Modelling the Impact of Emissions Trading on the Iberian Electricity Market

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ABSTRACT: The main purpose of this paper is the modelization and the analysis of the impact of the European market for emissions trading on the integration of Portugal and Spain into an Iberian electricity market (MIBEL). The integration of Portugal and Spain in a single-market may change the technological combination currently used to generate electricity as the current generation structure was mainly planned under monopoly and it may not be adequate for a scenario of liberalization. Further, the impact of emissions trading on the daily clearing prices, and generation scheduling will have important impacts on the value of the different generation technologies, and even on the benefits of integration as a whole. In this paper we analyze, through simulating, how the interaction between emissions trading and the MIBEL may re-shape the landscape of electricity generation, looking at clearing prices and the value of the different technologies, and how both countries are likely to be affected by it.

KEYWORDS. Energy markets; MIBEL; Emissions Trading; Cournot game;

1. INTRODUCTION

During the last two decades, the issue of market design has been the main concern of policy makers and academics. The liberalization of the electricity industry changed its structure by developing a competitive wholesale electricity market, and a system of independent regulation, while maintaining a monopoly regime in the transmission and distribution businesses.

As a result as this dramatic change an important research question has been the interaction between market design, market power, and the generation and prices resulting from the liberalization process. Therefore, an important research question has been the definition of the

market regulations that minimise the exercise of market power by generators (e.g., Green and Newbery, 1992; Green, 1999; Bunn and Oliveira, 2001, 2003).

Additionally, another research topic within market design (and quite an important one) relates the interactions between the different markets within the electricity industry. For example looking at the interaction between spot and forward markets (e.g., Allaz and Vila, 1993) and analysing the impact of regulatory activity (e.g., Borenstein and Bushnell, 1999; Garcia et al., 2001; Bunn and Oliveira, 2003).

The main purpose of this paper is the modelization and the analysis of impact of emissions trading on the integration of Portugal and Spain into an Iberian electricity market. The integration process will be a very interesting and difficult one both for regulators, generators, distribution companies and consumers. This process can change the technological combination used to generate electricity: the current generation structure was mainly planned under monopoly and it may not be adequate for a scenario of liberalization.

The main contribution of this paper is the development of a computational platform for policy testing which takes into account the interaction between emissions trading, generation, market prices and market integration. We intend to analyze how the integration of the two markets will interact with the market for emissions in order to change energy prices and the value of the different generation technologies.

This paper proceeds by describing the market structure in the Portuguese and Spanish electricity markets, section 2. In section 3 we describe the MIBEL, and in section 4 we describe the market for emissions trading. We conclude in section 5 by describing the models developed in this paper.

2. DESCRIPTION OF THE CURRENT MARKET STRUCTURE

Until 1995 the Portuguese electricity sector was organized in terms of a vertically integrated utility owning all large hydro and thermal stations, the transmission grid and the distribution networks all through the country. In this year, it was created the Electricity Services Regulatory Authority (ERSE) (www.erse.pt), the Portuguese regulatory agency. Only then a market driven system has developed in Portugal by integrating eligible consumers that opted by leaving the public system and generators that choose to operate in the free market.

By the end of 2004, the Portuguese power system had 170 nodes and a peak of demand of 8261 MW. The generation system comprised 11593 MW installed in:

- hydro stations (4356 MW, from which 1847 are run of river stations and 2509 are reservoirs);
- coal thermal plants (1776 MW);
- fuel oil stations (1476 MW);
- fuel oil/natural gas stations (236 MW);
- gasoil stations (197 MW);
- combined cycles (natural gas stations) (1774 MW).

It also included 1778 MW, generally connected to distribution networks (dispersed generation) and submitted to subsidized tariff conditions usually known as PRE (special regime generation) stations, installed in:

- small hydro's (331 MW);

- wind parks (405 MW);
- cogeneration stations (1042 MW).

