UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

Forecast of schedule of different technologies and prices for the period 2020 to 2030 for the Iberian energy market

Author: Miguel Roa Prieto
Supervisor: Juan Bogas Gálvez
Co-Supervisor:

Madrid, July 2018

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Summary

Introduction

This Project tries to forecast as precisely as possible the energy prices in the Iberian Market between the years 2020 and 2030, taking into account the European goal of reducing the emissions and the evolution of the different technologies in order to do so.

Therefore, this project will consider many factors: demand evolution, electricity generation technologies maturity, energy policy evolution, public opinion, etc. Some factors evolution are extremely uncertain, so, some of them are inputs for the model: efficiency rate, coal plants dismantlement, political decision of renewing nuclear plants operation license, CO_2 price rate and hydro management horizon.

Methodology

The forecast of electricity prices is carried out hourly, following the next steps:

Firstly, the demand is estimated based on the historical profile data and updated according to expected evolution of GDP, population and efficiency.

Then, the need of RES capacity to accomplish 2030's polluting emission objectives as well as satisfying demand is estimated. This is done by means of an iterative generation dispatch process only for 2030, starting the dispatch with capacity already installed in 2020. The capacity to be installed increases until carbon dioxide emission limit is not surpassed. The new capacity is allocated to one or another technology depending on expected availability factors at critical hours, which are calculated based on historical data.

Once the new capacity to be installed during the next decade is known, the model considers a progressive deployment of the capacity, installing every year the same amount.

At this point, the dispatch for all hours of the decade 20-30 is computed. Dispatching methodology is based on the lowest cost merit order.

Finally, hourly electricity prices are calculated based on previous generation dispatch. The electricity price is the cost of producing the most expensive MWh dispatched.

Results and conclusions

Several scenarios are analysed for different levels of demand efficiency, plants dismantlement and CO_2 price.

Model results show that political decisions to be taken in the near future in terms of RES support mechanisms design and nuclear and coal plants dismantlement; added to efficiency evolution are extremely critical regarding electricity prices and RES capacity needs. Figure below shows different efficiency scenarios of RES capacity to be installed before 2030 considering that nuclear plants renew their license for 20 years more and the contrary.

NUCLEAR (+20years)					
Annual efficiency rate (%)	0.00	0.25	0.50	0.75	1.00
Wind (GW)	52.3	50.6	45.8	39.8	35.7
Solar PV (GW)	32.6	29.5	26.6	24.1	21.8

NUCLEAR (off)					
Annual efficiency rate (%)	0.00	0.25	0.50	0.75	1.00
Wind (GW)	88.4	83.5	77.3	72.0	65.5
Solar PV (GW)	49.7	46.0	44.5	42.0	39.2

Figure: RES Capacity to be installed before 2030

Contents

1 Introduction

This Project will try to forecast as precisely as possible the energy prices in the Iberian Market between the years 2020 and 2030, taking into account the European goal of reducing the emissions and the evolution of the different technologies in order to do so. Therefore, this project will consider a large number of factors:

Firstly, we will obtain a perspective of the complete framework by analysing in depth the factors that impact in energy prices

Secondly, the direct relation of each of these affecting factors with the final energy prices will be set up. To do so, the level of impact has been evaluated attending studies carried out by the outstanding universities, institutions or research institutes, included in references, as it is necessary to develop advanced models in order to consider several scenarios.

Finally, a model which gives the resulting electricity prices will be developed by taking as a starting point, current price tendencies and several inputs that depend on the before-mentioned factors.

In this regard, the key point in the long-term energy prices is the energy transition. This transition has to be ambitious and realistic, as the social and natural resources claim for it. As per AEE (Asociación Empresarial Eólica), the energy transition is an opportunity for Spain in order to strengthen its security of supply and to be environmentally responsible. This transition must be [AEE_17]:

- Ambitious

The targets for the next years must be realistic and above all demanding, as it is important to push the institutions and private companies for:

  - 80% decarbonization of the electric power industry in 2030
  - 100% decarbonization of the electric power industry in 2050
  - At least a 35% of the final energy must be produced by renewable energy sources in 2030
  - At least an 85% of decarbonization of the economy in 2050

- Efficient and economic sustainable

It has to be done in a continuous way, ensuring the short-term and long-term energy supply to the consumers. As well as, keeping the investment made secure along the process.

Additionally, the Bonn Climate Conference, COP 23, held in Germany in November 2017 has decided to stop giving incentives to carbon dioxide emitting plants.

- Electric

The electric vector must enable the decarbonization with the most competitive technologies. Therefore, the electric power industry has an important role in this energy transition. This is the reason why energy prices are highly affected.

- Organized and secure

Carbon dioxide emissions reduction has to be carefully programmed with long perspective, as the decarbonization depends on the investments carried out in order to build more sustainable plants.

Hence, all measures that are being considered regarding energy generating technologies, have a specific objective: energy's decarbonization in order to eliminate the carbon dioxide emission that causes the climate change.

The international Paris Agreement signed in 2015 is not an energetic but an environmental agreement. The objective is to keep the rising average world temperature lower than 2ºC in 2050, which is very related to the energy sector. Additionally, this increase shall be lower than 1.5ºC, over the global pre-industrial average temperature.

To accomplish the mentioned objective, IPCC's models have established that carbon dioxide emissions at global level shall be reduced between an 80 and 90% with respect to 1990 [IPCC16]. It is translated into 70%-90% reduction of fossil fuel consumption with respect to current levels.

According to AEE, there are mainly seven reasons why energy transition is imperative:

1. Our current energetic model is incompatible with the climate and health protection, as it is based on fossil fuels, the main motor of climate change and the problems with air quality.
2. Electrification is the only way: In order to produce energy without emissions, the only way that exists is by means of electric generators: photovoltaic panels and wind turbines.
3. Long-term planning: The generators and lines constructed today are the ones that will be operating in 2030, and possibly repowered for 2050. Additionally, the energy policies must cover a huge number of sectors: hydro resources, air quality, construction incentives, industrial development, etc. Technology and financing are already available; therefore, it is necessary to set the framework.
4. Now is the appropriate political moment: Current political parties must start a plan for 2030-2050. Otherwise, in 2030 the Spanish society will not have room for maneuver. It is crucial to have a political consensus in order to guarantee sustainability on financing, social trust, etc.
5. Reflection on market design: Signals sent to investors must be the appropriate ones. The present design must change: The most expensive technologies producing energy are those that generate carbon dioxide emissions. If they start to disappear, the energy price will start to become lower and investors will not recover their costs. Therefore, new incentives or other tools must be designed.
6. Participation of all involved sectors: A rigorous and transparent debate is mandatory, as well as a framework that promotes social participation.
7. Communication and social consciousness.

This project will include several possible scenarios that could be able to achieve the objective, considering the current plans for the energy system. These scenarios will be evaluated in order to forecast the energy prices in 2020-2030.

2 Current situation of the energy market

The Iberian market is a very mature and competitive market. In this section is introduced the historical evolution and the main characteristics as per following sections:

2.1 Introduction and historical evolution of Iberian Electricity Market

At the end of XIXth century, electricity appears as an invention able to replace man and animal power. It started as a privately-owned business that expanded little by little, as small companies that distributed electricity in their communities.

Very quickly it turned into an essential good, required by the consumer to sustain health or life. Also, they realized that electricity transmission and distribution were natural monopolies, that is, what is been supplied can be supplied or produced in the most efficient way by concentrating all consumers in order to take advantage of economies of scale. All this made price control necessary.

In these times, companies realized it would be more efficient to gather together and electricity companies ended up being bigger. Then the government at that time divided territories into franchises and gave one to each. (In Madrid, the former Hidroelectrica and Unión Eléctrica, currently Iberdrola and Gas Natural Fenosa). Since then, regulation has changed based on technological changes.

Until then, generation was mainly distributed. However, when alternate current developed, long distance transmission with low losses was a possibility. Businesses realized that there was a way to take advantage of economies of scale also in generation. This meant, for instance, the development of big hydropower plants and coal power plants closer to the mines.

At the end of the Second World War, power systems were completely devastated, there was no money to restart the business. Therefore, power systems were fully nationalized in Great Britain, France, Italy, Belgium, etc. In Spain, the dictatorial State in collaboration with the most relevant energy companies funded UNESA (Unidad Eléctrica, S.A). Its aim was to coordinate the ensemble of the electric power system at national level, in order to supply the whole demand and cover the future capacity's requirements. However, UNESA was fully regulated and centralized planned.

Until the 1990's regulation worldwide was based on heavy State planning and intervention, prices were fixed to cover the costs incurred by utilities, which led typically to the existence of a single vertically integrated utilities with a territorial franchise.

Today, the traditional regulatory paradigm has changed in many countries through the creation of electricity markets, eliminating the limitations to competition and approving suitable legislation. As this requires a certain number of competitors, a solution may be to divide the monopoly horizontally into different companies and facilitating market entry to newcomers.

<u>European case</u>

At European level, the creation of a common energy market has been a critical issue in terms of financial growth and institutional relations reinforcement. Since Second World War, there have been a huge amount of treaties, codes, papers or packages, along the years; which have defined the common energy market. In

Annex 1. Chronology of Treaties, Laws and other agreements in the European Union is shown a summary including a brief description of each of these agreements.

However, as a general overview of the European evolution, it can be divided in three phases:

1) First phase – Creation of an internal energy market. 1990-2000 (First and Second Energy Packages)

The founding treaties use energy as a core subject to build up the EU but they did not properly develop an energy policy.

As a consequence of the first and second energy packages internal market is developed: liberalization of generation and supply, free competition, non-discriminatory principles and TPA, unbundling, independent national regulators.

2) Second phase – Market consolidation. Definition and execution of a Common Energy Policy. 200-2015 (Treaty of Lisbon, Third Energy Package):

Treaty of Lisbon includes, for the first time, a proper energy policy in Article 194 TFUE. The Third Energy Package further develops internal market:

- Third Party Access: in order to have effective competition, TSOs must allow any electricity or gas supplier non-discriminatory access to the transmission network to supply customers. TSOs must apply regulated tariffs to avoid any abuse of dominance and must comply with unbundling rules.

- Unbundling:
  - Ownership unbundling: no supply or production company is allowed to hold a majority share of the TSO
  - Independent System Operator (ISO): energy supply companies may formally own transmission networks but must leave the entire operation, maintenance and grid planning to an independent company.
  - Independent Transmission System Operator (ITO): energy supply companies may formally own and operate transmission networks but must do so through a subsidiary.
  - Independent regulators: regulators must be independent from both industry and government interests. They must be their own legal entity and have authority over their own budget. National governments must supply them with sufficient resources. They can issue binding decision to companies and impose penalties. Regulators from different EU countries must cooperate with each other.

- ACER: Agency for the Cooperation of Energy Regulators: drafting guidelines for the operation of cross-border gas pipelines and electricity networks, monitoring the functioning on the internal market, reviewing the implementation of EU-wide network development plans.

- Cross-border cooperation: develop standards and draft network codes to help harmonize different electricity and gas transmission systems. Establishment of ENTSO-E (European Network of TSOs for electricity)

3) Third phase – Towards the creation of a European Energy Union. 2015-present. (Clean Energy for All Europeans) Main proposals:

- ➢ Market design: strengthening of the only-energy market, capacity markets subject to adequacy analysis, new agents (aggregators, active consumers…), new European DSO entity, etc.

- ➢ Energy efficiency: binding target of 30% for the EU. Mandatory programs to obtain savings of 1,5% up to 2030. Buildings.

- ➢ Renewables: 27% of mix by 2030, support mechanisms, 6,8% share of EV by 2030, etc.

- ➢ Key role of consumer: protection of vulnerable consumers, easy change of supplier, transparent billing, standard format, etc.

2.2 Electric Power System Configuration

Once competitive energy market has been implemented, transmission and distribution must still continue to be run as monopolies. Therefore, they must be unbundled from the activities that can be conducted in competition. Measures must be taken to ensure that all market agents have grid access: Third-party access or TPA.

Attending to different regulatory models, it is necessary to distinguish:

- ➢ Which activities are conducted separately from the others? Unbundled systems.
- ➢ Which activities are conducted on a competitive basis? Deregulated systems.

Depending on the previous differentiation:

- None of the activities are unbundled or deregulated: Vertically integrated monopoly. See Figure 1.

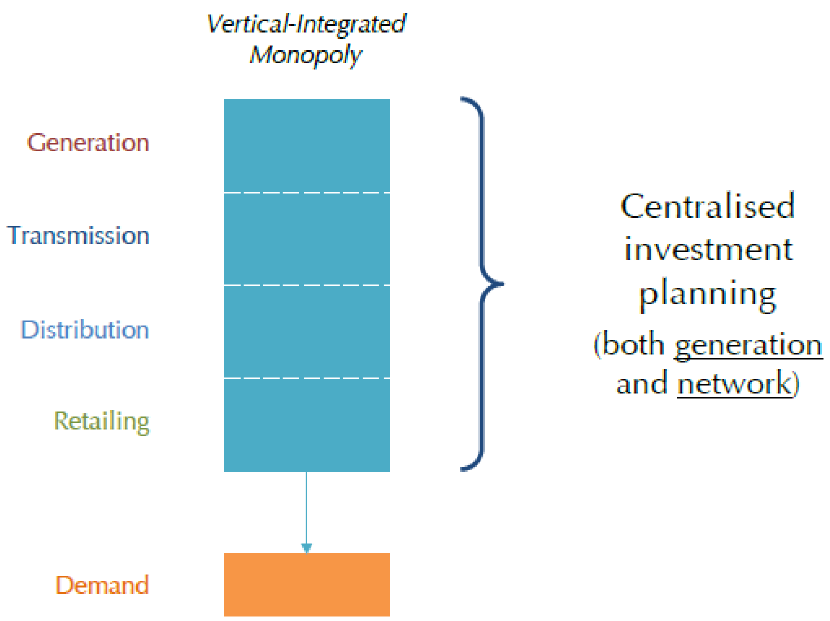

Figure 1: Vertical-Integrated Monopoly structure (IIT-Universidad Pontificia Comillas)

- The opposite: Full retail competition model. See Figure 2 and Figure 3.

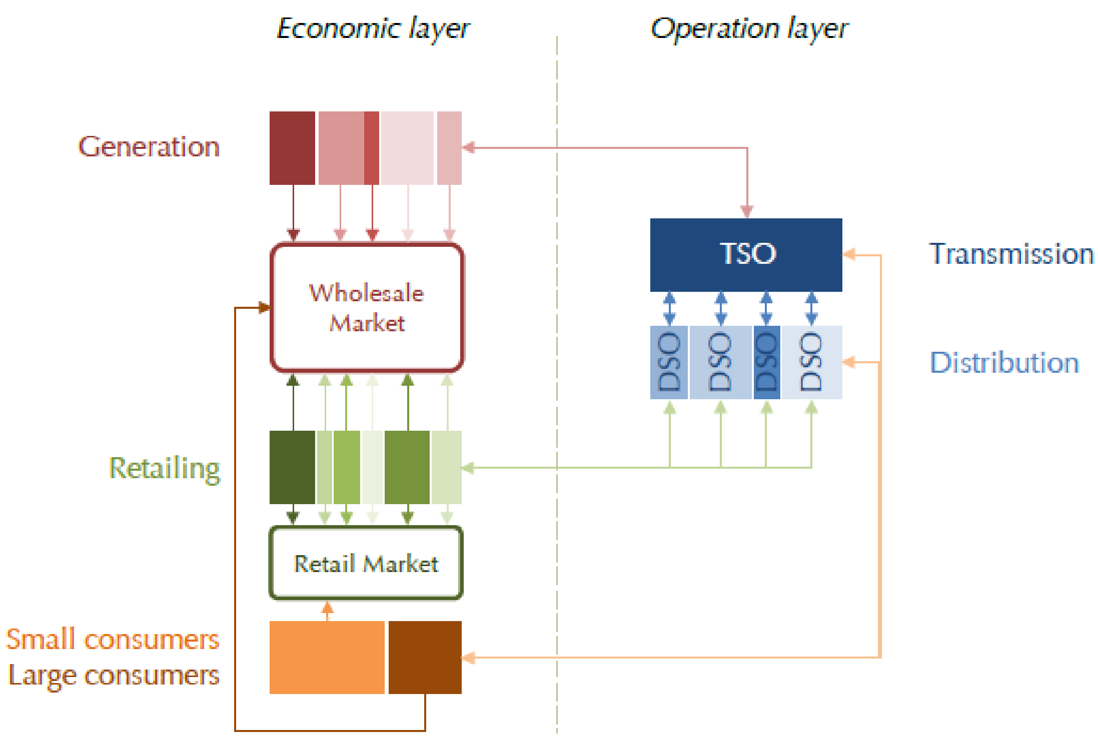

Figure 2: Fully-liberalized power sector structure (IIT-Universidad Pontificia Comillas)

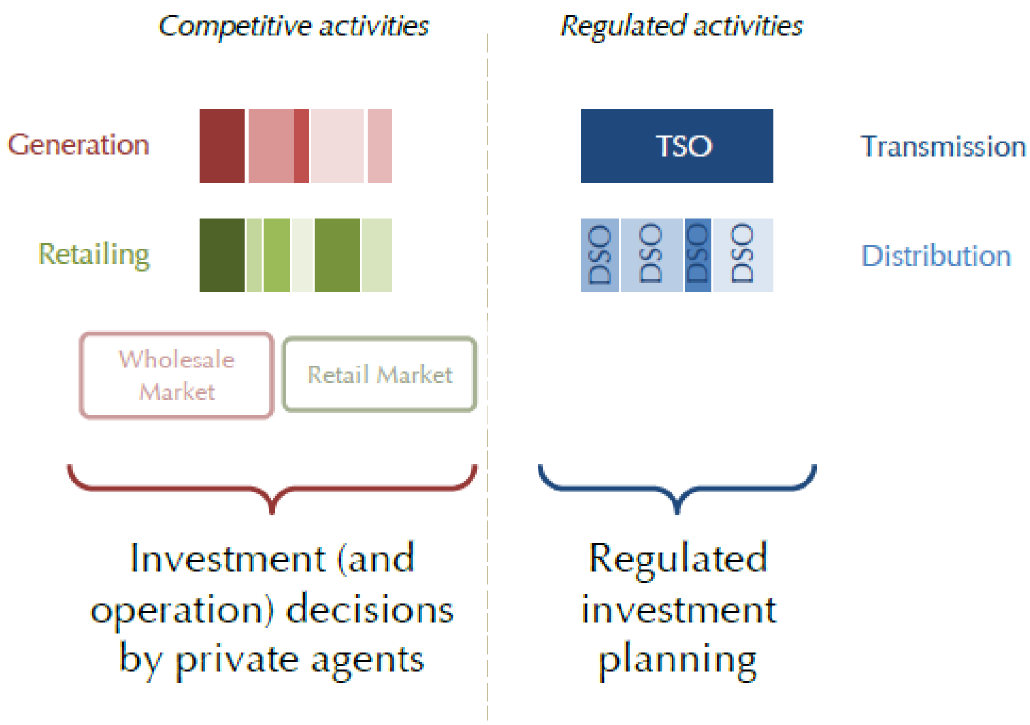

Figure 3: Fully-liberalized power sector. Level of unbundling and deregulation ((IIT-Universidad Pontificia Comillas)

Significant economies of scale can still be identified in transmission and distribution, which continue to be regarded as natural monopolies. However, markets are possible both in generation and retail and allow a higher efficiency in the operation and planning of power systems and a more efficient allocation of risks between producers and consumers. On a competitive market, each agent makes its own investment decisions. Investment profitability is consequently not guaranteed, and the consequences of errors are borne exclusively by the company committing them. Companies have, therefore, a higher incentive to be more efficient and to make well-informed decisions.

