THE IMPACT OF KYOTO AND POST-KYOTO CO2 PRICES ON THE IBERIAN ELECTRICITY MARKET AGENTS DECISIONS

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Abstract

The main purpose of this paper is the modelization and the analysis of the impact of the CO_2 prices expected for the Kyoto and Post-Kyoto periods on the Iberian electricity market (MIBEL) decisions of their agents. It is expected that the insertion of a price to the CO_2 emissions on electric utilities will change the technological combination currently used to generate electricity, as the recent generation structure was mainly intended to secure supply according to marginal costs of production (without the CO_2 balance), maximizing each companies profits. It is also expected that CO_2 prices will more than double in the Post-Kyoto period. Further, the integration of Portugal and Spain in a single and liberalized market may as well change the generation scheduling, and generate, in coordination with CO_2 pricing, 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 CO_2 pricing in Kyoto and Post-Kyoto levels and the starting of 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.

Introduction

The initial steps towards liberalization of the electricity industry in Portugal and Spain, almost ten years ago, are now transformed into the new organizational structure of electricity production and trade. Market design is, in result, an important technique to achieve a competitive wholesale electricity market, and a system of independent regulation, while maintaining a monopoly regime in the transmission and distribution businesses, achieving short-time efficiency (e.g., Bunn and Oliveira, 2001, 2003).

In this paper the objective is the modelization and the analysis of impact of emissions trading on the integration of Portugal and Spain into an Iberian electricity market, regarding electricity production technologies. It is expected that the integration of both markets will change the merit order and technological combination used previously to generate electricity by each market separately.

To do this analysis we solve Unit Commitment problems to determine the operating schedule of the power units for the considered period. Its aim is to determine the combination of production technologies that will supply the demand of electricity in each period of the planning horizon.

We also intend to analyse how the CO_2 prices expected for the commitment period of the Kyoto Protocol (2008-2012), and for the Post-Kyoto scenario (2013-2020) affect energy prices and the value of the different generation technologies.

Finally, all of these aspects are taken into an optimization procedure subject to different types of economical, technical and security constraints (e.g. Viana et al., 2003).

The Present Market Structure

By the end of 2004, the Portuguese power system had 170 nodes and a peak of demand of 8261 MW. In 2003, the generation system comprised 9754 MW installed in: hydro stations (4369 MW); coal thermal plants (1776 MW); fuel oil stations (1476 MW); gasoil stations (329 MW); combined cycles (natural gas stations) (1730 MW); wind parks (65 MW); biomass (9 MW).

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.

Spain, in terms of the installed capacity, comprises a total of 60 562 MW, installed in: hydro stations (16 530 MW); nuclear (7 640 MW); coal thermal stations (11 649 MW); gasoil stations (68 MW); fuel oil stations (4 850 MW); combined cycles (natural gas stations) (13 836 MW); wind parks (5 799 MW); biomass (solid urban residuals) (190 MW).

Both markets have production structures very similar to oligopolies.

The Mibel

The physical interconnection through 400 and 220 kV lines and common rivers of Portugal and Spain, must be synchronized. This coordination is being idealized for some years now, but officially started with the signature of a joint Declaration in November 2001 that leaded to the creation of the Iberian Electricity Market (MIBEL).

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).

The Mibel should be fully operational within one year and a half.

The European Market for Emissions Trading

The European Union has its EU Emissions Trading Scheme (EU ETS) operating since the 1st of January 2005. It sets caps for the emissions of CO_2eq of around 11500 power plants in the EU25. It is the largest multi-national greenhouse gas emissions trading scheme in the world: about 40% of the EU's total CO_2 emissions are covered (with transactions reaching 14.6 billion euros in 2006).

The installations comprised in this market have the flexibility to increase emissions above their caps, or decrease them, given that they acquire the equivalent allowances to their emissions in excess, or sell the unused ones. In fact, the tonne of CO_2equivalent price is a new production cost of these power plants that is incorporated in the final MWh price.

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.

