European Research Studies,
Volume XV, Issue 4, Special Issue on Energy, 2012

Are we Following the Right Path? Assessment of the Portuguese Electricity Generation on Atmospheric Emissions*

Monica Meireles[1], Isabel Soares[2], Oscar Afonso[3]

Abstract:

This paper examines the Portuguese electricity-supply-sector evolution within the EU-27 and its impact on atmospheric emissions. Using a dataset of SO_2, NOx, CO_2 and particulates emissions for Portuguese thermoelectricity plants between 1990 and 2008, the performed panel data model shows emissions to be a positive function of fossil fuel combustible use. Nevertheless, these results denote a more "impressive" correlation per GWh generated than in other EU countries. They also indicate that only SO_2 emissions are a negative function of liberalization, which may be explained by the market power of the incumbent that does not feel threatened to adopt environmental improvements.

Key Words: *Electricity Sector, Thermoelectricity Generation, Atmospheric Emissions*

JEL Classification*: Q32, Q40, Q53*

* **Acknowledgement:** The authors acknowledge Maria João Tavares, Filipa Freire and Pedro Paes from EDP, Conceição Ferreira from Turbogás, Maria José Lopes from Tejo Energia and Vítor Marques from ERSE for providing unpublished data. The authors also thank Anabela Carneiro for her precious comments. Mónica Meireles acknowledges financial support from FCT - Fundação para a Ciência e Tecnologia. The usual disclaimer applies.

[1] *Corresponding author: ISCTE-IUL and BRU-IUL – Lisbon University Institute, Department of Economics, Av. Forças Armadas, 1649-026 Lisboa, Portugal. Tel: +351 217 903 432. email: monica.meireles@iscte.pt*

[2] *Faculdade de Economia, Universidade do Porto and CEFUP, R. Roberto Frias, 4200-464 Porto, Portugal; Tel: +351 225571100. email: isoares@fep.up.pt*

[3] *Faculdade de Economia, Universidade do Porto and CEFUP R. Roberto Frias, 4200-464 Porto, Portugal; Tel: +351 225571100. email: oafonso@fep.up.pt*

1. Introduction

In the last 20 years considerable changes have been occurring on the energy markets. The traditional public management has been gradually replaced by private management and the traditional utility monopolies have given place to free and competitive markets. In the European Union (EU), in particular, important steps have been taken to meet liberalisation objectives in the energy market (Ferreira et al., 2005). The idea is to improve economic efficiency and service quality, to guarantee provision and energy availability in better economic conditions, to provide consumers free access to alternative supply sources and to provide a better environmental protection. All these objectives were set on the 96/92/EC and 2003/54/EC Directives and latter on the III Energy Package approved in 2009.

Simultaneously, the evolution of the EU-27 energy system has been characterised by a decoupling between energy demand and GHG emissions growth. Between 1997 and 2007 total GHG emissions decreased by 1.2% while final energy consumption grew by 5%. In the same period, final electricity consumption per capita also rose by 17%, continuing the trend observed in preceding years (Eurostat, 2009). This electricity demand is expected to grow about twice faster than the average energy demand (Pérez-Arriaga et al., 2005). Thus, further investments in new generation capacity will be needed during the next years.

Indeed, between 1997 and 2007 both total installed capacity of electricity generation and power generation increased by 18%. In 2007, thermal power plants provided the majority of capacity – with a share of 58% -, followed by hydro (18%) and nuclear plants (17%). Despite the strongly increase, the renewable energy sources (RES) still contribute to only 7% of total installed capacity of electricity generation. The most important change was registered by wind capacity, although hydro power still remains the largest contributor, with a 62% share of RES, in 2007, followed by wind energy (25%).

The power generation showed a similar trend, with thermal power plants contributing for the majority of generation (56%) and RES for only 6%, in 2007. Although electricity generated from RES had verified a 41% increase, between 1997 and 2007, its contribution to total electricity consumption has only increased by 19% over this period, reaching 15.6% in 2007. Furthermore, total energy dependency rate has increased by 8.1 percentage points. The EU-27 is highly dependent on oil (82.6%), natural gas (60.3%) and hard coal and derivatives (58.6%) and the forecasts show the same trend for the next decades (Eurostat, 2009). Additionally, there is an accelerating decline of fossil fuel domestic resources. Consequently, most of the energy consumption growth will need to be met by increasing imports from outside the EU.

Conversely, most environmental pressures show an improving trend. From 1990 to 2007 GHG emissions decreased by 9.3% slowing down (0.2%) between 2000 and 2007 (Eurostat, 2009). The changes operated in the fuel mix during that period, together with the restructuring of the Eastern European economies, were the key drivers for this improvement. This environmental enhancement has though an important exception. Total carbon emissions are expected to rise at a short-term rate of 0.3% per year, accelerating from 2015 onwards to a long-term rate of 0.5% per year (Pérez-Arriaga et al., 2005). Because the anthropogenic sources of carbon dioxide to the atmosphere are dominated by fossil fuel use, energy and electricity are the main components for the mitigation of those emissions (Edmonds et al., 2006). In Portugal, energy-related activities are the major sources of Greenhouse Gases (GHG) emissions, accounting in 2008, for 70.8% of total emissions, presenting an increase of 37.4% over the 1990-2008 period. By far the most important gas emitted by this sector is CO_2, with 97.2% of sector emissions (APA, 2010).

Therefore, renewable energy sources must become a very significant part of the electricity generation mix in a couple of decades if sustainability objectives are to be reached. In this context, the Energy and Climate Package has endorsed three legally binding targets to be accomplished by 2020, namely the reduction of greenhouse gas emissions by 20% (based on 1990 emissions), a 20% increase in the share of renewable energy compared to traditional energy sources and an overall 20% energy efficiency improvement. This package introduced the EU Emissions Trading Scheme (ETS) – regarding CO_2 emissions – and imposed national emission limitation targets on sectors not covered by the ETS. Besides this package, a previous Directive (2001/77/EC) had already established EU targets for 2010 regarding RES, specifying a 12% share of gross primary energy consumption and a 12% share of gross electricity produced from RES.

Notwithstanding, the European energy and the environmental performance is still far from being homogeneous and sustainable even for EU-15.

In the European context, Portugal seems to be one of the member countries that have invested the most in the renewable installed capacity of electricity generation. In 1999, electricity generation from RES represented 21.4%, whereas in 2009 it represented 35.1%. Since energy generation, in general, and electricity generation, in particular,[4] are the most responsible sectors for CO_2 emissions (and others), it should have been expected an excellent environmental performance of the Portuguese electricity sector in the last decade. However, the reality does not seem to show exactly that. In Portugal, the electricity market structure is characterised by a quasi monopoly, with a very strong incumbent that holds a substantial share of the market power, significant barriers to entry and low interconnection capacity. On January 2009, the incumbent Electricidade de Portugal (EDP) still held 93% of market share.[5] Thus, could this lack of market threat be the reason why the incumbent does not feel the incentive to make a “real” effort to visibly improve its environmental performance? At what point is this statement true?

---

[4] Besides energy and electricity generation, transport and heating are also considered to be the most responsible sectors for CO_2 emissions, albeit in Portugal they do not appear to have a significant contribution.

[5] Meanwhile, the present situation points to a 58% share.

