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The CO_2 emissions of the European power sector: economic drivers and the climate-energy policies ‘contribution.

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Abstract

In the frame of the ongoing debate on the 2030 energy and climate policies in the European Union, this article provides the first assessment of the effectiveness of European energy and climate policies on the CO_2 emissions reductions. This ex-post analysis deals with the CO_2 emissions of the electricity sector covered by the European Union Emission Trading Scheme (EU ETS) during its phases I and II (2005-2012). We analyze the contribution of different variables (including climate and energy policies, energy prices, economic activity and technical features of plants) in the evolution of CO2 emissions from electricity production plants in Europe. The empirical results allow drawing a number of conclusions regarding the causes of the downward trend in the carbon emissions generated by power production covered by the EU ETS between 2005 and 2012. First, we show that the increased use of renewable energy in electricity production has played a dominant role in the fall in CO2 emissions in the power sector. Second, the analysis confirms that the economic downturn has played a significant role, although not a dominant one. Third, price substitution effects between coal and gas also seem to have affected carbon emissions. Last but not least, we identify that the price of carbon has also pushed down power CO2 emissions.

JEL Codes: C23, L94, Q48, Q54.

Keywords: EU ETS, Energy and Climate policies, CO_2 emissions, European Electric Utilities, Panel Data Modelling.

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Table of Contents

1. Introduction

Phase II of the European Union Emissions Trading Scheme, or EU ETS, which lasted from 2008 to 2012, has now ended. The aim of this scheme, which was set up in 2005, is to reduce CO_2 emissions in Europe by setting emission caps for over 11.000 installations[1]which are required to return a volume of allowances that corresponds to their verified CO_2 emissions for each annual compliance assessment. The EU ETS is in force in 31 countries[2], and covers over 45% of their overall greenhouse gas (GHG) emissions.

The first period was a learning phase: around 1.2 billion allowances were allocated every year, almost entirely free of charge. As this surplus could not be used in Phase 2, the price of Phase 1 allowances fell to zero. The second period corresponded to the Kyoto Protocol application phase, where the EU ETS CO_2 emission reduction targets for each Member State were in line with those defined in the agreement. Allowances were still mostly allocated free of charge. Unlike in Phase 1, the option of holding Phase 2 allowances over to Phase 3 enabled the carbon price to remain at a significant level for a time, before gradually falling to below €4.00 per tonne. This second period between 2008 and 2012 was affected by the 2009 economic downturn, which was characterised by a world-wide economic contraction that began in late 2007 and took a serious turn for the worse in 2008. Against this backdrop, observers have repeatedly argued that the economic downturn, which is synonymous with a contraction in industrial output, was responsible for the recorded decrease in CO_2 emissions in the power sector.

In fact, the European Union stated this very clearly in its initial report on the operation of the EU ETS in November 2012, where it explained that *"the EU ETS is facing a challenge in the form of an increasing allowance surplus, primarily[3] due to the fact that the economic downturn has reduced emissions by more than was expected"*[4]. It is indeed likely that the slowdown in economic activity within the European Union did have an impact on the fall in CO_2 emissions, but can we argue that the downturn was the main reason or even the only reason for that fall?

Other factors could also have played a role, especially the actual efforts made to decarbonise the economy, and increase renewable energy's share in the energy mix. Indeed, the commitments made at

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[1] The sectors covered are mainly: energy production (which accounts for over 60% of the total emissions concerned by the EU ETS), and the "other combustion" segment, which includes units that are typically used to generate heat in order to support other industrial or urban activities, followed by cement plants, refineries and steel works, which account for roughly the same level of emissions.

[2] The 27 Member States, Croatia, Norway, Liechtenstein and Iceland.

[3] Capitalised by the author,

[4] European Commission, Climate Action, http://ec,europa,eu/clima/policies/ets/index_en,htm,

the European level, which resulted in the so-called "20-20-20"[5] targets, were implemented via a series of directives, including the directives on renewable energy and energy efficiency, which were combined with national policies. These commitments were reflected by a "notable development of renewable energy"[6] in most States. In which case, can we estimate to what extent these efforts contributed to reducing CO_2 emissions? Likewise, we need to ask whether changes in the price of energy affected CO_2 emissions or whether the allowance system, and specifically the carbon "price signal" that it reflects, effectively played a role by encouraging fuel-switching in energies and investments technologies that emit less carbon.

We choose to focus our analysis on the power sector for various reasons. First, it is the largest sector in the EU ETS in terms of CO_2 emissions. According to Berghmans et al (2012); 50% of allowances were allocated to power or combined heat and power (CHP) plants. It differentiated from the other sectors also because since 2005, it is the only industry that as a whole was short in EUAs, i.e. its free allocation of EU allowances was lower than the amounted of CO_2 it emitted. This has been anticipated by Member States and comes from two main reasons, the perception that cheaper abatement options exists in the power sector rather than in other industrial sectors, and the low risk of carbon leakage in power production (Ellerman and Buchner,2008). It has led to a well integration of the carbon price by power producers in their operating decisions.