Why must grid-associated activities be independent of competitive business? Since the baseline situation was normally a vertically integrated utility, industry organization and ownership must usually be restructured, as it was the case of Spain. The main reasons why unbundling is essential are:

- To avoid cross-subsidies: companies making less profit or being less efficient in an area in order to make more money in another area. For example, system operator dispatching, and generators could not be the same company, or the dispatch will not be the most efficient one but the one favouring most the whole company.
- To avoid restrictions on third-party access to the grid: a monopolist could, for example, deny access to the grid on the pretext of insufficient capacity, granting access priority to its own business units.

2.3 Annual energy consumption and installed generation capacity. Technology mix

The evolution of the energy sector will depend on the political and regulatory decisions taken in advance. Besides, these decisions will be taken based on current frame, therefore, it is not the same roadmap to follow through in a thermal-based system (Australia) than in a hydro-based system (Brazil).

The Spanish case is not as extreme as the Australian or Brazilian ones, as it has a high level of technological diversification regarding generation plants. Theoretically, the energy mix of a country should reflect the regulatory decisions implemented in that country and the social consciousness as well.

Figure 4 shows the energy mix in Spain in the year 2015. It is observed that more than 75% of the energy is produced by technologies which emit polluting gases. Moreover, this situation has not a positive tendency over the latest years. Figure 5 shows the energy consumption since 1990.

Although the polluting technologies reduced their production between 2008 and 2013, it was due to the economic recession and it is not the right signal of technology mix change. In the most recent years their consumption has increased again and, now, it is time to act.

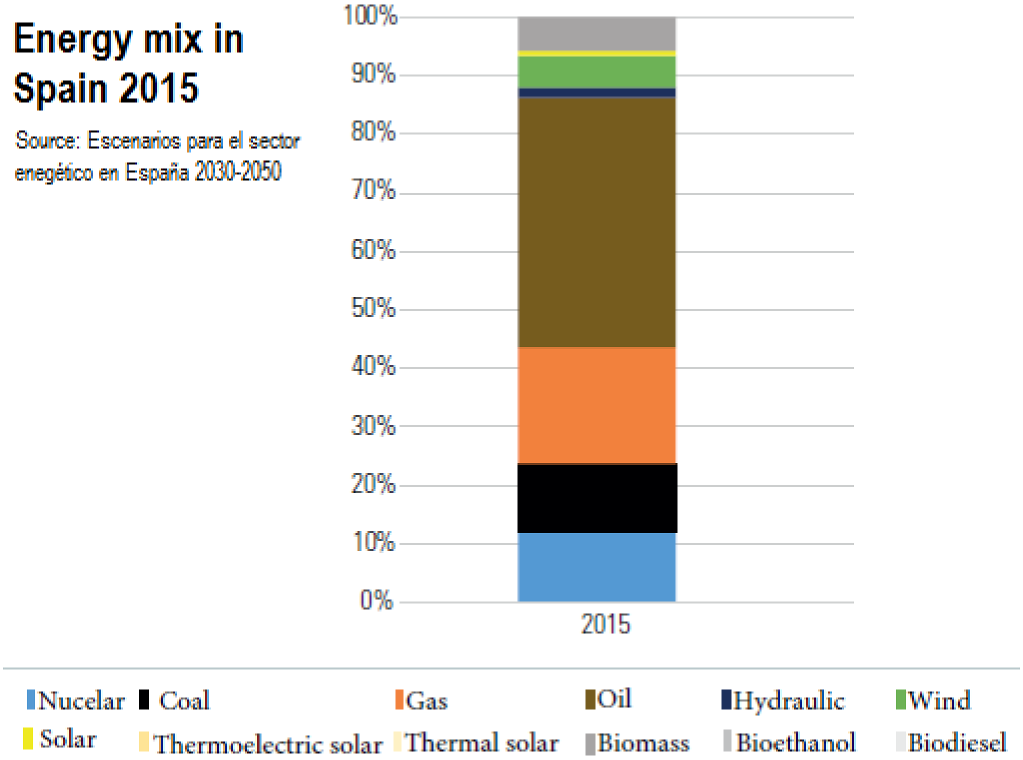

Figure 4: Energy mix in Spain in 2015

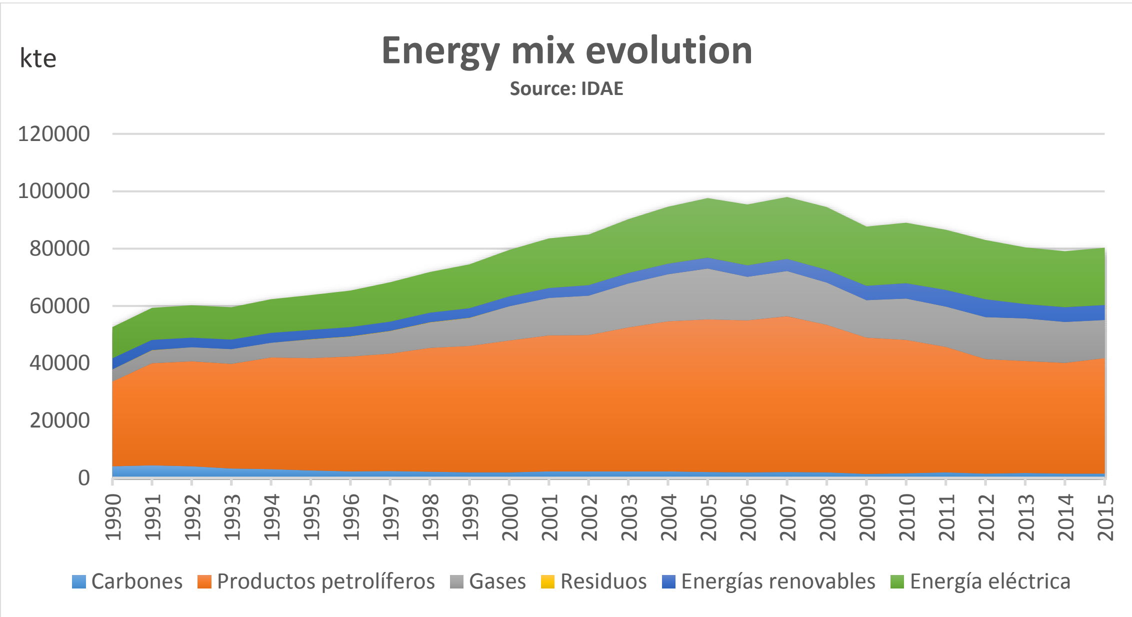

Figure 5: Energy mix evolution in Spain

On the contrary, the electricity production has experienced a continuous change in its mix, with a clear tendency to reduce carbon dioxide emissions. Figure 6 shows this tendency where the reduction of gas and the increase of wind turbine generation are remarkable While Figure 7 shows the Spanish electric mix in 2018, counting with less than 40% of installed capacity of carbon dioxide emitter plants.

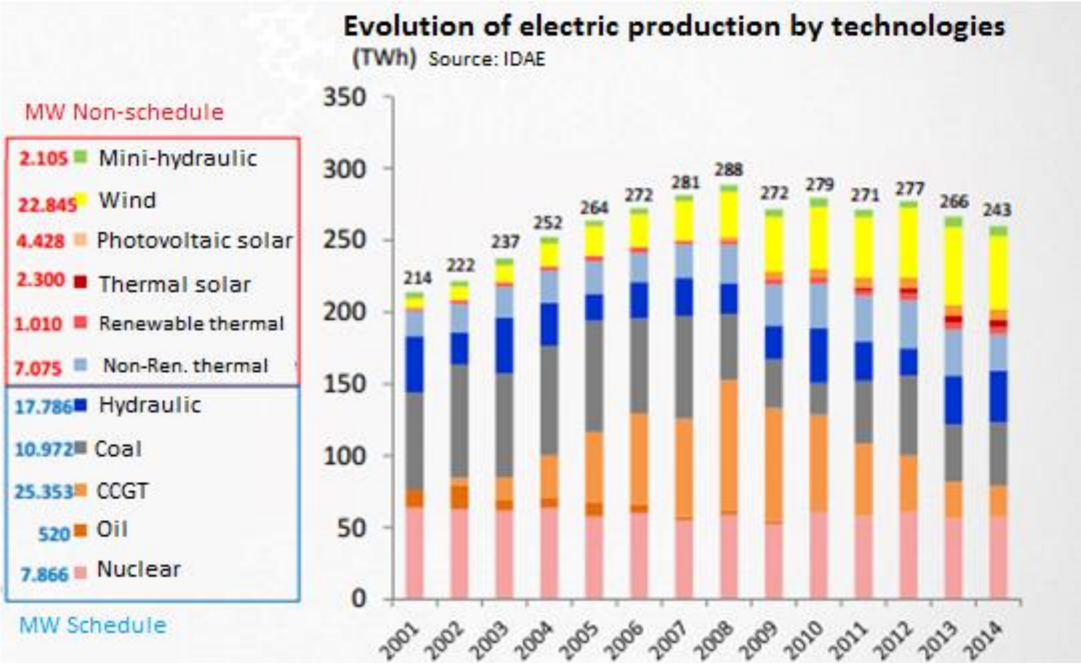

Figure 6: Evolution of electric production by technologies (TWh)

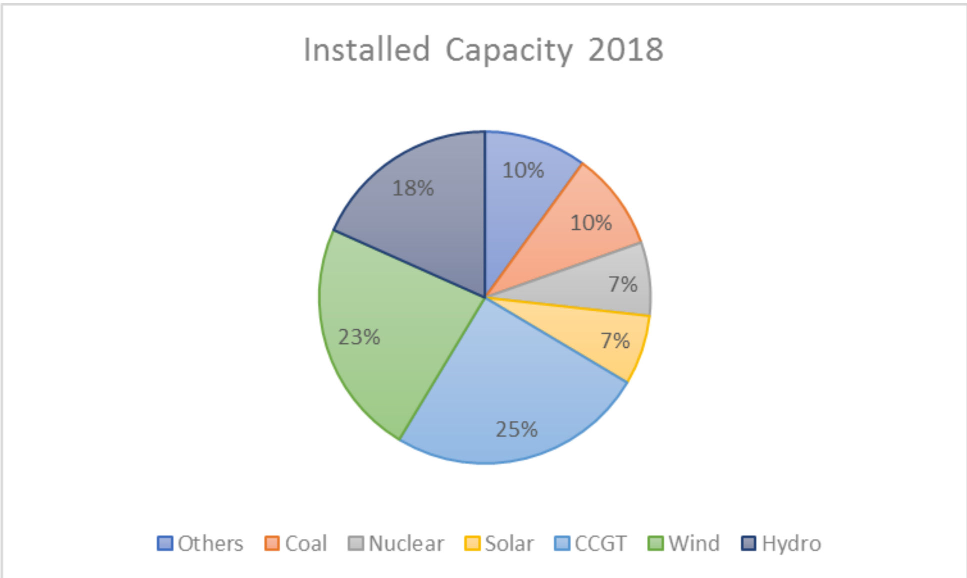

Figure 7: Electric Mix in Spain in 2018

Regarding the energy and electric mix, it is a matter of fact that currently there is not (or it has not penetrated enough) a technology able to substitute the energy consumed by polluting technologies. While the electric mix is being able to adapt its structure little by little. A priori, the solution is the electrification of the energy industry, in order to satisfy the transport, services, heating, cooling and all types of energy demand.

2.4 Major companies that provide electricity services

The electric power industry is a complex sector and it is highly regulated despite the fact that it is theoretically liberalized. There are several roles that should be played by any institution in order to maximize the social welfare; which means to maximize demand utility and consumer surplus.

Depending on their scope of action:

Regulatory Institutions

Including ministries and ministerial agencies, independent regulatory commission and competition authorities.

- Policy: Government sets the goals to be achieved.
- Regulation: It is the tool to get to that objective (economy, society…)
- Supervision: Once the rules are set, it is necessary to control that they are respected.

The Spanish case is captured in Figure 8.

The Spanish Government is the highest authority in collaboration with the European Commission. They decide the roadmap and the objectives for the short and long term. Then, the Agency for the Cooperation of Energy Regulator establishes the incentives and constraints necessities to guide the agents to that objective. Finally, the CNMC takes the role of supervising and arbitraging the agents and sanctioning when required.

Figure 8: Regulatory institutions in the Spanish electric power industry

System and Market Operator

They are the main agents, which enable the participation of generators and demand in the power system. They are basically defined as:

- System operator: Company in charge of assuring the correct operation of the grid.
- Market operator: Company in charge of matching demand and generation bids.

There are different models worldwide that are distinguished in the list below:

- Regional System Operator (RTO): A single company that only operates the grid, it is not the owner of it
- Transmission System Operator (TSO): A company that owns the transmission system and operates it
- Independent System Operator (ISO): Companies have different options to sell their company: OTC markets, power exchange with market facilitators. The ISO is the system operator but also a market facilitator. RTOs typically perform the same functions as ISOs but cover a larger geographic area.
- PX model: An independent market operator with nothing to do with system operator deals. In charge of market-price clearing and market functioning supervision, providing required services to all market agents.

Among the four models, the most typical ones are the TSO and ISO. The TSO model is the most common model in the European Union, and the ISO is the most common model in the US.

In Spain, the market and system operators are divided into:

- REE (Red Eléctrica Española) as transmission system operator (TSO), which operates the transmission grid and owns the vast majority of the transmission grid.
- OMIE (Operador del Mercado Ibérico de Energía), as the NEMO (Nominated European Market Operator).

<u>Other Utilities</u>

All private companies, which participate at any level on the energy system, are included here, like Iberdrola, Enagás, Gas Natural Fenosa, Endesa, EDP, etc.

2.5 Wholesale electricity market operation

What is the Iberian Electricity market used for? Like any other market, the energy market offers different products related to energy and capacity. It is important to point out that they are offered for a specific timeframe, as it will be developed afterwards.

There are three products in an electricity market:

- Energy: Energy can be sold or bought depending on the agent's role.
- Capacity: Referred to the installed capacity able to produce energy. There are several types of capacity mechanisms used to ensure security of supply. It is necessary a certain amount of "overcapacity" in the system: flexible units ready to produce in case of shortage.
- Ancillary Services/Reserves: Ancillary services and operating reserves prepared to correct the unbalances. The generators that are available to produce at any moment, they are paid for its service even if they do not produce energy. The remuneration received is different for the capacity available and the energy delivered in case of necessity.

On the other hand, it is considered that there are three timeframes represented in Figure 9.

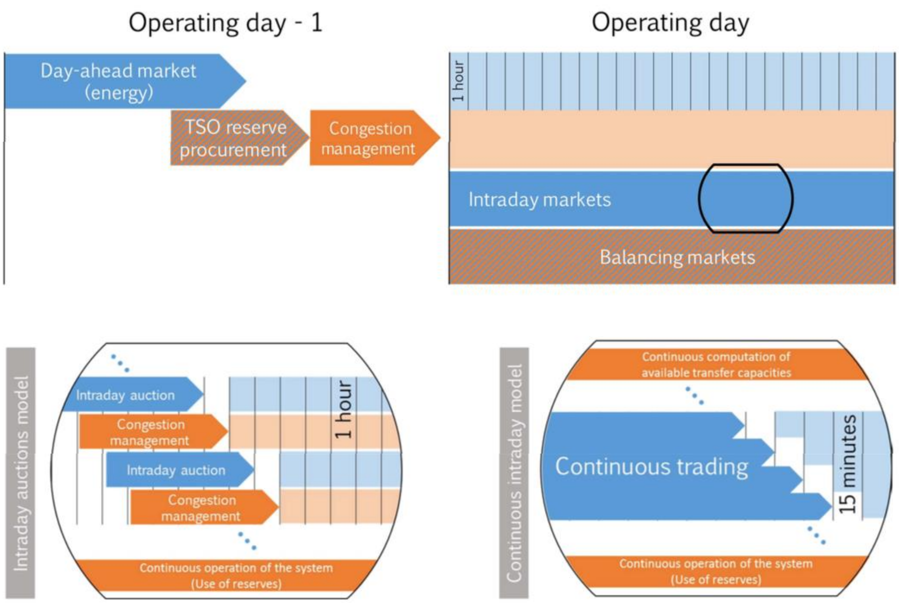

Figure 9: Energy Market timeframes

In the Iberian Market, most of electricity is traded in the day-ahead market (12 a.m), managing congestions and reserves. Some hours later (from 5 p.m. to 4 a.m. [+1]), there are six intra-day markets, the so-called adjustment markets. In addition, there is a real time managed by the System Operator, while the Market Operator manages the other ones. Real time market plays with reserves to respond to power/frequency unbalances.

