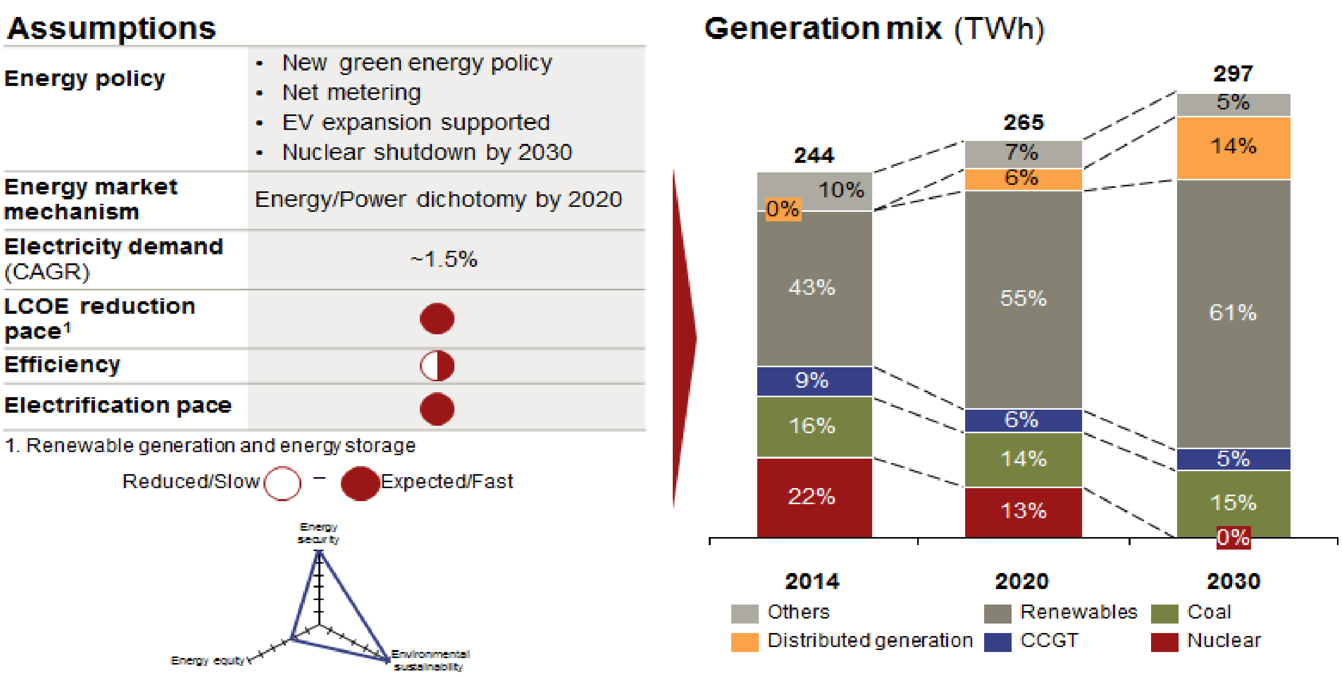


Figure 5.9: Overview of Scenario 3

Environmental sustainability wins the battle to energy equity in this scenario. Renewable energy is heavily supported again and net metering is approved for distributed generation. Leaded by social acceptance and influenced by the German case, a nuclear shutdown process starts: all nuclear power plants should have to stop generation by 2030. In addition, electric vehicles are supported in order to substitute oil consumption by electricity. Government supports EV with two different methods: installing recharging stations and offering fiscal advantages.

As a consequence, electric vehicles have a fast adoption (i.e. 20% by 2020 and 60% by 2030). Efficiency continues improving, especially in residential buildings. However, this efficiency improvement does not translate in a consumption decline because of fast electrification and economic growth. Electricity demand increases and has a CAGR from 2014 to 2030 of ~1.5%.

Renewable energy, promoted by subsidies, continues increasing its generation and reaches shares of 55% by 2020. Energy storage´s LCOE evolves as expected and it is already competitive at utility scale by the beginning of the 2020 decade. It is rapidly adopted and helps solving renewable intermittency. It allows renewable energy to partially substitute the gap left by the nuclear shutdown. Renewable generation reaches shares of 61% by 2030.

Distributed generation has a fast expansion promoted by net metering and reaches the generation of 15 TWh by 2020. Launched by affordable energy storage and solar PV LCOE reductions, distributed generation increases its market share to 14% by 2030 and generates 42 TWh annually.

The nuclear shutdown generates a base load energy gap. This gap is covered by renewable energy with storage and coal plants. So, coal plants increase their generation from ~40 TWh in 2014 to near 50 TWh in 2030. CCGT power plants are used just for back-up capacity and their production reduces to a 6% in 2020 and 5% by 2030.

The fast renewable energy expansion makes the current energy market mechanism unsustainable. The existing problem with profitability of CCGT plants worsens and creates the need of changing the current energy market mechanism. Technologies are separated into two groups depending in their main characteristic: important for their capacity of supplying energy (e.g. most renewable technologies and coal plants) and important for their capacity of assuring the required power levels (e.g. CCGT and hydroelectric energy). The first group is remunerated according to the energy generated, while the second one depending on the availability and power capacity.

Chapter 6

Potential impact on utility companies

In the previous chapter, the main disruptive factors have been shown. These drivers are originating some trends that are likely to change the Spanish electric system. As previously mentioned, the main driver for disruption lays in energy policies and it is the main difference between scenarios. Table 6.1 resumes the trends originated by the on-going drivers and their effect on the different scenarios.

Drivers	Trend	Adoption		
		Scenario 1	Scenario 2	Scenario 3
• Tendency towards liberalized framework	Complete liberalization of commercialization	◐	◐	◐
• Green energy policy • Renewable LCOE reduction • Efficiency in energy storage • Development of smart grids	Renewable energy expansion	◐	○	●
• Green energy policy • PV LCOE reduction • Efficiency in energy storage • Development of smart grids	Distributed generation expansion, Prosumers	◐	○	●
• Green energy policy • Increasing environmental consciousness • Electric vehicles competitiveness	Electrification of energy consumption	◐	○	●
• Increasing environmental consciousness • Energy efficiency development	Energy efficiency adoption	◐	◐	◐

Low ○ – ● High

Table 6.1: Overview of disruptive factors and consequences

Before discussing the impact it is necessary to better understand the sources of revenue and profitability of the different business for utilities. The financial statements of two sample utilities have been analyzed (Iberdrola Spain and Enel Group). The main revenue of the Spanish utility is generated in conventional generation and commercialization businesses, while profitability comes greatly from electricity distribution. The 82% of the revenue comes from conventional generation and commercialization, 12% distribution networks and 7% renewables generation. The business that generates the largest EBITDA is distribution (41%), followed by conventional generation and commercialization (39%) and finally renewable generation (20%). It is important to realize that although distribution has the higher EBITDA/Revenue ratio, it requires of large investments, having large amortization expenses and lower Benefit/Revenue ratio. These numbers are similar in the case of Enel (see Figure 6.1).

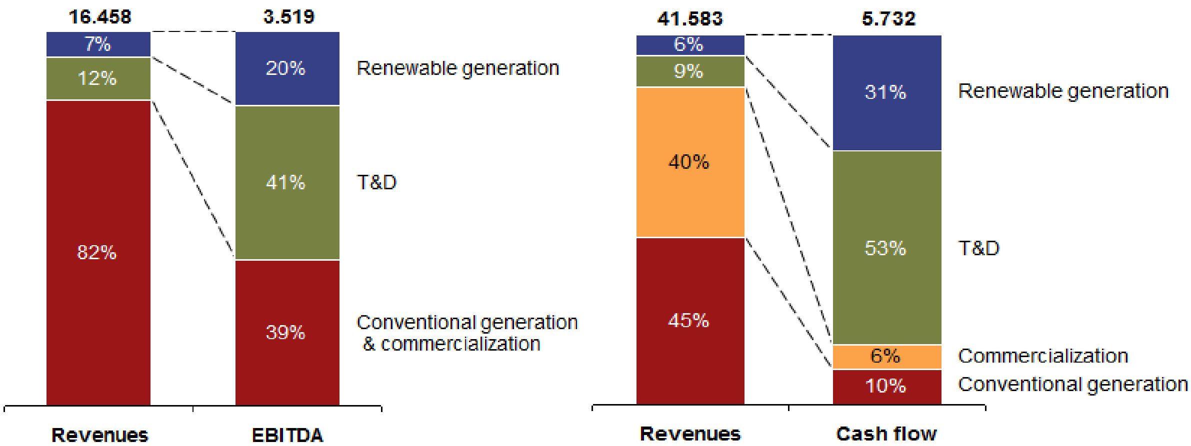


Figure 6.1: Revenues and EBITDA for Iberdrola Spain 2013 (left) and Enel Group Italy 2013 (right) *[Annual reports]*

These revenue and profits are being threatenend by the the different trends that are changing the electric sector. There are many challenges and some opportunities arising. Utilities will need to face the challenges and adapt to the new situation in order to maintain their profit level. In the meantime, they should leverage some of the opportunities. The following table shows the different challenges and opportunities on each incumbent utility business segment.

	Generation	Transmission & Distribution	Commercialization
Complete liberalization of commercialization			New entrants Higher margins Increase differentiation capacity (Value added services)
Renewable generation expansion	Reduce utilization of CCGT and Coal plants Reduce wholesale price *Merit of Order* gradually unsuitable mechanism	Complexity to manage grids	"Green" as marketing tool
Distributed generation expansion	Reduce system demand Reduce wholesale price *Merit of Order* gradually unsuitable mechanism	Complexity to manage grids Grid economic unsustainability	New entrants Reduce energy sales Enter non-traditional regions
Electrification of energy consumption	Increase need for capacity Increase wholesale price	Grid saturation Increase grid tolls	Marketing tool Enter non-traditional regions
Energy efficiency adoption	Reduce generation (TWh) Reduce wholesale price	Grid economic unsustainability	Reduce energy sales New entrants Increase differentiation capacity (Value added services)

Low impact – High impact Opportunities– Challenges

Table 6.2: Potential impact on incumbent utility business

a) Generation

- **Wholesale price** could reduce up to a **10%** by 2020 in Scenario 3

There are two factors that could reduce the wholesale price. The first one is a decrease on the demand. From one side, distributed generation and efficiency measures directly reduce the amount of electricity needed, and storage systems contribute to a deeper reduction of the demand as they are likely to reduce DG systems dependency to the grid. From the other side, electrification will bring an increase on electricity needs. Overall, the majority of predictions point that Spanish electricity demand is likely to increase (i.e. from 248 TWh in 2013 to 258 TWh in 2017 [58]).

The second factor is the irruption of low opportunity cost technologies such as renewable energy. As the markets follow a Merit of Order mechanism, low opportunity cost plants displace more expensive ones and the demand is fulfilled with more economic technologies. Its impact on the wholesale price is easily noticeable when there are abundant precipitations or strong winds (e.g. wholesale price was under 20 €/MWh for several days in March/April 2013 due to good renewable resources). However, it is difficult to measure the impact of renewable energy in the long run. Some theoretical studies state that each 10% increase of the amount supplied by renewables yields a decrease in the average wholesale price of 6.5 MWh/€ [59]. Moreover, Spanish average wholesale price in the free market has decreased an 8% from 2011 to 2014 while the demand increased a 6% and renewable generation grew in 6 p.p.

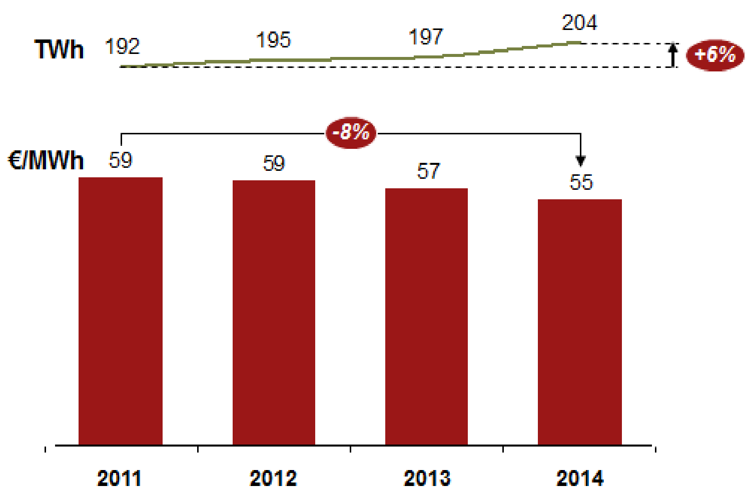


Figure 6.2: Free market wholesale price and demand evolution *[OMIE]*

In Scenario 1 and Scenario 2, wholesale price would slightly increase (~1-2%) by 2020 leaded by a demand growth and a moderate renewable expansion. This trend would keep until 2030, when prices would have increased 1% and 5% respectively. In Scenario 3, however, renewable generation share passes from 43% in 2014 to 55% in 2020 and 61% in 2030. It would mean a price decrease of ~10% (~50 €/MWh) in 2020 and 20% (~45 €/MWh) in 2030.

	2020		2030	
	Change (%)	Price (€/MWh)	Change (%)	Price (€/MWh)
Scenario 1	1	55	1	55
Scenario 2	2	56	5	57
Scenario 3	-10	50	-20	45

Table 6.3: Wholesale price predictions by scenario

- **Merit of Order gradually unsuitable** energy market mechanism

As explained in chapter 3, energy markets are ruled by a Merit of Order mechanism based in the opportunity cost. This mechanism was designed so that base load units (usually rigid and reliable technologies with low operating costs) were sold first. Thus, the majority of the demand would be covered by base load units and the resting by intermediate or peak units. Renewable energy was a minority (less than 2% excluding hydroelectric) when the Merit of Order mechanism was established in 1997. Nowadays, renewable energy is the main generation source with over the 26% of the electricity generation in 2014 and all the evidences (see Disruptive factors in chapter 5) point that RES will keep increasing generation capacity in the future. And, if the effect of distributed generation (i.e. potential to cover up to 11.4 GW of the power demand during midday, see chapter 8) is additionally taken into account, the thermal gap[1] is likely to shrink considerably, especially during midday hours.

The reduction of the thermal gap supposes a serious threat for the system´s sustainability. One consequence is that power plants that traditionally were considered intermediate units, such as combined cycles, have considerably lower load factors than predicted when they were build. This is a fact already happening in Spain. The annual average load factor of combined cycles in 2008 was over 50% and has reduced to 11.4% in the first ten months of 2014 [60]. As a result, CCGT power plants are not profitable anymore and the great majority of combined cycle operators want to close them: they are suggesting a permanent massive shutdown of combined cycles. However, the system needs these flexible technologies in order to guarantee the power supply, as renewable generation technologies are a source of energy but do not guarantee the

[1] Difference between power demand and power generated by RES, covered by conventional technologies

required power capacity in every moment. This problem will continue worsening as renewables continue increasing their share.

Under the threat of a massive CCGT plant shutdown, the government has reacted by proposing a hibernation plan [61]. It consists on the temporary shutdown of some combined cycles, but not decommissioning it. The proposed solution by combined cycle operators is a change of the remuneration method. This mechanism pays CCGT operators for the power availability instead of for the energy generated, as they are important for their power capacity and not for the amount of energy generated. However, this would probably mean an increase on the system costs, having two main alternatives for paying them: increasing electricity price to consumers or reducing revenue to other technologies.

Another grave result is the possibility of a nuclear shutdown. If renewable energy´s deployment endures and the thermal gap keeps diminishing, the point in which nuclear power plants have to be shutdown could be reached. If renewable energy had a penetration large enough, it might occur that the space left for nuclear energy was smaller than the whole nuclear capacity. As nuclear power plants are very rigid and are unable to adapt their output power to renewable generation´s pattern, the exceeding nuclear capacity would need to close.

In consequence, the current Merit of Order mechanism is becoming gradually unsuitable and unsustainable as renewable generation increases. There will be an increasing need of substituting it for an appropriate method that guarantees the sustainability of the electric system.

- **CCGT plants** may reduce their load factor to **8.16%** and their revenues in **300 million €** by 2020

As explained in the previous point, RES deployment has an impact on CCGT power plants. In Scenario 3, the electricity generated by combined cycles would decrease to the 6% of the total electricity consumption, resulting in a load factor of 8.16%[1]. It would mean a reduction of 6 TWh in their production and, assuming a wholesale price of 50 €/MWh, revenues would reduce almost in 300 million €.

- **Economic growth** originated by the end of the crisis will contribute to increase revenues in **1,500-1,650 million €** by 2020

[1] Assuming that CCGT capacity does not change from actual figures

During the development of scenarios in chapter 5, one assumption has been that Spain would have solid economic growth from 2014 to 2030 and it electricity demand increases. The assumption has been of 30 TWh by 2020. Assuming wholesale prices in Table 6.3, revenues would increase around 1,500-1,650 million € by 2020.

- **Efficiency measures** could reduce in **900-1,400 million €** the revenues from generation by 2020

Although electricity demand is likely to increase in all the scenarios, this raise is going to be slowed down by efficiency measures. An annual 1% of efficiency improvement would imply a reduction of the potential electricity demand in the range of 16-17 TWh by 2020. Assuming wholesale prices in Table 6.3, the amount of revenues that utilities would stop to earn is around 900 million €. These figures could increase up to 25 TWh and 1,400 million € if efficiency improved annually a 1.5%.

IEA´s prediction in the World Energy Outlook 2013 that residential buildings would reduce electricity consumption a 25% by 2030 would imply an annual reduction of ~18 TWh[1], or 900 million €.

- **Distributed generation** would additionally reduce revenues up to **750 million € by 2020**

Distributed generation has the potential to generate from almost 8 TWh (Scenario 2) to 15 TWh (Scenario 3) by 2020. Each kWh generated by DG means one kWh less consumed from the grid. Assuming wholesale prices in Table 6.3, this would mean a revenue reduction of 440-750 million € by 2020. These figures would increase to 1,300-1,900 million € in 2030.

- Revenues could potentially increase in **300 million €** by 2020 if **EVs** were leveraged

In a society that tends to reduce the energy used to do things, electrification is the main lever to increase electricity consumption. Electric vehicles have the greatest potential for this purpose. An EV consumes between 12 and 20 kWh/100km. Assuming 50 km/day and a consumption of 15 kWh/100km, one million electric vehicles would consume 2.7 TWh in one year. Revenues generated by EV consumption would be almost 300 million € greater in Scenario 3 than in Scenario 2 by 2020 and up to 1,450 million € by 2030 (see Table 6.4).

[1] Annual consumption for the totality of consumers <10 kW = ~70 TWh

	2020			2030		
	Adoption (%)	Consumption[1] (TWh)	Incomes[2] (mill€)	Adoption (%)	Consumption[1] (TWh)	Incomes[2] (mill€)
Scenario 1	2%	1.2	66	20%	12.1	663
Scenario 2	0.5%	0.3	17	5%	3	172
Scenario 3	10%	6.1	301	60%	36.2	1.628

1. Assuming 22 million of vehicles and 15 kWh/100km
2. Assuming wholesale prices in Table 6.3

Table 6.4: Adoption and impact of electric vehicles by scenario

- The **end** of **vertically integrated utilities**

While the majority of revenue comes from conventional generation and commercialization (82%), the larger amount of EBITDA (61%) is due to distribution and renewable generation. Moreover, the expansion of renewable technologies reduces the utilization factor of conventional generation technologies. So, electric utilities have to deal with a difficult challenge: moving towards renewable energy while keeping the profitability of conventional technologies. It is a difficult step and seems impossible to fulfill both objectives at the same time. At least, this is what E.ON has thought; they have decided to separate their activities into two different and independent companies [62]: one responsible for renewables and grids areas, and the other for conventional generation technologies. Other utilities could follow E.ON´s steps and separate the more and less profitable businesses into two different companies.

b) Transmission and distribution

- **Distributed generation** may increase a **2.5%** electricity **price per kWh** respectively

Electric system costs can be divided into two groups: energy costs and grid access costs (e.g. T&D grids investment and operation, especial regime support, annual deficit payments). This last group is independent to the energy consumed. Incomes to cover grid access costs have two different origins (see Figure 6.3). First, every person or company connected to the grid has to pay a toll for the contracted capacity, independently of the energy consumed. The second source is the variable term. From the price of each kWh consumed, a fraction goes to pay the system´s fixed costs. This income structures originates that, if the energy consumed decreases, the system´s incomes will decline while expenses do not change. Thus, any reduction of the consumed electricity supposes a threat for the electric system. In order to compensate the imbalance between incomes and costs, grid access tolls would have to be increased, either the fixed or the variable term. Let´s put numbers to this problem.