Secondly, the power sector is exposed to different kinds of energy or environmental policies that also impact fossil fuel power plant emissions level. On top of the carbon price that was established in 2005, national policies to develop renewable energy are widespread in the European Union. Since 2009, national targets are consolidated in a directive at the European level and Member States established action plans to reach the desired development in renewable energy[7]. According to them, electricity from renewable sources will reach 33 % of the total final electricity consumption at the European level in 2020, when it was only 15 % in 2005. To reach their objectives, many Member States put in place deployment policies such as feed-in tariffs or "green" certificates (Ringel, 2006) that were successful in channelling investments in renewable energy production without any connection with the CO_2 price level. Other environmental command and control policies are also applied in the European power sector, like the *Large Combustion Plant Directive* that limits the use of some power plants since 2008

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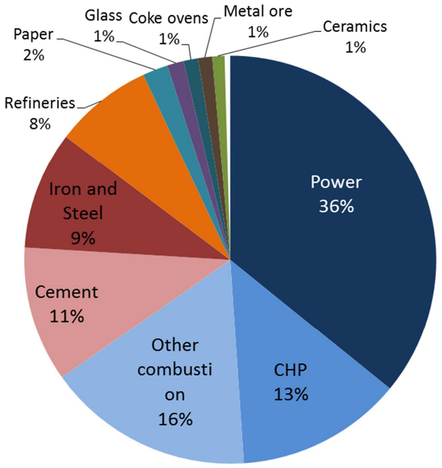
[5] Directive 2009/28/EC on renewable energies established a European framework for the promotion of renewable energies, which set binding national renewable energy targets, in order to achieve a 20% share of renewable energy in energy end-consumption by 2020, to reduce CO_2 emissions in European Union countries, and to increase energy efficiency by 20% by 2020,

[6] European Commission, *Renewable Energy Progress Report*, 2013, page 3, http://eur-lex,europa,eu/LexUriServ/LexUriServ,do?uri=COM:2013:0175:FIN:FR:HTML

[7] All national action plan on renewable energy are freely available on the European commission website: http://ec.europa.eu/energy/renewables/action_plan_en.htm

We thus can take advantage of the data provided in the EU Transaction Log on power plants participating in the EU ETS, to evaluate the impact in terms of CO_2 emission of the carbon price, but other complementary policies that affect emissions level.

Figure 1 – Free allocation by sectors between 2008 and 2012 (average of 1,999 $MtCO_2$ per year)



Source: Berghmans and Alberola (2012), based on EUTL and World Electric Power Plant (Platts) data.

From an original database of 1,453 electricity generation plants running on fossil fuels in Europe, the focus of this article is to provide quantitative answers to these questions, based on panel data econometrics for the EU 27. We attempt to link CO_2 emissions with a series of explanatory variables that have an impact on emission trends, and to gauge their relative contributions.

The remainder of the paper is organized as follows. Section 2 presents the literature review. Section 3 details variables. Section 4 contains the econometric methodology and empirical results. Section 5 concludes.

2. Analysing the explanatory factors for CO2 emissions

Early empirical academic literature has developed on the EU ETS has so far mainly focused on econometric evaluation of the explanatory factors in the price of carbon, less on CO2 emissions data. On the two first periods of the EU ETS several publications determined the main factors and their effects on prices of other energy prices. The aim of initial publications was to determine the main pricing factors and their effects on other energy prices, and among which we would mention Bunn and Fezzi (2007), Mansanet-Bataller et al . (2007), Alberola et al . (2008) and Alberola and Chevallier (2009). Generally speaking, this research concluded that the price of allowances reacted (i) to the publication of verified emissions and regulatory decisions (ii) to the price of primary energy and (iii) to climatic conditions.

In parallel, a piece of literature has developed on the optimal mix of policy to reduce CO_2 emissions in the power sector. Fischer and Newell (2004) argued that technology policies should remain confined to the promotion of research and development, thus rejecting promotion policies by early market deployment. De Jonghe et al. (2009) and Böhringer et al. (2008) show the interdependence of renewable policies and carbon pricing, which leads to the inefficiency of one of them if they are poorly calibrated. Fisher and Preonas (2010) argue that in the presence of efficient carbon pricing other policies such as renewable energy support offers no additional environmental benefits and so have to be justified by other market failures. Whereas, Hoel (2012) and Lecuyer and Quirion (2013) argues that in the presence of uncertainty about the environmental benefit of mitigation or the future policy, RE subsidies can be justified even only by their contribution to the mitigation of CO_2 emissions. Our aim is not to discuss the theoretical justification behind the design of the policy-mix, but to evaluate empirically the relative contribution of the EU ETS through its carbon price, RE deployment and command and control directive on local pollutants on the abatement in the European power sector.

The academic literature today provides no empirical evaluation of the explanatory factors of CO_2 emissions in the power sector over the period 2005-2012. None ex-post assessment of the contribution of other climate and-energy policies has yet been performed at the scale of the EU. Nevertheless, some studies evaluated the emissions reductions achieved by the implementation of the EU ETS. Ellerman and Buchner (2008) found that a reduction emissions between 50 and 100 million tonnes (Mt) during the first phase (2005-2007). Delarue et al. (2008a and 2008b) evaluated emissions reductions were between 34 and 88 Mt in 2005 and 19 and 59 Mt in 2006. Feilhauer and Ellerman (2008) concluded that reductions are between 13 and 122 Mt and finally Ellerman et all (2010) estimate reductions between 120 and 300 Mt for the first time.