There are two major approaches around how to integrate power system physics in the markets. But it also affects bidding formats, clearing, and pricing. Figure 10 shows the market sequence with these two structures: in the US (left) and in the EU (right).

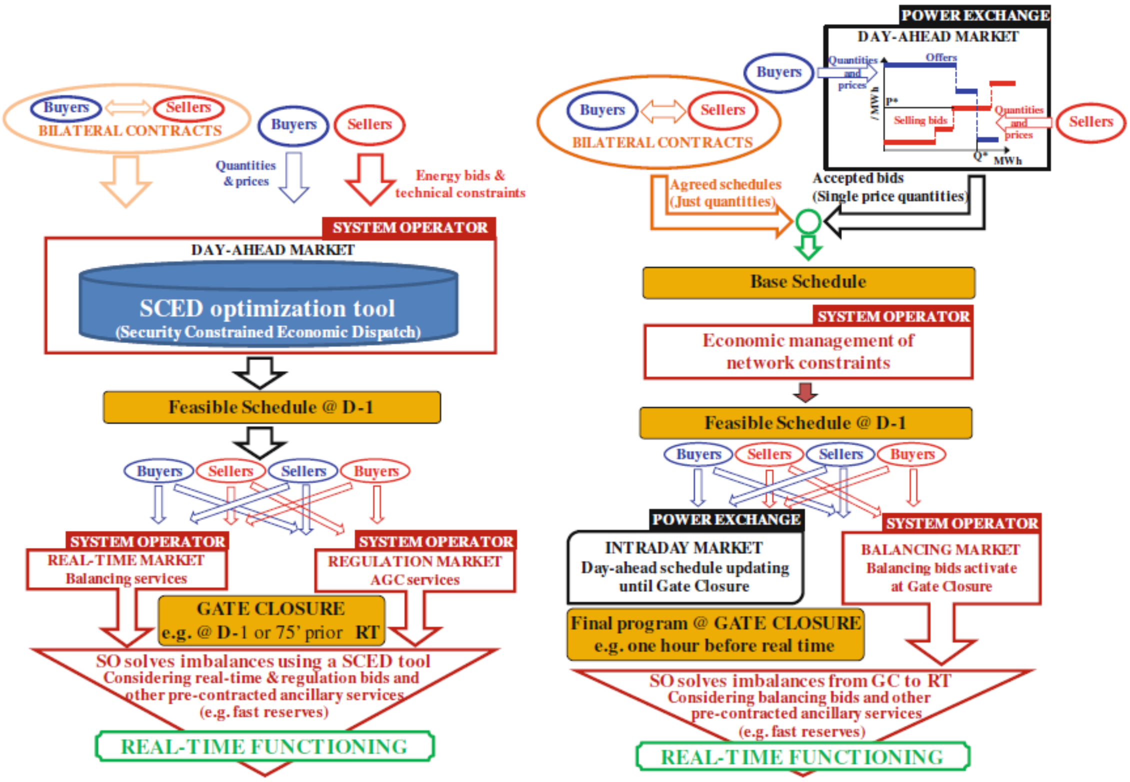

Figure 10: Market sequence in the US (left) and in the EU (right) model [IIT_13]

The US model is basically based on an optimization tool where demand and generators (buyers and sellers) bids match the day-ahead, resulting in a feasible schedule. This schedule has already considered physical restrictions in the system (generally transmission lines). Buyers and sellers can modify their bids before the gate closure (75' prior real time), and bids for ancillary services markets have to be set.

On the other hand, EU models have two main differences:

- As system operator and market operator is not the same company, firstly, the market operator matches buyers and sellers' bids in order to obtain a base schedule. Then, the System Operator manages the network constraints derived from the base schedule (day-ahead market) and determines the feasible redispatch: Feasible schedule.

- The EU's models have multi-settlement prices, as they have the called intra-day markets where energy can be traded after the day-ahead market.

Additionally, both models enable to trade energy out of the market by means of long-term contracts called: Bilateral Contracts. This type of contracts consists of energy exchanges between two parties at a fixed price. System Operator must know the amount of energy traded in these contracts in order to be aware of the amount of energy that is going to be produced through the lines, and the amount of demand already served, and market operator, in the physical markets, in order to know the available energy for the market.

Hence, in the EU models (Spanish model), the electricity is traded in the market regardless the physical constraints. Once the market has been cleared, the System Operator manages the constraints, modifying the dispatch when required. This approach is not arbitrary; it could seem useless, as the System Operator is going to modify the preliminary dispatch for sure. However, the objective is to make electricity market resemble as any other commodity market: with less physical constraints. Focusing on **simplicity and transparency**.

What are pros and cons of each system? Figure 11 shows the differences among them.

US (more elaborated bids) put the focus on obtaining the optimal dispatch, but there are pricing determination issues with this approach. These bids are more elaborated in the sense that they include a lot of information: emissions rate (SO_2, NOx, and CO_2), heat rate, minimum run time, fuel type, fuel price, % of each type of fuel, start-up cost, etc. With this "unit-commitment like" dispatch, the peaker generators do not recover all their costs, as there are fixed costs that are not considered. Then, the regulator gives side payments, which are the difference between their total operating costs and the price of energy.

EU (simpler bids) puts the focus on obtaining uniform prices and clearing simple bids based on prices, but this complicates the algorithm and, also, leads to a suboptimal dispatch.

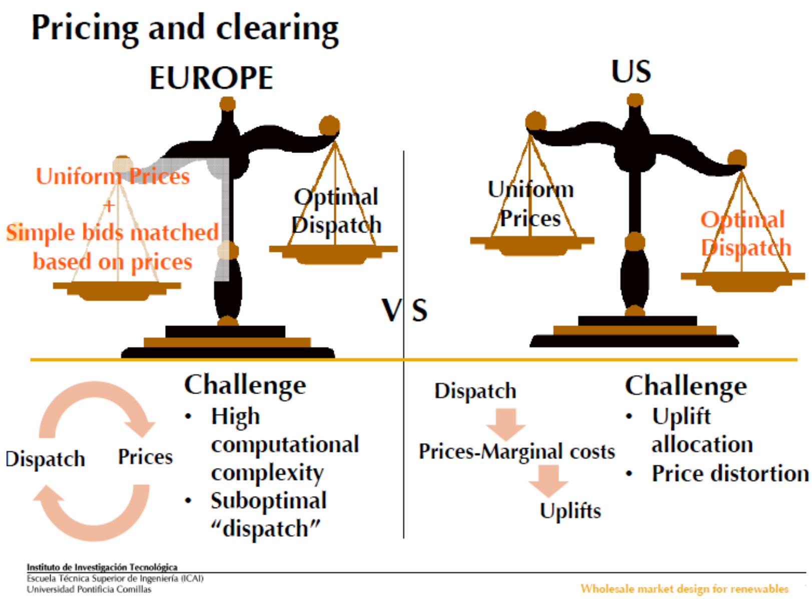

Figure 11: Pricing and clearing differences between Europe and US

At the end of XXth century, complex bids were not very common in EU's markets although they existed. However, the increasing penetration of RES lead conventional generation to uncertainty in costs recovery. As RES are schedule based on their availability and not on their cost, conventional generation plants could not predict when it would be appropriated to bid. So, a new tool was established: semi-complex bids.

Although semi-complex bids lead to a suboptimal schedule, they enable generators to be incentivized to participate in the market. There are several types of semi-complex bids, the most common ones are:

- Block bids: Commonly used in most of the European countries. Production over a horizon, subject to an average price and "fill or kill".
- Minimum income condition: The most typical case in the Iberian Market. Generators bid a quantity of energy at specific periods of time and establish a minimum income to be received for that energy; if income is higher than the minimum requested, they are committed.

The increasing use of these conditions is clear, as it is shown in Figure 12.

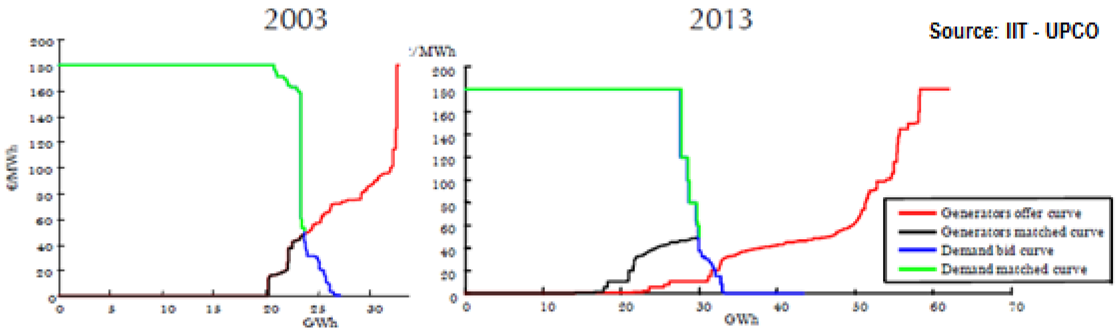

Figure 12: Semi-complex bids market impact

3 Analysis of future scenarios affecting energy prices

3.1 Demand evolution

The electricity sector rose worldwide due to the use human beings made of it in their daily live. Nowadays, electricity is an essential good for domestic demand and industrial growth. Electricity Market appears to serve the needs of demand. Therefore, its evolution is directly related to how demand behaves.

Demand historical data will be analysed in order to forecast electricity demand in the future. REE provides hourly electricity demand values differentiated by each kind of voltage value:

- E0: < 1kV
- E1: 1kV – 14kV
- E2: 14kV – 36kV
- E3: 36kV – 72,5kV
- E4: 72,5kV – 145kV
- E5: 145kV – 220kV
- E6: > 220kV
- EA: 1kV – 30kV
- EB: 30kV – 36kV

By means of this classification, data will be used in order to characterize demand.

Consumers can be connected to different voltage levels; residential consumers are usually connected to Low Voltage (<1 kV), meanwhile industrial and services consumers are connected to Medium or High Voltage, as their demand has a much more instantaneous power than a residential consumer.

In the case of industries and services, they are usually connected to high voltage because the power they need is more suitable to take it from high voltage feeders.

In this project, the electricity demand estimation will be done by aggregating the different kind of voltage level, as per the following list:

- Domestic demand: Demand < 1kV
- Industrial & Services demand: Remaining demand, > 1kV

In order to estimate the electricity demand in 2020-2030, current electricity demand will be corrected by means of several factors, which will lead to different scenarios. Depending on the demand sector, the factors explained afterwards will be considered.

These factors are used to forecast yearly aggregated electricity demand, a total of 13 estimations (one per year since 2018 until 2030). Once it has been estimated, yearly aggregated demand is multiplied by hourly ratios (8760 ratios per year). These ratios provide a coherent shape to the forecasted demand and are obtained from 2016's ratios, which are considered as the reference. The ratio for hour "i" is calculated as follows:

$$r_i = \frac{Demand\ in\ hour\ i}{Aggregated\ demand\ in\ year\ 2016}$$

The result of multiplying average ratios by forecasted aggregated demand is the hourly aggregated demand. Then, it is easy to subtract hourly demand. It is important to highlight that, in this first forecast, electric vehicle and storage systems penetration are not considered.

The factors to consider in the forecast are explained thereupon, differentiating them by sector:

- Domestic

Residential demand growth has been commonly related to Gross Domestic Product evolution. However, in the near future this tendency is about to change; due to childbearing decrease, and efficiency improvement. There are three factors that will be considered in influencing residential demand:

  - Number of homes growth:

There are two factors to consider when studying domestic demand growth: the evolution of the number of homes, and the evolution of number of people per home. According to the study "Proyección de Hogares 2014–2029" carried out by INE (Instituto Nacional de Estadística) [INDE14], their tendencies are opposite.

Hence, both tendencies shall be considered by calculating the weighted average growth. Taking into account that part of energy consumed is partially independent of the amount of people occupying a home. The percentage consumption by devices is shown in

Heating	Hot water	Stove	Refrigerator	Lighting	Appliances	Standby
5,9%	7,9%	9,8%	26,1%	5,0%	40,5%	4,9%

Table 1. In red are remarked those consumption uses that are most likely to be independent of every homes' number of occupants. They account for 77,4% of the total consumption.

Heating	Hot water	Stove	Refrigerator	Lighting	Appliances	Standby
5,9%	7,9%	9,8%	26,1%	5,0%	40,5%	4,9%

Table 1: Percentage electricity consumption by devices in Spanish homes

Weighted annual growth will be calculated as 77,4% of annual growth due to increase of homes and 22,6% due to increase of people per home. Table 2 shows resulting annual growth rates.

$$Weighted\ annual\ growth = H_{gr} * 0.774 + P_{gr} *\ 0.226$$

Year	nº people/home	nº people/home annual growth (P_{gr})	nº homes annual growth (H_{gr})	nº homes	nº domestic consumers	Weighted annual growth
2018	2,480	-0,60%	0,36%	18.583.813	46.087.856	**0,143%**
2019	2,465	-0,60%	0,36%	18.650.715	45.974.012	**0,143%**
2020	2,450	-0,61%	0,33%	18.717.857	45.858.751	**0,118%**
2021	2,435	-0,61%	0,33%	18.779.626	45.728.390	**0,118%**
2022	2,420	-0,62%	0,33%	18.841.599	45.596.670	**0,115%**
2023	2,410	-0,41%	0,33%	18.903.776	45.558.101	**0,163%**
2024	2,395	-0,62%	0,33%	18.966.159	45.423.950	**0,115%**
2025	2,380	-0,63%	0,34%	19.028.747	45.288.418	**0,121%**
2026	2,370	-0,42%	0,34%	19.093.445	45.251.464	**0,168%**
2027	2,359	-0,46%	0,34%	19.158.363	45.194.577	**0,159%**
2028	2,350	-0,38%	0,34%	19.223.501	45.175.227	**0,177%**
2029	2,340	-0,43%	0,34%	19.288.861	45.135.935	**0,166%**
2030	2,330	-0,43%	0,34%	19.354.443	45.095.852	**0,166%**

Table 2: Weighted annual growth evolution

- Demand income elasticity:

Demand income elasticity is the percentage increase in demand for percentage increase in household income (represented by GDP).

As per the study “Escenarios Energéticos en España para 2020-2030” [EFEI17], demand income elasticity is considered as shown in Table 3.

	Demand income elasticity	% Demand consumption
Heating system	0,9	38,59%
Air Conditioning	12,6	0,66%
Hot water	1,9	15,56%

Table 3: Demand income elasticity values

However, average estimation of domestic demand elasticity varies considerably from one study to another. Therefore, this value is considered as neutral. It means that the demand elasticity is considered as the unitary value. In data provided by REE [REEO16], the unpredictable variation of this indicator can be noticed (see Table 4).

País		Años 2010	2011	2012	2013	2014	2015	2016
Alemania	%Dem.	7,1%	-1,3%	0,1%	-0,5%	-2,0%	0,4%	0,7%
	%PIB	4,1%	3,7%	0,5%	0,5%	1,6%	1,7%	1,8%
	ε	1,7	-0,3	0,1	-1,0	-1,2	0,2	0,4
España	%Dem.	2,3%	-1,1%	-1,3%	-3,5%	-1,7%	2,3%	0,6%
	%PIB	0,0%	-1,0%	-2,9%	-1,7%	1,4%	3,1%	3,2%
	ε	-	1,1	0,5	2,1	-1,3	0,7	0,2
Francia	%Dem.	7,0%	-6,4%	4,2%	1,2%	-5,5%	1,8%	1,7%
	%PIB	1,9%	2,1%	0,2%	0,6%	0,6%	1,3%	1,2%
	ε	3,6	-3,1	21,4	2,1	-9,4	1,4	1,4
Italia	%Dem.	3,2%	0,8%	-1,7%	-3,1%	-2,1%	2,1%	-1,9%
	%PIB	1,7%	0,6%	-2,9%	-1,6%	0,1%	0,7%	0,9%
	ε	1,9	1,4	0,6	1,9	-19,7	2,9	-2,0
Reino Unido	%Dem.	2,2%	-3,3%	0,0%	-0,5%	-4,2%	-0,1%	-1,7%
	%PIB	1,9%	1,5%	1,3%	1,9%	3,1%	2,2%	1,8%
	ε	1,1	-2,2	0,0	-0,3	-1,4	0,0	-0,9

ε = elasticidad

Table 4: Evolution of average demand elasticity by European country

- Gross Domestic Product:

Annual Gross Domestic Product is applied to electricity demand. To do so, equivalent annual rate is obtained with the factors shown in Table 5 according to OECD forecast.

Year	GDP (M$)	Equivalent Annual Rate
2016	1.265.166	0,00%
2017	1.293.388	2,23%
2018	1.318.378	2,08%
2019	1.341.135	1,96%
2020	1.363.052	1,88%
2021	1.385.186	1,83%
2022	1.408.242	1,80%
2023	1.432.695	1,79%
2024	1.458.900	1,80%
2025	1.487.044	1,81%
2026	1.517.066	1,83%
2027	1.548.223	1,85%
2028	1.579.856	1,87%
2029	1.611.925	1,88%
2030	1.644.390	1,89%

Table 5: Expected Spanish GDP

Finally, domestic electricity demand is estimated applying the before-mentioned factors as done by the Economics for Energy Institute [EFEI17]:

$$FutDem = CurrDem * GDPgrowth * Housesgrowth$$

Where:

- GDPgrowth = Gross Domestic Product Growth
- CurrDem = Current demand
- FutDem = Future demand
- Housesgrowth = Houses' growth

- Industrial & Services
    - Annual GDP

The demand forecast for Industrial and Services sectors has always kept a closed correlation with Gross Domestic Product evolution. Therefore, GDP will be the factor used in order to predict Industrial & Services electricity demand. According to OECD forecast, Spanish GDP is expected to grow as previously shown in Table 5.

