Measuring the Impact of Renewable Energy Sources on the Optimal Generation Mix: An Application to the Iberian Electricity Market

by

Carla Manuela Tavares Mendes

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Supervisor:

Prof. Dr. Maria Isabel Rebelo Teixeira Soares

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Biographical Note of the Candidate

Carla Manuela Tavares Mendes was born on 19th March 1986. She grew up in Vila Nova de Gaia where she also finished high school. In 2009 she received a Bachelor of Arts in Economics from the School of Economics and Business at the University of Porto (Faculdade de Economia do Porto). After working for a year at a small company, she was accepted to the Master Program in Economics – area of specialization in Economic Regulation and Competition - at the same institution. The candidate's greatest research interest is in energy economics. Thus, she also completed several courses of the Master of Economics and Environmental Management program to expand her knowledge. In 2012, the candidate concluded the curriculum portion of the Master in Economics, whose dissertation is currently under proposal.

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Abstract

In the last few decades, electricity markets have undergone extensive reforms. On the one hand, there is the need to reduce the market power of the incumbents – the prior state-owned monopolies. To that end, a process of liberalizing the electricity markets has been implemented by several countries, where generation and commercialization are open to competition, and transmission and distribution remain regulated. On the other hand, the need to comply with the targets set by the Kyoto Protocol, in order to mitigate the climate change, has changed the generation mix. Thus, renewable energy sources, such as wind power, have been widely disseminated and supported by the State.

However, the recent economic crisis led to a decrease in State aid to renewable energy sources. Thus, it is important to study what the impact of wind power will be on the optimal generation capacity mix, assuming producers can invest in two generation technologies (wind and conventional power) and the wholesale market is open to competition.

This dissertation develops a two-stage model for MIBEL, where the choice of the capacity construction occurs in the first-stage, before electricity demand is known, and the optimal outputs and daily equilibrium prices are obtained in the second-stage, under the assumption that electricity demand does not exceed the installed capacity.

Through the application of the model, it can be concluded that, under the model's assumptions, generators can be expected to increase their renewable generation capacity, namely wind power.

Keywords: Electricity Markets, Renewable Energy Sources, Optimal Capacity Mix, Wind Power, Conventional Power.

Resumo

Nas últimas décadas, os mercados de eletricidade têm sofrido amplas reformas. Por um lado, existe a necessidade de reduzir o poder de mercado das incumbentes - os anteriores monopólios detidos pelo Estado. Desta forma, vários países têm implementado um processo de liberalização dos mercados de eletricidade, onde a produção e a comercialização são abertas à concorrência e a transmissão e distribuição mantém-se reguladas. Por outro lado, a necessidade de cumprir com os objetivos estabelecidos pelo Protocolo de Kyoto, por forma a mitigar as alterações climáticas, tem alterado o mix de produção. Desta forma, as energias renováveis, como é o caso da eólica, têm sido amplamente difundidas e apoiadas pelo Estado.

Contudo, a recente crise económica conduziu a um decréscimo dos apoios concedidos às renováveis. Deste modo, urge estudar qual será o impacto da energia eólica no mix ótimo de capacidade, tomando como pressupostos o facto de que os produtores podem investir em duas tecnologias de produção (eólica e convencional) e que o mercado grossista se encontra aberto à concorrência.

Esta dissertação desenvolve um modelo de dois estágios para o MIBEL, onde a escolha da capacidade a construir ocorre no primeiro estágio, antes da procura de eletricidade ser conhecida, e as quantidades ótimas e os preços de equilíbrio diários são obtidos no segundo estágio, de modo a que a procura não exceda a capacidade instalada.

Através da aplicação do modelo, chega-se à conclusão de que, face aos pressupostos assumidos, é expectável que os produtores invistam no aumento da capacidade produtiva renovável, no caso a energia eólica.

Palavras-chave: Mercados de Eletricidade, Energias Renováveis, Mix Ótimo de produção, Energia Eólica, Energia Convencional.

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Introduction

Since its invention, electricity has become an indispensable good for each home and an essential input for industry in almost every economy. Thus, for many years, vertically integrated and state-owned monopolies were responsible for providing electricity to everyone.

However, this scenario has changed drastically in the last two decades. The formation of a less-regulated and more competitive electricity market is currently taking place in many countries. In the European Union, the first great step to a reorganization process of the electricity market began in 1996, with the Directive 96/92/EC, and since then several additional measures have been taken in order to achieve an Internal Electricity Market. To achieve this goal, the member states have reinforced their interconnections through the creation of regional markets. As a result, an Iberian Electricity Market (MIBEL) was created.

Following in the steps of the UK and the Scandinavian countries (namely, Norway) in the reorganization process of their electricity markets, MIBEL provided a vertical unbundling of generation, transmission, distribution and retail supply. As a consequence, wholesale generation and retail supply were opened to competition, and the incentive of regulation in the transmission and distribution networks was established. Thus, an Iberian wholesale spot market was created, where the rules of a liberalized market prevailed. This is the market on which the present dissertation focuses.

Several technologies can be employed to produce electricity. Nevertheless, the growing concerns of global warming and the scarcity of fossil resources have led to an increase of State measures to promote renewable energy sources. For example, the European Union has set the goal of satisfying 20% of electrical demand with renewable energy by 2020 (Europa, 2009); and for Portugal and Spain, the targets are 31% and 20%, respectively (Parlamento Europeu and Conselho Europeu, 2009a).

In this, wind power has played a key role. According to GWEC (2012), "*the global wind power market grew by about 6% compared to 2010, and the 40.5 GW of new wind power brought on line in 2011 represents investments of more than €50 billion (about $68 billion)*". In Europe, new installed capacity of wind power reached 10,281 MW in 2011. Currently, the whole installed capacity of wind power in Europe is 96.6 GW. Thus, the technology used to produce wind power is mature, competitive, and it is well spread in the global market.

Since the electricity market has been subject to extensive reforms and wind power has experienced impressive growth, the following research question arises: what is the effect of well developed renewable energy sources, like wind power, on the generation capacity mix of a competitive market, such as the Iberian wholesale electricity market?

Presently, this is a crucial question since both Portugal and Spain have already approved the reduction of subsidies to the generators of wind power. Therefore, the purpose of this dissertation is to provide the necessary tools to understand the relationship between renewable energy sources and the optimal generation capacity mix in a liberalized, competitive market. Furthermore, since the literature on this specific topic is scarce, this dissertation has as its secondary objective to contribute to filling this gap.

The methodology used was the following: after a literature survey focused on the impact of renewable energy sources on the generation capacity mix, the article by Milstein and Tishler (2009) was selected because, it allows for a better understanding of the market reality. To explore the connection between renewable energy sources and optimal generation capacity mix in a competitive wholesale electricity market, this dissertation applies and solves that model to the Iberian Electricity Market. To that end, we present a two-stage game of endogenous investments and operations in a competitive electricity market with wind and conventional power[1] technologies under demand and supply uncertainties. In the first-stage of the game, each generator decides on its capacity investment in order to maximize their expected profits. In the second-stage of the game, the generator selects its daily electricity production subject to its

[1] It should be noted that conventional power includes the (large) hydro and thermal power for the Portuguese case. For Spain, the nuclear power needs to be added.

capacity availability, and the equilibrium prices are determined. The game is developed under Cournot conjecture, and it is solved using MATLAB software.

The dissertation proceeds as follows. The next chapter addresses the European liberalization process of the electricity market, explains the constitution process of MIBEL and characterizes it. Chapter 2 makes a literature survey about the research question and presents the model. Chapter 3 applies the model to the real world – the Iberian Electricity Market - and presents the main results. The last chapter concludes.

The main conclusion is that, in a competitive electricity market, when the generators can build both technologies, investment in wind power capacity is the optimal choice for the generators. This conclusion can eventually be developed for other renewable energy sources.

1. The Iberian Electricity Market in the Context of the Internal Electricity Market

Electricity markets, as we know them, are a recent reality. The reforms of the energy sector only began in the end of the 1980s. Before that, the electricity companies were vertically integrated and state-owned monopolies, and the value chain of the electricity sector – generation, transmission, distribution, and supply activities – was not subject to competition. But, different features of electricity also helped to start the sector restructuring process. As is known, the electricity sector is characterized by a single product and intensive capital industries. This fact associated with irreversible sunk costs, capacity constraints, and inelastic demand, act as a barrier to entry for new firms and increases the market power of incumbents.

Therefore, since the end of the 1980s, this market structure has been widely criticized due to the lack of competition and physical characteristics, and the liberalization process has taken place in many countries around the world. The first countries to implement this electricity sector reform were Chile, the UK, and Norway but quickly spread to other developed and developing countries. The elements of the reform are common. In the first place, the former vertically integrated electricity utilities were unbundled even as the generation and retail segments of industry were open to competition. In the second place, the segments of transmission and distribution remained regulated due to their natural monopoly characteristics. And finally, a wholesale and spot power market is developed, as well as the third party access is removed and an independent market and system operator emerge. In some cases, the privatization is establishment (Erdogdu, 2010). To sum up, and as it can be seen in table 1, a successful liberalization involves " *(...) a sector restructuring, introduction of competition in wholesale generation and retail supply, incentive regulation of transmission and distribution networks, establishing an independent regulator and privatisation"* (Jamasb, 2002; Joskow, 1998; Newbery, 2002a, cited by Jamasb and Pollitt, 2005, pp. 13).

Table 1: Main Steps in Electricity Reform

Restructuring	Vertical unbundling of generation, transmission, distribution and retail supply activities Horizontal splitting of generation and retail supply
Competition and Markets	Wholesale market and retail competition Allowing new entry into generation and retail supply
Regulation	Establishing an independent regulator Provision of third-party network access Incentive regulation of transmission and distribution networks
Ownership	Allowing new private actors Privatising the existing publicly owned businesses

Source: Jamasb and Pollit (2005, pp. 13)

The reasons behind these reforms are always the same: demolish the former monopolies and barriers to entry, improve the efficiency of the sector by better allocation of resources, and offer a superior quality of service. Nevertheless, according to Sioshansi (2006b), cited by Erdogdu (2010), there is an additional objective. Many times, the developing countries initialize the changes in power industry because they need to attract new investments to this sector.

After this short introduction, about the reforms in the energy sector, the liberalization process of electricity markets in the European Union (EU) can be studied.

1.1. The Liberalization Process in the EU Electricity Markets

Following the first steps given by the UK and Norway, the European Commission (EC) undertook a reorganization process of its electricity market in order to achieve an Internal Electricity Market (IEM). The IEM is justified by the EC in its Green Paper of 2006, because it will contribute to lower prices and increase the security of supply. This last point is achieved through the reinforcement of cross-border transactions and the application of the principle of solidarity between member states (European Commission, 2006).

However, this is a very ambitious goal. Europe is not a single entity, like a country, that has sufficient autonomy to implement and manage new proposals to reorganize the market and achieve its goals. Hence, the liberalization of the EU electricity markets was followed in two levels. In the first place, the EC develops the market reorganization

process and monitors it. Then, the member countries adopt policies in their jurisdiction and implement them as they wish. But, this political arrangement could bring disadvantages, as the desirable outcomes by the EC may be less than expected. So, to minimize this effect, in the second place, the EC promotes the increase of interconnections between national markets, in order to raise competition and lower the transport costs across borders (Jamasb and Pollitt, 2005). Thus, the IEM is closer to be achieved.

Until now, the European liberalization process of the electricity sector is based on three directives, presented in the following figure. It should be noted that, the principle accepted for restructuring the electricity sector was the breakdown of the different vertical activities of the electricity value chain. For that, three key measures were adopted: unbundling, encouragement to third party access to network, and creation of independent regulatory authorities (Cruz, 2008).

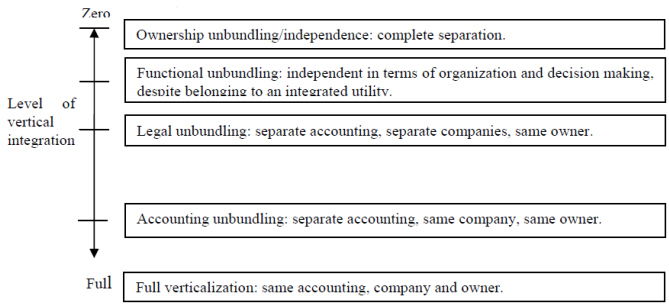
Figure 1: Liberalization Process Timeline

Source: elaborated by the author

In this paragraph, a parenthesis to speak about unbundling needs to be made. As Jamasb and Pollitt (2005) explained, there are two types of unbundling: horizontal and vertical. The horizontal unbundling allows the creation of competition in generation and retail supply, because these activities possess scale economies that promote it. And, the vertical unbundling aims to separate the potentially competitive activities, like generation and retail supply, from transmission and distribution networks that work as natural monopoly activities. To minimize the impacts of vertical integration - the increase of concentration and consequently the market power - several variations of transmission and distribution unbundling have been implemented. As can be seen in the following figure, there are five levels of vertical integration, ranging from ownership unbundling to full verticalization. In the basic level of vertical integration - accounting or administrative unbundling - the accounts of transmission system operator (TSO) and distribution system operator (DSO) must be separated. The next level, legal unbundling, establishes that, in the case of vertical integration between the activities of energy value

chain, the TSO and DSO must be legally separated. The functional unbundling is similar to legal unbundling, however, the only difference is that the management of the functionally unbundled business – the grid operator – is separated and the flows of information between the integrated utilities have limits (Marcu, 2010). Finally, the ownership unbundling guarantees the complete separation between ownership of generation assets and ownership of transmission assets. Moreover, also requires that all network functions are separated from other activities belonging to energy supply companies.

Figure 2: Levels of Vertical Integration in the Electricity Industry



Source: Marcu (2010, pp. 25)

The first directive to be implemented was the Electricity Directive 96/92/EC in 1996 and each country adopted it until February 1999. This directive had as principal goals, unbundling the industry and opening the national markets gradually. For that, the directive included (Weigt, 2009a, pp. 8):

- *"The introduction of "eligible customers" which could freely choose their supplier (at least 1/3 of the market in 2003);*
- *Three possible third-party access (TPA) models: negotiated TPA, regulated TPA, and single-buyer model;*
- *Administrative unbundling of network activities, generation, and supply".*

On the privatization issue, each member state has autonomy to resolve it, because there is a variety of cases that range from state-owned monopolies to regulated private firms (Weigt, 2009a).

However, the European Directive was severely criticized. As noticed by Erdogdu (2010), the directive allowed countries to escape from their commitments. A wholesale

market and a market regulator were not defined. The unbundling requirements and the negotiated TPA options, offered by the incumbent companies, did not guarantee independence and did not reduce the barriers to entry. And finally, retail competition was limited.

By the insufficient outcomes of first directive, the EC implemented the Electricity Directive 2003/54/EC in 2003. It promotes the competition by introducing more rigorous requirements on member countries to disintegrate their vertical utilities, and requiring an independent regulator and regulatory independence. So, the directive establishes that (Weigt, 2009a, pp. 9):

- *"Eligible customers: all non-household customers free to choose from July 1, 2004; and all consumers free from July 1, 2007;*
- *Grid access: only regulated TPA permitted and a regulator required;*
- *Unbundling: requiring legal unbundling for transmission after July 1, 2004, and for distribution after July 1, 2007"*.

In 2009, the EC adopted the "Third Energy Package" (Electricity Directive 2009/72/EC) to promote the ownership unbundling, as a result of privileged treatment given by network company to generators or retailers belonging to the same Group. This is the preferred option by the EC (Torrit, 2008, cited by Weigt, 2009a). Nevertheless, this directive is against the interests of some large European energy groups. So, two more mechanisms are proposed: Independent System Operator (ISO) and Independent Transmission Operator (ITO). According to ISO, the member state is obliged to appoint an external body, which does not belong to the vertically integrated company and assumes the responsibilities of TSO. In this mechanism, the transmission assets remain in the company's balance sheet. Regarding to ITO, the TSO continues inside the vertically integrated company and the transmission assets remain in the company's balance sheet. However, the regulation is more present. Following Weigt (2009a, pp. 10), the "Third Energy Package" addresses issues related to:

- *"Regulators:*
    - *Harmonizing and strengthening the powers and duties of regulators,*
    - *Ensuring independence,*

- *Mandating a co-operation between regulators.*

- *Creation of an European agency for the coordination of energy regulators (with limited powers, focused on cross-border issues),*
- *Establishment of an European Network for TSOs:*
  - *To develop harmonized standards regarding grid access,*
  - *To ensure coordination of operation,*
  - *To coordinate and plan network investments."*

To summarize section 1.1., the following table shows the key points of the European energy reform path.

Table 2: EU Electricity Directives

	Most Common Form pre-1996	**1996 Directive**	**2003 Directive**	**2009 Directive**
Generation	Monopoly	Authorization Tendering	Authorization	Free Entry
Transmission (T) **Distribution (D)**	Monopoly	Regulated TPA Negotiated TPA Single Buyer	Regulated TPA	Regulated TPA
Supply	Monopoly	Accounting separating	Legal separating from transmission and distribution	Complete separation from transmission and distribution
Customers	No choice	Choice for Eligible Customers (=1/3)	All non-household (2004) All (2007)	All
Unbundling T/D	None	Accounts	Legal	Ownership unbundling ISO ITO
Cross-Border Trade	Monopoly	Negotiated	Regulated	Regulated
Regulation	Government Department	Not specified	Regulatory Authority	Regulatory Authority

Source: elaborated by the author, data from: (Parlamento Europeu and Comissão Europeia, 2009b; Jamasb and Pollitt, 2005; Weigt, 2009a)

According to what is explained above, it can be concluded that a strong market-based system and an IEM have been achieved, thanks to all efforts of the EU to implement the electricity directives. Nevertheless, the lack of will among member countries and the EU Commission to reduce the concentration market and the power of the "national champions" in the electricity industry, constitutes a problem nowadays.

In the next section, it will be explained how the Iberian Electricity Market (MIBEL) was created and its main features.

1.2. The Constitution Process of MIBEL

Following the steps given by the EU, Portugal and Spain restructured their energy sector starting with the liberalization and then moving to the market integration[1]. To explain how this process has developed, in the first place it will be described how the liberalization of the energy sector in both countries started. Afterwards, the explanation of the constitution process of MIBEL will be made.

1.2.1. The Energy Sector Liberalization in Portugal and Spain prior to the Creation of MIBEL

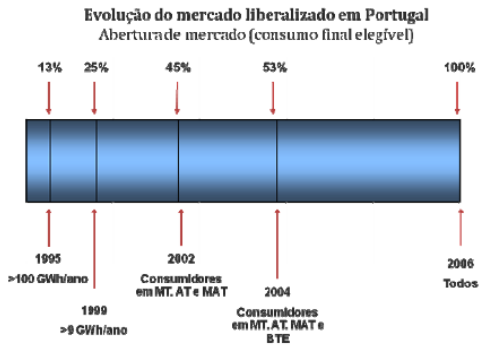
The Portuguese reform of the energy sector began long before the first EU Electricity Directive. In 1994, the *Energias de Portugal* (EDP) company was reorganized through the creation of companies linked to the Group and responsible for the production, transport and distribution activities. In 1995, the decrees-laws 182/95 and 185/95 were passed, which allowed the coexistence of a regulated and liberalized sector. In this same year, it was possible to create an independent regulatory entity and the Portuguese liberalization process of the energy industry was defined. In 1996, the Electricity directive enters our legal system and in 1997 the independent regulatory entity (*Entidade Reguladora dos Serviços Energéticos* - ERSE) started to operate (Marques, 2010).

As in most European countries, the liberalization process of the Portuguese energy industry followed a similar methodology: the market opened up gradually to everybody but the first consumers were the large industrial ones. Afterwards, it was sequentially

[1] Liberalization and integration are two different concepts but are connected. We can have liberalization without integration or integration without market liberalization. However, the market integration has strong implications in the market liberalization, since the integration process can mitigate the power market, increase the liquidity of the integrated market, reduce the fixed costs of the interconnections, and raise the economic efficiency (Sousa, 2005).

extended to all consumers who possess extra high, high, medium, and low voltage. Then, on 4th September 2006, nearly 6 million customers became eligible to choose their electricity supplier (Conselho de Reguladores do MIBEL, 2009). The process can be seen in the next figure.

Figure 3: Liberalization Timeline in Portugal

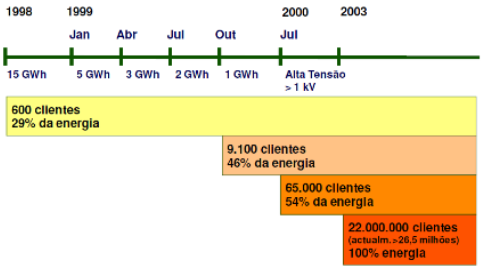


Source: Conselho de Reguladores do MIBEL (2009, pp. 55)

In Spain, the reforms of energy sector started in 1994 with the Spanish Electrical Act, in order to liberalize this sector and create the *Comisión Nacional de Energía* (CNE). However, its implementation was delayed. In 1997 the Spanish government passed the Spanish Electricity Power Act to implement the first EC Directive and delegate the CNE as regulator of the energy sector. The prior law, allowed the open of generation and retail markets to competition, guaranteed grid access, and legal unbundling (Weigt, 2009a).

Like Portugal, Spain had the same progressive eligibility timetable. Its liberalization process started in 1998 and finished on 1st January 2003. During this period, the consumers have been considered eligible: first based on consumption volume and later on supply voltage. So, currently, all consumers can freely choose their energy supplier. The Spanish liberalization process can be seen in the next figure.

Figure 4: Liberalization Timeline in Spain



Source: Conselho de Reguladores do MIBEL (2009, pp. 50)

1.2.2. The Constitution of MIBEL

The Electricity Directive 96/92/EC had as main objective, to develop an IEM. Nevertheless, the interconnections between member states are unsatisfactory, complicating the creation of such market. As a result, the member states have developed or are planning to do regional markets, resulting in the creation of markets like Nordpool (the electricity market in the north-european countries) and the MIBEL.

The first steps given by Portuguese and Spanish Governments towards an integrated electricity market occurred on 29th July 1998, when the memorandum of agreement for the cooperation in electrical matters was signed. Later, this memorandum gave rise to the Protocol for collaboration between the Portuguese and Spanish Governments, which was signed on 14th November 2001. This was one of the main moments for the boost given to the creation of MIBEL. As noticed by Domínguez and Bernat (2007, pp. 5119), this Protocol established:

- *"The entering into operation of the MIBEL on 1 January 2003.*
- *Guarantees of access to the market and the interconnections on equal conditions for all agents.*
- *The expansion of the existing interconnections within a term of 5 years through the construction or extension of at least four new lines.*
- *The development of harmonized operating procedures by the operators of the system which allow for joint management of the two systems."*

Another important moment of its construction was the signature of the Santiago de Compostela Agreement on 1st October 2004. This agreement aims the harmonization of prices structures among the countries and the creation of the Regulatory Council, comprising by the national energy bodies and stock market bodies[2].

In November 2006, the Portuguese-Spanish summit, which took place at Badajoz, aimed the reaffirmation of the determination to develop the MIBEL and the definition of the Plan for Regulatory Harmonization, by the National Administrations.

Finally, the last main step to MIBEL concretization was the Braga Summit in January 2008. This Summit amended the Santiago Agreement and clarifies some issues identified in the Plan for Regulatory Harmonization.

The main steps given by Portuguese and Spanish Governments for the constitution of MIBEL are summarized in figure 34 (see Annex 1).

Having this in mind, we can sustain that, MIBEL is based on principles of a single price for the whole peninsula, free competition, transparency, equal access among stakeholders, and economic efficiency to consumers' benefit in both countries (Cruz, 2008; Domínguez and Bernat, 2007). In fact, and as noticed by Cruz (2008), the MIBEL tries to converge in three dimensions: physical, economic, and legal. In physical terms, it tries to improve the coordination amongst both TSOs and strengthens the interconnection capacity between networks. In economic terms, it aims the definition of a market model and its running. Finally, in legal terms, it allows regulatory harmonization and the convergence of market tariffs.

All things considered, it is shown that Portugal and Spain have much in common. However, there are significant differences, which make the creation of MIBEL a major challenge for both. Though, greater efforts have been taken to minimize these differences.

[2] The Regulatory Council comprising the *Comisión Nacional de Energía* (CNE), the *Entidade Reguladora dos Serviços Energéticos* (ERSE), the *Comisión Nacional del Mercado de Valores*, and the *Comissão do Mercado de Valores Mobiliários* (CMVM).

1.3. Current Structure of the Electricity Market

Generally, the structure of the electricity market comprises four main activities: generation or production of energy, transmission, distribution, and commercialization or retail, as shown in the following figure.

Figure 5: Electricity Value Chain

Source: elaborated by the author

In the next paragraphs, the main activities of the electrical value chain will be briefly described, since it is not the interest of this study to address the issue comprehensively.

A. Generation

The first activity of the electricity value chain is the generation. The generation or production of energy is located upstream of the electrical value chain. It comprises the production of electricity in the power plants but also, all physical imports of electricity obtained through interconnections between countries. The generation is subject to licensing and it is divided in two regimes:

- *Special Regime:* comprises the production of electricity from renewable energy sources and cogeneration;
- *Ordinary Regime:* encompasses all other energy sources, including the large hydroelectric plants.

Most of the production is resold in the wholesale market, and the access to this market is not reserved exclusively for resellers. The large customers can also purchase electricity directly in the wholesale market[3].

Currently, this activity is subject to competition. The abundance of the natural gas and the technological progress made it possible to build smaller plants in record time with little risk. This allowed that barriers to entry were broken and capital-intensive nuclear and coal plants were regarded as less attractive to invest. So, these new developments

[3] It should be noted that only the wholesale market will be exhaustively analyzed and described due to its importance for the present study.

make the entry of newcomers in generation activity and their direct competition with incumbents easier (Marques, 2010; Sioshansi, 2006).

B. Transmission

The transmission activity allows that electricity may be carried in high voltage from power plants to distribution grid or to some large industrial consumers. Thus, the electricity can travel greater distances with minimum loss.

Furthermore, as this activity is considered natural monopoly, due to the fact that the companies, which explore the transmission grid, have declining average costs until reaching the minimum efficient scale. As noted by Kahn (1988), cited by Marques (2010, pp. 34), *"(...) as long as the tendency prevails for unit costs to decline with an increasing volume of business, because of economies of scale internal to the firm, it is more efficient, other things being equal, to have one supplier than several"*. On the other hand, as this activity is a natural monopoly, the application of regulation is justified by the high fixed costs of the transmission activity associated to investment and by the infrastructure duplication to make the market economically unfeasible. Therefore, the regulation of the activity guarantees the free access to the grid and allows its economic-financial viability.

Finally, it should be noted that, the transmission grid encompasses network externalities, since the investments made by the transmission companies in the grid influence the whole chain, which may increase the reliability and security in the electricity supply.

C. Distribution

The distribution activity allows that electricity be carried in medium or low voltage up to final consumers. Usually, this activity is interconnected with transmission grid but, sometimes, it can be linked to power plants in special regime.

Like the transmission activity, the economical features of the distribution, such as costs structures and the importance of the investments, make this activity a natural monopoly subject to economic regulation. So, naturally the distribution activity is not open to competition.

D. Commercialization

This activity is located downstream of the electricity value chain, it is open to competition, and it is subject to licensing. Thus, it is linked to a retail market, where retailers buy and sell electricity, through the access of the transmission and distribution grids. The retailers can have access to the grid if they pay an access tariff, charged by the regulatory entity. In general, the commercialization is the activity that connects the consumer to the electrical system.

Currently, the consumers may choose to purchase electricity in the regulated or liberalized market.

Figure 35 (see Annex 1) summarizes the current structure of the energy sector.

1.4. Characterization of MIBEL Generation Sector

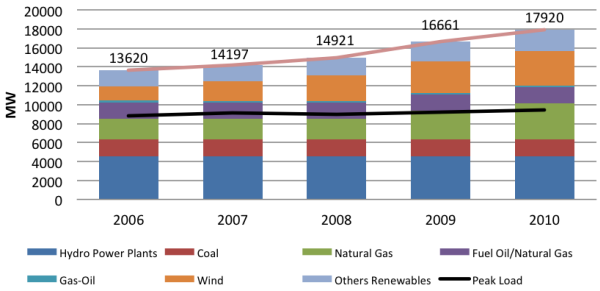
This section seeks to characterize the generation sector of the countries that constitute MIBEL, due to its importance in the development of this dissertation. The characterization of the Portuguese electricity generation sector will be made in the first place.