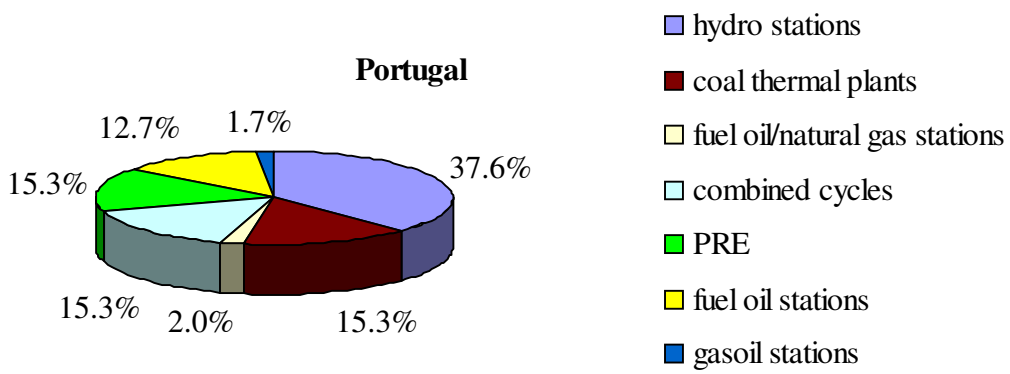

Figure 1 – Portuguese generation system by the end of 2004.

This means that total installed capacity was 11 593 MW by the end of 2004 (Figure 1). The Portuguese government has the commitment with the EU to increase the renewable share to 39% of the supplied energy by 2010. In this scope, the wind park stations already increased to 1100 MW by December 2005 and are planned to increase to 3500 MW by 2010.

In typical years, about 40% of the energy comes from hydro stations. Recently, new investments namely in large wind parks were started and several of them will be connected to the main grid. The generation system is very irregularly located through the country. Most of the large hydros as well as small ones are located in the north and central areas while thermal plants are located in the centre and south. This means that in typical wet winters there are strong flows from the north to the south and in dry summers they reverse.

In Spain, the electricity sector was also organized in terms of vertical utilities with the major difference that they were several monopoly based companies in regional franchised areas. In 1995 it was passed an Electricity Law that created the Electricity National Commission (www.cne.es), the Spanish regulatory agency, and that also organized the sector in a public driven system and in a competitive one. This model was deeply questioned so that by the end of 1997 it was passed a new law that eliminated the public driven sector and that lead to the creation of a pool based system. This day ahead market started its operation in January 1998 under the management of a market operator company (www.comel.es). The transmission company (www.ree.es) has the concession of the transmission system and also acts as System Operator, that is, it corresponds to a TSO.

In terms of the installed capacity, the electricity law divides power stations in ordinary regime and special regime. The ordinary regime, that is a total of 51 313 MW by the end of 2004, includes:

- hydro stations (16 657 MW);
- nuclear (7876 MW);
- coal thermal stations (11 565 MW);
- combined cycles (natural gas stations) (8285 MW);
- fuel oil/natural gas stations (6930 MW).

The special regime (PRE) includes stations that have a special remuneration system, namely:

- hydro stations (1599 MW);
- wind parks (8351 MW);
- others renewable and non-renewable stations (7162 MW).

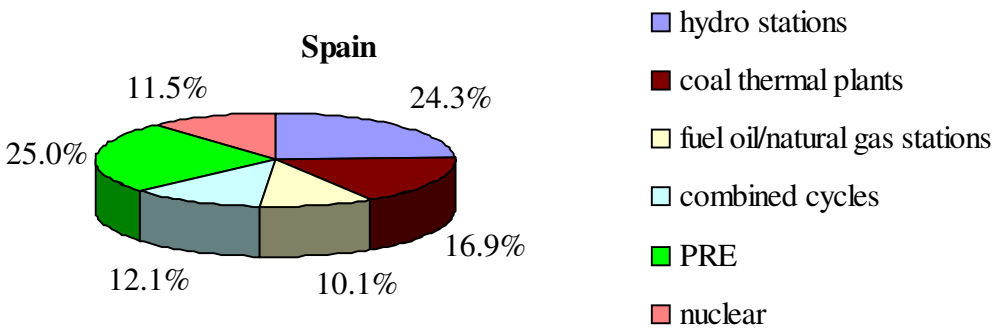

Figure 2 – Spanish generation system by the end of 2004.