As for the assessment of CO_2 abatement coming from renewable energy development, Weigt et al. (2012) examined the impact of the development of renewable energy (RE) in Germany on the demand for carbon allowances (and therefore on CO_2 emissions). They showed that approximately 10 to 16% of the fall in CO_2 emissions in the electricity sector for the period between 2005 and 2011 can be explained by the increase in RE's share of the energy mix. It also appears that the presence of the EU ETS market had a positive impact on emission reductions. Gloaguen and Alberola (2013) evaluated the contribution of RE development, CO_2 price and electricity intensity of the GDP in explaining the CO_2 emissions variation in the EU ETS through a panel data regression at the country level. They showed that RE deployment are the first cause of emission reductions in the EU ETS with a contribution of 500 to 600 $MtCO_2$ over the period 2005-2011, when the economic crisis contributes to an amount of 300 $MtCO_2$. They find no evidence of the CO_2 price contribution to emission reductions.

Previously, some studies tried to determine the factors behind CO_2 emissions variations. McGuinness and Ellerman (2008) presented an econometric study that focuses on the United Kingdom, and covers British fossil-fuelled power stations and their carbon emissions according to the price of energy and CO_2, the production of and the demand of electricity. The authors used a fixed-effect panel regression analysis and concluded to the significance of the CO_2 price in determining the use of thermal power plants. In 2009, Anderson. Di Maria and Convey studied the CO_2 emission reductions and the over-allocation of allowances during the pilot phase of the EU ETS (2005-2007) using a dynamic panel-based (on European countries) econometric model. The authors chose the following explanatory variables: the level of CO_2 in the prior period, the level of economic activity in the industrial and energy sectors, the cost of electricity, and weather-related factors. Given the lack of data for some countries in their panel, they opted for the least squared dummy variable or LSDV estimation technique using indicative variables developed by Bruno (2005). They concluded that only the emissions for the prior period and the annual output index for the energy sector were significantly different from zero (at 1% confidence level) and therefore had an influence on CO 2 emissions. Climate-related variables, the manufacturing sector output index[8] and the cost of electricity were not significant.

Other studies have been conducted on the explanatory factors for CO_2 emissions within the EU ETS at the company or sector level, or else in some countries (Albrell et al (2011), Anderson et al (2011) and Kettner et al (2011), but never on a scale involving a large number of the countries covered, and therefore of the installations, as this study aims to do. These other studies concluded that CO 2 emissions within the EU ETS reacted: (i) to allowance allocation levels. (ii), to economic activity, and (iii) to the development of renewable energy.

In fact, Albrell et al. focused on assessing the EU ETS’ impact on companies in 2011. Their study covers a panel of over 2.000 European companies, which they followed between 2005 and 2008. However, this study only concerns economic sectors, and the observations end in 2008, i.e. at the very beginning of the economic downturn. The authors nonetheless showed that allowance allocations did have an impact, as they reduced emissions, but did not specify the role played by changes in economic activity. Kettner et al . (2011) also looked at the changes in emissions for each sector, over a period that included the economic downturn (up until 2010). Their analysis covered the surplus allowances. as well as the economic activity for each sector. They concluded that the steep fall in emissions recorded in 2009 was actually a reflection of the economic downturn. Meanwhile, Chevallier (2011) looked at non-linear adjustments between industrial output and the price of carbon in the EU-27. He

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[8] Eurostat Code: NACE D.

specifically showed that economic activity probably affects the carbon price, but with a time lag, due to the specific institutional constraints of the market.

3. Technical and economic factors impacting CO2 emissions

The previous literature review introduces a number of variables that explains the variation of emissions from power plants. We selected and tested the following explanatory variables:

- Economic conditions influence positively the demand of electricity by companies and households, pushing fossil-fuel power plants production and hence CO_2 emissions up.
- The level of production of low carbon technologies. As they have typically a lower marginal-cost than fossil fuel power plants, nuclear, hydro and other renewable electricity are the first ones to respond to the electricity demand. They thus affect the level of residual demand that faces thermal power plants.
- Price of primary energy (coal and gas) that influence the use of respective power stations through their marginal cost.
- CO_2 price that can, when high enough, incite a switch of production between CO_2 intensive power plants to less emitting ones.
- The existence of a regulation on other pollutants limiting the use of the power plant.
- The production capacity of the power plant. Biggest thermal power plants will tend to emit more CO_2.
- The energy efficiency of the power plant. For a similar level of production, less energy efficient power plants will emit more CO_2. On the other hand, they will tend to be less used than more efficient ones as their use is less profitable.
- The presence of CHP units in the power plant. CHP units have part of their CO_2 emissions that can be attributed to heat production and respond to different economic incentives.
- The primary fuel used by the power plant.
- The technology of the turbine of the units of the power plant.

We neglected to consider meteorological conditions also influence CO_2 emissions through the demand for electricity. In case of extreme weather (i.e. colder than usual in winter or hotter than usual in summer), there is an increase in heating or cooling consumption. Nevertheless, weather variations already flatten on a yearly average, the timescale of our data. Indeed, we expect that weather variations would hardly be significant in explaining yearly CO_2 emissions in our sample, so we don't take into account any meteorological data variable to explain the variations of CO_2 emissions. We also will not analyse the magnitude of CO2 emissions off shoring as there is very few interconnection with distribution networks of countries outside the EU, so carbon leakage risks are limited.