Model Development

The experiments start by developing a classical model for the scheduling of plants by a system operator aiming to maximize the total surplus of the industry, as in equation (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 (5.8). We further assume a single-clearing market mechanism 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 (5.3) (these last ones reflecting the CO_2 market price and thus the emissions trading influence (5.4)). It is also included the start-up and the shutdown costs. The MWh demand is assumed known.

The model constraints include the rising and diminishing generation shifts maximum rate (5.6).

$$\min_{Q_{i,L,t},B_{i,L,t},\forall i,L,t} \pi \tag{5.1}$$

$$\pi = \sum_t \sum_i \sum_L C_{i,L} Q_{i,L,t} - B_{i,L,t}\left(1 - B_{i,L,t-1}\right)C^{up}_{i,L} - \left(1 - B_{i,L,t}\right)B_{i,L,t-1}C^{dn}_{i,L} \tag{5.2}$$

$$C_{i,L} = OM_{i,L} + F_{i,L} + CO2_{i,L} \tag{5.3}$$

$$CO2_{i,L} = C_{CO_2} . P_{CO_2} \tag{5.4}$$

$$\sum_i \sum_L Q_{i,L,t} \geq \overline{Q}, \forall t \tag{5.5}$$

$$-R^{dn}_{i,L} \leq Q_{i,L,t} - Q_{i,L,t-1} \leq R^{up}_{i,L}, \forall i, \forall t, \forall L \tag{5.6}$$

$$0 \leq Q_{i,L,t} \leq K_{i,L,t} B_{i,L,t}, \forall i, \forall t, \forall L \tag{5.7}$$

$$\sum_t Q_{i.L,t} \leq H_{i,L}, \forall i, \forall L \tag{5.8}$$

Where:

- π represents the total surplus of the industry;
- 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;
- $\overline{Q}$ represents the total demand 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.

The data for the Portuguese and Spanish simulations considered includes 1001 Spanish power plant groups, their capacities, and their 25 owners, and 74 Portuguese power plants, their capacities, and their 3 owners. All other parameters (fuel type, fuel price, availability, thermal efficiency, emission factor, O&M costs, capital costs, start-up and shutdown costs, rising and diminishing ramp rates, available capacity for the 24hour period and maximum number of shifts in operation status) were obtained for each technology type and capacity, and then applied to every power plant (Ultra-Systems Tech, 1999; Haq, 2002; Griffincoal; ERSE; CNE; UCTE; REN; REE; IPCC).

In this model demand is inelastic, as we are modelling short-term behaviour. We model a typical winter and summer day for both dry (2005) and wet (2001) year. These typical days (16/02/2005, 20/07/2005, 21/02/2001 and 18/07/2001,) (in REE and REN), were divided into 8 periods. Usually dry years are warmer, and in result have larger demand of MWh, which is consistent with the numbers employed.

For Spain and Mibel, in each typical day, three CO_2 prices were considered. As for the Portuguese electricity producing system, it is small enough, so it was possible to model prices from 4€/tCO_2eq to 41€/tCO_2eq.

The electricity demand is the only aspect that changes in each scenario, whereas all other data is kept unchanged (parameters).

Results: Effects of CO_2 Prices on the Merit Order and Electricity Prices

Portugal

In a typical dry year there is no significant variation in the merit order for all the CO_2 prices considered (from 4 to 41 €/tCO_2eq), but for a typical wet year, in summer and in winter, generation by technology is shown in Figure 3.