1.4.1. The Generation Sector in Portugal

During the 2006-2010 period, Portugal has had a significant growth in the installed capacity with a growth rate from 2006 to 2010 equal to 31.6%. The next figure[4] shows that Portuguese installed capacity increased from 13,620 MW in 2006 to 17,920 MW by the end of 2010.

[4] For more information see Annex 2.

Figure 6: Changes in the Installed Capacity by Technology



Source: elaborated by the author, data from: (REN, 2007, 2008, 2009, 2010)

This rise is mainly due to two great changes in the electricity production infrastructure. On the one hand, this increase was due to strong growth in the installed capacity under special regime, particularly with respect to wind power. Thus, it is confirmed that the wind power share, in the installed capacity under special regime, increased from 47.6% in 2006 to 62.4% in 2010. This growth also allowed that installed capacity under special regime changed from 3,187 MW in 2006 to 5,935 MW in 2010.

On the other hand, there was a significant growth in the installed capacity under ordinary regime. In the figure it is shown that installed capacity of natural gas power generators (Combined Cycle Gas Turbine – CCGT) increased from 2,166 MW in 2006 to 3,829 MW in 2010. This growth represents a rise of the CCGT share in the installed capacity under ordinary regime from 20.8% in 2006 to 31.9% in 2010. However, the Portuguese electricity generation sector depends largely on the installed capacity of hydroelectric power systems, which in 2010 amounted 38.2% of the installed capacity under ordinary regime.

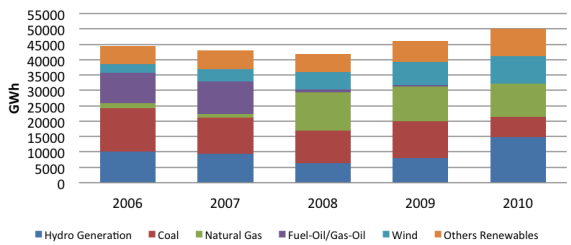
Regarding the trend of the annual peak load[5], the figure shows that the margin between the peak load and the installed capacity under ordinary regime is relatively small, since in 2010, the peak load represented 78.5% of the installed capacity under ordinary regime. This means that all the ordinary regime technologies are needed to satisfy Portuguese peak load (Conselho de Reguladores do MIBEL, 2009).

[5] The peak load is defined as the maximum load that the grid has to handle during a given period of time.

In terms of energy produced (figure 7[6]), it should be noted that, the thermal generation has seen a significant growth of the CCGT electricity generation, opposite to other technologies. Thus, in 2010, the electricity production by CCGT represented 21.4%, in the whole generation power, against the 3.4% in 2006.

On the other hand, the electricity generation by fuel-oil and coal power systems has decreased, reaching 0.15% and 20.4% of the electricity generation under ordinary regime in 2010, respectively.

Figure 7: Changes in the Electricity Generation by Technology



Source: elaborated by the author, data from: (REN, 2007, 2008, 2009, 2010)

In spite of the decline of the energy produced by the hydroelectric power systems since 2006, its increase in 2010, is justified by the fact that this year has been under a high hydraulicity (BPI, 2011).

Concerning the contribution of the production under special regime in total electricity production, it is confirmed that it has been increasing. Thus, in 2010, it represented 35.8% of the whole generation, with emphasis on wind power that represented 50.3% of the electricity generation under special regime.

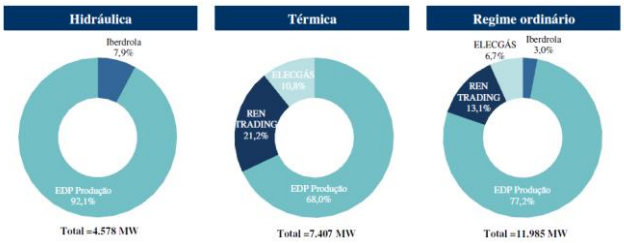
1.4.1.1. Players and Payment Mechanisms in the Ordinary Regime

As it can be seen in figure 8, EDP holds the majority of the installed capacity under ordinary regime (77.2%). In terms of hydro power, it is important to note the significant percentage of the installed capacity of EDP, reaching 92.1% in 2010. However, this

[6] For more information see Annex 2.

share is not greater because EDP transferred the exploration of two hydro power stations to Iberdrola (BPI, 2011).

Figure 8: Installed Capacity Shares by Agent in the Three Types of Electricity Production in 2010



Source: BPI (2011, pp. 78)

Thus, it can be concluded that, in terms of the installed capacity under ordinary regime, the concentration level of Portuguese energy sector is high.

Furthermore, in the Portuguese ordinary regime there are plants subject to different payment mechanisms. The main payment mechanisms are three and it will be explained below.

A. Power Purchase Agreements (PPAs)

Since the 90's that Portuguese electricity generation was subject to long-term power purchase agreements. These agreements were signed by each electricity production facility and a single buyer, which was responsible for satisfying the consumers' needs.

Nevertheless, with the beginning of the electrical liberalization process in 2007, it was necessary to reformulate the PPAs signed amongst REN and EDP. Thus, the PPAs ended, and the introduction of a mechanism to maintain contractual equilibrium (CMCE) was confirmed. This mechanism enables that power plants, which previously held the PPAs, participate in an organized market.

However, the agreements signed with Turbogás and Tejo Energia have continued under the PPAs regime. But to allow the participation of these companies on the spot market it was necessary to create an independent entity responsible for the management of the PPAs – the REN Trading. This way, the REN Trading acquires the energy produced by Tejo Energia and Turbogás power stations and resells it on the spot market. This is the base of the PPAs regime.

The difference between the energy costs (defined in the PPAs) and the market revenue (earned by REN Trading's energy sales) creates an additional cost that is supported by the consumers through the tariff for the global use of system.

Therefore, this mechanism allows that the producers' market risk be significantly reduced.

Currently, the power stations under PPAs regime represent 9% of the Portuguese installed capacity and it is expected that these agreements expire in 2012 for Tejo Energia and in 2024 for Turbogás (BPI, 2011).

B. Mechanism to Maintain Contractual Equilibrium (CMCE)

As it was seen in the prior section, the PPAs ended before its expiry date. So, it was necessary to create a mechanism that allowed the producers to keep the contractual equilibrium of the PPAs. The created mechanism was the CMCE, which enables the participation of prior power stations subject to the PPAs mechanism in the spot market. Thus, the revenue generated from the market participation of the power plants is equal to the revenue obtained by the application of the PPAs. Hence, according to Conselho de Reguladores do MIBEL (2009), if the market revenue is less than the PPAs revenue, the CMCE will cover the difference between the value obtained in market and the value that would be obtained with the PPAs. The additional cost of the system is supported by the consumers through the tariff for the global use of system. If the market revenue is greater than the PPAs revenue, the additional revenue earned by each power plant would result in a lower cost for the system through the tariff for the global use of system.

It is expected that, about 56% of the installed capacity under the CMCE regime will expire in 2018 and 60% in 2023. It should be noted that EDP holds about 94% of the installed capacity under the CMCE regime, and the Iberdrola holds the remainder 6% (BPI, 2011).

Like the PPAs, the CMCE allows that the producers' market risk be significantly reduced.

C. Power Assurance Mechanisms

The power assurance mechanism is regulated by the governmental order 765/2010, and it allows that electricity generators, who are not covered by the PPAs or the CMCE and which started their activity for less than 10 years, have (BPI, 2011):

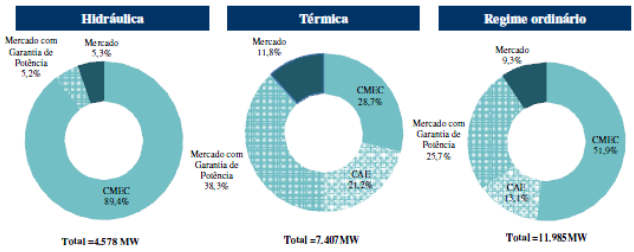
- An adequate matching of demand and supply;
- An appropriate availability of the power stations;
- And, a harmonization of the Iberian regulation, regarding the incentives for investment and the incentives for the availability of power plants.

Therefore, the electricity generators have the right to receive a tariff by the electricity production that is transacted in the liberalized market.

This mechanism will be supported by all consumers through the tariff for the global use of system.

According to figure 9, it is confirmed that only 9.3% of the installed capacity under ordinary regime is subject to the market regime. The remainders 90.7% are distributed by the three payment mechanisms. However, the 65% of the installed capacity under ordinary regime covered by the PPAs or the CMCE mechanisms may be emphasized. Thus, it can be concluded that, the PPAs or the CMCE mechanisms protect the majority of the installed capacity under ordinary regime from the market risk.

Figure 9: Installed Capacity Shares by Payment Mechanisms of the Ordinary Regime in 2010



Source: BPI (2011, pp. 78)

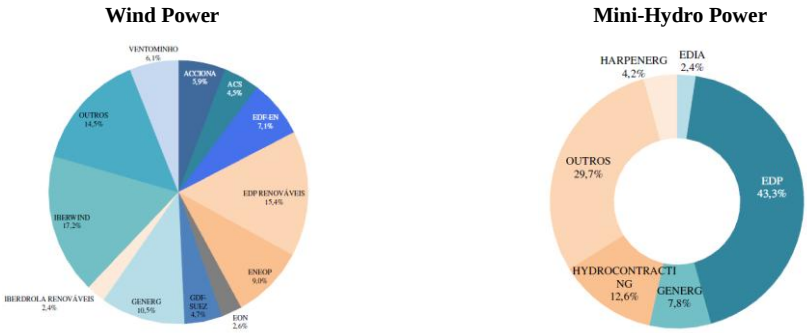
1.4.1.2. Players and Payment Mechanisms in the Special Regime

Due to the importance of the wind and hydro power in the special regime, this subsection will only address the market shares of the agents that act in the market of these two generation technologies.

Analyzing the producers' market shares, it can be concluded that, in terms of the installed capacity, the market concentration level of the special regime is low (see figure 10).

Thus, the Iberwind is the main company acting in the wind power market with a share of 17.2%. Concerning the EDP Renováveis, it is confirmed that 15.4% of the installed capacity under special regime is held by this company.

Figure 10: Wind and Mini-Hydro Installed Capacity by Agent in 2010



Source: BPI (2011, pp. 67, 68)

Regarding the hydro power, the prior figure shows that EDP controls 43.3% of the installed capacity and that Hydrocontracting, the second main player, have a market share of 12.6%.

Like the ordinary regime, the special regime is subject to a payment mechanism with the following features:

- The production of the renewable power stations starts before other technologies and the electricity produced by these plants has priority accessing through the provider of last resort (CUR);
- On the other hand, the energy produced through the renewable power stations is remunerated above the marginal costs of production. The additional cost of

system is supported by all consumers through the tariff for the global use of system.

Having finished the characterization of the Portuguese generation sector, the description of the Spanish generation sector is now possible.

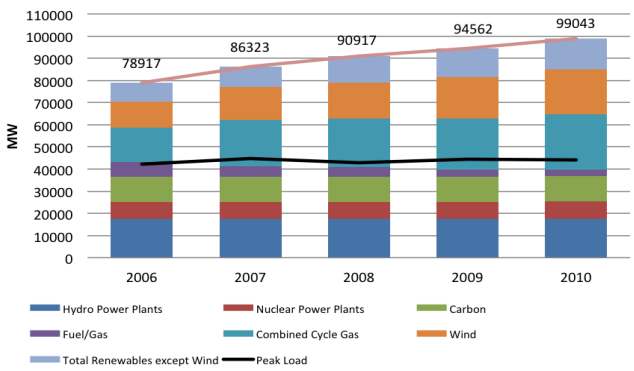
1.4.2. The Generation Sector in Spain

The following figure[7] shows that Spain has had a significant growth in the installed capacity, rising from 78,917 MW in 2006 to 99,043 MW in 2010. In other words, during the 2006-2010 period, the Spanish installed capacity rose about 25%.

On the other hand, the installed capacity under special regime rose 70%. This rise is mainly due to the construction of a new capacity under special regime, namely the wind power. Thus, it is confirmed that installed capacity of wind power increased 74.1%, going from 11,521 MW in 2006 to 20,057 Mw in 2010.

Regarding the installed capacity of CCGT power, it is shown that its contribution has become increasingly important, accounting 25.5% of the total installed capacity in 2010 and 38.9% of the installed capacity under ordinary regime in the same year.

Figure 11: Changes in the Installed Capacity by Technology



Source: elaborated by the author, data from: (REE, 2011)

[7] For more information see Annex 2.

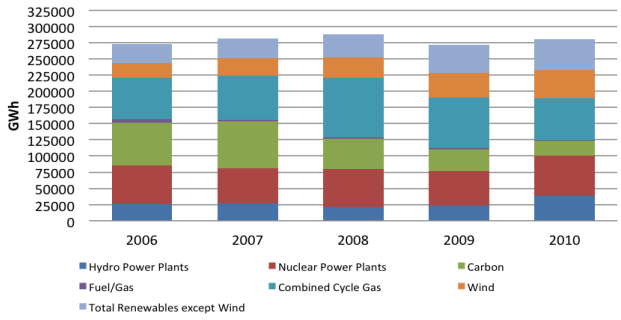
It is also shown that, Spain has reduced its investment in new capacity for fuel-gas power plants, and its installed capacity of carbon power has not had changes in the last years.

Finally, and unlike Portugal, Spain has access to nuclear power to generate electricity. This technology, in 2010, represented 12% of the installed capacity under ordinary regime. However, the changes in the installed capacity of nuclear power have been small.

In terms of the trend of the annual peak load, it is confirmed that the margin between the peak load and the installed capacity under ordinary regime is relatively high, since the peak load represented 68.1% of the installed capacity under ordinary regime in 2010. This was mainly due to weak oscillation of the annual peak load and the growth of the installed capacity (Conselho de Reguladores do MIBEL, 2009).

Regarding the electricity generation, presented in the next figure[8], it is important to note that thermal generation decreased its contribution to power generation under ordinary regime. However, Spain has seen a gradual rise in the percentage represented by the CCGT generation in comparison with the power generation under ordinary regime; this percentage increased from 28.8% in 2006 to 34.2% in 2010.

Figure 12: Changes in the Electricity Generation by Technology



Source: elaborated by the author, data from: (REE, 2011)

On the other hand, it should be noted that wind power significantly increased its contribution to power generation under special regime, reaching 47.7% in 2010.

[8] For more information see Annex 2.

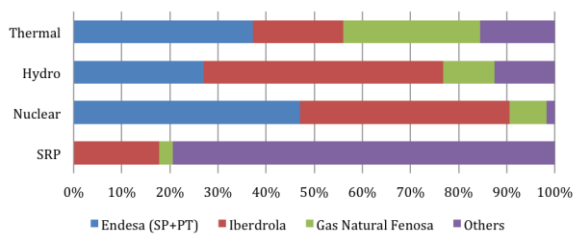
Regarding the hydro power plants, it is important to note that hydro generation has contributed to the power generation under ordinary regime, reaching 20.4% in 2010. Furthermore, the percentage represented by hydro generation in comparison with the whole production is 13.8% in 2010.

1.4.2.1. Players of the Spanish Generation Sector

Due to the lack of available data about the companies' market shares within the generation sector, the next two figures were constructed based on account reports published by the firms[9].

As it can be seen in the next figure [10], Endesa and Iberdrola jointly control a great part of the electricity market. Endesa holds the majority of thermal and nuclear installed capacity. Regarding the hydro and the capacity of production under special regime, Iberdrola has a significant market share. However, in the capacity of production under special regime the presence of other firms is evident.

Figure 13: Breakdown of the Business Groups by Technology in Terms of Capacity (2010)

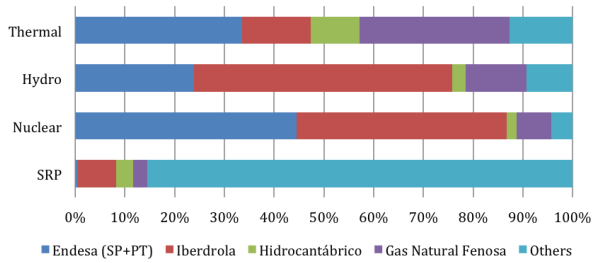


Source: elaborated by the author, data from: (Endesa, 2011: Gas Natural Fenosa, 2011; Iberdrola, 2010)

The next graph[11] shows that, in terms of electricity generation, the changes in the business market shares are similar to the prior graph. However, it should be noted that, in 2010, the *Hidrocantábrico* (an EDP Group company) had a reasonable market share in thermal generation.

[9] It should be noted that Endesa's account reports do not fragment the installed capacity by country. However, in percentage terms, the value aggregation will not be seen, because the weight of the Portuguese installed capacity in the total installed capacity, which belongs to Endesa, is small.
[10] Hidrocantábrico was not included in this graph because it would required harmonizing data between firms. For more information see Annex 2.
[11] For more information see Annex 2.

Figure 14: Breakdown of the Business Groups by Technology in Terms of Generation (2010)



Source: elaborated by the author, data from: (Endesa, 2011; Gas Natural Fenosa, 2011; HC energía, 2010; Iberdrola, 2010)

Under such circumstances, it can be concluded that two Spanish incumbents (Endesa and Iberdrola) jointly control a great part of the installed capacity under ordinary regime. Nevertheless, it is noteworthy that the special regime became significantly less concentrated during the related period.

1.4.2.2. Payment Mechanisms in the Spanish Generation Sector

Currently, the Spanish generators under ordinary or special regime have the right to a mechanisms that supports its electricity production. Notwithstanding, in 2012, the Spanish government has introduced a dramatic change on this current regulatory framework (Couture, 2012). In the ordinary regime, the generators have the right to a payment mechanism called power assurance mechanism. Its functioning was described in section 1.4.1.1., and results from a plan for regulatory harmonization among the countries (Conselho de Reguladores do MIBEL, 2007). However, this regime only applies to the quantities necessary to avoiding system ruptures. These rates are presently being renegotiated, having been considered too high. Concerning the special regime, its production starts before other technologies and the electricity produced by the plants has priority accessing the grid. Like the Portuguese case, electricity production under special regime is remunerated through a tariff, whose value is set above the marginal costs of production. Nevertheless, the Spanish government passed the Royal Decree-Law 1/2012 which states that renewable energy generators will be prevented from receiving the feed-in tariff contracts starting in January 2013.

To summarize, it can be concluded that the structure of the Portuguese and Spanish generation sector is highly concentrated. However, it is expected that this scenario may be altered, since the harmonization of the differences between the two market structures will allow the entry of new firms in both markets.

Having finished the description of MIBEL generation sector, the characterization of its wholesale market is now possible.

1.5. The Wholesale Market

As it was formerly seen, the generation sector is usually associated to a wholesale market since the introduction of the liberalization process in the electrical sector.

The wholesale market aims to open the production to competition and, currently, it comprises four main contract types: a derivatives market, a spot market, an ancillary services market, and a bilateral trading market.

These contract types will not be exhaustively characterized, because this characterization is not relevant for this dissertation. However, regarding the spot market, a later chapter will be dedicated to it, due to its importance for the development of this study.

The MIBEL derivatives market is a regulated market which began its activity on 3rd July 2006. The OMIP [*Operador do Mercado Ibérico de Energia SGMR, S.A* (Iberian Energy Market Operator, Portuguese Side)] is the responsible entity for the management of this market. The derivatives market establishes the future electricity production and the buying commitments. Furthermore, it can allow a physical settlement (energy if delivered) or a financial settlement (compensation of monetary values underlying the trade) (Conselho de Reguladores do MIBEL, 2009). Only the entities entitled to act directly in the derivative market can trade on it. So, they can be the producers under ordinary regime, the providers, and other electrical sector agents. Furthermore, if the other electrical players are recognized as market participants, they can act as dealers (on their own), as brokers (for third parties), or as dealer-brokers (on their own and for third parties) (BPI, 2011).

The MIBEL spot market comprises a day-ahead market and an intraday market. In this market the electricity selling (production) and the buying schedules are established for the day following the trade. This way, it is allowed a meeting point between the demand and the supply of energy. This spot market has worked for the Spanish system since 1st January 1998 and for the Portuguese system since 1st July 2007. The OMEL [*Operador del Mercado Ibérico de Energía, S.A* (Iberian Energy Market Operator, Spanish Side)] is the responsible entity for its management. The entities which act in this market can be the producers under ordinary or special regime, the distributors, the providers, the direct consumers, and the representatives of any the aforementioned participants (Conselho de Reguladores do MIBEL, 2009).

The ancillary services market is the market that allows the existence of a meeting point between demand and the supply of energy, and it operates in real time (Conselho de Reguladores do MIBEL, 2009).

Finally, the bilateral trading market is the place where the agents arrange electricity selling and buying for different time horizons (Conselho de Reguladores do MIBEL, 2009).

Next, the composition of the supply and the demand in the wholesale market will be described. Nevertheless, given the lack of the updated information to characterize the supply and the demand of MIBEL, the data provided in the study prepared by MIBEL Regulatory Council in 2009 will be used, for the period from July 2007 to December 2008.

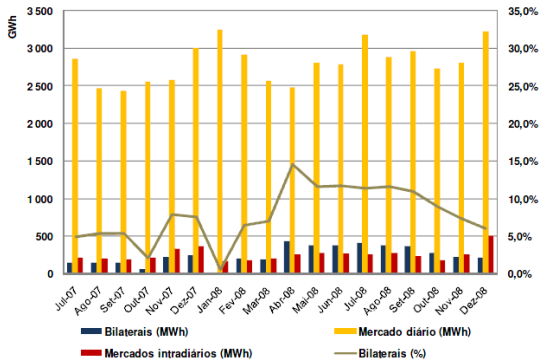
1.5.1. Composition of the Supply

1.5.1.1. The Wholesale Supply in Portugal

As the next figure shows, the majority of the electricity supply is traded on the spot market[12]; the others contract types have a smaller market share.

[12] It should be noted that Portuguese spot trading values include the settlement of future products purchased on derivatives market, as well as, the participation of Portuguese producers in the supply of

Figure 15: Changes in the Portuguese Supply by Market Segment

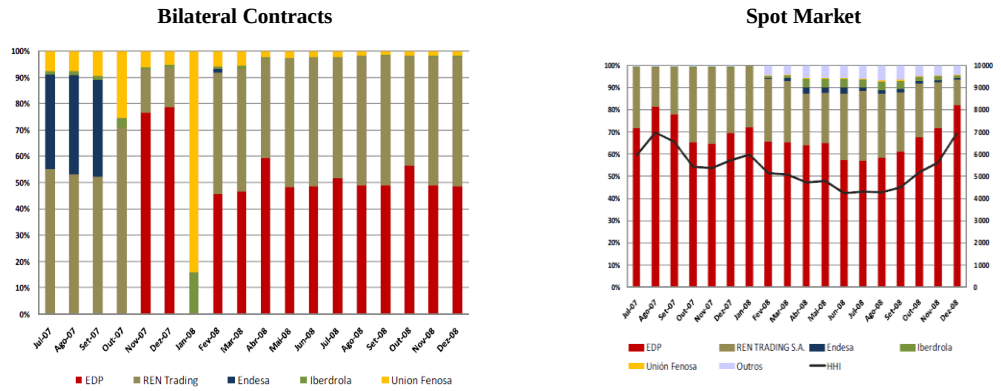


Source: Conselho de Reguladores do MIBEL (2009, pp. 39)

The following figure shows that main companies, which are responsible for the supply in both bilateral contracts market and spot market, are the REN Trading and EDP.

It should be noted that, during the period in question, these two big companies hold the majority of production under ordinary regime. However, probably these values are now different, because two power plants were transferred to Iberdrola, and an Endesa's CCGT plant started to operate (BPI, 2011).

Figure 16: Composition relating to Portuguese Supply in the Bilateral Contracts Market and the Spot Market



Source: Conselho de Reguladores do MIBEL (2009, pp. 40, 41)

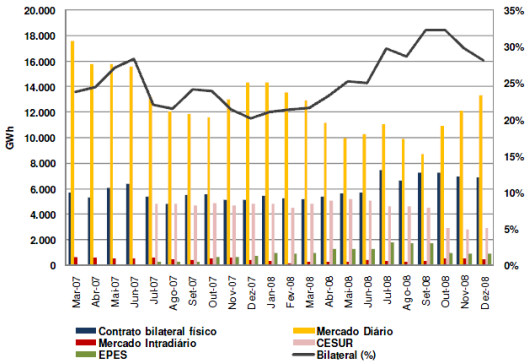
CESUR auctions. The CESUR auctions allow that distribution companies purchase energy to sale to customers, besides purchasing energy on the spot market and the derivatives market. See Conselho de Reguladores do MIBEL (2009) for more information.

Analyzing the Herfindhal-Hirschmann Index (HHI)[13] presented in the spot market graph, it can be concluded that there is a significant business concentration.

1.5.1.2. The Wholesale Supply in Spain

In Spain, it is confirmed that most of the energy supply is traded on the spot market. However, the bilateral contracts transactions increased. This increase is justified by " *(...) the beginning of operations of the OMIP organized derivatives market, the CESUR auctions and the requirement for distributors to purchase part of their energy through these mechanisms for regulated tariff supply"* (Conselho de Reguladores do MIBEL, 2009, pp. 34).

Figure 17: Changes in Spanish Supply by Market Segment

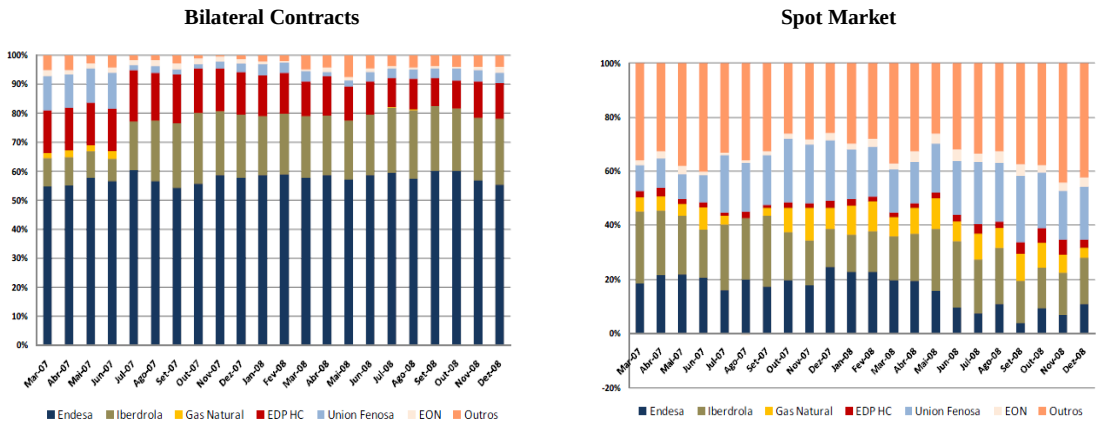


Source: Conselho de Reguladores do MIBEL (2009, pp. 35)

The next figure shows that, while in the bilateral contracts market there is a large market concentration (the Endesa market share is about 60%), in the spot market this concentration is lower, since there are other participants acting in the market (Conselho de Reguladores do MIBEL, 2009).

[13] The HHI is defined as the sum of the squares of market shares of all firms within the market, ranging from 0 (perfect competition) to 10.000 (monopoly). This way, the HHI index measures the size of firms in relation to the industry, due to the amount of competition that exists between them.

Figure 18: Composition relating to Spanish Supply in the Bilateral Contracts Market and the Spot Market



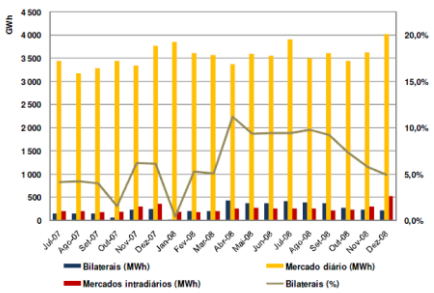
Source: Conselho de Reguladores do MIBEL (2009, pp. 36)

1.5.2. Composition of the Demand

1.5.2.1. The Wholesale Demand in Portugal

Regarding the Portuguese wholesale demand, it can be seen that, like in the wholesale supply graph, the majority of the energy demand is traded on the spot market. Notwithstanding, it is confirmed that demand values in the spot market exceed supply values, because the relationship among demand and supply reflects the existence of interconnections between the countries, where the Portuguese system tends to be the importer. On the other hand, the absence of auctions for the allocation capacity between Portugal and Spain, implies that values for supply and demand are more symmetrical in the bilateral contracts market (Conselho de Reguladores do MIBEL, 2009).