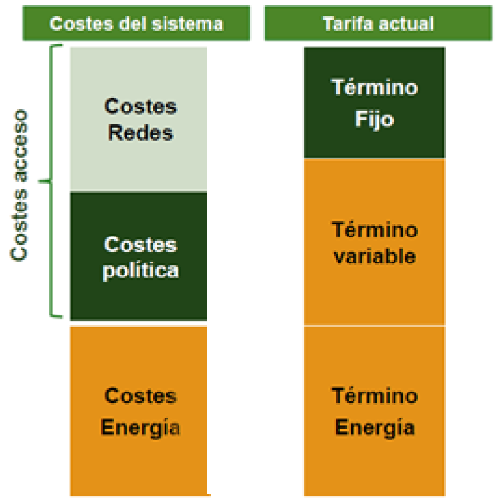


Figure 6.3: Structure of system costs and grid access tariff *["Análisis del autoconsumo en el Mercado del sector eléctrico español", Iberdrola – May 2012]*

In the case of distributed generation, the potential reduction is up to 15 TWh by 2020 in Scenario 3. The 34% of the energy is consumed by residential consumers and small companies (2.x tariffs), while big consumers (6.x tariffs) account for the 45% of the consumed energy. The 74% of the energy dependent incomes come from small consumers, while a 12% comes from big consumers (see Figure 6.4). A consumption reduction 15 TWh would suppose a revenue reduction of the energy term incomes of 288 million € over the total 4,382 million €[1]. If the measure for compensating this imbalance was increasing the energy term, this toll would have to increase a 7% its collected incomes. In the PVPC tariff, for example, it would mean a 2.5% increase on the price per kWh[2].

[1] Assuming that the consumption reduction occurs uniformly over all tariffs

[2] 65% of the incomes per kWh are directed to cover generation expenses and 35% to grid access costs

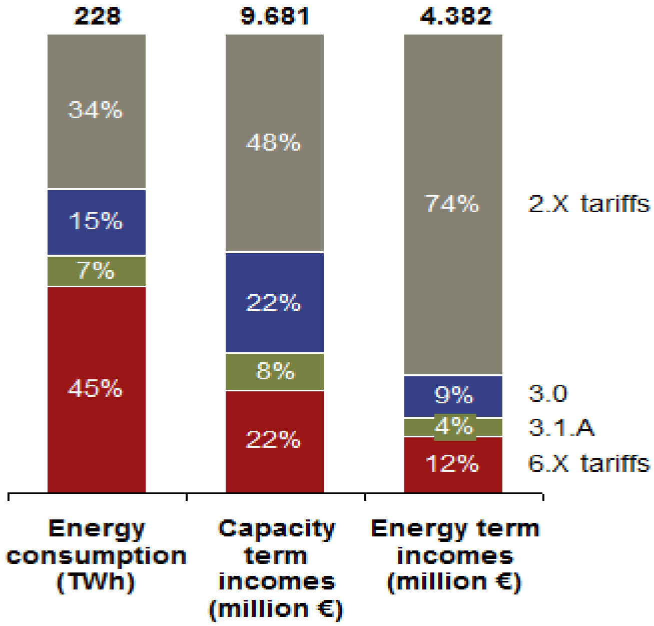


Figure 6.4: Energy consumption and grid access incomes by tariffs for distribution companies with > 100,000 consumers *["Informe sobre la liquidación provisional 7/2014 del sector eléctrico", CNMC]*

In order not to increase the electricity bill, the government brought up a possible solution in the draft RD of July 2013 (i.e. back-up toll). It is based on that, as self-consumption units keep connected to the grid and have the need of it, they should also contribute to its maintenance. It seems to be a measure to worsen the economics of DG and stop its expansion, instead of being a measure to ensure grid maintenance. However, technology development and increasing competitiveness would make self-consumption profitable again in a short/medium period of time. Moreover, this hypothetic measure would foster the DG with storage. As units not connected to the grid would not have to pay for back-up toll, the economics of self-consumption with storage would improve significantly against non-storage solutions. It would suppose even a worse scenario than the previous one.

Another possible solution could be that grid costs were assumed by the government and became another expense in the general administration budget. It seems to be a reasonable solution if it is taken into account that transmission and distribution grids are a national interest infrastructure, as they guarantee access to energy for every Spanish citizen.

In any case, the answer to this challenge is not trivial and regulators will need to find a satisfactory solution that guarantees system´s sustainability.

- **Distributed generation with storage** would reduce in **63.3 million €** grid access revenue **per each gigawatt** disconnected from the grid

Energy storage exacerbates the reduction of grid access incomes due to distributed generation. Storage allows the complete independence from the grid, not having to pay for the capacity term of the grid access toll. Just the impact of 2.0A consumers is analyzed as the effect of others tariffs is smaller (2.X tariffs proportionally pay more grid access tolls than other tariffs, see Figure 6.4). The impact of reducing 1 GW capacity for the tariff 2.0A is shown in Table 6.5.

	Average 2.0A consumer	Energetic impact	Grid access toll	Monetary impact
Capacity	4.1 kW	1 GW	38.043426 €/kW/year	38 million €
Energy	2,356 kWh/year	574 GWh/year	0.044027 €(kWh	25.3 million €
TOTAL				63.3 million €/GW

Table 6.5: Impact calculation of DG with storage

- **Extra grid capacity** needed to deal with electrification is **viable** in the required time frame

The electricity demand increase caused by electrification can potentially leave the grid unable to supply the required power. However, as electrification is likely to be leaded by electric vehicles expansion and these vehicles will probably be recharged at night (while they are not being used), in a first view, it seems that it would not be a critical challenge. Let´s put some numbers. In the green policies scenario, electricity consumption due to EV deployment would increase in 36 TWh by 2030. Assuming all EVs are charged every day during the same time frame of eight hours, it would mean an extra power demand of 12.4 GW. Additionally, if it is assumed that this time frame coincides with the peak demand period, the maximum power demand would be 51 GW (peak power demand of 38.9 GW in 2014 [63]). The peak power demand in 2007 was 45.45 GW [64]. So, grids would have to be able to supply 6 GW of power more in 2030 than in 2007, which seems reasonable and viable in a 23 years gap.

c) Commercialization

- Liberalization could allow increasing **margins up to +5 p.p**. while improving satisfaction indexes

The complete liberalization of the commercialization could bring potential benefits for both, consumers and utility companies. From one side, it would allow utilities to offer value added services in the electricity contract. They could offer efficiency and home management services or a dual tariff of gas and electricity, potentially reducing the price of the combination. Free commercialization ends generating higher satisfaction in countries with a complete liberalized market (see Figure 6.5).

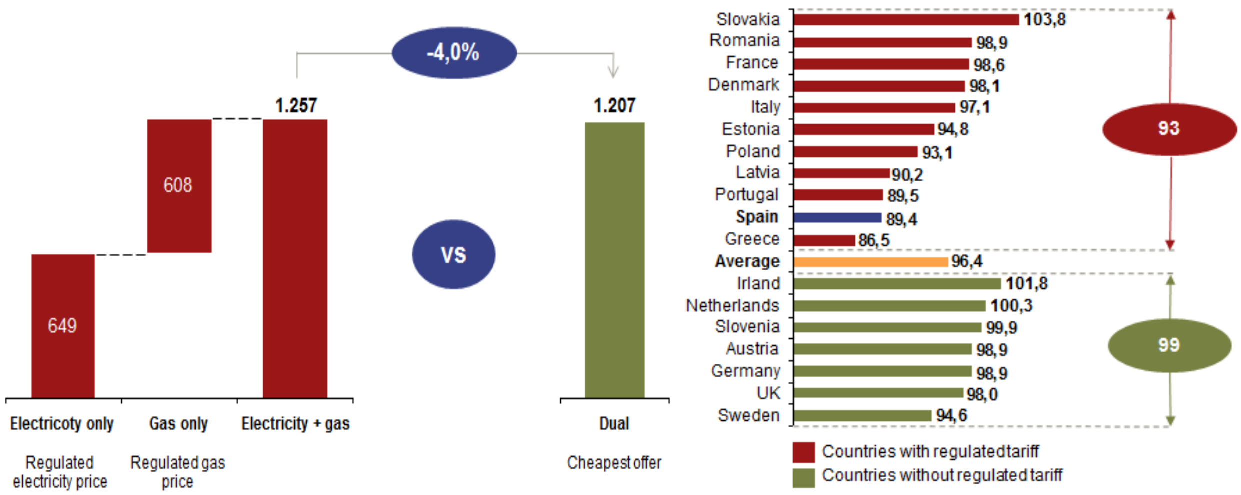


Figure 6.5[1]: Potential reduction of dual tariffs (left) *[Comparador de ofertas de energía CNMC]* and satisfaction indexes (right) *[European Commission]*

Additionally, it allows utilities to increase their commercialization margins. With the current PVPC tariff, the commercialization income is 4 €/kW/year, resulting on a 3% commercialization margin for the average PVPC consumer[2]. In Spain, the average commercialization margin for liberalized tariffs is 7% and it is an 8% in the UK (see Figure 6.6). So, the margin could potentially increase to a 7-8% (9-11 €/kW/year). These new margins would readjust the cost and income disequilibrium that generates the tariff deficit.

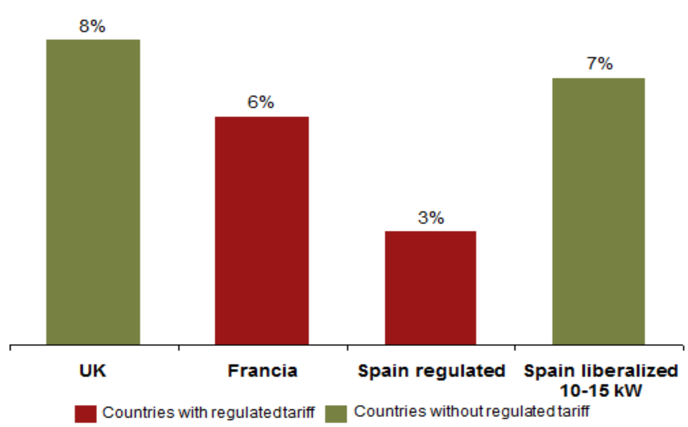


Figure 6.6: Commercialization margins for different countries *[CNMC, Ofgem, Observatoire de l´industrie Electrique]*

[1] Contracted power = 3.3 kW, electricity consumption = 3,000 kWh and gas consumption = 7,500 kWh

[2] Contracted power = 3.9 kW and electricity consumption = 2,123 kWh

- **Distributed generation** opens the door to **enter non-traditional regions**

Entering non-traditional regions is a complicated task as commercializing margins are usually low and there is no big difference between offers of different commercializers. Distributed generation creates the opportunity to enter these regions, especially those with better solar resources such as Andalucía or Extremadura. A simplified example is shown next[1].

Based on A.T. Kearney´s photovoltaic LCOE model, the LCOE for PV panels in the south of Spain would be ~10 cent€/kWh by 2020. Assuming an annual growth of 2% on the PVPC electricity price[2], the price for residential consumers would be around 14 cent€/kWh, almost 40% higher. Utilities could offer discounts of 10-15%[3] on electricity (around 12-12.5 cent€/kWh) if the consumer allowed the installation of a PV system in his rooftop.

Additionally, it gives utilities the opportunity to control the deployment pace of distributed generation. As LCOE reduces and electricity price increases, distributed generation with PV is a reality that will come sooner or later and it will allow new players to enter to the electric sector. Being the one who offers DG can make entrance more difficult for those new players.

- **Electrification** has to be **leveraged**

Apart from increasing the consumed energy, electrification can be used as a marketing tool by commercializers and make easier the entrance to non-traditional regions. So, if leveraged correctly, electrification would be greatly beneficial for utilities. The followings are some examples of how utilities could launch electrification and at the same time use it as a commercialization tool:

- An especial tariff for those consumer that own an electric vehicle and recharge it at home
- Funding a certain percentage of EV price if a term contract of electricity supply is signed for some years
- Lobbying or reaching agreements with local governments in order to install EV chargers in streets
- A cooperation agreement with an EV manufacturer

[1] Numbers are not exhaustive, just explanatory example

[2] 12.41 cent€/kWh in 2014 for 2.0A tariff

[3] Assuming half of the energy produced with PV and the rest taken from the grid

To conclude, Table 6.6 summarizes and groups the different impacts. Overall, the future does not seem easy for utilities. They are threatened to lose some of their current revenues. This impact will mainly depend on two factors. First, electricity demand. It is uncertain which will be the evolution of the demand. From one side, it seems reasonable to suppose it will grow after the great depression it has suffered during the last economic crisis. Moreover, electrification will gain power as electric vehicles become competitive. Efficiency measures, however, are a relevant threat that could cause a demand decline. For example, if the annual efficiency improvement was 1%, utilities would be likely to increase revenues in Scenario 1 and 2. But, if the improvement was of 1.5%, there would be high risk of revenue decrease. The second factor is distributed generation. It would reduce electricity demand from the grid even if overall electricity consumption might increase. It could reduce revenues in up to 750 million € by 2020 and almost in 2,000 million € by 2030 in Scenario 3.

In addition, conventional generation technologies, especially CCGT, are highly threatened by renewable generation expansion. The great majority of CCGT power plants are already unprofitable and the situation seems to get worse for them.

Finally, the electric system is in danger of unsustainability. The regulator has a complex task to carry: the current energy market mechanism has to be adapted to the new paradigm of the electric sector and the problem of the grid access income reduction has to be resolved.

			Scenario 1		Scenario 2		Scenario 3	
			2020	2030	2020	2030	2020	2030
Generation	Wholesale price	Change (%)	1	1	2	5	10	20
		Price (€/MWh)	55	55	56	57	50	45
	Potential demand decrease	Energy reduction (TWh)	25-33	73-100	18-27	55-81	32-40	94-124
		Revenue reduction (million €)	1,350-1,850	4,000-5,500	1,000-1,500	3,100.4,640	1,600-2,000	4,250-5,600
	Potential demand increase	Energy increase (TWh)	31	82	30	73	36	106
		Revenue increase (million €)	1,700	4,500	1,700	4,150	1,800	4,800
	Reduction of CCGT profitability	Load factor (%)	12.2	8.2	15.0	20.2	8.2	7.7
		Revenue reduction (million €)	75	327	367	915	297	313
Distribution	Potential demand decrease	Income reduction (million €)	96	461	38	154	288	807
		PVPC price increase (%)	0.80	4.17	0.31	1.29	2.50	8.01
	Effect of DG+storage	Income reduction (million €/GW)	63.3					
Total impact		(million €)	210-280	45-1500	165-640	890-630	75-520	275-1,600

Positive impact for utilities – Negative impact for utilities

Table 6.6: Summary of the different impacts on utilities

Chapter 7

Practical case 1: Can we afford renewable energy? Learnings from UK wind offshore

Renewable energy expansion is a trend that is going on in many mature electric systems. Green policies taken by different European countries are being reflected in power price increases and some are beginning to rethink the support mechanism in order to reduce its impact on the final consumer. This is the case of the UK, which is currently going through a transformation phase of its energy policy. It is a representative example of what could happen in other European countries. This chapter will explain this process with special focus on the offshore wind industry. It is a quite immature and new technology that is evolving rapidly and it is thought to be one of the main sources of energy in the North Europe countries by 2030. Additionally, UK is the leading country in this industry, having the larger installed capacity in the actuality and the prediction to be the country with greater capacity of offshore wind by 2020 [65].

7.1 UK´s renewable situation

7.1.1 2020 Objectives

As all European countries, the UK made the commitment to fulfill the European 20/20/20 targets in 2020. The objectives for the UK are the followings:

	2020 targets	2005 levels
Emissions reduction targets (compared to 2005 levels)	-16%	-
Renewable energy (in % of gross final energy consumption)	15%	1.4%
Energy efficiency (primary energy consumption expressed in Mtoe)	177.6	240.4

Table 7.1: European 20/20/20 targets for UK *[European Commission website]*

7.1.2 Affordability issue: renewable support called into question

Among the trilemma of competing energy needs (see Figure 3.10), environmental sustainability has dominated during the last years in UK, guided by the 2020 European targets. This has led to an increase on energy prices. Electricity prices have increased with a CAGR of 5% since 1978 and gas prices with a CAGR of 6%, as it is seen in Figure 7.1.

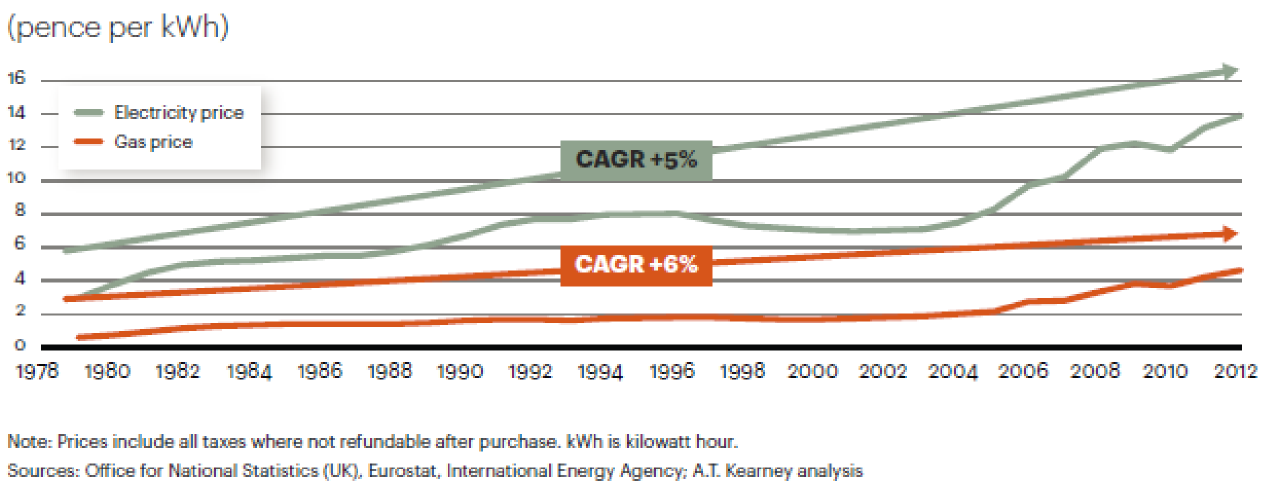


Figure 7.1: Historic evolution of domestic gas and electricity price *["Energy Affordability: The Rising Tide on UK Shores", A.T. Kearney - 2014]*

Moreover, predictions are that they will continue increasing with a CAGR of 6% and 4% respectively.

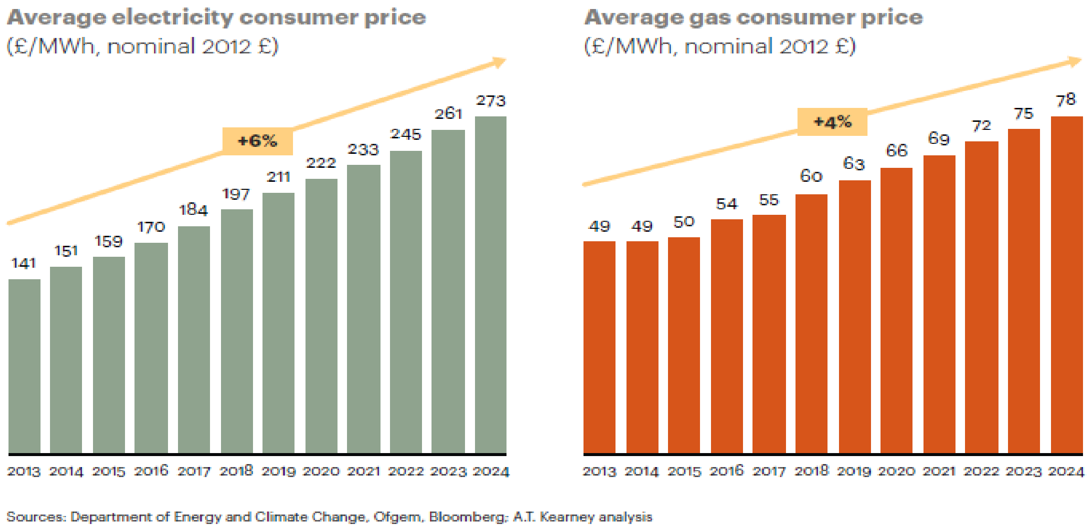


Figure 7.2: Domestic gas and electricity price projections *["Energy Affordability: The Rising Tide on UK Shores", A.T. Kearney - 2014]*

It is difficult to say which the reasons of this price increase are or which the effect of renewable support on this change has been. However, it seems that green policies have had and will have the greatest effect in price rises. Costs derived by UK green policy are expected to increase 11.4% annually and EU policy costs by 20%, rising on £210 the average dual fuel bill between 2013 and 2024.