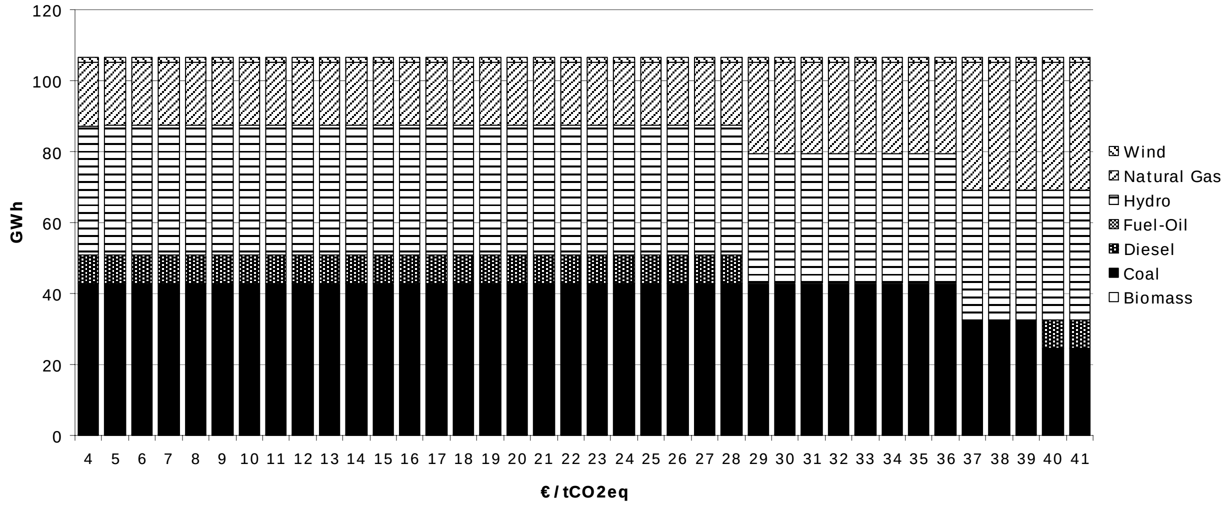

Figure 1 - Generation by Technology in the Wet Winter in Portugal

There are five distinct situations are of interest:

a) 4€ - 28€ /tCO_2eq the MWh generation-mix does not change, and it is mostly accomplished with coal, hydro, natural gas, wind, biomass, and some diesel.

b) 29 €/tCO_2eq, change of mix: diesel power plants (equal to 7.4% of total production) are substituted by natural gas power plants, because these last ones, although with a more expensive fuel, have lower emission factors (EF=54).

c) 37 €/tCO_2eq: some coal power plants are replaced with natural gas (about 10% of total generation). The coal power plants are shutdown because although their fuel price is very low, their EF is the highest, increasing the marginal cost of generation.

d) 40 €/tCO_2eq: 7.4% of total generation is transferred from coal to diesel power plants, because at this CO_2 price, generating the required amount by natural gas of MWh does not pays off.

e) At all times the wind and biomass power plants are permanently working, while the fuel-oil power plants are never started.

To sum up, there is full use of renewable energies (in the allowed % for hydro) for all CO_2 prices, and, when possible, generation is relocated from more polluting technologies to natural gas, or to the second least polluting, in terms of Emission Factors (EF).

Spain

Our analysis of the model for Spain, due to data size and the very high computation time required, only looks at 8, 25 and 40 €/tCO_2eq. As in the Portuguese market, the summer-winter differences are not of much relevance. However analysing dry and wet years shows us that, as expected, the 'extra' required MWh in dry years are fulfilled by natural gas generation.