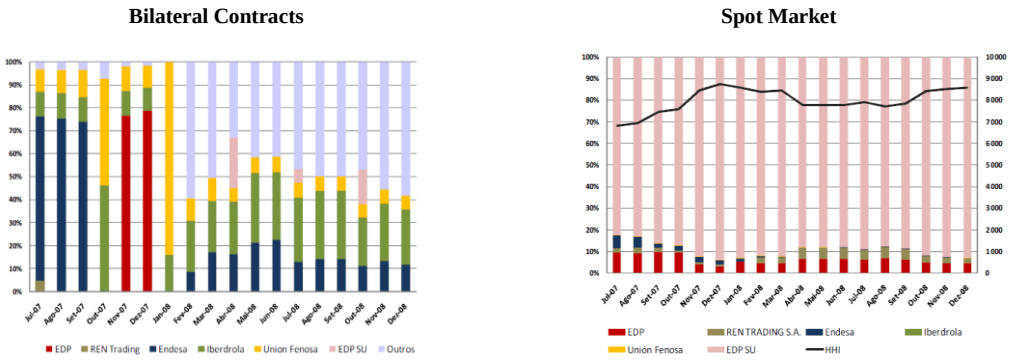
Figure 19: Changes in the Portuguese Demand by Market Segment



Source: Conselho de Reguladores do MIBEL (2009, pp. 47)

Regarding the firms that purchase electricity in MIBEL, the next figure shows that concentration level in the spot market is very high, and that the CUR (EDP *Serviço Universal*) is the main buyer agent. In the bilateral contracts market, this concentration level is not so evident.

Figure 20: Composition relating to the Portuguese Demand in the Bilateral Contracts Market and the Spot Market



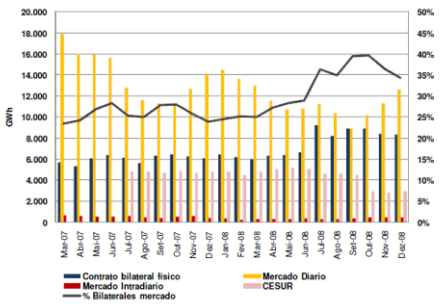
Source: Conselho de Reguladores do MIBEL (2009, pp. 48,49)

Bearing in mind that the majority of the wholesale demand is traded on the spot market, it is important to note that the wholesale demand under special regime is bought by the CUR to producers (Conselho de Reguladores do MIBEL, 2009).

1.5.2.2. The Wholesale Demand in Spain

Like the analysis made for the supply, the Spanish demand shows a similar pattern, where the majority of transactions are realized on the spot market and where the transactions in the bilateral contracts market have increased.

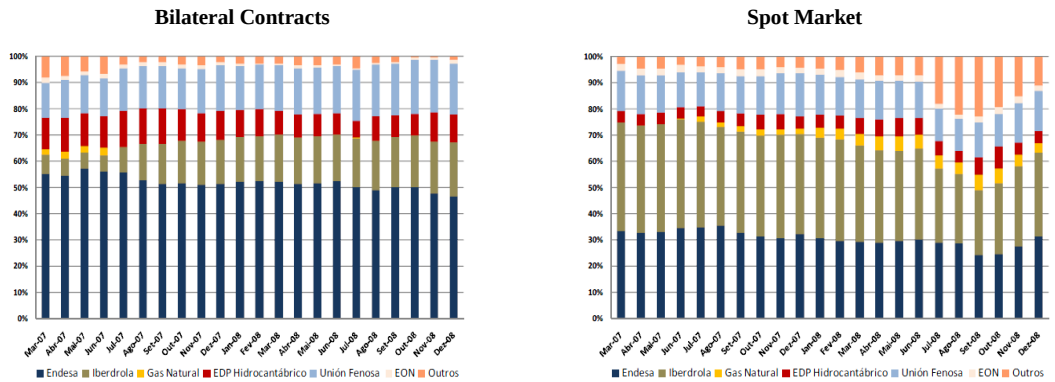
Figure 21: Changes in the Spanish Demand by Market Segment



Source: Conselho de Reguladores do MIBEL (2009, pp. 44)

On the other hand, if the composition of each segment by buyer is analyzed, it can be seen that Endesa has a significant market share in the bilateral contracts segment[14], and Iberdrola and Unión Fenosa are clearly present in the spot market. Thus, it can be concluded that main business groups account for over 60% of demand in both markets (Conselho de Reguladores do MIBEL, 2009).

Figure 22: Composition relating to the Spanish Demand in the Bilateral Contracts Market and the Spot Market



Source: Conselho de Reguladores do MIBEL (2009, pp. 45, 46)

Having this in mind, it can be said that in the Portuguese case the demand and supply market are controlled by EDP Group. In the Spanish case, market concentration is lower because there is a greater presence of other agents in the market, namely in electricity generation under special regime.

1.6. Characterization of the Day-Ahead and Intraday Market

The liberalization process of the electricity market allowed the development of an energy spot market, because it represents an important adjustment mechanism between demanders and suppliers (Newbery, 1998, cited by Castro and Leite, 2008). So, with the aim to characterize the day-ahead and the intraday market, the next section will explore the working of the energy spot market.

[14] It is important to note that bilateral contracts values include the volumes acquired through physical bilateral contracts and VPP auctions. The VPP auctions stipulate that energy producers with the status of dominant operator in the electricity sector must be obliged to offer purchase options for a pre-established amount of their power. Then, some of the remaining market participants can purchase the options during a certain period (EDP, 2009). See Conselho de Reguladores do MIBEL (2009) for more information.

1.6.1. Operation of an Uniform Price Auction

After the liberalization process, the majority of the wholesale electricity markets were organized according to the Uniform Price Auction (UPA) or the Pay-As-Bid Auction (PABA).

On the whole, in a wholesale electricity market, the sellers submit their selling bids and prices for each hour of the day. In the same way, the buyers submit their demand bids. Thereafter, the bids are processed through a matching algorithm.

According to Nogueira *et al.* (2003), the selling bids are ordered by increasing prices and the demand bids are ordered by decreasing prices. This ordering results in two aggregated curves for the supply and demand of energy. Thus, the market clearing price is achieved by the intersection of these curves. In other words, the last accepted selling bid[15] will pay all the selling bids (or all the demand bids) at lower prices. This is the operating base of an UPA market.

According to Caramanis (1982), cited by Marques *et al.* (2008), this kind of markets has, as underlying theory, the spot pricing theory. This theory defends that a day-ahead electricity market can provide an efficient outcome both in the short and in the long term. This happens because the system marginal price[16] will cover the fixed and variable costs of the remaining power plants.

In a PABA market, the sellers are not paid by the system marginal price, but by the price that they offer their production. If the market is competitive, the sellers are paid by the value of their long term marginal costs.

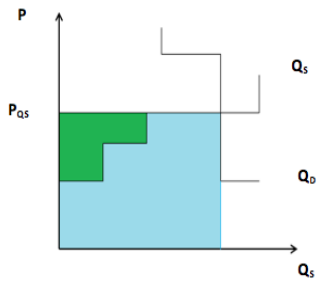
According to Soares and Marques (2009), the producers' income in an UPA market (green and blue area) are higher than the producers' income in a PABA market (blue area), for the same system marginal price (see figure 23). However, this result does not always occur.

According to authors like Kahn, Cramton, Porter, Tabors, cited by Kahn *et al.* (2001) (Marques *et al.*, 2008), the PABA system constitutes an inefficient system because it

[15] The last accepted selling bid is the bid that defines the system marginal price.
[16] The system marginal price is the price defined by a marginal technology with an almost zero fixed cost.

allows producers to increase electricity prices above their marginal costs, in order to cover their fixed costs. Thus, each producer will offer a price close to what they expect to be the system marginal price. Nevertheless, this price rise can result in anti-competitive practices, such as increasing of the barriers to entry, discouragement of new investments, and the less efficient generators produce more while the more efficient ones increase their mark-ups (Soares and Marques, 2009).

Figure 23: The Producers' Income in the UPA and PABA Market



Source: Soares and Marques (2009)

However, bearing in mind the arguments for and against of the both systems, the UPA was the system chosen by the Iberian Electricity Market.

1.6.2. Clearing Price

In a day-ahead market, the producers submit for the following day, on an hourly basis, and sorted by ascending price, the bids for the power supply. This way, the aggregated supply curve[17] for each hour is created.

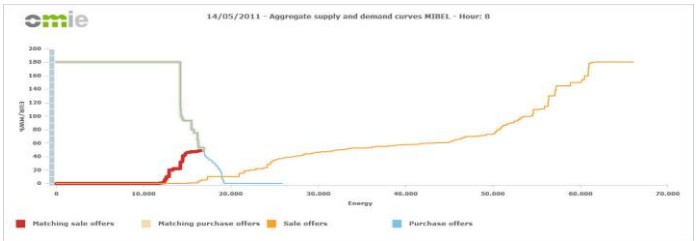
Moreover, the producers may introduce some degree of complexity in their bids, since their power plants have significant start-up costs that cause some constraints of

[17] For the Spanish zone, the nuclear power plants and the PSR usually appear in the lower part of the curve, because their opportunity cost is very low. In the Portuguese zone, the producers under special regime, do not participate in the spot market, due to a legal requirement which force them to sell their production to CUR. This production is incorporated in the demand bids of the CUR, reducing its needs of energy demand. In the middle zone of the curve, there are the CCGT and coal power plants. Regarding the hydroelectric power stations, while the adjustable hydroelectric power stations appear in the upper part of the curve, because their opportunity cost is high, the run-of-river plants usually appear on the lower part of the curve, because they do not have storage capacity. Finally, like the adjustable hydroelectric power stations, the fuel oil power plants appear in the highest end of the curve (Conselho de Reguladores do MIBEL, 2009).

indivisibility. Thus, the first accepted bid is always indivisible, which means that the buyer accepts the total quantity of energy and not just a part of it (Conselho de Reguladores do MIBEL, 2009).

After the market operator has established the economic precedence order of the sell bids, it will submit for the following day, on an hourly basis and sorted by descending price, the accepted bids for the power demand. Thus, the aggregated demand curve[18], for each hour, is created. Then, the market operator crosses the hourly sale (orange line) and purchase curve (blue line). In other words, the market operator matches the purchase and sale bids. The market equilibrium price arises from this intersection, as it can be seen by the following figure. It should be noted that the bid is only accepted if the price submitted by the generator is equal to or lower than the system marginal price. Moreover, the clearing price corresponds to the sell bid for the last production unit which is necessary to satisfy the energy needs.

Figure 24: Price in the Day-Ahead Market Hour 8 – 14/05/2011 of MIBEL



Source: OMIE (2012)

However, by the application of complex conditions in the sale units, some of them are eliminated from the clearing process. In this case, the market equilibrium price is given by the intersection between the red line and the blue line.

With respect to <u>intraday market,</u> we can say that its goal is to provide a match between supply and demand in real time. This way, the agents can correct their previous positions, since the producers can buy energy and the providers can sell it. Therefore,

[18] It should be noted that, the regulated suppliers demand appears in the upper part of the curve and they have been submitted to an instrumental price (180€ per MW), since 1st January 2007. This price includes the price obtained in the day-ahead market and a subsidy given to electricity renewable production – the tariffs feed-in. The middle and lower part of the curve includes the consumption of the pumping stations and the providers for their supply in the free market. Unlike supply bids, demand bids cannot incorporate complex conditions (Conselho de Reguladores do MIBEL, 2009).

the intraday market can provide a high level of flexibility for the agents. Thus, according to with the needs of each market participant, the agents can optimize their electrical portfolio.

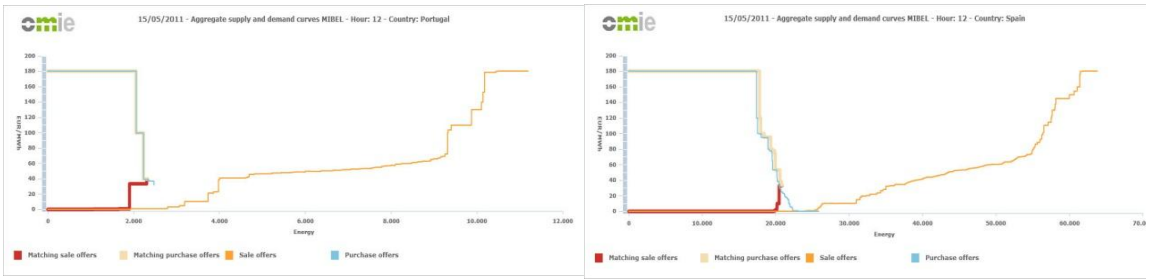
1.6.3. Market Splitting

In the former figure, it is possible to see an hour in which there was a single price for the whole MIBEL. However, this does not always occur. There are two possible situations that can result from the supply bid clearing process (Conselho de Reguladores do MIBEL, 2009):

a) When we match the demand and the supply bids, and if there is traffic, in the same direction, in the interconnection that is less than or equal to the available commercial capacity, the equilibrium price is the same for the Iberian system;
b) When we match the bids, and if there is traffic in the interconnection, in the same direction, that is greater than the available commercial capacity, the two areas are treated separately.

In this last situation, each country will define their supply and demand aggregated curves and the clearing prices for both two zones are determined by the intersection of these curves. This situation is referred to as market splitting and it is represented in the following figure.

Figure 25: Price in the Day-Ahead Market Hour 12 – 15/05/2011 in Portugal and Spain

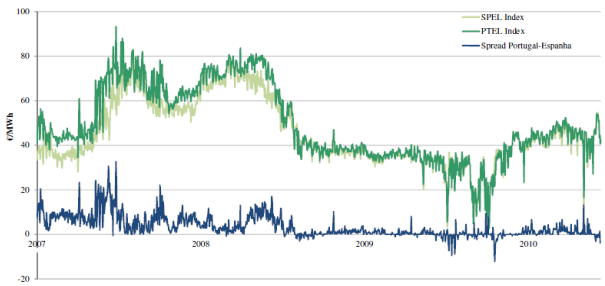


Source: OMIE (2012)

The prior figure shows that, in terms of merit order[19], the marginal technology in Spain is more efficient than in Portugal, because Spain can produce about 20.000 MW of energy using the nuclear and renewable power stations.

When the next figure is analyzed, the following conclusion can be drawn: the market splitting mechanism has prevailed, since the Portuguese price is greater than the Spanish one in 77% of the observations. However, it is important to note that spread has decreased, due to technological convergence between the countries, the joint production of the CCGT power plants, and the growth of production under special regime in the two countries, in similar proportions. (BPI, 2011)

Figure 26: Changes in the Arithmetic Average Price of the Day-Ahead Market in the Spanish and Portuguese Area together with Portugal-Spain Spread



Source: BPI (2011, pp. 132)

Having this in mind, it can be concluded that MIBEL is a very concentrated electricity market where the incumbents have a great market power. For the Portuguese market, this affirmation is very clear. However, it is expected that, with maturing and liberalization, this concentration and market power will be reduced.

It was also seen that production under special regime has had a significant growth, both in terms of installed capacity and electricity generation. In this respect, the wind power has had much influence. On the other hand, the CCGT and hydro power generation have a good share on the whole of the electricity generation.

[19] The energy merit order is used to organize into hierarchy the available sources of energy in ascending order of their short term marginal costs of production. This way, the power stations with the lowest marginal costs are the first ones to start to operate and the power plants with the highest marginal costs are the last ones to start the electricity production.

These are the two great motives to study the impact of wind power on the generation mix. The main objective will be analyzing if the introduction of renewable energy sources, such as wind power, will decrease the installed capacity of conventional power, as the hydro, nuclear and thermal power. This question will be addressed in the next chapter, where the importance of wind power in a global level is explained, a literature survey is made, the main models to analyze the question are presented and the chosen model is developed.

2. Analysis of the Impact of Wind Power on Generation Capacity Mix

In the last decades, the problem of global warming and climate change has dominated the public policy debates. Indeed, the growing awareness of populations about this question has led to the adoption by governments of several measures that reduce the consumption of fossil fuels.

The adoption of the Kyoto Protocol allowed the creation of policies that encourage the use of renewable energy sources, by the countries that ratified it. However, the Protocol is ending and its future is unclear. The problem is that, without the Protocol the major polluting countries do not have incentives in cutting their greenhouse gas emissions. Notwithstanding, the principles, which created the Protocol, need to be prevailed for the sake of humanity. In this sense, developed and developing countries have organized several summits to reach a consensus about the renewal of the Protocol. In the Copenhagen climate change conference (2009), the participants created the Copenhagen Accord where it was determined that the increase in global temperature should be below 2ºC[1]. On the other hand, the rich countries agreed to cut their emissions until 2020, but these pledges were not incorporated in the United Nations (UN) documentation. Regarding the decisions about the future of the Kyoto Protocol, they were postponed until the next conference.

In 2010, the Cancun climate change conference incorporated the previous pledges into the UN document with the assumption that the pledges may increase or decrease in the future. However, the renewal of the Kyoto Protocol was again deferred, and Russia pulled out of the Protocol. In spite of everything, the developing countries agreed to cut their greenhouse gas emissions, but the value of the decrease is not identified.

The last climate change conference took place in Durban (2011), and though Canada has decided to pull out of the agreement; China and the USA – the major greenhouse gas emitters – agreed to cut their emissions. Regarding the future of the Kyoto Protocol,

[1] According to *The Guardian*, this value *"will disappoint the 100-plus nations who wanted a lower maximum of 1.5ºC, including many small island states who fear that even at this level their homes may be submerged"* (The Guardian, 2009).

the negotiators agreed to create a new climate deal that needs to be approved by 2015 and come into force from 2020 on. This agreement will have legal force, so both developed and developing countries will have to cut their emissions. However, this new agreement is just a proposal. Although it is not an optimal solution, it is a pledge that something will be done.

Nevertheless, the EU has developed efforts to guarantee that objectives imposed by the Protocol and the summits be reached and even exceeded. Thus, the 2009/28/EC[2] Directive established a common framework for the production and promotion of renewable energy sources. According to the Directive, each Member State must design national action plans. These action plans will define the measures that will allow each country to reach the national overall target for the share of energy from renewable energy sources in gross final consumption of energy, in 2020. For Portugal and Spain, the target is 31% and 20%, respectively (Parlamento Europeu and Conselho Europeu, 2009a).

To achieve this goal, wind power develops an important role. In the first place, wind power is a clean technology because it captures the energy from natural forces, and in doing so, it becomes an emissions-free power generation technology. Actually, wind generation technology is mature and it is widely spread in the market. The price of the fuel needed to operate a wind turbine is zero and wind power is already a competitive technology when compared with new-built conventional technologies. In the second place, as the global demand for energy is increasing, the security of supply became a first priority problem to be solved. This means that, significant investments in new power generation capacity will be needed in the next years. Thus, wind energy will have a huge importance in this field, as it is more or less available as everywhere in the world. Finally, the governments have given financial support to increase the installed capacity of wind power.

[2] The directive is in line with the overall "20-20-20" goal for the Community, which was created because the need to increase the energy efficiency of Member States. So, the EC has the objective to save 20% of the Union's primary energy consumption and greenhouse gas emissions, and the inclusion of 20% of renewable sources in energy consumption until 2020 (Europa, 2009).

On the other hand, it is confirmed that wind power is one of the fastest growing renewable energy source, both at world and Iberian level. Globally and during 2006-2010 period, the annual average growth rate of installed capacity of wind power was 26.37% (GWEC, 2011). This rate was very influenced by the strong growth of the wind power in Asia. When we analyze the same rate for the Iberian Peninsula in the same period, we conclude that the annual average growth rate of installed capacity of wind power reached 25.01% in Portugal and 14.87% in Spain. These values are only exceeded by the photovoltaic power in Portugal (232.35%) and thermal solar power in Spain (180.61%), due to governmental support programs assigned to these kinds of renewable energies. It should be noted that, in 2006, the installed capacity of these energy sources was almost nonexistent.

However, if both countries obey to their national actions plans to reach the target, it is expected that the installed capacity of wind power will reach 8,500 MW and 37,750 MW for Portugal and Spain, respectively, in 2020 (DGEG, 2012; IDAE, 2011; República Portuguesa, 2009). This increase in the installed capacity of wind power will allow that, in 10 years, wind power will grow 129.42% in Portugal and 88.21% in Spain. Hence, it is confirmed that wind power can become the major renewable energy, when compared with other renewable energy sources.

Thus, the increase of wind power as an electricity production technology leads us to the following question: What is the effect of renewable energy sources, such as wind power, on generation capacity mix? This question is the core of the present dissertation and it will be explored in the next sections.

2.1. The Impact of Renewable Energy Sources on the Generation Capacity Mix: a Literature Survey

Regarding the impact of renewable energy sources on the generation capacity mix, there is a gap in the literature. Indeed, the literature on wind power says little about how this power source may affect the generation capacity mix. This way, as the main objective

of this dissertation is to fill this shortcoming and answer to the prior research question, the literature survey will only focus on the articles that address this specific issue.

Some recent studies have started to approach this topic, as there are serious concerns either on the way electricity power planning will change and how the management of the electricity system will be changed.

The research question has been approached in two ways: some studies use the idea of the credit concept and others use the screening curve method. However, there is a set of studies that use other methods to address the same question. The different ways to address the problem will be explained below.

A. The Capacity Credit Concept

Since wind power is an intermittent energy, its output can vary drastically from day to day and along the 24 hours of a single day. Thus, to ensure the security of supply, total substitution of conventional power plants by wind turbines is improbable (Weigt, 2009b). Nevertheless, it is possible to achieve a safe reduction in the installed capacity of conventional power with a sufficient increase in the installed capacity of wind power. This gain in capacity reduction is usually called capacity credit.

One of the main authors to look into this matter was Giebel (2005), cited by Weigt (2009b). He published a report that brought together several studies about wind power's capacity credit, and he concludes that the capacity credit obtained is strongly dependent on the electricity system, wind load factors, and the penetration level.

Strbac *et al.* (2007), developed a study which explores the costs and benefits of integrating wind power into the UK electricity market. The analysis concludes that wind generation only replaces a relatively small amount of conventional capacity. Thus, it is necessary to preserve a significant proportion of conventional capacity to ensure the security of supply.

Oswald *et al.* (2008), developed a model that analyzed the dynamic behavior, the volatility and the implications of 25 GW of wind on the UK power system. They conclude that, given wind power is a volatile power source, the electrical system will need to maintain the fossil fuel plants to handle peak demand. Therefore, the ability of

wind power capacity to replace fossil power capacity may be compromised, namely in peak demand situations.

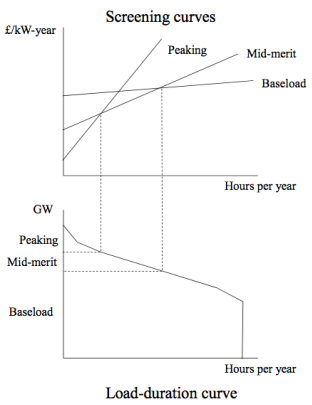
Østergaard (2008), analyzed the geographic aggregation of wind power in Denmark, and he concluded that it reduced the reserve capacity.

Finally, Weigt (2009b), sought to analyze the reserve capacity and the impact of wind power on generation costs and market price in Germany. Regarding capacity replacement potential, and in accordance with the conclusions of all the referenced studies, the author concluded that an increase in the installed capacity of wind power does not allow for a significant reduction of the installed capacity of conventional power.

B. The Screening Curve Methodology

Another way to address the impact of wind power on the generation capacity mix is to apply the screening curve methodology, which is designed to determine the optimal baseload, intermediate and peaking capacities, and the system costs. This method is well explained in Lamont (2008). According to the author, an optimization problem is used to minimize the total generation cost and, simultaneously, to satisfy the loads in each hour. The next figure summarizes the optimization problem.

Figure 27: The Derivation of Optimal Capacity



Source: Green and Vasilakos, (2011, pp. 4)

It should be noted that, the load-duration curve presented in the prior figure shows the cumulative probability distribution over system loads during the year (Lamont, 2008).

The main problem is to discover the optimal capacity of the intermittent technologies, since determining the optimal capacities of the other technologies is relatively simple. The trick is to consider them a negative load, i.e., subtract *"the generation of a given intermittent capacity from the load in each hour to obtain a residual load for each hour"* (Lamont, 2008, pp. 1210). Thus, the screening curve methodology can be applied through the construction of the load-duration curve for the residual loads. After that, the non-intermittent optimal capacity that matches the residual load will be determined. However, this analysis does not directly determine the intermittent optimal capacity.

The author uses this metod to show how the optimal capacity of non-intermitent technologies changes when the intermittent technologies are added to the California electricity system. To that end, he uses a long-term model of theoretical equations to obtain the marginal costs of an intermittent technology as a function of its capacity factor and based on the screening curve methodology. He finds that, in the long-term, the introduction of intermittent technologies will reduce the non-intermittent component of baseload capacity.

Sáenz de Miera *et al.* (2008), applied a simulation analysis to study the impact of the introduction of wind energy on wholesale market prices in Spain. They use the previous method to determine the optimal capacities for each considered technology. The authors state that, there is a reduction of residual thermal demand when wind power is introduced, due to a shift down and to the left of the electricity demand curve. In turn, this alteration reduces the need for thermal power plants, because the baseload technologies operate longer than mid and peaking load technologies. Usaola *et al.* (2009), add to the previous analysis and conclude that when wind power is introduced on the system, energy prices will not change in the long-term, but its inclusion will modify the optimal generation mix.

Green and Vasilakos (2011), used the concept of screening curves to make a market equilibrium model to analyse the changes of an introduction of large amounts of intermittent generation in the capacity mix. Regarding wind's impact on generation capacity, the authors find that the changes in the capacity mix are much greater than the changes in the electricity prices.

Recently, De Jonghe *et al.* (2011), concluded that the baseload capacities are replaced by mid-load capacities when there is a high penetration of wind power in the electrical system. To achieve this conclusion, a linear programming investment planning model based on screening curve method was developed.

C. Other Studies

Nevertheless, there are studies that do not use the concepts of capacity credit and the screening curve. Notwithstanding, they arrive at similar conclusions. One such study was undertaken by Rosen *et al.* (2007). They developed long and short-term models to estimate the effects of wind power in Germany, and they showed that the introduction of wind replaced conventional, mainly in base-load and intermediate-load production.

In Bushnell (2010), the author used an equilibrium model of generating investment to study how the introduction of intermittent generation, such as wind power, would change investment in conventional thermal generation. He concluded that, in equilibrium, the amount of coal-fired base load production decreases when wind is introduced in the generation capacity mix.

In a recent publication, Chao (2011), developed a simulation study to assessment renewable energy strategy and alternative pricing mechanisms through an updated economic model of pricing and investment in a restructured electricity market. He concluded that "*the wind generation capacity generally substitutes the investment in combined cycle GT capacity but complements the investment in gas turbine units"* (Chao, 2011, pp. 3951).

Brand and Zingerle (2011), applied a linear electricity market optimization model to analyze the impacts of the national renewable energy goals[3] on a regional electricity market formed by the three Maghreb countries and adjacent EU countries. They showed that renewable energy sources – wind and solar, in this case – replaces approximately

[3] The Moroccan government defined its renewable energy goal for wind power to be an increase from the current 253 MW to 2 GW by 2016. Regarding solar power and photovoltaic, installed capacity is expected to reach 2 GW by 2020 and 150 MW by 2015, respectively. Algeria's renewable energy goal is 5% of production by 2017. By 2030, the Algerian government expects that 20% of total electricity generation will be produced by renewable energy, of which 70% is to be solar power, 20% wind power and 10% photovoltaic. Finally, the Tunisian government aims to have 120 MW of solar and photovoltaic installed capacity added to the system by 2016. With regard to wind power, it is expected that 1200 MW and 1800 MW shall be brought onto to grid by 2020 and 2030, respectively (Brand and Zingerle, 2011).

20% of fossil fuel generation, if the Maghreb countries met their respective targets to integrate renewable energy into their electricity markets by 2025.

On the other hand, several authors like Short *et al.* (2003), Bouzguenda and Rahman (1993), Hirst and Hild (2004), cited by Lamont (2008), also drew interesting conclusions. They argue that the marginal benefit from the introduction of wind power in the electrical system decreases as more capacity is added, but they not explain why this happens. However, while Grub (1988, 1991), and Kelly and Weinberg (1993), also cited by Lamont (2008) find the same result, but they explain that the decline in marginal cost occurs because the intermittent technologies begin to displace the lower cost power plants. Thereafter, they contribute less and less to the system.