Hence, the formula that will be used is the following one:

$$FutDem\ (Ind\&Serv) = CurrDem * GDPgrowth$$

- Energy efficiency:

To forecast the levels of energy efficiency is not an easy task. There are too many uncertainties. The studies carried out by main energy institutions differ a lot in their estimations from one to another. Therefore, this model considers the efficiency rate as an input.

However, several scenarios will be analysed in section 5 Analysis of results obtained with forecasting model.

3.2 Thermal plants production and construction

Thermal plants generators include coal, fuel oil, gas and nuclear technologies, although nuclear plants are a particular case of thermal generation, as they do not produce polluting emissions. Hereinafter, when referring to thermal plants, nuclear plants will not be included. They will be treated as a special case.

It is a matter of fact that thermal plants are supposed to reduce their production and install capacity. In the beginning, they appeared as a flexible technology able to install small generation plants near to consumption points or near mines where coal was being extracted.

Nowadays, part of these plants has to be closed due to environmental issues. However, it is not an easy procedure, as renewable generation technologies are not matured enough to face demand evolution due to their intermittent production. It would dramatically reduce security of supply.

On the other hand, political decisions should not affect competition in such a way that investors do not recover their investments. It would not be the right signal to new investors and government could be penalized.

High levels of RES penetration lead to lower prices and unpredictable generation profile, which is critical for conventional technologies. However, Spanish Energy Ministry forces them to keep these plants opened if they are needed for **security of supply** reasons.

RES penetration is not the main reason why thermal plants are not profitable. The real reason is the inefficient investment planning. **Spanish system suffers overcapacity and thermal plants are untapped**.

At the beginning of XXIth century electricity demand was continuously increasing and utilities started to build new plants up to the point of installing 67 CCGT between 2002 and 2011. It is translated to a total capacity of 25.353 MW, being the technology with higher installed capacity in Spain. The total amount invested in those 67 CCGT was 13.161 million€ [RARO17].

Figure 13 and Figure 14 show how the CCGT installed capacity is completely exaggerated, resulting on an average capacity factor lower than 10%.

Nevertheless, current RES penetration is not enough to satisfy the demand due to its intermittency and some of this installed capacity is needed.

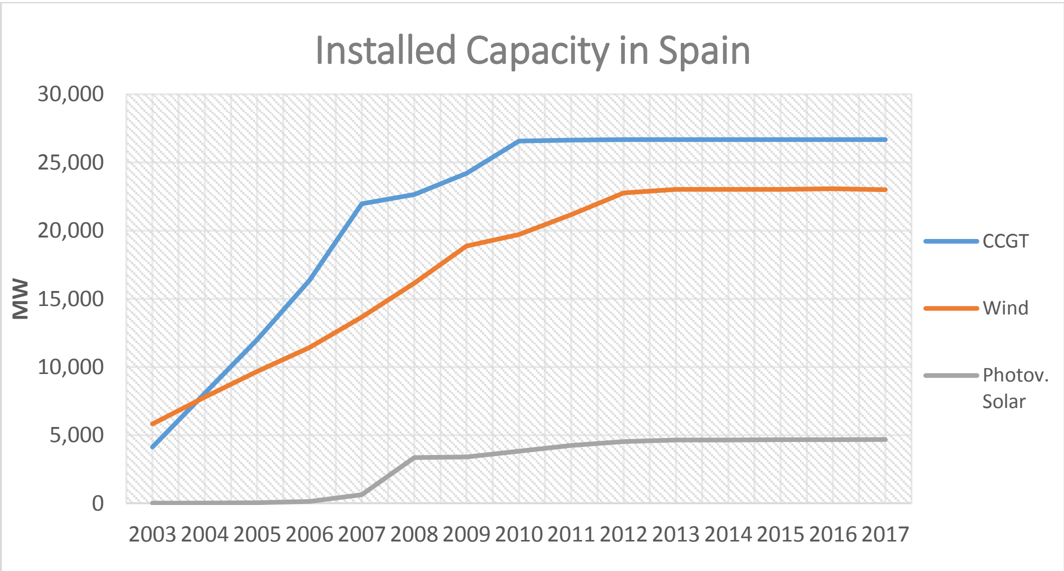

Figure 13: Evolution of Installed Capacity in Spain for CCGT, Wind and Photovoltaic technologies

The CCGT's dependency of wind production is clearly reflected in Figure 14. In the latest years, Spain has suffered low wind levels; wind generation has decreased and CCGT plants have covered the difference.

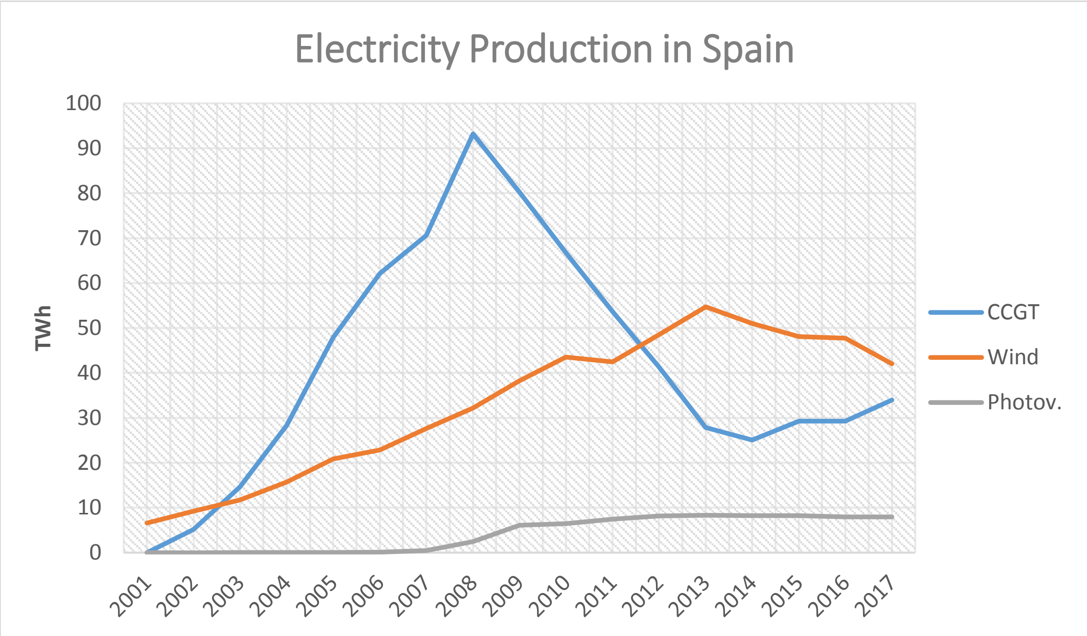

Figure 14: Evolution of Electricity Production in Spain for CCGT, Wind and Photovoltaic technologies

Is the right decision of the Spanish Government to force utilities and to keep thermal plants operating? It could not be the right signal for investors as it is not typical from a liberalized market, but it is worthy as long as utilities receive up-lifts in order to recover their costs, the so-called capacity mechanisms.

Capacity mechanisms reinforce the short-term price with additional remuneration. They attract investment and ensure system adequacy in liberalized power sectors.

Therefore, the expected future of Spanish thermal plants is going to depend on the Spanish Government. By means of capacity payments, thermal plants will continue operating as long as it is necessary in terms of security of supply. Then, these plants will be closed when required, based on carbon dioxide emissions objectives. The former Spanish Government has set 2025 as the expected year to close; at least, all coal plants.

Despite the fact overall electricity consumption has increased during the latest ten years, carbon dioxide emissions have been reduced by half, as shown in Table 6.

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Coal	67.099	44.183	33.053	22.516	41.103	51.123	37.551	41.154	50.150	35.617	34.222
Fuel + Gas	8.401	8.223	7.684	7.322	6.057	6.117	5.491	5.103	5.258	5.491	4.751
Combined Cycle	27.124	35.538	30.729	25.826	21.050	16.461	11.548	10.635	12.155	12.069	11.759
Térmica renovable	404	451	518	539	728	807	861	802	0	0	0
Non-renew able thermal / Cogeneration	8.664	9.871	10.568	11.441	11.929	12.464	11.922	9.547	9.416	9.585	8.598
Wastes	-	-	-	-	-	-	-	-	792	814	691
Emissions (MCO2)	**111.691**	**98.266**	**82.552**	**67.643**	**80.868**	**86.971**	**67.373**	**67.241**	**77.770**	**63.577**	**60.021**
Emission factor CO2 (MCO2/MWh)	**0,388**	**0,332**	**0,295**	**0,234**	**0,289**	**0,307**	**0,246**	**0,252**	**0,290**	**0,242**	**0,252**

Table 6: Evolution of carbon dioxide emissions of the Spanish electric power industry

Hence, the expected installed thermal capacity available in the system will be based on allowed carbon dioxide emission, considering coal thermal plants closed by 2025. The model will include as input the amount of CO_2 emissions for 2030. Then, the most polluting plants will be closed taking into account this limit.

In addition, carbon dioxide emissions rate price will be considered as input for the model. This price set by regulation as a penalty to be paid by generator in € per ton CO_2, directly affects the generation dispatch order. The most polluting technologies internalized this penalty increasing its hourly bid.

Regarding nuclear power plants, their lifetime operation is a critical issue for the Spanish system security of supply and electricity prices. Nuclear technology is not polluting, with very low operating costs and extremely high investment cost.

Nuclear plants in Spain exercise their generation right with the permission of the Spanish Government. It is up to the current Government to fix the permission period. Currently, these permission periods for all nuclear power plants are about to end, between 2020 and 2021 (except for Trillo's plant, which renovated its permission in 2017 until October 2024).

In the beginning, nuclear plants were designed to operate for a period of 40 years with the possibility of increasing their operating lifetime until 60 years by means of technical improvements. Nowadays, most of the plants are reaching their 40th year since construction. Figure 15 shows the current operating permission period of each plant, and their 40th since they were constructed.

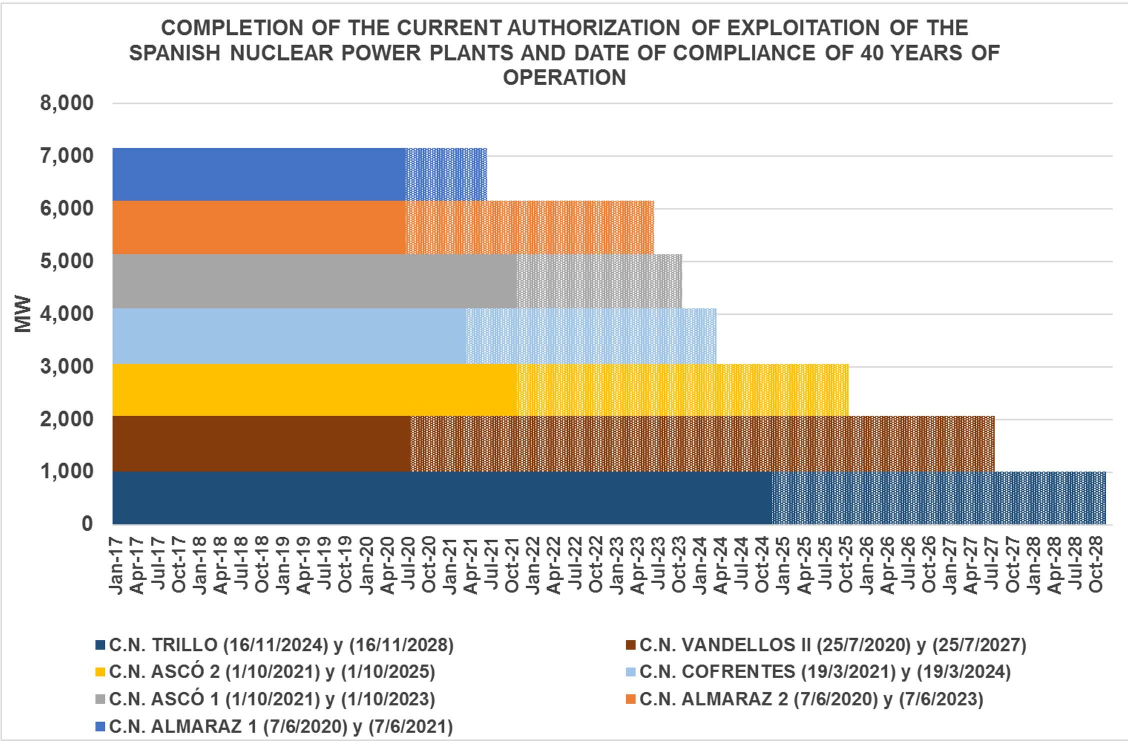

Figure 15: Completion of current authorization of exploitation of nuclear plants and date of compliance of 40 years operation

At this stage, Government's intervention is critical. The first measure has been to reduce the period that plant's owners had to request the exploitation consent ahead of time from three years to almost one year. Clearly, this is a measure taken in order to favour the continuity of nuclear generation.

Despite the fact that public opinion is against nuclear generation, reducing to zero energy produced by nuclear plants will lead to a lack of 23.5% of electricity generated by a non-polluting technology to be covered by immature renewable technologies or polluting technologies.

Nevertheless, due to political uncertainty, the model to be developed will consider two independent scenarios:

- Nuclear power plants are to be closed in their 40^{th} year since construction
- Nuclear power plants extend their lifetime to 60 years

3.3 Renewable energy production and construction

This section seeks to evaluate how each renewable technology generation impacts on electricity prices, analysing the historical correlation between electricity prices and technologies' production. Then, it will be easier to understand the basics about the future model's results. These correlations will be later implemented in the forecasting model.

Among all renewable technologies, this study will consider the impact of the most relevant ones, dividing them into four groups:

- Hydroelectric power generation
- Wind generation
- Solar generation: Including solar photovoltaic and thermal
- Cogeneration and others

Firstly, it is necessary to predict the expected electric mix in Spain, in order to forecast how prices will evolve in the next decade, as prices are directly related to the operating technologies.

The renewable capacity to be installed will be calculated as explained in section 3.2. Thermal plants production and construction; based on allowed amount of carbon dioxide emissions.

The key issue is how to divide the non-emitting capacity to be installed between solar o wind plants. One possibility is to select the cheapest one based on the levelized cost of energy (LCOE). "Levelized cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competitiveness of different generating technologies" [EIA_17], including investment cost, rate of return and operation and maintenance costs.

Figure 16 shows the evolution of mean LCOE values. Attending to the evolution, the expectation is that solar photovoltaic generation will be the most affordable technology. However, it is necessary to take into account two factors:

- Solar capacity factor is lower than wind one. This means that wind generation produces more energy for the same capacity.
- Solar plants only produce energy in a specific period of time. If storage systems are not enough developed, high penetration of solar generation could be inefficient.

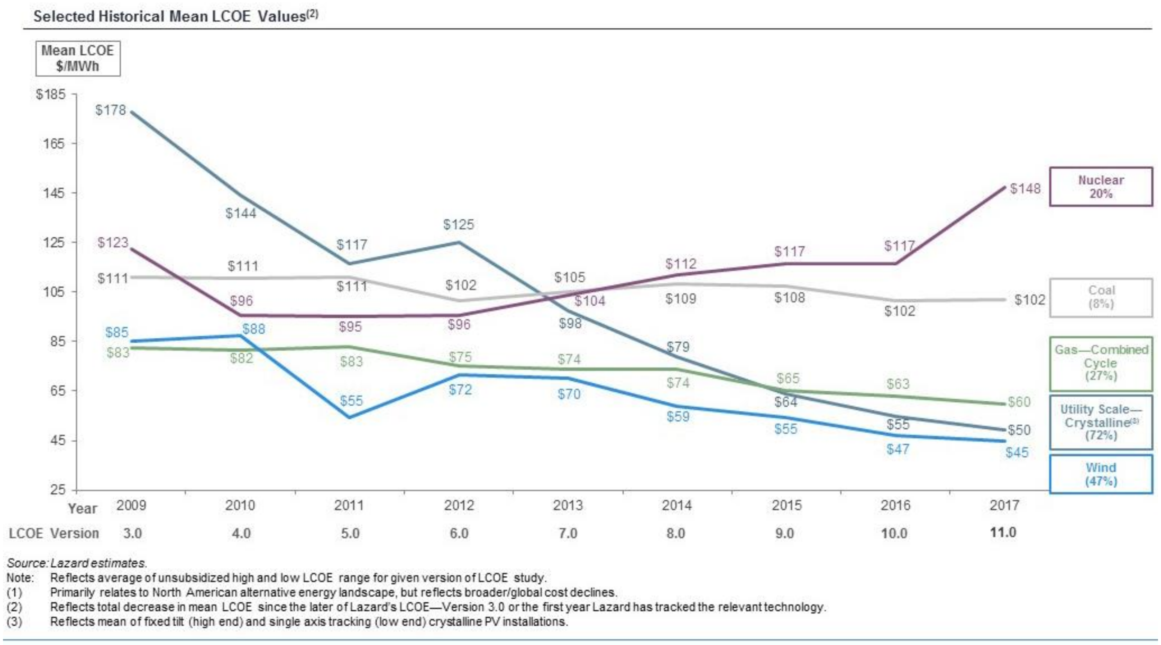

Figure 16: Selected Historical Mean LCOE Values

A production-price sensitivity analysis will be carried out for each type of renewable technology.

Wind

This is the most noticeable case in Spain. The high and increasing level of wind penetration in Spain allows to easily analyse the impact of its production in electricity prices. Figure 17 shows the penetration of wind generation in Spain, provided by the system operator, REE.