This means that total installed capacity was 68 425 MW by the end of 2004 (Figure 2). The peak demand in 2004 reached 37 724 MW in the 2nd of March and the total generated energy was 235 411 GW.h in that year. Regarding the ownership structure, it should be said that the Spanish electricity sector is dominated by 4 large groups that act both in generation and in distribution and retailing. By the end of 2004, ENDESA owns 40 % of the ordinary generation and provides 41% of the demand. IBERDROLA owns 25% of the generation and supplies 38% of the demand, Union Fenosa owns 12% of the generation and provides 15% of the demand and finally, HidroCantabrico owns 7% of the generation and supplies 6% of the demand. The Special Regime Generation corresponded to about 12% of the installed capacity.

3. MOTIVATIONS FOR THE CREATION OF THE MIBEL

The Portuguese and the Spanish system share for quite a long time a common experience given their physical interconnection through 400 and 220 kV lines and also considering that both systems have an important hydro sector that share common rivers. These facts suggested a long time ago that some kind of coordination was required. Apart from that, the Iberian electricity system operates almost as an island in Europe given that the degree of interconnection of Spain with France is very reduced when compared with the demand and the interconnection with Morocco is negligible.

Given the interrelation already existing between the Portuguese and the Spanish systems and their complementarities it was signed a joint Declaration in November 2001 that lead to the creation of the Iberian Electricity Market (MIBEL). Apart from the advantages from its creation inside the peninsula, it was also positive in view of the integration national markets leading to regional ones and progressively building the Internal European Electricity Market, strongly supported by the EU Commission.

In the MIBEL the day ahead and the intra-daily markets will result from the extension of the activities of the Spanish market operator, OMEL, to the whole peninsula. The short and the medium term future contract markets will be managed by a Portuguese market operator (OMIP) that is currently under operation tests. It is expected that these two market entities will merge leading to the Iberian Market Operator (OMI). In the bilateral negotiation both retailing agents and generation companies can sell energy to other generation companies or external agents. The

external agent is assumed to be a foreign electricity trading company that is qualified to buy or sell energy in the Iberian market. The market operator should communicate the result of the daily pool to both system operators. The system operators will also receive information from the agents responsible for bilateral contracts desegregated by physical units. System operators are then responsible for the validation of the generation program checking and solving eventual network constraints.

In each control area, the corresponding TSO will operate as a single buyer following the definition, for each hour of the day ahead, of the required amounts. These will be defined according to UCTE (Union for the Co-ordination of Transmission of Electricity) criteria or other specific criteria that may result for instance of the integration of larger shares of PRE.

Although not all rules are yet public, we foresee the following aspects:

A) Primary reserve is a mandatory service, non-remunerated, according to what is presently being already followed in the two systems;

B) Secondary reserve is to be considered a non-mandatory service subjected to market mechanisms inside each control area;

C) Tertiary reserve should also be considered as a non-mandatory service to be managed under a market approach, taking into account the reserve margins defined by the system operators for each control area. Interruptability contracts will be managed under this umbrella and also adopting market rules;

D) Reactive power allocation to each generating unit should also be managed under market rules, following the same type of conceptual procedures to be adopted for secondary reserve. However and due to security reasons, it will be defined a minimum requirement level of reactive support to be delivered in a mandatory way and without remuneration.

4. THE EUROPEAN MARKET FOR EMISSIONS TRADING

Even before the actual Kyoto Protocol came into force the most expected designed market mechanism started to work: The Emissions Trading Scheme (ETS). Under the Protocol, nations that emit less than their quota of greenhouse gases (GHG) will be able to sell emissions permits to polluting nations. The Protocol also allows emissions trading schemes to be established as climate policy instruments at the national level (e.g. in the United Kingdom) and the regional level (e.g. in the European Union). Under such schemes, governments set emissions caps to be reached by the participant companies, and enables them to trade carbon dioxide emissions in order to achieve the established cap: it is a cap-and-trade scheme, based on the one used for SO2 in the "Acid Rain Program" of 1990 in the USA.

There are four active markets for GHG allowances as of May 2005: the European Union Greenhouse Gas Emission Trading Scheme (EU ETS), the UK Emissions Trading System, the New South Wales trading system and the Chicago Climate Exchange. The EU ETS is working since the 1st of January 2005, and is now the largest multi-national, greenhouse gas emissions trading scheme in the world including about 12000 large industrial plants in the EU. All 25-member states of the European Union participate, and about 40% of the EU's total CO2 emissions are covered (estimated in Euro 35 billion per year, and potentially rising to over Euro 50 billion per year by the end of the decade).