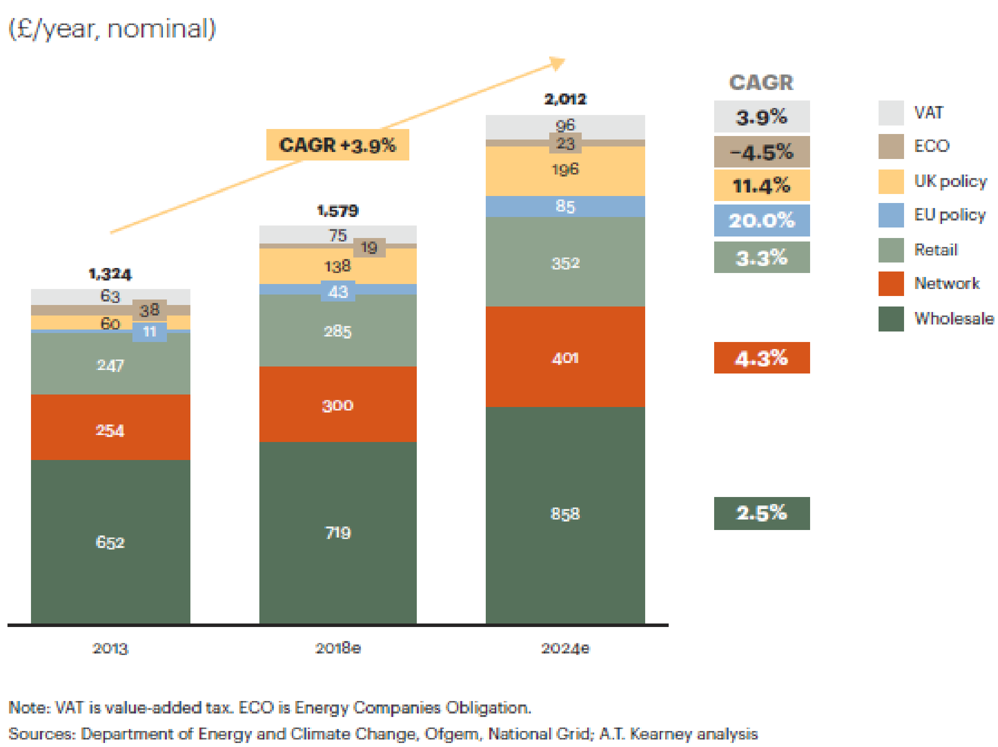


Figure 7.3: Average consumer dual fuel bill projections price *["Energy Affordability: The Rising Tide on UK Shores", A.T. Kearney - 2014]*

There are people starting to point out the affordability of renewables subsidies and it has already become a political issue: the Conservatives are moving some green costs into the general taxation system, Labour party has promised to freeze energy prices and everyone blames the energy companies for profiteering. Affordability is gaining again great relevance on UK´s trilemma.

7.1.3 Malfunctioning subsidy framework

From one side, the affordability issue has been caused by an ineffective renewable support mechanism. The Renewables Obligation (RO) is the main support mechanism for renewable technologies in the UK. It came into force in 2002. The mechanism works as follows:

- Electricity suppliers in UK have the obligation to source an increasing proportion of the electricity they supply from renewable resources. This proportion is set annually by regulators. In order to demonstrate they have met with this obligation, suppliers have to present a sufficient number of Renewable Obligation Certificates (ROCs)
- ROCs are green certificates issued to operators of renewable generating stations for the renewable electricity they generate. They can be traded by operators to other parties
- If suppliers do not present a sufficient number of ROCs to meet their obligation, they must pay an equivalent amount into a buy-out fund. The administration cost of the scheme is recovered from the fund and the rest is distributed back to supplier in proportion to the number of ROCs they produced in respect of their individual obligation

In a simpler way, each renewable operator receives a number of ROCs for each MWh it generates. This number depends on the renewable technology (see Table 7.2). Then, electricity suppliers buy these certificates to fulfill the required amount they are obligated. This means that the price, in which each ROC is sold by operators to suppliers, depends on the required amount of ROCs by supplier and the quantity of ROCs produced. So, the price is not going to be fixed, but fluctuates with the market. However, it is usually around the buy-out price fixed by the regulator (see Table 7.3).

	13/14 (ROC/MWh)	14/15 (ROC/MWh)	15/16 (ROC/MWh)	16/17 (ROC/MWh)
Anaerobic digestion	2	2	1.9	1.8
Dedicated biomass with CHP	2	2	1.9	1.8
Geothermal	2	2	1.9	1.8
Onshore wind	0.1	0.1	0.1	0.1
Offshore wind	2	2	1.9	1.8
Building mounted PV	1.7	1.6	1.5	1.4

Table 7.2: Received RO Certificates for a sample of technologies *[DECC]*

	09/10	10/11	11/12	12/13	13/14	14/15
Buy Out Price (£/MWh)	37.19	36.99	38.69	40.71	42.02	43.3

Table 7.3: Historic buy out price for RO certificates *[Ofgem]*

Focusing on the revenues received by renewable plant operators, they would result in the following:

$$Revenues\left(\frac{£}{MWh}\right) = Wholesale\,price\left(\frac{£}{MWh}\right) + ROCs\,(\#) * Buy\,Out\,price\left(\frac{£}{MWh}\right) + LEC\left(\frac{£}{MWh}\right)$$

LEC (Levy Exemption Certificates) are some certificates that non-domestic end users of energy can purchase in order not to pay a Climate Change Levy of £4.3 per MWh. It is a similar system to RO but with non-domestic end users of energy. It is a small amount compared to the rest of the revenues, thus, it will not be analyzed in greater depth.

For instance, an offshore wind operator would have earned in 2013 per MWh generated:

- *Wholesale price:* £60-70/MWh (April)
- *Number of ROCs per MWh:* 2
- *ROC price:* £42.02
- *LEC:* ~£4/MWh

} Total revenues ≈ £150-160/MWh

ROCs are given to all those who apply and meet the required specifications; and the support has a duration of 20 years. Hence, RO mechanism has mainly three advantages for operators: there is not a competitive process to obtain ROCs, it is a 20 year support and revenues are usually high.

The main drawback from the renewable operator point of view is that revenues fluctuate. On one side, the revenues depend on the wholesale market. On the other side, ROCs price can fluctuate even if they usually move around the buy-out price. This means that there is no certainty of which the exact revenues are going to be, increasing the risk of projects and, in the meantime, the interest demanded by financial institutions.

However, the real disadvantages are suffered by the end consumer of electricity. ROC costs are added by suppliers to final power prices, increasing them as seen in the previous point. Moreover, as it is not a competitive process, renewable power plant developers do not make efforts to reduce cost and improve efficiency as they would do if they were competing to each other for the subsidy. It results in low improvements in LCOE. This means that people are supporting renewables in order to pollute less and have an affordable renewable energy in the future, and the result is that their bills continue increasing but renewable generation does not reduce costs, creating the affordability problem.

7.1.4 Industry failing to deliver

In the meantime, the offshore wind industry has not developed as it was thought. Costs have not decreased as low as expected, leading to higher actual LCOE figures than predicted. Fraunhofer ISE predicted that the LCOE in 2015 would be in the range of £86-140/MWh [66]. The actual LCOE can be assumed to be in the range of the price per MWh that the UK government is ready to pay in the new support mechanism, around £130-140/MWh.

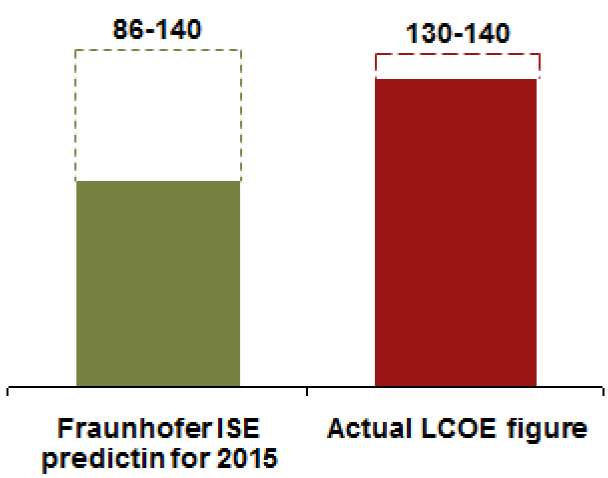


Figure 7.4: Predicted and actual offshore wind LCOE comparison

7.2 New regulatory framework

The two solutions to the affordability problem taken by the UK government are, from one side, reducing renewable capacity targets, and from the other side, changing the renewable support mechanism. In the *UK renewable energy roadmap* of 2011 [67], the prediction was of 18 GW for offshore wind by 2020. It was reduced to 16 GW in the 2013 edition [68] and nowadays, this number has gone to 10 GW [69].

In January 2013, the UK government launched the Electricity Market Reform (ERM) [70]. It is a government policy to incentivize in secure, low-carbon electricity, improve the security of Great Britain´s electricity supply, and improve affordability for costumers. ERM introduced two main mechanisms:

- A Capacity Market (CM), which will help ensure security of electricity supply at the least cost to the consumer
- Contracts for Difference (CfD), which will provide long-term revenue stabilization for new low carbon initiatives

The focus in this work will be in the CfD as it is the new renewable support mechanism that will occupy the place of Renewable Obligations.

7.2.1 Transition from Renewable Obligation Certificates (ROC) to Contract for Difference (CfD)

Nowadays, RO and CfD mechanism are living together during the transition from one to the other. ROCs will come to an end in March 2017. Projects developed before this date can still apply for them. The first CfD allocation round has taken place from October 2014 to February 2015.

The new mechanism guarantees a fixed price per MWh for 15 years whatever the wholesale price is; the difference between the awarded price and the wholesale price is subsidized. For example, if a renewable power plant operator receives the CfD at £130/MWh, the government guarantees that for 15 years this plant will earn that amount for each MWh generated. If one day the wholesale price is £50, the subsidy will pay for the difference, £80; and if the next day it is £70, the subsidy will decrease to £60. This implies a good advantage for power plant operators.

As incomes are guaranteed, it reduces the risk of projects, having easier bankability and lower finance costs.

Another change introduced by CfD mechanism is the way it is granted. ROCs were awarded to all those projects of renewable energy that met with some requirements. CfD, however, is given by a competitive process. One allocation round will be held each year, being the first one in October 2014. Each allocation round works as follows:

- The government fixes a maximum budget. The budget can be divided into different pots. Renewable technologies will be grouped in one of those pots depending on their maturity. Each pot has its own competitive process, being the regulation equal but autonomous between them. This is done because less mature technologies (e.g. offshore wind) could not compete in price with more mature technologies (e.g. onshore wind)
- The government fixes the Administrative Strike Price (ASP). It is the maximum price per MWh that each technology could aim for (£/MWh)
- The candidates present their projects: technology, size, commissioning date, etc.
- The required budget for giving the CfD to all the projects is calculated. If it does not exceed the announced budget, all of them are given the CfD at the ASP. If it does, the auction begins

In order to calculate the impact that a project of certain technology and size has on the budget, the following formula is used:

$$Budget\ impact\ (£) = \left(ASP\ \left(\frac{£}{MWh}\right) - Reference\ price\ \left(\frac{£}{MWh}\right)\right) * Load\ factor\ (\%) * Capacity\ (MW) * (Days\ (\#) * 24) * (1 - TLM)$$

Where the reference price is the estimated average wholesale price on the year the project is expected to be commissioned and it is given by the regulator. Load factor is the ratio between the predicted average generated energy over the possible maximum energy. It depends on the conditions of each location, but the regulator fixes it so that projects are comparable between them. Capacity is the power installed in MW. TLM (Transmission Loss Multiplayer) is a factor included not to take into account losses during the transmission of the power from the generation location to the grid.

The main principles of the auction are the followings:

- Each candidate presents a bid with a strike price (limited by the ASP), the size of its project and the commissioning year
- Bids are ordered from the lowest strike price to the largest
- First bid is considered. Its impact in the budget is calculated with the previous formula
- If it fits in the budget, it is awarded a CfD contract. And next bid is considered
- If a bid does not fit in the budget, the commissioning year of that bid is closed. All others bids with the same commissioning year are discarded
- When all years are closed or there are no more bids, the auction ends

Being a competitive process means that candidates will try to reduce its costs to the minimum and become as competitive as possible, reducing the incomes for each MWh and the cost for consumers. With the RO mechanism, an offshore wind could earn up to £150-160 for each MWh generated. In the first CfD allocation round, the ASP was £140/MWh (see Table 7.6) and the winner offshore projects have obtained a CfD price in the range of £114-120/MWh.

7.2.2 First CfD allocation round overview

It took place during Q4 2014. These are the key initial dates for this round (see Figure 7.5): until October 30 submission of the candidates; in November 13, notice if there is need of auction or not; in case of auction, bids have to be presented before December 9; and finally, winners are known in January 2015.

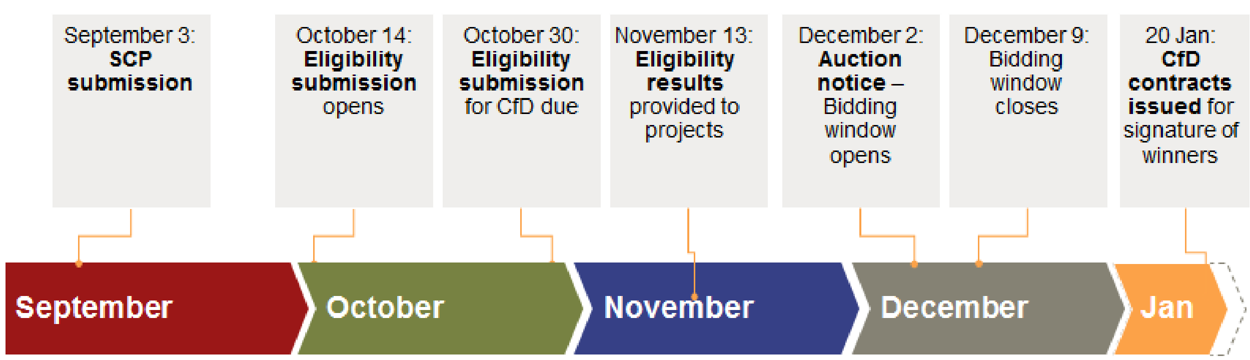


Figure 7.5: Initially proposed key dates on CfD process *[DECC]*

<u>Initial situation</u>

In June 2014, there are 10 potential offshore wind candidates to apply for a CfD contract. The main characteristics of each of them are showed in Table 7.4. Four of these candidates can potentially also apply for ROCs due to their early commissioning date (i.e. Rampion, Race Bank, Neart na Gaiothe and Galloper). Projects larger than 300 MW have to submit a Supply Chain Plan (SCP) in September. This SCP has to show mainly three things: project is feasible and has low risks, technology used is innovative and it will bring several local benefits. The SCP will be then examined and marked. In order to be eligible in this allocation round, the SCP has to be successful.

	Size	Ownership	Depth	Distance to shore	Commissioning date
East Anglia One	1.200 MW	• Iberdrola 50% • Vattenfall 50%	30-53 m	45.4 km	April 2018
Navitus Bay	900-970 MW	• Eneco 50% • EDF 50%	32-53 m	10 km	2017
Triton Knoll	300-900 MW	• RWE Innogy UK 100%	10-20 m	33 km	2018
Inch Cape	784 MW	• Repsol 51% • EDPR 49%	40-57 m	15 km	2018
Rampion	665-700 MW	• E.ON 100%	20-40 m	19.8 km	2016
Race Bank	580 MW	• DONG 100%	4-22 m	32 km	April 2015
Seagreen Alpha	525 MW	• SSE Renewables 50% • Fluor Corporatio 50%	31-71 m	27 km	June 2018
Moray Firth	504 MW	• EDPR 67% • Repsol 33%	35-48 m	22 km	2018
Neart na Gaiothe	450 MW	• Mainstream 100%	40-60 m	15.5 km	December 2016
Galloper	340 MW	• SSE Renewables 50% • RWE Innogy UK 50%	25-39 m	27 km	2016

Table 7.4: Main characteristics of projects initially competing for a CfD *[4coffshore]*

The budget has not been announced yet, but it is thought to be big enough to allocate around 2 GW of offshore wind.

Process

The 24th of July, the government publishes a draft budget notice, showing a first draft of the ASPs, pots and budget. Three pots are defined, but just two of them have a budget.

- *Pot 1 (established technologies):* Onshore wind (>5MW), Solar PV (>5mW), Energy from Waste with CHP, Hydro (>5mW and <50MW), Landfill Gas and Sewage Gas
- *Pot 2 (less established technologies):* Offshore Wind, Wave, Tidal Stream, Advanced Conversion Technologies, Anaerobic Digestion, Dedicated biomass with CHP and Geothermal, Scottish island onshore wind
- *Pot 3:* biomass conversion

	Delivery Year[2]					
£m (2011/12 prices)	***15/ 16***	***16/ 17***	***17/ 18***	***18/ 19***	***19/ 20***	***20/ 21***
CFD Budget (2014 release)	**50**	**205**	**205**	**205**	**205**	**205**
Pot 1 (established technologies)	50	50	50	50	50	50
Pot 2 (less established technologies)	-	155	155	155	155	155

Table 7.5: Budget distribution between pots[1] *[DECC]*

	CFD Strike Prices (£/MWh, 2012 prices)				
Technology	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**
Advanced Conversion Technologies (with or without CHP)	155	155	150	140	140
Anaerobic Digestion (with or without CHP) (>5MW)	150	150	150	140	140
Biomass Conversion	105	105	105	105	105
Dedicated Biomass (with CHP)	125	125	125	125	125
Energy from Waste (with CHP)	80	80	80	80	80
Geothermal (with or without CHP)	145	145	145	140	140
Hydro (>5 MW and <50MW)	100	100	100	100	100
Landfill Gas	55	55	55	55	55
Sewage Gas	75	75	75	75	75
Offshore Wind	155	155	150	140	140
Onshore Wind (>5 MW)	95	95	95	90	90
Solar Photo-Voltaic (>5MW)	120	120	115	110	100
Tidal Stream	305	305	305	305	305
Wave	305	305	305	305	305

Table 7.6: Administrative Strike Price by Commissioning date and technology *[DECC]*

A budget of £155m in the Pot 2 means that the maximum capacity of offshore wind that can obtain a CfD contract (at the ASP and supposing being the only allocated technology) is less than 550 MW. It means a big reduction in comparison to the 2 GW previously thought. It is also announced that a minimum of 10 MW of Wave and Tidal technologies have to be allocated, leaving space for ~500 MW of offshore wind. Moreover, Scottish islands onshore wind is likely to be in the same pot. It is a project of 370 MW in a location of very good wind conditions, making it highly competitive and potentially leaving a very low budget for offshore wind. This means that,

[1] The Budget of £155m is the total Budget for all the years, not for each individual year, e.g., a project of £100m in year 2016/17 takes that amount from all the years, not only from 2016/17

in the best scenario, an only offshore project will be successful and that there is no space for the biggest ones.

In September, Navitus Bay, Triton Knoll, Race Bank and Seagreen Alpha do not deliver the SCP, going out of the competition for the CfD.

The 2nd of October, DECC makes the final budget announcement with two main changes: Scottish islands onshore wind is not in Pot 2 and the budget is changed, increasing the amount of Pot 1 to £65m and to £235m in Pot 2. This announcement has two positive points: first, as Scottish island onshore wind is left out Pot 2, competition is reduced, potentially increasing the proportion of Pot 2 budget going for offshore wind; and the budget increase means that there is potentially more space for offshore wind. So, the new situation is: a maximum capacity for offshore wind of ~780 MW (at maximum strike price and supposing no other technology obtains CfD). Due to competition from other technologies, especially from dedicated biomass with CHP, the estimated capacity left for offshore wind is just ~600 MW.

With this last announcement, the situation has improved considerably, but not enough. As the estimation of budget left for offshore wind is around 600 MW, there is space for just one of the projects and big projects will have to reduce capacity.

The 23rd October, Galloper project is abandoned due to the "*difficulties in raising finance in time to meet government rules*" [71]. A week later, Iberdrola says that "*was being forced to scale back its proposed 1.2 gigawatt (GW) wind farm off the coast of East Anglia in order that its total annual subsidy requirement would be less than £235m"* [72].

The bidding process does not take place during the expected window (i.e. December 2-9) and all the process is delayed due to appeals of the different participants. The 28th January of 2015, DECC announces an increase on Pot 2 budget of £25m [73]. It means an increase around 90-100 MW of offshore capacity, which benefits larger projects. In addition, new bidding dates are announced, the new bidding window is from 29th of January to the 4th of February.

Winners are announced on 26th of February and there are two awarded offshore wind projects [74]:

- *East Anglia One:* capacity of 714 MW and CfD price of £119.89/MWh
- *Neart na Gaoithe:* capacity of 448 MW and CfD price of £114.39/MWh

These prices are a significant reduction from the £150-160/MWh offered by the previous subsidy mechanism.

7.3 Offshore wind industry evolution

In the meantime, the offshore wind industry is evolving rapidly and becoming more competitive. There are different best practices and techniques in the industry that are contributing to this competitiveness improvement. The followings are the most relevant ones:

a) Building larger wind farms

As Table 7.7 shows, the newest offshore wind farms have larger capacities (e.g. London Array, West of Duddon Sand and Greater Gabbard) and projects currently under development are even larger (e.g. East Anglia One, Inch Cape, Rampion).

Wind farm	Capacity (MW)	Commissioning date	Status
Kentish Flats	90	July 2005	In operation
Barrow	90	March 2006	
Burbo bank	90	October 2007	
Robin Rigg	180	September 2010	
Thanet	300	September 2010	
Walney Phase 1	183.6	July 2011	
Ormonde	150	September 2012	
London Array	630	April 2013	
Greatter Gabbard	504	August 2013	
West of Duddon Sands	389	October 2014	
Rampion	665-700	2016	Under development
Incha Cape	784	2018	
East Anglia one	1,200	April 2018	

Table 7.7: Sample of relevant UK offshore wind farms and projects *[4coffshore]*

Building larger wind farms implies some benefits on cost reductions. From one side, there are some costs that do not depend on the capacity installed (e.g. design and development costs, offshore substation, mobilization and demobilization cost of vessels, etc.), and, as a consequence, a larger wind farm would have lower cost per MW. From the other side, it enables taking advantage of economy of scales. For example, a developer who is planning to build a wind farm of 1,000 MW may have more relative negotiation power than other one developing a 300 MW wind farm, and he would, presumably, obtain more competitive prices.

