



# **The effect of renewable energy production in the Spanish electricity market**

**Master Thesis**

**by**

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Period: 2010 – 2011

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# Abstract

Renewable electricity development is nowadays one of the ongoing political priorities across all European governments, because of its positive externalities. However, since the beginning of renewable production there has been a widespread debate concerning its economic implications. Electricity from Renewable Sources, or RES-E, is supported in many forums because of the resulting reduction on the daily market price, due to the merit-order effect. Nevertheless, one of the main arguments against this kind of generation is the excessive costs imposed on the public support scheme (feed-in tariffs), which contribute to the deficit of regulated activities. Therefore, the question raised in this paper is whether RES-E deployment increases final electricity prices, leading to a greater burden on the consumer, or not, providing an additional argument for RES-E support. In this sense, a counterfactual analysis without renewables is made, in order to take a first step in the quantification of the influence of renewable sources in electricity market prices in Spain. Time series of hourly prices have been simulated by means of the analysis of simple offers and the results show that the incentives received by Special Regime generators in 2010 were too high compared to the reduction of the annual average price they entailed.

Keywords: Energy policy, electricity market, renewable electricity, feed-in tariffs, merit order effect, sealed-bid auctions



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# Chapter 1

## Introduction

Renewables play an important role in defining the new economic model in Spain. In recent years renewable energy sources (RES-E) <sup>1</sup> have been promoted due to their environmental and socio-economic benefits. On the one hand, it is clear that the development of this kind of energy reduces the pollution produced by traditional fossil-fuel-based electricity, contributing to the CO<sub>2</sub> emissions abatement required by the Kyoto Protocol. On the other hand, some of the socio-economic advantages derived from the deployment of renewable energy include the diversification of energy supply, new regional and rural development, the creation of a domestic industry and an increase in the export market [dRG04]. Moreover, according to the Trade Union Institute of Employment, Environment and Health (ISTAS), more than 1,000 companies directly employ 89,000 people and indirectly provide 99,000 jobs related to the renewable energy sector.

Both European and Spanish governments are aware of these positive externalities and public support schemes for electricity from renewable energy sources, comprising a system of premiums and feed-in tariffs, have been approved so that renewable energy may compete in the electricity market. In fact, in March 2007 European Union members agreed that 20% of energy demand will be covered by renewable energy by 2020. Thanks to this effort, the sector is now one of the most competitive, internationalised, and renowned in our economy.

Such promotion in renewable energy has a predictable impact on energy market price. According to what is called "the merit order effect", the system marginal price of the Spanish electricity spot market (managed by OMEL<sup>2</sup>) is the result of the intersection of the electricity demand curve and the supply curve and it is determined by the plant with the highest marginal cost. These high-cost plants bid at higher prices and are usually fossil-fuel-based units (mainly thermal plants). On the contrary, renewable electricity represents low marginal cost generation, owing to the fact that the absence of fossil fuels results in lower variable costs. Therefore, the increase in renewable production would reduce the demand for high marginal cost generation, driving higher marginal cost plants out of the market and leading to a reduction of the wholesale price of electricity [SdMdRGI08].

However, the incentives given to green energy have also pushed generation costs up to higher

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<sup>1</sup>RES-E includes wind power, solar thermal, solar photovoltaic, solar thermoelectric, biomass, biogas, biofuels, small hydro (<50MW), marine energy and geothermal.

<sup>2</sup>Electricity market operator in Spain and Portugal.

levels. As a result, the deficit of regulated activities in Spain, which consumers are expected to repay in the long term, has increased.

In this sense, some questions may be raised. From a theoretical point of view it is clear that there is a drop in the spot price for electricity. But, how much have prices changed since renewable energy entered the market? Was the change in the regulatory framework too fast? And, finally, to what extent are consumers' tariffs affected?

Therefore, the aim of this analysis is to quantify the effect of renewable energy in the Spanish electricity spot market and its influence on the deficit of regulated activities and, thus, on the consumer burden.

The document is structured as follows. Chapter 2 characterizes the regulatory framework in Spain and the evolution of renewable energy in the Spanish electricity market. Chapter 3 provides an overview of the existing literature related to the study of renewable energy prices. Later, Chapter 4 outlines the empirical work, including a description of the Spanish electricity market, data, specifications and model. Simulations and results are presented in Chapter 5, whereas the implications, recommendations and future extensions of the model are evaluated in Chapter 6. Finally, Chapter 7 summarizes the main conclusions of this work.

## Chapter 2

# Theoretical foundations

This chapter begins with a general description of what renewable energy represents and its evolution in Spain over recent years. An overview of the main aspects of renewable energy policy and legislation is stated thereafter, with special focus on the feed-in tariffs and the tariff deficit. Finally, the Spanish electricity system is introduced, including a characterization of the main actors.

### 2.1 Renewable energy

According to the EU Directive 2001/77/EC [EU01], renewable energy sources (RES) include the following non-fossil energy sources: wind power (onshore and offshore), solar power (photovoltaics and solar thermal electricity), geothermal power, hydro power, wave power, tidal power, biomass and biogas (landfill and sewage gas). Furthermore, depending on the allocation of the energy production they can be classified in three categories: Renewable Energy Sources for Electricity (RES-E), Renewable Energy Sources for Transport (RES-T) and Renewable Energy Sources for Heating (RES-H). RES-E is the type of renewable energy that takes an active part in the electricity market, and it is the main focus of our analysis.

Regarding the trend in renewable energy in Spain, the Ministry of Industry, Tourism and Trade reports (see Table 2.1) that renewable energy sources covered approximately 10.5% of our final energy (E) consumption at the end of 2008. Additionally, forecasts indicate that nearly 23% of gross inland consumption of energy will come from RES by 2020, fulfilling the European target that stipulates that Spain must meet 20% of its energy demand using renewable sources. Targets are set for renewables as a whole (RES-E, RES-T and RES-H), but these figures and the corresponding estimations are lower considering electricity from renewable sources (RES-E) exclusively: 5.2% in 2008, 9.1% in 2012, 11.1% in 2016 and 13.7% in 2020.

Furthermore, Figure 2.1 illustrates the contribution of RES-E to national electricity consumption from 1990 to 2008. This indicator is the ratio between the electricity produced from renewable energy sources and gross national electricity consumption for a given calendar year. It measures the contribution of electricity produced from renewable energy sources to national electricity consumption. Electricity produced from renewable energy sources comprises the electricity generation from hydro plants (excluding pumping), wind, solar, geothermal and elec-

	2008	2012 (e)	2016 (e)	2020 (e)
<b>FINAL CONSUMPTION OF RENEWABLE ENERGY (ktoe)</b>				
Renewable energy for electricity generation, RES-E (Art. 5.1.A)	5,342	8,477	10,682	13,495
Renewable energy for heating/cooling, RES-H (Art. 5.1.B)	3,633	3,955	4,740	5,618
Renewable energy in transport, RES-T (Art. 5.1.C)	601	2,073	2,786	3,500
<b>TOTAL RENEWABLES</b>	<b>9,576</b>	<b>14,504</b>	<b>18,208</b>	<b>22,613</b>
<b>TOTAL RENEWABLES (corrected as per directive)</b>	<b>10,687</b>	<b>14,505</b>	<b>17,983</b>	<b>22,382</b>
<b>FINAL CONSUMPTION OF ENERGY</b>				
Gross final consumption of energy (Art. 5.6)	101,918	93,321	95,826	98,677
% FINAL RES/ FINAL E	10.5%	15.5%	18.8%	22.7%
% RES-E/FINAL RES	50.0%	58.4%	59.4%	60.3%
% RES-E/FINAL E	5.2%	9.1%	11.1%	13.7%

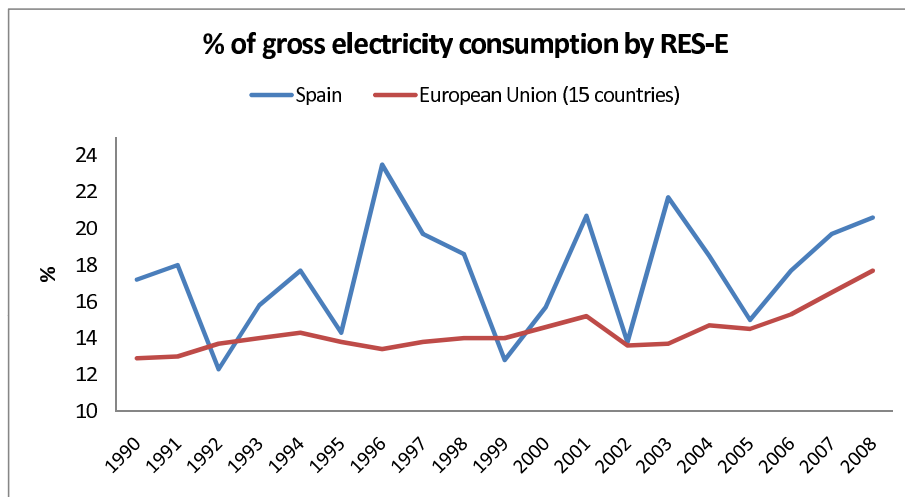
**Table 2.1:** Present and future regarding the 2020 target. Source: Report from IDAE(2010)

tricity from biomass/waste. Likewise, gross national electricity consumption comprises the total gross national electricity generation from all fuels (including self-production), plus electricity imports, minus exports. As the figure shows, renewable energy consumption is clearly on an upward trend both in Spain and in Europe. From 2005 on pumped-storage hydroelectricity<sup>1</sup> is excluded from the data. Since pumped-storage is closely related to electricity demand, data is more independent from external conditions when these schemes are removed and, as a result of this, a more steady growth path is observed, showing fewer fluctuations than in the previous years. Additionally, the UE-15 curve is smoother because the particular conditions of one country are compensated by the others. However, in the Spanish case there are fluctuations, mainly due to the meteorological variations affecting hydraulic resources every year.

Finally, in terms of renewable generation, as Figure 2.2 shows, producers in the Special Regime<sup>2</sup> supplied 33% of the electricity generated in 2010, from which 2% corresponds to small hy-

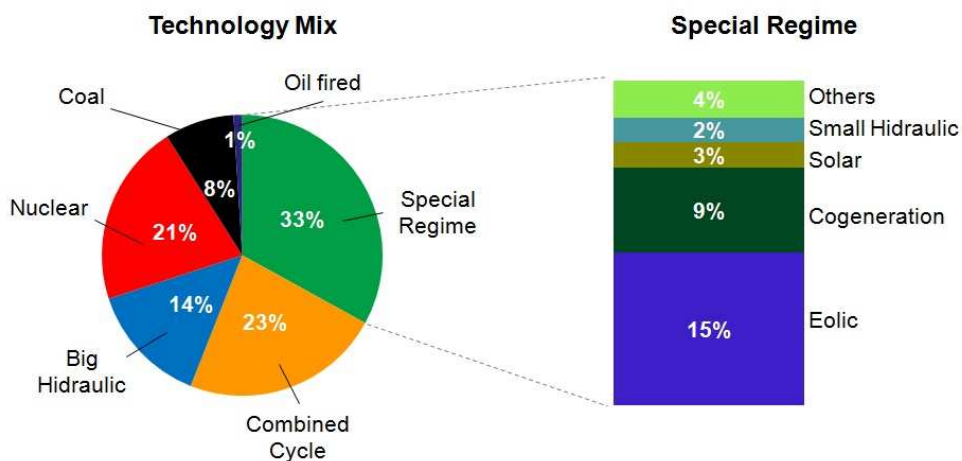
<sup>1</sup>It is a system of generating electricity with hydroelectric power by moving water between reservoirs at different elevations during the hours of low consumption. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine. This method produces electricity to supply high peak demands and provide a commercially important means of large-scale grid energy storage, improving the daily capacity factor of the generation system.