From this collection of papers we can draw the broad conclusion that, one way or another, whether to a greater or lesser extent, the introduction of renewable energies replaces conventional technologies. Nevertheless, all the studies are very static in their approach. They do not take into consideration the factors that affect wind output, like the costs associated to capacity construction of the renewable energy source and uncertain demand after capacity construction, which can influence the level of adoption of intermittent and conventional technologies. To address this shortcoming, Milstein and Tishler (2009), developed a dynamic two-stage game, where in the first stage the producers built the generation capacity that maximized their expected profit; and in the second stage the output is determined, where the market equilibrium ensures that market demand does not exceed the installed capacity. This model has as its main goal to assess the effect of the introduction of different generation technologies on the generation capacity mix and market prices. On the one hand, this work is an extension of the article published by Tishler *et al.* (2008), where the authors only use one generation technology. One the other hand, the study is the predecessor of the work of Milstein and Tishler (2011), which combine the methodologies used in the previous articles to analyze the impact of intermittent technologies on the generation capacity mix, using more than one generation technology. Generally, the last two articles, Milstein and Tishler (2009) and Milstein and Tishler (2011), conclude that the introduction of generation technologies with lower marginal costs on the generation capacity mix will decrease the investment in generation technologies with higher marginal costs. This

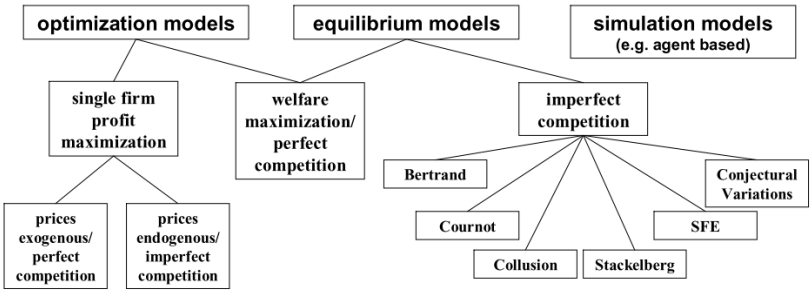
result is valid when the number of firms, which act in the market, increases, and when the capacity costs of generation technology with lower marginal costs decrease. These three articles of Milstein and Tishler will serve as the basis for the formulation of the model that will address the research question.

The next section describes the different models, which can be applied to electricity oligopoly markets[4].

2.2. Modeling Oligopoly Equilibrium

According to Ventosa *et al.* (2005), cited by Weigt (2009a), three types of models can be used to study the electricity markets: optimization, equilibrium, and simulation models. Moreover, these models can be subdivided into perfect or imperfect competition (figure 28).

Figure 28: Classification of Different Models



Source: Weigt (2009a, pp. 25)

Optimization models aim to maximize or to minimize a specific objective: a single firm's profit, subject to technical or economic constraints; besides, they allow the study of the whole market through welfare maximization or cost-minimizing approaches. The

[4] At the beginning, the companies, which were responsible for satisfying all electricity market's demand, were vertically integrated and were state-owned monopolies. The investments required to operate in an electricity market were too high and irreversible, which acted as a natural barrier for the entry of new firms. This way, as we were in the presence of a monopoly, the market competition was almost nonexistent; which increased the incumbents' market power. But in a long term, the consumers will be harmed, because the prices charged by the incumbents were high and the quality of the service was poor. Due to these weaknesses, this market structure was criticized and thus, the liberalization process of the electricity market started. Then, the segments of the value chain were open to competition and new firms entered the electricity market. Therefore, nowadays we can say that, the electricity market is an oligopoly due to small number of firms that control it.

main advantage of these models is their capacity to use large-scale basis under several restrictions. Notwithstanding, the model's capacity is compromised, because pursuing a single objective makes the exploration of all market behavior difficult to achieve (Weigt, 2009a).

Another type of models used to analyze electricity markets models are the equilibrium models. These models allow us to study market situations where there are several players in imperfect market setting. This way, the different players' strategic behaviors can range from the classic models of Bertrand and Cournot competition to sophisticate mathematical models like Supply Function Equilibrium (SFE) model. In these models, if there is a solution, it satisfies the Nash equilibrium condition. Therefore, the market participants will not change their decision, because they are playing their best strategy. Through this model, we can address several market players' profit maximization simultaneously.

Finally, we can have Simulation Models. These models are usually applied if the problem becomes too complex to use the equilibrium models. Normally, the type of models commonly used is the agent-based model, because it can bridge the fact that market participants base their decisions on historic information. Equilibrium models cannot do that (Weigt, 2009a).

In the case of the electricity market, perfect competition is far from being a reasonable assumption. As mentioned in Chapter 1, MIBEL is controlled by a small group of firms where market power is strong. Therefore, it can be proved that the Iberian Electricity Market is an oligopoly, and the models that should be applied are the oligopoly equilibrium models, which are subject to imperfect competition.

Normally, three types of equilibrium models are frequently used to study electricity oligopoly markets: Cournot, Bertrand and SFE (Borenstein and Bushnell, 1998; Green, 2004; Klemperer and Meyer, 1989; Rubin, 2010; Weigt, 2009a).

In the Cournot model the decision variable is the quantity. Hence, each firm competes on the amount of output that they will produce and therefore, the producers will decide how much of their capacity will be put on market in each period (Green, 2004). The quantities of its rivals are taken as given.

Regarding the Bertrand model, this type of model is developed when the decision variable is the price. This way, if there is a Bertrand competition in the market, the firm sets its price below its rival, and it will become the only supplier of the market.

Finally, the SFE model[5] does not use the prices or quantities as decision variables. According to this model, each firm chooses, as its strategy, a supply function that relates the prices with quantities. Thus, the supply function, as a firm's decision variable, allows the firm to adapt better to the uncertain environment.

The firms are subject to decisions about the size and the structure of the organization, its culture and values, and decision rules for its workers. These decisions usually influence the supply function, which relates the quantity that the firm will sell with the price that the market will bear. Hence, only with a SFE model, and given the competitors' behavior, a firm can adjust the market uncertainty environment in an optimal way.

In the electricity market, the utilization of these models is justified by the fact that the majority of the wholesale markets are organized according to the UPA. In this market organization, the last accepted selling bid is the bid that defines the system marginal price, and it will pay all the selling bids at lower prices. Hence, the operation of an electricity market resembles a repeated game, which occurs every hour. This way, as the SFE model can incorporate the suppliers' bids in its supply function, it describes much better the market's behavior than the Cournot or the Bertrand models do (Rubin, 2010). However, this kind of models is very complex and the solutions are not always found. One the other hand, it should be noted that, the SFE models study the collusive behaviors in the spot market better than other subjects.

Bearing the previous explanation in mind, the SFE models will be left aside and it will only be justified if the electricity market is an oligopoly that works under the Cournot or the Bertrand models.

According to Borenstein and Bushnell (1998) the Cournot model seems to correspond to electricity markets much more closer than the Bertrand model. The justification for the statement is given by the following transcript: "*The Bertrand equilibrium is*

[5] The SFE model was developed by Klemperer and Meyer (1989) and it was used, for the first time for the electricity markets, in Green and Newbery (1992).

supported by the assumption that any firm can capture the entire market by pricing below others and can expand output to meet such demand. Since firms have increasing marginal costs of producing electricity at a point in time and since generation capacities present significant constraints in electricity markets, an assumption of Bertrand behavior is not tenable. Capacity constraints on generation are significant in both the medium-term – based upon investments in construction of new capacity – and the short-term, in which plants are rendered "unavailable" due to maintenance and other reliability considerations" (Borenstein and Bushnell, 1998, pp. 5).

With this in mind, the Cournot model will be adopted as oligopoly equilibrium model.

2.3. The Model

Following the methodology used in Milstein and Tishler (2009)[6], two types of generating technologies will be considered: wind power, to be denoted **W**, and conventional technologies, to be denoted **C**. In the Portuguese case, the conventional technology includes thermal and large hydro. In the Spanish case, we must add the nuclear power.

Before the description of the model, two notes will be needed. First of all, as it was seen in subsection 1.6.3, MIBEL works under market splitting scheme most of the times. This way, and for the sake of simplification, the Portuguese and Spanish markets will be analyzed separately. On the other hand, as the only difference in the model of the two markets is the composition of the conventional technology, the following equations presented will describe both markets.

Other assumptions of the model are that the wholesale generation market works as an oligopoly, it is deregulated[7], and it only comprises the MIBEL spot market. For the sake

[6] The article developed by Milstein and Tishler (2011) is more appropriate to address the research question of this dissertation, because the authors include in their study the intermittency of the renewable energy. However, the complexity of the model, the lack of information, and the lack of resources, forced the choice of a simpler model. This way, the present section will describe the model used in Milstein and Tishler (2009).

[7] In the MIBEL case, it should be noted that there is some state supports to electricity generation (for more information see sub-chapter 1.4), and in the Portuguese case, the electricity produced under special

of simplicity, the spot market only encompasses the day-ahead market, because the share of intraday market in the total transactions of the spot market is small. Therefore, it may be disregarded.

The considered market comprises N identical firms that employ both technologies and they purchase all the electricity needed to satisfy the daily demand in the spot market. Each firm will build generating capacity, which is then used to generate and sell electricity for a horizon of T days. Regarding this horizon, and as assumed in the article, it will be of 365 days (one year).

The daily electricity demand is given for a typical Cournot demand function:

$$P_t = a - bQ_t + \varepsilon_t \tag{2.1}$$

And, the electricity price and output on day t are represented by P_t and Q_t, respectively, where Q_t is given by:

$$Q_t = \sum_{i=1}^{N} (Q_{it}^{W} + Q_{it}^{C}) \tag{2.2}$$

Regarding parameters a and b, they are positive known constants ($a > 0, b > 0$), and the parameter ε_t is a random variable that contains all those which are not explicit in the model but that may affect prices, like weather for example. This way, we can define ε_t as a random variable that measures the effect of presence or absence of wind under the daily electricity demand. These conditions are revealed to producers on day t. On the other hand, this random variable is associated to $f(\varepsilon_t)$ - the probability density function of ε_t – which is known by the firms when they choose their capacity. It is also assumed that the availability of wind and ε_t are independent, reflecting the assumption that demand is driven by temperature, much less so by daily wind conditions, i.e., the demand for electricity only depends on the variation of temperature. Finally, it is also assumed that $E\ (\varepsilon_t) = 0$ and $Var\ (\varepsilon_t) = \sigma^2$.

regime does not enter in the spot market. Thus, the generators are protected, to a certain extent, against the market risk of an liberalized market.

Regarding the total production costs, the annual production cost of *i*-th firm employing wind or conventional technology (using a generator K_i^W or K_i^C MW of capacity) can be defined as:

$$C_i(K_i^W, Q_i^W) = \theta^W K_i^W + c^W Q_i^W \tag{2.3}$$

$$C_i(K_i^C, Q_i^C) = \theta^C K_i^C + c^C Q_i^C \tag{2.4}$$

Note that, Q_i^W and Q_i^C give us the annual wind and conventional production by firm *i*, respectively, and its formula is:

$$Q_i^W = \sum_{i=1}^{T} Q_{it}^W \tag{2.5}$$

$$Q_i^C = \sum_{i=1}^{T} Q_{it}^C \tag{2.6}$$

Finally, the terms θ^W (θ^C) and c^W (c^C) denote the capacity cost in €/MW-year and the marginal cost in €/MWh for technology W (technology C). As the wind technology exhibit high capacity costs and zero marginal costs and the conventional technology have low capacity costs and high marginal costs, it will be assumed that $c^C \gg c^W \cong 0$, and $\theta^C < \theta^W$. The parameters c^C, c^W, θ^C and θ^W are known constants and $c^W < a + \varepsilon_t$[8].

The decision process of the market players is made in a two-stage game, as follows:

- **Stage 1:** each of the *N* firms decides on its capacity investment (K_i^W and K_i^C), so as to maximize its expected profits over T days. The capacities of the other *N-1* firms, the probability function of ε_t, and wind conditions are taken as given.
- **Stage 2:** as the firms have information about the parameter ε_t and wind conditions on day *t*, each firm will decide how much quantity of electricity will be produced, so that its daily operating profit be maximized. As the

[8] This assumption is commonly assumed when it sets the Cournot model. For more information see Gibbons (1992).

firms' decision is based in the Cournot conjecture, the quantity produced by the other *N-1* firms and the capacity of all *N* firms are taken as given. This stage is repeated *T* independent times.

To solve this two-stage game and find the subgame-perfect Nash equilibrium[9], the backward induction is used. This way, the second stage of the game is solved in the first place, and then, the obtained solutions (the reaction functions[10]) are used to solve the first stage of the game.

In our case, the daily electricity production of each firm is obtained by solving the operating profit maximization problem of the *i*-th firm in stage 2, conditional on ε_t, and it is given by:

$$\begin{aligned} &\max_{Q_{it}^C, Q_{it}^W} \pi_{it} = (P_t - c^C)Q_{it}^C + (P_t - c^W)Q_{it}^W \\ &\quad s.t.\ Q_{it}^C \leq K_i^C, Q_{it}^W \leq K_i^W \\ &\quad\quad Q_{it}^C \geq 0,\ Q_{it}^W \geq 0 \\ &\quad\quad i = 1,\ldots,N \end{aligned} \tag{2.7}$$

When the solutions of the second-stage are found, the optimal capacities can be determined; the *i*-th firm uses the second-stage reaction functions to solve the profit maximization problem of stage 1, given by:

$$\max_{K_i^C, K_i^W} E\left[\sum_{t=1}^{T} (\pi_{it} | K_i^C, K_i^W)\right] - \theta^C K_i^C - \theta^W K_i^W, \qquad i = 1, \ldots, N \tag{2.8}$$

[9] According to Gibbons (1992), the Nash equilibrium assumes that each player plays his best response, given the conjecture that it has about the other players' strategies. However, when we have a dynamic game with imperfect competition, we must define the concept of subgame-perfect Nash equilibrium. Thus, Selten (1965) says that *"a Nash equilibrium is subgame-perfect if the players' strategies constitute a Nash equilibrium in every subgame"* (Gibbons, 1992, pp. 124), i.e., if each player plays his best response in every subgame.

[10] The reaction function gives us the best strategy for each firm *i*, given the conjecture that the firm was formed on the rivals' strategies.

2.3.1. The Theoretical Formulation of Optimal Solutions

As mentioned above, to solve this two-stage game the backward induction method is needed.

Beginning with the second-stage maximization problem, described by equation (2.7), the optimal solutions are shown in Milstein and Tishler (2009).

The authors solve the maximization problem using Karush-Kuhn-Tucker (KKT) formulation, because the maximization problem involves inequality constraints and a set of nonnegativity constraints. When this happens, the KKT conditions are usually used to solve the problem (Simon and Blume, 1994).

To do so, the Lagrangian must be defined:

$$L\,(Q_{it}^{C}, Q_{it}^{W}, \lambda_1, \lambda_2, \lambda_3, \lambda_4) = (P_t - c^C)Q_{it}^{C} + (P_t - c^W)Q_{it}^{W} - \lambda_1(K_i^C - Q_{it}^{C}) - \lambda_2(K_i^W - Q_{it}^{W}) + \lambda_3 Q_{it}^{C} + \lambda_4 Q_{it}^{W}, \qquad i = 1, \dots, N \tag{2.9}$$

Once the Lagrangian is written, the KKT conditions are given by:

$$\begin{aligned}
&\frac{\partial L}{\partial Q_{it}^{C}} = 0 \Leftrightarrow P_t - c^C - \lambda_1 + \lambda_3 = 0 \Leftrightarrow a - b(N+1)Q_{it}^{C} - b(N+1)Q_{it}^{W} + \varepsilon_t - c^C - \lambda_1 + \lambda_3 = 0 \\
&\frac{\partial L}{\partial Q_{it}^{W}} = 0 \Leftrightarrow P_t - c^W - \lambda_2 + \lambda_4 = 0 \Leftrightarrow a - b(N+1)Q_{it}^{C} - b(N+1)Q_{it}^{W} + \varepsilon_t - c^W - \lambda_2 + \lambda_4 = 0 \\
&\lambda_1\left(K_i^C - Q_{it}^{C}\right) = 0 \qquad \lambda_1 \geq 0 \qquad K_i^C - Q_{it}^{C} \geq 0 \\
&\lambda_2\left(K_i^W - Q_{it}^{W}\right) = 0 \qquad \lambda_2 \geq 0 \qquad K_i^W - Q_{it}^{W} \geq 0 \\
&\lambda_3 Q_{it}^{C} = 0 \qquad \lambda_3 \geq 0 \qquad Q_{it}^{C} \geq 0 \\
&\lambda_4 Q_{it}^{W} = 0 \qquad \lambda_4 \geq 0 \qquad Q_{it}^{W} \geq 0, \qquad i = 1, \dots, N
\end{aligned} \tag{2.10}$$

The Nash equilibrium is obtained when the set of equations (2.10) are simultaneously satisfied. The authors' present nine possible solutions $(Q_{it}^{C*}, Q_{it}^{W*})$ for the Nash equilibrium, of which, only four solutions simultaneously satisfy the KKT conditions[11]. Together, these four solutions constitute the Nash equilibrium. They are the following:

[11] For simplicity, the remaining five solutions of the maximization problem of Equation (2.7) are not presented, as they do not meet all the necessary conditions of the Nash equilibrium. For more information see Milstein and Tishler (2009, pp. 63-65).

Solution 1:

$$(Q_{it}^{C*}, Q_{it}^{w*}) = \left(0, \frac{a - c^W + \varepsilon_t}{b(N+1)}\right), if\ c^W - a < \varepsilon_t \leq c^W - a + b(N+1)K_i^W \tag{2.11}$$

Solution 2:

$$(Q_{it}^{C*}, Q_{it}^{w*}) = (0, K_i^W),\ if\ c^W - a + b\ (N+1)K_i^W < \varepsilon_t \leq c^C - a + b(N+1)K_i^W \tag{2.12}$$

Solution 3:

$$(Q_{it}^{C*}, Q_{it}^{w*}) = \left(\frac{a - c^C + \varepsilon_t}{b(N+1)} - K_i^W, K_i^W\right),\ if\ c^C - a + b\ (N+1)K_i^W < \varepsilon_t \leq c^C - a + b(N+1)K_i^W + b(N+1)K_i^C \tag{2.13}$$

Solution 4:

$$(Q_{it}^{C*}, Q_{it}^{w*}) = (K_i^C, K_i^W),\ if\ \varepsilon_t > c^C - a + b(N+1)K_i^W + b(N+1)K_i^C \tag{2.14}$$

It should be noted that, when the total capacity of all *N* firms is less than the optimal Cournot solution, due to the large realization of ε_t, we have $Q_{it}^C = K_i^C$ or $Q_{it}^W = K_i^W$. This way, each firm will choose their output on day *t* equal to their capacity investment. When this happens, our daily electricity demand is given by $P_t = a - b(K_i + K_{-i}) + \varepsilon_t$, where $K_{-i} \equiv \sum_{j \neq i}^{N} K_j$ is the aggregate capacity of the other *N-1* firms (Tishler *et al.*, 2008).

Once the second-stage optimal solutions are found, the first-stage maximization problem can be solved. To do so, equations (2.11) to (2.14) should be substituted into the expected operating profit equation of the *i*-th firm on day t, given by:

$$E\left[\sum_{t=1}^{T}(\pi_{it}|K_i^C, K_i^W)\right] = \int_{c^W - a}^{\infty} [(P_t - c^C)Q_{it}^C + (P_t - c^W)Q_{it}^W] f(\varepsilon_t) d\varepsilon_t \tag{2.15}$$

After the substitution of uniform distribution[12] on equation (2.15), the i-th firm's profit-maximization capacities, K_i^{C*} and K_i^{W*}, are obtained[13]:

$$K_i^{C*} = \frac{2(\beta-\alpha)\theta^W/T - \left[c^C - c^W + \sqrt{2(\beta-\alpha)\theta^C/T}\right]^2}{2b(N+1)(c^C - c^W)} \tag{2.16}$$

$$K_i^{W*} = \frac{(\beta + a - c^W)^2 - (\beta + a - c^C)^2 - 2(\beta-\alpha)(\theta^W - \theta^C)/T}{2b(N+1)(c^C - c^W)} \tag{2.17}$$

This way, and according the authors, the solutions of the model can be summarized in three points (Milstein and Tishler, 2009):

a) A unique Nash equilibrium exists in the second stage of the game, given by the equations (2.11) to (2.14).
b) The optimal first-stage solution exists if and only if the following condition holds:

$$\sqrt{2(\beta-\alpha)\theta^C/T} < \frac{(\beta-\alpha)(\theta^W - \theta^C)/T}{c^C - c^W} - \frac{c^C - c^W}{2} < \beta + a - c^C \tag{2.18}$$

c) If the prior condition holds, the total capacity of the industry is bounded from above and the price spikes are independent of the number of firms. That is,

$$N \times (K_i^{C*} + K_i^{W*}) < \left(\beta + a - c^C - \sqrt{2(\beta-\alpha)\theta^C/T}\right)/b \tag{2.19}$$

Since the model was fully formulated and the optimal solutions were found, we can accept the model as valid and apply it to our case. The following chapter will describe the application of the model to the Portuguese and Spanish cases, as well as the main results and conclusions.

[12] According to the authors, it may be boring but not difficult to obtain the expressions of the optimal capacities in an implicit form. However, *"extensive simulations show that the optimal capacities obtained under the assumption that $f(\varepsilon_t)$ is uniform or normal are very similar, practically identical, to those obtained for the true (data-generating) distribution, provided the true distribution is not too asymmetric"* (Milstein and Tishler, 2009, pp. 13). Thus, the first-stage maximization problem will be solved through the assumption that $f(\varepsilon_t)$ follows a uniform distribution.
[13] The solutions are detailed in the proof of Annex 3.

3. An Application to the Iberian Electricity Market: Methodology and Empirical Results

In this chapter, the model will be applied to Portuguese and Spanish data to illustrate its real world relevance. One of the great objectives behind the creation of MIBEL is the increase of the efficiency in electricity markets and the utilization of renewable energy sources. Thus, it is expected that, having reached this goal, the use of conventional power can be reduced. Therefore, the application of the model is suitable because it will confirm if the reduction is true or not.

The year 2011 was chosen because it gives us a relative distance from the start of MIBEL and it is also the year in which the majority of the necessary data to develop the model are available. However, the data of the marginal and capacity costs belong to year 2010, due to the unavailability of updated data and the need of consistency of information between the countries. Nevertheless, this assumption does not invalidate the analysis, because the time difference is small.

3.1. Methodology and Data

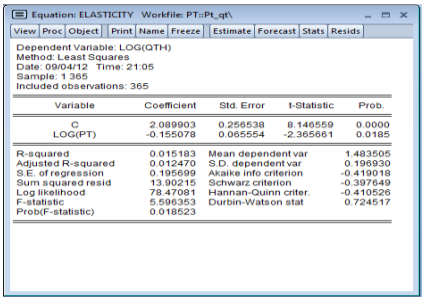
To apply the model, a and b are first estimated - the parameters of the demand function (equation 2.1) - for Portugal and Spain. For that, the daily data for electricity prices (P_t) and daily averages of hourly electricity outputs (Q_t) for both countries are needed. This information was collected from official pages of OMIE (2012), REN (2012), and REE (2012)[1].

[1] Regarding the Portuguese case, the renewable energy output does not enter on the spot market, so these data are not available in OMIE's official page. They were collected from REN's website.
It should be noted that the energy dispatched to the grid does not always come from the wholesale market. As it was seen in chapter 1, the energy can be traded through bilateral contracts or intraday market. However, for the sake of simplicity, it is assumed that all renewable energy collected from REN's website will be available in the spot market for trading.
In the Spanish case, the renewable energy output is available in OMIE's official page but the data are aggregated. This way, I had to resort to data provided by REE's website.
Despite all the discrepancies, these options were the best way to get the best approximations for the real numbers.

After the data collection, the estimation of *a* and *b* parameters was obtained through the price elasticity. The program used for the estimation of the price elasticity was *Eviews*, where the OLS (ordinary least squares) method[2] was applied. The results are presented in the next figure.

Figure 29: The Estimation of Price Elasticity for the Portuguese and Spanish Cases

Portugal



Equation: ELASTICITY Workfile: PT::Pt_qt\

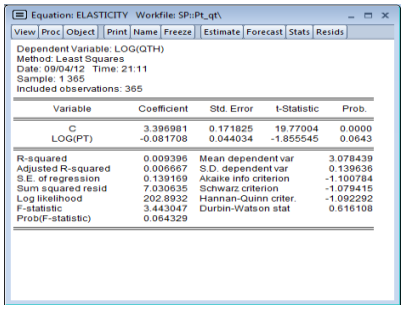
View | Proc | Object | Print | Name | Freeze | Estimate | Forecast | Stats | Resids

Dependent Variable: LOG(QTH)
Method: Least Squares
Date: 09/04/12 Time: 21:05
Sample: 1 365
Included observations: 365

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.089903	0.256538	8.146559	0.0000
LOG(PT)	-0.155078	0.065554	-2.365661	0.0185

R-squared	0.015183	Mean dependent var	1.483505
Adjusted R-squared	0.012470	S.D. dependent var	0.196930
S.E. of regression	0.195699	Akaike info criterion	-0.419018
Sum squared resid	13.90215	Schwarz criterion	-0.397649
Log likelihood	78.47081	Hannan-Quinn criter.	-0.410526
F-statistic	5.596353	Durbin-Watson stat	0.724517
Prob(F-statistic)	0.018523		

Spain



Equation: ELASTICITY Workfile: SP::Pt_qt\

View | Proc | Object | Print | Name | Freeze | Estimate | Forecast | Stats | Resids

Dependent Variable: LOG(QTH)
Method: Least Squares
Date: 09/04/12 Time: 21:11
Sample: 1 365
Included observations: 365

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.396981	0.171825	19.77004	0.0000
LOG(PT)	-0.081708	0.044034	-1.855545	0.0643

R-squared	0.009396	Mean dependent var	3.078439
Adjusted R-squared	0.006667	S.D. dependent var	0.139636
S.E. of regression	0.139169	Akaike info criterion	-1.100784
Sum squared resid	7.030635	Schwarz criterion	-1.079415
Log likelihood	202.8932	Hannan-Quinn criter.	-1.092292
F-statistic	3.443047	Durbin-Watson stat	0.616108
Prob(F-statistic)	0.064329		

Source: elaborated by the author

The values of LOG(PT) represent the estimations for the price elasticity.

This way, $a = \overline{P_t} + b\overline{Q_t}$ and $b = -\frac{\overline{P_t}/\overline{Q_t}}{\delta}$, where, $\overline{P_t}$ is the price average, $\overline{Q_t}$ is the mean of daily averages of hourly electricity output, and δ is the price elasticity. Through the descriptive statistics of the prices and daily averages of hourly electricity output, and the price elasticity, parameters *a* and *b* were calculated. They are presented in the next table[3].

Table 3: The values of the parameters of the demand function for Portugal and Spain

	Portugal	Spain		Portugal	Spain
$\overline{P_t}$	50.45	49.92	a	375.95	660.95
$\overline{Q_t}$	4.4927	21.94	b	72.45	27.85
δ	-0.155	-0.0817			

Source: elaborated by the author

The data are presented in Annex 4, tables 14 to 17.

[2] An exponential regression model was used to estimate the price elasticity. This way, if the equation $\log(Q_t) = \beta_1 + \beta_2 \log(P_t) + u_i$ is estimated by OLS, the price elasticity is given by the value of β_2, since $\beta_2 = \frac{\Delta Q_t}{\Delta P_t} \times \frac{P_t}{Q_t}$.

[3] To validate the applicability of this method to estimate the demand parameters, the values exposed in the article of Milstein and Tishler (2009) will be used. According to the authors, using the average price of 66.4$/MWh, a price elasticity of -0.25 and a mean of daily averages of hourly electricity output of 5.75 (1000 MWh), the estimates are: *a=332.0* and *b=46.2*. However, they do not explain how these values are calculated. Nevertheless, if these data are applied to the equations of the parameters of demand function, it is proved that the estimates of *a* and *b* are, indeed, *a=332.0* and *b=46.2*. Thus, it can be concluded that the method used to estimate *a* and *b* for Portugal and Spain is in accordance with the article.

Another variable of demand function, which needs to be estimated, is the ε_t. They are obtained solving the equation $\varepsilon_t = P_t - a + bQ_t$. The results are presented in Annex 4.

The OLS method could be used to estimate the parameters of demand function and the values of the random variable. However, to apply this method in the estimation of the parameters of a regression, it is necessary that the expected value of the ε_t must be zero and its variance must be a constant, the values of ε_t must be independent, and finally, ε_t must follow a normal distribution. The first two conditions are confirmed by the assumptions of the model. However, it was assumed that $f(\varepsilon_t)$ follows a uniform distribution. This way, the OLS method cannot be applied to the model (Guimarães and Cabral, 2011).