3.1. CO_2 emissions of power plants

All industrial sites participating in the EU ETS (approx. 12,000 sites in 31 countries) are required to report their CO_2 emissions every year. We identified power plants by matching the freely available database on the website of the European Commission[9], with the World Electric Power Plants edited by Platts[10] (see Annex 6.1. for methodological details). We thus identified 1453 accounts in the EUTL that corresponding to Power or CHP plants.

Among these1,453 power plants, 1,141 were active from 2005 to 2012, 68 retired between 2005 and 2012 when 244 appeared after 2005 either because it was new entrants or because their country integrated the EU ETS : 53 came from the integration of Bulgaria and Romania in the EU ETS in 2007 and Norway in 2008. We include in the sample all this power plants for each year they were in service, i.e. they reported verified emissions.

As a whole, power and CHP power plants saw a decrease in their CO_2 emissions by 186 Mt during Phase 2 (2008-2012), equal to a 14.2% fall from 1,306 Mt in 2007 – the last year of Phase 1 – to 1,120 Mt in 2012. The fall in CO_2 emissions in the power industry would therefore appear to be more circumstantial than structural. Trends in CO_2 emissions were different according to the primary fuel used by the power plant.

After declining sharply in 2008 and 2009, primarily due to the economic downturn, CO2 emissions from coal-fired power plants actually increased between 2009 and 2012, reaching 846 MtCO2 in 2012. This increase is partly explained by a rebound in coal's competitiveness as a fuel for thermal power plants in Europe, particularly due to the export of the excess coal produced in the United States to Europe, and to the collapse in the carbon price in Europe, which no longer penalised coal-fired power plants in 2011 and 2012.

Gas and oil-fired power plants experienced the sharpest decline in their CO2 emissions, which fell by 34% and 30% respectively between 2008 and 2012: CO2 emissions from gas-fired power plants fell from 273 to 175 MtCO2, while emissions from oil-fired power plants fell from 50 to 37 MtCO2.

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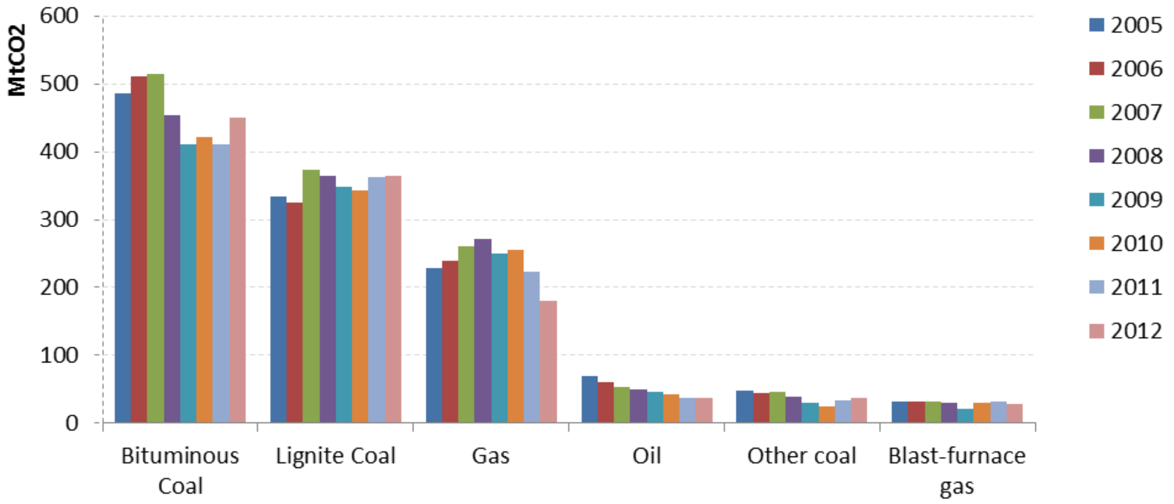
[9] http://ec.europa.eu/environment/ets/

[10] http://www.platts.com/products/world-electric-power-plants-database

Figure 2 -CO_2 emissions for the EU ETS power and CHP generation by primary fuel used (2005-2012)



Note: excluding Bulgaria and Romania, as their inclusion in the EU ETS became effective in 2007, the date when they joined the EU.

Source: Berghmans and Alberola estimates, based on EUTL and World Electric Power Plant (Platts) data (2013)

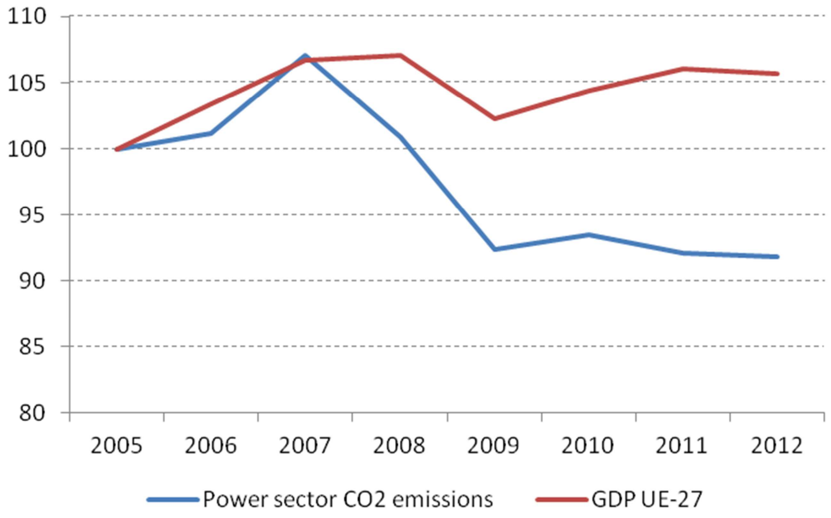
3.2. Economic factors influencing CO_2 emissions

We are looking to explain the variation of CO_2 emitted by power plants by three main kinds of data:

- Economic activity and energy markets data;
- Energy and Environmental policies data;
- Technical data of the power plants.