A good example of developing larger wind farms to obtain cost reductions is the case of East Anglia One. Initially, they were planning to build a 1,200 MW wind farm and expected to have big economies of scale. As seen in the previous point, Iberdrola had to shrink East Anglia One´s capacity from the initial 1,200 MW due to an insufficient CfD budget. Mr Anderson, head of Scottish Power (Iberdrola´s subsidiary in UK), stated the following after the budget announcement: *"Our belief is if you drove the process to do projects of that size and scale (over 1 GW) you would drive the costs down harder and faster. If you push the projects down to smaller size and scale, we don´t think you will get the cost reduction coming through the industry as quickly as you could"* [75].

b) Using larger and more powerful turbines

As it occurs in onshore wind turbines, offshore turbines are becoming more powerful with time. In July 2013, the London array wind farm was fully commissioned. It was the biggest offshore wind farm until the moment and 175 Siemens WTGs of 3.6 MW were used. Nowadays, the biggest commercial turbine is being produced by MHI Vestas and has a capacity of 8 MW and there are turbines of 10 MW being developed by several manufacturers. Table 7.8 shows some of the current larger commercial WTG, as well as, the model employed by the London Array wind farm.

	Capacity	Year	Supplier	Dimensions		
				Ø	Swept area	Hub height
SWT-3.6-120	3.6 MW	<2012	Siemens	120 m	11,300 m^2	90m
Haliade 150-6MW	6 MW	2014	Alstom	150 m	17,860 m^2	100m
SWT-6.0-154	6 MW	2014	Siemens	154m	18,600 m^2	
6.2M 152	6.15 MW	2015	Senvion	152 m	18,150 m^2	95-110 m
S7.0-171	7 MW	2015	Samsung	171m	23,020 m^2	
V164-8.0	8 MW	2015	MHI Vestas	164m	21,000 m^2	

Table 7.8: Sample of relevant WTG models *[4coffshore]*

For a same capacity wind farm, CAPEX and OPEX are reduced by using larger turbines as well as the load factor is increased. If turbines are bigger and the wind farm capacity does not change, the number of WTGs is reduced. It means a reduction in the number of substructures and foundations used, bringing reductions in CAPEX. In the meantime, O&M costs are reduced as there are fewer turbines. Finally, the load factor is increased due to a smaller weak effect. In the study made by BVG associates (see Figure 7.6), CAPEX and OPEX reductions are 3% and 26% respectively, and the load factor increases by a 3% if the turbine size is 8 MW instead of 4 MW.

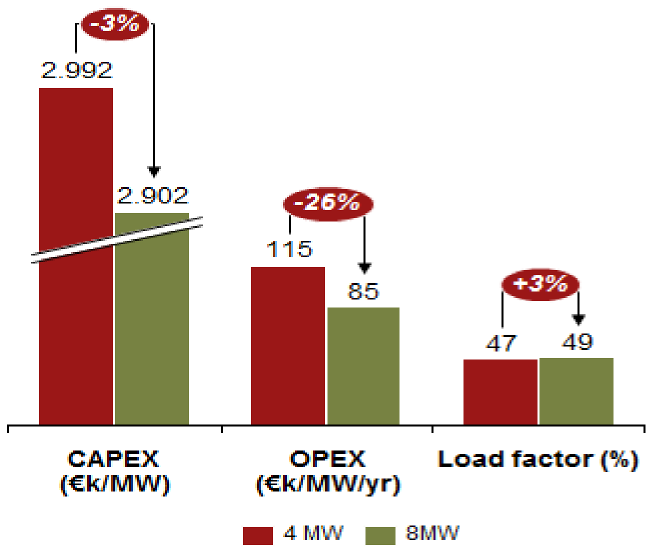


Figure 7.6: Effect of larger turbines in different aspects *["Future renewable energy costs: offshore wind". BVG associates - 2014]*

c) Moving to better wind locations while costs keep affordable

One of the most important factors to have a competitive wind farm is wind characteristics of the site. So, the election of the site is extremely important. However, better wind conditions are often given further from the shore which, in the meantime, usually means deeper waters. By the end of 2014, the average water depth of offshore wind farms in the Europe was 22.4 m and the average distance to the coast was 32.9 km [76]. There are projects announced in water depths up to 215 m and distance from the shore up to 200 km [77]. Table 7.9 shows the average wind speeds, distance to shore and depth of some UK wind farms.

It seems logical that regulators and developers should join efforts in order to harvest first those locations close to shore and with good wind characteristics. This way, the combination of good winds and low costs would enable the construction of competitive wind farms. However, these locations are limited and there is the need of going to deeper waters further from the shore and this is generating two problems:

- Traditional substructures are not suitable for deeper waters
- The greater distance from the shore increases power transmission losses

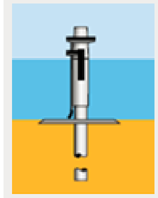
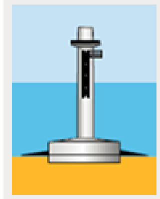
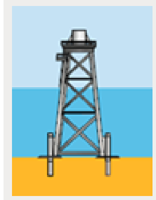
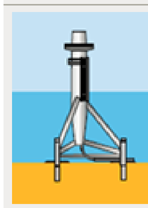
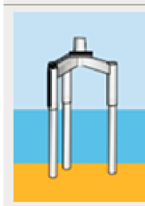
Wind farm	Wind speed (m/s)	Distance to shore (km)	Depth (m)	Status
Moray Firth	10.12	22	35-48	Under development
Thanet	10.06	17.7	20-25	In operation
London Array	9.94	20	0-25	
Greatter Gabbard	9.87	32.5	20-32	
Kentish Flats	9.8	9.8	5	
Burbo bank	9.78	8	0-8	
Walney Phase 1	9.78	19.3	19-28	
West of Duddon Sands	9.78	20.1	17-24	
Rampion	9.76	19.8	20-40	Under development
East Anglia one	9.73	45.4	30-53	
Incha Cape	9.62	15	40-57	
Robin Rigg	9.55	11.5	4-13	In operation

Table 7.9: Wind and location characteristics of a sample of wind farms *[4coffshore]*

<u>How is industry solving the deeper waters issue?</u>

Substructures and foundations have to adapt and evolve in concordance with the trend of going to deeper waters. From the monopiles and Gravity-Based Structures used in shallow waters, substructures are evolving to space frame solutions (e.g. jackets, tri-piles and tripods), and is likely that floating platforms are used in the future.

There are five main types of fixed substructures:

	Description	Advantages	Disadvantages	Share [1]	Illustration
Monopiles	• Single steel pile which is embedded into the sea bed • Depth: 0-25 m	• Simplicity • Low labour content	• Less stable in depths >25 m • Difficult to remove	75.4%	
Gravity-Based Structures (GBS)	• Constructed in building yards and transported to the site. Then, filled with sand increasing their weight • Depth: 0-30 m (currently under consideration for 30-50 m)	• Easy installation	• Expensive due to high weight • Difficult to remove	12.2%	
Jackets	• Steel structure • Pinned to the seabed using piles • Technology from O&G industry • Depth: 30-50 m	• Lower mass than tripods and tri-piles • Automated production potential to reduce costs • Rigid	• Higher manufacturing and assembly costs than tripods and tri-piles • Complex installation	5.3%	
Tripods	• Three-legged structure made of cylindrical steel tubes • Either vertical or inclined pile sleeves • Depth: 20-50 m	• Rigid and versatile	• Expensive construction and installation • Difficult to remove • Higher weight than jackets	4.7%	
Tri-piles	• Three foundation piles connected via a transition piece to the turbine tower • Depth: 20-50 m	• Rigid and versatile	• Expensive construction and installation • Difficult to remove • Higher weight than jackets	2.2%	

1. By the end of 2013

Table 7.10: Main characteristics for the different fixed substructures *[based on "Wind in our Sails", EWEA - 2011]*

These substructures, except GBS, use piles as foundations. Suction caisson foundation is an alternative to piles that is nowadays under development and testing. Its working mechanism relies on two fundaments. First, its own weight, as in the GBS case, that gives stability to the structure by using gravity. The other basis is suction, it takes out material from the inside of the foundation creating a pressure differential that keeps the foundation attached to the seabed (see Figure 7.7). The main advantages are that installation is easier and less expensive equipment is required (e.g. cost reductions around 34% could be obtained [78]). Some of the companies developing this technology are Dong Energy, E.ON, Statkraft and Statoil.

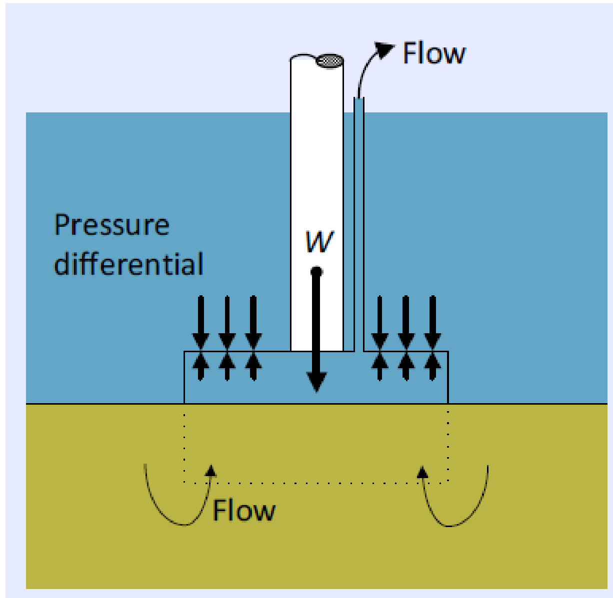


Figure 7.7: Illustrative of Suction Caisson working principle *["Foundations for Offshore Wind Turbines", University of Oxford - Dec. 2014]*

Monopiles have traditionally and are expected to dominate the market due to their simplicity and low costs. Their deployment will be limited by deeper water sites where monopiles are not technically feasible. Jackets should grow in these more challenging sites. They are already the chosen type of substructure in projects under development: jackets are the most probable solution for projects that have applied for CfD in the first allocation round and have depths larger than 30 m (e.g. East Anglia One, Seagreen Alpha, Inch Cape or Neart na Gaoithe).

Nowadays, all commercial offshore wind farms under development are using fixed substructures. However, the use of fixed substructures is limited to water depths not higher then 50-60 m and there are many countries where the number of shallow water sites is limited (e.g. Mediterranean, Atlantic basins and Norway; 66% of the North Sea has a water depth between 50 m and 220 m). So, floating structures are being developed. There are three main primary types [79]: tensioned-leg platform (TLP), semi-submergible and the spar buoy (see Figure 7.8).

- *Spar buoy*: a large cylindrical buoy that stabilizes the wind turbine using ballast. The center of gravity is much lower in the water than the center of buoyancy. Whereas the lower parts of the structure are heavy, the upper parts are usually empty elements near the surface, raising the center of buoyancy
- *TLP*: tensioned mooring lines are attached to a semi-submerged structure and are anchored on the seabed to add buoyancy and stability

- *Semi-submergible*: combining the main principles of the two previous designs, a semi submerged structure is added to reach the necessary stability

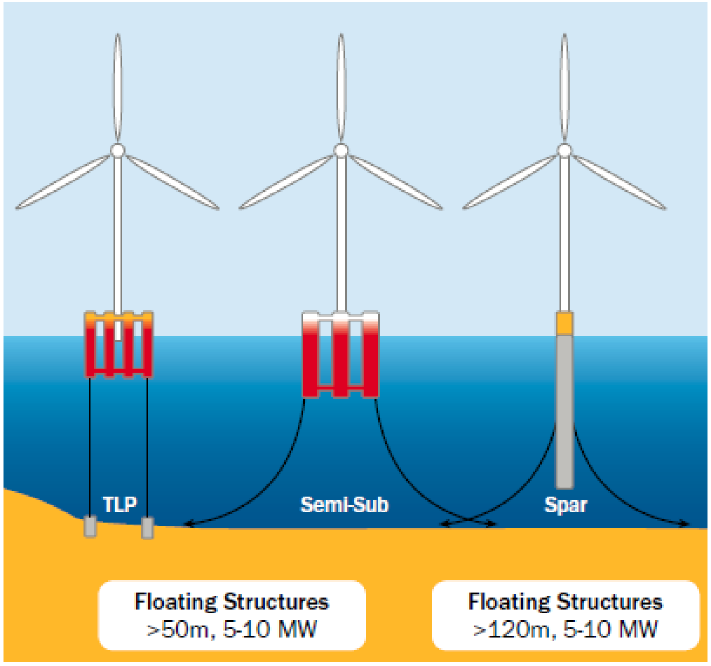
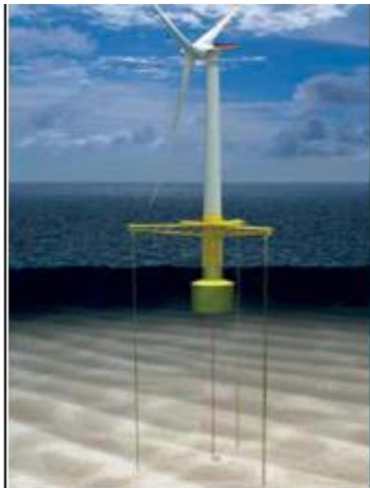


Figure 7.8: Illustrative of floating substructure *["Deep Water. The next step for offshore wind energy", EWEA - July 2013]*

There are already 5 floating prototypes connected to the grid and 35 projects under development. The followings are some examples among those:

	Company	Manufacturer	Type of floater	Turbine capacity	Commercial installation
Hywind	Statoil	Siemens	Spar-buoy	3-7 MW	2015-2016
WindFloat	Principle Power	Vestas	Semi-submersible	5-7 MW	2017
Blue H TLP	Blue H	-	Submerged deep water platform	5-7 MW	2016
Floating Haliade 150	Alstom	Alstom	• Tension Leg Buoy (depths 50-80m) • Tension Leg Platform (depths 80-300m)	6 MW	-
WINFLO	Nass & Wind, DCNS and Vergnet	-	Semi-submersible	2.5 MW	2016
PelaStar	The Glosten Associates	-	Tension-leg turbine platform	2.5 MW	2015-2017
IDEOL	IDEOL	-	Concrete Floater	5-6 MW	2014 (Pilot)
Hexicon Energy Design	Hexicon	-	Floater	54 MW (wind) 15 MW (wave)	-

Table 7.11: Sample of relevant floating project and prototypes *["Deep Water. The next step for offshore wind energy", EWEA - July 2013]*



Floating Haliade 150

WindFloat

Hywind

Blue H TLP

PelaStar

WINDFLO

Hexican Energy Design

IDEOL

Table 7.12: Pictures of projects in Table 7.11 *["Deep Water. The next step for offshore wind energy", EWEA - July 2013]*

How is industry solving the greater transmission losses due to longer export cables?

As offshore wind farms are built further from shore and have larger capacities, minimizing transmission losses is becoming of increasing relevance. Electrical transmission systems have changed considerably since the first offshore wind farms. At the beginning, those wind farms close to shore were directly connected to the onshore electrical grid at Medium Voltage. However, the maximum power that could be exported by one cable was of the order of 30-40 MW and large project needed a large number of cables [80]. So, as wind farms started moving away from shore the chosen solution has been high voltage AC systems. An offshore substation is installed in the wind farm and it converts power from medium voltage (power is generated in medium voltage in WTGs) to high voltage. Then, power is transmitted using a small number of high voltage cables (typically in the range of 120 to 220 kV). Table 7.13 shows some of the most relevant offshore wind farms with an HVAC connection.

Offshore wind farm	Location	Capacity (MW)	Collector Substations (#)	Voltage (kV)	Cable Length (miles)		Cables (3-core) (#)	Cable size (mm²)
					Sea	Land		
London Array	UK	630	2	150	33	0	4	630/800
Greater Gabbard	UK	504	2	132	28	0	3	800
Anholt	Denmark	400	1	220	15	35	1	1600
Sheringham Shoal	UK	317	2	132	14	13	2	630
Thanet	UK	300	1	132	16	2	2	1000/630
Lincs	UK	270	1	132	30	8	2	630
Horns Rev 2	Denmark	209	1	150	26	37	1	800
Rodsand 2	Denmark	207	1	132	32	18	1	

Table 7.13: Main electrical transmission characteristics for sample of projects *["Offshore Wind Transmission Study, Final Report", ESS Group, Inc – September 2014]*

Nevertheless, AC transmission lines have some limitations [81]:

- Charging current and related thermal ratings of the cables
- Systems voltage issues due to the use of long cables
- Line losses due to length
- System stability issues during AC cable faults during cable operation

These limitations are playing in favor of HVDC transmission as wind farms become larger and are further from shore. HVDC avoids the large charging currents causing energy losses in 50/60 Hz AC cable systems. However, it has two main barriers. First, it is an immature technology with lack of widespread application. It has suffered from various complications during the last years that have slowed the shift to HVDC (e.g. Siemens has suffered from significant write-offs for over-budget transmission HVDC projects) [82]. The second barrier is the AC/DC converters. These converter stations are very large, expensive and present some logistical challenges due to their size and weight. Overall, HVDC installations are thought to be cost-effective for projects of around 500 MW with a cable route of around 100 km [83], although these figures are rather uncertain and larger capacities might be required. Figure 7.9 shows an example of the structure of a HVDC system.

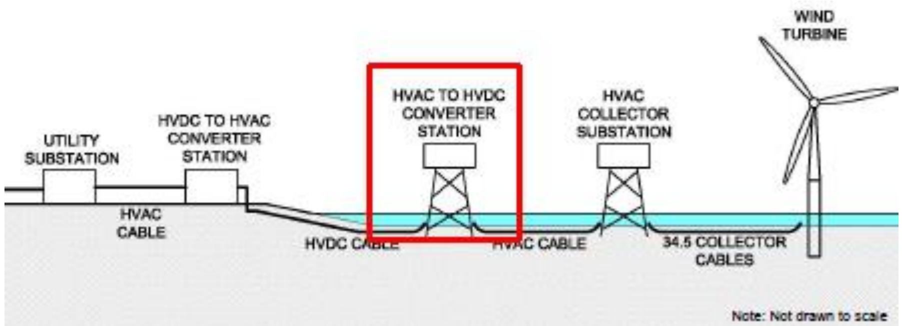


Figure 7.9: HVDC transmission structure *["Offshore Wind Transmission Study, Final Report", ESS Group, Inc – Sept. 2014]*

d) Making wind farm execution more efficient, effective and reliable

The objectives of every developer during the construction phase of a wind farm are to guarantee the following three aspects:

- There are not cost overruns
- Execution goes in time
- Quality of installation

As it is an immature industry, the construction of an offshore wind farm faces several risks. These risks can have a significant impact on project´s profitability (see Table 7.14) and it is important to manage them correctly. Buffers are introduced in the construction schedule to handle unexpected delays and contingencies are added to CAPEX previsions in order to make more accurate cost estimations. Buffers have a cost (i.e. later generation of incomes, personnel and vessels waiting for the next phase to start, etc.), but they are necessary for the success of a project. So, there is a trade-off between guaranteeing buffers are long enough and minimizing costs.

Execution risks	Impact on profitability (-p.p.)
WTG installation – 3 month delay	0.2-0.5
Substructure vessel delay	0.1-0.3
Land acquisition delay/cost escalation	0-0.1
25% higher contingencies than base case	0.2-0.3
Steel cost increase	0.1-0.2

Table 7.14: Impact of sample of relevance risks on profitability *[A.T. Kearney experience]*

As a consequence, it is important to have vast experience and the required capacities in order to build a wind farm successfully at the lower possible costs. For example, DONG, which is the leading developer in the offshore wind industry (i.e. 24.1% of the European offshore wind capacity by the end of 2014 [84]), haves enough experience and capacities to reduce buffers considerably and make very accurate estimations of CAPEX. They have an experienced team of engineers and managers that guarantee the certainty of their calculations and cost estimations. A new entrant to the wind offshore industry, however, would need to leave longer buffers and larger contingencies due to the reduced experience and capacities. Furthermore, the new entrant should subcontract these lacking capacities to another company.

The construction of an offshore wind farm is a very complex work. There are many components and each component has different installation stages. So, developers often have to subcontract other companies to develop certain tasks. In addition, there are several interfaces between the different tasks (see Figure 7.10) and it is crucial to manage those interfaces correctly in order to reduce delays and cost overruns. Going to the extreme cases, there would be two types of subcontracting. The first one would consist on subcontracting all tasks to the same experienced contractor. The subcontracted company would manage the whole wind farm construction and the developer would not need to have especial capacities. This option, however, would result being quite expensive. The second type is subcontracting each task to a different company. It implies that the developer would have to manage those interfaces and would need to know how to do it, but they would usually mean fewer costs. So, developers have to take the decision between having fewer costs or having lower uncertainty in execution. This decision is often conditioned by funding institutions. They usually tend to prefer the first option, as the responsible for the management of the construction is an experienced company and reduces project risks. In the contrary, companies tend to prefer the second option as it means less costs. It consists on a negotiation with the bank, and depending on how experienced the developer is, banks will accept more or less packetized subcontracting.