The data of the marginal costs c^C and c^W were hard to find. As it was previously assumed, the marginal costs of hydro, nuclear, and wind power are zero. However, the problem was to find the value for the thermal power. Nevertheless, according to ERSE and CNE information, the Portuguese and Spanish thermal technologies are very similar. Thus, the value of 65€/MWh is assumed as the marginal cost of thermal power and, consequently, the marginal cost of the conventional power for both countries.

Regarding the values of the capacity costs $\theta^C$and θ^W, there is little updated information about them. The most recent study is a work developed by OCDE, NEA, and IEA (2010), where it was used the concept of levelized cost of electricity. The same concept is used in this dissertation, because it gives us a good proxy of the capacity costs. According to the study, the levelized cost is an approximation to the real costs of investment in electricity production, assuming the certainty of production costs and the stability of electricity prices. However, this study does not present the levelized costs for Portugal and Spain in detail. Thus, we shall assume the values assigned to EURELECTRIC, because this electrical sector association represents the interests of the whole European electricity industry. The values are presented in the following table:

Table 4: The Levelized Costs for the Different Production Technologies, in 2010

Levelized Cost		USD/MWh		EUR/MWh	
Discount rate		5%	10%	5%	10%
Hydro	River run	34.74	70.89	26.20	53.47
	Pump storage	72.95	148.88	55.03	112.30
Nuclear		59.93	105.84	45.21	79.84
Wind		112.71	154.71	85.02	116.70
Coal	Black coal	74.43	90.11	56.14	67.97
	Brown coal	62.73	79.61	47.32	60.05
	Black USC w/ 90%	74.51	102.00	56.20	76.94
CCGT		86.08	93.84	64.93	70.78

Source: elaborated by the author, data from: (OCDE *et al.*, 2010; BP, 2009)

As the data are in USD/MWh and all the parameters are presented in EUR/MWh, there is a need to make a conversion. For that, the arithmetical average of the exchange rates of 2010 was used. The rate was calculated based in information removed from the official page of Portugal Bank and it is equal to EUR/USD =1.325717 (BP, 2009).

Nevertheless, there are two problems. On the one hand, the percentage of hydro power that belongs to river run or pump storage must be known. For that, the net maximum capacity[4] was used. This way, the capacity of river run is calculated by the difference between, the total capacity of hydro power and the total capacity which belongs to pump storage. The results are presented in the next table.

Table 5: Net Maximum Electricity Generating Capacity on 31 December 2010 for Portugal and Spain, in GW

		Portugal		Spain	
		Value (GW)	%	Value (GW)	%
Large Hydro	River run	4,06	79,68%	13,19	71,10%
	Pump storage	1,03	20,32%	5,35	28,90%
	TOTAL	5,09	100,00%	18,54	100,00%

Source: elaborated by the author, data from: (IEA, 2012)

Thus, the levelized costs of hydro power, which belongs to river run or pump storage, are calculated by the application of these percentages on the values of table 4.

[4] The net maximum capacity can be defined as "*the sum of the net maximum capacities of all stations taken individually at a given period of operation. It is the maximum active power that can be supplied, continuously, with all plants running, at the point of outlet to the network. (...) The capacity is net in the sense that it is the output capacity measured at the station busbars, i.e. after deducting the power consumed by station auxiliaries and losses in station transformers*" (IEA, 2012, pp. I.5 - I.6).

On the other hand, in table 4 there are three types of coal: black coal, brown coal and black USC w/ 90%. However, the Portuguese and Spanish coal power stations primarily use one of these types of coal. After consulting the energy balances of Portugal and Spain published by DGEG and Ministerio de Industria, Turismo y Comercio for 2010, it is confirmed that most of coal power stations use black coal (DGEG, 2010; Ministerio de Industira, Turismo y Comercio, 2011). Hence, in this present study only the levelized costs of coal power stations that use black coal will be used.

Once the simplifications were made, the capacities costs $\theta^C$and θ^W can be summarized in the following table:

Table 6: The Arithmetical Average of Levelized Costs for Portugal and Spain, in 2010

EUR/MWh	Portugal		Spain	
Discount rate	5%	10%	5%	10%
Conventional power	30,63	40,84	40,16	57,81
Wind power	85,02	116,70	85,02	116,70

Source: elaborated by the author

As the recent studies have used a discount rate of 10%, the present dissertation will follow the same methodology.

Regarding the number of firms present in the electricity market, the analysis will consider a *N*=1,2,3,4,5,10. The choice of these values can be explained by the fact that the electricity market is an oligopoly where the level of market concentration is high. Thus, in a near future it is improbable that more than five major firms act in the market. To fill this shortcoming, a case for *N*=10 is considered.

Finally, as $f(\varepsilon_t) \sim U[\alpha, \beta]$, the values of α and β are needed to be found. For that, I turned to descriptive statistics of ε_t presented in the following table:

Table 7: The Descriptive Statistics of ε_t for Portugal and Spain

	Portugal	Spain
Mean	-0.000552	-0.117959
Median	-2.057456	-2.476992
Maximum	189.1088	218.6859
Minimum	-211.5799	-192.6480
Std. Dev.	62.19964	84.45288

Source: elaborated by the author

Then, knowing that $\alpha = \mu - \sqrt{3} \times \sigma$ and $\beta = \mu + \sqrt{3} \times \sigma$, in Portugal $f(\varepsilon_t) \sim U[-107.73;\ 107.73]$, and in Spain $f(\varepsilon_t) \sim U[-146.39;\ 146.39]$[5].

With all the parameters estimated, the model can be solved and its solution can be found. The software program used to solve the model was *MATLAB*[6], and the results and the main conclusions will be presented in the next section.

3.2. Empirical Results

The application of the model previously described, will allow us to draw conclusions about the optimal market structure of the electricity market and the optimal capacity choice. But, before presenting the empirical results, their validity must be proven.

As it was explained in section 2.3.1, an optimal first-stage solution exists if and only if the equation (2.18) holds. Applying the Portuguese and Spanish parameters in the equation, it is confirmed that it is valid. If this happens, the total industry capacity is bounded from above by the equation (2.19), and its value is 3,948 MW for the Portuguese case and 20,049 MW for the Spanish case.

Considering these values and what it was seen in chapter 1, it is confirmed that Portuguese and Spanish installed capacity are far above these bounds, i.e., both systems have an installed capacity exceeding the optimal. Nevertheless, two corrections need to be made. In the first place, the study does not consider all the quantities, which enter the electricity market. As it was explained above, the quantities traded through bilateral contracts or intraday market, and the quantities of other renewable energies do not matter for this study. Only the amounts traded in the day-ahead market (spot market) are considered. If these quantities were introduced, the optimal bound would be superior, but not necessarily equal to or greater than the installed capacities of chapter 1. In the second place, the bound of the optimal industry capacity is likely to be much smaller in a deregulated market than in a regulated one. According to Milstein and Tishler (2009),

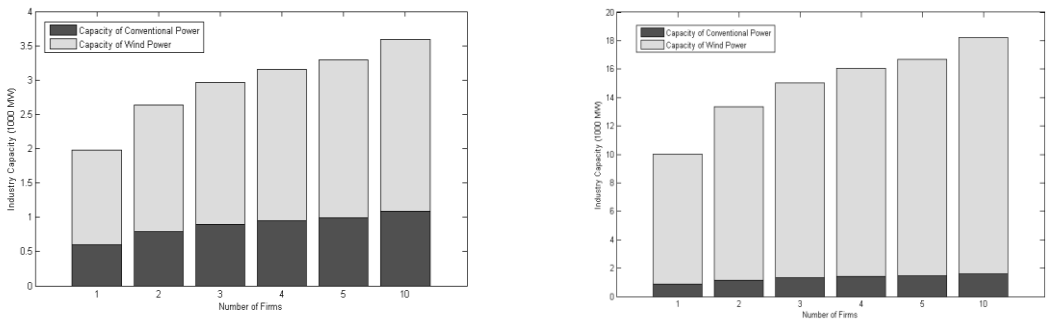
[5] In reality, for Spain $f(\varepsilon_t) \sim U[-146.3946;\ 146.157]$. However, if these values or the symmetric ones were applied, the results are very similar. Thus, the symmetric values will be adopted.
[6] For more information about programming the two-stage model through MATLAB, contact the author (carlamtmendes@gmail.com).

in a regulated market it is common that the regulatory entity sets electricity prices during the year. This happens, for example, with the feed-in tariffs applied to electricity generation from renewable energy sources. Thus, when the regulatory entity sets the electricity prices, the generators do not have the price mechanism to respond to changes in electricity demand over the day and during the year. This way, and taking into account the electricity price announced by the regulator, the installed capacity in a regulated electricity market is very close to the maximal value of the hourly demand over the year plus reserves. So, the value of the bound in a regulated market is superior.

Economic theory suggests that the optimal capacity of each firm is reduced as the number of firms increases, but in the whole, the industry capacity increases. Figure 30[7] corroborates the prior statement, and it shows the optimal industry capacity for Portugal and Spain.

Figure 30: Optimal Industry Capacity for Portugal and Spain, 2011

Portugal **Spain**



Source: elaborated by the author

As it is shown, both in Portugal and in Spain, the optimal industry capacity is increasing as the number of firms increases, but it cannot exceed the prior theoretical bound. This phenomenon happens because the equilibrium electricity prices decrease and the quantities demanded increase, with the entry of new firms on the electricity market.

On the other hand, the figure shows that the optimal industry capacity in Portugal is much lower than the optimal industry capacity in Spain, since the Portuguese electricity demand is less than the Spanish one.

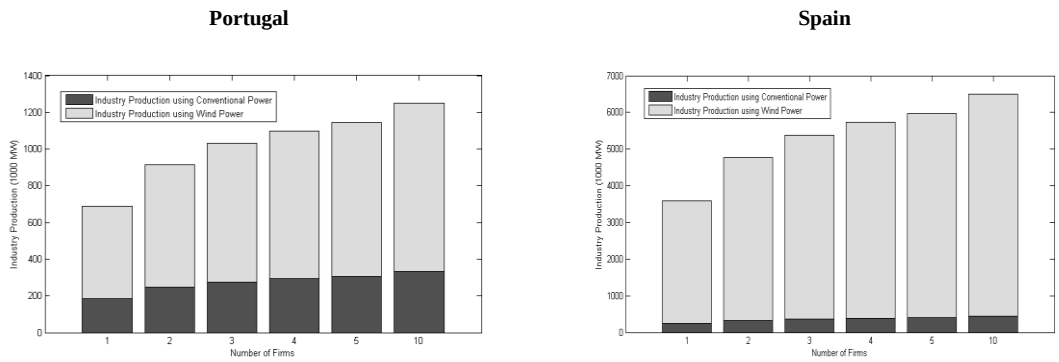
[7] For more information see Annex 4.

Finally, it can be concluded that, independently of the number of firms, in Portugal, the optimal capacity of conventional power and wind power represent 30.17% and 69.83% of the industry capacity, respectively. For Spain, a similar conclusion can be drawn. The Spanish optimal capacity for conventional power and wind power represent 8.73% and 91.27% of the total of industry, respectively. This is mainly due to higher capacity costs of conventional power in Spain, resulting from the addition of the costs of nuclear power, which do not exist in Portugal.

Having this in mind, and in accordance with Bushnell (2010), Milstein and Tishler (2009, 2011), Sáenz de Miera *et al.* (2008), and Weigt (2009b), it can be concluded that the introduction of installed capacity of wind power will reduce the installed capacity of conventional power, since the need of building capacity of conventional power to satisfy the demand is reduced. Naturally, when the firms can employ both technologies, the generator will invest in technology with lower marginal costs. Thus, the share of technology **W** in the total capacity of the industry will be greater. This conclusion can be extended to other renewable energy sources. Nevertheless, and as Oswald *et al.* (2008) and Strbac *et al.* (2007) say, a significant proportion of installed capacity of conventional power must be preserved, due to security of supply.

The optimal industry production is shown in the next figure[8].

Figure 31: Optimal Industry Production for Portugal and Spain, 2011



Source: elaborated by the author

The conclusions of these graphs are analogous to those, which were taken in the prior figure, since their evolution pattern is very similar. This way, and as it can be seen by

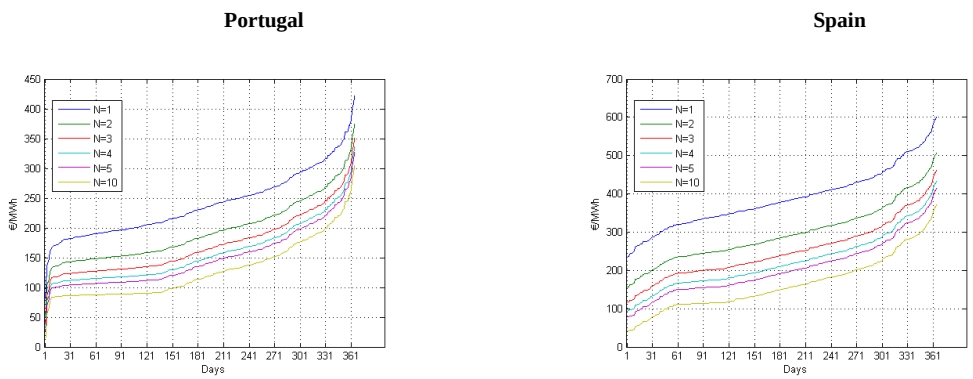
[8] For more information see Annex 4.

the figure, in Portugal, the optimal industry production is five times less than the Spanish optimal industry production, and the share of conventional power in the total of production is greater than in Spain. Regarding the wind power, it is shown that, in Portugal and Spain, the share of wind power in the total of production is 73.2% and 93.2%, respectively. These conclusions do not depend on the number of firms.

As it shown in the beginning of the present section, the installed capacity of the system exceeds the optimal. An indicator to study the excess of capacity could be the price spike of electricity. The common sense suggests that electricity demand fluctuate wildly over the day and during a year. Thus, to satisfy the demand, the construction of new capacity could be a solution. Nevertheless, this new capacity requires time and money, and likely, it would be idle most of the times. This way, the capacity already installed has to serve the daily demands. When a peak demand, which exceed the available capacity, occurs, the generators let the electricity price soar, with the aim to cut the excess of demand. Therefore, the price spike of electricity could be a substitute to evaluate the excess on generation capacity.

The next figure presents the distribution of the equilibrium electricity prices for the 365 days of 2011, for both countries. The prices are organized in ascendant order subject to quantity demand. Thus, on day 1 the demand reaches its minimal value and on day 365 it reaches its maximal value.

Figure 32: Distribution of the Electricity Prices during the Year 2011, for Portugal and Spain



Source: elaborated by the author

Analyzing the figure, it is confirmed that, when the number of firms increase, the price levels decrease in both countries. On the other hand, Spain has higher price levels than

those recorded in Portugal: the maximal equilibrium prices reached 422.05€/MWh in Portugal and 600.46€/MWh in Spain, when there is a monopoly market; and, it reached 305.04€/MWh in Portugal and 372.05€/MWh in Spain, when there are 10 firms. In the last case, the price difference amongst the countries is not so pronounced.

These results are not as strange as it might seem. When MIBEL spot prices are analyzed under the market splitting scheme, it is confirmed that the difference of prices between the countries is very small. This happens because all the generators of both countries participate in a single spot market. As the economic theory affirms, the more the number of firms increase, the more the prices decrease. Thus, when the market comprises 10 firms, a similar reality, to the one which happen in MIBEL, occurs. Nevertheless, it should be noted that Portuguese and Spanish prices are very stilted. This happens, because the energy generated by hydro and nuclear power were added to conventional power. Considering that, they usually enter first the merit order because their marginal costs are zero, the prices would have a lower increase than it is shown by the figure.

On the other hand, and in accordance to Tishler *et al.* (2008), the figure shows that the frequency of price spikes does not depend on the number of firms in the market. Thus, even if a competition policy to promote the entry of new firms to mitigate price volatility is applied, it is still unlikely that the frequency of prices spikes will change.

Figure 32[9] also demonstrates that both technologies reach full capacity at the end of four and a half months for the Portuguese case, and at the end of four months for the Spanish case. After that, the electricity prices start to spike. By the explanation mentioned above, the price spikes occur when the demand exceed the available capacity. This means that, the optimal system does not have sufficient capacity to satisfy the demand most of the times. However, as it was seen in the beginning, the Portuguese and Spanish installed capacity exceeds the optimal, which allows the system to match the demand levels.

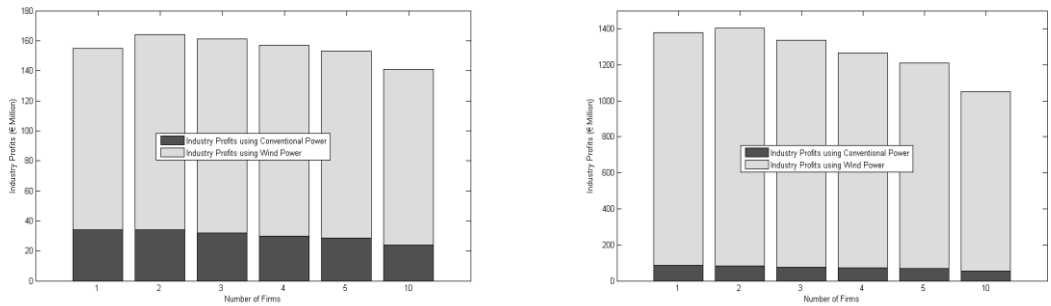
Regarding the profits, the next figure presents the profits of the industry for Portugal and Spain, in 2011. Generally, it can be concluded that, when the number of firms

[9] For more information see Annex 4.

increase, the profits of industry tend to decrease. The only exception is when the electricity market passes from one firm to two firms. As it can be seen, the profit has a small increase, due to the great increase of the optimal industry production.

Figure 33: Industry Profits for Portugal and Spain, 2011

Portugal **Spain**



Source: elaborated by the author

On the other hand, the conventional power is less profitable. As it can be seen by the figure, the share of conventional power on the industry profits decreases when the number of firms increases. In Portugal, this share decreases from 22% when N=1 to 17% when N=10. In Spain, the share of conventional power on the industry profits is very small. This share decreases only one percentage point, from 6% when N=1 to 5% when N=10. On the other hand, the share of wind power on the industry profits rises when the number of firms increases.

The reason for this behavior is simple: the marginal costs of technology **C** are much higher than those of technology **W**, so when the firms can construct both technologies they will reduce the use of technology **C**. Thus, and according to Milstein and Tishler (2009), the generators tend to eliminate the weaker product from the market.

As expected, the main results of this work closely follow the main conclusions drawn by Milstein and Tishler (2009). Thus, it can be concluded that, when the generators can operate two technologies, the introduction of wind power replaces the choice of investments in conventional power, both in Portugal and Spain. This conclusion shows that, the investment in new renewable capacity will be the most efficient choice.

Conclusion

This dissertation's main goal was to provide and to apply a methodology to understand the relationship between renewable energy sources and the optimal generation capacity mix in a competitive market.

The literature on this important topic is scarce. The Iberian Electricity Market (MIBEL) was chosen due to the urgency and importance of obtaining more knowledge about this market's functioning. Thus, a description of the operation of MIBEL was presented in order to provide the reader a brief, yet substantial, perspective of this market. A literature survey on this specific research topic was performed, followed by the selection of the model.

This dissertation is based on the methodology developed by Milstein and Tishler (2009) because this model mimics the real world decision processes in a competitive electricity market. A two-stage model was developed under Cournot conjecture, where the Nash equilibrium of the optimal endogenous generation capacity and the optimal outputs are deducted. The capacity to be built is determined in the first-stage, when electricity demand is unknown, and the outputs are determined in the second-stage, when daily demand is revealed.

This work shows that in both countries the investment in renewable capacity would be greater than the investment in conventional capacity when wind power is considered in the investment choices of the generators. It should be noted that wind power was chosen in this dissertation from among all the available renewable technologies as it has been one of the fastest growing renewable technologies over the last several years. These results prove that despite the decline in State support to electricity production in renewable energy, the generators would invest more in wind power capacity than in conventional capacity. An analogous result is obtained regarding optimal industry production. Just as the majority of investment in installed capacity is in wind power, so too the share of wind power in the total of optimal industry production is greater than the share of conventional power. This result is valid for Portugal and Spain. Regarding equilibrium prices, it was confirmed that in Portugal electricity generation would be at

full capacity during 37% of the year. In Spain, the percentage is 33%. These results show that there is inadequate investment capacity, which implies that it is be more profitable to generators to let the prices spike than build new capacity, which would otherwise be idle during most of the year. Lastly, conventional power is less profitable. This way, and in accordance with the first conclusion, the generators would invest in wind power capacity.

Therefore, in a competitive electricity market, where each firm can choose between two technologies to construct and operate, the generators tend to eliminate the weaker product from the market, i.e., there is a reduction in the use of conventional power technology. This result is very important because it gives the regulatory entity the necessary understanding that the less valuable technologies would likely be reduced.

On the other hand, it was proved that generators prefer to let the price spike, when the peak demand exceeds the availability capacity, than invest in new installed capacity. With this in mind, the regulatory entity must provide the necessary conditions to promote the investment in new capacity for the most profitable technology –wind power. Thus, it is important to provide the financial incentives to electricity production from renewable energy sources, despite wind power being the optimal choice to produce electricity. This conclusion can be extended for others renewable technologies.

There were difficulties in harmonizing the data from different sources and countries, yet this was ultimately done satisfactorily. Limitations include the following. First, wind power is an intermittent energy. That intermittency was not considered in the present study, though it would better converge of the analysis with the reality. Secondly, different generating technologies were not considered. Thus, if the conventional power technology was disaggregated and the intermittency was included, it should be possible measure, with more precision, the effect of the introduction of wind power on each production technology. This analysis would have been developed in this dissertation, but the lack of resources and time prevented its realization. This next step is recommended for further research.

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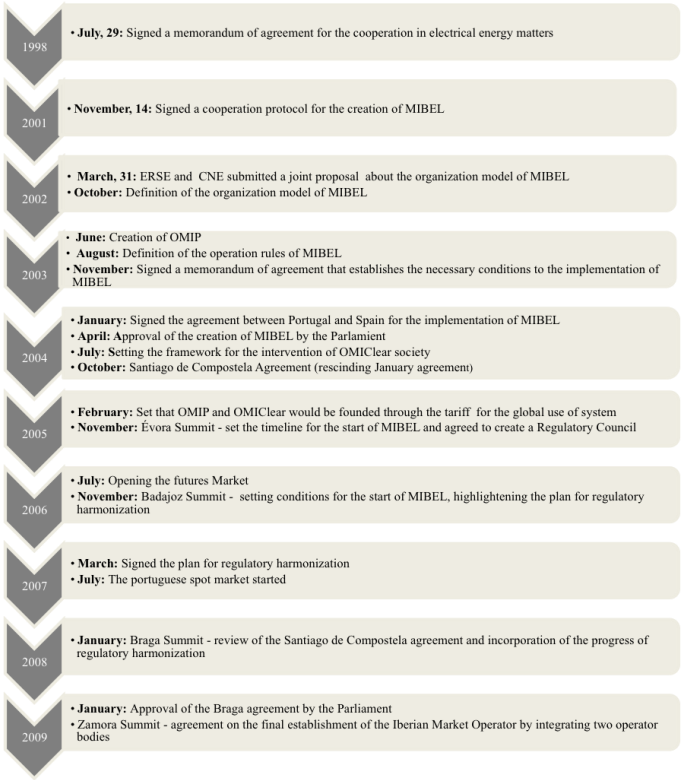
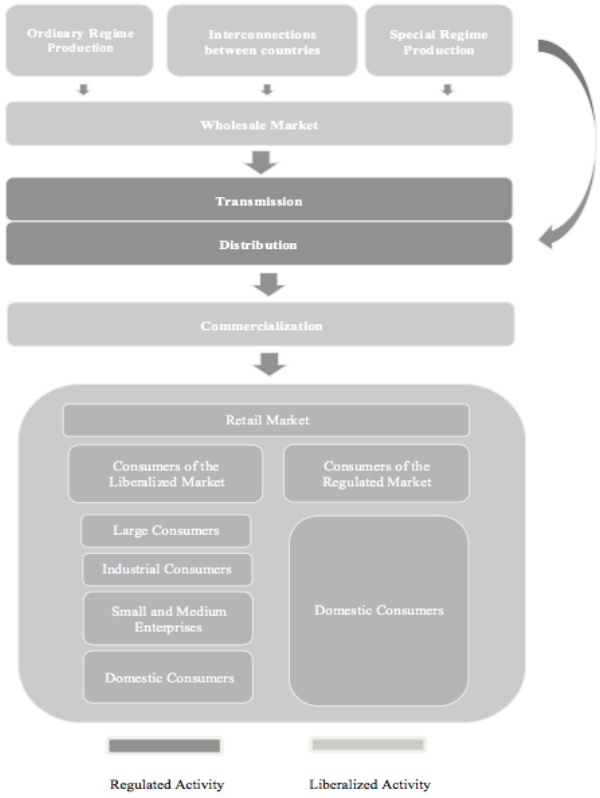
Annex 1: Information about the Formation Process and Structure of MIBEL

Figure 34: Main Steps between Portugal and Spain for the Establishment of MIBEL



Source: elaborated by the author, data from: (BPI, 2011; Lagarto *et al.*, 2010)

Figure 35: Current Structure of the Energy Sector



Source: elaborated by the author

Annex 2: Installed Capacity and Power Generation for Production Sector

Table 8: Evolution of the Installed Capacity in Portugal and Peak Load

Installed Capacity and Peak Load in Portugal					
(MW)	**2006**	**2007**	**2008**	**2009**	**2010**
Installed Capacity under Ordinary Regime	**10433**	**10397**	**10397**	**11204**	**11985**
Hydro Power Plants	4582	4578	4578	4578	4578
Thermal Power Plants	5851	5819	5819	6626	7407
Coal	1776	1776	1776	1756	1756
Natural Gas	2166	2166	2166	2992	3829
Fuel Oil/Natural Gas	1712	1712	1712	1713	1657
Gas-Oil	197	165	165	165	165
Installed Capacity under Special Regime	**3187**	**3800**	**4524**	**5457**	**5935**
Thermal	1299	1365	1424	1610	1698
Mini-Hydro	370	374	385	395	410
Wind	1517	2048	2662	3357	3705
Photovoltaic	1	13	53	95	122
TOTAL	**13620**	**14197**	**14921**	**16661**	**17920**
Peak Load	**8804**	**9110**	**8973**	**9217**	**9403**

Source: elaborated by the author, data from: (REN, 2007, 2008, 2009, 2010)

Table 9: Evolution of the Power Generation in Portugal

Power Generation in Portugal					
(GWh)	**2006**	**2007**	**2008**	**2009**	**2010**
Power Generation under Ordinary Regime	**35682**	**32948**	**30238**	**31692**	**32169**
Hydro Generation	10204	9523	6441	7984	14869
Thermal Generation	25478	23425	23797	23708	17300
Coal	14070	11663	10423	11942	6553
Natural Gas	1505	1268	12573	11463	10700
Fuel-Oil/Gas-Oil	9903	10494	801	303	47
Power Generation under Special Regime	**8754**	**10163**	**11565**	**14423**	**17923**
Mini-Hydro	993	694	660	825	1379
Thermal	4869	5437	5177	5966	7313
Wind	2892	4012	5695	7493	9024
Photovoltaic	0	20	33	139	207
TOTAL	**44436**	**43111**	**41803**	**46115**	**50092**

Source: elaborated by the author, data from: (REN, 2007, 2008, 2009, 2010)

Table 10: Evolution of the Installed Capacity and Peak Load in Spain

Installed Capacity and Peak Load in Spain					
(MW)	**2006**	**2007**	**2008**	**2009**	**2010**
Installed Capacity under Ordinary Regime	**58790**	**62307**	**62707**	**62703**	**64813**
Hydro Power Plants	17499	17505	17554	17554	17561
Nuclear Power Plants	7716	7716	7716	7716	7777
Thermal Power Plants	33575	37086	37437	37433	39475
Carbon Power Plants	11424	11356	11359	11359	11380
Fuel/Gas Power Plants	6647	4768	4401	3008	2860
Combined Cycle Gas	15504	20962	21677	23066	25235
Installed Capacity under Special Regime	**20127**	**24016**	**28210**	**31859**	**34230**
Mini-Hydro	1786	1887	1940	1981	1991
Wind	11521	14667	16148	18961	20057
Biomass	459	472	512	660	711
Photovoltaic	142	652	2961	3051	3458
Thermal Solar	11	11	61	282	682
Others Renewables (1)	339	339	339	339	339
No Renewables (2)	5869	5988	6249	6585	6992
TOTAL	**78917**	**86323**	**90917**	**94562**	**99043**
Peak Load	**42153**	**44876**	**42961**	**44440**	**44122**