The first data selected to represent the economic activity is the national GDP coming from the Eurostat database, measured as chained volumes in base 100 for the reference year 2005.

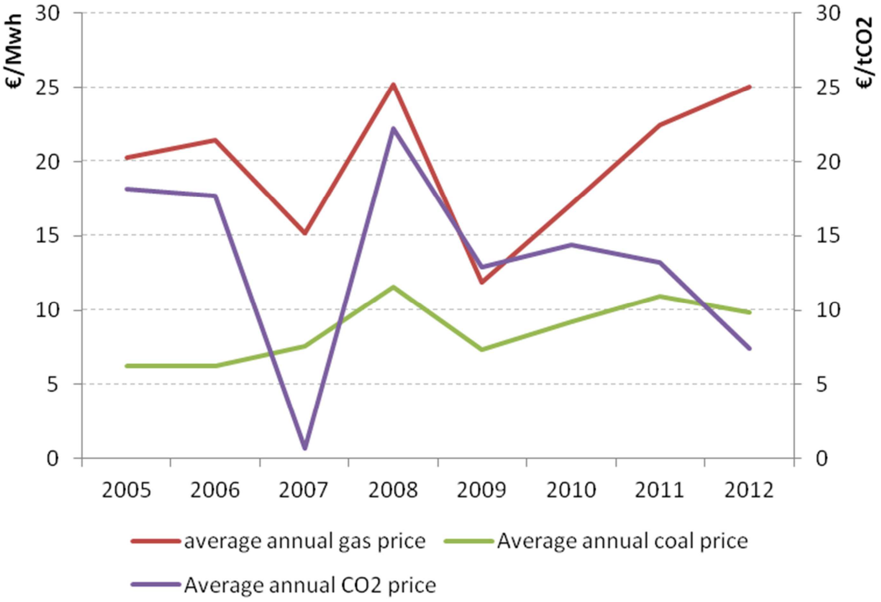
Figure 3 Power sector emissions vs GDP UE-27



Source: EUTL, WEPP(Platts) and Eurostat

To evaluate the impact of production costs in thermal power plants use, we selected coal and gas that are the two main fuels used in thermal power plants in Europe. Their prices were drawn from the Thomson-Reuters database, using the API 2 CIF ARA Month Ahead contract for coal, and the Zeebrugge spot contract for gas. The annual averages were calculated and the prices converted into euros per MWh.

Figure 4 Energy and CO_2 prices in Europe



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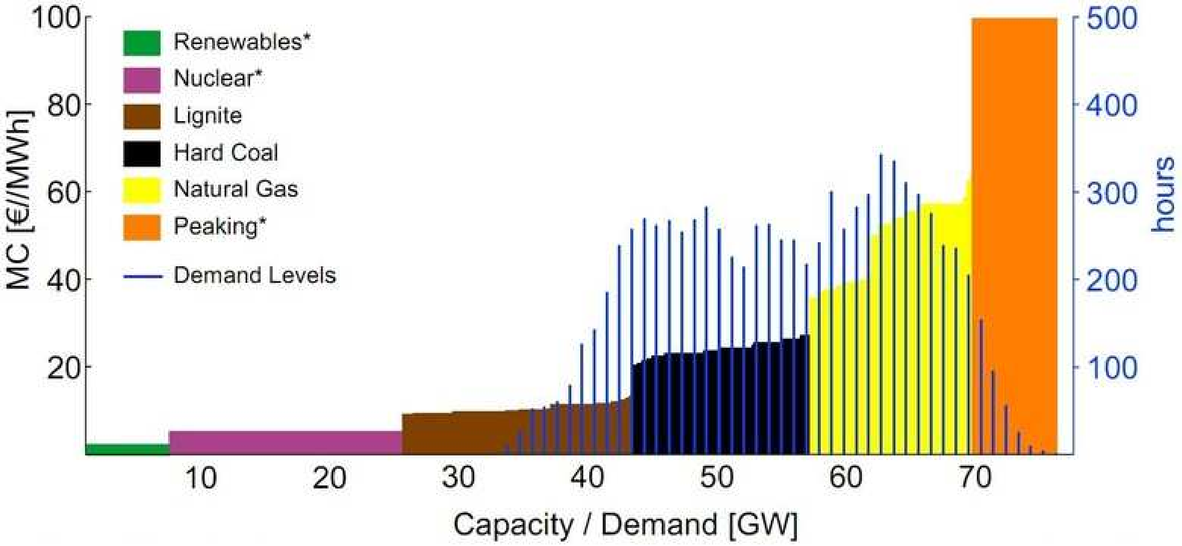
Source: ICE, Reuters

The CO_2 price in Euros/tCO_2 comes from ICE exchange database. We used the price of the contract for delivery for next December as it is the most liquid carbon asset traded. Annual average was calculated as a simple average of all closing prices of the year.