The first phase will be held until 2007, just before the first commitment period of the Kyoto Protocol (2008-2012) starts. At this stage, the activities covered by the EU ETS include energy

activities (combustion installations with a rated thermal input exceeding 20 MW, mineral oil refineries, coke ovens), production and processing of ferrous metals, mineral industry (cement clinker, glass and ceramic bricks) and pulp, paper and board activities. The second phase (2008-12) will cover other GHGs than CO2, and most certainly other economic sectors, although it is not necessary to wait for the first phase to end in order to include other sectors: an explicit example is "aviation" that is most certainly to be integrated in the EU ETS within this year.

The main purpose of the ETS is to allocate the emission cutting efforts where they are less expensive, minimizing all costs of compliance. The scheme should be a cheaper alternative to achieve the CO2 goal, stimulating emissions reduction innovations, and creating all other kinds of incentives to reduce GHGs emissions.

At this time the market is testing its premises, and the revision of the directive is now a top subject. The Commission's report should be ready by mid-2006 and will include the accounting of other gases and sectors, the effects of the system on competitiveness, including international competition, the impact on electricity prices, and the harmonisation of national allocation methods for CO2 emissions. The main concerns for power companies regard direct and indirect costs of compliance, like the costs of investing in cleaner production methods, switching to alternative production methods, and buying emission units allowances (EUAs), and indirectly, the costs arising from higher electricity prices, reflecting the EUA price.

5. MODEL DEVELOPMENT

The experiments start by developing a classical model for the scheduling of plants by a system operator aiming to minimize the social cost of electricity generation (or to maximize the total surplus of the industry 5.1) computes the clearing price, analysing how trading emissions influence the optimal schedule of the different plants. In this case the model is represented by equations 5.1 to 5.11. We further assume a single-clearing market mechanism (uniform auction) and therefore we have only a given price at any time, P_t. It is assumed that the generation units initial status is similar to the last period status, meaning that it is simulated equal successive days.

Each plant marginal cost includes fuel costs, Operation and Management (O&M) costs and CO_2 costs (5.4) (these last ones reflecting the CO_2 market price, and thus the emissions trading influence (5.5)). It is also included the start-up and the shutdown costs in (5.3). The MW.h demand is non-linear with constant elasticity (5.6).

The model constraints include the rising and diminishing generation shifts maximum rate (5.8) and the maximum number of shifts in operation status in a given day (5.11).

$$\max_{Q_{i,L,t},B_{i,L,t},\forall i,L,t} \pi = \pi_1 + \pi_2 \tag{5.1}$$

$$\pi_1 = \sum_t \left(\frac{A_t}{\alpha_t + 1} Q_{D,t}^{\alpha_t+1} - P_t Q_{D,t} \right) \tag{5.2}$$

$$\pi_2 = \sum_t \sum_i \sum_L \left(\left(P_t - C_{i,L}\right) Q_{i,L,t} - B_{i,L,t}\left(1 - B_{i,L,t-1}\right) C_{i,L}^{up} - \left(1 - B_{i,L,t}\right) B_{i,L,t-1} C_{i,L}^{dn} \right) \tag{5.3}$$

$$C_{i,L} = OM_{i,L} + F_{i,L} + CO2_{i,L} \tag{5.4}$$

$$CO2_{i,L} = C_{CO_2} . P_{CO_2} \tag{5.5}$$

$$P_t = A_t Q_{D,t}^{\alpha_t}, \forall t \tag{5.6}$$

$$Q_{D,t} = \sum_i \sum_L Q_{i,L,t}, \forall t \tag{5.7}$$

$$-R_{i,L}^{dn} \le Q_{i,L,t} - Q_{i,L,t-1} \le R_{i,L}^{up}, \forall i, \forall t, \forall L \tag{5.8}$$

$$0 \le Q_{i,L,t} \le K_{i,L,t} B_{i,L,t}, \forall i, \forall t, \forall L \tag{5.9}$$

$$\sum_t Q_{i.L,t} \le H_{i,L}, \forall i, \forall L \tag{5.10}$$

$$\sum_t \left| B_{i,L,t} - B_{i,L,t-1} \right| \le B_{i,L}^{max}, \forall i, \forall L \tag{5.11}$$