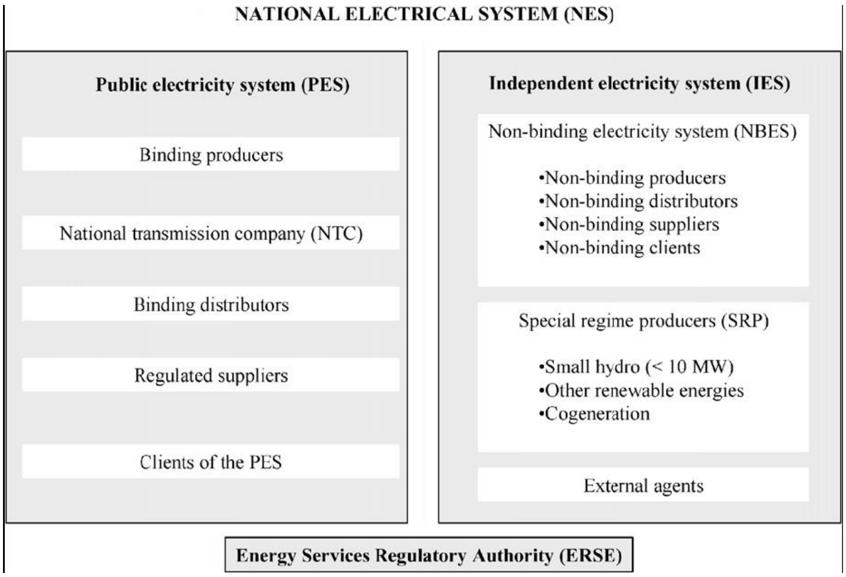
The remainder of the paper is organised as follows. Section 2 characterises the recent path of the Portuguese electricity supply and its environmental impact. Section 3 presents the model and the empirical evidence of the whole Portuguese thermoelectricity utilities and section 4 concludes.

2. Recent Path of the Portuguese Electricity Supply and its Environmental Effect

2.1. Overview

In 1994, the Portuguese electricity sector was reorganized. The monopolist, vertically integrated incumbent EDP, was transformed into a holding composed by several subsidiaries (Leite, 2001). Consequently, on the 27th of July 1995, a law package (D.L. 182/95 to 188/95) was published. With that, the bases of the new organisation of National Electricity System (NES) were created. NES, which was initially a state-owned monopoly, gave place to two distinct subsystems: the Public (PES) and the Independent (IES) systems. PES, which was tendentially limited to small consumers, was transformed into a non-competitive system, organised to fulfil the obligation of supplying a public service with adjusted standards of service quality and uniformed tariff, and thus subject to regulation. IES, composed by a Non-Binding Electricity System (NBES) and by Special Regime Producers (SRP), became a competitive system dealing with all large consumers, organized according to a market-based, non-regulated system – see Fig.1 (Penedos, 2001; Marques, 2003; Ferreira et al., 2007).

Fig.ure 1. National Electricity System before 2006



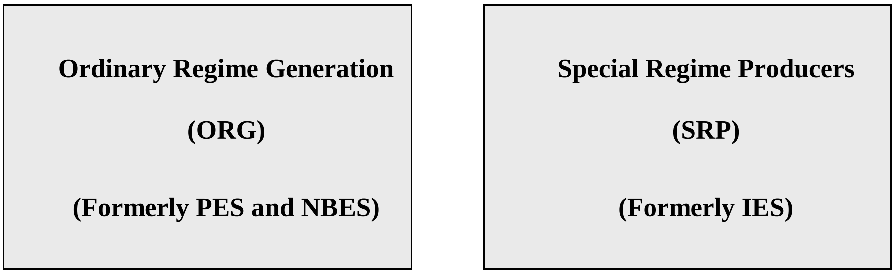
Source: Ferreira et al., 2007

Recently, the basic principles for the new organisation model of the National Electricity System were settled by the law package D.L. 29/2006 of February 15 and D.L. 172/2006 of August 25,[6] which transposes the European Directive 2003/54/CE.

NES is now divided into the Ordinary Regime Generation (ORG, formerly PES and NBES) and the Special Regime Producers (SRP) – see Fig.2.

Figure 2. National Electricity System in 2010

NATIONAL ELECTRICITY SYSTEM (NES)



ORG includes the electricity generation, based on traditional non-renewable sources and on large hydro power plants. SRP embraces the electricity generation subject to a special legal regime that benefits from incentives to use endogenous and renewable sources of generation or combined generation of heat and electricity. The rationale of centralised planning of the generation plants is abandoned. Within a liberalised framework, the Portuguese State only intervenes additionally to the private initiative, covering market failures and guaranteeing the electricity supply, through public tenders. Notwithstanding, ORG is characterised by a very high level of concentration. In 2008, 72.2% of installed capacity belonged to the three biggest producers (EDP, Turbogás and Tejo Energia), corresponding to a HHI of 4521 (EC, 2010).[7] Currently, EDP is the largest producer and it is also a shareholder of the remaining two. The National Energy Grids (REN),[8] which holds 70% of the National Transmission Grid, already follows the ownership unbundling model proposed by the Third Energy Package.

[6] Before this law package, the law package D.L. 184/2003 and D.L. 185/2003 of August 20, and D.L. 192/2004 of August 17, had already introduced some transitory measures.

[7] HHI is the Herfindahl-Hirshman Index calculated by summing the squared market shares of each individual company. Markets in which HHI is in excess of 1800 points are considered to be highly concentrated.

[8] REN has got the concession of high pressure (gas transmission) and high voltage (electricity transmission).

2.2. Evolution of the Energy Profile

The Portuguese energy profile can be summarised in table 1 and table 2.

Table 1 shows that crude oil and petroleum products are still dominating in the domestic energy consumption. However, following its late introduction in 1997, natural gas expressed an outstanding increase along the period. Solid fuels consumption has strongly decreased (16.6% in the analysed period) and renewables have increased by 20.8%.

Table 1. Gross Inland Consumption of Primary Energy (1000 toe)

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Solid Fuels	3463	3491	3171	3790	3803	3192	3476	3281	3372	3347	3308	2886
Crude Oil + Petroleum Products	13055	14111	15546	15856	15335	15891	16253	15167	15274	15768	13593	14047
Natural Gas	0	87	697	1945	2034	2255	2729	2636	3303	3751	3640	3808
Renewable Energies	3795	3750	3734	3369	3826	4070	3643	4336	3894	3578	4320	4584
Total	20408	21688	23171	24887	25078	25229	26264	25665	26409	27035	25334	25975

Source: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

A careful analysis of the Portuguese final energy consumption in the same period (Table 2), allows verifying that electricity consumption has increased its relative importance. Indeed, while electricity consumption increased 62.25%, total final energy consumption increased only 29.5%. This evolution is quite surprising since it denotes a weak substitutability between electricity and natural gas. Such fact might be related to the late introduction of the natural gas liberalisation in Portugal.[9]

Table 2. Gross Inland Consumption of Final Energy Consumption (1000 toe)

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Electricity	2599	2746	2910	3106	3299	3434	3566	3711	3841	3983	4107	4217
Total	14527	15291	16151	16732	17694	18113	18389	18393	20177	18723	18544	18813

Source: http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database

[9] The Portuguese liberalisation of natural gas, settled by D.L. 30/2006, started in January 2007, for electricity producers in the ordinary regime, and it was only extended to all eligible customers in January 2010.

Table 3 shows that electricity consumption has increased more than electricity generation from 1999 to 2009. While electricity consumption raised about 39.3%, electricity generation increased only 23.9%. Consequently, most of the consumption growth will have to be met by increasing imports and/or by improving and increasing electricity generation by endogenous renewable energies.