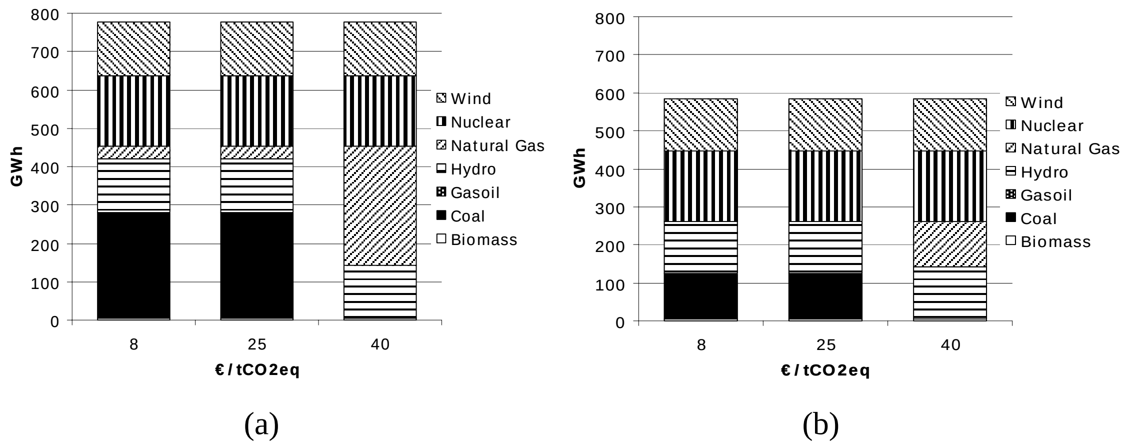

Figure 2 - Generation by Technology in Spain: (a) Dry Summer (b) Wet Summer

Spain, as Portugal, makes use of all the possible capacity of renewable power plants. The difference here is that Spain has nuclear energy that is also always producing electricity.

MIBEL

As expected, the Mibel is almost a sum of the Portuguese and Spanish situations, because the premises are the same, with no extra constraints. A single region equal to "Portugal + Spain" is then considered, without any grid limits. Again the differences between summer and winter are not of much importance. For the three CO_2 prices analyzed the merit order achieved is represented in Figure 5.

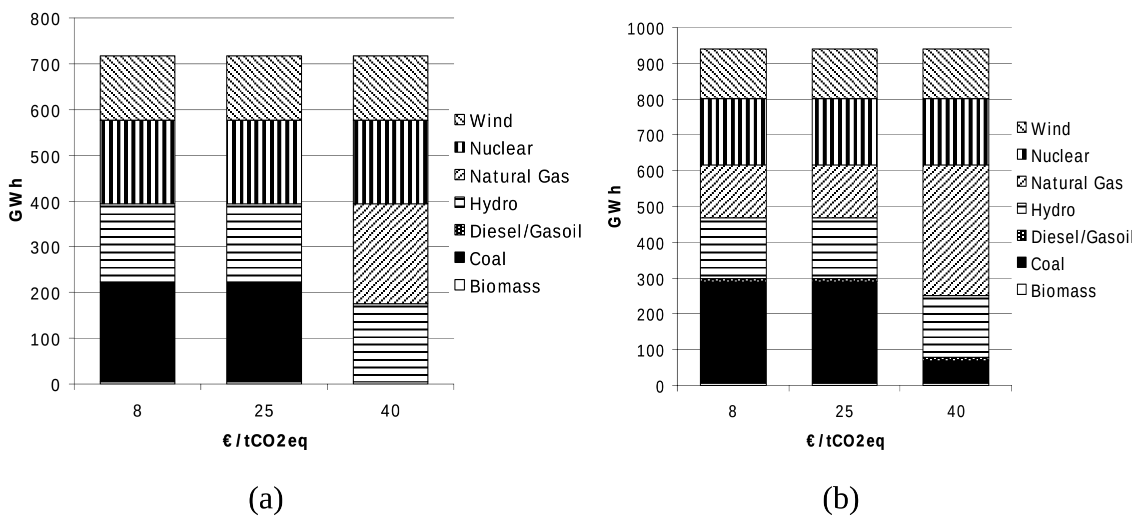

Figure 3 - Generation by Technology in the Mibel: (a) Wet Winter, (b) Dry Winter

The generation-mix adds up the renewable power plants of both countries, and the nuclear from Spain (as there is none in Portugal), fuel-oil is not used ever for the three CO_2 prices considered, and at 40 €/tCO_2eq, reflecting what happens in each separate country, there is a transfer from coal generation to natural gas.