Where:

- π represents the total surplus of the industry;
- π_1 represents the consumer surplus;
- π_2 represents the generation surplus;
- P_t represents the market price at time t;
- $C_{i,L}$ stands for the marginal cost of plant L (owned by player i);
- $OM_{i,L}$ represents the operation costs of plant L (owned by player i)
- $F_{i,L}$ represents the fuel costs of plant L (owned by player i)
- $CO2_{i,L}$ represents the carbon costs of plant L (owned by player i)
- C_{CO2} represents the carbon content of producing in plant L (owned by player i)
- P_{CO2} represents the market price of one tonne of CO2 equivalent
- $Q_{i,L,t}$ stands for the generation at time t of a plant L (owned by a player i);
- $B_{i,L,t}$ stands for plant L's (owned by player i) operation status at time t, binary variable with value 1 if it is on and value 0 if it is off;
- $Q_{D,t}$ represents the total demand at time t;
- A_t and α_t represent the intercept and slope of the inverse demand function at time t;
- $C_{i,L}^{up}$ and $C_{i,L}^{dn}$ represent for plant L's (owned by player i) the start-up and the shutdown costs;
- $R_{i,L}^{up}$ and $R_{i,L}^{dn}$ stand for plant L's (owned by player i) rising and diminishing generation shifts maximum rate;
- $K_{i,L,t}$ stands for plant L's (owned by player i) total available capacity at time t;
- $H_{i,L}$ stands for plant L's (owned by player i) available capacity in a given day;
- $B_{i,L}^{max}$ stands for plant L's (owned by player i) maximum number of shifts in operation status in a given day.

Then, in a second set of experiments we follow Ramos at al. (1998), Borenstein et al. (1999, 2002), and Hobbs, (2001), and develop a Cournot game to model separately the Portuguese and Spanish markets and the MIBEL. In a Cournot each generator maximises the value of his

portfolio of power plants as a whole. Therefore, for a player i, the profit (π_i) maximisation problem is represented by equations (5.12) to (5.20).

The constraints and demand are similar to the previous ones, the only difference remaining in the objective functions (5.12).

$$\max \pi_i = \sum_t \sum_L \left[(P_t - C_{i,L}) Q_{i,L,t} - B_{i,L,t}(1 - B_{i,L,t-1}) C_{i,L}^{up} - (1 - B_{i,L,t}) B_{i,L,t-1} C_{i,L}^{dn} \right] \quad (5.12)$$

s.t.

$$C_{i,L} = OM_{i,L} + F_{i,L} + CO2_{i,L} \quad (5.13)$$

$$CO2_{i,L} = C_{CO_2} . P_{CO_2} \quad (5.14)$$

$$P_t = A_t Q_{D,t}^{\alpha_t}, \forall t \quad (5.15)$$

$$Q_{D,t} = \sum_i \sum_L Q_{i,L,t}, \forall t \quad (5.16)$$

$$-R_{i,L}^{dn} \le Q_{i,L,t} - Q_{i,L,t-1} \le R_{i,L}^{up}, \forall i, \forall t, \forall L \quad (5.17)$$

$$0 \le Q_{i,L,t} \le K_{i,L,t} B_{i,L,t}, \forall i, \forall t, \forall L \quad (5.18)$$

$$\sum_t Q_{i.L,t} \le H_{i,L}, \forall i, \forall L \quad (5.19)$$

$$\sum_t \left| B_{i,L,t} - B_{i,L,t-1} \right| \le B_{i,L}^{max}, \forall i, \forall L \quad (5.20)$$

6. RESULTS AND CONCLUSIONS

We analyzed the impact of emissions trading on the MW.h theoretical prices and on the production levels in two hypothetical companies, each one with two power plants of different technologies: coal and natural gas. These companies have different capacities, as well as start-up and shutdown costs. The simulation also considered 24 periods (hours) with different demands for each period.