Table 3. Electricity Consumption and Electricity Generation (GWh)

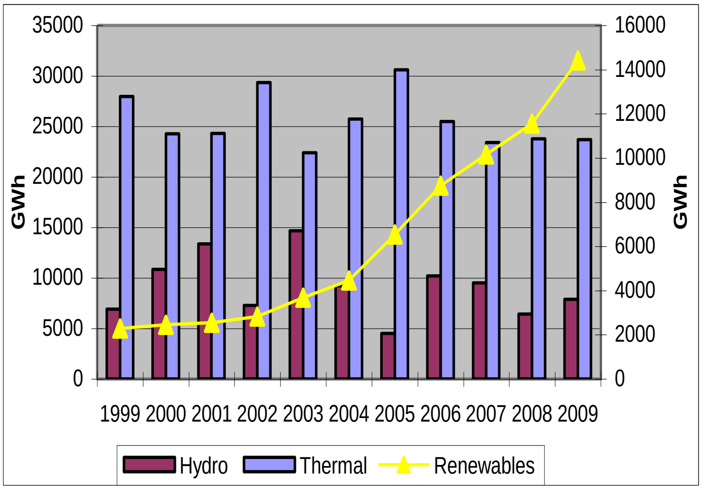
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Consumption	35799	37930	40015	40664	43061	45500	47940	49174	50059	50595	49865
Generation	37147	37571	40261	39435	40752	39429	72310	44436	43111	41803	46017

Source: http://www.centrodeinformacao.ren.pt/PT/InformacaoTecnica/DadosTecnicos/2009.pdf

2.3. Evolution of the Electricity Supply

The Portuguese electricity generation has been primarily assured by thermal production, as shown in Fig. 3. Indeed, in 1999, 2002, 2005 and 2008 thermoelectric power plants have generated more than 2/3 of total production greatly due to the dry hydrological year (HPI of 0.68; 0.75; 0.41 and 0.56, respectively).[10] However, the major increase in electricity generation is attributable to the renewables, especially in 2002 onwards.

Figure 3. Electricity supply in the national electricity system (NES),1999-2009

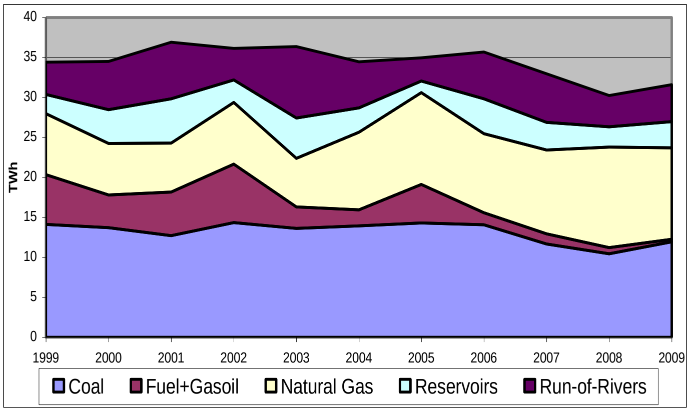


Source: http://www.centrodeinformacao.ren.pt/PT/Informacao Tecnica/Paginas/DadosTecnicos.aspx

[10] The Hydrological Productivity Index (HPI) takes the value of 1 for the hydrological average. Values higher than 1 mean years with higher precipitation. Values inferior to 1 mean dry years.

Fig. 4 depicts a significant increase of coal and natural gas power plants relative to fuel-oil combustion. In 2009, these two fuel types were the prevailing ones.

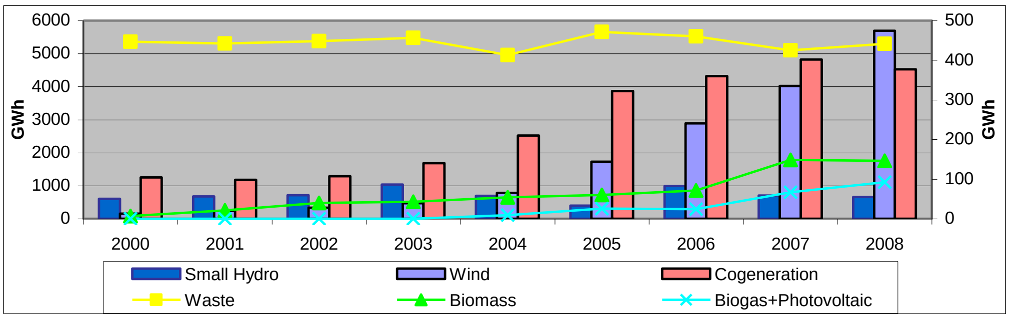
Figure 4. Electricity supply in the Ordinary Production Regime (ORG) by combustion type, 1999-2009



Source: http://www.centrodeinformacao.ren.pt/PT/Informacao Tecnica/Paginas/DadosTecnicos.aspx

In Special Regime Producers (SRP), cogeneration attained a significant production share between 1999 and 2009, falling a little in the last four years in favour of the wind turbines generation. In the last 5 years (2004-2008), the wind production rose 86%. In 2006 it increased 67%, in 2007, 38%, and in 2008, 42%. Within electricity generation from RES, wind production reported a 40.1% share in 2009 (DGEG, 2010). In 2009, SRP represented about 32.7% of the total installed generation capacity of inland Portugal (REN, 2010).

Figure 5. Electricity supply in the Special Production Regime (SRP), 2000-2008



Source: ERSE (2010), "Informação sobre produção em regime especial (PRE) – Portugal Continental" (http://www.erse.pt)

In short, Portuguese electricity generation has been essentially characterized by thermal generation, with coal and natural gas as the main combustibles. Indeed, natural gas has increased substantially and replaced fuel-oil in thermoelectricity generation. The hydroelectricity shows some instability due to the hydrological year dependency. Meanwhile, over the past 5 years, there was a steady increase of renewable generation, especially attributable to the substantial increase in wind turbines and cogeneration.

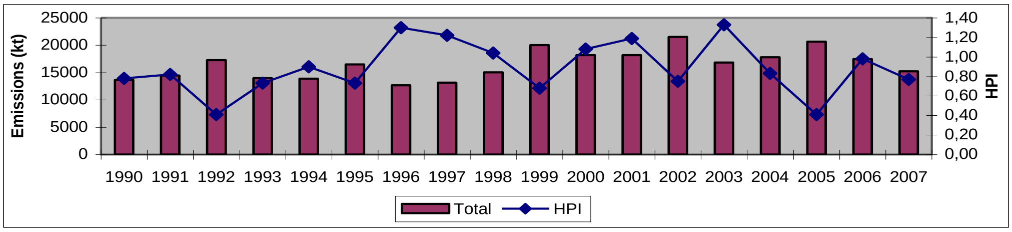
2.4. The Evolution of the Atmospheric Emissions from Electricity Generations

Energy-related activities are the major sources of Portuguese Greenhouse Gases (GHG) emissions, accounting, in 2008, for 70.8% of total emissions, presenting an increase of 37,4% over the 1990-2008 period. By far, the most important gas emitted by this sector is CO_2, with 97.2% of sector emissions (APA, 2010). Nevertheless, the most serious problem caused by this sector is the release of acid gases (Yang et al., 2009). The energy sector is the largest responsible for Sulphur Dioxide (SO_2) emissions and the second largest pollutant of Nitrogen Oxides (NOx), after the transport sector.

Electricity generation, as distinguished from electricity use, gives rise to a variety of environmental concerns. In particular, thermal electricity generation is, among all types of electricity generation, the one that most contributes to the increase of CO_2 emissions and acid gases. It is well established that air pollution and acid deposition have negative effects both on human health and on the environment. For example, human health is affected in terms of reduced life expectancy and increased respiratory hospital admissions, while the environment is affected through global warming (Longo et al., 2008).