<sup>2</sup>Special Regime (RE) includes renewable sources and cogeneration. Big hydropower units (>50MW) are not included.



**Figure 2.1:** Contribution of RES-E to national electricity consumption. Source: Eurostat. Own elaboration

dropower plants (<50MW), 15% to eolic, 3% to solar fotovoltaic, 9% to cogeneration and 4% to biomass, waste and others.



**Figure 2.2:** Demand coverage in Spain, 2010. Source: CNE and REE. Own elaboration

## 2.2 Renewable energy policies

Renewables are clean and practically inexhaustible sources of energy, which frees them to a large extent from the price fluctuations suffered by fossil fuels. Therefore, driven by a very intensive energy policy, renewable sources have made an increasing contribution in Spain over the last decade. There are several policy instruments to promote renewable energy ([Bod06]):

- Price-based instruments:
  - Feed-in tariffs (FIT): Producers of renewable energy receive a minimum guaranteed price per kWh, so long-term minimum price is guaranteed for electricity or heat from renewable sources.
- Quantity-based instruments:
  - RE-Quotas: Certain market participants (e.g. supplier, consumer) are required to supply or consume a minimum quantity of electricity or heat from renewable sources.
  - RE-Tenders: A national authority puts a certain quantity of electricity or heat from renewable sources to tender. Winners of the tender get a fixed price for the length of the contract.
- Direct subsidies: (Parts of) capital costs are borne by a national authority.

Choosing the right economic support model is critical to the development of successful renewable electricity generation. Spain supports the sales price of renewable electricity by establishing either a fixed tariff scheme, including different fees by technology; or a FIT system, which consist of a premium paid on top of the market price for installations that sell their electricity on the market. Because of their relevance in Spain, in this paper we focus exclusively on the effect of feed-in tariffs. Based on reflections from literature [Sij02], the promotion of FIT is regarded with the following criteria:

**Investment certainty:** FIT guarantee that producers of renewable electricity receive a fixed price for each MWh of power fed into the grid over a certain period of time. Therefore, they offer a high level of investment certainty to risk-averse investors and manufacturers, improving the chances of investment in R&D. In fact, theoretical analysis of the relations between regulated utilities and input suppliers shows that rent-sharing between them implies that regulated firms are more likely to face higher costs, compared to the competitive ones, in a free market [BK70].

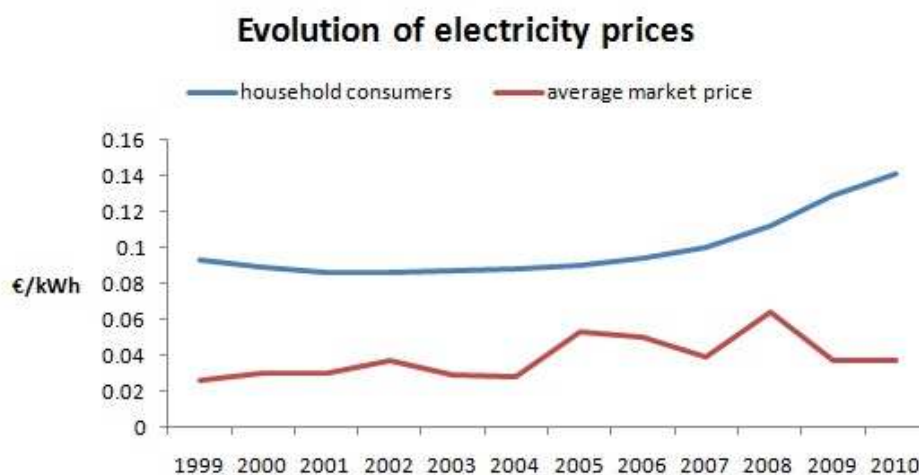
**Effectiveness:** Due to their investment certainty, FIT have been very effective in promoting some renewable technologies, i.e., wind energy. However, they have been less effective in encouraging other technologies, i.e., solar energy. In this sense, their effectiveness depends on many other factors, such as the level of tariffs set, the production costs involved, the existence of other promotion schemes, administrative procedures, natural conditions



or other specific characteristics at a local level.

**Efficiency:** Compared to other promotion schemes, FIT have generally failed to result in price reductions for electricity (although the spot market price reduces, the final price remains more or less stable). As Figure 2.3 shows, even though the electricity market price in Spain has significantly decreased with the participation of renewable agents over recent years<sup>3</sup>, the final price to households is increasing. Since FIT are fixed by a regulatory authority lacking in up-dated information, it is very difficult to fix and maintain the adequate price for all technologies over time. Furthermore, reducing the FIT may be an unpopular political measure, since existing producers have strong economic interests in ensuring continued high feed-in payments [CEC99].

**Market competition:** Another factor of criticism is that the FIT system is not based on direct competition, neither among renewable power producers nor between these producers and non-renewable electricity generators.



**Figure 2.3:** Evolution of electricity prices in Spain (final consumers vs. wholesale market price). Source: Eurostat and OMEL. Own elaboration

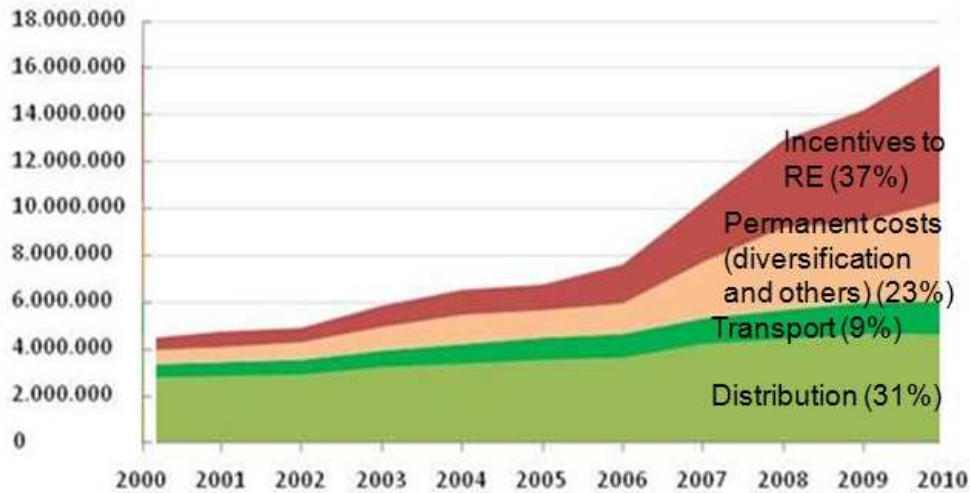
Despite the major drawbacks of a FIT system, they are justified by the strategic and environmental benefits offered by renewables and aim to guarantee reasonable returns on investments while learning curves and economies of scale gradually enable the various technologies to become competitive with conventional sources [IDA10].

### Tariff deficit

The tariff deficit is the main consequence of the difference between the total amount collected by the Administration and the real costs associated to the electricity tariffs. The total cost of electricity production includes production costs, transport costs, distribution costs and other

<sup>3</sup>There is a peak in 2008 due to the fact that the demand that year was higher, but the trend is downwards.

permanent costs. Incentives to the Special Regime (FIT) are considered as a production cost and they represented 37% of the total cost in 2010 [MoIT10]. Additionally, as Figure 2.4 shows, there has been a sharp increase in total access costs since 2006 because of the FIT.



**Figure 2.4:** Evolution of electricity access costs in Spain (in thousands of euros). Source: "Energía y Sociedad"

### 2.2.1 Regulatory context

This section gives an overview of the main legislation on electricity from renewable sources in Spain. In Spain, renewable energy has been regulated since 1980, when **Law 82/1980** on energy conservation was enacted, which claimed an increase in energetic efficiency and a reduction in energetic dependence. It happened as a consequence of the second international oil crisis and represented the start of the development of renewable energies in the country. Since then, renewable energy promotion has been a national policy priority and legislation has been in constant change [CNE11]. In 1985 the government firmly pledged its commitment to renewable energy with the **Royal Decree 916/85** supporting the small-hydraulic energy, the one renewable source existing at that time.

After the entry into the European Union, the **Law 54/1997** [Law] liberalized the electricity sector in Spain and established a plan for the promotion of renewable sources for achieving the goal of 12% of gross inland consumption of energy from renewable sources by 2010. After this law, the Special Regime and the corresponding feed-in tariffs were first established.

Later, **The Royal Decree 436/2004** [RD:b], known as the Spanish Renewable Energy Act, was set up to fit into the existing general framework supporting RES-E. It provided incentives for new installed capacity of renewable energy sources and was subsequently renewed in the **Royal**

**Decree 661/2007** [RD:c], where new tariffs and premiums for renewable electricity generators were established.

In June 2009, the **Directive 2009/28/EC** [Com] came into force to reinforce the use of energy from renewable sources. This Directive established procedures for the reform of planning and pricing schemes and access to electricity networks, promoting energy from renewable sources. Following this European directive, the Member States have established national action plans which set the share of renewable energy sources. In Spain, the target is to meet 20% of gross final energy demand with renewable energies by 2020 and 10% in the transport sector. Experts therefore consider that the Directive is extraordinarily valuable in ensuring the renewables sector continues to grow and gain market share [IDA10].

Eventually, the Spanish government seems to have become aware of the excessive weight given to FIT and the **Royal Decree 1614/2010** [RD:a] adjusts electricity feed-in tariffs allocated to wind generated power, leading to important savings and adapting to new market structures. In addition to this, an array of new measures to reduce the tariff deficit have been approved in the **Royal Decree-Law 14/2010** [RDL]. The first of these measures includes a toll which will be paid by generators both from the ordinary regime and the Special Regime for the use of the electric transportation and distribution grid, costs that were traditionally paid by consumers. The second measure involves cuts on the FIT of solar photovoltaic installations whose economic regime is set in Royal Decree 661/2007 by means of a limitation of the number of hours of energy produced depending on the climatic solar zone where the installation is located. Other measures designed to reduce the tariff deficit comprise an extension of the earnings deficit limit and of the maximum amount of the guarantees to be supplied by the state during 2011. Furthermore, the term for carrying out the first review of the financing of the social bonus<sup>4</sup> is extended. Finally, the last new measure proposes that the financing of savings and energy efficiency plans for 2011 to 2013 will be carried out by the generation companies under the ordinary regime.

## 2.3 Spanish electricity system

The main actors of the Spanish electricity system are the National Energy Commission (CNE), Red Eléctrica Española (REE) and the Operador del Mercado Ibérico (OMEL).

CNE is the regulatory body for the electricity system. It is a public body attached to the Ministry of Industry, Tourism and Trade and its main activity consists of ensuring the effective competition and transparent functioning of the electricity market in Spain.

REE is the grid manager and electricity system operator. The system operator is usually responsible for managing the stability of the transmission grid and all the involved technical

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<sup>4</sup>The social bonus, created by Royal Decree 6/2009, established a bonus on the domestic electricity rates for certain consumers which did not surpass certain levels of income (pensioners, large families, etc). It is financed by power generation companies.

constraints. Moreover, it prepares wind prediction models, access and connection procedures, network planning and it analyzes the maximum wind power penetration.