We take into account power production from low carbon technologies: nuclear and renewable. As they have a lower marginal cost of production than thermal power plants, they usually come first in the merit order of production. Figure 5 illustrates the order of production technology in Germany.

Figure 5 Stylized German merit order and demand distribution without carbon price

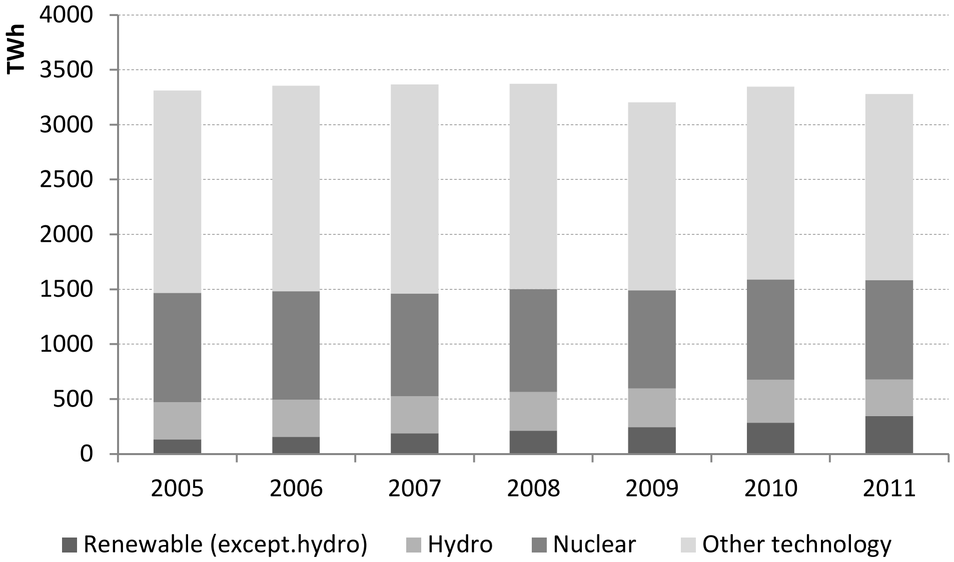


Source: Pahle et al. (2011)

We also take into account low carbon power generation. We take the national data from Eurostat in GWh and separate them between Hydro, Nuclear and other renewable technology, so we can evaluate the contribution of each one in CO_2 emissions reduction. Unfortunately, this data is only available to 2011, so it limits the timescale of the study from 2005 to 2011. Hydroelectricity production mainly depends on precipitation variations as the park of production is almost not increasing in Europe. Nuclear production depends mainly on the availability of nuclear reactors that can overcome long periods of outage for maintenance.

For other renewable technologies, although climatic variations play an important role in the production level of these technologies, the large increase in recent years illustrated by Figure 6 is mostly due to the expansion of the production capacity in Europe, mainly wind farms and solar panels.

Figure 6 Electricity production from non-CO_2 emitting sources in Europe versus Others



Source: Eurostat

Power plants that are submitted to use restriction under the Large Combustion Plant directive (20 000 hours between 2008 and 2015) are identified on the European Environmental Agency website.The generation capacity of power plants in MW is the sum of the capacity of all production units in the power plant, comes directly from the database World electric power plant edited by Platts. We take the year of commissioning of the power plant from the same source as a proxy of energy efficiency of the power plant, assuming older plants are less efficient. Cogeneration plants are identified as a percentage of MW that comes from CHP units. Primary fuel and type of units are modelled as dummies.

4. Results

According to the discussion presented previous Section, some technical power plants characteristics but also economic and energy market conditions should have an influence on the CO2 emissions of power plants. But the magnitude of the influence of these CO2 emissions determinants seems also to depend on the power plant under consideration, which varies widely among the EU ETS. Following this discussion, and to take into account the different regional air transport market maturities, the role played by these variables on the CO2 emissions of power plants concerned by the EU ETS is estimated using panel-data econometrics. As detailed below, cross-sectional units of the panel-data sample correspond to the 1,453 electricity generation plants running on fossil fuels in Europe.

We first present the econometric methodology used and then the results for various models and sub-samples.

4.1. Econometric methodology

Using panel-data modeling, we propose the following general framework to test for the influence of previously identified CO_2 emissions of power plants determinants:

$$y_{i,t} = x'_{i,t}\beta + z'_{i,t}\alpha + \varepsilon_{i,t} \text{ , } \forall\, i,t \tag{1}$$

with $t = \{2005, \cdots, 2012\}$ the period on which CO2 emissions data have been obtained, i corresponds to each of the 1,453 electricity generation plants running on fossil fuels in Europe and, as usual, $\varepsilon_{i,t}$ is the composite error term.. Thus specified the dependent variable of our model, $y_{i,t}$, corresponds to the verified CO2 emissions (expressed in ton) of the *i-th* power plant at time *t*. $x'_{i,t}$ is the vector of explanatory variables summarized in Annex 6.4.

There are *K* regressors in $x_{i,t}$, not including a constant term. The heterogeneity, or individual effect is $z'_{i,t}$ where z_i contains a constant term and a set of individual or group specific variables which may be observed or unobserved; all of which are taken to be constant over time *t*.