Between 1990 and 2007, carbon dioxide total emissions (CO_2) of the Portuguese ORG combustion power plants showed to be highly dependent on the precipitation levels, which have also a significant effect on hydropower generation (see Fig. 6). As a result, dry years (HPI<1), result in a considerable reduction of hydroelectric power and in a subsequent increase in CO_2 emissions from electricity production in thermal plants.

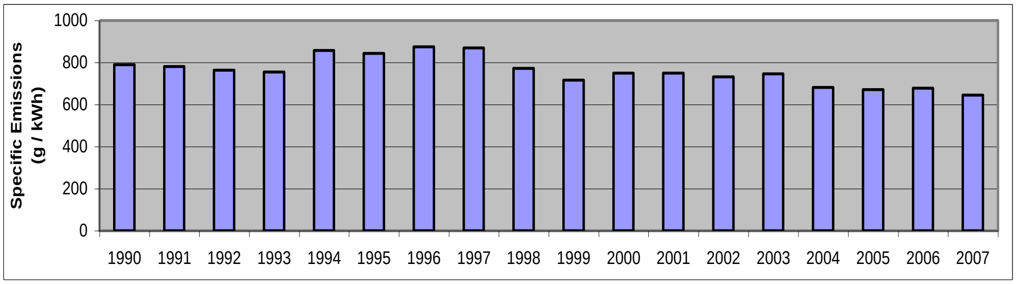
Figure 6. CO_2 total emissions of ORG combustion power plants, 1990-2007



<u>Source</u>: ERSE, 2008 (http://www.erse.pt)

Fig. 7 shows an increase of CO_2 specific emissions, after the introduction of Pego power plant[11] in 1993, and a decrease in 1998, 1999 and 2004 onwards. This better performance is associated with the introduction of natural gas into two groups of Carregado power plant in 1997,[12] the installation of a new combined cycle unit in Tapada do Outeiro[13] in 1998 and the installation of the new combined cycle gas turbine (CCGT) in Ribatejo[14] in 2004.

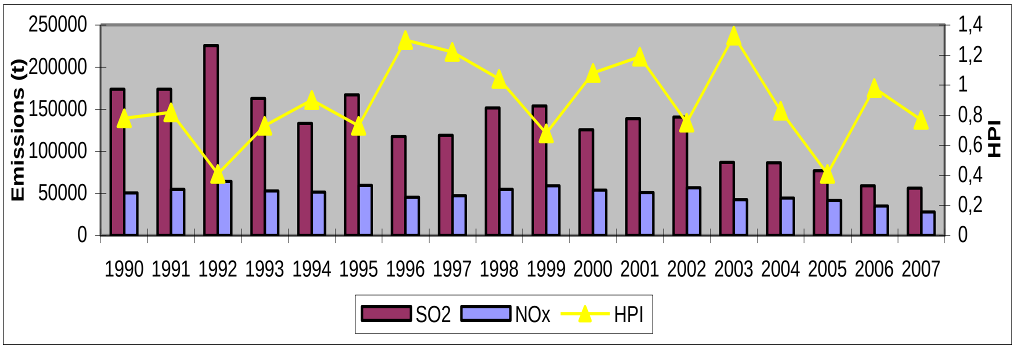
Figure 7. CO_2 specific emissions of ORG combustion power plants, 1990-2007



Source: ERSE, 2008 (http://www.erse.pt)

Like CO_2, total emissions of sulphur dioxide (SO_2) and Nitrogen Oxides (NOx) also depend highly on the hydrological fluctuations as presented in Fig.8.

Figure 8. SO_2 and NOx total emissions of ORG combustion power plants, 1990-2007

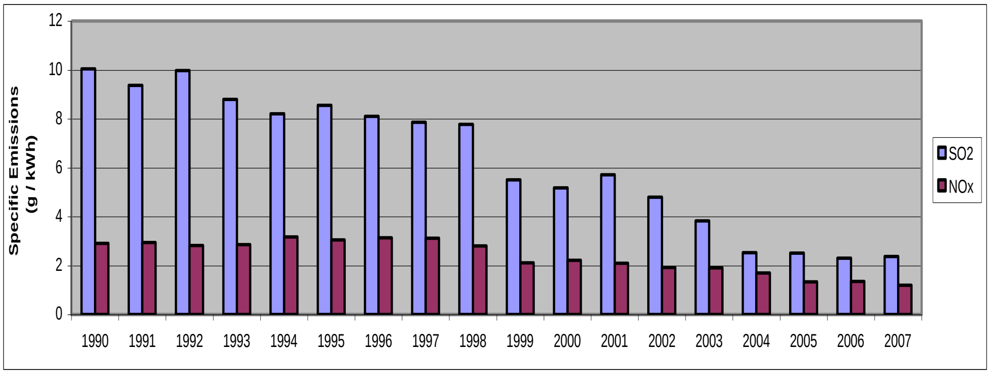


Source: ERSE, 2008 (http://www.erse.pt)

[11] Pego is a coal power plant with a Total Installed Capacity (TIC) of 314 MW by 1993 and 628 MW by 2010 that belongs to Tejo Energia.
[12] Carregado is a thermal power plant with a TIC of 710 MW that operates with fuel-oil and natural gas and belongs to EDP.
[13] Tapada do Outeiro is a natural gas power plant with a TIC of 990 MW that belongs to Turbogás.
[14] CCGT Ribatejo is a natural gas power plant with a TIC of 1176 MW that belongs to EDP.

Fig. 9 shows a gradual decrease of SO_2 and NOx specific emissions. This trend can be explained by the use of less sulphur container fuels and desulphurisation techniques, together with the installation of low NOx burning devices. The years of 1999, 2003 and 2004 outstand because of the considerable decrease of these acidifying pollutant emissions. In 1999, it was introduced natural gas in Tapada do Outeiro power plant and in 2004 a new thermoelectric power plant operating with natural gas (CCGT Ribatejo) was installed.

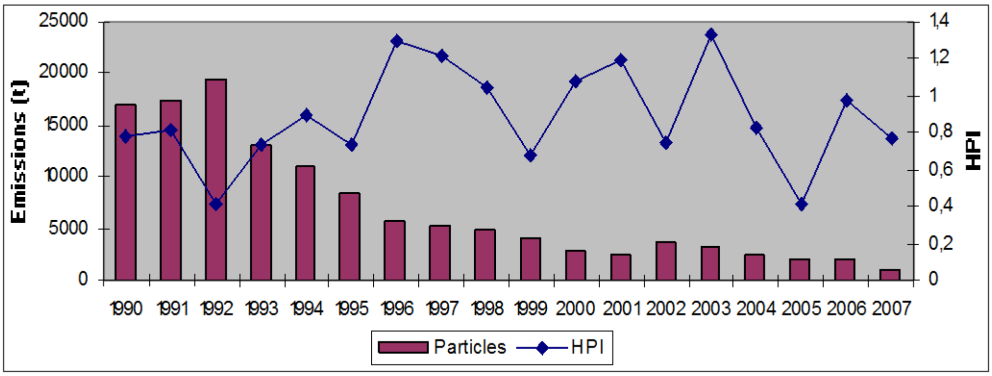
Figure 9. SO_2 and NOx specific emissions of ORG combustion power plants, 1990-2007



Source: ERSE, 2008 (http://www.erse.pt)

The particles total emissions show a decreasing trend, without any relationship with HPI fluctuations. This performance can be explained by the installation of electrostatic precipitators that retain the suspended particles and, more recently, by the natural gas use.