OMEL is the electricity market operator in Spain and Portugal, responsible for regulating the market (it manages the pool setting the market price). The difference between the market operator and the system operator is that, whereas the first is responsible for price setting and the electric system economic management, the second is in charge of the technical management of the electricity system. The main functions of OMEL can be summarized as follows [Gon03]:

- Performance of the economic management of the electric power market
- Reception of sale bids, purchase bids and whatever guarantees may be appropriate.
- Match the bids and communicate the matching results.
- Reception from the System Operator of information regarding modifications made to the matching due to technical constraints
- Determination of the final energy prices
- Settlement and reporting of the payments and collections
- Reception of information regarding producers which may justify their exemption from bidding
- Definition, development and operation of the computer systems needed to guarantee the transparency of the transactions.

Finally, the market participants can be classified in three main groups as follows [Gon03]:

- Producers: They participate in free competition, with freedom to build new power plants. They submit bids to the market or trade directly with qualified consumers.
- Traders: They participate in free competition. They buy energy in the market to sell it to qualified consumers.
- Qualified Consumers: They acquire energy through trading companies, directly in the market, or through bilateral contracts.

## Chapter 3

# Literature Review

There are two main lines of research studying the effect of renewable sources on electricity prices. The first one studies the effect of regulation, whereas the second one analyzes the market itself and how renewable generators interact in it.

Since renewable energy has become a priority for many governments, there is an increasing concern for the study on its regulation, market effect and the consequent influence on consumers. In this sense, Jensen and Skytte [JS03] were the first authors to point out in 2003 that, as renewable energy generation has lower variable costs than conventional fossil-fuel electricity, it could reduce final electricity prices. They discussed the analytical effects of introducing emission permits, green certificates and quotas as regulatory mechanisms to reduce emissions and ensure the use of renewable energy. They agreed that it is always optimal to reach a renewable energy deployment goal by the use of green certificates. However, it is not very clear which one is more favourable to reach an emission goal, with regard to consumer prices.

In 2006, Bode [Bod06] claimed that, although it is true that a support scheme for renewable energy increases power costs for the consumers, it neglects the fact that it reduces wholesale power prices, which are part of the power costs of the consumers. According to this author, the net effect may become positive or negative depending on the specific characteristics of the market.

In turn, Rathmann in 2007 [Rat07] discussed that electricity from renewable energy sources (RES-E) can reduce electricity prices in the presence of emission trading schemes. In spite of this, since most RES-E support systems are financed via the electricity market, the author concluded that the retail electricity price rises.

Schmalensee (2011) [Sch11] analyzed both US and EU markets and reported that incentives based on FIT are the most popular regulatory policy because, even though they may not help to reduce risk to society as a whole, they remove risk from investors in renewable generation.

Additionally, regarding the second line of research mentioned above, there are also some studies which have been carried out in order to quantify the effect of renewable electricity generation on spot market prices in different countries.

In 2004, Martin [Mar04] estimated the impact of photovoltaic power generation on prices with a model based on detailed historical data of the regional US power markets, focusing on the case

of New England. The author showed that if 1 GW of photovoltaic energy had been installed in the New England states in 2002, average wholesale electricity prices would have been reduced by 2 to 5 percent.

Furthermore, Sensfuss [SRG08] analyzed in 2008 the impact of privileged renewable electricity generation on the electricity market in Germany through the merit-order effect. By using an agent-based simulation platform, they showed that the financial volume of the price reduction is considerable. They concluded that the feed-in support can lead to a net profit for consumers in the short run, if the potential savings for consumers created by the merit-order effect are taken into account.

As regards to the Spanish market, Sáenz de Miera [SdMdRGI08] analyzed in 2008 the case of wind energy. He empirically proved the reduction in the Spanish wholesale price of electricity as a result of more wind generation. They found that the net reduction in the retail electricity price is positive from a consumer point of view, contradicting one of the usual arguments against renewable energy deployment: the excessive burden on the consumer.

Later, Green and Vasilakos [GV10] used a market equilibrium model to analyze the long-term equilibrium in the case of the British electricity industry, focusing on the mix of generating capacity. In their discussion paper in 2010 they concluded that the introduction of large amounts of wind generation would tend to change the mix of the rest of the generation scheme. However, they claim that the impact on electricity prices due to variations in wind speeds is smaller than those that have resulted from variations in fuel prices over the last ten years.

Finally, in 2010 Bushnell [BSPM10] also worked on the effect of wind variability on energy prices. He described the western United States case and concluded that in an energy-only market, prices are typically highest in hours of little wind generation.

## Chapter 4

# Empirical Model

Considering that the implemented model is based on the Spanish electricity market, this chapter begins with a description of the main features of the daily market in Spain. Afterwards, all required data and their corresponding sources will be presented. To conclude, the empirical model will be described.

### 4.1 Market rules

The main purpose of electricity markets is to ensure the secure and efficient operation of the system and to decrease the cost of electricity through competition [PRVC03]. The market environment in Spain consists of a pool, as well as a floor for bilateral contracts and a forward market. Most transactions are carried out in the daily market, which is the focus of our analysis. The result ensures that maximum interconnection capacity with external electricity systems is not exceeded, considering physical bilateral contracts that affect international interconnections.

The daily market, managed by OMEL since January 1998, is an integral part of the electricity production market and it is in charge of handling electricity transactions for the following day through the presentation of electricity sale and purchase bids by market participants. All available production units that are not bound by physical bilateral contracts are obliged to present bids in the pool for the daily market.

#### 4.1.1 Bids classification

Bids are presented by sellers for each hour and production unit. There are two different kinds of electricity sale bids: simple or complex. On the one hand, simple offers only state price and volume of power. Price bids can cover the range from 0 to 180.3€/MWh. On the other hand, complex bids incorporate complex sale terms and some technical or economic conditions [OME07]:

- Indivisibility: Generation units agree to be dispatched if and only if their offer is completely accepted.

- Load gradients. It refers to the ramping up and down of the production units. It establishes the maximum difference between the starting hourly power and final hourly power of the plants, in order to avoid sudden and unaffordable changes (from a technical standpoint) in the production units.
- Minimum income. Production units refuse to take part in the daily matching result if the total production obtained by them in the day exceed an income level above an established amount.
- Scheduled stop. Production units that have been withdrawn from the matching process because they failed to comply the minimum income condition are allowed to carry out a scheduled stop for a maximum period of three hours, providing that they accept the first slot of the first three hours of their bids as simple bids and that the energy offered drops in each hour.

In the spot market only sellers are allowed to present complex bids when they submit block bids. A block bid is a firm offer for a number of consecutive hours, meaning that either the block bid is cleared for all the stated hours or none of them. After an initial hourly price calculation, an average of the market prices for the hours included in the block bid is calculated. Then, a sales block bid is accepted if the average market price of the hours included in the block bid is higher or equal to the price of the block bid. Consequently, a purchase block bid is accepted if the average market price of the hours included in the block bid is lower than the price of the block bid. However, the initial solution is valid if and only if all conditions are satisfied, otherwise one of the unfulfilled block bids is eliminated and the price calculation is run again. This checking is iterated until all the remaining block bids can be fulfilled [MPB04].

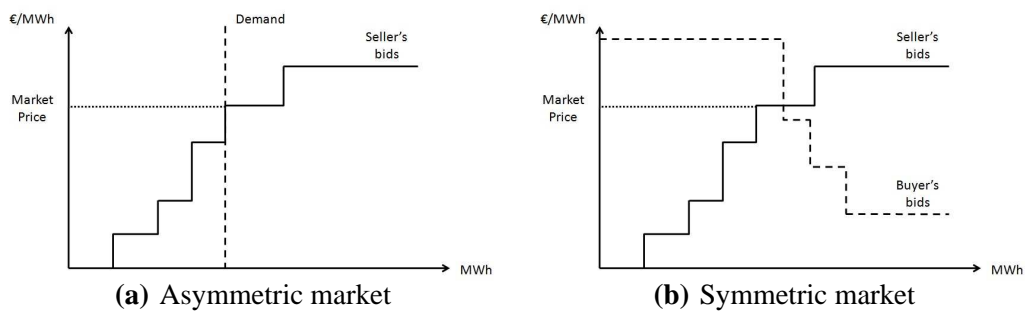
In this paper only simple offers will be discussed.

### 4.1.2 Pool mechanisms

The day-ahead pool or spot market is the marketplace where power is exchanged between sellers and buyers. The most common type of negotiation in the electricity market is a standard uniform auction [Kle99], which can be symmetric or asymmetric depending on who competes in the market (see Figure 4.1). In an asymmetric market, only suppliers compete. In a symmetric market, which according to auction theory is similar to a double auction, both suppliers and consumers submit their bids.

The Spanish pool works as a symmetric market where sellers represent entities able to sell electricity in the market, such as generating companies holding electricity production units. They submit production bids and their corresponding market prices. Similarly, buyers, who are electricity consumers and electricity distribution companies, submit bids to purchase electricity on the daily market. Bids made by these players are presented to the market operator and included in the matching procedure. Sale and purchase bids can be made considering between 1 and 25

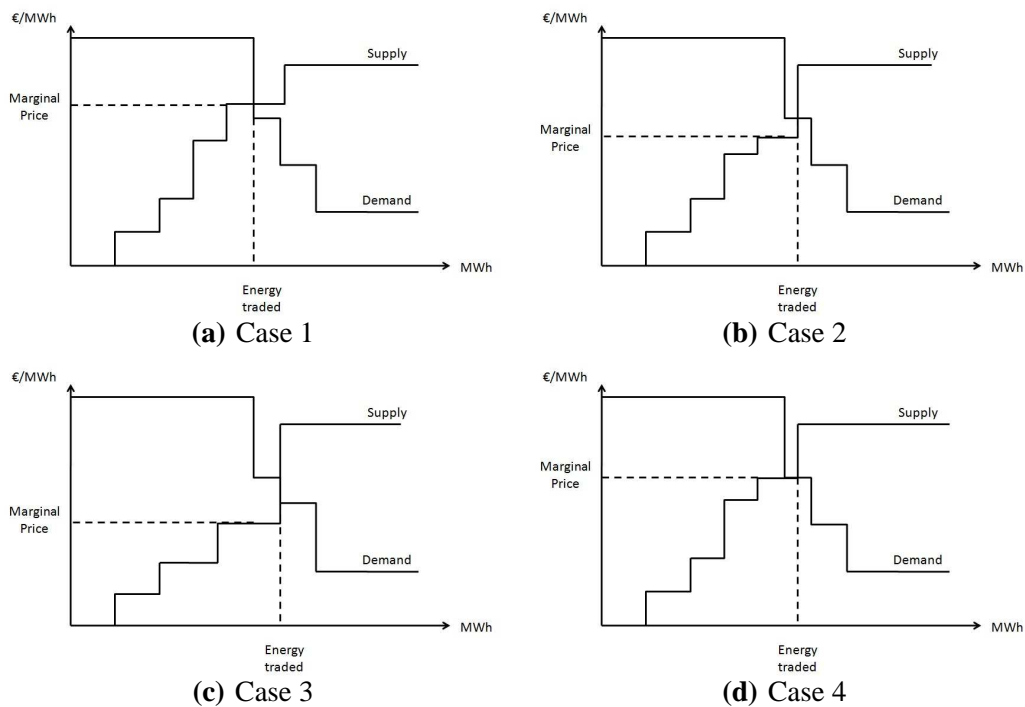




**Figure 4.1:** Auction mechanisms. Own elaboration. Source: OMEL

energy blocks in each hour, with power and prices offered in each block. The deadline for the reception of orders by the market operator for day D is 10:00 (CET) of day D-1.