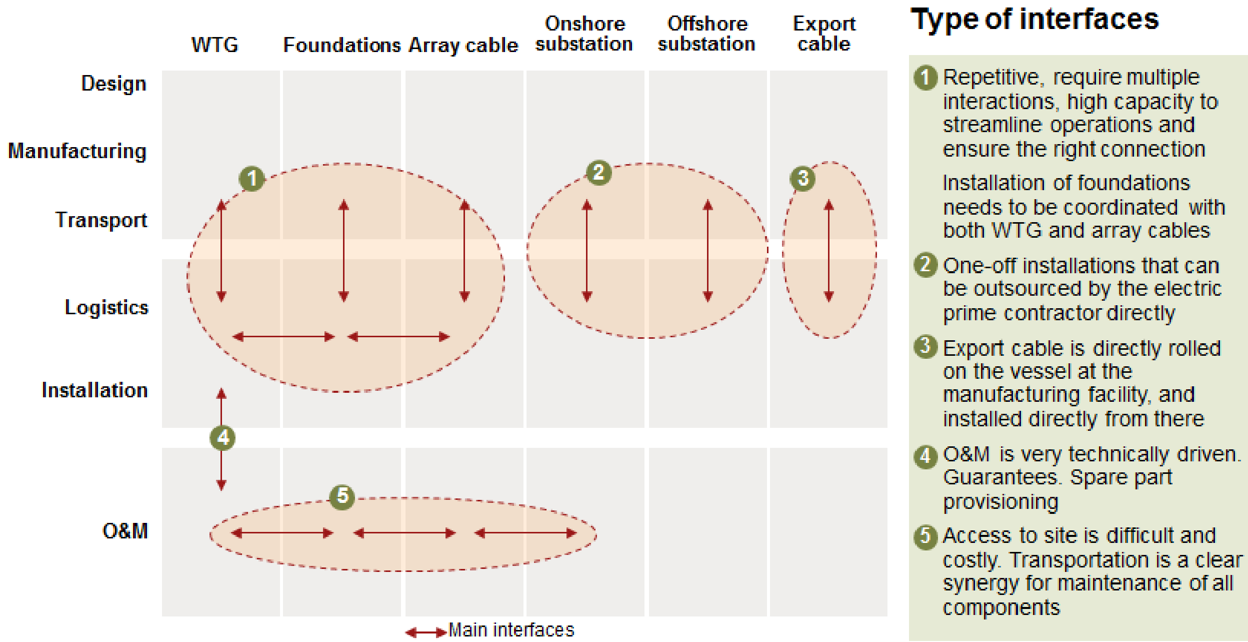


Figure 7.10: Interfaces between tasks during the construction of a wind farm *[A.T. Kearney experience]*

Finally, it is very important to have good information about the composition of soil and weather characteristics of the location (i.e. wind speed at sea level and wave height). While the first one would prevent from unexpected problems and delays during the piling and foundation installation tasks, good weather measurements would help to accurate estimations of vessel operability and make more certain estimations of installation tasks durations.

e) Having a more stable regulatory framework

Stability on the regulatory framework is an important aspect to contribute in LCOE reductions. A regulatory framework with few or no changes gives developers visibility and certainty of which the subsidies and regulation will be. It will motivate developers to start new projects and, in the meantime, it also reduces institutional risks, improving projects bankability. A clear example of this is the case of East Anglia One. They were intending to construct a 1,200 MW wind farm in order to take advantage of big economies of scales. The change of support mechanism from ROCs to CfD and the different changes on CfD budget have made Iberdrola to reduce the size.

In addition, there are usually some requirements that have to been fulfilled in order to obtain subsidies. These requirements often mean some extra costs that could be avoided if there were fewer. For instance, one of the aspects that the Supply Chain Plan should demonstrate in order to be approved and be able to bid for CfD was high local content, this is, the development and construction of the wind farm should create wealth in the UK. It obligates, for example, wind turbine manufacturers to open a new factory in the UK. As a consequence, turbines are more expensive that if the manufacturer had an only factory to supply all Europe.

f) Reducing O&M costs

While the total CAPEX for a 500 MW is in the range of 1,750-2,000 million €, OPEX is around 100-120 million € per year [85]. Considering that the predicted life of an offshore wind farm is around 25 years, O&M costs are a relevant aspect to take into account.

BVG associates predict that the larger cost reductions on a wind farm will be given by OPEX improvements. They estimate that OPEX will reduce by a 15-20% in 2025 due to several technology innovations [86]. One of the mentioned innovations is the direct drive technology (see point 4.3.1). It removes the gearbox resulting in a simpler drive train with fewer mechanical parts. Gearboxes are usually one of the components with higher failure rates in a wind turbine.

Additionally, O&M synergies between wind farms that are close to each other could reduce considerably these costs. For example, having a vessel for the maintenance of just one wind farm can result in being too costly. So, sharing this vessel and its crew between two, three or more wind farms would mean significant reductions in OPEX.

g) Bits & pieces

There are many other things that can be done in order to minimize development, construction and operating costs, every small detail counts in the process of maximizing profitability. An example of this is the dilemma that surges due to wind farms´ layout.

The layout of an offshore wind farm is designed with the objective of maximizing the load factor for a given site and the number of turbines. Ideally, the annual output energy of a wind farm would be the production of one turbine times the number of turbines. However, it is slightly smaller. When wind goes through a WTG, it losses a bit of energy, so the turbine behind will have a weaker wind. This effect is known as *weak effect*.

There are two things that can be done to reduce the weak effect to the minimum. The first one is to use the whole area of the site and place turbines as far as possible from each other. Although it may seem possible, there may be cases in which this is not the chosen option. For instance, if a site has the consent to build 1,000 MW and the developer aims to build a 500 MW wind farm, it has to take the decision between making the 500 MW wind farm as profitable as possible (occupying the whole area and maximizing the load factor) or leaving open the possibility for a second 500 MW phase sacrificing profitability of the first phase (occupying just the half of the area and maximizing the weak effect).

The second one consists on taking into account site´s wind characteristics. In order to minimize the weak effect, wind turbines do not have to be aligned in the direction in which wind comes from more often.

7.4 Learnings

The renewable affordability problem is a fact that is not only happening in the UK, other European countries are also beginning to doubt about its sustainability and there have been some changes in regulation. This reaction is not surprising as it is true that renewable energy results being expensive. For instance, in the case of offshore wind, operators are earning over £150/MWh with the RO mechanism when the pool price moves usually below £70/MWh. However, subsidies are the only way for now to expand renewable energy and reduce the environmental impact of human´s energy consumption.

There are some support mechanisms than result less costly to consumers. The comparison between RO and CfD is a good example of this. Awarding subsidies by a competitive process forces developers to be creative and apply the latest techniques in order to reduce costs as much as possible. In addition, just the best projects are granted a CfD contract and most costly projects are discarded. As a consequence, the first CfD allocation round has managed to reduce offshore wind´s revenues per MWh from over £150/MWh to £115-120/MWh. It is a real success as it means a reduction higher than a 25% in a very short period of time. The UK has managed to subsidy renewable energy while having a reduced impact in the consumer.

In the meantime, the offshore wind industry is evolving very fast. There are plenty techniques used to reduce cost and reach better wind locations. It is translating in LCOE reductions and competitiveness increase, but it is still an immature technology with plenty of development and construction risks.

Nevertheless, there are still many things to improve that would contribute in faster LCOE reductions. A greater harmony between developers and regulator seems necessary, and cooperation of both sides would result on a faster technology evolution. There are many examples for this. For instance, encouraging developers to build larger wind farms in order to take advantage of economies of scale. It would likely contribute in significant cost reductions for the consumer. Or, developers and regulator could jointly work to encourage wind farm construction in best wind locations. Finally, eliminating some regulatory requirements (e.g. local content) would significantly avoid some extra costs.

To sum up, there are ways of supporting renewable energy while reducing the economic impact on the consumer. So, adopting a well-designed support framework is crucial in order to launch renewable generation and have a mechanism that lasts for long and gives stability to developers. UK´s case is a good reference for other countries to learn how renewable support can be maintained with a reduced impact on the consumer.

Chapter 8

Practical case 2: Can distributed generation threaten the status quo of utilities in Spain?

Among all the drivers explained in chapter 5, special attention should be paid to prosumers and distributed generation, even more in the Spanish case where the abundant solar resource makes economic fundamentals more attractive. Furthermore, as seen in chapter 6, self-consumption would have considerable effects on the electric sector and on utilities.

Grid parity is likely to be reached during this decade and DG deployment can be exponential. In this chapter, the main barriers for DG expansion have been identified and a model has been built in order to make estimations of DG adoption in 2020.

8.1 Profitability analysis

In the electric sector decisions historically have been taken in a centralized way and thinking in what the best option for the sustainability and reliability of the system was. In distributed generation, however, the decision is taken based on an individual profitability analysis and personal interests may not be aligned with system´s interest. So, profitability is not compared with other generation technologies but with the grid electricity price, i.e. grid parity. There are two types of grid parities: static and dynamic grid parity.

Static grid parity happens when the levelized cost of generation (LCOE) of PV is equal to the electricity price. It is a snapshot of the competitive position and the relative strength of PV.

Static grid parity has already been reached in 2014 in Seville, it will be obtained in Madrid between 2015 and 2016 and by 2017 in Bilbao (see Figure 8.1[1]).

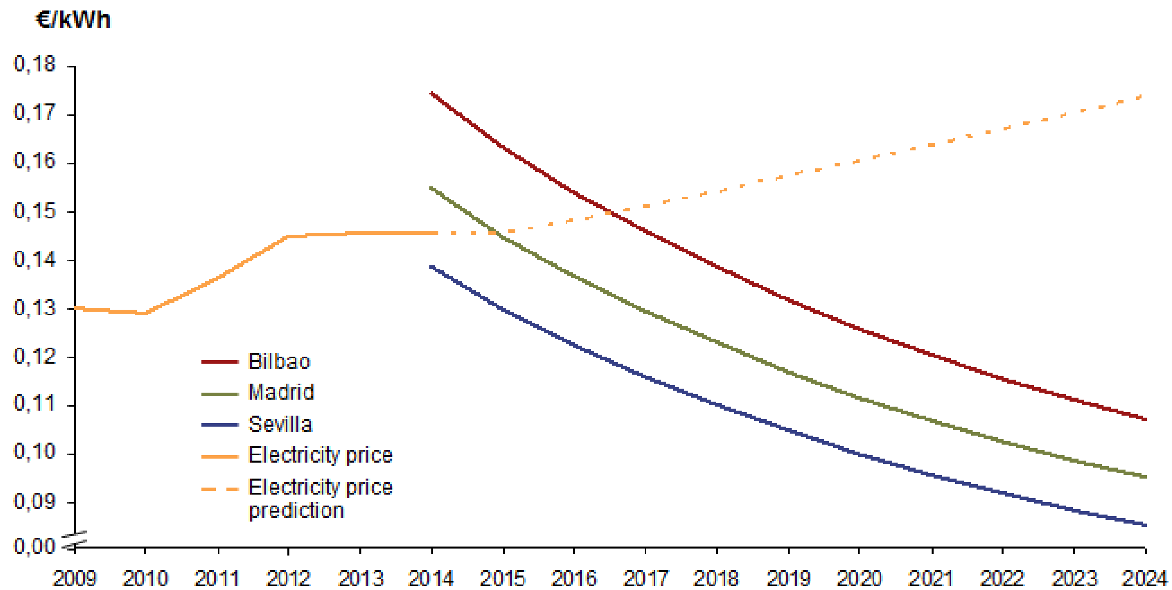


Figure 8.1: Static grid parity for different Spanish regions (Bilbao, Madrid and Seville)

Dynamic grid parity (also known as investment parity) happens when the lifetime PV-related project costs are equal to the total savings generated. It is a movie over a relevant period of the competitive position. A 100 kW system installed in 2015 would have a pay-back period of 11-12 years in Bilbao, 10-11 years in Madrid and around 9 years in Seville (see Table 8.1).

	Bilbao	Madrid	Seville
Total system life cycle cost (€/W)		1.9	
Installed power (kW)		100	
Total investment (€)		190.000	
Annual generated power (MWh)	108	121	136
Year 1 savings (€)	~14,758	~16,634	~18,578
Year 2 savings (€)	~15,053	~16,966	~18,949
...	...	...	...
Investment pay-back period (years)	11-12	10-11	~9

Table 8.1: Dynamic grid parity for Bilbao, Madrid and Seville

[1] 100kW PV system and elec. prices for 20 MWh < Consumption < 500 MWh

8.2 Market volume projection

Distributed generation´s installed capacity could reach up to 11.4 GW by 2020 if net-metering was approved. It would mean a 6.5% of the total contracted capacity[1] in 2014. Generation would be ~15 TWh which is around the 6% of the energy demand in 2014. These numbers would significantly reduce to 1.8 GW and 2.5 TWh in the case of back-up toll (~1% in both cases). Finally, figures for the no regulation case would be 5.8 GW and 7.5 TWh (3.3% and 3% respectively).

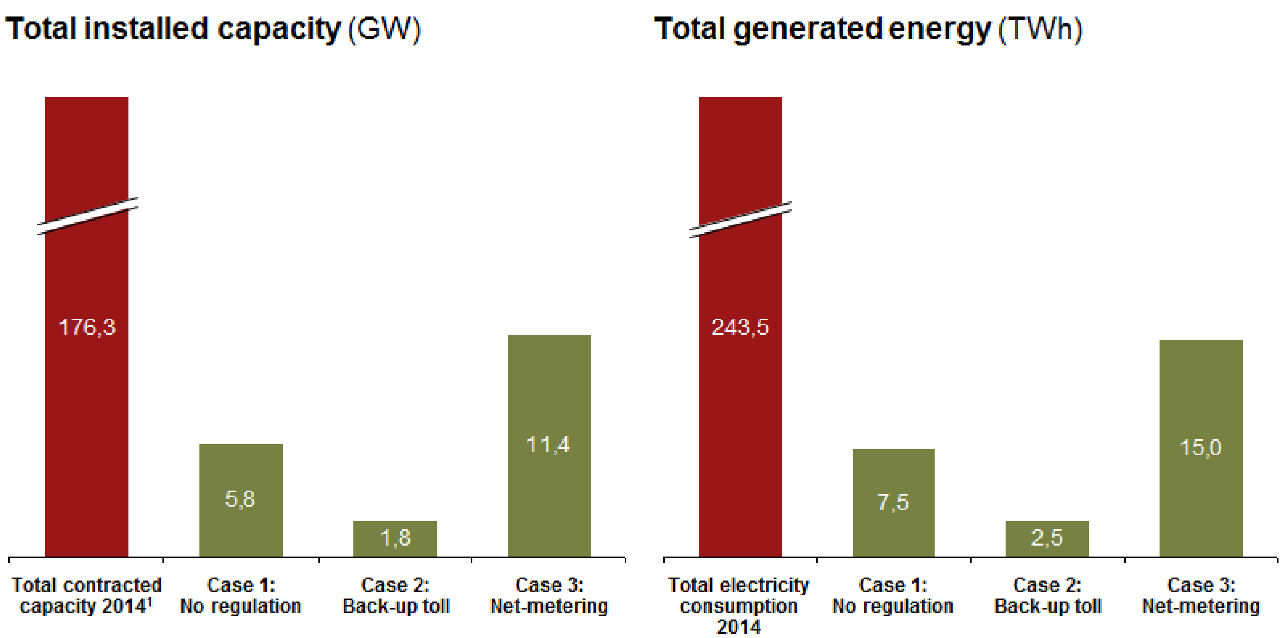


Figure 8.2: Installed capacity and energy generation 2020 predictions of distributed generation

8.2.1 Methodology

There can be different possible approaches to estimate the distributed generation market volume in 2020, e.g. calculate the potential available area for distributed generation or calculate the potential number of prosumers. In this work, the second approach has been considered the most suitable one as it gives a clearer and more realistic vision of the situation. The next methodology has been followed: segmentation of the different types of electricity consumers, identification and quantification of potential barriers for distributed generation in each of the segments and application of these barriers over the total amount of electricity consumers in each segment in order to obtain the prediction of prosumers in 2020.

Five different segments have been identified depending on their type of activity. Four of them include businesses and companies, while the last one is formed by residential consumers. CNAE´s classification of professional activities has been use as a reference on the segmentation [87]:

- *Agriculture:* it covers the range of activity numbers 0XXX
- *Energy intensive industry:* it includes from 20XX to 25XX activity numbers
- *Energy non-intensive industry:* activity numbers in the range of 1XXX and 26XX-29XX
- *Other activities:* it includes the following range of activities: 3XXX-9XXX. Next references to this group will be made as Commerce, as this activity predominates over the rest in this group
- *Residential consumer:* it includes both, apartments inside a building and individual houses

The segment of energy intensive industry has been excluded from calculations as they have low electricity prices (i.e. under 8 cent€/kWh in 2014[2]) compared with solar PV LCOE (i.e. over 9 cent€/kWh by 2020). In addition, secondary houses are not going to be taken into account in the residential segment as they will not be profitable in the short and medium term. They currently have pay-back periods larger than 35 years (see *Investment pay-back period* point).

Four main barriers for the expansion of distributed generation have been identified: space, financial, mindset and regulatory barriers. Figure 8.3 shows an example of the methodology employed.

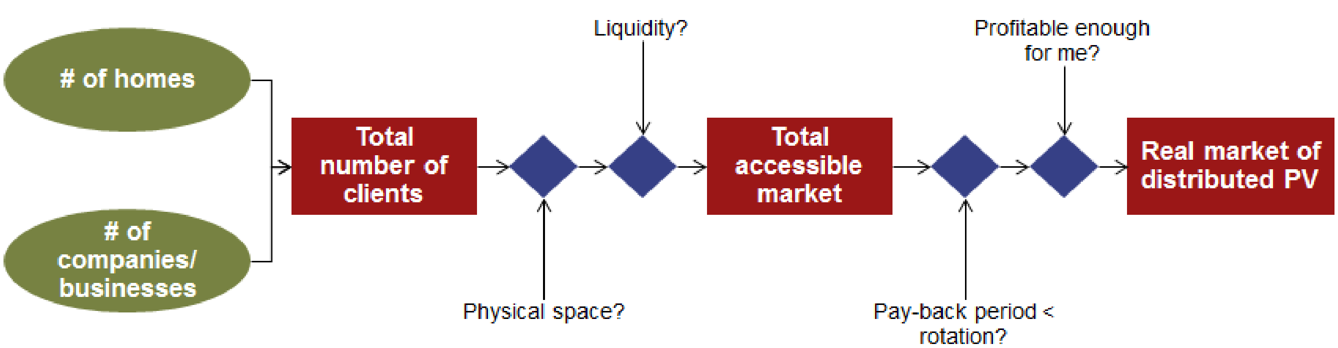


Figure 8.3: Illustrative example of methodology

[1] During tariff period 1

[2] Industrial consumers and consumption < 70,000 MWh, Eurostat

- *Space barrier:* distributed generation has one limitation on space. Even if a company or an individual have the willingness of self-generating, they may not have space for the installation of the PV panels. This barrier has especial relevance in cities, where the available surface for DG is mainly limited to rooftops. This barrier will imply a reduction of the accessible market for distributed generation
- *Financial barrier:* this barrier covers three aspects
  - *Liquidity*: there may be people or companies who do not even consider self-consuming as they do not have enough money to buy and install a PV system. This barrier is taken into account as a reduction of the accessible market
  - *Profitability:* it is related to the static grid parity, comparison between electricity prices and PV system LCOE. Potential prosumers will look for a certain profitability of their investment before installing self-consumption systems
  - *Investment pay-back period:* it is related to dynamic grid parity, comparison between the pay-back period and the rotation rate. In case the pay-back period is larger than the rotation rate, it may make no sense to invest as money is not going to be recovered
- *Mindset barrier:* as explained in chapter 5, solar PV is a relatively new technology and people may be reluctant to it. The impact of this barrier is taken into account combined with profitability
- *Regulatory barrier:* it will affect considerably the DG expansion as it can worsen or improve its financials. Three cases are going to be modelled in order to simulate the possible changes in regulation: no regulation case (neither favorable nor contrary regulation), back-up toll case (contrary regulation) and net-metering case (favorable regulation)

Finally, once the estimation of prosumers is done, this figure is going to be transformed into estimated power capacity and estimated generation. This process is developed by assigning a certain capacity for each segment.