Figure 10. Particles total emissions of ORG combustion power plants, 1990-2007

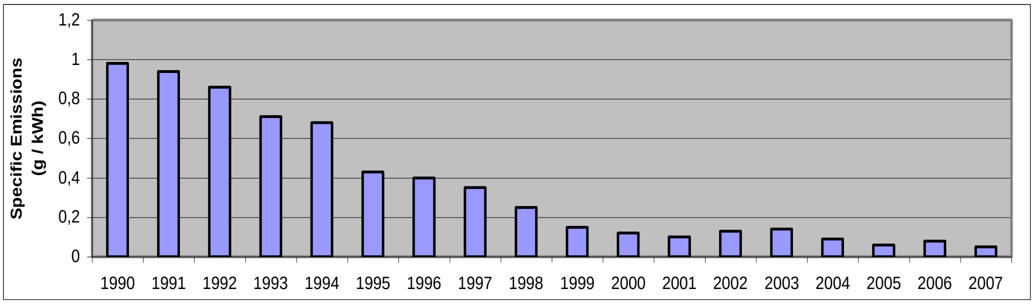


Source: ERSE, 2008 (http://www.erse.pt)

Fig. 11 also shows a gradual tendency for the particles specific emissions decrease until 1999. From that year onwards those emissions have remained particularly low.

In short, the studied emissions show a gradual decrease explained by the installation of combined cycle thermal plants and co-generation units, the introduction of natural gas together with the use of lower carbon and sulphur intensive fuels, and with the installation of both low NOx burning devices and electrostatic precipitators that retain the suspended particles. Moreover, in most recent years there has been an expressive development and installation of equipments for the use of RES with a particular relevance of wind turbines.

Figure 11. Particles specific emissions of ORG combustion power plants, 1990-2007



<u>Source</u>: ERSE, 2008 (http://www.erse.pt)

3. Modelisation and Empirical Evidence

3.1. Overview

The electricity sector, although being essentially a clean and benign energy source at consumption, presents a variety of environmental impacts at the generation level, including atmospheric pollution. As the sector has suffered a substantial restructuring, it becomes imperious to study, how the Portuguese electricity generators, namely the thermal ones, have integrated environmental features into their companies as a competitive force.[15]

3.2. Data

For the empirical estimation it was used a sample of all the existing Portuguese power plants, of which 10 are owned by EDP Holding (representing

[15] Most air pollutants stem at least in part from the combustion of fossil fuels. Therefore, this empirical analysis addresses the study of large combustion plants, because they are, among all electricity power plants, the ones that present the highest values of atmospheric emissions.

more than a half of global generation) and the other two are owned by Turbogás and Tejo Energia, for the period between 1990 and 2008 (Table 4).

Table 4. Selected Combustion Power Plants

Combustion Power Plants	Fuel Use	Technology
Tapada do Outeiro (EDP)	Coal and fuel-oil; later only fuel-oil	Steam turbine
Carregado (EDP)	Initially fuel-oil and later fuel-oil and natural gas	Steam turbine
Barreiro (EDP)	Fuel-oil	Steam turbine
Setúbal (EDP)	Fuel-oil	Steam turbine
Sines (EDP)	Coal	Steam turbine
Tunes (EDP)	Gasoil	Gas turbine
Mortágua (EDP)	Natural gas	Steam turbine
SOPORGEN (EDP)	Natural gas	cogeneration
ENERGIN (EDP)	Natural gas	cogeneration
Ribatejo (EDP)	Natural gas	Combined cycle
Tapada do Outeiro (Turbogás)	Natural gas	Single Shaft Combined cycle
Pego (Tejo Energia)	Coal	Steam turbine

For the atmospheric emissions study we have chosen the following pollutants: sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2) and suspended particulates, for having the worst environmental impact, among all pollutants, and for being the only cases subject to monitoring thus, disposed by EDP Produção.

The option for the Specific Emissions ($\frac{Atmospheric\,Emissions}{Net\,Production}$) as the dependent variable, instead of Total Atmospheric Emissions (Atmospheric Emissions only), was to capture the impacts of the electric production on the environment in a trustworthy way. The annual atmospheric emissions depend substantially on the use given to thermo power plants, which in turn, is highly dependent on the hydroelectric productivity index (IPH). So, to get the correct evolution of the environment performance in terms of atmospheric emissions, it is necessary to eliminate the hydrological variations. This can only be captured if atmospheric emissions are divided by the net electricity production.[16]

[16] The option for the net production instead of gross production is not casual. Although gross production means total quantity of production energy, the use of net production enables to reflect efficiency gains in the combustion plants. This means that, if a thermoelectric plant diminishes its

The chosen independent or explanatory variables were the following: (i) 5 quantitative variables, one for each fuel type (national coal, imported coal, fuel-oil, gasoil and natural gas) for each unit of net electricity production; (ii) 1 dummy variable for the liberalisation; and (iii) 1 dummy variable for the gases treatment.

The quantitative variable $\frac{Fuel\,Type}{Net\,\mathrm{Pr}\,oduction}$ deserves special attention, as energy content differs among fuel types. A unit of imported coal, for example, does not have the same impact on the environment as a unit of fuel-oil or natural gas. Ideally, it should be used a variable that expresses this information: the Net Calorific Value (NCV) of each fossil fuel. NCV expresses the total amount of energy released in the complete combustion of a ton of a certain fuel. Thus, it gives the notion of the energy amount that can be get from each fuel.

To construct this variable, NCV of each fossil fuel was multiplied by the amount of the respective annually consumed fuel, which in turn was divided by the net production of each power plant, as illustrated for the imported coal case, as it follows:

$$\frac{Amount\ of\ imported\ coal * NCV\ of\ imported\ coal}{Net\,\mathrm{Pr}\,oduction}$$

This relation expresses the total amount of energy released by the combustion of imported coal for each unit of electricity produced.

In relation to the dummy variable – liberalisation – it was assumed the value of zero for the period between 1990 and 1998 – period without liberalisation – and the value of 1 otherwise. As the completely liberalisation of the electricity market is a relatively recent event, it is not expected to have strong statistically significant results.[17] However, if it does, some caution should be taken in the interpretation of the results as it can be due, for example, to the more restricted environmental regulation.

For the dummy variable – Gases Treatment – zero is taken for the time period when the device that retains the suspended particulates is not installed in the combustion plants and the value of 1 otherwise. The reason for the inclusion of this variable was to analyse whether this technology has, in fact, positive impacts on the environment or not.

internal electricity consumptions, its electricity net production increases, even if gross production remains the same. So, if net production increases, the specific emissions diminish, i.e., for the same amount of electricity, a smaller atmospheric emission was released. This effect could not be seen if gross production was used instead.

[17] The complete liberalisation of the Iberian electricity sector is relatively recent. In Portugal, liberalisation started in 1999, but it was completed only in 2007, when all consumers had free access to suppliers.

3.3. Econometric Approach

Following Meireles (2003), we estimated the following 4 regressions, one for each pollutant type, using the Panel Data approach:

$$SpecEmis_{j,it} = \beta_0 + \beta_1 NICNCV_{it} + \beta_2 NFNCV_{it} + \beta_3 NNGNCV_{it} + \beta_4 GT_{it} + \beta_5 LIB_{it} + v_{it} \quad (1)$$

where:

$SpecEmis_{1,it} = spso2 = \dfrac{SO_2}{NP}$, $SpecEmis_{2,it} = spnox = \dfrac{NO_x}{NP}$,

$SpecEmis_{3,it} = spco2 = \dfrac{CO_2}{NP}$, $SpecEmis_{4,it} = sppart = \dfrac{Part}{NP}$.