In the Spanish symmetric model there are four possible matching cases (see Figure 4.2), depending on how the demand and supply curves intersect.

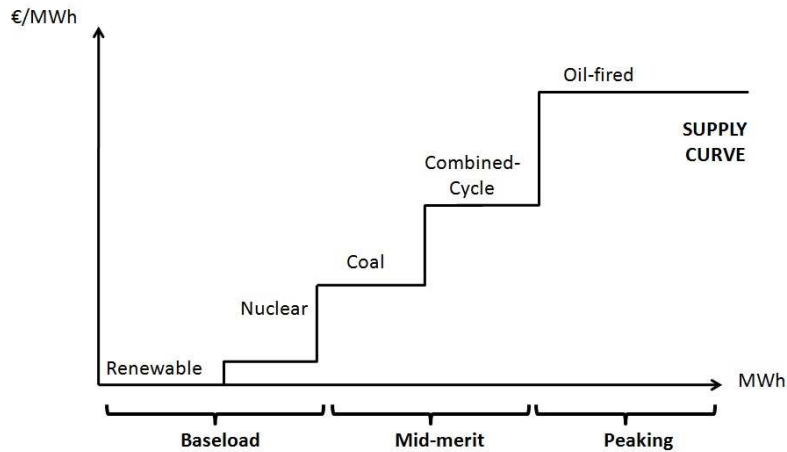


**Figure 4.2:** Matching cases. Own elaboration. Source: OMEL

### 4.1.3 Merit order

In a power market, the supply curve is called the *merit order curve*. Such a curve goes from the cheapest to the most expensive technology in the generation mix and presents the costs and capacities of all units [EWEA10]. Each generation plant is shown as a step in the curve. The differences between costs are mainly due to the technology used and the fuel consumed. As

Figure 4.3 shows, the bids from nuclear and renewable sources enter the supply curve at the lowest level, due to their low marginal costs, while traditional fossil-fuel plants are those with the highest marginal costs of power production.



**Figure 4.3:** Merit Order Effect. Own elaboration

This merit order defines the short-run marginal-cost curve that governs power supply. As long as the generator receives the market clearing price, and there are enough competitors so that each generator assumes that it will not be providing the marginal plant, then the optimal bid for each generator is the true marginal cost. To bid more would only lessen the chance of being dispatched, but not change the price received. To bid less would create the risk of running and being paid less than the cost of generation for that plant [Hog95].

In general, since the production of electricity from renewable sources is cheaper, the price of power is expected to be lower during periods with higher renewable supply. That is, the more renewable generators take part in the market, the higher marginal cost plants (fossil-fuel-based electricity) are driven out of it. This is called the *merit order effect* and it is what is going to be quantified in this paper.

#### 4.1.4 Market splitting

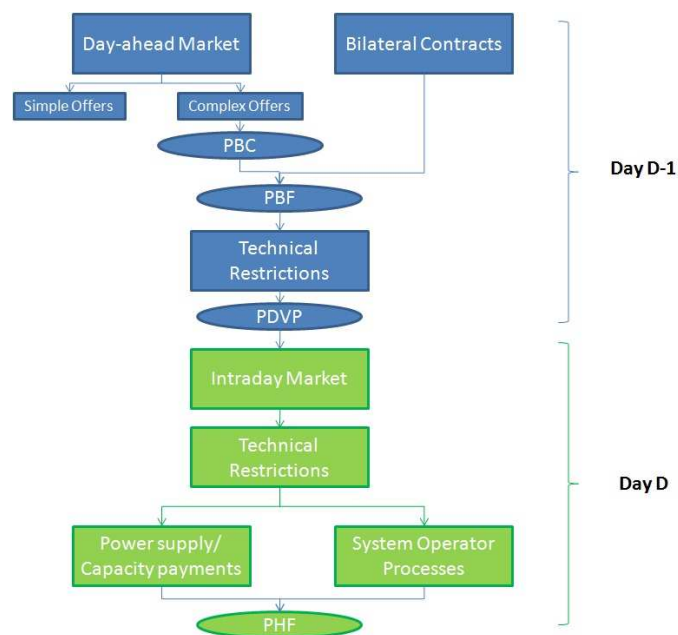
Spanish and Portuguese electricity markets are interconnected, which means that the cross-border lines between both countries operate so that there is one single price for both zones. However, flows across these two areas are limited to the capacity of the interconnection lines and we observe that there are certain hours in which clearing prices are different for both areas. This is known as the congestion phenomenon. According to the Regulation (EC) No 714/2009, "congestion means a situation in which an interconnection linking national transmission networks cannot accommodate all physical flows resulting from international trade requested by market participants, because of a lack of capacity of the interconnectors and/or the national transmission systems concerned" [Com]. In a situation of congestion the area downstream of

the congestion will have a higher clearing price, whereas the area upstream of the congestion will have a lower pool price.

Market splitting is the congestion management method for day-ahead capacity allocation used between Portugal and Spain. When congestion happens, energies from both zones of MIBEL are integrated through the market splitting procedure and instead of having one single equilibrium price (MIBEL) there are two separate prices (one for Spain and one for Portugal).

### 4.1.5 Price structure

Once the daily programming horizon is established, different processes from the market are performed during the previous day (D-1) and the day (D) for which the demand has to be covered. Figure 4.4 illustrates all the steps of this procedure, so that generation and demand curves are optimally adjusted [OME07].



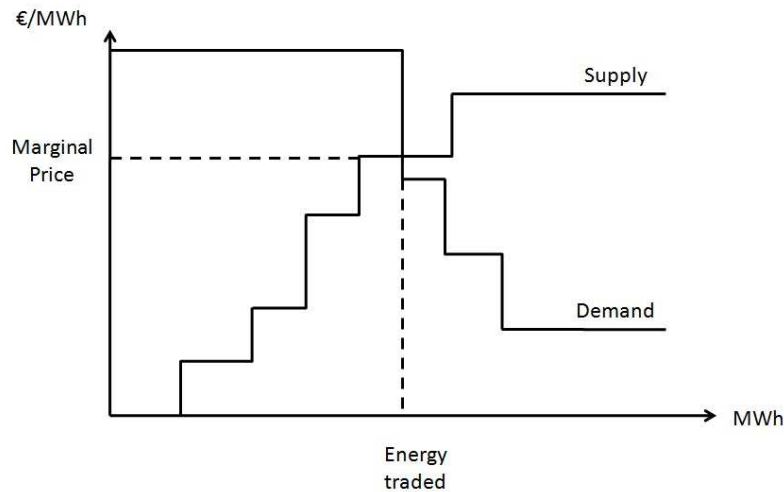
**Figure 4.4:** Price structure of the Spanish electricity market. Own elaboration. Source: OMEL

#### Day D-1

##### Simple matching method

The simple matching method obtains for each hour the marginal price and the volume of electricity that is accepted for each production and purchase unit. Selling bids are ordered upwards starting at the lowest price, whereas demand bids are ordered downwards starting at the highest price. Once the aggregate supply and demand step curves are built, the market price is fixed as

the point where both curves meet (see Figure 4.5). Then, as a result of what is called market-clearing algorithm (more details in subsection 4.3), the market price and a batch of accepted production and consumption bids are set every hour. The market price is the price of the last unit of the last bid whose acceptance has been required in order to meet the demand that has been matched (the unit with the highest price). All supply bids offering prices lower than the established market price and all demand bids offering prices higher than the market price will be accepted.



**Figure 4.5:** Day-ahead market matching procedure for one hourly period. Own elaboration. Source: OMEL

This mechanism is repeated every hour and it affects the daily programming schedule corresponding to the day after the deadline date for the reception of bids for the session, and comprising twenty-four consecutive programming hours (twenty-three or twenty-five periods on days on which the clocks are changed).

#### Complex matching method

Once the simple matching method has been applied, the market operator executes the simple conditioned matching, finding a solution which complies with the conditions derived from the complex bids, except the minimum income condition (it satisfies the conditions of indivisible bids, the restrictions derived from the load gradient and the conditions of planned stoppage).

Afterwards, the minimum income restriction is added in an iterative procedure which performs several simple conditioned matchings. The process works as follows: all sale bids corresponding to production units that do not comply with the minimum income condition are successively eliminated until all the sales bids corresponding to the production units considered in the solution satisfy the condition. This process is called complex matching and marginal prices are determined. This is the first provisional solution and it represents the day-ahead market price ("Programa Básico de Casación", PBC).

### Bilateral contracts

Once the simple and complex matching procedures have concluded, the market operator adds the national bilateral contracts in order to find the "Programa Básico de Funcionamiento" (PBF). This matching result between electricity sale and purchase bids represents the hourly production and demand schedule on the network and determines the volume of electricity production required to cover electricity demand in each hour of the same day.

### Technical restrictions

However, the first solution derived from simple and complex matching procedures considers that the capacity in international interconnections is unlimited. The process of technical restrictions stands to verify that the economic solution is technically feasible. Therefore, if the result of daily market matching and physical bilateral contracts does not respect the maximum exchange capacity between electricity systems or the mandatory security requirements, the technical constraints solution procedure should be applied. Then, the system operator agrees the withdrawal of blocks of sale or purchase bids affected by technical constraints and the viable daily schedule ("Programa Diario Viable Provisional", PDVP) is obtained. This is the last process performed the day prior to the programming horizon.

## **Day D**

The processes carried out in the production market on the day of the programming horizon are as follows:

### Intraday market

The intraday market is an adjustment market that is open to production units, last resort resellers, resellers, direct consumers and non resident retailers engaging as buyers and sellers who are market agents. It is organized in six sessions performed during the days D-1 and D of the programming horizon and all agents participating on the corresponding daily market session can take part in it. Afterwards, another revision of the technical constraints should be done in order to guarantee supply quality.

### Ancillary services and deviation management

Finally, after the daily market and intraday market sessions have been held, power supply and capacity payments and other system operator processes are made in order to ensure that energy is supplied under established conditions of quality, reliability and security and that production and demand are balanced at all times. The system operator manages any deviations in real time using ancillary services and the deviation management procedure and the final price is set ("Programa horario final", PHF).