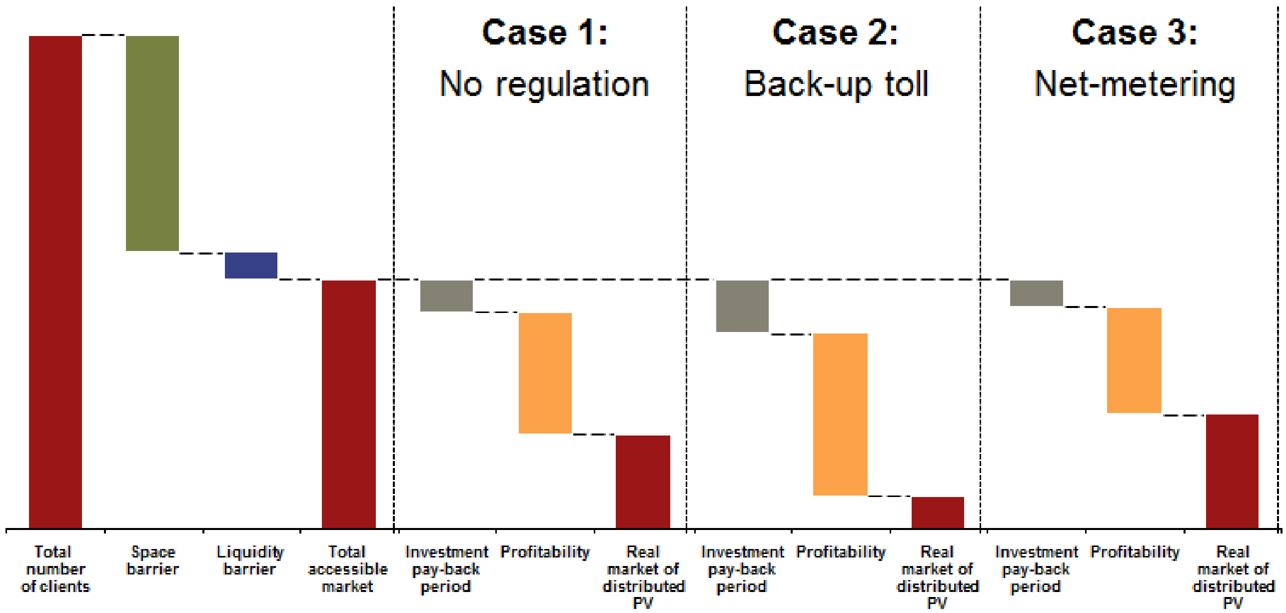


Figure 8.4: Illustrative example of the estimation process

Additionally, as the LCOE of a PV installation depends greatly on the site´s solar resource, Spain has been divided into four regions according to the global horizontal irradiance (GHI) (see Figure 8.5). GHI is the sum of the direct normal irradiance (DNI) and the diffuse horizontal irradiance (DHI) and it is the more appropriate measure in the case of PV panels. Regions are North (Galicia, Asturias, Castilla y León, Cantabria, País Vasco, Navarra and La Rioja), Centre (Comunidad de Madrid, Cataluña, Aragón, Comunidad Valenciana and Castilla la Mancha), South (Andalucía, Extremadura, Murcia, Ceuta and Melilla) and Islands (Baleares and Islas Canarias).

	GHI (kWh/m^2)
North	1,425
Centre	1,606
South	1,793
Islands	1,700

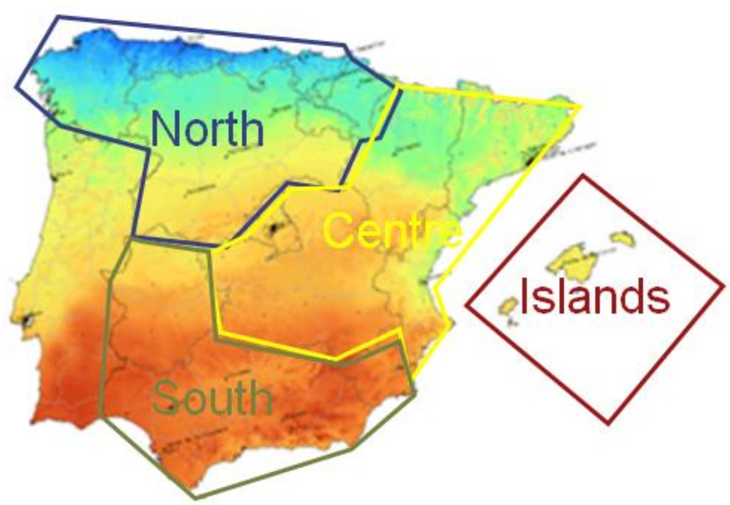


Figure 8.5: regions and GHI by region *[NASA Surface meteorology and Solar Energy database]*

Each of the barriers is going to be discussed deeply in the following points.

a) Space barrier

This is one of the main barriers and probably the one which reduces more the number of potential prosumers. There are many businesses, companies or people that do not have even the choice to self-consume due to lack of space. In addition, this barrier will also serve to eliminate all those activities that are very unlikely to self-consume due to their characteristics (e.g. forestry).

Space barrier has especial impact on the commerce and the residential community segments. These two segments have more presence in town and cities than the other segments. They may be located in vertically erected building, sharing the reduced rooftop space with the other electricity consumers in the same building. The agriculture segment has enough space for a ground mounted installation, while the industry and residential house segments usually have enough rooftop area, or they may even have the possibility for a ground mounted installation.

		Rooftop	Ground mounted	Utility scale
Agriculture		No	Yes	Out of scope
Industry		Yes	Yes/No (depends on the case)	
Commerce		Yes (depends on activity and location)	No	
Residential	**House**	Yes	Yes/No (depends on the case)	
	Communities	Yes (if approval from the community, limited space)	No	

Table 8.2: Space availability by segment

In order to quantify the impact of this barrier, the activities of each segment that would have the potential to install a DG system have been selected (see Table 8.3). This way, those activities that do not have enough space or are not considered to be suitable for self-consumption are discarded. Additionally, only companies and businesses with annual revenues over 100 k€ have been selected in order to reject possible enterprises without activity. In the case of the activities 46 and 47, this figure has been increased to 500 k€. These activities have greater presence in urban locations, so a higher limit is taken in order to avoid small businesses inside buildings.

	Agriculture	Industry	Commerce
		Energy non-intensive	
Selected activities	• 01. Crop and animal production, hunting and related service activities • 021. Silviculture • 032. Aquaculture	• 10. Manufacture of food products • 11. Manufacture of beverages • 13. Manufacture of textiles • 14. Manufacture of wearing apparel • 15. Manufacturing of leather and related products • 16. manufacture of wood and of products of wood and cork, except furniture • 17. Manufacture of paper and paper products • 26. Manufacture of computer, electronic and optical products • 27. Manufacture of electrical equipment • 28. Manufacture of machinery and equipment nec • 29. Manufacture of motor vehicles, trailers and semi-trailers • 30. Manufacture of other transport equipment • 31. Manufacture of furniture • 32. Other manufacturing	• 451. Sale of motor vehicles • 46. Wholesale trade, except of motor vehicles and motorcycles • 47. Retail trade, except of motor vehicles and motorcycles • 52. Warehousing and support activities for transportation • 55. Accommodation • 61. Telecommunications • 72. Scientific research and development • 85. Education • 861. Hospital activities

Table 8.3: Selected activities by segment

In the case of the residential community segment, this impact is quantified by calculating the equivalent number of consumers by community that could have space for a PV installation in the roof. For this purpose, communities have been divided into two groups: communities with two or four apartments per floor. So, the rooftop space of each community will be calculated as (1) and the number of consumers per community as (2):

$$(1) \quad Aparments\ per\ floor\ (\#) * Average\ size\ of\ apartment\ (m^2) + Common\ areas\ (m^2)$$

$$(2) \quad \frac{Rooftop\ space\ (m^2)\ *\ Rooftop\ availability\ (\%)}{Power\ per\ installation\ (kW)\ *\ Area\ needed\ per\ power\ unit\ \left(\frac{m^2}{kW}\right)}$$

The average size of apartments in Spain [88] is in the range of 76-90 m^2, while the common areas are assumed to have 15 m^2 on average. As seen in chapter 4, the area needed for c-Si panels is 7 m^2 per kW and each installation is assumed to be of 3 kW. The available rooftop surface for PV panel installation has considered being around 45-50%. There are some buildings with flat roofs that have almost all the rooftop surface available for DG (see Figure 8.6 A). There are others, however, with the roof tilted (see Figure 8.6 B). Thus, they could only install PV panels on the side facing south. In addition, there are obstacles (e.g. chimneys) limiting the area in both cases. Assuming an availability of 70-75% and 25-30% respectively, the average availability has been taken as the arithmetic mean of both.

Figure 8.6: Pictures of two type of rooftops. A (left) and B (right)

Finally, the number of equivalent installation per community that would have space are 3.3 (communities of two apartments per floor) and 6.3 (communities of four apartments per floor).

b) Financial barrier

<u>Liquidity</u>

Consumers fulfilling the next criteria will be considered to have enough liquidity in order to afford the installation of a DG system, while the rest will be discarded:

- Monthly incomes per home of at least 2,000 € for residential consumers [89]. It is considered that people with less incomes may have financial difficulties to afford a 3 kW installation (~6,500 €)
- The last two years with positive cash flow for companies for businesses with annual revenues below 50 million €. Hence, only companies that have been generating money during the last two years are considered
- All companies and businesses with annual revenues over 50 million €, as they are considered to have access to external funding even if they do not have enough liquidity by their own

<u>Profitability</u>

A study carried by Ofgem [90] about customer engagements states that the 16% of the consumers would change of electricity supplier if they had annual savings of £0-50, another 35% would do it if this number was £51-100, a 34% if £101-200 and the resting 14% for +£201. As the average energy bill for residential consumers in the UK is £587 [91], the resulting adoption curve as a function of the percentage of savings is given by Figure 8.7 (it has been extrapolated by a fifth order polynomial function in order to have a continuous curve).

This curve is going to be the basis for the estimation of the DG adoption as a function of profitability. In this work, profitability plays the role of savings and is calculated as the percentage difference between electricity price and PV LCOE.

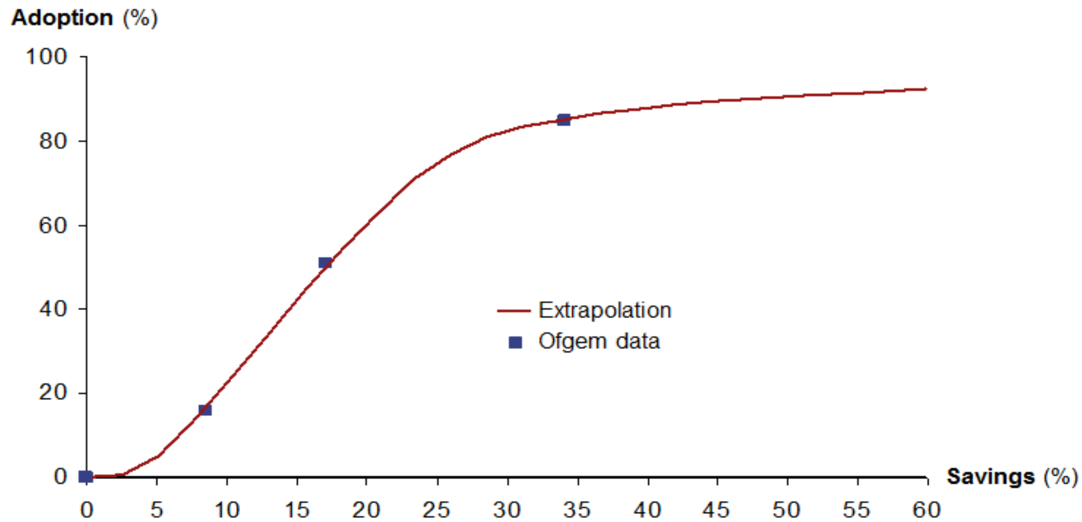


Figure 8.7: Adoption curve depending on saving *[based on "Customer Engagement with the Energy Market – Tracking Survey 2013", Ofgem – June 2013]*

Figure 8.8 shows the different elements that have to be taken into account during the profitability calculation. These elements are described next. The LCOE has been calculated using an excel model based on A.T. Kearney´s proprietary PV model.

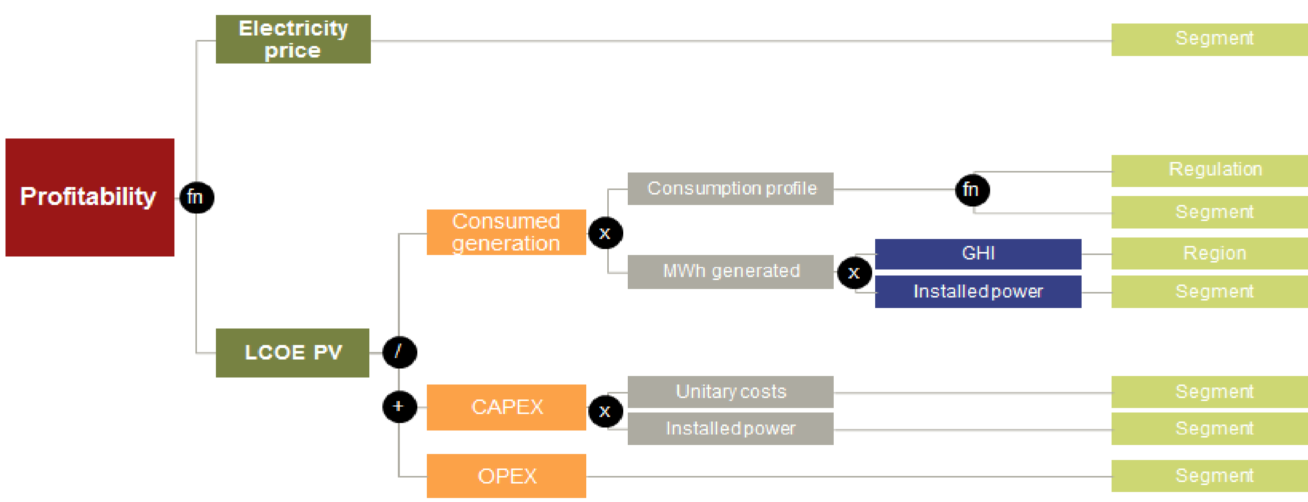
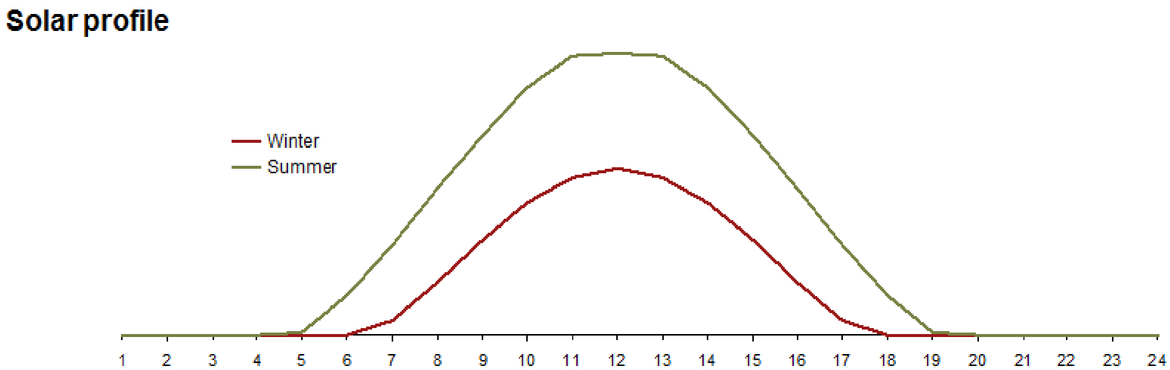


Figure 8.8: Profitability dependence chart

- *Electricity price:* it varies for the different segments. Each of the segments has been associated to the access tariff that fits with its characteristics (i.e. Agriculture: 3.1 A, Industry 3.1 A, Commerce: 3.0 A and Residential: 2.0 A - PVPC). In the case of PVPC, the price per kWh is immediate as it is fixed by the government and had a value of

0.1241 €/kWh in 2014. However, calculating the price for tariffs 3.0A and 3.1A is more complicated. These tariffs are divided into three periods and each period has its price. In order to obtain an unique price per kWh, the solar profile has been compared to the three periods and the percentage of energy generated on its period has been calculated. Then, the average weighted price is obtained. The prices shown in Table 8.4 are the arithmetic mean between prices in 2014 offered by Endesa and Gas Natural Fenosa. Figure 8.9 shows the solar profile and the period division for both tariffs.



3.0A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Summer	P3	P3	P3	P3	P3	P3	P3	P3	P2	P2	P2	P1	P1	P1	P1	P2	P2	P2	P2	P2	P2	P2	P2	P2
Winter	P3	P3	P3	P3	P3	P3	P3	P3	P2	P2	P2	P2	P2	P2	P2	P2	P2	P2	P1	P1	P1	P1	P2	P2

3.1A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Summer	P3	P3	P3	P3	P3	P3	P3	P3	P2	P2	P1	P1	P1	P1	P1	P1	P2	P2	P2	P2	P2	P2	P2	P2
Winter	P3	P3	P3	P3	P3	P3	P3	P3	P2	P2	P2	P2	P2	P2	P2	P2	P2	P1	P1	P1	P1	P1	P1	P2

Figure 8.9: Solar profile and period division for 3.0A and 3.1A tariffs *[based on MINETUR]*

Comparing the solar profile and period divisions in summer and winter, results for a 3.0A consumer are that almost 60% of generation is done during period 2, almost 30% during period 1 and the resting 10% in period 3. In the case of a 3.1A consumer, figures are 42.5% during period 1, 48% during period 2 and 10% during period 3. In order to obtain an only price for each kWh consumed, the weighted average of prices is calculated using the following formula:

$$Weighted\ average\ price\left(\frac{€}{kWh}\right) = Price\ P1\left(\frac{€}{kWh}\right) * Generation\ P1\ (\%) + Price\ P2\left(\frac{€}{kWh}\right) * Generation\ P2\ (\%) + Price\ P3\left(\frac{€}{kWh}\right) * Generation\ P3\ (\%)$$

Results are shown in the next table:

Access tariff	Prices 2014 (€/kWh)			Generation per period (%)			Weighted average price (€/kWh)
	P1	P2	P3	P1	P2	P3	
3.0 A	0.1643	0.132	0.0905	29.96	59.75	10.29	0.1374
3.1 A	0.1331	0.1161	0.0845	42.59	47.11	10.29	0.1201

Table 8.4: Weighted average price calculation for 3.0A and 3.1A tariffs

- *Consumed generation:* all the generated energy may not be consumed instantly. So, unless the system has storage or net-metering is approved (see Regulatory barrier), the electricity that is not consumed at the moment will be lost. The generation pattern and the consumption profile for each segment have been compared. Ideally, the system can be sized so that the generated power and the consumed power are equal during the peak generation moment. Next figure shows the comparison between both profiles and the percentage of energy consumed instantly.

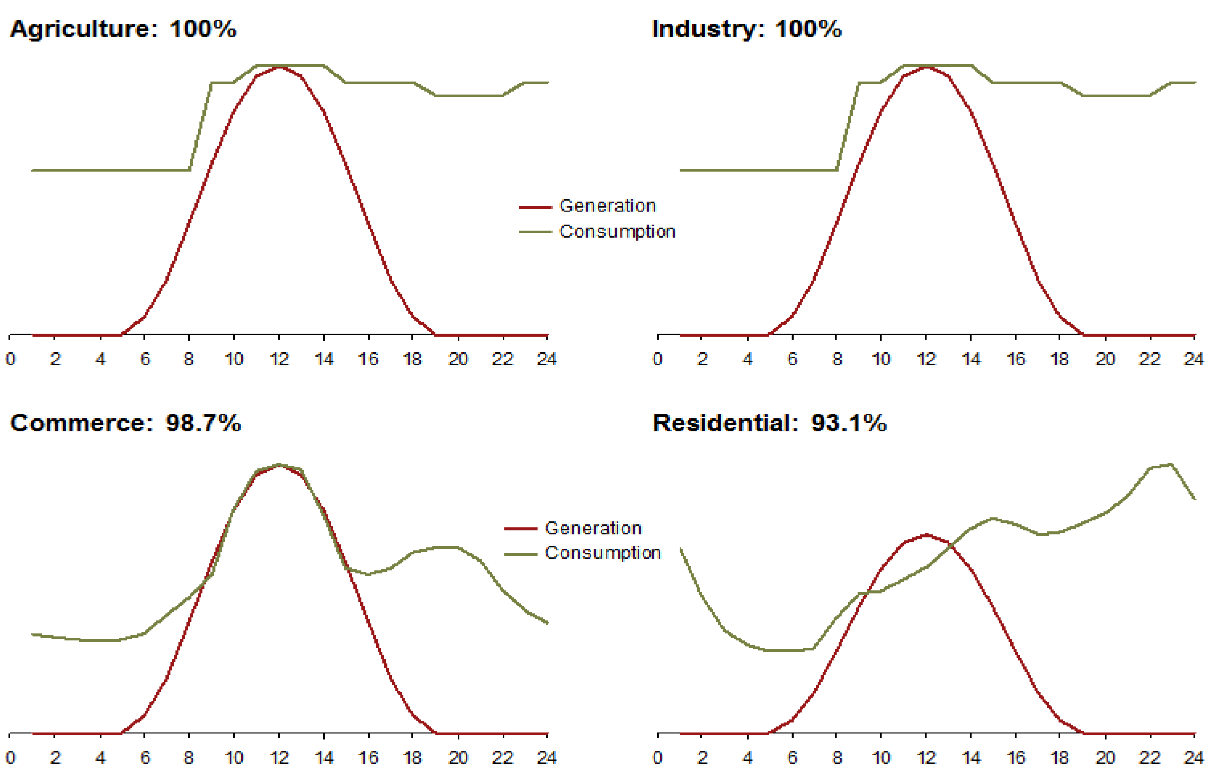


Figure 8.10: Solar and consumption profile comparison *[based on REE and MINETUR]*

- *CAPEX and OPEX:* inputs have been taken from A.T. Kearney´s PV model and some have been reviewed and updated. Module price is one of the most relevant inputs. Its price at utility scale is currently in the range of 0.48-0.52 €/Wp (0.52 €/Wp for European and Chinese modules, 0.48 €/Wp for other Asian modules) [92]. It has been assumed that residential prosumers could buy modules a 20% more cost than utilities, Commerce and Agriculture segments a 15% and Industry a 10%. Some of the most important inputs are shown in the next table:

	Agriculture	Industry	Commerce	Residential
Module price (€/Wp)	0.552	0.528	0.552	0.576
Log slope of price experience curve (%)	-20	-20	-20	-20
Inverter price (€/Wp)	0.21	0.17	0.21	0.33
Operation, monitoring & maintenance (€/Wp)	0.36	0.36	0.36	0.27
Total system life cycle cost (€/Wp)	1.93	1.82	1.93	2.18

Table 8.5: Sample of relevant LCOE model inputs

Investment pay-back period

This barrier is only considered in the residential case. The other segments are assumed to have lower rotation rates and going deeper has been considered of reduced relevance. The impact of this barrier has been calculated as the percentage of consumers that change of house before the pay-back period. For the calculation, it has been assumed an electricity price of 0.1241 €/kWh in 2014 and an annual average growth of 2%.