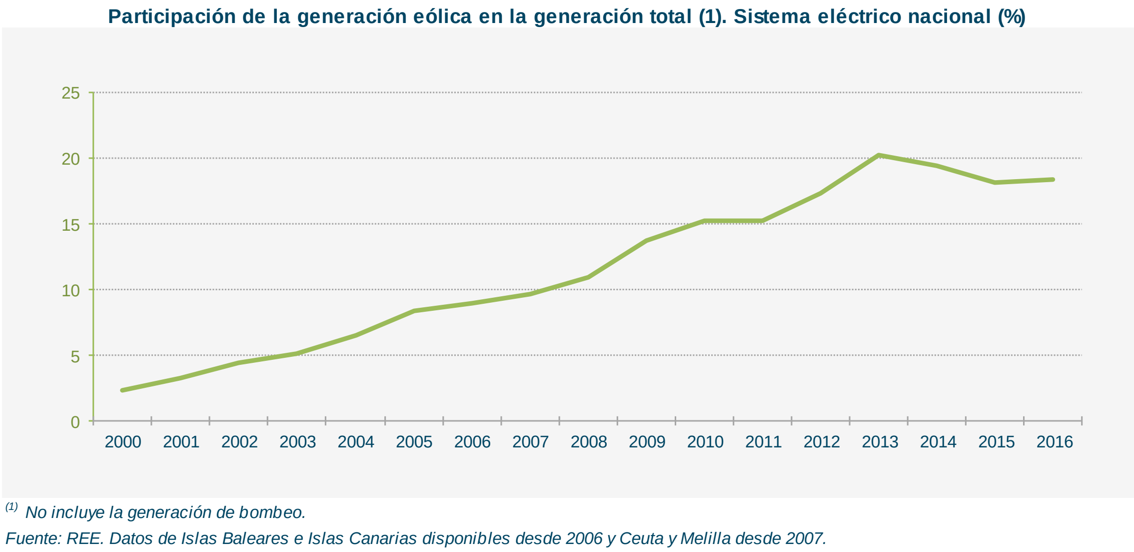

Figure 17: Evolution of the wind generation share in the Spanish Electric Power System

Figure 18 shows the evolution of prices and wind generation of renewable energy sources in January 2016.

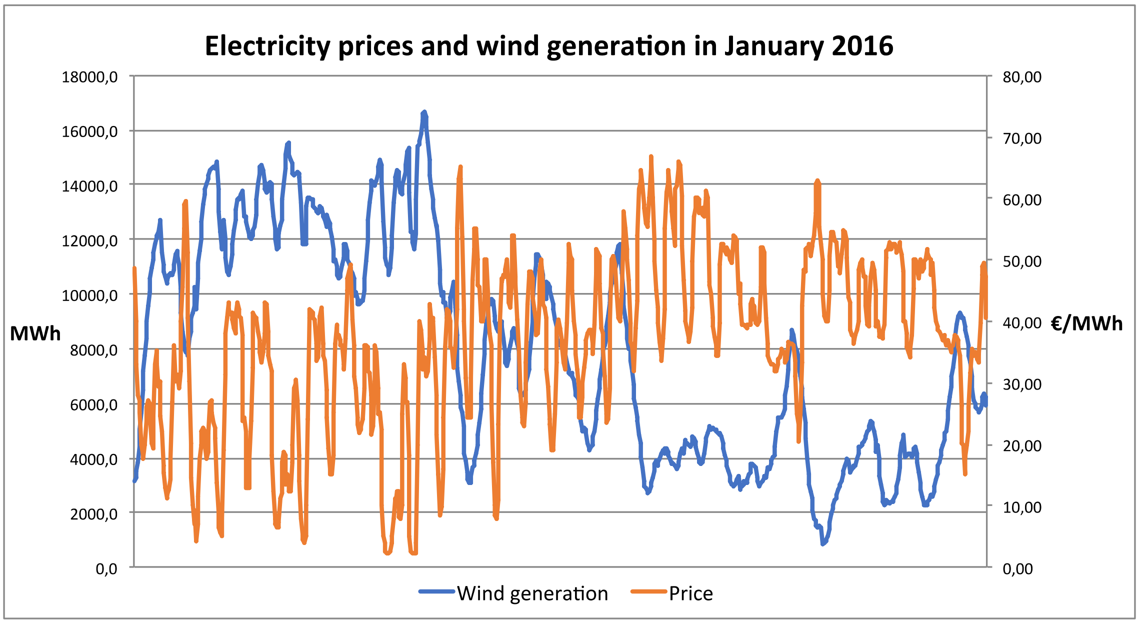

Figure 18: Relationship between electricity prices and wind generation

The impact is obvious. The higher the production, the lower the prices. In order to get a clearer representation of this correlation, the same values have been represented in ascending price values, with the corresponding energy from wind resources; line in dark blue represents the tendency of the series.

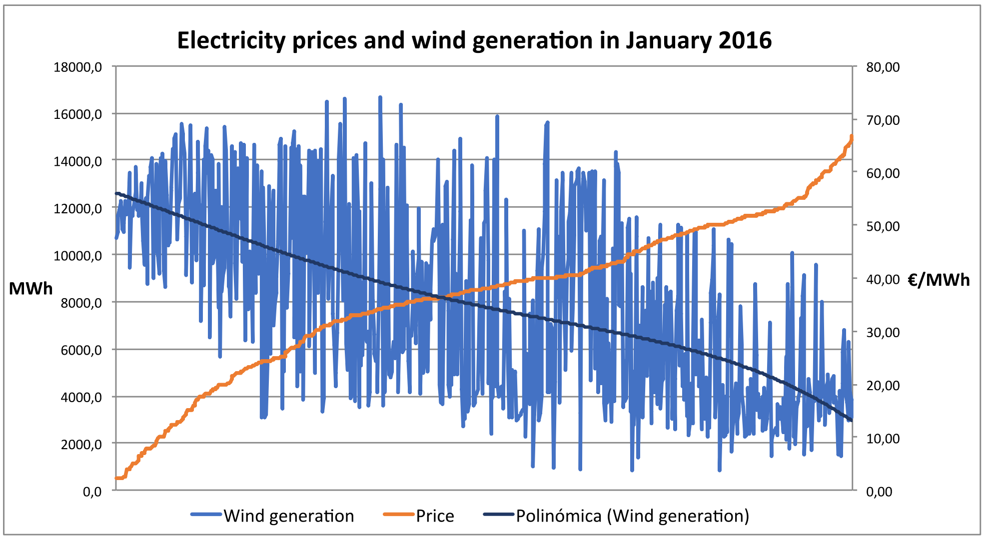

Figure 19: Relationship between electricity prices and wind generation ordered by ascending price

Solar

Currently, the impact of solar generation in electricity prices is not as relevant as desired. The low level of solar penetration in Spain does not allow the solar to be a relevant source in terms of price variation. Figure 20 shows photovoltaic penetration level in Spain in the latest years, while Figure 21 shows the low correlation between photovoltaic generation and electricity prices.

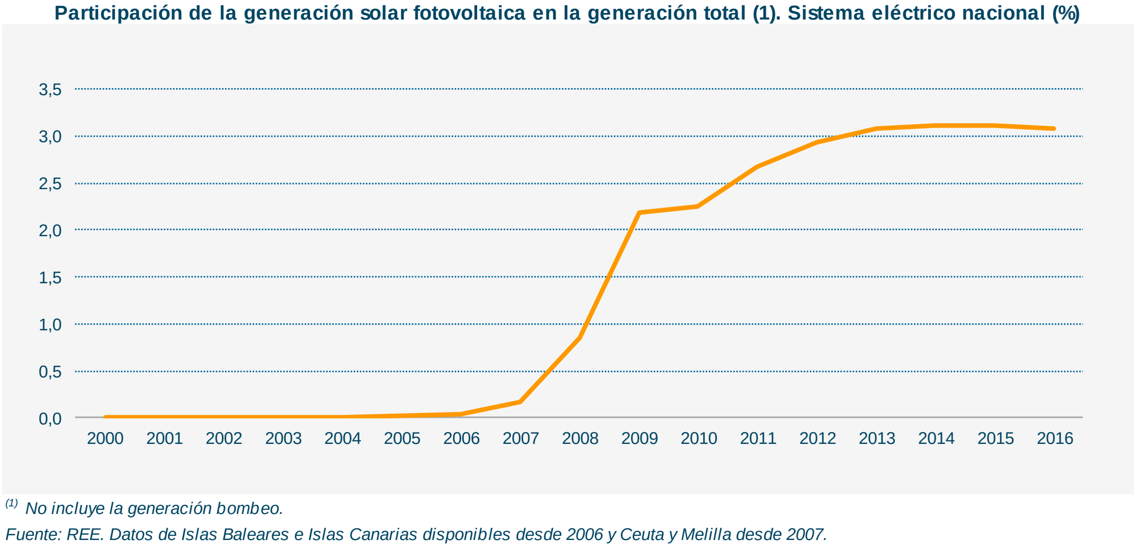

Figure 20: Evolution of the solar PV generation share in the Spanish Electric Power System

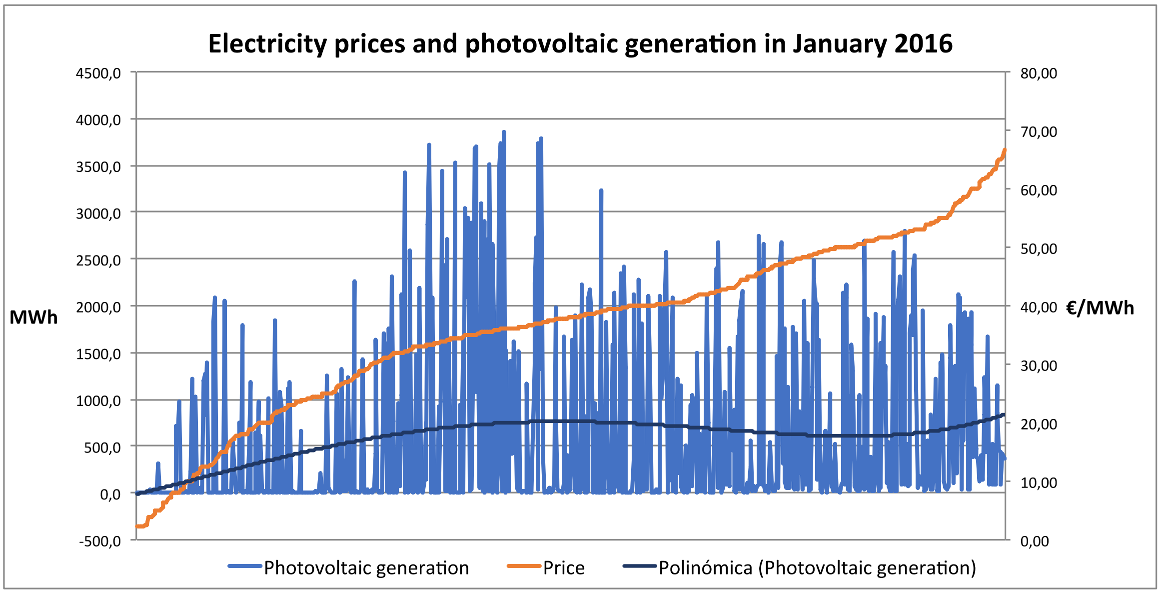

Figure 21: Relationship between electricity prices and solar PV generation ordered by ascending price

In addition, it is important to mention that photovoltaic generation is a limited source in this regard, due to its short production period; being able to produce in the hours when the Sun is radiating over the panels. However, this technology has the pro that it is easy to forecast and with a very firm supply, not being the case of wind production.

Photovoltaic generation technology has a high potential to be the electricity resource of the future in case the storage systems technology correctly improves. As it is cheaper time by time and its production is firm and easy to predict.

Hydraulic generation

The impact of hydraulic generation in prices is very relevant; although it is not that easy to notice how the prices are affected attending to historical data. The reason is that the hydro-reserves can be managed. Then, their water is used to reduce the prices when they are too high, the prices decrease, and the generators are remunerated at higher prices.

Therefore, the correlation between hydro generation is maximum and positive: the higher the prices, the higher the hydraulic generation. Unless there is a suboptimal management of hydro resources or there is no water available.

Figure 22 and Figure 23 show an example of the correlation between electricity prices and hydraulic generation. Suboptimal use of hydro resources is remarked in Figure 22.

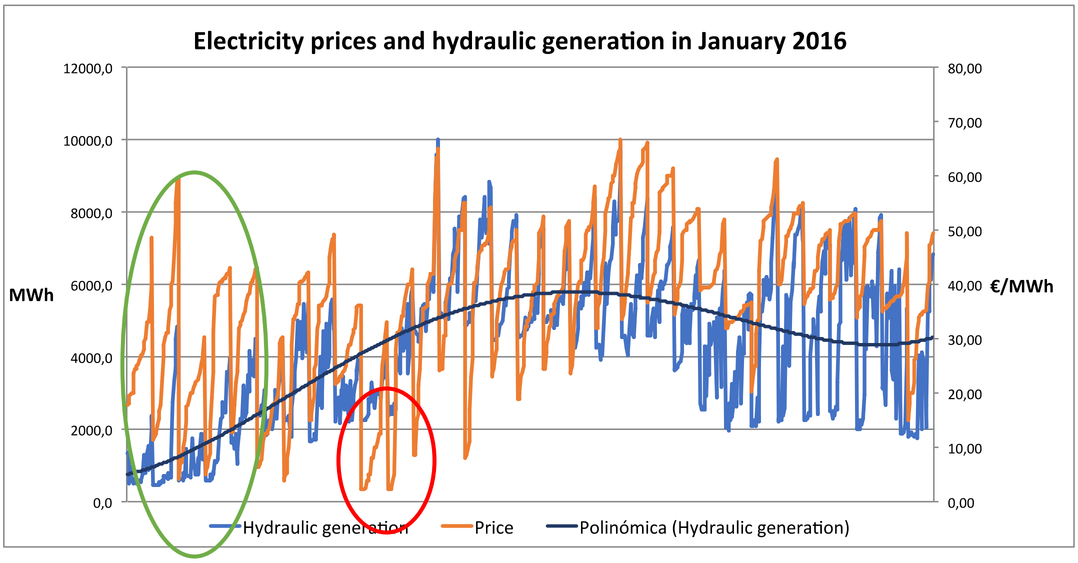

Figure 22: Relationship between electricity prices and hydraulic generation

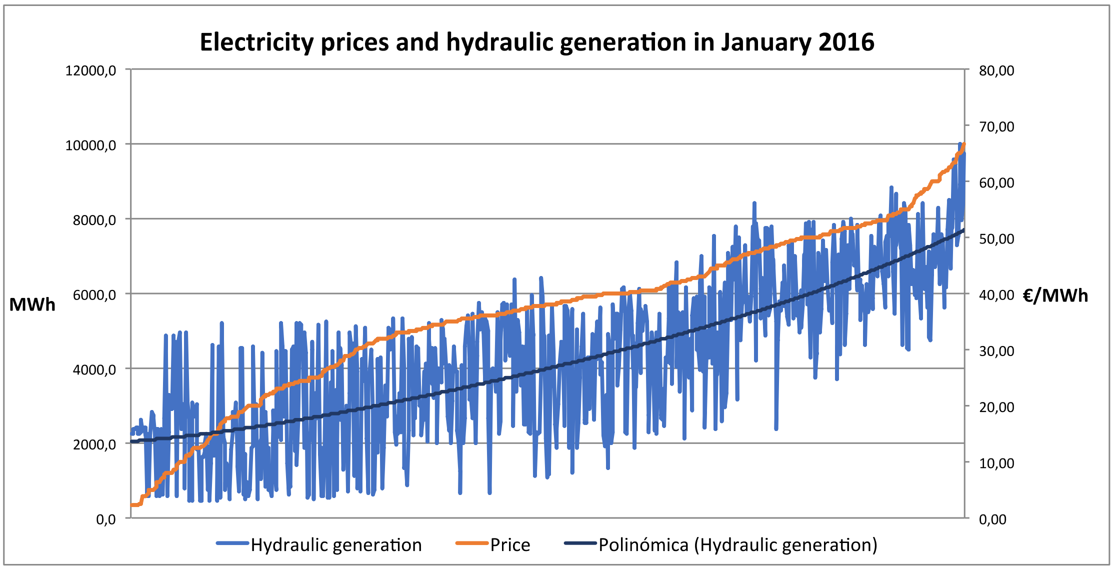

Figure 23: Relationship between electricity prices and hydraulic generation ordered by ascending price

3.4 Demand response: Storage systems, EV and Smart-buildings

Storage energy systems will be needed in the long-term. The reduction of carbon dioxide emissions is directly related to the disappearance of flexible units. Therefore, the electricity storage systems are the unique alternative to having non-emitting flexible electricity available.

Nowadays, this technology is the most competitive and mature alternative to combustion engines. Considering that transport consumes more than 35% of the total final energy in Spain, it is crucial to develop this technology as soon as possible.

As the evolution of storage systems is uncertain and not easily predictable, this technology cannot be considered as a real alternative. Hopefully, in the future, it evolves and gives the opportunity to improve energy management in the whole system. But the model develop in this project will not consider a significant penetration of storage in the system.

The demand response could be a key factor when trying to reduce energy prices and CO_2 emissions, as naturally, the generation is produced to cover the demand. An efficient use of resources can lead to lower prices.

Several factors have a huge potential to impact on energy prices:

- Smart grids: Self-consumption
- Energy management in smart buildings
- Electric Vehicles charging periods

3.5 Out of scope

There are several factors that are not considered in this report but could partially affect the results obtained with this forecasting model. However, they have not been considered due to the complexity in modelling compared to its impact and the limitations of VBA programming algorithms:

- Interconnection exchanges of electricity: Currently, the interconnexion capacity with France amounts to a total of 1.400 MW and it is planned to increase up to 2.800 MW by 2025.
- National transmission lines constraint dispatch: As an approximation for 10 years ahead, the redispatch of units in the hourly dispatch is not relevant.
- Generators ramp-up and ramp-down limits: Each technology is modelled as a total capacity (sum-up of all individual generators), which is dispatched when needed.