Final price:

To sum up, the results of all those previous calculations form the final electricity price, which consist of the following components [Gon03]:

- Daily market marginal price
- Price/cost caused by technical constraints solution
- Price/cost of the regulation band service
- Intraday market marginal price
- Price/cost Technical System Operation real time processes, reported imbalance management, regulation and operating reserve energies
- Imbalances from the Final Hourly Schedule
- Capacity payment
- Surplus/Deficit of the REE pre-law international contracts
- Imbalances from the international regulation and security exchanges

Lastly, in order to compute the final price, according to the Royal Decree RD 1454/2005<sup>1</sup> the following formula should be applied [CNE07]:

$$PFM_h = PMD_h + \frac{IMMI_h - ENMI_h \cdot PMD_h}{ENMBC_h} + \frac{IMOSAJ_h - ENOSAJ_h \cdot PMD_h}{ENMBC_h} + \frac{IMDV_h - ENDV_h \cdot PMD_h}{ENMBC_h} + \frac{IMRRTT_h - ENRRTT_h \cdot PMD_h}{ENMBC_h} + \frac{IMBS_h}{ENMBC_h} + \frac{IMGPh}{ENMBC_h}$$

Where (the subindex  $h$  means that all variables are on an hourly basis):

- PMD is the marginal price of the daily market.
- ENMI is the amount of energy traded in the intraday market.
- IMMI is the price of valuating energy at the price of the corresponding session in the intraday market.
- ENOSAJ is the quantity of energy traded in the adjustment services markets (the technical restrictions market is not included).
- IMOSAJ is the price of the energy traded in the adjustment services markets (the technical restrictions market is not included).
- ENDV is the quantity of energy of the measured diversion corresponding units.

<sup>1</sup>The National Energy Commission is responsible of computing and publishing the final prices on a monthly basis.

- IMDV is the price of the energy of the measured diversion evaluated at the diversion price.
- ENRRTT is the quantity of energy traded in the technical restrictions market.
- IMRRTT is the price of the energy traded in the technical restrictions market.
- IMBS is the cost of the secondary band.
- IMGp is the cost of the power supply.
- ENMD is the amount of energy traded in the daily market.
- ENCB is the amount of energy traded in bilateral contracts.
- ENMBC is the amount of energy measured in plant bars. The following holds:

$$ENMBC_h = ENMD_h + ENMI_h + ENOSAJ_h + ENDV_h + ENRRTT_h + ENCB_h$$

## 4.2 The data

In order to determine the impact of renewable electricity generation we exploit the information provided by the Spanish market operator OMEL, which is publicly available through its web page. We use two different databases <sup>2</sup>:

- **Curva\_pbc\_uof:** It specifies the main characteristics about the offers of all production units. Each text file (.txt) contains all the hourly bids submitted by all the production units in an entire day. The database consists of the following fields:
  - Date of the bid: Year, Month, Day and Hour. There are data since 2001, but we focus on the year 2010 exclusively, although the analysis could be extended to any year if required.
  - Type of the bid: buy ("compra",C) or sell ("venta",V).
  - Who makes the bid: Code identifying the unit.
  - Price and quantity of energy.
  - Type of matching: according to simple offers ("ofertada",O) or complex offers ("casada",C). We use simple offers.
  - Country: One single price (MIBEL) per hour if there is no congestion. Two different prices (Spain and Portugal) if there is congestion. We only consider the Spanish price in case of congestion, but the model admits adding Portugal if necessary.
- **Lista de Unidades:** It provides information about the generation units taking part in the pool.

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<sup>2</sup>Note that the original file and identifying names are in Spanish.

- Code identifying the unit. It is the field we use to merge the data.
- Name of the plant
- Who makes the bid: Code identifying the unit.
- Price (€/MWh) and quantity of energy (MWh).
- Type of unit<sup>3</sup>: Renewable or standard. It allows us to identify the renewable energy sources.

The number of observations corresponding to the year 2010 provided by OMEL is as follows. As Table 4.2 shows, we managed more than 18 million observations in order to analyze the Spanish electricity market behaviour.

Monthly observations. Year 2010					
January	1,482,794	May	1,562,373	September	1,568,665
February	1,421,560	June	1,553,442	October	1,615,772
March	1,496,601	July	1,619,713	November	1,558,481
April	1,466,638	August	1,596,392	December	1,679,824
<b>Total: 18,622,255</b>					

**Table 4.1:** Number of observations in OMEL files

In addition to this, we also use official data from the regulator CNE. They provide three different Excel files (.xls) concerning total energy traded and final prices for the year 2010:

- Hourly prices: One file per day (30/31 files per month) with 24 rows each.
- Monthly prices: One file with 12 monthly average prices (12 rows).
- Yearly prices: Annual average price (one row).

Each file presents all the energy price components in €/MWh, so that we are able to identify the influence of each element in the final price:

- Day ahead Market price
- Intraday Market
- Restrictions
- System Operator Processes
- Power supply Capacity payments
- Final price

<sup>3</sup>This field is not included in the original file, it was subsequently added manually.



### 4.2.1 Special Regime identification

According to the CNE, electricity producers in the special scheme (RE) in Spain are those that use co-generation, renewable sources and waste products in facilities with power of no more than 50 MW. Even though not all of them represent renewable energy sources, for the sake of simplicity we consider them as a single block in this work, leading to an overestimation of the results. In future research it is planned to separate all the RE sources. Table 4.2 illustrates the distribution of the energy under Special Regime by source. This helps us to identify that a 66% of the energy in Special Regime in the year 2010 comes from renewable sources. Note that the big hydraulic is not considered in the Special Regime, so it is not included in our analysis.

Source of energy	Energy sold (GWh)	Demand covered (%)
Co-generation	23,522	8,55(%)
Solar Photovoltaic	6,279	2,28(%)
Solar Thermal	691	0,25(%)
Eolic	42,642	15,49(%)
Small-hydraulic (<50MW)	6,623	2,41(%)
Biomass	3,107	1,13(%)
Waste	3,118	1,13(%)
Waste treatment	4,284	1,56(%)
<b>Total RE</b>	<b>90,266</b>	<b>32,79(%)</b>
Total Renewable RE	59,342	21,56(%)
Total Non-renewable RE	30,925	11,24(%)
Big hydraulic(>50MW)	38,001	13,81(%)
<b>Total Renewable (RES)</b>	<b>97,343</b>	<b>35,36(%)</b>

**Table 4.2:** Special Regime production in 2010 (provisional data). Source: CNE

## 4.3 The model

As it was mentioned in the previous section, we use data associated with the following information: hourly bids and production units. The software used in the analysis is STATA version 11.

First of all, we implement the market algorithm as an `ado-file` to find the amount of energy traded and the market price in equilibrium<sup>4</sup> for a specific hour. By running this code we replicate the real behaviour of the market for the selected date. Then, we identify the Special Regime units, including both renewable and cogeneration plants and we simulate the counterfactual time series in order to see how prices would be built without Special Regime sources. The

<sup>4</sup>We compute the price related to simple offers.

combination of real and simulated data allows us, first, to check that our software works properly and, second, to identify the influence of renewable sources. Finally, we prepare a `do-file` that automatically computes all the hourly prices for a whole year, 2010 to be precise. The matching algorithm (`ado-file`) is called inside the `do-file`.

The flowchart of the process is visualized in Figure 4.6(a) and can be divided into three different parts: data reading, price computing and data storing.

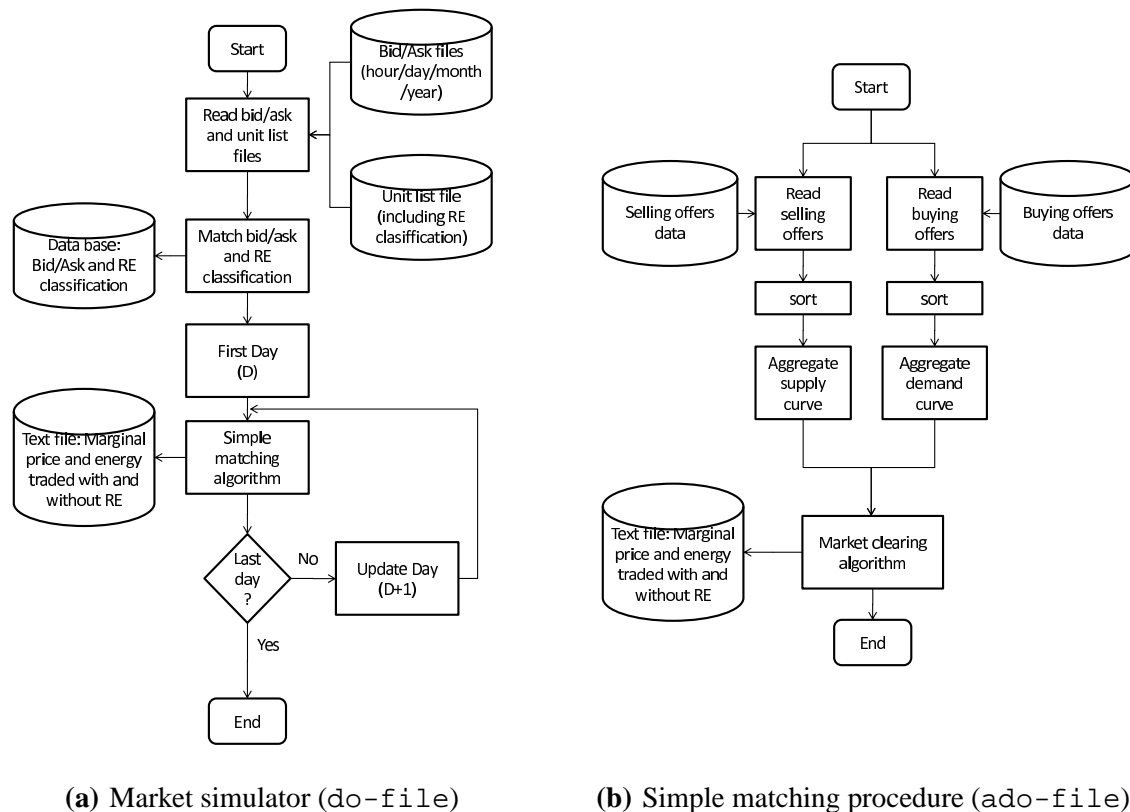


Figure 4.6: Program flowcharts. Own elaboration

### Step 1. Input data reading

As a first step, the program reads data from two different databases. On the one hand, the bids and asks notified by the market participants of Spain and Portugal and on the other hand, the identification of production units: Special Regime or Ordinary Regime. Recall that all of the buy or sell offers are made in the same market place (MIBEL), specifying the area concerned: MIBEL (when there is no congestion) or Spain/Portugal separately (when there is congestion).

### Step 2. Special Regime recognition

Afterwards, the program labels the entire bid and ask offers, so that Renewable Energy generators are identified. This information is stored in a new database and it will be used in the matching algorithm.

### Step 3. Simple matching algorithm (iterative)

Subsequently, the program acts as the market operator proceeds and the equilibrium or clearing price calculation starts (see Figure 4.6(b)).

The simple matching algorithm aims to maximize the consumer and producer surplus, that is, the net social welfare. Clearing a single market involves setting the price and consequently matching demand and supply at that price. In Spain the market is cleared separately for every hour of the next day on the day ahead of the actual dispatch. The algorithm applied by OMEL to compute the equilibrium price is a stepwise market-clearing algorithm, which is a uniformly priced and sealed auction. This means that the same price applies to every accepted offer and offers are not disclosed to participants. Since both sellers and buyers can submit offers, the algorithm is also called a double side auction. The clearing price is determined according to the maximum volume and minimum price criteria. That is, if there is more than one price with equal volume of energy, the minimum price is chosen. Thus, the EP is the minimum price at which the biggest possible volume can be executed.