Effects of CO_2 Prices (€/tCO_2eq) on Electricity Prices (€/MWh)

For all three situations, we have the results presented in Table 2:

Mibel	€/MWh **Summer Dry**	€/MWh **Summer Wet**	€/MWh **Winter Dry**	€/MWh **Winter Wet**
8 €/tCO2eq	37.097	25.763	37.097	25.763
25 €/tCO2eq	43.952	39.460	43.952	39.460
40 €/tCO2eq	51.545	50.000	51.545	50.000
Spain				
8 €/tCO2eq	36.433	25.763	37.097	25.763
25 €/tCO2eq	43.838	39.460	43.952	39.460
40 €/tCO2eq	50.000	50.000	50.174	50.000
Portugal				
8 €/tCO2eq	46.279	37.097	46.279	37.097
25 €/tCO2eq	58.213	43.952	58.213	43.952
40 €/tCO2eq	68.743	51.545	68.743	51.545

Table 1 - MWh Prices in Mibel, Spain and Portugal

It is clear that Portuguese MWh prices are always higher than Mibel MWh Prices, although the Spanish prices while usually are equal to Mibel MWh, in 4 situations are in effect lower.

In Spain**,** it is of some importance to notice that instead of the constant almost parallel evolution of MWh prices we see in the Portuguese situation (between the dry and the wet year), here we have almost the same merit order in the wet and in the dry year, when considering 40 €/tCO_2eq. The result is the same MWh price of 50€ in all situations (wet or dry, summer or winter).

In the Mibel, because the Spanish market is much larger than the Portuguese one, the effect previously mentioned has some influence in the MWh price in MIBEL: the generations with 40 €/tCO_2eq aren't the same in all 4 types of years considered only because Portugal has some small weight in the market.

Conclusions

In this paper we develop a computational intensive model of the electricity market in Portugal and Spain, at generator technology level, taking into account marginal costs, start-up costs, and ramp rates. We analyse two main important impacts of CO_2 price, as simultaneously analysing the different impacts on Portugal, Spain and the Iberian market:

Merit Order

In Portugal the merit order changes notoriously at 29€/tCO_2eq, 37€/tCO_2eq and 40€/tCO_2eq (CO_2 prices ranging from 4€/tCO_2eq to 41€/tCO_2eq were analysed).

Usually the most pollutant technology is replaced by natural gas (that is the least pollutant) considering that all the non-pollutant technologies (wind, hydro, and biomass) are already producing at their full capabilities, while fuel-oil plants are never started. This is because of the higher marginal costs that have to be paid for fuels with higher emission factors (like coal), when the CO_2 price rises.

In Spain and Mibel only 3 CO_2 prices were analysed (8, 25 and 40€/tCO_2eq), and, as expected, the 'extra' required MWh in dry years are fulfilled by natural gas generation, for higher prices of CO_2. And Spain, as Portugal, makes use of all the possible capacity of renewable power plants. The difference here is that Spain has nuclear energy that is also always producing electricity.

In Mibel, the generation-mix adds up the renewable power plants of both countries, and the nuclear from Spain, fuel-oil is not used ever for the three CO_2 prices considered, and at 40 €/tCO_2eq, reflecting what happens in each separate country, there is a transfer from coal generation to natural gas.

Electricity Price

For all three situations (Portuguese, Spanish and Mibel), the MWh price is the higher MgCost of generation in each period, as the generators need to recover the start-up costs.

For the CO_2 prices considered of 8, 25 e 40€/t CO_2eq the MWh price, in Portugal, ranges from 37,097€/MWh (in Wet Winter or Summer with 8€/t CO_2eq) to 68€/MWh (for 40€/t CO_2eq, in Dry Winter or Summer). In Spain, the prices range from 25,763€/MWh to 50,000€/MWh.

Finally, MIBEL prices for the MWh are in all situations lower than Portuguese prices, and in four situations (Summer Dry for the 3 CO_2 prices, and Winter Dry for 40€/tCO_2eq) higher than the Spanish MWh price.

Moreover, our analysis shows that the CO_2 trading has an impact on the benefits of the Iberian market due to the changes that it causes in the MWh price, mainly in Portugal, where the MWh price is higher. For Spain the price is essentially the same with the exception of 4 situations where it is lower than the Mibel MWh price.

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Electricity National Commission (www.cne.es)

UCTE **-** Union for the Co-ordination of Transmission of Electricity (www.ucte.org)

REN **-** Rede Eléctrica Nacional, S. A. (www.ren.pt)

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