		North	Centre	South	Islands
Total installation costs for 3 kW system	(€)	6,540			
Generation per kW	(kWh/kWh/year)	1,078	1,215	1,357	1,287
Total generation	(kWh/year)	3,234	3,645	4,071	3,861
First year electricity price	(€/kWh)	0,137			
First year savings	(€)	443	499	558	529
Pay-back period	(years)	13.1	11.8	10,6	11.2
Average 2007-2013 home purchases	(units)	453,045			
Total number of houses	(units)	18,125,000			
Rotation during pay-back period	(units)	5,921,402	5,324,874	4,822,011	5,057,726
	(%)	32.67	29.38	26.6	27.9

Table 8.6: Calculation of investment pay-back period impact

Similarly, the pay-back period for secondary residential houses has been calculated. These houses are usually located in sunny region and their usage is limited to holidays or some weekends. So, in this case, South's region irradiation is going to be used and two months of usage per year are going to be assumed. It results in pay-back periods longer than 35 years.

c) Mindset barrier

Everyone has this barrier, in some cases it may be larger than in other ones, but it is always present. The quantification of its impact is based on the idea that a higher profitability overcomes this reluctance. So, it has been implemented as an extra percentage of the profitability demanded for a given adoption, this is, a displacement of the adoption curve in Figure 8.11. Three levels of reluctance have been defined. Each of these levels has associated an extra percentage of profitability required: low (0 p.p.), medium (+5 p.p.) and high (+10 p.p.). The resulting adoption curves are shown in the next figure:

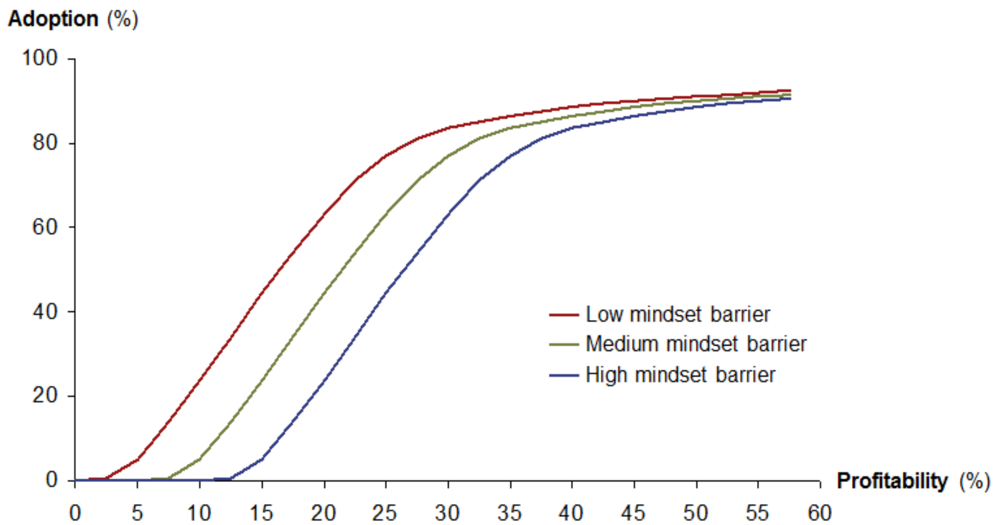


Figure 8.11: Adoption curve for the different mindset barrier levels

Each of the segments and activities has been classified into one of the levels depending on their predisposition to changes and new technology. The default level is set to be the medium level. Some activities have been moved to the lower level due to greater affinity to technology (i.e. 61. Telecommunications and 72. Scientific research and development). The residential community segment has been moved to the higher level as it requires from the approval of the whole community (There may be people with different affinities to PV and it could imply difficulties).

d) Regulatory barrier

Each of the cases is based in the energy policies taken in the different scenarios in chapter 5. The three different cases and their implications on the model are shown next.

- *Case 1, no regulation:* self-consumption is neither supported nor discouraged with tolls. So, energy that is not consumed instantly is wasted. The impact has been modelled applying the percentages in Figure 8.10 to the generated energy
- *Case 2, back-up toll:* this case simulates the situation in which the draft RD announced in July 2013 is approved. It has the following implications in the model:
  - As in the no regulation case, energy not consumed instantly is wasted
  - Each generated and consumed unit of energy is penalized with a toll. The toll for the 3.0 A and 3.1 A tariffs is given in three periods. Methodology followed to obtain a weighted average toll is the same as in the case of the electricity price. Additionally, the draft RD considered self-consumption only those units under 100 kW. So, as the DG systems for the industry system are going to be larger than 100 kW, there is no toll for the industrial segment

	Agriculture	Industry	Commerce	Residential
Back-up toll (cent€/kWh)	2.64	0	2.87	6.76

Table 8.7: Back-up toll by segment *[based on Draft RD for self-consumption, July 2013]*

- *Case 3, net-metering:* It is assumed that each kWh introduced to the grid can be consumed later without any cost. In the practice, net-metering would be comparable to a DG system with storage. So, all the generated energy would be consumed, even if it is not instantly. It has the following implications in the predictions:
  - The consumption profile is not taken into account in the LCOE model and all the energy generated is consumed
  - As the grid acts like a storage system, the PV size does not have to match with the consumption profile. Thus, a 50% more installed capacity is assumed per each DG unit

e) Prosumer to MW and MWh conversion

As a result of applying the previously explained barriers, the predicted number of consumers is obtained. This figure, however, is not representative of the threat that distributed generation supposes to utilities. The last step consists on converting the number of self-consumer in capacity and energy. This measure will give a more accurate idea of the impact of DG.

For this purpose, each segment has been assigned a kW per prosumer ratio. In the case of Commerce segment, as it groups different kind of activities, it has been divided into three groups and each of the groups has its own kW per consumer ratio (see Table 8.8).

	Agriculture	Industry	Commerce			Residential
			Group 1	Group 2	Group 3	
Capacity (MW)	50	120	25	50	75	3

Table 8.8: Capacity per installation by segment

Finally, the capacity to energy conversion depends on three factors. The first one is the solar irradiance of each region. So, each region has a kW to kWh conversion. Secondly, large installations usually have better performance factors than smaller ones. As a consequence, the residential segment has a slightly smaller kWh per kW ratio. And finally, it depends on the regulatory case. For instance, in the net-metering case all the generated energy is consumed, but in no regulation and back-up toll cases, percentages in Figure 8.10 have to been applied. Table 8.9 shows the kW to kWh conversion taking into account just the first two factors.

(kWh/kW)	Residential	Agriculture, Industry and Commerce
North	1,078	1,153
Centre	1,215	1,299
South	1,357	1,450
Islands	1,287	1,375

Table 8.9: Capacity to Energy conversion table

f) Summary

Figure 8.12 and Figure 8.13 show the flow diagram of the explained methodology. Steps in Figure 8.12 are common in all regulatory cases. Steps in Figure 8.13, however, are different depending on the regulatory case. So, first steps have been done just once, while the last steps have to be repeated for each regulatory case.

Two sources have been used to determine the initial number of homes and companies. In the case of the residential segment, data has been taken from the *Encuesta Continua de Hogares 2013*[1] elaborated by INE (Spanish statistics national institute). In the case of the other segments, the SABI database of companies has been used.

[1] Continuous home survey 2013

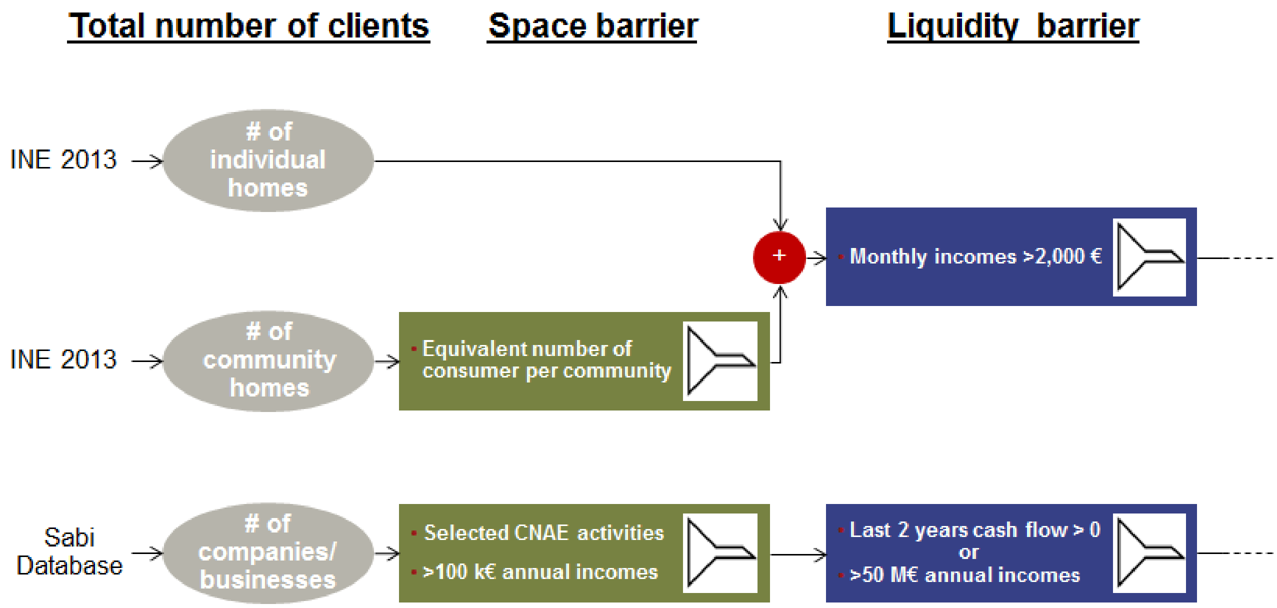


Figure 8.12: Flow diagram of methodology (1/2). Common for all regulatory cases

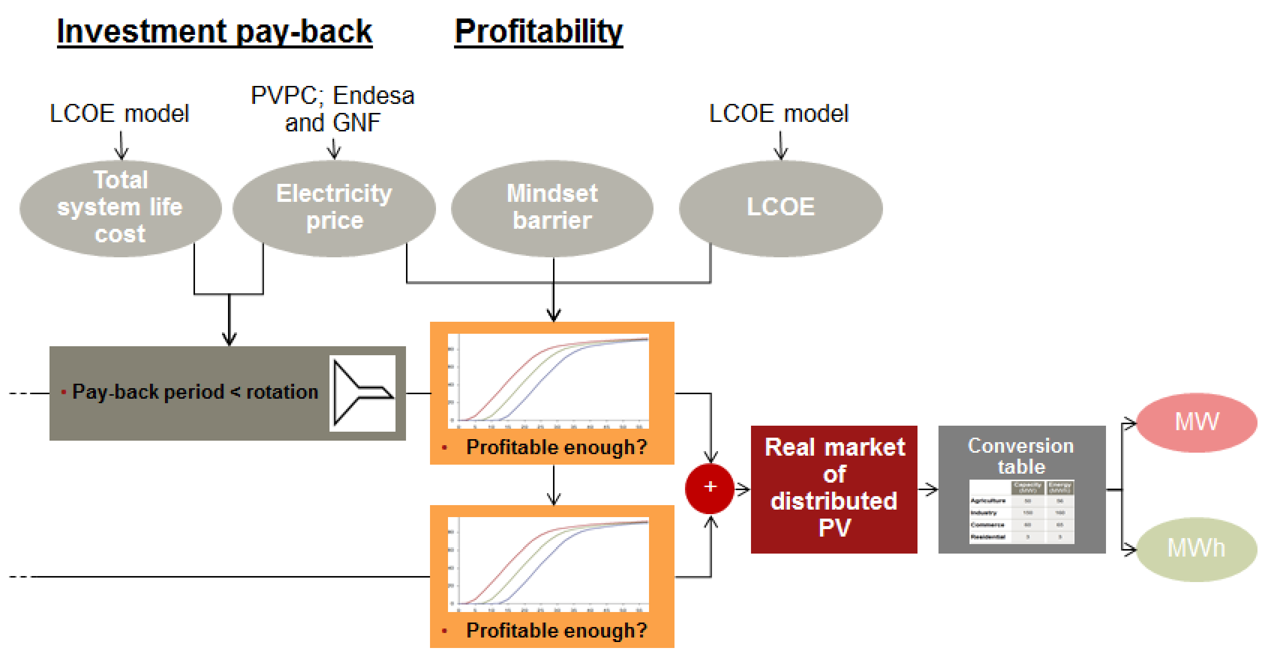


Figure 8.13: Flow diagram of methodology (2/2). Repeated for each regulatory case

8.2.2 Detailed projections

Results are presented from different perspectives in order to gain in clarity and make easier their understanding. Final results for each of the regulatory cases are shown first. This is the adequate snapshot to identify which segments and regions have the greater potential for distributed generation. Then, intermediate results of the procedure are presented for each segment. This photo shows the effect different barriers have on each segment.

8.2.2.1 By regulatory case

<u>Case 1: No regulation</u>

Distributed generation has the larger potential in the commercial segment. From the 5.7 GW of installed capacity, more than the half corresponds to this segment. In the residential segment, although the predictions point almost 400 thousand prosumer (85%), they only account for the 20% of the installed capacity and 19% of the consumed energy.

The region with greater adoption is the Centre region with more than 45% of the installed capacity. South region occupies a second place with more than 36%. This results show that, as stated in chapter 5, self-consumption would start first in the sunniest regions. The share of Islands region is reduced due to the small number of people and companies they have. The North region, however, has the lowest adoption (7.6%) due to the lack of solar resource. So, one thing can be concluded: even if grid parity will be reached in all Spanish regions, the obtained profitability is not good enough in less solar irradiance locations and it will take longer than 2020 to have significant adoptions.

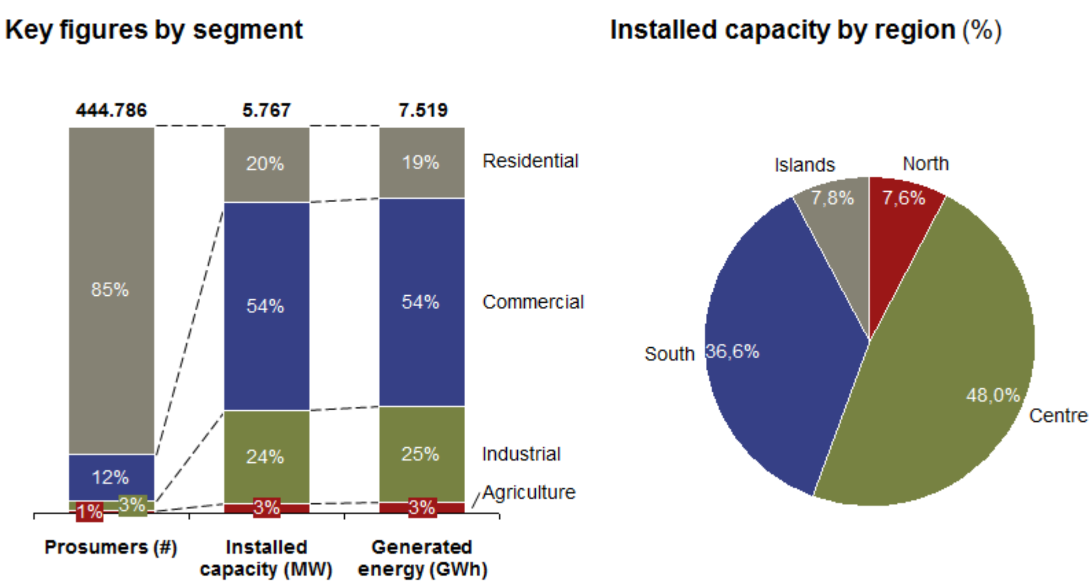


Figure 8.14: Snapshot of key results for Case 1

Case 2: Back-up toll

One main conclusion can be derived looking at Figure 8.15: the back-up toll would have a very impactful discouraging effect, i.e. installed capacity less than a third than in the previous case (and it would be significantly lower if the industry segment was excluded). In the residential segment, this toll would make DG totally unprofitable; in the commerce segment installed capacity would reduce to less than a 20%; and in the industry segment, it would not have segment as installations over 100 kW would not be considered self-consumption and would not have a toll.

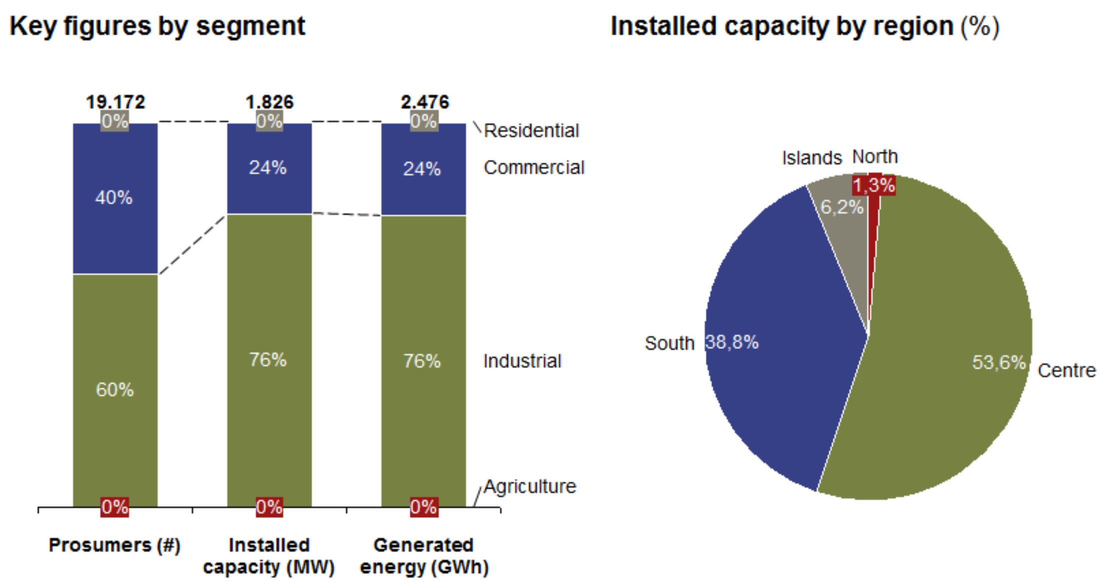


Figure 8.15: Snapshot of key results for Case 2

Case 3: Net-metering

Net-metering would mean a real impulse for distributed generation: installed capacity would be almost double than in the no regulation case (i.e. 11.4 GW). It would specially boost the residential segment. The reason is simple: while other segment´s electricity consumption peak matches almost perfectly with the solar profile, it is shifted to three hours later and the coincidence between consumption and solar profile is not the 100% as in the other cases. So, as in net-metering the grid works as a storage system for the prosumer, all the previously wasted energy is now consumed and profitability improves.

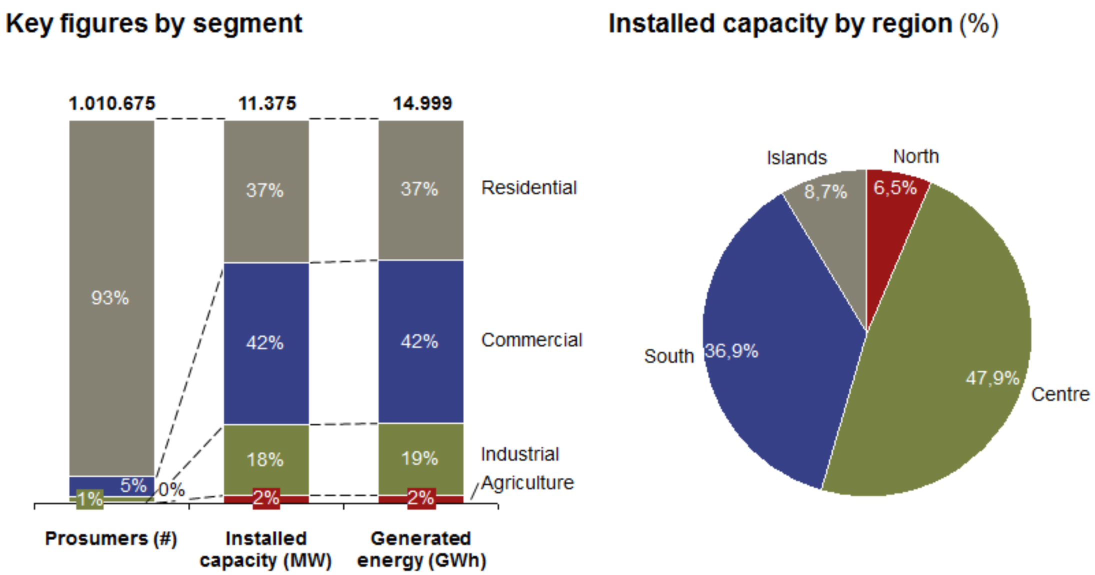


Figure 8.16: Snapshot of key results for Case 3

8.2.2.2 By segment

Next, the estimation processes for each of the segments are shown. As it can be seen in the different figures, space barrier is the barrier that has the greatest impact followed by profitability and liquidity barriers.