First, the supply (sell or ask offers) and demand (buy or bid offers) data is read and the stepwise aggregate supply (AS) and aggregate demand (AD) curves are computed. Offers are arranged by ascending price, so that Bid Volume (BV) is written in descending order and Ask Volume (AV) in ascending order. In case there are two or more stretches with the same ask price, they will be sorted as follows:

1. Date, hour, minute and second of the offer
2. Quantity of energy of each stretch
3. Units in alphabetical order

Once bid and ask offers are ordered, the market-clearing algorithm is solved in two steps. First, the Tradable Volume (TV) for each order is determined according to equation 4.1:

$$TV(P_i) = \min[BV(P_i), AV(P_i)], \text{ where} \quad (4.1)$$

- $BV(P_i)$  (Bid Volume) represents the aggregated volume of bids orders with prices  $\geq P_i$ ;
- $AV(P_i)$  (Ask Volume) represents the aggregated volume of ask orders with prices  $\leq P_i$ ;
- $P_i$ , which can take values between 1 and  $i$ , represents the price of the corresponding aggregate volume.

Second, the Maximum Tradable Volume (MTV) is selected and the corresponding price limit is defined as the equilibrium or marginal price (EP). In case that more than one price limit originates the MTV, the lowest of those prices is chosen as the EP:

$$MTV(EP) = \max[TV(P_1), TV(P_2), \dots, TV(P_i)], \text{ where} \quad (4.2)$$

- $TV(P_1), TV(P_2), \dots, TV(P_i)$  represents the tradable volume of orders at prices  $P_1, P_2, \dots, P_i$ , respectively;

- $MTV(EP)$  represents the maximum tradable volume that occurs for a price  $P_E$ ;
- $EP$  represents the equilibrium price.

The examples in Table 4.3 and Table 4.3 illustrate the resolution of the algorithm in different scenarios. The equilibrium price is marked in grey.

Bid		Ask	
Price	Volume	Price	Volume
49	10	47	10
48.5	20	48.5	40
48	30	49	20
47	10		

Price	Bid Volume	Ask Volume	Tradable Volume	Maximum Tradable Volume
47	70	10	10	
48	40	10	10	
48.5	20	50	20	20
49	10	70	10	

**Table 4.3:** Example 1: One pair (EP,MTV). EP=48.50€/MWh

Bid		Ask	
Price	Volume	Price	Volume
49	10	47	20
48.5	20	48.5	40
48	30	49	20
47	10		

Price	Bid Volume	Ask Volume	Tradable Volume	Maximum Tradable Volume
47	70	20	20	20
48	40	20	20	
48.5	20	60	20	
49	10	80	10	

**Table 4.4:** Example 2: One MTV, multiple prices. EP=47€/MWh

#### Step 4. Results saving

Finally, all the hourly prices and quantities are stored in another database. It is a new text file which contains all the equilibrium results, with and without renewable energy, of the whole year. It includes date, hour, price, quantity and country and it is the information interpreted in the following chapters 5 and 6.

# Chapter 5

## Results

The model we have developed in Chapter 4 is able to replicate the Spanish electricity market's behaviour and it enables us to compute the hourly equilibrium price. Once we have all the hourly prices for one month, we are able to compute the weighted average monthly price and the weighted average annual price for 2010. Some illustrative graphics are shown in the following sections.

### 5.1 Hourly marginal price

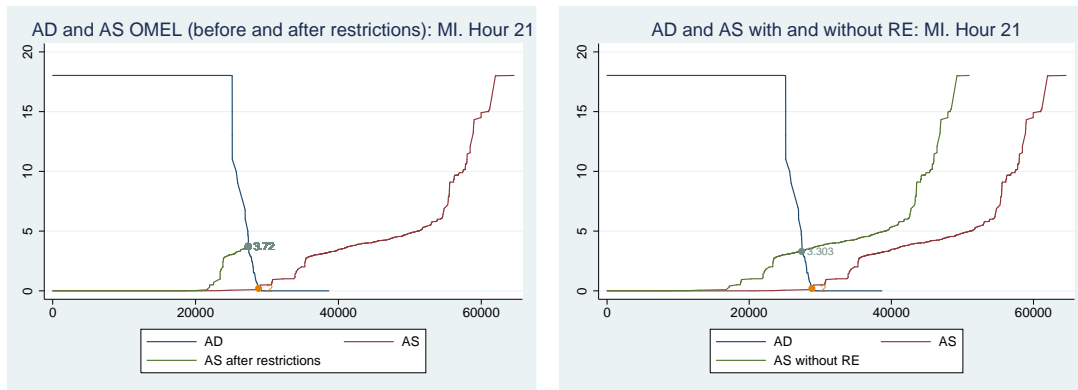
We have calculated the equilibrium price of every hour of every day of every month of 2010 with and without Special Regime generators, 17,520 marginal prices in total. Figure 5.1(a) represents the Spanish market replication including both simple and complex offers for a specific hour. The blue line outlines the demand curve and the red and green lines represent the supply curves considering simple and complex offers, respectively. As can be seen, the use of complex offers reduces the volume of energy matched, leading to an increment of the equilibrium price. This graphic allows us to check that the model is able to replicate the market, so the market-clearing algorithm is well implemented.

Afterwards, we observe the market behaviour removing renewable generation in the supply curve and leaving the demand unchanged, because market energy needs do not change whatever generators may take part. Market reduction is due to the fact that renewable generators mostly bid at price zero. They are interested in selling their energy at any price because it is costless for them and in addition to this they receive incentives to take part in the market. Figure 5.1(b) shows an example of simulation with and without energy (only simple offers). As we can see, the market price is reduced by 31.3€/MWh (or 3.31c€/kWh) thanks to the RES-E.

Showing all the hourly prices in the same graph would not lead to any significant result, because their behaviour is different depending on the hour scheduled. We can divide the hours of the day into three different periods, according to the energy demand in each of them.

**On-peak hours:** 4 hours per day. From 18h to 22h in winter and from 11h to 15h in summer.

**Off-peak hours:** 8 hours per day. From 0h to 8h both in winter and summer.



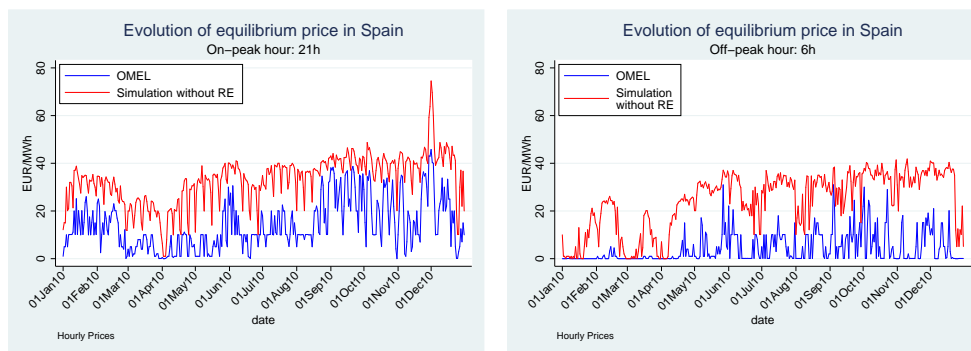
(a) Simple and complex offers

(b) Simple offers with and without RE

**Figure 5.1:** Example Market Simulation. Hourly Curve (€/MWh). May 13, 2010. Hour 21. MIBEL. Own elaboration

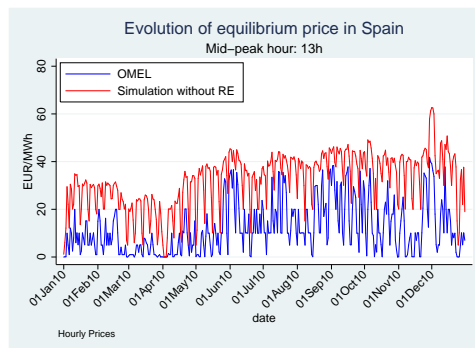
**Mid-peak hours:** 12 hours per day. From 8h to 18h and from 22h to 0h in winter and from 8h to 11h and from 15h to 0h in summer.

Figures 5.2(a), 5.2(b) and 5.2(c) illustrate the price evolution in 2010 for three demand scenarios. The different classification of winter and summer has not been considered. As we expected, the price gap with and without renewable sources is higher in hours of lower demand.



(a) On-peak hour

(b) Off-peak hour



(c) Mid-peak hour

**Figure 5.2:** Evolution of the Equilibrium Price in the year 2010 (€/MWh). Own elaboration

## 5.2 Average monthly price

Table 5.1 quantifies the reduction in the average monthly price in 2010, which represents a decrease of 19.80€/MWh in the annual average price. Note that this price is a weighted average considering both prices and energy traded in every hour and, once again, prices are obtained after simple offers.

Period	Day ahead market: OMEL		Day ahead market: Simulation without RE		Price difference
	quantity (MWh)	price (€/MWh)	quantity (MWh)	price (€/MWh)	
Jan	22,258,899	6.60	20,661,229	23.94	17.34
Feb	19,998,833	7.83	18,581,453	25.20	17.36
Mar	20,853,563	2.68	19,465,326	16.96	14.28
Apr	17,955,027	5.56	17,026,659	21.40	15.85
May	18,791,550	10.12	17,709,325	32.96	22.84
Jun	19,177,563	13.63	17,901,185	32.69	19.06
Jul	19,422,699	15.49	17,960,376	37.07	21.58
Aug	18,937,336	15.40	17,573,066	36.19	20.78
Sep	18,990,515	23.28	18,067,115	39.97	16.69
Oct	19,006,526	15.78	17,730,812	38.80	23.02
Nov	19,774,343	14.72	18,530,395	39.43	24.72
Dec	20,911,095	14.86	19,679,511	39.10	24.24
<b>2010</b>	<b>236,077,949</b>	<b>12.06</b>	<b>220,886,451</b>	<b>31.86</b>	<b>19.80</b>

**Table 5.1:** Evolution of the average monthly price in Spain in 2010

Considering monthly magnitudes, the highest prices were in September, because of the low wind production in that period. Wind energy is the most relevant renewable technology in Spain, so a reduction in its production implies that the price in the actual and counterfactual time series is similar. Similarly, the lowest prices were in March, when hydraulic generation rose. Since hydraulic plants over 50MW are not under RE, both market prices with and without renewables are lower in rainy months.

Finally, the greatest impact of renewable sources on market prices is shown in November and December, when the price reduction due to RE was 24.72€/MWh and 24.24€/MWh, respectively. As REE reports, the electricity demand during those months was higher and renewable generation substituted for thermal production, leading to a greater use of renewables.

### 5.3 Statistical Testing

We present a test of unconditional means in order to check the significance of our results. The null hypothesis is that renewable generation is zero, so that actual market clearing prices (with and without renewable generators) are equal to the counterfactual prices (without renewable electricity). We test this hypothesis considering all the observations, on-peak demand hours, off-peak demand hours and mid-peak demand hours.

Results reported in Table 5.2<sup>1</sup> show that, since all price differences are negative, the deployment of renewable electricity leads to a price reduction. In addition to this, the null hypothesis can be rejected at 1%, so renewable energy has a significant effect on electricity prices.