Eq.(1) is a classical regression model: if z_i is observed for all individuals, then the entire model can be treated as an ordinary linear model and fit by least squares. Basically, three kind of estimators may be used to estimate eq.(1), depending on the way the individual effect $z'_{i,t}$ is specified.

- First, if z_i is supposed to only contain a constant term, then ordinary least squares provides consistent and efficient estimates of the common α and the slope vector β. Eq(1) the becomes:

$$y_{i,t} = x'_{i,t}\beta + \alpha + \varepsilon_{i,t} \text{ , } \forall\, i,t \tag{2}$$

Eq.(2) corresponds to the pooled regression model.

- Second, if z_i is unobserved, but correlated with $x_{i,t}$, then the least squares estimator of β is biased and inconsistent as a consequence of an omitted variable. However, in this instance, eq(1) becomes:

$$y_{i,t} = x'_{i,t}\beta + \alpha_i + \varepsilon_{i,t} \text{ , } \forall\, i,t \tag{3}$$

Where $\alpha_i = z'_{i,t}\alpha$, embodies all the observable effects and specifies an estimable conditional mean. Eq.(3) corresponds to the fixed effects (FE) model. This fixed effects approach takes α_i to be a group-specific constant term in the regression model. The term fixed is used here to indicate that the term does not vary over time (not nonstochastic).

- Finally, the unobserved individual heterogeneity, however formulated, may be assumed to be uncorrelated with the included variables. Then eq.(1) may be formulated as follow:

$$y_{i,t} = x'_{i,t}\beta + \alpha + \mu_i + \varepsilon_{i,t}\ ,\ \forall\, i,t \quad (4)$$

Eq.(4) corresponds to the random effects (RE) model where μ_i is a group specific random element, similar to $\varepsilon_{i,t}$, except that for each group there is but a single draw that enters the regression identically in each period.

In this article, the relationship between the CO_2 emissions of European power plants and their main determinants, as specified in eq(1), is estimated thanks to the FE estimator (eq.(3)) and the RE one (eq.(4)). Note that the crucial distinction between the FE and the RE models is whether the unobserved individual effect embodies elements that are correlated with the regressors in these models.

The econometric methodology has been explained in details. The next section presents estimates of these two estimators.

4.2. Econometric analysis

We start out by presenting the results obtained for the "whole" sample (Section 4.2.1), which includes all types of primary fossil-fuel used by power plants included in the database: coal, gas, oil (and others) power plants. Recall that our database includes variables representing i) technical power plants characteristics and ii) economic and energy market conditions. As technical data are specific to each type of power plants, it is not possible to include this set of variables in the "whole" sample in order to test and quantify their respective influence. In order to capture characteristics of each kind of primary fuel and the type of power plant analyzed, one needs to break the "whole" sample into these respective sub-samples.

The subsequent sections present then results for the "whole" and smaller samples named as follows: "Coal" (Section 4.2.2), "Gas" (Section 4.2.3) and "Oil" (Section 4.2.4) power plants sub-samples. So-defined, the "whole" sample includes 1,453 power plants, the "Coal" power plants one contains 352 power plants, the Gas one 671 power plants and the Oil one 248 power plants (see Annex 6.3).

Tables 1 to 4 present the results for the "whole" sample and the "Coal", the "Gas" and the "Oil" power plants sub-samples respectively. In each of these Tables, column 1 presents result for the reduced model estimated by the fixed effects estimator. Colum 2 presents the same model estimated by random effects whereas column 3 presents the reduced model estimated by random effects. All variables presented in Annex 6.4 have been tested. For each estimate, results are systematically reported after having used the robust variance-covariance matrix estimates (i.e. after using the standard. errors adjusted for the *N* clusters, that is the number of installations under consideration).

Unless it is indicated (column (2)), column (1) and (3) regression results are presented in reduced form. These models were chosen by the general to specific approach to econometrics modeling. As usual, "***", "**" and "*" respectively indicate 1%, 5% and 10% significance levels and (robust) standard errors of the coefficient estimates are reported into brackets. In each column, "-" means that the variable under consideration has been first included but finally removed from the reduced form because its coefficient estimate was not statistically significant at the 10% significance levels. Regarding model information, *Number of observations* and *Number of groups* indicate respectively the number of observations and the corresponding cross-sectional units of the panel-data sample used to perform each regression. In all Tables, the *F test for FE* and the *Breusch & Pagan LM test for RE* correspond respectively to the Poolability tests of the *i)* FE model (eq.(3)) and the *ii)* RE model (eq.(4)) against the pooled regression model (eq.(2)). Both tests following the regression (P-Value < 0.01) indicates that there are significant individual (installation level) effects, implying that pooled OLS would be inappropriate. We then perform a *Hausman test* to test the null hypothesis that the extra orthogonality conditions imposed by the RE estimator are valid. Recall that if the regressors are correlated with the μ_i , the FE estimator is consistent but the RE estimator is not consistent. If the regressors are uncorrelated with theμ_i , the FE estimator is still consistent, albeit inefficient, whereas the RE estimator is consistent and efficient. In all Tables, the *Hausmman test*'s null hypothesis – that the RE estimator is consistent – is soundly rejected (P-Value < 0.01). The state-level individual effects do appear to be correlated with the regressors in all Tables.