4 Forecasting model for schedule and energy prices

Once showing how technologies behave, in this section, the forecasting model structure will be explained. The aim objective of this model is to obtain the expected prices and technologies' hourly schedule based on already taken measures and considering that the optimal investment decisions will be taken for the next decade.

As previously explained in section 3.2 Thermal plants production and construction, nuclear issue is critical. It is under discussion to extend the authorisation of the operation of Nuclear power plants over the 40 years of operation. Depending on the final Government's decision, if it gives or not to the nuclear plants the authorisation to operate for a 60 year lifetime, the electric mix will be extremely affected. Therefore, two completely independent scenarios will be run:

- Nuclear power plants are to be closed after 40th year of operation
- Nuclear power plants extend their lifetime to 60 years of operation

Despite the fact that the results will vary hugely from one scenario to another, the model runs the same optimization model.

The objective is to satisfy the already forecasted demand with the cheapest and cleaner technologies. To do so, the order in which technologies cover the demand is listed below:

1. Firstly, nuclear power plants produce their available energy.
2. Cogeneration and mini-hydraulic technologies are the following ones covering the demand.
3. Solar photovoltaic generation.
4. Solar thermal generation.
5. Wind generation. As wind generation is easier to curtail compared to solar generation, by means of changing blades orientation, it is dispatched later.
6. Coal generation plants.
7. Combine cycle generation plants.
8. Hydraulic (with capacity to manage the reserves).

Among all these technologies some of them produce electricity based on their install capacity and resources instantaneously available, and not depend on their operational cost. Of course, they are non-emitting generation plants. These technologies are:

- Nuclear: It is not a flexible technology; it means that the plants cannot vary their production rapidly. Its operational costs are very low.
- Cogeneration (residual renewable): Its production depends on industrial processes. Always these industries are working; cogeneration electricity is "free".
- Mini-hydraulic: It is referred to those hydraulic plants that are non-manageable. Therefore, they are continuously producing without incurring any cost (maintenance costs are not considered).
- Solar thermal and photovoltaic: The operational costs, which is very low, have not been taken into account.
- Wind: The operational costs, which is very low, have not been taken into account.

In order to determine the amount of energy available of these clean technologies, firstly, the hourly capacity factor will be determined. Then, multiplying this capacity factor by the installed capacity (to be determined by the algorithm) at that hour, the total available generation is obtained.

Although the algorithm calculates the installed capacity, the hourly capacity factors are inputs of this algorithm. Therefore, capacity factors need to be estimated for the period 2020-2030 for each one of the before-mentioned technologies.

The capacity factor tendencies of these technologies are roughly similar from one year to another. Solar technologies do not vary a lot, they change between one year and another just due to the improvement of technology. While wind conditions have a lot of fluctuations, but they have a clear tendency: producing more during the nights and winter than during the day and summer time.

In order to forecast future capacity factors, historical data will be used. Firstly, historical capacity factors are calculated as the ratio between energy produced by each technology in hour *k*, divided by total installed capacity of that technology at that moment. Then, the capacity factor for a specific hour *k* in the future is calculated as the average capacity factor of hour *k* in the years 2014, 2015, 2016 and 2017, being these estimated factors equal for all future years. Finally, the hourly energy produced in every hour is obtained by multiplying hourly capacity factors by expected installed capacity in every hour.

Regarding the wind capacity factor, as it is the most fluctuating one, different scenarios of wind have been considered: capacity factors in 2014, 2015, 2016 and 2017. In case of considering the average capacity factor for the four years, the result would tend to be a very stable capacity factor, which is not realistic. Figure 24 shows this tendency.

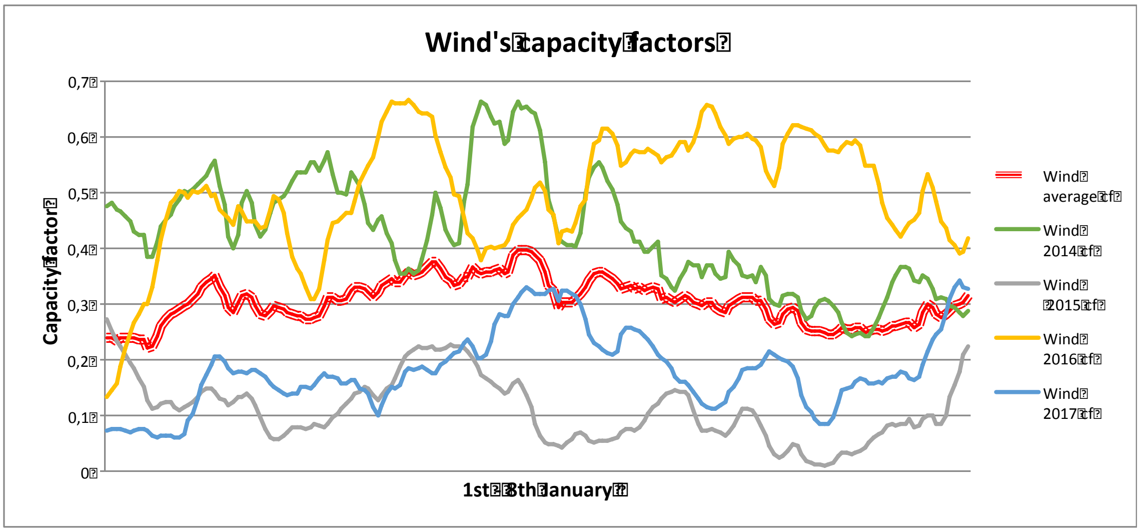

Figure 24: Comparison of average wind capacity factors and annual capacity factors

Therefore, all scenarios are run and the most unfavourable one is considered.

Finally, the expected installed capacity of each technology shall be estimated. The process differs from one technology to another as described hereunder:

Installed capacity:

In order to obtain the definitive hourly schedule of technologies and the expected installed capacity, all assumptions and calculations will be based on current installed capacity values. REE provides this information on its database website "esios".

Taking these values of installed capacity in January 2018 as starting point, the expected evolution is calculated based on the following estimations:

- Nuclear, cogeneration, solar thermal, mini-hydraulic and others:

They are expected to keep its installed capacity constant.

The case of nuclear plants is peculiar and will be divided into two scenarios, as previously commented.

Mini-hydraulic generation is not able to change considerably due to scarcity of natural hydro-resources in Spanish geography. While solar thermal generation is not as mature as photovoltaic, therefore it is a more expensive technology.

- Coal plants:

Regarding coal plants future operation, several scenarios could happen: they continue operating until 2030 as they have incurred huge investments to reduce emissions; they disappear from the electricity mix by the time the Government expects, around 2025; etc.

However, it is a matter of fact that some Spanish Utilities are trying to close their coal plants as soon as possible, no matter if this affects the market price. Coal plants as Anllares (365.2 MW, León), Compostilla (1341 MW, León) and Teruel (1101.4 MW, commonly known as Andorra's Thermal Plant), which represent almost a third of the coal's total installed capacity, have announced their intention to close by 2020.

Hence, this process of dismantling is an input for the model, being requested the expected dates of closure for each individual coal plant.

- Combined cycle gas turbines

As explained in section 3.2 Thermal plants production and construction, Spanish system suffers overcapacity due to the excessive amount of investments on CCGT carried out in the latest decades. It has led to capacity factors around 10% in CCGT power plants. They are not expected to be dismantled as they pollute below the maximum limit of carbon dioxide emissions expected to be established by the European Commission (around 370 g/MWh, below the limit of 550 g/MWh).

Therefore, CCGTs are modelled as continuously available plants. However, they are going to produce electricity subject to a maximum quantity of carbon dioxide emissions. The official objective is for 2030, not fixing a specific limitation ever year.

4.1 Model's methodology

The methodology to be followed by the model is schematically represented in Figure 25. Each step is explained below.

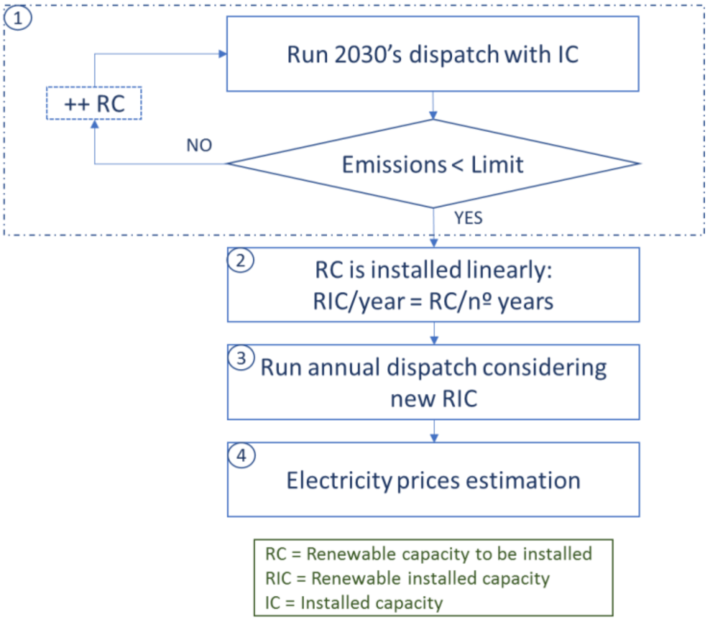

Figure 25: Model's methodology, renewable capacity estimation

The electricity dispatch needs to be run several times, as per Figure 25. Firstly, the process followed to dispatch hourly energy will be explained:

Once the demand to be covered is known, shall be satisfied by the available generation technologies, following the order described below. For each hour, and following the dispatching order, it is checked if each technology is able to cover the lacking demand with the hourly available energy. If it is not enough, the checked technology produces at maximum capacity and the next technology in the priority dispatching order is checked to cover the lacking demand.

1. Nuclear power plants produce at maximum power each hour, due to its low variable cost, bidding in the spot market at variable cost or even lower. The cost of starting up the nuclear power plant is very high, and it takes a lot of time. Then, these plants try to produce every hour at maximum capacity.
   The available hourly energy is calculated based in available capacity, which is multiplied by the availability factor. This factor is calculated based on historical data: average value of availability factors in 2014, 2015, 2016 and 2017.

2. Cogeneration and mini-hydraulic technologies are the following ones covering the demand. Cogeneration plants take advantage of heat given off by industrial processes, using it to generate electricity. It elevates the efficiency of the industrial plants and gives the opportunity to sell energy in the electricity market.
   The process to dispatch the electricity is similar to the nuclear one.

3. Photovoltaic solar generation. As explained in section 3.3 Renewable energy production and construction, the amount of solar installed capacity is multiplied by the average capacity factor in 2014, 2015, 2016 and 2017; resulting the available electricity to be dispatched. All generation available is directly dispatched.
4. Solar photovoltaic generation. The process followed is similar to the photovoltaic one.

5. Wind generation. As wind generation operation and maintenance cost is considerably higher than solar one, it is dispatched later. In addition, wind generation is easier to curtail compared to solar generation, by means of changing blades orientation. The process

followed is similar to the solar one, although there are several wind scenarios that are run randomly every year.

Once the cheapest and cleaner generation technologies have been dispatched, the thermal ones cover the lacking demand. Thermal plants are more expensive, but easily schedulable due to its flexibility. In Spain, there are mainly two thermal technologies: coal and combined cycle gas turbine.

6. Coal generation plants are typically dispatched before CCGT ones as they have lower operational cost. Although they are more polluting, and they will be dismantled earlier. Combine cycle generation plants are typically the latest ones in enter the dispatch. The overcapacity that Spain suffers makes CCGT available energy more than enough to cover lacking demand. Depending on the value of carbon dioxide price rate (€/tonCO_2), and the demand to be covered by thermal plants, coal and CCGT plants can variate its priority of dispatch order.

7. Hydro reservoirs are dispatched following an iterative process with the thermal plants. The cost associated to each "MWh" of energy produced by hydraulic reserves is zero. However, the energy bids in the electricity market are not offered at variable cost, but at the "water value" (€/MWh).

   Hydro-reservoirs management is based on water-value theory. The hydraulic generators will bid in the electricity market at their estimated water value.

   The water value is equal to the cost/price of the offer that is non-dispatched due to the hydro production. It means, hydraulic generators will bid at the price at which they think they would enter in the programmed dispatch by substituting the most expensive technology that would be dispatched if they are not. Therefore, the water value is the operational cost of the peaker technology.

   In this model, the hydro-reservoirs are managed with a variable scope to be introduce as input. There are several possibilities for this period:

   - 1 year ahead
   - 6 months ahead
   - 4 months ahead
   - 3 months ahead
   - 2 months ahead

   It means that the expected inflows during the following months selected are managed in such a way that they are completely wasted along this period. In case the maximum capacity of reservoirs is achieved, the water that would be spilled is redispatched in the previous hours at the maximum price possible.

   This simplification has been considered because there are several kinds of reservoirs according to the management period they work with: daily, monthly, annual, and hyper-annual. However, modelling hydro reservoirs would require a most sophisticated programming software. But this simplification is good enough to represent schedule the hydraulic generation, as it reflects the periods in which there are more inflows by producing more hydraulic generation.

Hence, the before described process is followed every time the model requires an energy dispatch.

4.1.1 Renewable energy capacity to be installed

The first step is to estimate the expected hourly dispatch in the following years, in order to forecast the electricity prices. To do so, it is necessary to calculate the expected renewable capacity to be installed in 2030, which enables the accomplishment of European objectives regarding carbon dioxide emissions.

The amount of renewable capacity to be installed in 2030 is estimated by means of an iterative process:

a) To run 2030 energy dispatch with 2020's installed capacity.

The amount of generation capacity in 2020 is already known, as the Spanish's auctions held in 2016 and 2017 have 2020 as the objective date to have already built plants that have win the auctions. It is supposed that there will not be new plants to be erected until 2021, which is the supposed objective date for the next auction in Spain.

In this case, the dismantlement of coal plants, the lack of investment and the probable increase of demand, lead to a huge amount of demand to be covered by CCGT plants.

Computing the whole year carbon dioxide emissions, the production exceeds by far the maximum level pre-fixed by the international objectives. In this regard, the method to calculate the amount of photovoltaic and wind capacity to install is based on a progressive decrease of CCGT capacity.

There is a point in which the capacity of CCGT is not enough to satisfy the demand. Then, the not satisfied demand at each hour is saved in a vector. This vector is swept looking for the critical hour where the coefficient of demand unsatisfied and capacity factor of wind or photovoltaic generation is the highest. This critical value is the one that determines the capacity to be installed:

$$Capacity\ to\ be\ installed = \frac{Demand\ unsatisfied\ in\ hour\ k}{Max\ (cap.factor\ wind, cap.factor\ PV)\ in\ hour\ k}$$

The energy is dispatched one more time considering the new installed capacity. If the carbon dioxide emission produced is still over the maximum limit, the capacity of CCGTs is reduced one more time. This process is repeated until the objectives of emissions are achieved.

4.1.2 Clock-step for renewable capacity installation

Once the total capacity to be installed in 2030 is known, it is supposed that the installation will be progressively carried out.

The model considers that there is an auction every year and the amount of capacity resulting of that auction is the total capacity to be installed in 2030 divided by the number of auctions (2030-2020 = 10 auctions).

4.1.3 Generation dispatch for 2020-2030

At this point, the capacity to be installed is perfectly known. Then, the previously process of dispatching and scheduling the different technologies is applied to every year. Resulting the final dispatch of the complete decade.

4.1.4 Electricity prices estimation

Once the hourly dispatch for the years between 2020 and 2030 has been run, the electricity prices can be estimated. In this Project, the prices that will be obtained are referred to the price of produce a specific amount of electricity in the Iberian market. It is not the same that the price at which electricity is billed to the end consumers, which includes regulated costs in addition to generation costs.

The process to be followed is simple. As explained in 2.5 Wholesale electricity market operation, the hourly electricity price in the market is the bid's value of the most expensive unit that have been dispatched. Following the dispatch process, the most expensive unit is the latest one.

In this study, the dispatch order has been the following:

1) Nuclear
2) Cogeneration + mini-hydro
3) Solar PV
4) Solar thermal
5) Wind
6) Coal or CCGT
7) Hydro

Despite the fact that hydro generation is the latest dispatched, the bids of hydro generators are similar to the bid of the most expensive unit dispatched.

The bids submitted to OMIE's platform has been analysed in order to estimate the final prices. OMIE publishes after 90 days the hourly bids of all generators. Base on bids submitted by every type of generators, OMIE has carried out a regression analysis in order to estimate the curve that better fits with the bidding strategy of thermal generators. The cheaper generators are the ones that are first dispatched, therefore, the higher the penetration of one technology, the higher the bid value of the next generator of that technology.

Figure 26 and Figure 27 carried out by OMIE represent this before-mentioned fact, for CCGT and coal plants, respectively. Moreover, the tendency curve has been drawn in order to implement it in the model. Knowing the amount of penetration of each technology, the maximum bid can be obtained. These equations are also used to dispatch coal and CCGT plants according to its expected variable cost.