(€/MWh)	Period	All hours	On-peak (21h)	Off-peak (6h)	Mid-peak (13h)
pOMEL-pNoRE	Jan	-16.51***	-16.53***	-6.01***	-17.79***
	Feb	-17.28***	-14.82***	-15.04***	-17.24***
	Mar	-13.76***	-15.74***	-6.27***	-15.80***
	Apr	-15.45***	-15.35***	-15.41***	-15.36***
	May	-22.36***	-24.41***	-25.10***	-22.16***
	Jun	-19.10***	-20.04***	-20.41***	-17.64***
	Jul	-21.77***	-22.99***	-25.76***	-20.81***
	Aug	-20.90***	-20.73***	-21.07***	-20.63***
	Sep	-17.22***	-12.91***	-21.17***	-18.77***
	Oct	-23.41***	-18.94***	-26.64***	-24.10***
	Nov	-24.92***	-20.97***	-28.84***	-25.21***
	Dec	-24.04***	-22.16***	-25.98***	-24.61***
	<b>2010</b>		<b>-19.76***</b>	<b>-18.85***</b>	<b>-19.83***</b>

Table 5.2: Test of means

### 5.4 Final Price Composition

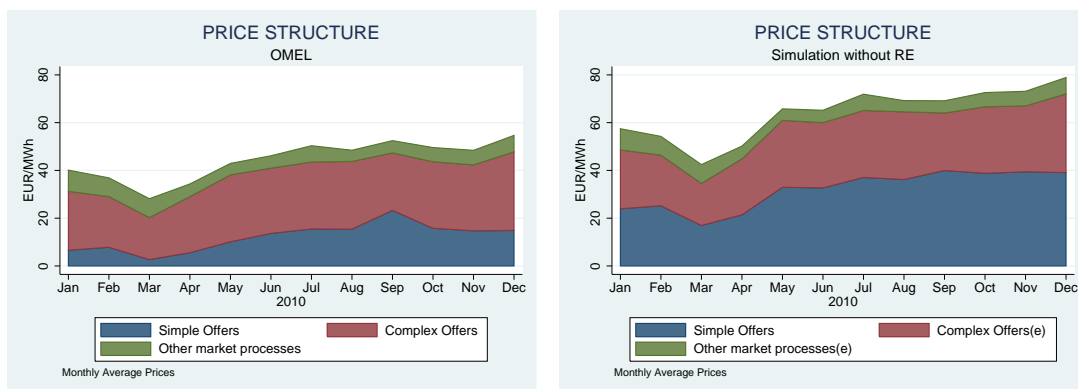
Using both the market simulations made with (actual time series) and without (counterfactual time series) renewable energy for the case of simple offers and the prices reported by OMEL after complex offers and other market processes, we can plot Figures 5.3(a) and 5.3(b). The prices after complex bids and other market processes are estimated considering that they are proportional to the change in the equilibrium price after simple bids with and without RE. We are aware that this may not be completely accurate, but it is useful to jump to the first conclusions (see Chapter 6 for more detail). As we can see, assuming that complex bids in a

<sup>1</sup>\*\*\* represents significance at 99%.



scenario without RES-E behave as they do with renewables, the greatest impact lies on simple offers.

As already stated, there are monthly differences. For instance, there was a significant rise in the marginal price in September because of the drop in the wind production. However, this fluctuation does not appear in the graph without renewables. Likewise, the lowest price in 2010 occurred in March, when hydraulic energy reached a record with a 23% of total generation. Since only small-hydraulic plants are included in the Special Regime, this reduction in the price is also noticeable in the figure without RES-E.



(a) OMEL

(b) Simulation without RE

**Figure 5.3:** Price Composition in Spain. Own elaboration



## Chapter 6

# Discussion

This chapter is divided into two sections. First, the main conclusions of the analysis will be reported. Then, the shortcuts of the research will be described and future extensions of the model will be detailed.

### 6.1 Conclusions and policy implications

As the preliminary results of Chapter 5 show, renewable energy units bid at the pool at zero price and this has the effect of decreasing market prices. However, as stated in Chapter 2, there has been a sharp increase in consumer costs since 2006 because of the incentives to the Special Regime. The debate is therefore to see if the decrease in the system marginal price is able to pay for the incentives, contributing to a reduction of the deficit of regulated activities. In this sense, it is worth saying that incentives for RES-E are more than justified because of the positive externalities of renewable sources (environmental and socio-economic). However, if the net effect on the retail electricity price was positive, there would be an additional argument for RES-E support.

Special Regime	Equivalent premium (thousands €)	Premium (€/MWh)
Cogeneration	1,304,214	55.45
Solar PV	2,618,891	417.1
Solar TE	184,876	267.36
Wind	1,936,810	45.42
Small-hydraulic	291,133	43.96
Biomass	236,380	76.09
Waste	93,121	29.86
Waste Treatment	350,902	81.9
<b>Total RE</b>	<b>7,016,327</b>	

**Table 6.1:** Incentives to the Special Regime in Spain in 2010. Source CNE

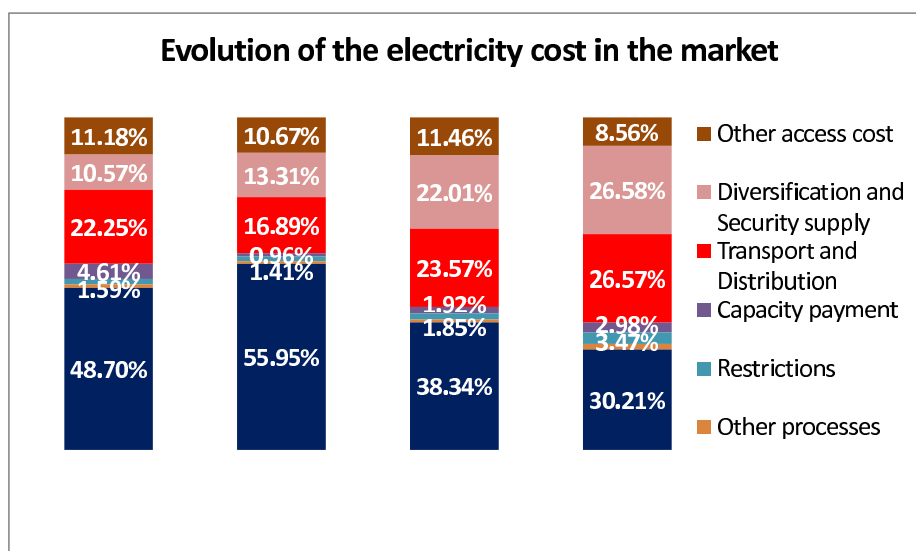
Renewable energy is rewarded at a fixed price depending on its technology (see Appendix A.1). According to the forecast of the National Energy Commission, in the year 2010 more than

7,016 million euros were delivered as incentives to the Special Regime in Spain (see Table 6.1). However, the market price savings in simple offers due to renewables reached only 4,191 million euros (see Table 6.2). Therefore, we may conclude that renewables were not able to pay for the premiums received.

	Market revenue (simple offers)	Premium
All generators (market)	2,847	7,016
Only ordinary regime generators	7,038	
Reduction due to RE	4,191	

**Table 6.2:** Market revenue and premiums in Spain in 2010 (million €). Data from CNE and own estimations

Furthermore, as Figure 6.1 points out, despite the reduction in the market price, it still is the highest component affecting the electricity cost structure in Spain (although its influence is smaller than before: 30.21% in 2010 against 48.7% in 2007). But not only that, the penetration of renewables has led to an increase of the diversification and security supply costs, due to their high volatility, from 10.57% in 2007 up to 26.58% in 2010. Since the security supply costs depend on the technological developments (the more able we are to reduce RES-E volatility, the less security supply costs will be needed), renewables can only interfere in the market price costs.



**Figure 6.1:** Evolution of electricity costs in Spain. Source: Pedro Mejía ("Los retos del mercado", 2010). Own elaboration

Therefore, two measures should be taken in order to reduce the costs of the electricity system:

1. Study the feasibility of introducing more renewable energy in the market, given their ability to reduce the marginal price.

2. Analyze the incentive system more exhaustively and determine if some renewable technologies could survive with a lower level of premiums or even without them.

## 6.2 Limitations and model extensions

Because of the influence that both demand and meteorological conditions have on renewable electricity production, the fact that only one year (2010) is considered in the analysis could lead to misleading conclusions in the long run. That is, the gap between market revenue and incentive costs due to the participation of the Special Regime could be overestimated. In order to make a more accurate interpretation, we should simulate the market behaviour with and without renewable sources for a prolonged period of time (2002-2010)<sup>1</sup>. The STATA code designed at this stage is already optimized to compute prices for more than one year, but it is very time consuming<sup>2</sup>, so it will be included in future versions.

On the other hand, the incentive scheme in Spain establishes that each type of generator in the Special Regime receives a different reward per MWh (recall Table 6.1). However, according to data from the National Energy Commission, the highest incentive does not seem to be aimed at the most productive technology, i.e. solar (see Table 6.3). This conclusion gives us the feeling that it would be interesting to separate prices by technology, but so far we have presented overall results and we have not computed the prices and volumes for cogeneration, wind, solar, . . . , separately. Nevertheless, even though OMEL is the operator publishing the best market data in Europe, it is hard to find which production units correspond to renewable sources. Therefore, this analysis was also left for the future.

Special Regime	% Equivalent Premium	% Demand/Total demand covered with RE
Solar PV	37.33	6.95
Wind	27.6	47.24
Cogeneration	18.59	26.08
Waste treatment	5.00	4.76
Small-hydraulic	4.15	7.35
Biomass	3.37	3.45
Solar TH	2.63	0.76
Waste	1.33	3.45

**Table 6.3:** Special Regime classification by incentives vs. demand coverage. Own calculations based on data from CNE

Another shortcoming of the model is that only simple offers have been considered for the

<sup>1</sup>The first complete year in OMEL database is 2002.

<sup>2</sup>It takes more than one hour to compute all hourly prices for one month and the whole year needs 15 hours of runtime.

time being. This means that we have not simulated the real marginal price reported by OMEL and, consequently, the impact of renewable energy in the daily market price is not completely measured (we have assumed that complex offers behave the same with and without RES-E). In any case, the next step in the development of the model will be to include complex offers in the designed simulation tool.

In addition to this, the research could be complemented with the study of different renewable production scenarios. We could see the impact on prices of adding fictitious marginal plants of different technologies.

Finally, our conclusions stand for the counterfactual market behaviour removing renewable generation in the supply curve, but we will never know how the current policy measures (incentives) would have changed if renewable sources had never entered the electricity market. Investment in fossil energy may have been issued and market results could have been completely different. Anyway, we present our conclusions being aware of this unavoidable limitation.

## Chapter 7

# Conclusions

As this paper shows, supported by a wide range of literature, it may be concluded that the system of feed-in tariffs has been an effective instrument in the promotion of the generation of renewable electricity in Spain. It has contributed to the take-off of green participation, leading to a significant reduction of the daily market price. However, the cost of RES-E has been extremely high to consumers and such a system may be hard to sustain in the long run. The increase that the deficit of regulated activities has suffered in Spain recently is conclusive proof.

According to our preliminary results, which are based on the simulation of simple offers, the annual average price in 2010 is almost three times lower than the price there would have been if renewable generators had not taken part in the market (monthly average prices fluctuate between a minimum of 1.72 times in September and a maximum of 6.33 times in March). However, this price contraction is not still able to support the increase in the feed-in tariffs and the tariff deficit continues to rise as a result of this.

These results are only a first step of further more widespread analysis. We propose to extend the analysis by working on two new questions. First, could this problem be solved by introducing even more renewables in the market? Or on the contrary, is it necessary to reduce the feed-in tariffs of certain generators<sup>1</sup>?