(1) Residues included
(2) Includes residual heat, carbon, fuel-oil, residual gas, and natural gas

Source: elaborated by the author, data from: (REE, 2011)

Table 11: Evolution of the Power Generation and Net Available Capacity in Spain

Power Generation in Spain					
(GWh)	**2006**	**2007**	**2008**	**2009**	**2010**
Power Generation under Ordinary Regime	**220873**	**223823**	**220340**	**190846**	**189169**
Hydro Power Plants	25330	26352	21428	23862	38653
Nuclear Power Plants	60126	55102	58973	52761	61990
Thermal Power Plants	135417	142369	139939	114223	88526
Carbon Power Plants	66006	71833	46275	33862	22097
Fuel/Gas Power Plants	5905	2397	2378	2082	1825
Combined Cycle Gas	63506	68139	91286	78279	64604
Power Generation under Special Regime	**51633**	**57548**	**68045**	**80351**	**90902**
Mini-Hydro	4149	4125	4638	5474	6811
Wind	22881	27249	31758	37401	43355
Biomass	2274	2314	2620	2850	3119
Photovoltaic	102	463	2406	5896	6027
Thermal Solar	0	8	15	103	692
Others Renewables (1)	1483	1807	1844	1839	1862
No Renewables (2)	20744	21582	24764	26788	29036
TOTAL	**272506**	**281371**	**288385**	**271197**	**280071**
Consumption in Generation	**8904**	**8753**	**8338**	**7117**	**6673**
Net Available Capacity	**263602**	**272618**	**280047**	**264080**	**273398**

(1) Residues included
(2) Includes residual heat, carbon, fuel-oil, residual gas, and natural gas

Source: elaborated by the author, data from: (REE, 2011)

Table 12: Installed Capacity of the Spanish Business Groups by Technology

Installed Capacity										
	Spain		Endesa (SP+PT)		Iberdrola		Gas Natural Fenosa		Others	
	MW	%	MW	%	MW	%	MW	%	MW	%
SRP	34230	100%	0	0%	6094	18%	958	3%	27178	79%
Nuclear	7777	100%	3664	47%	3382	43%	589	8%	142	2%
Hydro	17561	100%	4731	27%	8753	50%	1860	11%	2217	13%
Thermal	39475	100%	14720	37%	7360	19%	11230	28%	6165	16%
TOTAL	99043		23115		25589		14637		35702	

Source: elaborated by the author, data from: (Endesa, 2011; Gas Natural Fenosa, 2011; Iberdrola, 2010)

Table 13: Power Generation of the Spanish Business Groups by Technology

Power Generation												
	Spain		Endesa (SP+PT)		Iberdrola		Hidrocantábrico		Gas Natural Fenosa		Others	
	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%
SRP	90902	100%	558	1%	6892	8%	3134	3%	2529	3%	80217	86%
Nuclear	61990	100%	27619	45%	26160	42%	1190	2%	4325	7%	2696	4%
Hydro	38653	100%	9208	24%	20081	52%	1038	3%	4752	12%	3574	9%
Thermal	88526	100%	29665	34%	12183	14%	8714	10%	26732	30%	11232	13%
TOTAL	280071		67050		65316		14076		38338		95291	

Source: elaborated by the author, data from: (Endesa, 2011; Gas Natural Fenosa, 2011; HC energía, 2010; Iberdrola, 2010)

Annex 3: Determining Optimal Solutions

Proof: Determination of the Optimal Capacities Solutions

To solve the first-stage maximization problem equations (2.11) to (2.14) should be substituted into the expected operating profit equation of the *i*-th firm on day *t* (equation 2.15):

$$
\begin{aligned}
E(\pi_{it}|K_i^C, K_i^W) = & \int_{c^W-a}^{c^W-a+b(N+1)K_i^W} \frac{1}{b}\left[\frac{a+\varepsilon_t-c^W}{N+1}\right]^2 f(\varepsilon_t)\, d\varepsilon_t \\
& + \int_{c^W-a+\,b\,(N+1)K_i^W}^{c^C-a+b(N+1)K_i^W} [a-b(K_i^W+K_{-i}^W)+\varepsilon_t-c^W]K_i^W f\,(\varepsilon_t)d\varepsilon_t \\
& + \int_{c^C-a+\,b\,(N+1)K_i^W}^{c^C-a+b(N+1)K_i^W+b(N+1)K_i^C} \left[\frac{a+\varepsilon_t+Nc^C-(N+1)c^W}{N+1}\right]K_i^W f(\varepsilon_t)d\varepsilon_t \\
& + \int_{c^C-a+\,b\,(N+1)K_i^W}^{c^C-a+b(N+1)K_i^W+b(N+1)K_i^C} \left[\frac{1}{b}\left[\frac{a+\varepsilon_t-c^C}{N+1}\right]^2-\left[\frac{a+\varepsilon_t-c^C}{N+1}\right]K_i^W\right]f(\varepsilon_t)d\varepsilon_t \qquad \text{(A3.1)} \\
& + \int_{c^C-a+b(N+1)K_i^W+b(N+1)K_i^C}^{\infty} [a-b(K_i^W+K_{-i}^W)-b(K_i^C+K_{-i}^C)+\varepsilon_t \\
& - c^C]K_i^C f(\varepsilon_t)d\varepsilon_t \\
& + \int_{c^C-a+b(N+1)K_i^W+b(N+1)K_i^C}^{\infty} [a-b(K_i^W+K_{-i}^W)-b(K_i^C+K_{-i}^C)+\varepsilon_t \\
& - c^W]K_i^W f(\varepsilon_t)d\varepsilon_t
\end{aligned}
$$

Differentiating equation (A3.1) with respect to K_i^C and K_i^W yields:

$$
\begin{aligned}
& \frac{\partial}{\partial K_i^C} E(\pi_{it}|K_i^C, K_i^W) \\
& = \int_{c^C-a+b(N+1)K_i^W+b(N+1)K_i^C}^{\infty} [a-b(2K_i^W+K_{-i}^W)-b(2K_i^C+K_{-i}^C)+\varepsilon_t \qquad \text{(A3.2)} \\
& - c^C]f(\varepsilon_t)d\varepsilon_t
\end{aligned}
$$

$$\frac{\partial}{\partial K_i^W} E(\pi_{it} | K_i^C, K_i^W)$$

$$= \int_{c^W - a + b\,(N+1)K_i^W}^{c^C - a + b(N+1)K_i^W} [a - b(2K_i^W + K_{-i}^W) + \varepsilon_t - c^W] f\,(\varepsilon_t) d\varepsilon_t$$

$$+ \int_{c^C - a + b\,(N+1)K_i^W}^{c^C - a + b(N+1)K_i^W + b(N+1)K_i^C} (c^C - c^W)\, f(\varepsilon_t) d\varepsilon_t \tag{A3.3}$$

$$+ \int_{c^C - a + b(N+1)K_i^W + b(N+1)K_i^C}^{\infty} [a - b(2K_i^W + K_{-i}^W) - b(2K_i^C + K_{-i}^C) + \varepsilon_t$$

$$- c^W] f(\varepsilon_t) d\varepsilon_t$$

The *i*-th firm's profit-maximization capacities, K_i^{C*} and K_i^{W*}, are obtained when equation (2.8) is solved with basis in equations (A3.2) and (A3.3). The authors determine these optimal capacities in an implicit form, as follows:

$$K_i^{C*}: \int_{c^C - a + b(N+1)K_i^{W*} + b(N+1)K_i^{C*}}^{\infty} [a - b(N+1)(K_i^{W*} + K_i^{C*}) + \varepsilon_t - c^C] f(\varepsilon_t) d\varepsilon_t = \frac{\theta^C}{T} \tag{A3.4}$$

$$K_i^{B*}: \int_{c^W - a + b\,(N+1)K_i^{W*}}^{c^C - a + b(N+1)K_i^{W*}} [a - b(N+1)K_i^{W*} + \varepsilon_t - c^W] f\,(\varepsilon_t) d\varepsilon_t$$

$$+ \int_{c^C - a + b\,(N+1)K_i^{W*}}^{c^C - a + b(N+1)K_i^{W*} + b(N+1)K_i^{C*}} (c^C - c^W)\, f(\varepsilon_t) d\varepsilon_t \tag{A3.5}$$

$$+ \int_{c^C - a + b(N+1)K_i^{W*} + b(N+1)K_i^{C*}}^{\infty} [a - b(N+1)(K_i^{W*} + K_i^{P*}) + \varepsilon_t$$

$$- c^W] f(\varepsilon_t) d\varepsilon_t = \frac{\theta^W}{T}$$

However, these formulations do not allow us to obtain a closed-form expression of K_i^{C*} and K_i^{W*}. To achieve these closed-form expressions, the authors adopt the assumption that $f(\varepsilon_t)$ does not follow a normal distribution, but rather a uniform distribution.

Therefore, $f(\varepsilon_t) = 1/(\beta - \alpha)$, where $\alpha \leq \varepsilon_t \leq \beta$, $\alpha < c^W - a$, and $\beta > c^C - a + b(N+1)\left(K_i^{W*} + K_i^{C*}\right)$.

Thus, substituting the density function into equations (A3.4) and (A3.5) and solving them in order to satisfy $\partial^2 E(\pi_{it})/\left(\partial K_i^C\right)^2 < 0$ and $\partial^2 E(\pi_{it})/(\partial K_i^W)^2 < 0$, we obtain equations (2.16) and (2.17).

Annex 4: Country-Specific Data and Main Results: Portugal and Spain

Table 14: The Electricity Prices of Spain and Portugal during 2011

Day	January		February		March		April		May	
	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)
1	46.19	46.19	48.67	48.67	46.86	46.86	44.00	44.00	46.27	46.27
2	43.76	43.76	49.14	49.14	45.52	45.52	47.86	47.86	49.51	49.51
3	45.44	46.46	50.32	50.32	49.36	49.36	42.45	42.45	49.92	49.92
4	45.59	45.59	50.68	50.68	49.23	49.05	47.20	47.20	50.87	50.87
5	35.35	35.35	50.88	50.88	49.01	47.16	47.95	47.95	52.94	52.94
6	21.02	21.02	50.25	50.25	49.35	49.13	43.92	43.92	49.79	49.79
7	16.16	16.16	51.91	51.82	49.72	49.28	47.13	47.13	43.81	43.81
8	21.31	21.07	51.46	50.06	47.04	46.79	45.98	45.98	44.60	44.60
9	41.32	41.32	51.24	49.76	46.50	45.84	45.76	45.76	52.22	52.22
10	41.18	41.18	50.62	50.62	50.28	49.94	36.94	36.94	48.67	48.67
11	32.65	33.97	51.13	51.13	49.39	49.18	44.50	44.50	49.35	49.35
12	36.19	38.20	52.94	52.94	49.07	49.07	37.20	42.66	48.09	48.09
13	42.47	42.58	47.02	46.99	46.92	46.92	49.02	49.38	49.30	49.30
14	43.50	43.50	45.38	45.38	49.21	49.21	49.09	49.61	47.76	47.76
15	47.57	47.57	47.39	47.39	49.24	49.02	44.43	57.03	29.78	31.94
16	43.83	43.83	43.60	43.60	41.54	45.88	43.06	49.30	47.45	49.11
17	45.60	45.60	43.76	43.76	41.85	42.14	42.66	42.66	51.76	51.72
18	46.82	48.34	47.59	47.69	49.51	49.83	46.93	46.93	50.69	50.69
19	46.54	46.54	50.51	50.05	49.35	49.35	48.55	48.55	49.75	49.75
20	43.15	43.15	43.72	43.72	46.19	46.19	48.67	50.90	51.24	51.24
21	36.70	35.91	44.47	44.47	50.72	50.03	45.10	50.03	51.42	51.42
22	33.18	32.04	43.55	43.55	47.99	47.33	39.80	41.51	48.99	48.99
23	42.99	41.51	48.79	48.79	45.19	45.19	48.82	48.82	52.15	52.15
24	37.53	37.53	49.07	49.07	42.35	43.11	41.57	43.34	49.50	49.50
25	42.37	42.37	49.43	49.40	48.14	53.87	42.06	47.52	51.74	51.74
26	49.00	49.00	47.00	47.00	47.85	44.48	47.56	48.15	51.88	51.88
27	49.07	49.07	39.05	39.05	25.46	40.16	47.95	47.95	48.60	48.66
28	48.84	48.84	45.37	45.37	44.98	44.98	49.63	49.63	50.35	50.35
29	50.30	50.30			45.63	46.26	49.78	49.78	50.17	50.17
30	50.03	50.03			44.51	46.38	47.93	47.93	50.90	50.90
31	51.21	51.21			48.79	49.15			46.45	46.45

Day	June		July		August		September		October	
	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)
1	43.37	48.26	54.41	54.41	51.71	51.71	54.53	54.53	55.66	55.66
2	41.38	46.41	55.37	55.37	52.20	52.20	56.33	56.33	52.70	52.70
3	46.98	49.65	52.09	52.02	54.72	54.72	55.42	55.42	61.61	61.61
4	50.27	50.27	54.44	54.44	53.08	53.08	54.11	54.11	63.49	63.49
5	46.95	46.95	54.33	54.33	52.73	52.73	55.84	55.84	59.28	59.36
6	48.19	48.19	52.55	52.55	48.90	48.90	56.37	56.37	61.34	61.34
7	46.09	46.09	52.00	52.00	51.40	51.40	57.48	57.48	54.39	58.30
8	49.13	49.13	51.53	51.53	49.84	49.80	58.53	58.53	48.74	51.62
9	51.25	51.25	52.85	52.85	47.43	48.71	57.26	57.26	45.32	52.02
10	49.45	49.45	50.73	50.73	47.66	48.52	54.86	54.86	60.50	63.93
11	50.55	50.55	53.13	53.13	53.26	53.26	50.91	50.91	63.82	66.03
12	50.42	50.42	52.78	52.78	52.93	52.93	58.62	58.86	59.10	67.93
13	49.84	49.84	49.85	50.37	54.15	54.15	58.35	58.35	61.30	63.43
14	52.29	52.29	52.14	54.83	52.02	52.02	56.91	57.62	63.63	64.36
15	52.77	52.77	53.46	53.46	53.61	53.61	59.01	59.01	56.91	59.85
16	51.73	51.73	52.61	52.61	54.67	54.67	62.71	62.71	55.21	59.33
17	51.75	51.75	41.77	41.86	52.87	52.87	59.76	59.76	64.35	65.15
18	49.45	49.45	53.16	53.16	54.30	54.30	49.52	49.71	64.00	64.38
19	51.70	51.70	47.76	49.25	54.09	54.09	56.29	56.41	60.82	62.55
20	51.87	51.87	50.20	50.20	53.27	53.27	60.72	60.72	55.83	58.48
21	53.14	53.14	49.54	49.54	51.51	51.51	62.55	62.55	61.35	61.35
22	52.52	52.52	47.72	48.52	54.59	54.59	63.43	63.43	57.68	57.68
23	51.00	51.00	48.39	48.39	58.22	58.22	62.18	62.18	41.92	42.32
24	47.20	49.95	45.64	45.64	58.35	58.35	59.91	59.91	51.85	60.96
25	52.74	52.74	50.53	50.99	56.53	56.53	57.22	57.22	54.60	55.02
26	51.92	51.92	50.92	51.26	54.23	54.23	65.31	65.31	54.17	54.14
27	53.15	53.15	47.79	48.77	55.89	55.89	64.80	64.87	47.85	49.19
28	55.01	55.00	46.93	49.08	53.54	53.54	63.43	63.43	62.52	62.52
29	49.39	50.46	50.70	51.69	58.29	58.29	61.89	61.89	62.83	62.83
30	48.45	51.32	50.15	50.15	57.91	57.91	59.82	61.33	60.06	60.06
31			49.83	49.83	55.63	55.63			58.29	58.29

Day	November		December	
	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)	Spanish Arithmetical Average Price (EUR/MWh)	Portuguese Arithemetical Average Price (EUR/MWh)
1	55.39	55.39	53.47	53.47
2	42.13	48.57	49.97	49.74
3	39.31	42.58	55.12	55.12
4	59.82	59.55	47.26	47.26
5	38.81	39.91	49.61	49.61
6	26.64	29.50	52.02	52.02
7	51.23	55.01	54.11	54.11
8	53.34	53.34	55.31	55.31
9	52.66	52.66	53.58	53.58
10	51.52	51.52	57.06	57.06
11	49.43	49.43	51.84	51.84
12	45.03	44.83	58.27	58.27
13	15.52	18.60	47.66	49.04
14	40.54	40.62	46.79	48.49
15	52.82	52.82	47.69	47.69
16	53.19	54.10	37.78	42.12
17	56.29	56.29	48.59	48.59
18	48.96	48.96	47.75	47.75
19	50.07	50.07	60.08	60.08
20	47.44	47.44	51.91	51.91
21	55.90	55.90	51.74	52.00
22	48.53	48.53	51.16	52.16
23	47.39	47.90	52.32	52.32
24	51.69	51.69	41.33	41.66
25	53.71	53.71	39.71	43.61
26	50.09	50.20	47.00	47.94
27	49.33	49.33	53.22	53.22
28	56.68	56.68	53.72	53.72
29	53.30	53.30	43.46	47.12
30	54.59	54.59	49.45	50.00
31			43.14	43.63

Source: elaborated by the author, data from: (OMIE, 2012)

Table 15: The Outputs of Portugal during 2011

MWh	January					February					March				
Day	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	64,671	22,166	86,837	2,100	88,937	65,420	52,731	118,151	23,800	141,951	51,637	32,665	84,302	26,900	111,202
2	64,698	19,953	84,651	1,500	86,151	61,022	61,905	122,927	27,700	150,627	47,993	32,123	80,116	23,600	103,716
3	66,488	51,310	117,798	4,500	122,298	53,032	76,433	129,465	20,700	150,165	51,598	54,005	105,603	25,500	131,103
4	61,550	38,985	100,535	28,700	129,235	51,093	84,363	135,456	3,800	139,256	48,658	63,026	111,684	28,100	139,784
5	58,412	20,874	79,286	58,900	138,186	48,754	73,685	122,439	2,400	124,839	43,092	44,110	87,202	53,500	140,702
6	60,968	8,285	69,253	70,500	139,753	47,849	74,659	122,508	4,300	126,808	48,754	45,078	93,832	37,300	131,132
7	69,589	4,920	74,509	65,800	140,309	51,625	93,218	144,843	8,300	153,143	49,623	61,436	111,059	33,500	144,559
8	72,445	1,852	74,297	50,600	124,897	45,363	90,337	135,700	34,900	170,600	46,115	38,848	84,963	47,000	131,963
9	86,475	14,146	100,621	18,700	119,321	44,745	84,000	128,745	37,200	165,945	48,561	46,845	95,406	44,700	140,106
10	85,506	14,961	100,467	34,100	134,567	38,516	83,380	121,896	20,500	142,396	52,119	64,169	116,288	29,800	146,088
11	81,816	13,252	95,068	30,700	125,768	37,910	74,203	112,113	33,000	145,113	49,227	57,117	106,344	31,300	137,644
12	85,006	15,807	100,813	6,600	107,413	35,707	83,105	118,812	8,300	127,112	43,331	64,983	108,314	12,400	120,714
13	89,541	15,869	105,410	9,800	115,210	29,589	52,775	82,364	56,900	139,264	35,766	50,116	85,882	11,100	96,982
14	90,631	20,326	110,957	5,100	116,057	32,842	52,188	85,030	44,800	129,830	43,266	71,131	114,397	19,900	134,297
15	89,164	21,714	110,878	14,000	124,878	37,742	60,905	98,647	49,300	147,947	45,108	73,562	118,670	23,500	142,170
16	81,708	19,699	101,407	22,500	123,907	29,700	36,265	65,965	63,700	129,665	39,767	29,490	69,257	40,500	109,757
17	82,803	33,286	116,089	14,300	130,389	39,668	43,344	83,012	56,400	139,412	44,989	31,704	76,693	22,400	99,093
18	84,669	25,000	109,669	3,500	113,169	52,151	58,238	110,389	32,000	142,389	54,650	54,076	108,726	6,200	114,926
19	81,962	25,031	106,993	13,800	120,793	60,927	57,669	118,596	14,400	132,996	50,847	50,509	101,356	9,500	110,856
20	79,129	24,692	103,821	31,500	135,321	48,677	30,906	79,583	38,200	117,783	44,334	22,883	67,217	15,900	83,117
21	76,692	22,508	99,200	70,800	170,000	51,657	49,525	101,182	51,300	152,482	52,439	57,096	109,535	24,100	133,635
22	72,633	15,593	88,226	73,800	162,026	57,338	49,528	106,866	49,400	156,266	43,565	51,091	94,656	41,900	136,556
23	77,034	13,451	90,485	69,200	159,685	61,208	62,689	123,897	11,100	134,997	39,750	21,106	60,856	58,100	118,956
24	73,619	23,599	97,218	69,800	167,018	62,474	65,171	127,645	3,500	131,145	36,832	24,827	61,659	30,600	92,259
25	72,226	29,712	101,938	51,600	153,538	65,136	68,143	133,279	9,700	142,979	50,629	62,591	113,220	19,400	132,620
26	71,986	49,598	121,584	21,800	143,384	55,213	42,526	97,739	30,800	128,539	32,096	37,322	69,418	41,800	111,218
27	68,020	52,498	120,518	11,500	132,018	42,601	12,788	55,389	35,700	91,089	32,572	14,611	47,183	49,400	96,583
28	69,118	43,469	112,587	10,000	122,587	50,640	20,861	71,501	37,400	108,901	42,092	27,711	69,803	16,700	86,503
29	70,677	45,227	115,904	15,200	131,104						37,796	23,303	61,099	21,500	82,599
30	66,488	47,270	113,758	16,700	130,458						41,340	28,787	70,127	19,500	89,627
31	69,305	52,069	121,374	22,300	143,674						45,324	56,061	101,385	9,500	110,885

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	April					May					June				
Day	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	46,508	24,931	71,439	49,700	121,139	30,099	30,376	60,475	6,700	67,175	15,409	46,957	62,366	47,800	110,166
2	51,245	24,499	75,744	10,200	85,944	35,083	59,592	94,675	12,500	107,175	10,255	44,359	54,614	47,500	102,114
3	44,438	14,857	59,295	30,100	89,395	35,715	67,435	103,150	20,200	123,350	15,798	51,639	67,437	24,900	92,337
4	52,947	32,895	85,842	20,600	106,442	40,243	72,674	112,917	9,300	122,217	14,510	52,672	67,182	10,700	77,882
5	52,541	29,106	81,647	32,800	114,447	42,209	81,326	123,535	4,700	128,235	12,977	42,123	55,100	7,200	62,300
6	43,862	26,908	70,770	50,900	121,670	29,642	67,255	96,897	18,100	114,997	18,244	46,179	64,423	20,600	85,023
7	44,331	28,216	72,547	33,600	106,147	25,917	35,430	61,347	47,800	109,147	12,257	41,014	53,271	40,600	93,871
8	45,429	33,388	78,817	29,600	108,417	29,011	34,261	63,272	28,900	92,172	19,290	55,410	74,700	24,800	99,500
9	42,891	28,811	71,702	24,900	96,602	36,709	72,207	108,916	8,700	117,616	18,173	60,510	78,683	7,400	86,083
10	36,552	6,538	43,090	38,700	81,790	30,340	66,113	96,453	7,000	103,453	14,148	52,843	66,991	15,300	82,291
11	45,110	23,934	69,044	31,400	100,444	33,999	52,024	86,023	9,400	95,423	14,352	56,890	71,242	10,300	81,542
12	42,346	26,958	69,304	27,900	97,204	33,670	56,599	90,269	6,300	96,569	14,218	55,932	70,150	11,900	82,050
13	44,477	30,470	74,947	6,700	81,647	34,291	65,737	100,028	12,000	112,028	16,239	59,534	75,773	24,200	99,973
14	40,529	30,931	71,460	9,000	80,460	28,148	50,761	78,909	19,100	98,009	19,701	63,169	82,870	19,900	102,770
15	45,538	52,833	98,371	20,100	118,471	21,974	12,678	34,652	56,700	91,352	20,823	65,492	86,315	28,000	114,315
16	37,109	34,294	71,403	28,700	100,103	38,054	61,759	99,813	36,100	135,913	18,510	66,892	85,402	23,200	108,602
17	27,180	15,854	43,034	22,800	65,834	35,960	78,152	114,112	17,400	131,512	20,841	58,069	78,910	33,700	112,610
18	36,250	24,361	60,611	25,200	85,811	32,845	75,024	107,869	17,000	124,869	15,609	55,517	71,126	34,600	105,726
19	38,446	25,463	63,909	22,900	86,809	27,400	77,890	105,290	13,400	118,690	19,259	61,968	81,227	11,900	93,127
20	35,142	25,985	61,127	11,800	72,927	27,707	81,491	109,198	4,500	113,698	20,887	66,698	87,585	14,300	101,885
21	23,832	25,378	49,210	21,200	70,410	27,224	82,143	109,367	10,700	120,067	17,288	68,745	86,033	16,900	102,933
22	16,121	16,778	32,899	7,800	40,699	26,444	41,982	68,426	7,500	75,926	14,320	62,089	76,409	31,600	108,009
23	26,094	23,736	49,830	14,200	64,030	30,799	75,317	106,116	5,900	112,016	11,259	63,231	74,490	27,900	102,390
24	22,577	21,242	43,819	33,700	77,519	27,570	76,312	103,882	6,600	110,482	12,165	60,119	72,284	19,100	91,384
25	25,387	18,440	43,827	26,700	70,527	30,749	88,266	119,015	8,500	127,515	20,315	61,548	81,863	15,000	96,863
26	32,625	39,100	71,725	28,700	100,425	27,465	83,670	111,135	4,100	115,235	18,694	60,128	78,822	10,000	88,822
27	37,188	43,309	80,497	25,200	105,697	20,163	77,347	97,510	5,000	102,510	25,927	57,153	83,080	14,300	97,380
28	37,842	48,789	86,631	5,700	92,331	18,634	77,386	96,020	11,800	107,820	24,620	76,851	101,471	26,500	127,971
29	34,761	49,505	84,266	6,900	91,166	16,578	55,706	72,284	12,100	84,384	18,208	61,006	79,214	29,300	108,514
30	27,977	50,354	78,331	4,900	83,231	19,012	79,035	98,047	12,900	110,947	15,090	58,823	73,913	18,700	92,613
31						17,812	45,042	62,854	24,100	86,954					