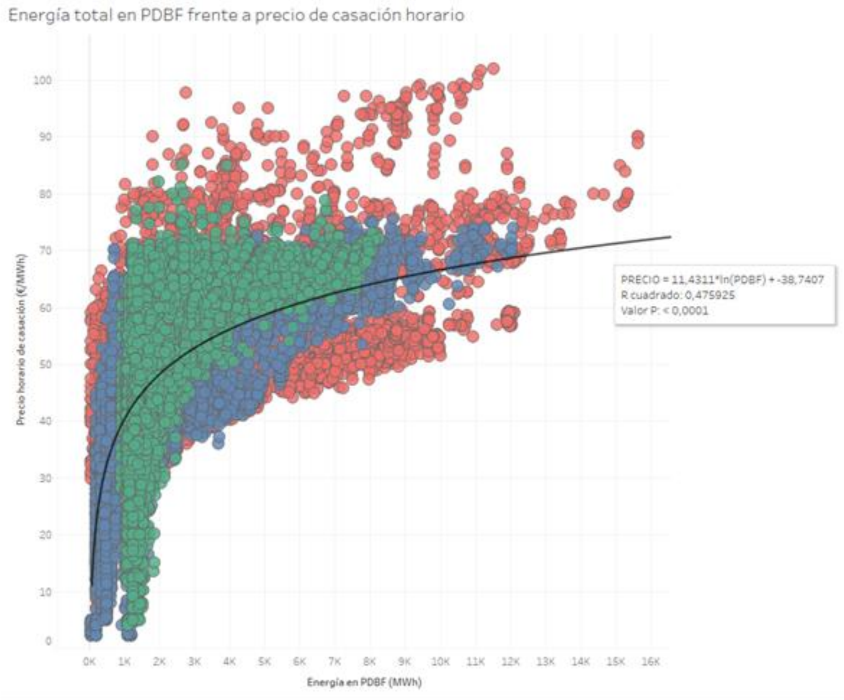

Figure 26: Relation of energy produce by CCGT plants in the daily program (PDBF) with hourly resulting price

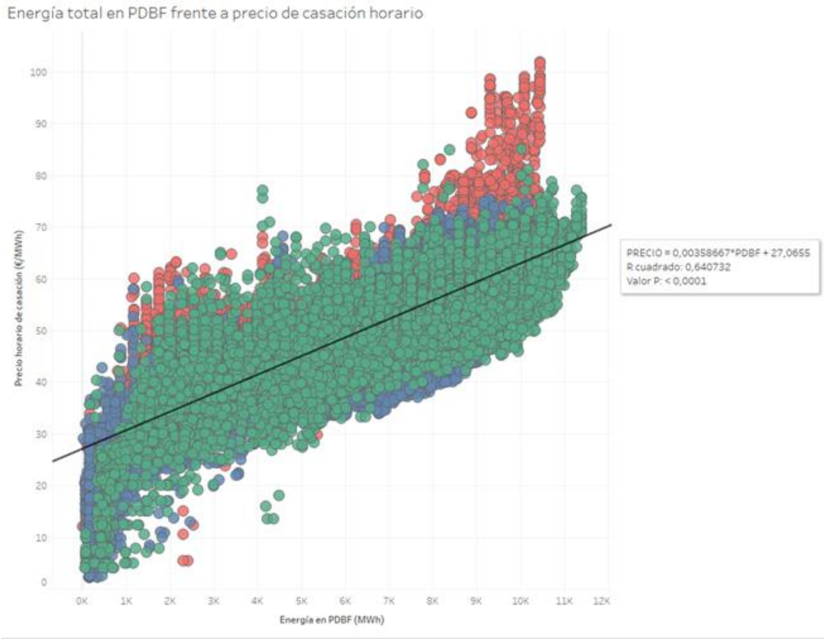

Figure 27: Relation of energy produce by coal plants in the daily program (PDBF) with hourly resulting price

4.2 Maximum level of carbon dioxide emissions in 2030

The maximum level of carbon dioxide emissions must be reduced a 40% with respect to emissions in 1990. In 1990, the total emissions produced by combustion of fossil fuels combustion is 202.6 Mton CO_2, according to data provided by IEA in "IEA CO2 Emissions from Fuel Combustion, OECD/IEA, Paris, 2017". However, the limit for the electricity power industry in 2030 is not so straightforward, as the emissions provided by IEA considers the full country's emissions.

Therefore, the maximum limit for the emissions in 2030 is directly calculated as:

$$\boldsymbol{Max\ CO_2\ emissions\ 2030} = 202.6 \cdot (1 - 0.4) = \boldsymbol{121.56\ Mton\ CO_2}$$

This value is the maximum quantity of carbon dioxide emissions in 2030 taking into account the production of all sectors. There are five sectors attending to IEA's differentiation, whose carbon dioxide emissions' level in year 2015 is represented in Table 7.

	Total CO_2 emissions from fuel combustion	Electricity and heat production	Other energy industry own use	Manuf. Industries and construction	Transport	Other sectors
2015	247,0	81,4	18,8	28,9	85,5	32,4
Share		32,9%	7,6%	11,7%	34,6%	13,1%

Table 7: Total amount of carbon dioxide emissions in Spain by sector (Mton CO_2)

As IEA's statistics only provides 1990's emissions value for the totality of Spain: 202.6 Mton eq CO_2. The emissions corresponding to electricity sector are obtained from REE website, accounting for a total of 54.82 Mton eq CO_2.

In order to estimate the maximum limit of carbon dioxide emissions for the electricity sector in 2030, it is considered that the remaining sectors will just increase their efficiency a 20% with respect to 1990. It is a conservative assumption based on the continuous decrease of energy intensity in Spain. If it is not accomplished, the electricity sector will not be able to reduce by itself the required amount of carbon dioxide emissions for 2030.

The total amount of carbon dioxide emissions produced by the remaining sectors in 1990 accounts for

$$Total - Electricity\ sector\ emissions = 202.6 - 54.82 = 147.78\ Mton\ eq\ CO_2$$

Considering the efficiency of these sectors, 20% from 1990 to 2030, the maximum limit of CO_2 emissions for the electricity sector in 2030 is:

$$121.56 - 147.78 * (1 - 0.8) = 3.336\ Mton\ eq\ CO_2$$

In addition, the estimation of emissions per unit of electricity production will be based on data provided by IDAE, as shown in Figure 28. The value of emission factor considered in the model is the referred to “at terminals of the plant” (“en bornes de la central”), as the electricity produced is measured at this point.

ELECTRICIDAD									
TECNOLOGÍA	ENERGIA FINAL		ENERGÍA PRIMARIA				FACTOR DE EMISIÓN		
			Bornas de central		En punto de consumo		En bornas de alternador (bruta)	En bornas de central (neta)	En punto de consumo
	MWh	tep	MWh	Tep	MWh	tep	tCO_2/MWh	tCO_2/MWh	tCO_2/MWh
Hulla+ antracita	1	0,086	2,52	0,22	2,73	0,24	1,13	1,17	1,27
Lignito pardo	1	0,086	2,68	0,23	2,91	0,25	0,90	0,93	1,01
Lignito negro	1	0,086	2,68	0,23	2,91	0,25	0,97	1,00	1,09
Hulla importada	1	0,086	2,52	0,22	2,73	0,24	0,90	0,94	1,02
Nuclear	1	0,086	3,03	0,26	3,29	0,28	0	0	0
Ciclo Combinado	1	0,086	1,93	0,17	2,09	0,18	0,34	0,35	0,38
Hidroeléctrica	1	0,086	1,00	0,09	1,09	0,09	0	0	0
Cogeneración MCIA (3)	1	0,086	1,67	0,14	1,74	0,15	0,37	0,38	0,42
Cogeneración TG (4)	1	0,086	1,61	0,14	1,69	0,15	0,33	0,34	0,37
Cogeneración TV (6)	1	0,086	1,72	0,15	1,80	0,16	0,41	0,42	0,46
Cogeneración CC (6)	1	0,086	1,54	0,13	1,61	0,14	0,31	0,32	0,35
Eólica y fotovoltaica	1	0,086	1,00	0,09	1,09	0,09	0	0	0
Solar termoeléctrica	1	0,086	4,56	0,39	4,95	0,43	0	0	0
Biomasa eléctrica	1	0,086	4,88	0,42	5,29	0,46	0	0	0
Biogás	1	0,086	3,70	0,32	4,02	0,35	0	0	0
RSU	1	0,086	4,02	0,35	4,36	0,38	0,24	0,25	0,27
Centrales de fuelóleo	1	0,086	2,52	0,22	2,73	0,24	0,71	0,73	0,79
Gas siderúrgico	1	0,086	2,86	0,25	3,10	0,27	0,64	0,69	0,75

Figure 28: Emission's factor per technology

Therefore, the emission factor used for all coal plants and combined cycle power plants are the ones shown in Table 8.

	Emission factor
Coal plants: Hulla importada	0,94
Combined cycle	0,35

Table 8: Emission factors used in the model

5 Analysis of results obtained with forecasting model

In this section, several scenarios that could occur in the future depending on demand evolution and/or existing generation plants evolution are analysed.

Demand evolution will be analysed taking into account different scenarios of efficiency in consumption. As explained in section 3.1 Demand evolution, depending on efficiency rate entered as an input for the model, the demand will be affected as follows:

$$FutDem = CurrDem * GDPgrowth * Housesgrowth * (1 - efficiency\ rate)^{(year-2017)}$$

Where "year" stands for the year to forecast the demand.

An efficiency rate of 0.5% would represent a factor of hourly electricity consumption in 2030 with respect to 2017 of 93.7%:

$$\left(1 - \frac{0.5}{100}\right)^{2030-2017} = 0.937$$

It means an hourly reduction of 6,3%. In order to get a clear idea, Figure 29 represents the resulting demand profile for different values of efficiency rate for an arbitrary day of 2030.

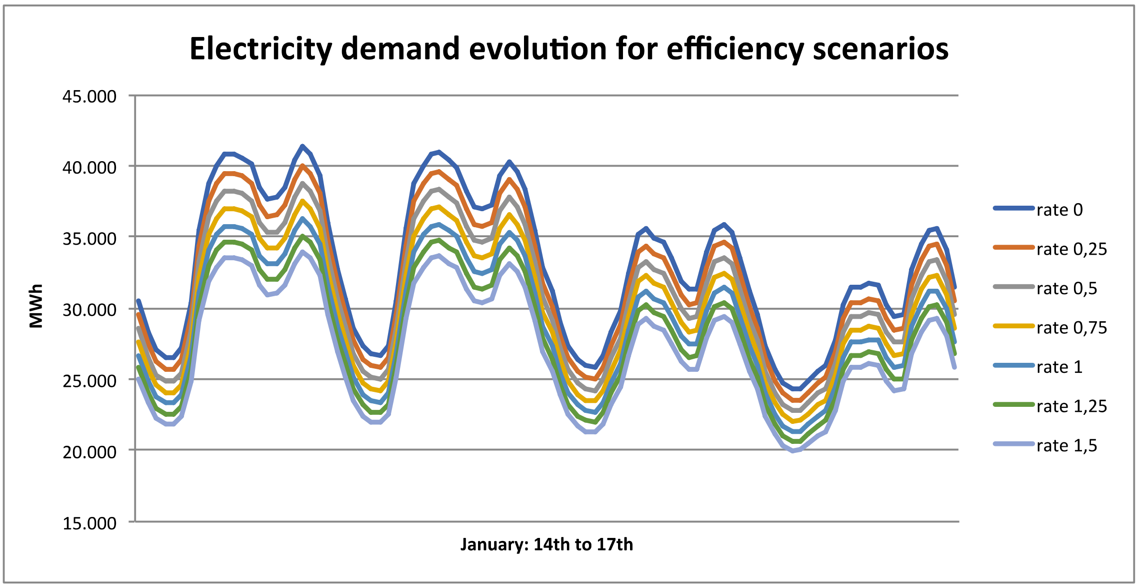

Figure 29: Electricity demand evolution for different scenarios of efficiency in 2030

In addition to generation dispatch, hourly schedule of technologies and electricity prices estimation, there is a critical parameter which the model estimates and uses for doing all calculations, which is the amount of new renewable energy sources capacity to be installed along the decade. The model forecasts the capacity to be installed during 2020 and 2030, considering the capacity already auctioned for starting to work in 2020 as installed.

Firstly, several scenarios of efficiency rate value are shown, considering nuclear plants working and not. Then, some of these scenarios are deeply evaluated, including generation dispatch and price results.

RES capacity to be installed

Efficiency is very relevant when talking about electricity demand evolution. Therefore, it has an enormous potential to decrease carbon dioxide emissions while reducing the needs of RES deployment.

The same case of efficiency occurs with nuclear plants in this regard. The fact of stopping nuclear plants functioning has a huge impact on electricity prices, carbon dioxide emissions and, therefore, in RES to be deployed. Socio-political uncertainty with regards to this issue makes it unforeseeable to know if Spanish nuclear generation plants will have license renewal for 20 additional years, reaching its 60 years' operation. From the security point of view, it seems that there is no concern, the uncertainty comes from public opinion, and, finally, political resolution.

Hence, several scenarios have been run in order to consider all possible cases. Resulting capacity values are shown in Table 9.

NUCLEAR (+20years)					
Annual efficiency rate (%)	0.00	0.25	0.50	0.75	1.00
Wind (GW)	52.3	50.6	45.8	39.8	35.7
Solar PV (GW)	32.6	29.5	26.6	24.1	21.8

NUCLEAR (off)					
Annual efficiency rate (%)	0.00	0.25	0.50	0.75	1.00
Wind (GW)	88.4	83.5	77.3	72.0	65.5
Solar PV (GW)	49.7	46.0	44.5	42.0	39.2

Table 9: RES scenarios of capacity to be installed before 2030

Results show how the need of RES deployment is completely related to political decisions to be taken right now, technological progress concerning efficiency issues and social awareness.

However, the critical decision is whether Spanish Government will opt for a future with nuclear or not. Best scenarios of efficiency without nuclear plants are even far from those scenarios of worst efficiency with them.

In any case, it can be concluded that average needs of RES deployment are around 65 GW of wind and 35 GW of solar PV to be installed along next decade.

Electricity prices

Considering a reasonable efficiency rate of 0.5% for both cases of nuclear operating life, scenarios are set by varying input parameters:

- All coal plants are closed before:
  - 2020
  - 2025
  - Progressively closed down between 2020 and 2025
- Carbon dioxide emissions price rate increases. Considering that CO_2 price in 2020 is 20€/tonCO_2.
  - + 5 €/tonCO_2 every year
  - + 10 €/tonCO_2 every year

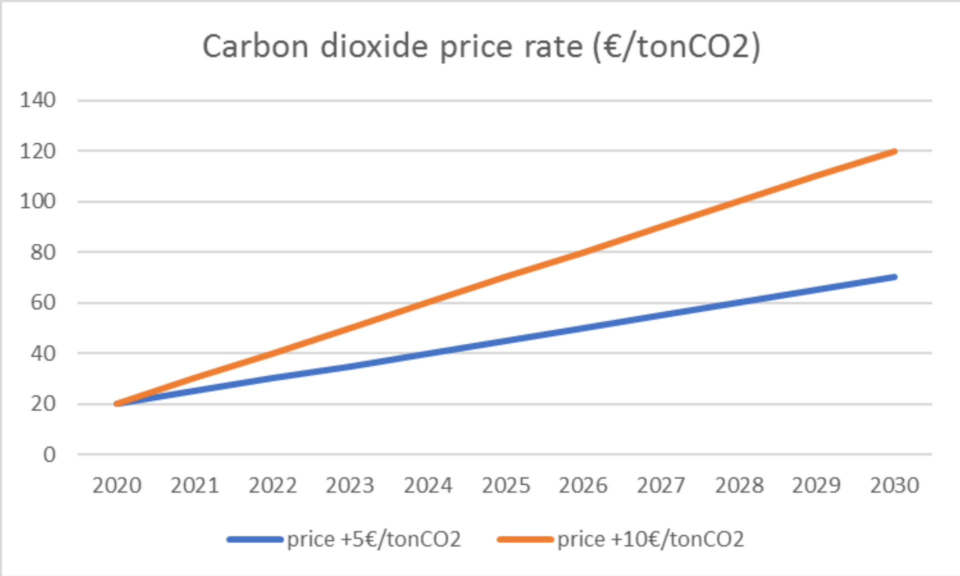

Figure 30: Evolution of carbon dioxide price rate (€/tonCO2) in both scenarios

Both scenarios of carbon dioxide emissions price evolution have considered based on studies which estimate a nearly linear increase of this concept. As it is the case of "*2015 Carbon Dioxide Price Forecast*" [SEE_15], which represents the rate evolution as shown in Figure 31.

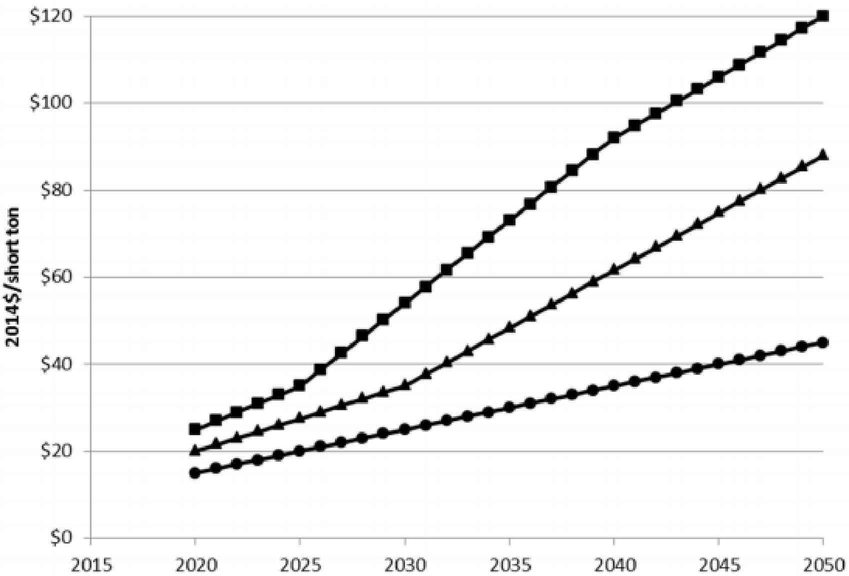

Figure 31: Evolution of carbon dioxide emission price

The scenarios analyzed in this section are shown in Figure 32.