In this sense, improvements in the model can be undertaken by introducing complex offers, analysing the different renewable technologies separately and studying the market behaviour in a scenario with more renewable participation. This is planned to be done in the short term and it will lead us to more consistent conclusions.

Finally, it is worth saying that incentives for RES-E are more than justified because of the positive externalities of renewable sources (environmental and socio-economic). However, if the net effect on the retail electricity price was positive, there would be an additional argument for RES-E support.

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<sup>1</sup>Government has already approved a reduction of the incentives given to solar producers in 2011 (Ministerial Order ITC/3353/2010 of 28 December.), but we still have to wait to see the results





# A.1 Incentives of the Special Regime in Spain

According to the Royal Decree 661/2007 of 25 May 2007, Special Regime generators are classified as follows:

- a Cogeneration
  - a.1 High return cogeneration
    - a.1.1 Gas cogeneration
    - a.1.2 Fuel-oil cogeneration
    - a.1.3 Biomass/Biogas cogeneration
    - a.1.4 Others
  - a.2 Cogeneration based on sources not aimed to electricity production
- b Renewable sources
  - b.1 Solar
    - b.1.1 Solar photovoltaic
    - b.1.2 Solar thermal
  - b.2 Eolic
    - b.2.1 Onshore
    - b.2.2 Offshore
  - b.3 Geotermical and tides
  - b.4 Hydroelectric  $\leq 10\text{MW}$
  - b.5 Hydroelectric  $> 10\text{MW}$  and  $\leq 50\text{MW}$
  - b.6 Biomass
    - b.6.1 Energetic farming
    - b.6.2 Waste from agriculture
    - b.6.3 Waste from forests

b.7 Biogas

b.7.1 From dumps

b.7.2 From industrial waste

b.7.3 From liquid biofuel

b.8 Biomass from industry

b.8.1 From the agricultural industry

b.8.2 From the forestry industry

b.8.3 From paper mill

c Waste

c.1 Solid urban waste

c.2 Others

C.3 Waste ( $\geq$  50% of primary energy)

c.4 Plants under Royal Decree Real 2366/1994 of 9 December 1994

In addition to this, figures A.1.1, A.1.2 and A.1.3 illustrate the established incentives by technology. Note that these values change according to the legislation currently in force.

Grupo	Subgrupo	Combustible	Potencia	Tarifa regulada c€/kWh	Prima de referencia c€/kWh
a.1	a.1.1		$P \leq 0,5$ MW	12,0400	
			$0,5 < P \leq 1$ MW	9,8900	
			$1 < P \leq 10$ MW	7,7200	2,7844
			$10 < P \leq 25$ MW	7,3100	2,2122
			$25 < P \leq 50$ MW	6,9200	1,9147
	a.1.2	Gasoleo / GLP	$P \leq 0,5$ MW	13,2900	
			$0,5 < P \leq 1$ MW	11,3100	
			$1 < P \leq 10$ MW	9,5900	4,6644
			$10 < P \leq 25$ MW	9,3200	4,2222
		Fuel	$25 < P \leq 50$ MW	8,9900	3,8242
			$0,5 < P \leq 1$ MW	10,4100	
			$1 < P \leq 10$ MW	8,7600	3,8344
			$10 < P \leq 25$ MW	8,4800	3,3822
	a.1.4	Carbón	$P \leq 10$ MW	6,1270	3,8479
			$10 < P \leq 25$ MW	4,2123	1,5410
			$25 < P \leq 50$ MW	3,8294	0,9901
Otros		$P \leq 10$ MW	4,5953	1,9332	
		$10 < P \leq 25$ MW	4,2123	1,1581	
a.2		$P \leq 10$ MW	4,6000	1,9344	
		$10 < P \leq 25$ MW	4,2100	1,1622	
		$25 < P \leq 50$ MW	3,8300	0,6142	

Subgrupo	Combustible	Potencia	Plazo	Tarifa regulada c€/kWh	Prima de referencia c€/kWh
a.1.3	b.6.1	$P \leq 2$ MW	primeros 15 años	10,0113	11,0008
			a partir de entonces	11,0030	0,0000
		$2 \text{ MW} \leq P$	primeros 15 años	14,6690	10,0964
			a partir de entonces	12,3470	0,0000
	b.6.2	$P \leq 2$ MW	primeros 15 años	12,7998	8,4643
			a partir de entonces	8,6294	0,0000
		$2 \text{ MW} \leq P$	primeros 15 años	10,7540	6,1914
			a partir de entonces	8,0660	0,0000
	b.6.3	$P \leq 2$ MW	primeros 15 años	12,7998	8,4643
			a partir de entonces	8,6294	0,0000
		$2 \text{ MW} \leq P$	primeros 15 años	11,8294	7,2674
			a partir de entonces	8,0660	0,0000
	b.7.1		primeros 15 años	8,2302	4,0788
			a partir de entonces	6,7040	0,0000
	b.7.2	$P \leq 500$ kW	primeros 15 años	13,3474	10,0842
			a partir de entonces	6,6487	0,0000
		$500 \text{ kW} \leq P$	primeros 15 años	9,9598	6,1009
			a partir de entonces	6,6981	0,0000
	b.7.3		primeros 15 años	5,3000	3,0844
			a partir de entonces	5,3000	0,0000
	b.8.1	$P \leq 2$ MW	primeros 15 años	12,7990	8,4643
			a partir de entonces	8,6294	0,0000
		$2 \text{ MW} \leq P$	primeros 15 años	10,9497	6,3821
			a partir de entonces	8,2128	0,0000
b.8.2	$P \leq 2$ MW	primeros 15 años	9,4804	5,1591	
		a partir de entonces	6,6506	0,0000	
	$2 \text{ MW} \leq P$	primeros 15 años	7,1347	2,9959	
		a partir de entonces	7,1347	0,0000	
b.8.3	$P \leq 2$ MW	primeros 15 años	9,4804	5,4193	
		a partir de entonces	6,6506	0,0000	
	$2 \text{ MW} \leq P$	primeros 15 años	9,3000	4,9586	
		a partir de entonces	7,5656	0,0000	

Figure A.1.1: Special Regime Incentives, type a. Source: Royal Decree 661/2007 of 25 May 2007

Grupo	Subgrupo	Potencia	Plazo	Tarifa regulada €/kWh	Prima de referencia €/kWh	Límite Superior €/kWh	Límite Inferior €/kWh	
b.1	b.1.1	P<100 kW	primeros 25 años	44,0381				
			a partir de entonces	35,2305				
		100 kW<P<10 MW	primeros 25 años	41,7500				
			a partir de entonces	33,4000				
		10<P<50 MW	primeros 25 años	22,0764				
			a partir de entonces	18,3811				
	b.1.2		primeros 25 años	26,9375	25,4000	34,3376	25,4000	
			a partir de entonces	21,5498	20,3200			
	b.2	b.2.1		primeros 20 años	7,3228	2,9291	8,4644	7,1275
				a partir de entonces	6,1200	0,0000		
	b.3			primeros 20 años	6,8900	3,9444		
				a partir de entonces	6,5100	3,0600		
b.4			primeros 25 años	7,8000	2,5044	8,5200	6,5200	
			a partir de entonces	7,8200	1,3444			
b.5			primeros 25 años	*	2,1044	8,0000	6,1200	
			a partir de entonces	**	1,3444			
b.6.1	P<2 MW	primeros 15 años	15,8890	11,5294	16,6300	15,4100		
		a partir de entonces	11,7931	0,0000				
	2 MW ≤ P	primeros 15 años	14,0590	10,8964	15,0900	14,2000		
		a partir de entonces	12,2470	0,0000				
b.6.2	P<2 MW	primeros 15 años	12,5710	8,2114	13,3100	12,0900		
		a partir de entonces	8,4752	0,0000				
	2 MW ≤ P	primeros 15 años	10,7540	6,1914	11,1900	10,3790		
		a partir de entonces	8,9660	0,0000				
b.6.3	P<2 MW	primeros 15 años	12,5710	8,2114	13,3100	12,0900		
		a partir de entonces	9,4752	0,0000				
	2 MW ≤ P	primeros 15 años	11,8294	7,2674	12,2500	11,4400		
		a partir de entonces	8,9660	0,0000				
b.7.1		primeros 15 años	7,9920	3,7784	8,9600	7,4400		
		a partir de entonces	6,5100	0,0000				
b.7	b.7.2	P<500 kW	primeros 15 años	12,0690	9,7696	15,2200	12,2600	
			a partir de entonces	6,5100	0,0000			
	500 kW < P	primeros 15 años	9,6800	5,7774	11,0300	9,5500		
		a partir de entonces	6,5100	0,0000				
b.7.3		primeros 15 años	5,3600	3,0844	8,3000	5,1000		
		a partir de entonces	5,3600	0,0000				

Grupo	Subgrupo	Potencia	Plazo	Tarifa regulada €/kWh	Prima de referencia €/kWh	Límite Superior €/kWh	Límite Inferior €/kWh
b.8	b.8.1	P<2 MW	primeros 15 años	12,5710	8,2114	13,3100	12,0900
			a partir de entonces	8,4752	0,0000		
		2 MW ≤ P	primeros 15 años	10,7540	6,1914	11,1900	10,3790
			a partir de entonces	8,9660	0,0000		
	b.8.2	P<2 MW	primeros 15 años	9,2800	4,9214	10,0200	8,7900
			a partir de entonces	6,5100	0,0000		
2 MW ≤ P		primeros 15 años	6,5080	1,9454	6,9400	6,1200	
		a partir de entonces	6,5080	0,0000			
b.8.3	P<2 MW	primeros 15 años	9,2800	5,1696	10,0200	8,7900	
		a partir de entonces	6,5100	0,0000			
	2 MW ≤ P	primeros 15 años	8,0000	3,2199	9,0900	7,5000	
		a partir de entonces	6,5080	0,0000			

Figure A.1.2: Special Regime Incentives, type b. Source: Royal Decree 661/2007 of May 25

Grupo	Tarifa regulada c€/kWh	Prima de referencia c€/kWh
<b>c.1</b> .....	<b>5,36</b>	<b>2,30</b>
<b>c.2</b> .....	<b>5,36</b>	<b>2,30</b>
<b>c.3</b> .....	<b>3,83</b>	<b>2,30</b>
<b>c.4</b> .....	<b>5,20</b>	<b>1,74</b>

**Figure A.1.3:** Special Regime Incentives, type c. Source: Royal Decree 661/2007 of May 25



# Glossary

**AD** Aggregate Demand

**AS** Aggregate Supply

**AV** Ask Volume

**BV** Bid Volume

**CNE** Comisión Nacional de Energía (National Energy Commission)

**E** Energy

**EP** Equilibrium Price

**FIT** Feed-in tariffs

**MTV** Maximum Tradable Volume

**OMEL** Operador del Mercado Eléctrico (Electricity Market Operator)

**PBC** Programa Básico de Casación

**PBF** Programa Básico de Funcionamiento

**PDVP** Programa Diario Viable Provisional

**PHF** Programa Horario Final

**RE** Régimen Especial (Special Regime)

**REE** Red Eléctrica Española

**RES** Renewable Energy Sources

**RES-E** Renewable Energy Sources for Electricity

**RES-H** Renewable Energy Sources for Heating

**RES-T** Renewable Energy Sources for Transport

**TV** Tradable Volume





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