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	July					August					September				
Day	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	23,107	58,360	81,467	11,500	92,967	11,412	62,716	74,128	12,900	87,028	15,719	76,272	91,991	23,600	115,591
2	12,276	66,522	78,798	14,700	93,498	13,713	61,919	75,632	11,400	87,032	13,945	77,512	91,457	5,700	97,157
3	9,340	58,723	68,063	33,700	101,763	17,809	63,577	81,386	12,200	93,586	11,946	63,352	75,298	12,000	87,298
4	14,540	73,320	87,860	22,000	109,860	11,079	63,819	74,898	29,100	103,998	12,540	55,943	68,483	30,000	98,483
5	14,944	79,324	94,268	23,300	117,568	12,451	62,197	74,648	26,700	101,348	16,360	74,464	90,824	24,800	115,624
6	12,552	67,117	79,669	36,300	115,969	7,198	47,911	55,109	30,500	85,609	15,588	79,211	94,799	12,100	106,899
7	11,601	57,414	69,015	47,100	116,115	9,576	53,452	63,028	28,200	91,228	16,749	81,340	98,089	12,600	110,689
8	11,090	58,163	69,253	33,500	102,753	9,971	60,941	70,912	29,100	100,012	17,085	79,828	96,913	6,400	103,313
9	11,455	67,103	78,558	17,500	96,058	8,492	55,019	63,511	28,300	91,811	10,274	80,384	90,658	20,300	110,958
10	10,067	52,119	62,186	17,300	79,486	12,048	53,006	65,054	22,700	87,754	11,236	56,051	67,287	19,000	86,287
11	14,585	67,655	82,240	10,700	92,940	16,452	61,241	77,693	10,500	88,193	11,439	49,560	60,999	22,900	83,899
12	13,507	60,033	73,540	39,000	112,540	17,761	59,690	77,451	15,700	93,151	23,634	70,564	94,198	10,500	104,698
13	10,406	54,987	65,393	35,800	101,193	10,750	65,638	76,388	20,300	96,688	17,959	74,302	92,261	12,100	104,361
14	15,081	61,684	76,765	21,000	97,765	5,998	58,494	64,492	22,100	86,592	17,457	62,684	80,141	17,000	97,141
15	11,561	63,184	74,745	19,800	94,545	9,751	66,359	76,110	11,100	87,210	14,142	74,030	88,172	6,700	94,872
16	8,100	61,529	69,629	36,800	106,429	11,246	65,097	76,343	12,400	88,743	24,553	77,076	101,629	8,500	110,129
17	7,967	24,631	32,598	53,600	86,198	11,074	61,697	72,771	15,500	88,271	15,095	75,453	90,548	22,900	113,448
18	12,919	55,850	68,769	45,600	114,369	10,887	63,472	74,359	8,500	82,859	8,667	43,166	51,833	55,300	107,133
19	10,211	51,682	61,893	47,500	109,393	13,339	61,138	74,477	7,100	81,577	17,042	66,959	84,001	23,200	107,201
20	10,891	53,628	64,519	36,700	101,219	8,097	68,039	76,136	23,100	99,236	20,568	73,402	93,970	13,900	107,870
21	11,672	52,693	64,365	38,100	102,465	6,528	53,446	59,974	28,400	88,374	21,175	77,207	98,382	7,600	105,982
22	12,086	46,253	58,339	33,600	91,939	15,466	76,133	91,599	5,300	96,899	23,380	77,308	100,688	7,800	108,488
23	13,042	47,447	60,489	24,600	85,089	20,073	85,241	105,314	17,200	122,514	14,589	77,523	92,112	15,200	107,312
24	11,691	33,340	45,031	28,700	73,731	17,504	82,625	100,129	15,800	115,929	10,476	62,257	72,733	13,400	86,133
25	15,478	46,135	61,613	26,700	88,313	13,370	79,792	93,162	19,900	113,062	8,834	62,353	71,187	4,700	75,887
26	14,430	48,622	63,052	28,500	91,552	9,328	68,956	78,284	32,600	110,884	19,930	63,143	83,073	4,900	87,973
27	11,971	47,739	59,710	31,900	91,610	11,253	61,903	73,156	15,500	88,656	19,166	63,040	82,206	5,300	87,506
28	14,552	49,288	63,840	19,200	83,040	9,614	53,129	62,743	12,300	75,043	13,356	62,390	75,746	12,100	87,846
29	15,938	61,229	77,167	9,700	86,867	17,560	73,514	91,074	11,600	102,674	12,181	61,319	73,500	14,600	88,100
30	9,376	58,915	68,291	22,000	90,291	18,094	69,477	87,571	17,500	105,071	11,993	60,297	72,290	13,700	85,990
31	8,896	57,270	66,166	18,900	85,066	14,869	69,420	84,289	27,500	111,789					

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	October					November					December				
Day	**Hydro Power**	**Thermal Power**	**Conventional Power Total (1)**	**Wind Power**	**TOTAL**	**Hydro Power**	**Thermal Power**	**Conventional Power Total (1)**	**Wind Power**	**TOTAL**	**Hydro Power**	**Thermal Power**	**Conventional Power Total (1)**	**Wind Power**	**TOTAL**
1	10,203	61,220	71,423	39,100	110,523	13,468	46,945	60,413	20,200	80,613	33,258	61,616	94,874	37,300	132,174
2	11,403	53,507	64,910	25,200	90,110	20,357	24,547	44,904	75,500	120,404	28,846	57,844	86,690	56,100	142,790
3	15,451	73,654	89,105	8,000	97,105	20,803	22,460	43,263	60,200	103,463	32,393	61,744	94,137	24,100	118,237
4	18,613	79,925	98,538	11,800	110,338	24,689	62,894	87,583	20,600	108,183	19,144	56,114	75,258	27,400	102,658
5	13,735	72,080	85,815	11,500	97,315	14,419	7,853	22,272	56,700	78,972	30,265	56,445	86,710	31,800	118,510
6	14,868	67,864	82,732	29,400	112,132	20,529	180	20,709	35,300	56,009	28,068	61,418	89,486	21,700	111,186
7	13,940	55,116	69,056	46,300	115,356	26,411	48,332	74,743	9,800	84,543	35,126	61,290	96,416	8,700	105,116
8	12,126	51,681	63,807	37,800	101,607	22,118	53,225	75,343	30,200	105,543	33,289	62,246	95,535	2,500	98,035
9	11,829	45,704	57,533	35,700	93,233	24,690	54,481	79,171	21,900	101,071	29,814	62,980	92,794	8,400	101,194
10	22,250	64,073	86,323	20,000	106,323	26,625	59,245	85,870	40,300	126,170	34,244	63,848	98,092	22,000	120,092
11	24,402	79,742	104,144	5,700	109,844	34,383	53,327	87,710	41,400	129,110	19,891	65,175	85,066	13,700	98,766
12	29,005	65,050	94,055	4,800	98,855	21,931	39,165	61,096	78,900	139,996	40,802	61,913	102,715	23,800	126,515
13	28,834	74,918	103,752	7,600	111,352	19,633	4,113	23,746	81,000	104,746	20,216	57,941	78,157	57,400	135,557
14	25,938	74,719	100,657	7,500	108,157	25,674	39,040	64,714	60,900	125,614	18,904	56,536	75,440	51,500	126,940
15	14,752	66,503	81,255	4,100	85,355	27,131	55,778	82,909	41,900	124,809	19,274	57,989	77,263	43,500	120,763
16	16,293	51,836	68,129	3,900	72,029	29,267	55,729	84,996	4,800	89,796	19,057	48,248	67,305	72,900	140,205
17	38,684	64,156	102,840	5,000	107,840	40,206	68,742	108,948	7,500	116,448	26,024	61,313	87,337	27,900	115,237
18	22,071	75,845	97,916	9,800	107,716	30,360	43,618	73,978	42,800	116,778	30,285	62,189	92,474	19,800	112,274
19	18,161	67,749	85,910	25,600	111,510	31,428	55,138	86,566	16,800	103,366	48,620	65,326	113,946	7,500	121,446
20	14,158	51,497	65,655	38,600	104,255	26,687	48,524	75,211	8,300	83,511	29,114	64,046	93,160	28,100	121,260
21	14,163	73,020	87,183	19,200	106,383	39,651	58,290	97,941	27,100	125,041	29,085	63,248	92,333	21,900	114,233
22	8,536	44,858	53,394	18,500	71,894	28,377	52,600	80,977	47,000	127,977	26,730	63,883	90,613	11,500	102,113
23	7,993	21,429	29,422	71,300	100,722	30,781	48,188	78,969	41,800	120,769	21,392	64,048	85,440	46,800	132,240
24	16,307	41,559	57,866	60,200	118,066	33,224	58,255	91,479	24,700	116,179	17,780	33,206	50,986	54,800	105,786
25	15,839	35,330	51,169	31,900	83,069	36,472	60,469	96,941	18,100	115,041	21,212	31,913	53,125	40,600	93,725
26	13,453	42,259	55,712	75,400	131,112	29,779	52,722	82,501	16,000	98,501	24,532	54,397	78,929	21,700	100,629
27	13,838	37,350	51,188	62,300	113,488	23,886	56,222	80,108	8,100	88,208	29,683	59,481	89,164	7,400	96,564
28	24,000	57,253	81,253	23,300	104,553	37,397	67,298	104,695	6,400	111,095	25,301	60,723	86,024	17,100	103,124
29	20,882	59,123	80,005	7,900	87,905	33,833	60,424	94,257	12,500	106,757	20,757	42,624	63,381	41,100	104,481
30	19,837	53,401	73,238	9,800	83,038	33,720	61,846	95,566	15,800	111,366	20,612	43,840	64,452	17,900	82,352
31	17,230	44,480	61,710	29,500	91,210						19,347	32,699	52,046	24,400	76,446

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

Source: elaborated by the author, data from: (OMIE, 2012, REN, 2012)

Table 16: The Outputs of Spain during 2011

MWh	January						February					
Day	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	124,782	155,554	126,197	406,533	34,000	440,533	141,875	151,040	251,937	544,852	160,000	704,852
2	121,220	155,530	108,801	385,551	123,000	508,551	144,458	154,069	233,164	531,691	184,000	715,691
3	155,558	155,554	209,264	520,376	83,000	603,376	145,028	153,956	259,263	558,247	122,000	680,247
4	145,757	155,650	216,204	517,611	107,000	624,611	142,196	154,048	289,623	585,867	78,000	663,867
5	136,582	155,695	109,155	401,432	194,000	595,432	127,939	154,546	297,071	579,556	42,000	621,556
6	108,382	155,683	47,207	311,272	240,000	551,272	111,874	154,503	258,680	525,057	30,000	555,057
7	112,482	155,688	44,655	312,825	242,000	554,825	129,991	154,506	297,447	581,944	47,000	628,944
8	166,548	155,684	37,574	359,806	221,000	580,806	126,526	154,510	299,324	580,360	54,000	634,360
9	199,952	155,667	57,962	413,581	91,000	504,581	124,055	155,024	297,876	576,955	77,000	653,955
10	206,096	155,602	152,731	514,429	152,000	666,429	115,868	155,264	279,195	550,327	96,000	646,327
11	182,773	155,602	133,348	471,723	222,000	693,723	122,024	155,240	283,731	560,995	79,000	639,995
12	204,612	155,619	165,099	525,330	146,000	671,330	97,409	155,263	315,165	567,837	67,000	634,837
13	213,743	155,641	203,684	573,068	72,000	645,068	77,988	155,242	166,048	399,278	178,000	577,278
14	214,736	155,626	207,220	577,582	67,000	644,582	96,878	155,249	175,906	428,033	229,000	657,033
15	201,728	131,893	170,281	503,902	63,000	566,902	93,939	155,229	224,863	474,031	173,000	647,031
16	183,068	131,894	115,470	430,432	94,000	524,432	95,076	155,262	145,998	396,336	249,000	645,336
17	196,065	131,898	265,957	593,920	52,000	645,920	103,245	155,241	133,599	392,085	241,000	633,085
18	197,741	131,902	267,551	597,194	52,000	649,194	126,294	155,234	174,737	456,265	185,000	641,265
19	201,787	138,478	265,852	606,117	49,000	655,117	105,533	151,193	212,741	469,467	88,000	557,467
20	178,703	155,713	218,191	552,607	107,000	659,607	95,711	155,229	96,705	347,645	161,000	508,645
21	176,153	155,720	95,305	427,178	255,000	682,178	109,679	155,205	119,318	384,202	281,000	665,202
22	156,625	155,722	43,019	355,366	261,000	616,366	129,421	152,407	124,675	406,503	268,000	674,503
23	160,613	154,409	47,621	362,643	221,000	583,643	138,309	147,489	216,606	502,404	134,000	636,404
24	156,988	155,673	165,161	477,822	220,000	697,822	133,490	148,276	256,572	538,338	85,000	623,338
25	168,607	155,744	222,902	547,253	151,000	698,253	124,795	148,115	242,285	515,195	83,000	598,195
26	179,418	155,624	287,453	622,495	79,000	701,495	114,043	151,270	135,953	401,266	154,000	555,266
27	178,976	162,945	295,790	637,711	73,000	710,711	104,856	140,835	87,773	333,464	209,000	542,464
28	179,797	160,826	273,099	613,722	97,000	710,722	115,685	150,687	124,012	390,384	251,000	641,384
29	152,057	140,415	244,243	536,715	81,000	617,715						
30	138,662	150,324	175,621	464,607	88,000	552,607						
31	160,881	151,090	246,036	558,007	120,000	678,007						

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	March						April					
Day	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	137,546	153,975	132,419	423,940	213,000	636,940	145,985	129,995	116,085	392,065	143,000	535,065
2	139,279	153,975	144,399	437,653	209,000	646,653	157,486	129,973	91,701	379,160	131,000	510,160
3	154,377	148,107	167,153	469,637	124,000	593,637	134,648	129,916	79,770	344,334	103,000	447,334
4	146,461	153,941	159,445	459,847	109,000	568,847	165,319	129,894	156,924	452,137	75,000	527,137
5	126,181	152,091	193,279	471,551	99,000	570,551	158,205	132,880	186,009	477,094	77,000	554,094
6	119,985	146,781	168,742	435,508	59,000	494,508	152,197	131,416	128,085	411,698	125,000	536,698
7	131,509	153,256	185,919	470,684	121,000	591,684	151,367	132,815	172,146	456,328	82,000	538,328
8	121,204	153,138	137,550	411,892	238,000	649,892	148,324	137,951	170,638	456,913	54,000	510,913
9	146,877	153,070	147,741	447,688	155,000	602,688	136,148	146,124	110,119	392,391	94,000	486,391
10	153,692	141,785	186,161	481,638	115,000	596,638	105,613	151,150	42,641	299,404	166,000	465,404
11	142,149	141,996	179,980	464,125	164,000	628,125	140,962	154,215	93,831	389,008	187,000	576,008
12	129,179	142,135	180,989	452,303	112,000	564,303	131,892	154,162	77,876	363,930	196,000	559,930
13	126,792	152,070	145,878	424,740	75,000	499,740	155,076	154,103	165,402	474,581	81,000	555,581
14	140,553	152,190	178,794	471,537	166,000	637,537	141,334	153,847	181,369	476,550	91,000	567,550
15	136,527	152,111	168,755	457,393	154,000	611,393	117,623	156,081	113,231	386,935	152,000	538,935
16	129,920	151,937	130,940	412,797	268,000	680,797	114,291	153,743	78,116	346,150	162,000	508,150
17	141,550	151,617	140,569	433,736	204,000	637,736	98,327	156,075	73,820	328,222	114,000	442,222
18	159,852	151,545	156,761	468,158	118,000	586,158	139,097	156,134	118,255	413,486	134,000	547,486
19	136,241	130,366	153,557	420,164	134,000	554,164	147,652	156,117	139,318	443,087	108,000	551,087
20	115,955	130,317	134,256	380,528	119,000	499,528	152,839	156,077	101,982	410,898	133,000	543,898
21	137,319	130,335	178,686	446,340	151,000	597,340	113,771	155,873	83,096	352,740	146,000	498,740
22	125,427	130,264	150,275	405,966	184,000	589,966	95,601	155,892	76,675	328,168	97,000	425,168
23	119,754	130,236	142,026	392,016	256,000	648,016	132,043	155,868	89,594	377,505	42,000	419,505
24	133,011	130,165	131,402	394,578	233,000	627,578	83,725	156,113	69,154	308,992	101,000	409,992
25	151,280	130,213	184,787	466,280	110,000	576,280	109,829	155,725	71,078	336,632	124,000	460,632
26	137,055	123,219	137,119	397,393	111,000	508,393	119,462	155,668	114,583	389,713	143,000	532,713
27	100,057	124,061	51,316	275,434	220,000	495,434	115,669	155,421	133,379	404,469	115,000	519,469
28	153,012	130,011	125,809	408,832	153,000	561,832	147,622	155,502	139,617	442,741	86,000	528,741
29	149,413	129,941	153,731	433,085	140,000	573,085	147,514	154,727	134,057	436,298	67,000	503,298
30	154,335	129,882	143,424	427,641	154,000	581,641	117,798	153,775	106,321	377,894	54,000	431,894
31	176,723	129,851	177,275	483,849	69,000	552,849						

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	May						June					
Day	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	99,325	144,535	52,656	296,516	70,000	366,516	68,702	131,470	115,577	315,749	237,000	552,749
2	129,902	144,519	86,774	361,195	48,000	409,195	77,302	136,023	106,782	320,107	236,000	556,107
3	111,387	144,013	115,175	370,575	84,000	454,575	80,289	154,240	150,627	385,156	124,000	509,156
4	116,736	143,900	171,321	431,957	54,000	485,957	81,538	167,060	121,480	370,078	75,000	445,078
5	123,340	121,661	178,967	423,968	52,000	475,968	79,806	171,067	97,131	348,004	59,000	407,004
6	106,489	121,608	107,755	335,852	184,000	519,852	85,792	172,878	187,688	446,358	60,000	506,358
7	87,045	94,393	61,830	243,268	198,000	441,268	81,998	176,921	135,088	394,007	113,000	507,007
8	91,574	96,687	62,864	251,125	114,000	365,125	83,643	178,774	141,249	403,666	99,000	502,666
9	134,327	96,677	151,055	382,059	68,000	450,059	84,989	178,428	187,388	450,805	42,000	492,805
10	136,263	102,950	106,200	345,413	121,000	466,413	79,985	178,156	141,726	399,867	62,000	461,867
11	137,637	114,495	133,705	385,837	106,000	491,837	80,647	176,790	126,286	383,723	29,000	412,723
12	116,241	121,519	134,756	372,516	119,000	491,516	62,947	166,670	78,242	307,859	56,000	363,859
13	120,538	121,488	146,830	388,856	84,000	472,856	75,753	155,232	121,587	352,572	77,000	429,572
14	92,989	121,280	54,406	268,675	161,000	429,675	84,617	155,261	199,253	439,131	41,000	480,131
15	62,243	121,265	17,620	201,128	233,000	434,128	73,536	155,146	209,855	438,537	53,000	491,537
16	109,041	96,500	70,622	276,163	140,000	416,163	74,620	154,983	192,014	421,617	63,000	484,617
17	107,117	118,710	141,519	367,346	88,000	455,346	75,180	154,910	166,338	396,428	112,000	508,428
18	100,277	121,328	137,571	359,176	135,000	494,176	71,150	154,828	91,136	317,114	125,000	442,114
19	101,690	121,328	152,622	375,640	80,000	455,640	73,701	154,818	110,854	339,373	45,000	384,373
20	103,613	121,299	185,585	410,497	47,000	457,497	84,056	154,865	207,435	446,356	54,000	500,356
21	95,258	121,252	160,582	377,092	31,000	408,092	93,244	154,807	208,421	456,472	63,000	519,472
22	78,230	121,251	102,310	301,791	78,000	379,791	85,457	154,866	201,574	441,897	83,000	524,897
23	102,410	111,483	187,737	401,630	66,000	467,630	75,993	154,779	127,180	357,952	88,000	445,952
24	103,661	117,086	149,305	370,052	110,000	480,052	71,246	154,789	102,700	328,735	112,000	440,735
25	95,612	120,957	184,474	401,043	79,000	480,043	84,085	154,722	118,028	356,835	91,000	447,835
26	98,356	120,937	187,365	406,658	90,000	496,658	83,622	154,770	99,169	337,561	85,000	422,561
27	100,751	124,704	136,180	361,635	124,000	485,635	96,709	154,774	209,784	461,267	104,000	565,267
28	88,622	121,303	135,429	345,354	63,000	408,354	73,724	154,681	224,761	453,166	104,000	557,166
29	82,655	124,818	119,493	326,966	56,000	382,966	76,232	153,973	157,090	387,295	196,000	583,295
30	109,828	128,898	184,005	422,731	63,000	485,731	79,571	153,926	154,521	388,018	176,000	564,018
31	83,681	130,975	136,783	351,439	157,000	508,439						

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	July						August					
Day	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	86,092	153,957	228,645	468,694	100,000	568,694	74,135	169,698	171,474	415,307	100,000	515,307
2	69,059	151,315	238,367	458,741	52,000	510,741	75,166	168,786	178,094	422,046	79,000	501,046
3	61,396	152,600	159,009	373,005	102,000	475,005	77,207	164,663	234,606	476,476	38,000	514,476
4	68,483	152,623	273,966	495,072	75,000	570,072	73,695	164,508	207,609	445,812	55,000	500,812
5	81,662	152,459	270,669	504,790	63,000	567,790	74,245	164,512	206,538	445,295	60,000	505,295
6	83,250	152,779	235,181	471,210	100,000	571,210	52,456	164,453	109,401	326,310	134,000	460,310
7	90,016	152,690	203,258	445,964	116,000	561,964	46,097	164,338	71,277	281,712	94,000	375,712
8	96,420	152,654	195,376	444,450	100,000	544,450	60,965	167,811	134,051	362,827	120,000	482,827
9	83,291	152,777	172,486	408,554	46,000	454,554	57,994	167,971	112,590	338,555	176,000	514,555
10	79,537	153,099	122,795	355,431	58,000	413,431	58,066	172,424	136,217	366,707	136,000	502,707
11	84,781	153,119	221,339	459,239	71,000	530,239	59,856	175,001	170,361	405,218	95,000	500,218
12	91,309	152,708	220,702	464,719	127,000	591,719	60,540	174,501	197,975	433,016	84,000	517,016
13	96,126	152,761	164,004	412,891	167,000	579,891	51,290	174,058	170,595	395,943	43,000	438,943
14	96,299	152,674	195,480	444,453	79,000	523,453	46,547	173,944	94,696	315,187	63,000	378,187
15	97,710	152,881	220,401	470,992	61,000	531,992	55,869	173,769	113,655	343,293	44,000	387,293
16	84,052	152,959	166,168	403,179	92,000	495,179	56,136	173,934	207,887	437,957	43,000	480,957
17	62,777	153,002	84,036	299,815	159,000	458,815	62,919	173,794	204,471	441,184	79,000	520,184
18	82,401	152,928	184,879	420,208	106,000	526,208	59,351	174,187	209,014	442,552	95,000	537,552
19	82,208	152,912	128,726	363,846	180,000	543,846	52,410	174,364	209,987	436,761	110,000	546,761
20	84,996	152,993	197,809	435,798	86,000	521,798	46,270	173,943	127,898	348,111	114,000	462,111
21	87,780	158,546	179,427	425,753	99,000	524,753	41,562	174,142	100,133	315,837	116,000	431,837
22	91,718	157,276	169,634	418,628	142,000	560,628	51,780	174,065	191,619	417,464	89,000	506,464
23	61,959	163,482	112,418	337,859	139,000	476,859	53,016	172,187	255,465	480,668	41,000	521,668
24	52,652	161,622	82,277	296,551	137,000	433,551	45,482	158,009	271,172	474,663	49,000	523,663
25	78,842	162,011	136,599	377,452	106,000	483,452	41,233	165,369	256,874	463,476	99,000	562,476
26	89,711	161,658	191,618	442,987	98,000	540,987	38,361	173,062	179,504	390,927	153,000	543,927
27	89,409	161,389	167,622	418,420	138,000	556,420	36,689	173,271	163,015	372,975	76,000	448,975
28	80,543	161,236	170,137	411,916	137,000	548,916	42,276	172,676	118,415	333,367	85,000	418,367
29	87,990	161,279	198,319	447,588	89,000	536,588	50,328	172,413	240,638	463,379	60,000	523,379
30	53,549	166,980	146,171	366,700	114,000	480,700	51,095	172,968	261,290	485,353	60,000	545,353
31	62,336	169,826	116,866	349,028	56,000	405,028	51,494	173,114	215,513	440,121	101,000	541,121

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	September						October					
Day	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	51,713	171,634	222,141	445,488	85,000	530,488	57,805	150,755	145,183	353,743	118,000	471,743
2	62,766	173,858	243,457	480,081	36,000	516,081	65,027	150,779	113,306	329,112	73,000	402,112
3	48,554	171,893	176,399	396,846	72,000	468,846	76,626	151,239	250,088	477,953	38,000	515,953
4	42,021	171,770	101,479	315,270	83,000	398,270	75,024	151,368	258,535	484,927	54,000	538,927
5	57,551	171,204	218,633	447,388	64,000	511,388	76,470	151,468	261,242	489,180	53,000	542,180
6	62,044	169,806	244,715	476,565	58,000	534,565	75,384	151,504	257,905	484,793	77,000	561,793
7	61,078	168,097	246,588	475,763	50,000	525,763	58,137	151,506	165,093	374,736	180,000	554,736
8	62,117	170,988	254,099	487,204	47,000	534,204	42,310	151,464	100,504	294,278	205,000	499,278
9	50,718	170,993	228,604	450,315	100,000	550,315	42,565	152,744	92,286	287,595	163,000	450,595
10	42,191	170,810	156,877	369,878	124,000	493,878	77,098	152,937	226,027	456,062	71,000	527,062
11	40,705	170,599	95,846	307,150	116,000	423,150	78,132	152,838	252,666	483,636	39,000	522,636
12	55,618	170,482	261,499	487,599	59,000	546,599	63,597	152,621	204,528	420,746	32,000	452,746
13	46,201	170,509	263,691	480,401	91,000	571,401	75,541	153,041	224,214	452,796	55,000	507,796
14	44,924	171,311	237,114	453,349	139,000	592,349	80,618	152,719	228,072	461,409	37,000	498,409
15	45,712	169,296	283,357	498,365	88,000	586,365	54,454	152,690	185,599	392,743	73,000	465,743
16	61,146	169,461	291,608	522,215	54,000	576,215	39,465	151,832	154,260	345,557	65,000	410,557
17	44,319	166,288	199,286	409,893	53,000	462,893	72,892	152,328	241,825	467,045	55,000	522,045
18	37,215	169,192	80,552	286,959	161,000	447,959	66,554	152,328	265,591	484,473	35,000	519,473
19	54,756	170,732	201,130	426,618	125,000	551,618	72,214	152,074	224,958	449,246	75,000	524,246
20	61,418	171,649	248,009	481,076	77,000	558,076	64,202	152,344	205,093	421,639	159,000	580,639
21	59,312	172,025	279,398	510,735	55,000	565,735	77,163	152,389	247,263	476,815	85,000	561,815
22	66,949	171,625	267,396	505,970	69,000	574,970	69,090	152,640	194,788	416,518	96,000	512,518
23	62,691	171,423	263,738	497,852	47,000	544,852	35,037	152,654	77,957	265,648	195,000	460,648
24	51,063	167,383	223,875	442,321	37,000	479,321	67,239	129,151	144,366	340,756	232,000	572,756
25	48,855	150,996	177,246	377,097	39,000	416,097	75,030	129,185	152,601	356,816	196,000	552,816
26	75,451	150,839	276,022	502,312	46,000	548,312	72,740	129,228	135,213	337,181	200,000	537,181
27	61,608	151,370	279,430	492,408	54,000	546,408	78,494	129,580	144,843	352,917	172,000	524,917
28	58,143	151,224	273,323	482,690	83,000	565,690	78,544	129,743	208,116	416,403	104,000	520,403
29	51,639	151,194	256,412	459,245	94,000	553,245	60,947	129,610	203,198	393,755	31,000	424,755
30	50,577	151,172	237,279	439,028	93,000	532,028	76,652	141,650	174,800	393,102	24,000	417,102
31							82,487	151,983	153,288	387,758	103,000	490,758

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

MWh	November						December					
Day	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL	Hydro Power	Nuclear Power	Thermal Power	Conventional Power Total (1)	Wind Power	TOTAL
1	70,795	153,317	143,557	367,669	70,000	437,669	90,744	131,155	171,915	393,814	130,000	523,814
2	58,693	153,073	66,073	277,839	254,000	531,839	85,660	155,917	130,536	372,113	178,000	550,113
3	54,227	153,089	61,479	268,795	248,000	516,795	93,300	156,787	133,181	383,268	98,000	481,268
4	93,932	152,862	133,012	379,806	103,000	482,806	77,371	156,761	96,659	330,791	128,000	458,791
5	53,099	153,072	61,801	267,972	263,000	530,972	86,555	156,733	144,954	388,242	160,000	548,242
6	50,563	153,424	30,973	234,960	261,000	495,960	84,778	156,785	131,016	372,579	135,000	507,579
7	98,624	153,596	138,522	390,742	119,000	509,742	89,961	156,785	172,528	419,274	91,000	510,274
8	89,873	155,973	153,765	399,611	109,000	508,611	89,621	156,785	162,854	409,260	33,000	442,260
9	88,077	153,635	170,056	411,768	75,000	486,768	87,272	156,809	166,587	410,668	44,000	454,668
10	80,341	153,792	158,421	392,554	101,000	493,554	86,360	156,809	144,205	387,374	69,000	456,374
11	91,069	147,537	132,643	371,249	123,000	494,249	66,152	156,833	107,418	330,403	82,000	412,403
12	55,589	130,708	62,268	248,565	206,000	454,565	88,970	156,833	158,497	404,300	171,000	575,300
13	46,502	134,264	17,518	198,284	256,000	454,284	63,436	156,809	122,306	342,551	266,000	608,551
14	86,023	151,679	62,925	300,627	219,000	519,627	68,576	156,761	111,934	337,271	267,000	604,271
15	102,805	145,369	116,888	365,062	118,000	483,062	73,618	156,785	129,866	360,269	241,000	601,269
16	117,967	149,857	173,606	441,430	79,000	520,430	66,585	156,785	62,591	285,961	269,000	554,961
17	120,590	145,245	189,056	454,891	45,000	499,891	74,204	156,809	95,713	326,726	217,000	543,726
18	117,676	153,713	116,086	387,475	148,000	535,475	69,605	155,043	92,346	316,994	130,000	446,994
19	103,408	156,269	114,189	373,866	126,000	499,866	99,716	156,761	203,764	460,241	115,000	575,241
20	83,600	154,090	90,961	328,651	121,000	449,651	78,634	156,809	178,374	413,817	191,000	604,817
21	120,690	154,098	172,377	447,165	54,000	501,165	74,231	156,826	180,085	411,142	204,000	615,142
22	102,895	154,188	126,637	383,720	126,000	509,720	75,912	156,818	190,199	422,929	145,000	567,929
23	98,602	156,162	124,162	378,926	140,000	518,926	82,740	156,262	163,618	402,620	109,000	511,620
24	110,945	155,967	162,616	429,528	58,000	487,528	66,427	156,274	54,240	276,941	196,000	472,941
25	115,853	155,941	179,385	451,179	56,000	507,179	65,872	156,302	50,626	272,800	112,000	384,800
26	106,627	155,896	143,206	405,729	54,000	459,729	80,280	156,327	115,232	351,839	64,000	415,839
27	97,035	156,413	117,758	371,206	36,000	407,206	98,618	156,327	175,897	430,842	39,000	469,842
28	121,357	156,147	201,664	479,168	31,000	510,168	92,718	156,276	167,755	416,749	84,000	500,749
29	110,854	156,693	189,878	457,425	76,000	533,425	70,358	156,281	96,691	323,330	197,000	520,330
30	113,336	156,650	197,359	467,345	71,000	538,345	86,190	156,257	107,758	350,205	158,000	508,205
31							59,295	156,264	76,184	291,743	165,000	456,743

(1) The value of conventional power is defined as the sum of hydro, nuclear and thermal power.