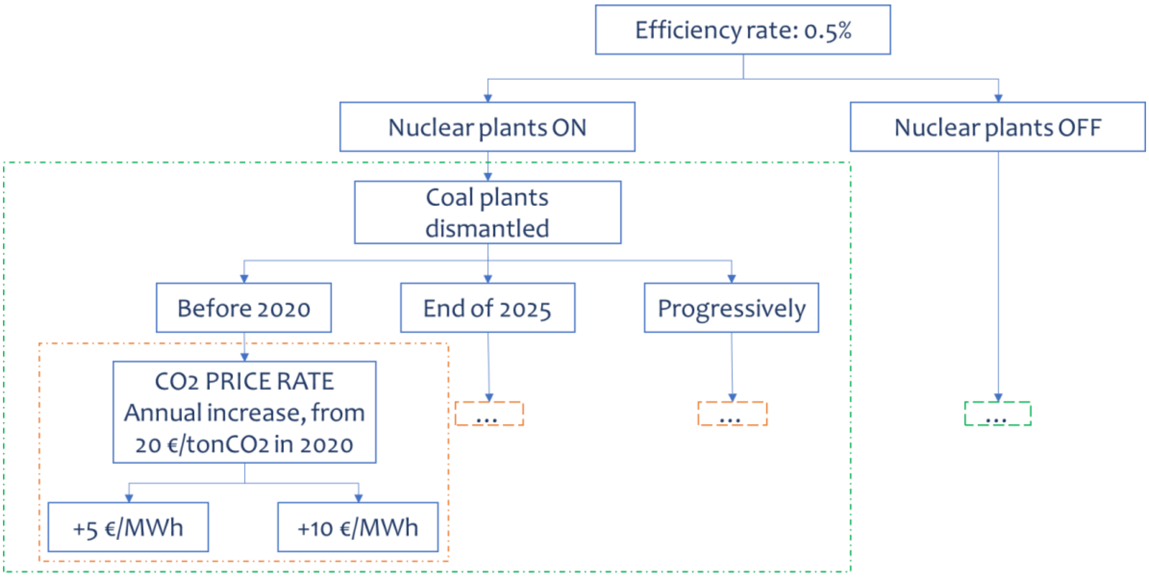

Figure 32: Scenarios analyzed

The price resulting from these scenarios, shows a similar tendency in average electricity prices decrease when nuclear is dismantled and when it is not. It is because nuclear plants are progressively dismantled when their license expire (see 3.2 Thermal plants production and construction), as well as renewables are progressively installed. The only difference is that price variations are more aggressive with renewables than with nuclear plants, due to intermittency.

Figure 33 and Figure 34 show annual average electricity prices for all scenarios mentioned in Figure 32.

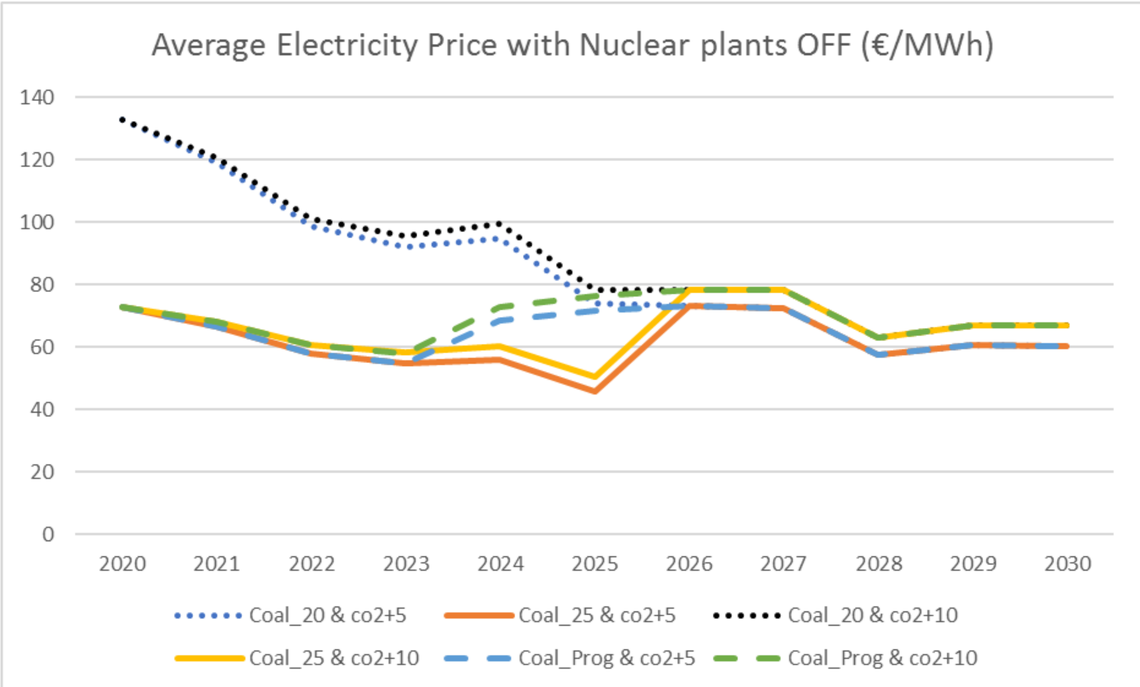

Figure 33: Average Electricity Price with Nuclear plants dismantled

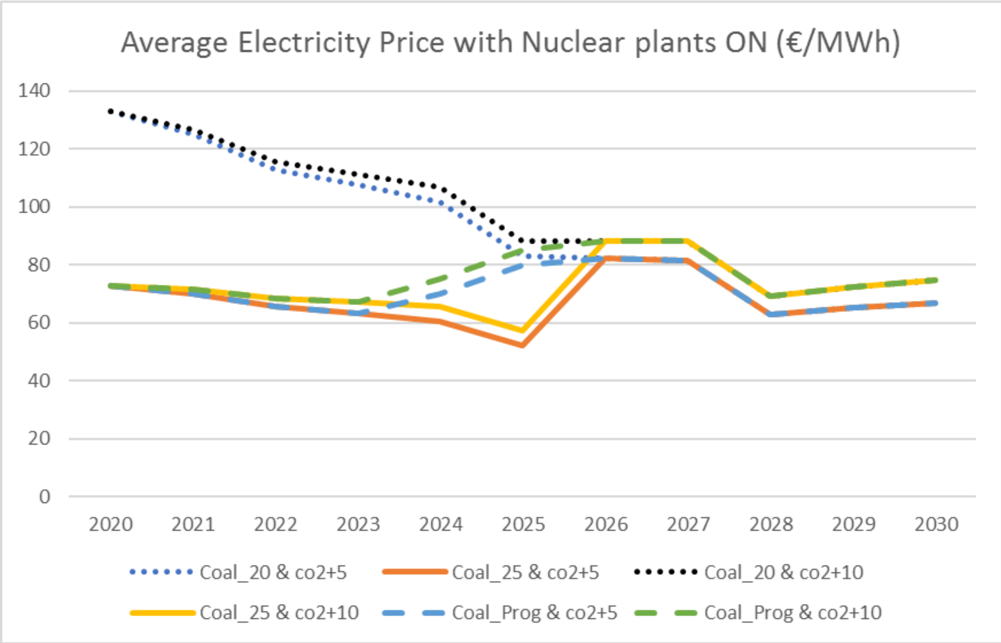

Figure 34: Average Electricity Price with Nuclear plants operating

The main conclusion from both figures is that electricity production prices tendency keeps similar for both cases of nuclear plants operation. However, the final electricity bill would increase if nuclear plants are stopped due to the need of RES as substitutes.

The only difference appreciated in prices profile is that, in the case of nuclear plants' license renewal, the profile is smoother. It is reasonable, because the nuclear plants would be substituted by RES, resulting in a very high RES production dependency, which causes higher volatility of electricity prices with respect to stable production of nuclear plants. Therefore, the intermittency in generation is transformed into volatility and a more unstable profile in average electricity prices.

The following points represent the main conclusions that can be extracted taking into account the Figure 33 or Figure 34:

- Coal plants dismantlement has a huge impact on electricity prices production, being the most relevant factor when considering evolution of production price. It is important to remark that the final electricity bill could be more affected by decisions regarding nuclear plants dismantlement rather than coal plants dismantlement. It is due to the need of installing huge amounts of RES capacity in the near future in order to substitute nuclear production, with the corresponding cost of RES support mechanisms.

- In the scenarios in which coal plants are dismantled before 2020, the electricity price almost doubles. Here comes the recent discussion between the former Spanish Government and the Spanish Utilities when deciding when coal plants could/should be closed. Some Spanish Utilities demanded the closure of their coal plants arguing that they were economically unviable or for environmental reasons. Apparently, and attending to Utilities' rights, in a liberalized market, a Government should not intervene in such decision. However, the former Spanish Government thought to forbid the Utilities to close their coal plants until it was demonstrated that they were inefficient, giving them the possibility to sell that plant to another agent. It was done in the sake of avoiding the increase of the market price.

Attending the huge impact that this fact could have in electricity production prices, it seems reasonable that this strategy could be an exercise of market power.

- The progressive dismantlement of coal plants compared to sudden dismantlement at the end of 2025, also shows the importance of coal plants for the reduction of electricity prices production.

- The tendency of production prices in the period of 2026-2030 in not clear. It tends to a decrease in electricity prices, but there is a huge dependency on intermittent generation. Moreover, every year has been run with a different profile of wind/solar availability (based on historical data).

- The progressive increase of carbon dioxide emission price shows that there is an increasing spread between both scenarios (+5 €/tonCO_2 and +10€/tonCO_2). Despite the fact that emission prices increase considerably every year, the spread is not that exaggerated because the generation of thermal plants is reduced year by year, and CCGT plants are not that affected by emissions price rate as coal plants. The impact of emission prices in every MWh produced by a coal or CCGT plant is:

$$CO_2\ price\ rate\ (P) \cdot Emissions\ factor$$

In the case of a coal plant:

$$P \frac{€}{tonCO_2} \cdot 0.94 \frac{tonCO_2}{MWh} = P \cdot \frac{0.94€}{MWh}$$

In the case of a CCGT plant:

$$P \frac{€}{tonCO_2} \cdot 0.35 \frac{tonCO_2}{MWh} = P \cdot \frac{0.35€}{MWh}$$

Figure 35 shows the evolution of average electricity price for different fixed values of carbon dioxide emission prices, 50 €/tonCO_2 and 80 €/tonCO_2. Clearly, the impact of CO_2 price decreases progressively as coal plants are progressively dismantled.

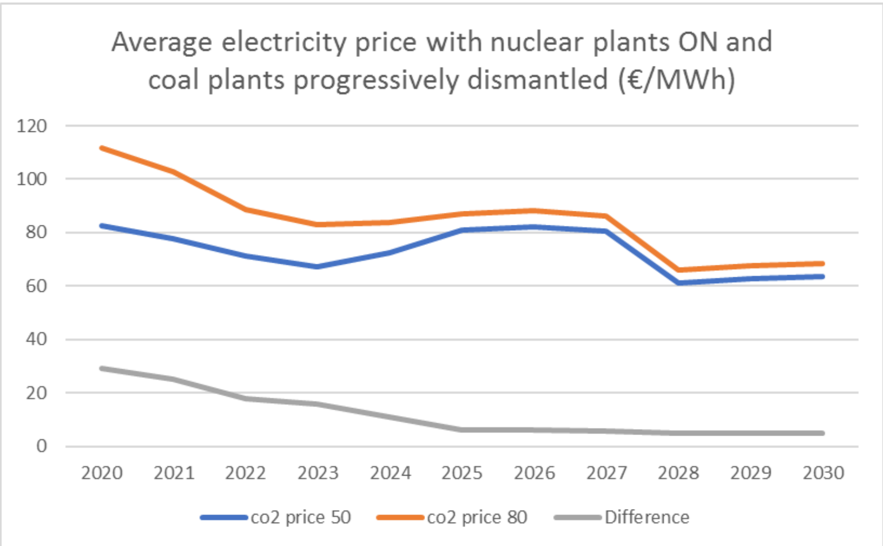

Figure 35: Average electricity price: Nuclear plants keep operating and coal plants progressively dismantled, for carbon dioxide price of 50 and 80 €/tonCO2

6 Conclusions

Considering the results and analysis shown in “5 Analysis of results obtained with forecasting model”, even taking into account the structure of the model itself, with a considerable number of inputs; the main conclusion to be extracted is that there is **too much uncertainty with regards to the electricity sector evolution**. Some political and industrial decisions, which are nowadays unpredictable, are the drivers of the electricity sector. The impact that these decisions have in the final consumer and in the Spanish industry are huge.

In addition, there is no time to lose when deciding which is going to be the path to follow in terms of energetic policy. System stability could be at risk if the deployment of RES is not done progressively, and the objectives to be achieved will not be possible if there is no consensus soon. Besides, the **wrong decisions will be heavily penalised** as previous experience has shown. The Spanish case in RES support mechanism is a good reminder of how deficit is affected by a wrong design of a needed strategy.

There are four main points to take into account in the near future in order not to suffer an energetic crisis:

- Nuclear plants dismantlement. Public opinion has continuously manifested a negative attitude with regards to nuclear plants operation due to previous dramatic experiences (Chernobyl or Fukushima). However, there are too many difficulties when trying to stop the operation of nuclear plants: the fact that nuclear power plants operation price is very low, it is a non-CO_2-emitting technology and its share in Spanish production mix is very high (20%).

  Considering that the Spanish nuclear plants licence expires soon, there is uncertainty whether current government will execute the possibility to renew their license for 20 years more. According to results shown in this report, the impact of not renewing licences affects dramatically the need of RES installation in the near future due to CO_2 and electricity prices emissions increase. Moreover, the sudden deployment of huge amounts of RES capacity could put in threat the system stability.

  Nuclear plants dismantlement is an important issue in terms of carbon dioxide emissions potential increase, public opinion and system stability in case it has to be substituted urgently by RES.

- There had been some disputes between former Spanish Government and Utilities with regards coal plants dismantlement. Utilities announced the request for dismantling their plants, but former Government decreed that it was forbidden until there were no shadow of doubt about exercising market power or any effect in the market prices. Attending to results previously shown, the impact of closing coal plants in electricity prices is huge; as it is also huge the impact of carbon dioxide emissions reduction.

- RES support mechanism design has to be done carefully and paying attention to the system needs, not focusing only into labels (Feed-in tariff, Green certificates, etc.). There is a common question that electricity market consultants ask themselves when deciding the way of promoting RES in order to reduce CO_2 emissions: What is more efficient, to charge those polluting plants with an extra-cost per tonCO_2, or remunerate RES per capacity installed/Energy produced?

Besides the fact that carbon dioxide emissions price is expected to continue increasing as per section 5 Analysis of results obtained with forecasting model, the common thought is that RES should be promoted by remunerating either by capacity installed or energy produced rather than penalizing the polluting technologies. This last strategy could lead to polluting technologies internalizing the CO_2 price in their bids and resulting in an increase of electricity pool price more than a mechanism to promote RES deployment.

- Energy efficiency and new forms of demand response need a policy framework in order to contribute to accomplish objectives regarding energy system.

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Annex 1. Chronology of Treaties, Laws and other agreements in the European Union

Year	Treaties and Laws	Integration Level	Countries
1951	Treaty of Paris	**European Coal and Steel Community**: Free Trade Agreement, Customs Union, Common Market in Coal and Steel in order to ensure primary energy sources, a rational source of resources, ensure low prices…	Belgium, Netherlands, Luxemburg, Germany, France, Italy
1957	Treaties of Rome	European Economic Community (EEC) A common energy policy is NOT established, however the instruments for developing it are. European Atomic Energy Community (EURATOM)	
1957			
1973	UK, Ireland, Denmark		
1981	Greece		
1986	Spain, Portugal		
1986	Treaty of Brussels/Single European Act	Ammend to EEC Treaty and paved the way for completing the single Internal Market: a common market including more competences and technical, regulatory and tax harmonization among countries.	EU-12
1992	Treaty on European Union / Treaty of Maastricht	Established the European Union, added new policy areas of cooperation Single Currency: EURO	EU-12
1995	Austria, Finland, Sweden		
1996	First Energy Package: Principles, Directives and Regulations, then implemented as national laws.	**Internal Energy Market** and Liberalization Process in Electricity and Natural Gas Markets: liberalization of generation and supply, non-discriminatory principles for transmission and distribution, TPA, accounting and legal separation of VIC, free choice of supplier	EU-15
1997	Treaty of Amsterdam	Amendment of previous treaties	
2000	Green Paper: "Towards a European strategy for the security of energy supply"	Community economic competitiveness, security of supply and environmental protection	
2001	Treaty of Nice	Streamline the EU institutional system	
2003	Second Energy Package: Principles, Directives and Regulations, then implemented as national laws.	**Internal Energy Market** and Liberalization Process in Electricity and Natural Gas Markets: liberalization of generation and supply, non-discriminatory principles for transmission and distribution, TPA, accounting and legal separation of VIC, free choice of supplier	EU-15
2004	Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovenia, Slovakia		
2006	Green Paper: "Strategy for a sustainable, competitive and safe energy"	Community economic competitiveness, security of supply and environmental protection	
2007	Romania, Bulgaria, Croatia		
2007	Treaty of Lisbon Treaty of Functioning of the European Union	Among other things: **Energy Policy:** Ensure the **functioning of the energy market**, ensure **security of supply** in the Union, promote **energy efficiency and energy saving**, promote the **development of new and renewable energies**, **promote interconnections.** This policy does not affect **Member State's right** to determine the conditions for exploiting its energy resources, its **choice between different energy sources** and the general structure of its energy supply	EU-28
2007	Climate and Energy Package (Green Package): 2020 Horizon	Fight against climate change: reduce emissions by 20%, reduce energy consumption by 20% improving energy efficiency, meet 20% of EU energy needs with RES-E	EU-28
2009	Third Energy Package: Principles, Directives and Regulations, then implemented as national laws.	**Third Party Access, Unbundling** of suppliers from distributors, increase **independence of regulators,** establishment of **ACER**, **cross-border cooperation**, **transparency in retail markets**	EU-28
	Clean Energy for All Europeans (Winter Package)	Energy efficiency targets, global leaders in renewable energies, consumer protection and empowerment	EU-28