Agriculture

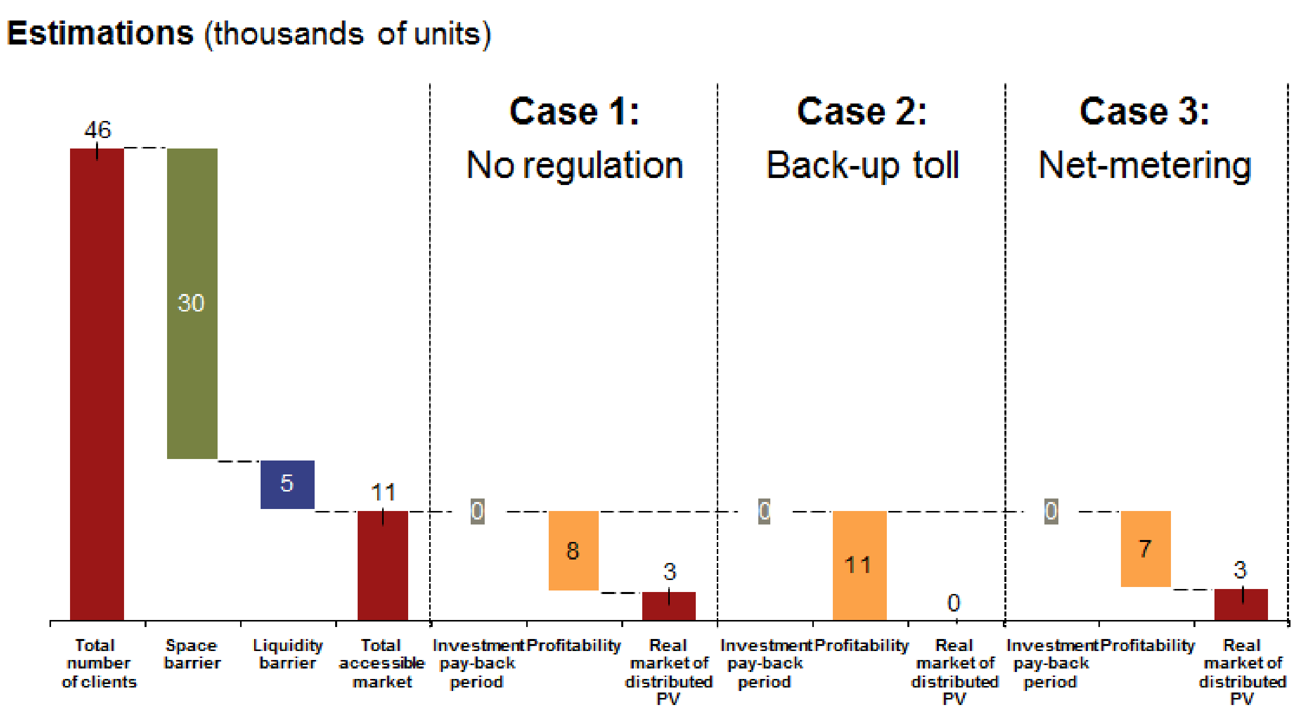


Figure 8.17: Step-by-step results of the prediction procedure (1/4) Agriculture segment

Industry

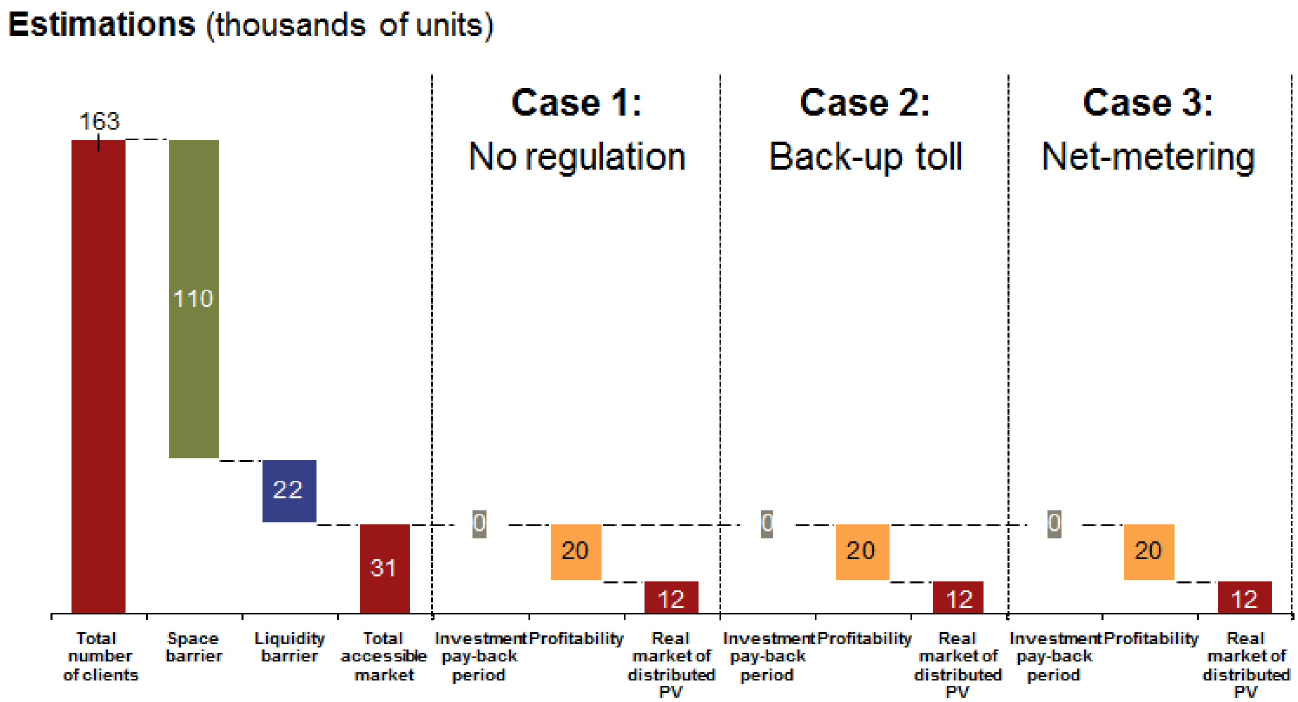


Figure 8.18: Step-by-step results of the prediction procedure (2/4) Industry segment

Commerce

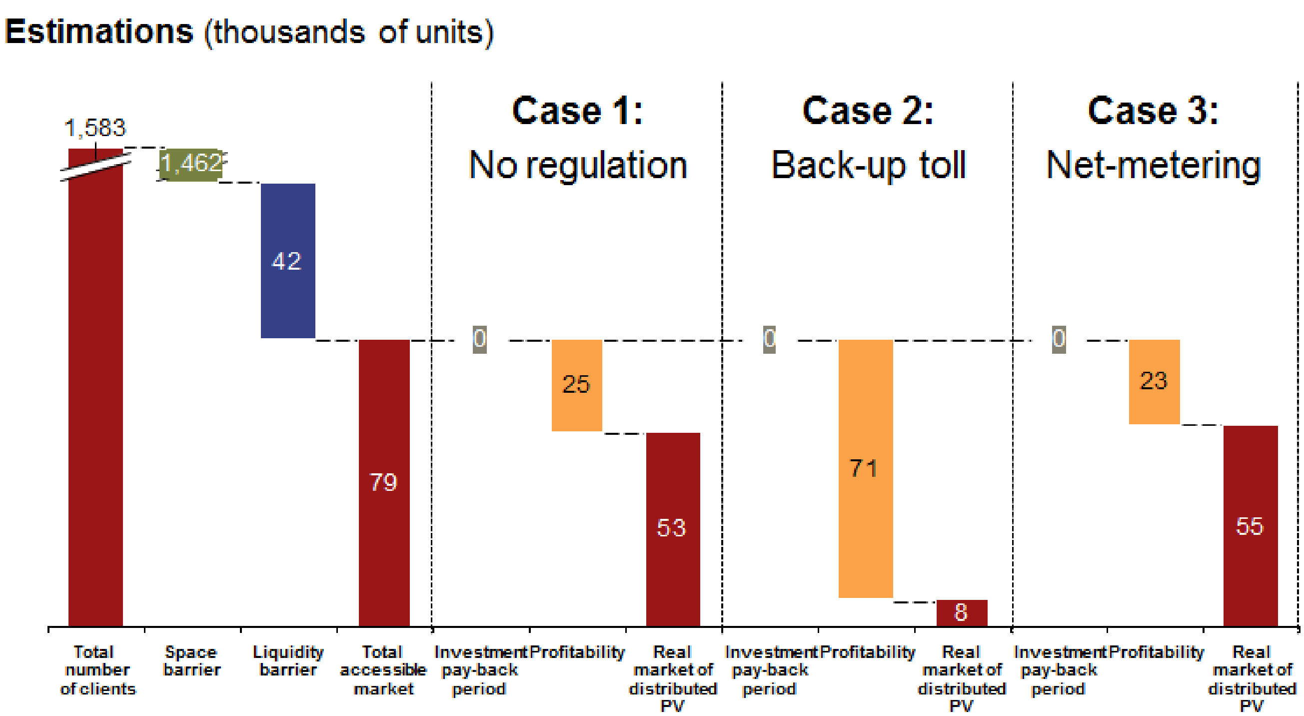


Figure 8.19: Step-by-step results of the prediction procedure (3/4) Commerce segment

Residential

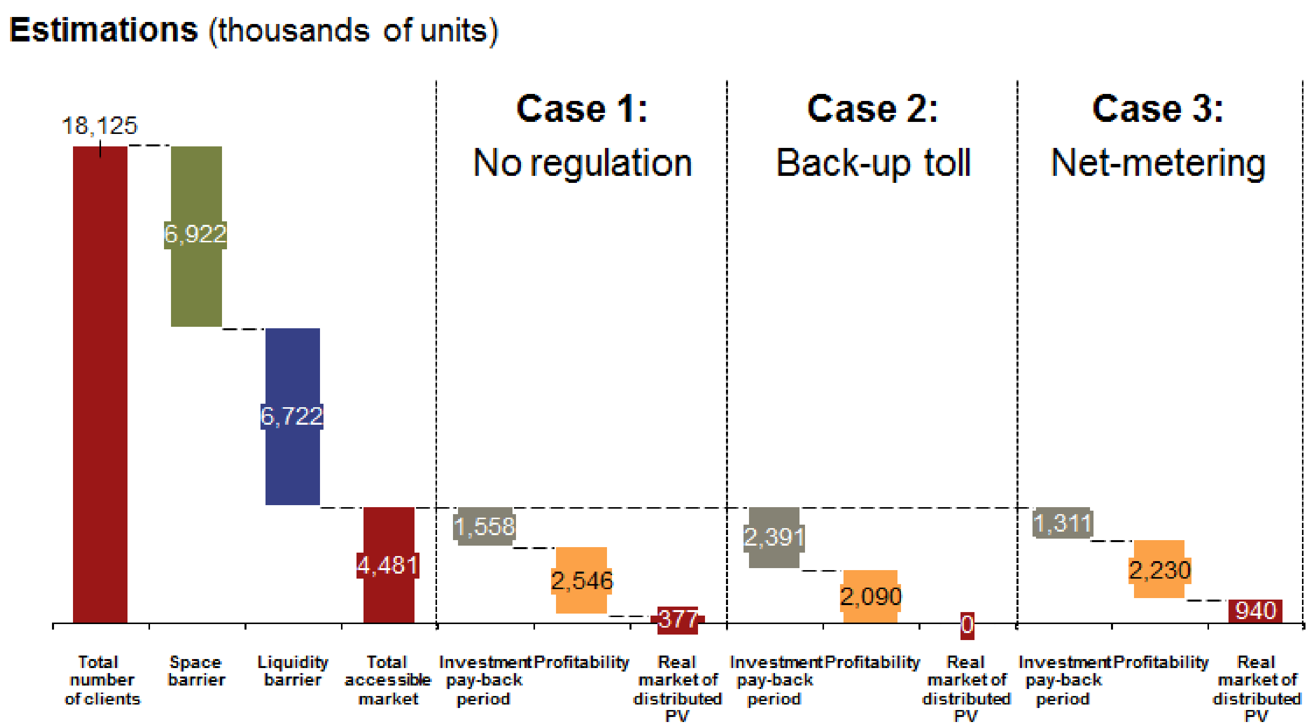


Figure 8.20: Step-by-step results of the prediction procedure (4/4) Residential segment

Chapter 9

Conclusions

Disruption in the electric sector is imminent and unstoppable. It started in the last decade with green energy policies driving the rally towards renewable energy (e.g. already a 43% of electricity consumption in Spain). Even if there are certain doubts about the affordability of this transition, the process keeps moving forward. Booming innovation in renewable is gradually improving its competitiveness. So the moment in which green energy policies will not be the main driver for renewable expansion will arrive for sure. Moreover, even if regulation tries to oppose renewable expansion, solid economic fundamentals will enable the deployment. The case of distributed generation is a good example. A back-up toll has been announced in Spain to retribute the grids and create barriers to distributed generation. Moreover, the toll increases the incentives of “prosumers” to install storage capacity, thus further fostering innovation and investment in DG.

The benefits of renewable energy are clear: reducing environmental impact and dependence on fossil fuels and foreign energy. Nevertheless, green energy policies have considerably increased the final consumer’s energy bill in Spain and in Europe as a whole. So, if regulators have the aim to keep subsidizing renewable energy, they have to find the way of doing it with the minimum impact on the consumer. Europe is realizing how to balance these two objectives at a minimum cost (though probably after significant investments have been committed). For instance, the UK has successfully moved to a more efficient mechanism with their last energy reform. They have managed to foster best practices and techniques in the renewable industry by establishing a competitive budget allocation process. As a result, the new mechanism is driving LCOE reductions while keeping renewable support affordable.

Finally, the disruption of the electric system is a challenge for electric utilities as it will affect their P&L. Traditionally, the electric sector has been a profitable business in which there were several barriers for new entrants. This is about to change and utilities have two alternatives: either they try to prevent disruption from happening by establishing barriers, or they radically reshape their business model to sustain their positioning in the new paradigm of electric sector. This project has shown enough evidence about disruption being unstoppable. In the long run, barriers will have a very limited effect and it would imply losing ground against competitors. There is therefore only one choice for utilities: to reshape their business model. Utilities have to *adapt or die*. Several utilities have already started this reshaping process. As previously discussed, E.ON has placed a bet on these trend, and has decided to focus on renewable energy, networks and distributed generation, spinning-off their conventional generation business. Some other European utilities might replicate this move in order to sustain their profitability and gain competitive advantage. But in addition to challenges, there are also attractive opportunities that utilities will need to capture. Storage, electrification of energy consumption, and the electric vehicle in particular, could place utility companies next to the client, in the center of the new energy paradigm.

Annex: Shortlist of energy start-ups and companies

The following table shows the list of the start-ups and companies that have been selected to be analyzed during the project due to having relevant innovative technologies:

Technology			Start-up/Company	Country
Generation				
Solar	Photovoltaic	si-PV	Beacon Solar Energy	USA
		si-PV	EverGreenSolar	China
		si-PV	Enphase Energy	USA
		si-PV	SunEdison	USA
		si-PV	SunPower	USA
		si-PV	tenKSolar	USA
		Thin-film PV	Anwell technologies	Hong Kong
		Thin-film PV	Ascent Solar	USA
		Thin-film PV	First Solar	USA
		Thin-film PV	Solar Frontier	Japan
		Thin-film PV	Xunlight Corporation	USA
		CPV	Soitec	France
		CPV	Suncore Photovoltaic Technology	China
		CPV	Zytech	Spain
		Organic PV	Heliatek	Germany
		Silicon gas made PV	Solexel	USA
	CSP	Parabolic trough and Solar Tower	Abengoa Solar	Spain
		Parabolic trough	Sener Group	Spain
		Parabolic trough	Solar Millennium	Germany
		Solar Tower	BrigthSource Energy	USA
		Solar Tower	eSolar	USA
		Solar Tower	SolarReserve	USA
		Solar Tower	Torresol Energy	Spain
		Linear Fresnel	Novatec Solar	Germany

Wind	Onshore wind	AML	USA
	Onshore wind	Angle Wind	Norway
	Onshore wind	Atlantic Bearing Services	USA
	Onshore wind	Boulder WindPower	USA
	Onshore wind	ChapDrive	Norway
	Onshore wind	Enercon	Germany
	Onshore wind	Skyacht Aircraft	USA
	Onshore/Offshore wind	Dong Energy	Denmark
	Onshore/Offshore wind	Vestas	Denmark
	Offshore wind	Alstom	France
	Offshore wind	Blue H	UK
	Offshore wind	E.ON	Germany
	Offshore wind	Hexicon	Sweden
	Offshore wind	IDEOL	France
	Offshore wind	Nass & Wind	France
	Offshore wind	Principle Power	USA
	Offshore wind	Samsung	South Korea
	Offshore wind	Senvion	Germany
	Offshore wind	Statoil	Norway
	Offshore wind	The Golsten Associates	USA
	High Altitude Wind Power	Altaeros Energies	USA
	High Altitude Wind Power	Ampyx Power	Netherlands
	High Altitude Wind Power	KiteGen	Italy
	High Altitude Wind Power	Makani Power	USA
	High Altitude Wind Power	SkySails Power	Germany
Less established technologies	Geothermal	Ecoforest	Spain
	Geothermal	Green Energy Group	Norway
	Ocean Energy	AWS Ocean Energy	UK
	Ocean Energy	Oceanlinx	Australia
	Ocean Energy	OPT ocean power technologies	USA
	Ocean Energy	Pelamis wave power	UK
	Ocean Energy	Wave Dragon	Denmark
Conventional generation	CCS	SaskPower	USA
	Fission	Generation IV International Forum	International
	Nuclear Fusion	ITER	International
	Nuclear Fusion	Lockheed Martin	USA

Storage				
Chemical energy		Hydrogen	Altergy Systems	USA
		Hydrogen	Ballard	Canada
		Hydrogen	École Polytechnique Fédérale de Lausanne	France
		Hydrogen	Hydrexia	Australia
		Hydrogen	Hydrogenics	Canada
		Hydrogen	McPhy Energy	France
Electrochemical energy	Batteries	Aqueous Hybrid Ion	Aquion Energy	USA
		Lithium-ion	ABB	Switzerland
		Lithium-ion	China BAK Storage	China
		Lithium-ion	Envia Systems	USA
		Lithium-ion	Tesla Motors	USA
		Liquid metal battery	Ambri	USA
		Zinc Hybrid Cathode Technology	Eos Energy Storage	USA
	Ultracapacitors		Ioxus	USA
Mechanical energy		CAES	Airlight energy	Switzerland
		CAES	LightSail Energy	USA
		LAES	Highview Power	UK
		Flywheel	Beacon Power Corporation	USA
Thermal energy		PHES	Isentropic	UK
Efficiency				
Performance efficiency			4energy	UK
			Bridgelux	USA
			Cooltech Applications	France
			NovaLed	Germany
			Nualight	Ireland
			Phoebus Energy	Israel
			Phononic	USA
			SorTech	Germany
			Va-Q-tec	Germany
Monitoring and management			Digital Lumens	USA
			Enlighted	USA
			FirstFuel	USA
			Gridpoint	USA
			iControl Networks	USA
			Ijenko	France
			Nest	USA
			Opower	USA
			Qualisteo	France
			Tendril	USA
			Wattio	Spain

Building materials	Next step living	USA
	Project Frog	USA
	SageGlass	USA
	Sefaira	UK
	Serious Energy	USA
Infrastructure		
Grid management	AutoGrid	USA
	Cisco Systems	USA
	Enbala	Canada
	Gridco Systems	USA
	Intel	USA
	Itron	USA
	On-Ramp Wireless	USA
	Schneider Electric	France
	Space-Time insight	USA
	Trilliant	USA
T&D grids	Amantys	UK
	Transphorm	USA
Wide Technology portfolio		
Wind, Solar Photovoltaic, CSP, Hydroelectric, Biomass	Acciona	Spain
Nuclear, Wind, Solar, Hydrogen storage	Areva	France
Wind, Solar, Nuclear	NextEra Energy resources	USA
Renewable energy, Fossil fuel, Smart grids, Hydrogen Storage	Siemens	Germany
Si-PV, Thin-film, Hydrogen storage	The Linde Group	Germany

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