Source: elaborated by the author, data from: (OMIE, 2012, REE, 2012)

Table 17: Daily Averages of Hourly Electricity Outputs for Portugal and Spain during 2011 (1000 MWh)

Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain
1	3.71	18.36	**41**	5.93	26.93	**81**	5.69	24.58	**121**	2.80	15.27	**161**	3.43	19.24
2	3.59	21.19	**42**	6.05	26.67	**82**	4.96	27.00	**122**	4.47	17.05	**162**	3.40	17.20
3	5.10	25.14	**43**	5.30	26.45	**83**	3.84	26.15	**123**	5.14	18.94	**163**	3.42	15.16
4	5.38	26.03	**44**	5.80	24.05	**84**	5.53	24.01	**124**	5.09	20.25	**164**	4.17	17.90
5	5.76	24.81	**45**	5.41	27.38	**85**	4.63	21.18	**125**	5.34	19.83	**165**	4.28	20.01
6	5.82	22.97	**46**	6.16	26.96	**86**	4.02	20.64	**126**	4.79	21.66	**166**	4.76	20.48
7	5.85	23.12	**47**	5.40	26.89	**87**	3.60	23.41	**127**	4.55	18.39	**167**	4.53	20.19
8	5.20	24.20	**48**	5.81	26.38	**88**	3.44	23.88	**128**	3.84	15.21	**168**	4.69	21.18
9	4.97	21.02	**49**	5.93	26.72	**89**	3.73	24.24	**129**	4.90	18.75	**169**	4.41	18.42
10	5.61	27.77	**50**	5.54	23.23	**90**	4.62	23.04	**130**	4.31	19.43	**170**	3.88	16.02
11	5.24	28.91	**51**	4.91	21.19	**91**	5.05	22.29	**131**	3.98	20.49	**171**	4.25	20.85
12	4.48	27.97	**52**	6.35	27.72	**92**	3.58	21.26	**132**	4.02	20.48	**172**	4.29	21.64
13	4.80	26.88	**53**	6.51	28.10	**93**	3.72	18.64	**133**	4.67	19.70	**173**	4.50	21.87
14	4.84	26.86	**54**	5.62	26.52	**94**	4.44	21.96	**134**	4.08	17.90	**174**	4.27	18.58
15	5.20	23.62	**55**	5.46	25.97	**95**	4.77	23.09	**135**	3.81	18.09	**175**	3.81	18.36
16	5.16	21.85	**56**	5.96	24.92	**96**	5.07	22.36	**136**	5.66	17.34	**176**	4.04	18.66
17	5.43	26.91	**57**	5.36	23.14	**97**	4.42	22.43	**137**	5.48	18.97	**177**	3.70	17.61
18	4.72	27.05	**58**	3.80	22.60	**98**	4.52	21.29	**138**	5.20	20.59	**178**	4.06	23.55
19	5.03	27.30	**59**	4.54	26.72	**99**	4.03	20.27	**139**	4.95	18.99	**179**	5.33	23.22
20	5.64	27.48	**60**	4.63	26.54	**100**	3.41	19.39	**140**	4.74	19.06	**180**	4.52	24.30
21	7.08	28.42	**61**	4.32	26.94	**101**	4.19	24.00	**141**	5.00	17.00	**181**	3.86	23.50
22	6.75	25.68	**62**	5.46	24.73	**102**	4.05	23.33	**142**	3.16	15.82	**182**	3.87	23.70
23	6.65	24.32	**63**	5.82	23.70	**103**	3.40	23.15	**143**	4.67	19.48	**183**	3.90	21.28
24	6.96	29.08	**64**	5.86	23.77	**104**	3.35	23.65	**144**	4.60	20.00	**184**	4.24	19.79
25	6.40	29.09	**65**	5.46	20.60	**105**	4.94	22.46	**145**	5.31	20.00	**185**	4.58	23.75
26	5.97	29.23	**66**	6.02	24.65	**106**	4.17	21.17	**146**	4.80	20.69	**186**	4.90	23.66
27	5.50	29.61	**67**	5.50	27.08	**107**	2.74	18.43	**147**	4.27	20.23	**187**	4.83	23.80
28	5.11	29.61	**68**	5.84	25.11	**108**	3.58	22.81	**148**	4.49	17.01	**188**	4.84	23.42
29	5.46	25.74	**69**	6.09	24.86	**109**	3.62	22.96	**149**	3.52	15.96	**189**	4.28	22.69
30	5.44	23.03	**70**	5.74	26.17	**110**	3.04	22.66	**150**	4.62	20.24	**190**	4.00	18.94
31	5.99	28.25	**71**	5.03	23.51	**111**	2.93	20.78	**151**	3.62	21.18	**191**	3.31	17.23
32	5.91	29.37	**72**	4.04	20.82	**112**	1.70	17.72	**152**	4.59	23.03	**192**	3.87	22.09
33	6.28	29.82	**73**	5.60	26.56	**113**	2.67	17.48	**153**	4.25	23.17	**193**	4.69	24.65
34	6.26	28.34	**74**	5.92	25.47	**114**	3.23	17.08	**154**	3.85	21.21	**194**	4.22	24.16
35	5.80	27.66	**75**	4.57	28.37	**115**	2.94	19.19	**155**	3.25	18.54	**195**	4.07	21.81
36	5.20	25.90	**76**	4.13	26.57	**116**	4.18	22.20	**156**	2.60	16.96	**196**	3.94	22.17
37	5.28	23.13	**77**	4.79	24.42	**117**	4.40	21.64	**157**	3.54	21.10	**197**	4.43	20.63
38	6.38	26.21	**78**	4.62	23.09	**118**	3.85	22.03	**158**	3.91	21.13	**198**	3.59	19.12
39	7.11	26.43	**79**	3.46	20.81	**118**	3.80	20.97	**159**	4.15	20.94	**199**	4.77	21.93
40	6.91	27.25	**80**	5.57	24.89	**120**	3.47	18.00	**160**	3.59	20.53	**200**	4.56	22.66

Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain
201	4.22	21.74	**241**	4.28	21.81	**281**	4.23	20.80	**321**	4.85	20.83	**361**	4.02	19.58
202	4.27	21.86	**242**	4.38	22.72	**282**	3.88	18.77	**322**	4.87	22.31	**362**	4.30	20.86
203	3.83	23.36	**243**	4.66	22.55	**283**	4.43	21.96	**323**	4.31	20.83	**363**	4.35	21.68
204	3.55	19.87	**244**	4.82	22.10	**284**	4.58	21.78	**324**	3.48	18.74	**364**	3.43	21.18
205	3.07	18.06	**245**	4.05	21.50	**285**	4.12	18.86	**325**	5.21	20.88	**365**	3.19	19.03
206	3.68	20.14	**246**	3.64	19.54	**286**	4.64	21.16	**326**	5.33	21.24			
207	3.81	22.54	**247**	4.10	16.59	**287**	4.51	20.77	**327**	5.03	21.62			
208	3.82	23.18	**248**	4.82	21.31	**288**	3.56	19.41	**328**	4.84	20.31			
209	3.46	22.87	**249**	4.45	22.27	**289**	3.00	17.11	**329**	4.79	21.13			
210	3.62	22.36	**250**	4.61	21.91	**290**	4.49	21.75	**330**	4.10	19.16			
211	3.76	20.03	**251**	4.30	22.26	**291**	4.49	21.64	**331**	3.68	16.97			
212	3.54	16.88	**252**	4.62	22.93	**292**	4.65	21.84	**332**	4.63	21.26			
213	3.63	21.47	**253**	3.60	20.58	**293**	4.34	24.19	**333**	4.45	22.23			
214	3.63	20.88	**254**	3.50	17.63	**294**	4.43	23.41	**334**	4.64	22.43			
215	3.90	21.44	**255**	4.36	22.77	**295**	3.00	21.35	**335**	5.51	21.83			
216	4.33	20.87	**256**	4.35	23.81	**296**	4.20	19.19	**336**	5.95	22.92			
217	4.22	21.05	**257**	4.05	24.68	**297**	4.92	23.86	**337**	4.93	20.05			
218	3.57	19.18	**258**	3.95	24.43	**298**	3.46	23.03	**338**	4.28	19.12			
219	3.80	15.65	**259**	4.59	24.01	**299**	5.46	22.38	**339**	4.94	22.84			
220	4.17	20.12	**260**	4.73	19.29	**300**	4.73	21.87	**340**	4.63	21.15			
221	3.83	21.44	**261**	4.46	18.66	**301**	4.36	21.68	**341**	4.38	21.26			
222	3.66	20.95	**262**	4.47	22.98	**302**	3.66	17.70	**342**	4.08	18.43			
223	3.67	20.84	**263**	4.49	23.25	**303**	3.46	17.38	**343**	4.22	18.94			
224	3.88	21.54	**264**	4.42	23.57	**304**	3.80	20.45	**344**	5.00	19.02			
225	4.03	18.29	**265**	4.52	23.96	**305**	3.36	18.24	**345**	4.12	17.18			
226	3.61	15.76	**266**	4.47	22.70	**306**	5.02	22.16	**346**	5.27	23.97			
227	3.63	16.14	**267**	3.59	19.97	**307**	4.31	21.53	**347**	5.65	25.36			
228	3.70	20.04	**268**	3.16	17.34	**308**	4.51	20.12	**348**	5.29	25.18			
229	3.68	21.67	**269**	3.67	22.85	**309**	3.29	22.12	**349**	5.03	25.05			
230	3.45	22.40	**270**	3.65	22.77	**310**	2.33	20.67	**350**	5.84	23.12			
231	3.40	22.78	**271**	3.66	23.57	**311**	3.52	21.24	**351**	4.80	22.66			
232	4.13	19.25	**272**	3.67	23.05	**312**	4.40	21.19	**352**	4.68	18.62			
233	3.68	17.99	**273**	3.58	22.17	**313**	4.21	20.28	**353**	5.06	23.97			
234	4.04	21.10	**274**	4.61	19.66	**314**	5.26	20.56	**354**	5.05	25.20			
235	5.10	21.74	**275**	3.75	16.75	**315**	5.38	20.59	**355**	4.76	25.63			
236	4.83	21.82	**276**	4.05	21.50	**316**	5.83	18.94	**356**	4.25	23.66			
237	4.71	23.44	**277**	4.60	22.46	**317**	4.36	18.93	**357**	5.51	21.32			
238	4.62	22.66	**278**	4.05	22.59	**318**	5.23	21.65	**358**	4.41	19.71			
239	3.69	18.71	**279**	4.67	23.41	**319**	5.20	20.13	**359**	3.91	16.03			
240	3.13	17.43	**280**	4.81	23.11	**320**	3.74	21.68	**360**		17.33			

Source: elaborated by the author, data from: (OMIE, 2012, REN, 2012, REE, 2012)

Table 18: The Results of Estimation of ε_t for Portugal and Spain

Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain
	εt	εt		εt	εt		εt	εt		εt	εt		εt	εt
1	-61.28	-103.56	**39**	189.11	126.63	**77**	20.81	68.75	**115**	-115.53	-84.36	**153**	-21.28	25.75
2	-72.12	-27.06	**40**	174.76	149.15	**78**	8.05	31.46	**116**	-24.64	4.78	**154**	-47.56	-23.14
3	39.70	84.66	**41**	104.53	139.68	**79**	-78.85	-35.10	**117**	-8.93	-10.20	**155**	-90.57	-94.20
4	59.77	109.45	**42**	113.24	132.84	**80**	77.49	82.93	**118**	-47.60	2.24	**156**	-140.93	-141.70
5	76.55	65.35	**43**	60.71	128.66	**81**	83.61	71.65	**119**	-50.96	-27.13	**157**	-71.10	-25.17
6	66.95	-0.22	**44**	91.44	55.95	**82**	28.34	136.21	**120**	-76.77	-111.84	**158**	-46.49	-26.52
7	63.77	-0.96	**45**	61.35	146.86	**83**	-54.33	109.65	**121**	-126.90	-189.36	**159**	-26.45	-28.52
8	22.15	34.34	**46**	118.06	137.26	**84**	78.27	55.91	**122**	-2.91	-136.60	**160**	-64.84	-37.84
9	25.57	-34.10	**47**	59.08	131.51	**85**	4.27	-23.15	**123**	46.33	-83.53	**161**	-78.08	-75.54
10	71.45	153.56	**48**	88.66	117.45	**86**	-44.23	-60.58	**124**	43.86	-46.17	**162**	-79.25	-131.47
11	37.68	176.70	**49**	101.58	130.77	**87**	-69.84	35.99	**125**	64.10	-55.69	**163**	-77.84	-188.30
12	-13.50	154.26	**50**	75.58	36.45	**88**	-80.34	49.70	**126**	20.99	-7.91	**164**	-24.32	-112.62
13	14.42	130.07	**51**	23.33	-26.99	**89**	-59.01	58.51	**127**	-2.65	-105.08	**165**	-13.42	-51.51
14	17.90	130.53	**52**	128.83	155.43	**90**	7.93	29.38	**128**	-53.11	-192.65	**166**	21.91	-37.79
15	48.60	44.46	**53**	139.33	165.30	**91**	33.74	3.95	**129**	31.32	-86.47	**167**	3.62	-46.86
16	41.92	-8.56	**54**	80.36	126.33	**92**	-68.65	-21.09	**130**	-14.98	-71.04	**168**	15.74	-19.21
17	63.26	134.18	**55**	69.01	111.45	**93**	-63.64	-99.40	**131**	-38.54	-40.86	**169**	-7.34	-98.46
18	14.02	139.20	**56**	105.07	82.63	**94**	-7.43	-2.05	**132**	-36.34	-42.49	**170**	-43.12	-163.21
19	35.23	145.80	**57**	59.08	30.39	**95**	17.49	29.98	**133**	11.53	-62.94	**171**	-16.51	-28.46
20	75.70	147.62	**58**	-61.93	7.58	**96**	35.26	5.76	**134**	-32.33	-114.58	**172**	-12.08	-5.01
21	173.15	167.36	**59**	-1.84	128.69	**97**	-8.39	10.87	**135**	-68.24	-127.40	**173**	2.62	0.67
22	145.21	87.47	**60**	6.60	125.02	**98**	-2.69	-22.10	**136**	83.45	-130.57	**174**	-15.86	-92.46
23	147.61	59.31	**61**	-17.34	134.95	**99**	-38.57	-50.77	**137**	72.77	-80.80	**175**	-50.13	-102.31
24	165.77	186.34	**62**	69.18	77.28	**100**	-92.11	-83.95	**138**	51.69	-36.81	**176**	-30.80	-88.53
25	129.91	191.68	**63**	95.07	48.38	**101**	-28.23	51.96	**139**	32.10	-82.47	**177**	-55.90	-118.68
26	105.89	202.07	**64**	95.95	50.14	**102**	-39.86	26.00	**140**	18.52	-78.82	**178**	-28.83	48.15
27	71.65	212.84	**65**	69.03	-37.76	**103**	-80.10	32.78	**141**	37.92	-135.97	**179**	65.36	40.60
28	42.95	212.62	**66**	109.72	75.37	**104**	-83.45	46.73	**142**	-97.76	-171.24	**180**	2.09	65.30
29	70.12	106.16	**67**	69.20	140.23	**105**	38.71	8.87	**143**	14.35	-66.15	**181**	-45.05	42.00
30	67.90	30.33	**68**	92.83	84.92	**106**	-24.46	-28.22	**144**	7.07	-54.39	**182**	-40.90	53.38
31	108.98	177.03	**69**	114.99	81.68	**107**	-134.55	-105.13	**145**	60.73	-52.16	**183**	-38.33	-12.91
32	101.23	205.64	**70**	88.74	117.33	**108**	-69.98	21.29	**146**	23.80	-32.74	**184**	-16.73	-57.65
33	127.90	218.69	**71**	37.53	42.95	**109**	-65.35	27.09	**147**	-17.84	-48.81	**185**	10.13	55.01
34	127.68	178.74	**72**	-36.27	-34.12	**110**	-104.90	18.87	**148**	-0.12	-136.74	**186**	33.29	52.25
35	95.11	160.09	**73**	78.67	128.07	**111**	-113.37	-37.10	**149**	-71.05	-166.38	**187**	26.68	54.44
36	51.79	111.19	**74**	102.25	97.76	**112**	-211.58	-127.77	**150**	9.87	-46.40	**188**	26.57	43.16
37	57.10	33.40	**75**	1.26	170.60	**113**	-133.84	-125.33	**151**	-67.01	-24.50	**189**	-14.23	22.37
38	138.17	120.80	**76**	-34.67	120.94	**114**	-98.60	-143.61	**152**	4.87	23.84	**190**	-33.12	-80.63

Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain	Day	Portugal	Spain
	εt	εt		εt	εt		εt	εt		εt	εt		εt	εt
191	-85.27	-130.46	**229**	-56.61	-4.45	**267**	-56.03	-44.83	**305**	-77.21	-97.68	**343**	-16.89	-79.76
192	-42.26	7.48	**230**	-71.52	17.13	**268**	-89.65	-120.88	**306**	36.09	-1.66	**344**	43.64	-74.30
193	16.56	78.47	**231**	-75.60	27.61	**269**	-45.07	40.63	**307**	-21.04	-21.94	**345**	-25.96	-130.55
194	-20.10	61.81	**232**	-23.11	-71.44	**270**	-46.92	37.91	**308**	10.18	-40.87	**346**	64.24	64.91
195	-25.99	-1.39	**233**	-57.66	-108.33	**271**	-47.33	58.92	**309**	-97.64	-5.99	**347**	82.30	92.88
196	-37.08	9.84	**234**	-28.85	-18.65	**272**	-48.11	42.93	**310**	-177.37	-58.79	**348**	55.74	87.05
197	-2.06	-33.72	**235**	52.11	2.62	**273**	-55.04	16.24	**311**	-65.73	-18.21	**349**	36.29	84.46
198	-73.88	-86.76	**236**	32.36	5.07	**274**	13.35	-57.87	**312**	-4.00	-17.41	**350**	89.41	20.82
199	22.46	2.83	**237**	21.89	48.29	**275**	-51.23	-141.63	**313**	-18.18	-43.43	**351**	20.51	18.59
200	3.53	17.90	**238**	13.01	24.46	**276**	-21.20	-0.62	**314**	56.45	-36.70	**352**	10.73	-94.50
201	-20.20	-5.25	**239**	-52.43	-84.06	**277**	20.62	27.92	**315**	63.23	-37.98	**353**	50.75	66.65
202	-17.09	-2.48	**240**	-95.87	-121.93	**278**	-22.82	27.49	**316**	91.49	-88.43	**354**	42.01	92.80
203	-49.89	37.33	**241**	-7.71	4.68	**279**	23.89	52.30	**317**	-41.15	-118.27	**355**	20.89	104.61
204	-70.70	-59.20	**242**	-0.86	29.80	**280**	30.58	37.17	**318**	43.87	-17.43	**356**	-15.54	49.24
205	-107.73	-112.21	**243**	17.14	22.61	**281**	-17.60	-32.84	**319**	53.64	-47.57	**357**	75.57	-14.94
206	-58.37	-49.41	**244**	27.52	9.17	**282**	-42.48	-92.75	**320**	-50.78	-3.84	**358**	-14.95	-70.81
207	-48.32	17.74	**245**	-26.33	-5.75	**283**	8.94	11.16	**321**	31.87	-24.58	**359**	-49.41	-174.71
208	-50.63	32.52	**246**	-57.00	-61.47	**284**	21.67	9.35	**322**	25.53	9.38	**360**	-24.24	-131.40
209	-76.19	22.95	**247**	-24.54	-144.68	**285**	-9.60	-76.47	**323**	-13.84	-30.83	**361**	-31.23	-62.52
210	-62.03	12.42	**248**	28.93	-11.69	**286**	23.62	-10.39	**324**	-76.41	-91.72	**362**	-10.92	-26.15
211	-53.23	-52.99	**249**	3.12	15.74	**287**	14.91	-18.96	**325**	57.42	-23.49	**363**	-13.43	-13.69
212	-69.33	-141.11	**250**	15.67	6.64	**288**	-58.43	-63.58	**326**	58.91	-20.93	**364**	-77.35	-21.77
213	-61.52	-11.27	**251**	-5.54	17.48	**289**	-99.18	-129.32	**327**	36.52	-11.39	**365**	-101.55	-87.80
214	-61.02	-27.33	**252**	16.26	34.90	**290**	14.74	9.19	**328**	26.46	-43.52			
215	-38.72	-9.22	**253**	-60.61	-32.98	**291**	13.60	5.86	**329**	25.04	-18.70			
216	-8.93	-26.72	**254**	-71.77	-119.01	**292**	23.22	8.21	**330**	-28.40	-77.38			
217	-17.28	-21.87	**255**	-1.03	31.95	**293**	-2.75	68.66	**331**	-60.34	-139.09			
218	-68.62	-77.90	**256**	-2.56	60.46	**294**	6.54	52.34	**332**	16.10	-12.26			
219	-49.16	-173.56	**257**	-25.09	83.33	**295**	-101.24	-8.53	**333**	-0.38	11.35			
220	-24.24	-50.83	**258**	-30.55	78.49	**296**	-29.58	-84.48	**334**	14.83	18.35			
221	-50.09	-16.42	**259**	19.21	70.41	**297**	41.42	55.54	**335**	76.52	0.36			
222	-62.52	-29.94	**260**	26.28	-64.04	**298**	-70.17	35.15	**336**	104.84	27.38			
223	-56.46	-27.23	**261**	-2.83	-91.61	**299**	73.98	16.57	**337**	36.10	-47.36			
224	-41.82	-8.06	**262**	4.07	35.45	**300**	15.83	-3.98	**338**	-18.79	-81.30			
225	-29.92	-97.44	**263**	10.40	47.37	**301**	2.19	5.46	**339**	31.41	24.85			
226	-62.53	-170.07	**264**	6.53	58.09	**302**	-47.76	-105.22	**340**	11.71	-19.93			
227	-59.07	-157.91	**265**	14.98	69.68	**303**	-65.22	-116.87	**341**	-4.52	-14.71			
228	-53.39	-48.17	**266**	10.18	33.49	**304**	-42.32	-33.17	**342**	-24.70	-92.43			

Source: elaborated by the author

Table 19: Optimal Industry Capacity in Portugal, 2011 (1000 MW)

	Number of Firms					
	1	**2**	**3**	**4**	**5**	**10**
K_i^{C*}	0.5956	0.3971	0.2978	0.2382	0.1985	0.1083
K_i^{W*}	1.3783	0.9189	0.6892	0.5513	0.4594	0.2506
Total K_i^{C*}	0.5956	0.7941	0.8934	0.9530	0.9927	1.0829
Total K_i^{W*}	1.3783	1.8378	2.0675	2.2053	2.2972	2.5060
Total Industry	1.9739	2.6319	2.9609	3.1583	3.2899	3.5889
Total K_i^{C*} **(%)**	30.17%	30.17%	30.17%	30.17%	30.17%	30.17%
Total K_i^{W*} **(%)**	69.83%	69.83%	69.83%	69.83%	69.83%	69.83%

Source: elaborated by the author

Table 20: Optimal Industry Capacity in Spain, 2011 (1000 MW)

	Number of Firms					
	1	**2**	**3**	**4**	**5**	**10**
K_i^{C*}	0.8756	0.5837	0.4378	0.3502	0.2919	0.1592
K_i^{W*}	9.1487	6.0991	4.5743	3.6595	3.0496	1.6634
Total K_i^{C*}	0.8756	1.1675	1.3134	1.4010	1.4594	1.5920
Total K_i^{W*}	9.1487	12.1982	13.7230	14.6379	15.2478	16.6340
Total Industry	10.0243	13.3657	15.0364	16.0389	16.7072	18.2260
Total K_i^{C*} **(%)**	8.73%	8.73%	8.73%	8.73%	8.73%	8.73%
Total K_i^{W*} **(%)**	91.27%	91.27%	91.27%	91.27%	91.27%	91.27%

Source: elaborated by the author

Table 21: Optimal Industry Capacity in Portugal and Spain, 2011 (1000 MW)

		Number of Firms					
		1	**2**	**3**	**4**	**5**	**10**
Portugal	**Total Q_i^{C*}**	184.3057	245.7410	276.4586	294.8892	307.1762	335.1013
	Total Q_i^{W*}	502.8426	670.4568	754.2639	804.5482	838.0710	914.2593
	Total Industry	687.1483	916.1978	1030.7225	1099.4374	1145.2472	1249.3606
	Total Q_i^{C*} (%)	26.82%	26.82%	26.82%	26.82%	26.82%	26.82%
	Total Q_i^{W*} (%)	73.18%	73.18%	73.18%	73.18%	73.18%	73.18%
Spain	**Total Q_i^{C*}**	244.3968	325.8624	366.5952	391.0349	407.3280	444.3578
	Total Q_i^{W*}	3335.0714	4446.7619	5002.6071	5336.1143	5558.4524	6063.7662
	Total Industry	3579.4682	4772.6243	5369.2023	5727.1492	5965.7804	6508.1240
	Total Q_i^{C*} (%)	6.83%	6.83%	6.83%	6.83%	6.83%	6.83%
	Total Q_i^{W*} (%)	93.17%	93.17%	93.17%	93.17%	93.17%	93.17%

Source: elaborated by the author

Table 22: Industry Profits for Portugal and Spain, 2011 (€ Million)

		Number of Firms					
		1	**2**	**3**	**4**	**5**	**10**
Portugal	**Profits Tec C**	34.2107	34.1567	31.9814	29.9888	28.3739	23.8515
	Profits Tec. W	120.498	130.1759	129.2983	126.9424	124.6097	117.0402
	Profits Industry	154.7087	164.3326	161.2797	156.9312	152.9836	140.8917
	Profits Tec C (%)	22.11%	20.79%	19.83%	19.11%	18.55%	16.93%
	Profits Tec. W (%)	77.89%	79.21%	80.17%	80.89%	81.45%	83.07%
Spain	**Profits Tec C**	85.6827	83.9988	77.4858	71.7634	67.1923	54.5539
	Profits Tec. W	1293.6707	1320.0027	1257.2515	1195.3072	1143.8888	996.9128
	Profits Industry	1379.3534	1404.0015	1334.7373	1267.0706	1211.0811	1051.4667
	Profits Tec C (%)	6.21%	5.98%	5.81%	5.66%	5.55%	5.19%
	Profits Tec. W (%)	93.79%	94.02%	94.19%	94.34%	94.45%	94.81%

Source: elaborated by the author