$SpecEmis_{j,it}$ = Specific emissions level of Atmospheric Emission *i* for the 12 combustion power plants in *t* period.

$NNCNCV_{it}$ = (*Net National Coal*NCV*) = amount of energy released by national coal for each unit of electric energy produced in the 12 combustion power plants in *t*.

$NICNCV_{it}$ = amount of energy released by imported coal for each unit of electric energy produced in the 12 combustion power plants in *t*.

$NFNCV_{it}$ = amount of energy released by fuel-oil for each unit of electric energy produced in the 12 combustion power plants in *t*.

$NGNCV_{it}$ = amount of energy released by gasoil for each unit of electric energy produced in the 12 combustion power plants in *t*.

$NNGNCV_{it}$ = amount of energy released by natural gas for each unit of electric energy produced in the 12 combustion power plants in *t*.

GT_{it} = *dummy* for Gases Treatment, where it takes the value of: $TG = 0$ for periods when gases treatment does not exist, and $TG = 1$ otherwise.

LIB_{it} = *dummy* for the liberalisation, where: $LIB = 0$ for $T = 1990, ..., 1998$ (not liberalised period); $LIB = 1$ for $T = 1999, ..., 2008$ (liberalised period).

$v_{it} = (c_i + u_{it})$ *composite* term (unobserved effect + idiosyncratic error or disturbance).

The model can be estimated either by using Random Effects or Fixed Effects. Formally, the assumptions underlying the consistency of the Random Effects and Fixed Effects estimators can be tested by using the Hausman test. Assuming that the orthogonality condition holds for u_{it}, the null hypothesis that it is intended to test is H_0: $E(c_i|x_{it})=0$, meaning that the unobserved effect, c_i, and the observed explanatory variables, x_{it}, are not correlated (Wooldridge, 2002). Under the null, the random effects estimator is consistent and efficient, whereas the fixed effects estimator is consistent but inefficient. *H* is distributed asymptotically as χ^2 degrees of freedom equal to 7. If *H* is higher than the preferred critical value, it means that there is a statistically significant difference between the two estimators. In that case, only the fixed effects estimator is consistent. The random effects estimator is inconsistent because the orthogonality condition fails, that is, H_0 is rejected (Wooldridge, 2002).

In the present study, the statistic test failed to reject H_0 for both CO_2 and particulates specific emissions regressions, favouring the random effects over the fixed effects model. This result suggests that in case of existing unobserved effects, they would not be correlated with the explanatory variables. Conversely, for both SO_2 and NOx specific emissions regressions, the Hausman specification test rejected H_0, suggesting that there is some correlation between the explanatory variables and the error terms, and that greater emphasis should be placed on the fixed effects results rather than on random effects model (Table 5).[18]

Table 5. Hausman Test

	Hausman Test			
	spso2	**spnox**	**spco2**	**sppart**
$\chi^2_{crít}$	**27,65**	**19,68**	**6,86**	**8,48**
P-value	**0,000254**	**0,006311**	**0,443928**	**0,292087**

Although the Hausman test failed to reject H_0 for two specific emissions regressions, some individual dummies' coefficients are significant. Thus, given the conflicting results, we decided to include heterogeneity, using the fixed effects approach, as in this case the inference will be always consistent regardless of the result for the Hausman test.[19]

[18] A dummy variable regression, for each air pollutant, was also performed to find out for observed heterogeneity through the dummies significance. The results corroborated the Hausman test revealing significance of the individual effects for SO_2 and NOx specific emissions.

[19] Nevertheless, we also estimated a model of random effects and first differences and engaged into a model of pooled OLS, where time series and cross-sectional observations are pooled together (see Appendix A).

3.4. Results

Table 6 presents the estimated results using the fixed effects specification.

Table 6. Fixed effects results

	Fixed effects			
	spso2	**spnox**	**spco2**	**sppart**
Constant				
NNCNCV	0,1596 (0,6773)	**0,6235***** (0,0001)	**126,6403***** (0,0024)	**1,0029***** (0,0000)
NICNCV	-2,6437 (0,6801)	2,4996 (0,3277)	488,0098 (0,4767)	0,1634 (0,8535)
NFNCV	0,2025 (0,1889)	**0,3832***** (0,0000)	**65,4192***** (0,0001)	**0,0382*** (0,0736)
NGNCV	**0,3234***** (0,0000)	**0,3185***** (0,0000)	**66,5797***** (0,0000)	0,0003 (0,9528)
NNGNCV	-0,0006 (0,1331)	0,0002 (0,1921)	0,0289 (0,5269)	0,00001 (0,7989)
GT	-1,4357 (0,4523)	-0,2661 (0,7261)	-212,4705 (0,2985)	**-0,5737**** (0,0307)
LIB	**-3,9402***** (0,0000)	**1,0251***** (0,0028)	**408,3636***** (0,0000)	-0,1438 (0,2215)
n	157	157	157	157
R^2	0,80	0,85	0,80	0,88
Adjusted R^2	0,78	0,83	0,77	0,86
F **P-value**	31,41 (0,0000)	43,49 (0,0000)	30,66 (0,0000)	53,73 (0,0000)

Note: ***, **, * = significance at 1%, 5% and 10% level, respectively.

Both the sign and significance of the estimated coefficients are very similar to those estimated using random effects, first differences and pooled OLS (see Table A.1 and A.2). This means that, combustion power plants effects are jointly significant within our fixed effects model suggesting that such effects do play a role.

Although our prior expectations for liberalisation was that it would be a negative determinant for air pollutants, with the exception of SO_2 specific emissions, it turned out to be a positive determinant of NOx and CO_2 specific emissions. The positive impact of liberalisation on SO_2 specific emissions might be due to the attempt to fulfil the environmental regulation rather than from the liberalisation itself, as this kind of regulation has become more restricted, especially when it comes to the content of SO_2 levels in fossil fuels. This result corroborates the initial hypothesis that liberalisation was not accompanied by a significant HHI decreasing.

With regard to gases treatment, the results show that their use diminishes, effectively, the number of particles expelled in the electric energy production.

In relation to the fossil fuels impact on the specific emissions level of the studied pollutants, it can be concluded that gasoil is a positive and highly significant determinant of SO_2, NOx and CO_2. Furthermore, coal as well as fuel-oil showed to be the main responsibles for the NOx, CO_2 and particles specific emissions, although fuel-oil has showed to have fewer impacts. Conversely, natural gas has showed to be, by far, the least responsible for all atmospheric emissions increment, albeit not presenting statistical inference estimators. From all the analysed combustibles, only gasoil presented statistical inference estimators for SO_2 specific emissions. By far, the largest impact of the combustibles used in the electricity generation is over CO_2 specific emissions level.

The small statistical significance of the coefficients might be due to the small number of observations, restraining the interpretation and the illations concerning the estimation results. It is worth noting that for the Portuguese case itself the sample is very significant, as it includes all the Portuguese power plants. One way to solve this problem would be to increase the sample, introducing the Spanish thermoelectric power plants. However, due to the unavailability of detailed data concerning both the NCV combustible and the amount of combustible of each power station, the Spanish thermoelectric plants were not considered in this study.[20]

4. Concluding Remarks

In the last 20 years, the European electricity sector has been facing several reforms. The traditional public management has been gradually replaced by private management and the traditional utility monopolies have given place to free and competitive markets. This perception of the coexistence of different market structures in the electricity sector, has raised some concern about the equitable access of the competitive electricity generators to the monopolistic transport and distribution networks (Joskow, 1998; Newbery, 2001; Soares, 1997). Simultaneously, environmental concerns have become stronger and emissions reducing policies have become important in the recent years.