The fuel prices were considered to be of 4,14 €/GJ for natural gas, 1,55 €/GJ for coal, and the CO2 prices ranged from 5 €/tCO2 to 50 €/tCO2. The main consequences of this rising in CO2 prices on the distribution of the electricity generation and on total demand for MW.h are, as expected, a falling in total demand and consequent generation due to the good's elasticity, and, most importantly, an abrupt change of generation from coal to natural gas above a certain CO2 price (in this case at 32€/tCO2) (Figure 3). For prices higher than this one, it does no longer pay off to keep producing with the most pollutant technology, although a coal power plant is a lot more expensive to shutdown and restart. Above the 32€/tCO2 the less expensive to start-up natural gas power plant (cp2.ng) works at a lot more periods than the most expensive coal power plant (cp1.coal). The remaining natural gas power plant (cp1.ng) after this turn price starts to work more, and the opposite happens to the second coal power plant (cp2.coal).

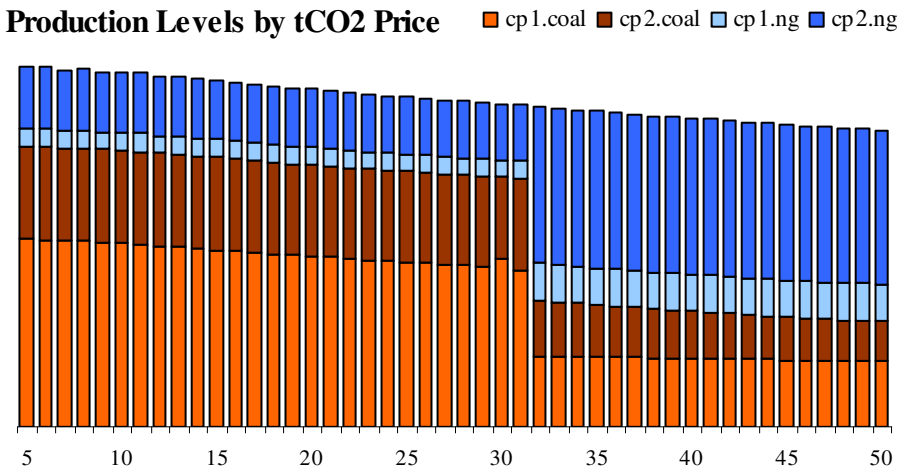

Figure 3 – Production Levels for different CO2 prices.

Another important aspect to observe is the increase of the MW.h price when we raise the tCO2 price witch is shown in the Figure 4. The decrease of electricity demand due to higher prices of tCO2 is also more explicit.

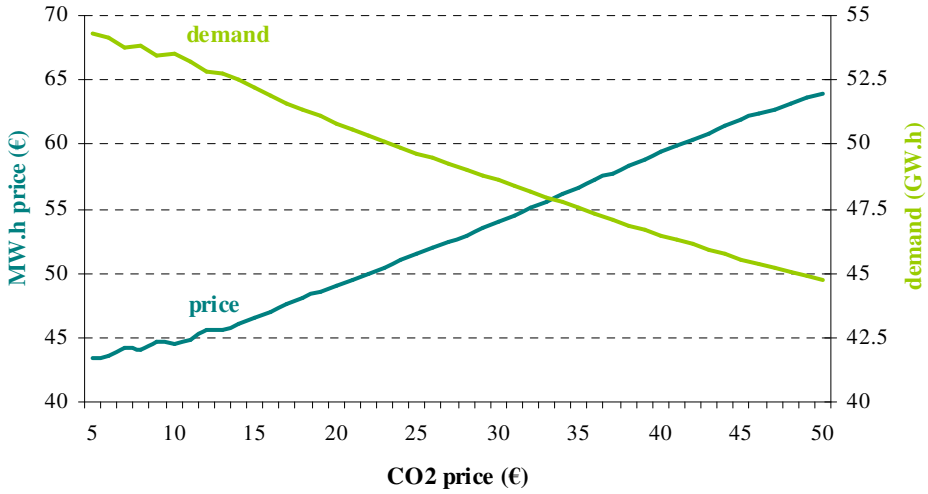

Figure 4 – Electricity price and demand for different CO2 prices.

7. ACKNOWLEDGEMENTS

The research work described in this paper was supported by Portuguese FCT through the project MILES - *The Impact of the Iberian Electricity Market on the Companies´ Performance and Long-Term Security of Supply: A Simulation Analysis* with reference **POCI/EGE/61555/2004**.

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