This reorganization has affected all EU member states. However, even with full liberalisation, Portugal still presents a very high market concentration at the generation level: EDP still holds 58% of market share.

The energy sector, in general, and the electricity generation, in particular, present severe impacts on the environment. Thus, we proceeded with an empirical analysis to inquire the existing relationship between the thermal generated electricity and its atmospheric emissions, as well as between liberalisation and those emissions. For the empirical estimation, we used a sample of the 12 existing Portuguese thermoelectric power plants. It was possible to conclude, as expected, that coal is the most responsible for the atmospheric quality deterioration, in general, and natural gas the least responsible. These results are in line with the literature since coal, with

[20] The requested unavailable data in the Spanish "Informes Anuales" was not provided.

its high carbon intensity, is often regarded as the fossil fuel that should be substantially replaced to mitigate those atmospheric emissions (Takeshita et al., 2006).

The strong investment on renewable generation along the last decade, should have reduced atmospheric emissions. Nevertheless, the estimation denotes a more "impressive" correlation per GWh generated than in other European countries with similar production structures. These findings may be explained by the strong increase of the Portuguese electricity consumption, together with the existence of a very strong incumbent that does not feel sufficiently threatened to invest in environmentally friendly combustibles. These results, though, should be interpreted with care owing to the strong economic crisis and the high precipitation levels observed in the last two years of the period under analysis, which are not significant in the tendency.

For the liberalisation, it was not possible to find a sharp statistical inference. Our results indicate that only SO_2 specific emissions are a negative function of liberalisation. This weak impact on atmospheric emissions may be explained by the Portuguese electricity market structure characterised by a quasi monopoly, significant barriers to entry and low interconnection capacity. This absence of threat does not induce the incumbent, which holds a substantial share of the market power, to adopt environmental improvements, attempting to accomplish just the environmental regulation, which has turned out to be more restricted with the liberalisation process, especially regarding the SO_2 emission levels.

The limitation of the results consistency, which ought to be more significant, has to do with the unavailability of detailed, homogenous observations concerning the environmental impacts of the combustion power plants in a broader Iberian Market (Portugal and Spain). Absence of reliable data has replaced the sample initially chosen to a smaller one (Portugal). Nevertheless, it is worth noting that for the Portuguese case itself the sample is very significant, since it includes all the Portuguese power plants.

Although the electricity market restructuring had introduced considerable changes in the Portuguese electricity market, its generation remains extremely dependent on the hydro generation, which is strongly related to hydrological fluctuations. In dry years, the Portuguese electricity sector needs to use thermal capacity to meet electricity demand, whose operation is responsible for higher atmospheric emissions.

In most recent years, there has been an expressive development and installation of RES equipments in Portugal at a much superior level than in the other EU countries. In 2002 total electricity generation from RES represented 21.8% whereas in 2009 it represented 35.1% (DGEG, 2010). However, contrary to the expectations, the environmental performance did not improve considerably. In fact, for the case of CO_2 and NOx emissions, the environmental commitments for the sector might not be accomplished in years of low hydroelectric power productivity. Portugal is significantly above the EU average for all the studied pollutants.

- Appendix A. Random Effects, First Differences and Pooled OLS Results

Table A1 depicts the results estimated using random effects for SO_2, NOx, CO_2 and particles. Table A.2 presents the results obtained both from pooled OLS specification, without controlling for combustion power plants effects, and from first differences.

Table A1. Random Effects results

	Random Effects			
	spso2	**spnox**	**spco2**	**sppart**
Constant	**4,7542***** (0,0018)	**-2,6047***** (0,0002)	**-411,0597***** (0,0012)	**0,3275**** (0,0294)
NNCNCV	**0,6835**** (0,0388)	**0,5510***** (0,0001)	**138,7762***** (0,0000)	**0,9644***** (0,0000)
NICNCV	0,3280 (0,1448)	**0,4176***** (0,0003)	**110,2249***** (0,0000)	0,0104 (0,5262)
NFNCV	**0,7379***** (0,0000)	**0,3676***** (0,0000)	**87,8182***** (0,0000)	**0,0266***** (0,0018)
NGNCV	**0,2818***** (0,0000)	**0,3071***** (0,0000)	**63,4226***** (0,0000)	-0,0039 (0,3336)
NNGNCV	-0,00005 (0,8072)	**0,0002**** (0,0352)	**0,0617***** (0,0000)	-0,00001 (0,3979)
GT	-0,0409 (0,9741)	0,8423 (0,1301)	27,9925 (0,7923)	-0,0978 (0,4243)
LIB	**-4,4336***** (0,0000)	**0,9665***** (0,0032)	**352,5727***** (0,0000)	-0,1490 (0,1686)
n	157	157	157	157
R^2				
Adjusted R^2				
F P-value				
DW				

Note: ***, **, * = significance at 1%, 5% and 10% level, respectively.

Table A2. First Differences and Pooled OLS results (corrected for autocorrelation)

	First Differences				Pooled OLS			
	spso2	**spnox**	**spco2**	**sppart**	**spso2**	**spnox**	**spco2**	**sppart**
Constant	-0,3438 (0,1460)	0,1878 (0,3070)	36,1006 (0,2903)	-0,0594 (0,1208)	**5,2106***** (0,0046)	**-3,8124***** (0,0000)	**-461,6309***** (0,0014)	**0,2972*** (0,0936)
NNCNCV	**0,6770*** (0,0579)	0,3784 (0,1723)	**89,8182*** (0,0816)	**0,7968***** (0,0000)	**0,7295**** (0,0328)	**0,3919**** (0,0118)	**134,4743***** (0,0003)	**0,9384***** (0,0000)
NICNCV	1,7468 (0,6501)	0,3318 (0,9119)	126,3214 (0,8205)	0,1183 (0,8915)	**0,3306*** (0,0781)	**0,4443***** (0,0000)	**126,8755***** (0,0000)	0,0092 (0,6552)
NFNCV	**1,0288***** (0,0000)	**0,2684***** (0,0027)	**68,9312***** (0,0000)	**0,0573**** (0,0147)	**0,9176***** (0,0000)	**0,4260***** (0,0000)	**100,7762***** (0,0000)	**0,0305***** (0,0021)
NGNCV	**0,2709***** (0,0000)	**0,2692***** (0,0000)	**45,5539***** (0,0000)	0,0011 (0,8326)	**0,2941***** (0,0000)	**0,2832***** (0,0000)	**61,3709***** (0,0000)	-0,0037 (0,3545)
NNGNCV	0,0002 (0,5098)	0,0002 (0,3496)	0,0456 (0,1774)	0,0000 (0,6344)	-0,00001 (0,9364)	**0,0003***** (0,0002)	**0,0699***** (0,0001)	-0,00001 (0,6433)
GT	0,3635 (0,8509)	-0,1920 (0,8986)	-35,7174 (0,8984)	0,0426 (0,9143)	**-3,1388***** (0,0072)	**1,8640***** (0,0004)	-47,5842 (0,7100)	-0,0325 (0,8315)
LIB	-0,7143 (0,5031)	-0,2016 (0,8081)	127,1638 (0,4100)	0,2403 (0,2786)	**-3,9155***** (0,0000)	**0,9559**** (0,0400)	**323,0527***** (0,0028)	-0,1853 (0,1671)
n	145	145	145	145	157	157	157	157
R^2	0,60	0,58	0,55	0,30	0,74	0,76	0,78	0,86
Adjusted R^2	0,58	0,56	0,53	0,27	0,72	0,75	0,77	0,86
F P-value	29,08 (0,0000)	27,09 (0,0000)	23,97 (0,0000)	8,42 (0,0000)	59,35 (0,0000)	67,58 (0,0000)	77,34 (0,0000)	135,48 (0,0000)
DW	2,204	2,416	1,913	2,205	2,056	2,135	2,068	2,345

Note: ***, **, * = significance at 1%, 5% and 10% level, respectively.

Although our prior expectations for liberalisation was that it would be a negative determinant of air pollutants, with the exception of SO_2 specific emissions, it turned out to be a positive determinant of NOx and CO_2 specific emissions for both fixed and random effects, as well as for pooled OLS. For first differences model the inference showed to be not statistically significant.

In relation to the fossil fuels impact on the specific emissions level of the studied pollutants, it can be concluded that gasoil is a positive and highly significant determinant of SO_2, NOx and CO_2. Furthermore, coal as well as fuel-oil showed to be the main responsibles for the SO_2 specific emissions for presenting, respectively, lower heat power (small NCV) and higher sulphur content, for pooled, first differences and random effects specifications. Table A1 and A2 also indicate that coal is the worst polluting combustible for NOx, CO_2 and particulates specific emissions. Conversely, natural gas has showed to be, by far, the least responsible for all atmospheric emissions increment, albeit presenting statistical inference estimators only for SO_2 (pooled OLS), NOx (pooled and random effects) and CO_2 (pooled and random effects) specific emissions. By far, the largest impact of the combustibles used in the electricity generation is over CO_2 specific emissions level.

References

- Bibliography

1. APA, 2010, “Portuguese National Inventory Report on Greenhouse Gases, 1990-2008”, submitted under the UNFCCC and the Kyoto Protocol, Portuguese Environment Agency, April, Amadora.
2. Commission of the European Communities, 2010, “Technical annex to the Report from the Commission on the progress in creating the internal gas and electricity market”, SEC (2010) 251 final, Brussels, 11.3.2010.
3. DGEG, 2010, “Renováveis”, Estatísticas Rápidas 65, Direcção Geral de Energia e Geologia, Julho, Lisboa.
4. Edmonds, Jae, Tom Wilson, Marshall Wise and John Weyant, 2006, “Electrification of the economy and CO_2 emissions mitigation”, Environmental Economics and Policy Studies 7, issue 3, 175-203.
5. Eurostat, 2009, “Energy, transport and environment indicators”, Eurostat Pocketbooks, European Comission, Luxembourg.
6. Ferreira, Paula, Madalena Araújo and M.E.J. O’Kelly, 2007, “An overview of the Portuguese electricity market”, Energy Policy 35, issue 3, 1967-1977.
7. Ferreira, Paula, Isabel Soares and Madalena Araújo, 2005, “Liberalisation, consumption heterogeneity and the dynamics of energy prices”, Energy Policy 33, issue 17, 2244-2255.
8. Joskow, Paul L.,1998, “Electricity Sectors in Transition”, The Energy Journal 19, issue 2, 25-52.
9. Leite, António N., 2001, “Funcionamento dos Mercados e Regulação” in A Regulação em Portugal, ERSE (ed.), Março, 127-156.
10. Longo, Alberto, Anil Markandya and Marta Petrucci, 2008, “The internalization of externalities in the production of electricity: Willingness to pay for the attributes of a policy for renewable energy”, Ecological Economics 67, issue 1, 140-152.
11. Marques, Vítor, 2003, “Poder de Mercado e Regulação nas Indústrias de Rede”, Gabinete de Estudos e Prospectiva Económica do Ministério da Economia, Junho, Lisboa.
12. Meireles, Mónica, 2003, “Ambiente, Liberalização e Reestruturação: Uma abordagem do Sector Eléctrico Ibérico”, M. Sc. (Econ.) Thesis, Economics Faculty of Oporto.
13. Newbery, David M., 2001, “Privatization, Restructuring and Regulation of Network Utilities” (The MIT Press, Cambridge (Mass.) and London).
14. Penedos, José, 2001, “A Estrutura do Sector da Energia em Portugal: o Sector Eléctrico”, in Colóquio Internacional: Energia e Direito – a Regulação da Electricidade e do Gás, 5 e 6 de Abril, CEDIPRE, Faculdade de Direito da Universidade de Coimbra.
15. Pérez-Arriaga, Ignacio and Barquín, Julián, 2005, “Investing for Sustainability”, paper presented at the Conference Implementing the Internal Market of Electricity: Proposals and Time-Tables, 9 September, Brussels.
16. Soares, M. Isabel, 1997, “Formas Avançadas de Concorrência e a Directiva Comunitária de Abertura dos Mercados de Electricidade. Que Compromisso?”, Investigação - Trabalhos em Curso 68, Faculdade de Economia do Porto.
17. Takeshita, Takayuki and Kenji Yamaji, 2006, “Potential contribution of coal to the future global energy system”, Environmental Economics and Policy Studies 8, issue 1, 55-87.
18. Wooldridge, Jeffrey M., 2002, “Econometric Analysis of Cross Section and Panel Data” (MIT Press, Cambridge, MA).
19. Yang, Ying-Hsien, Sue-Jane Lin and Charles Lewis, 2009, “Reduction of acidification from electricity – Generating industries in Taiwan by life cycle assessment and Monte Carlo optimization”, Ecological Economics 68, issue 6, 1575-1582.
20. Decreto Lei 182/95 to 188/95 (July, 27)
21. Decreto Lei 29/2006 (February, 15)

22. Decreto Lei 172/2006 (August, 25)
23. CPPE, Relatório Técnico – from 1990 to 2000.
24. EDP, 2004, "Centros Produtores".
25. EDP Produção, Relatório Técnico – from 2001 to 2008.
26. EDP, Relatório e Contas – from 1990 to 2008.
27. EDP, Relatório do Ambiente – from 1997 to 2002.
28. EDP, Relatório de Sustentabilidade – from 2003 to 2008.
29. European Directive 2003/54/EC (June, 26)
30. European Directive 2001/77/EC (September, 27)
31. European Directive 96/92/EC (December, 19)
32. Turbogás, Sumário Ambiental - from 2002 to 2008
33. Pego, Sumário Ambiental – from 1999 to 2008
34. REN, 2010, "Dados Técnicos: Electricidade – Valores provisórios 2009"

- Internet Resources

1. http://www.centrodeinformacao.ren.pt/PT/InformacaoTecnica/DadosTecnicos/2009.pdf
2. http://www.centrodeinformacao.ren.pt/PT/InformacaoTecnica/Paginas/DadosTecnicos.aspx
3. http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database
4. http://www.dgge.pt
5. http://www.erse.pt/vpt/entrada/factosenumeros/ambiente/emissoesatmosfericasdaproducao/
6. http://www.erse.pt/vpt/entrada/factosenumeros/ambiente/producaoemregimeespecial/
7. http://www.erse.pt/vpt/entrada/factosenumeros/sectorelectrico/portugalcontinental/producaogeneration/
8. http://www.centrodeinformacao.ren.pt/PT/InformacaoExploracao/Paginas/EstatisticaMensal.aspx