We turn now to the comments of the results obtained for each samples and sub-samples. We only focus on the signs and significance of the coefficients estimated thanks to the FE model (column 1) since the FE model is always preferred to the RE one (see the *Hausmman test*'s results). However, we let the RE model estimates (column 2 and 3) for robustness check.

4.2.1. Results for the Whole Sample

Table 1 column 1 presents result for the reduced model estimated by fixed-effect. Colum 2 presents the same model estimated by random effect whereas column 3 presents the reduced model estimated by random effect. All variables presented in Annex 6.4 have been tested.

In the Whole sample model, variables that were not significant include geographical location of the power plant, technical data such as cogeneration percentage of the power capacity of the power plant, commission year, the type of production unit. Regarding geographical location irrelevance of the power plant, from an economic point of view, this result tends to indicate that electricity markets are sufficiently integrated to avoid country-specific distortions. On top of this economic explanation we may add a statistical reason: other explanatory variables - such as GDP, Renewable and Nuclear production- are also defined at the national level. It is not surprising that technical variables are not statistically significant in the whole sample, as they are specific to the kind of primary fossil-fuel used by power plants. For example, some types of turbines are specific to a kind of fuel: gas turbines or combined-cycle for example are gas specific. Also, the economic life cycle of a coal power plant is longer than a gas or an oil power plant. Thus, the commission year will not have the same relevance in explaining their CO2 emissions level.

The economic activity (*Gdp*) is statistically significant at the 1% significance level. It positively influences the variation of CO_2 emissions as indicated by its positive sign. This result is in line with our previous assumption. The nuclear (*Nuke*) and Hydro (*Hydro*) productions are also statistically significant at the 1% significance level. They negatively influence the variation of O_2 emissions as indicated by its negative sign. This result is in line with our previous assumption as these productions reduce the residual demand for thermal power plants. The other renewable (*RNW*) is equally statistically significant at the 1% significance level. It negatively influences the variation of CO_2 emissions as indicated by its negative sign. Its coefficient of -10.18 is interpreted as 1 GWh of renewable electricity in the network reduces on average 10.18 tCO_2 in a single power plant. The coefficient is slightly lower than the one of *Nuke* (-8.23) and *Hydro* (-7.12). New renewable electricity production reduces emissions as anticipated.

The large combustion plant directive (*LCPD*) percentage is statistically significant at the 1% significance level. It negatively influences the variation of CO_2 emissions as indicated by its negative sign as anticipated power plants that have their time of use limited by the LCPD tend to emit less CO_2 than the others. Gas (*Gas_moy*) and Coal (*Coal_moy*) prices are also statistically significant at the 1% significance level. The coefficient estimator for the gas price is positive where it is negative for coal price, which is consistent with the following interpretation: an increase in the gas price and/or a fall in the price of coal results in substituting the use of coal for gas, which actually leads to an increase in carbon emissions[11]. Carbon price (*Co2_moy*). is also statistically significant at the 5% significance level. The coefficient estimator is negative as it is expected. An increase of 1 €/tCO_2 reduces on average 2,312 tCO_2 by power plant.

Oil power plants dummy (*Oil*) is statistically significant at the 1% significance level. Its coefficient estimator is negative which means that oil power plants are all other things being equal less emitting

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[11] We would note that even if the coefficients are not significantly different from zero, the sign of the coefficient estimator for the CO_2 price to switch price ratio is as expected, i.e., negative: an increase in this ratio means an increase in the price of CO_2 and/or a fall in the switch price, which encourages a switch to technologies that emit less carbon, and therefore does in fact reduce CO_2 emissions.

than gas and other power plants. It is consistent with the fact that oil power plants are generally less used than other power plants as a large part of them are used during peak time, only a few hours per year. On the contrary, Coal power plants dummy (*Coal*) is not statistically significant which means that Coal power plants doesn't differentiate themselves from gas and other power plants. Lastly, the power plant capacity of production is statistically significant at the 1% significance level. Its coefficient estimator is positive, the biggest the power plant, the most it will emit.

Table 1 – Regression results for all power plants - Model (1)

	(1) Verified emissions (reduced model)	(2) Verified emissions	(3) Verified emissions (reduced model)
mw	1287.008***	2441.966***	2450.286 ***
	(340.517)	(285.7516)	(285.7335)
lcpd	-424739.7***	-454081.6 ***	-455052.1 ***
	(114455.3)	(109549.8)	(109529.2)
production_rnw	-10.17908***	-4.596867***	-4.389048 ***
	(1.398421)	(.6714472)	(.632382)
production_hydro	-8.235557***	-6.298934 ***	-6.782382 ***
	(2.09412)	(1.532337)	(1.520657)
production_nuke	-7.12151***	-.4155172	-
	(1.179792)	(.3020818)	
GDP	6409.582***	6856.897***	6870.332***
	(1866.049)	(1902.568)	(1903.441)
gas_moy	11243.27***	10830.44 ***	10557.61***
	(1682.356)	(1681.197)	(1680.772)
coal_moy	-21717.91***	-25949.17***	-25503.67 ***
	(3795.301)	(4013.322)	(4046.977)
co2_moy	-2311.812***	-2467.554 ***	-2436.145 ***
	(945.7293)	(951.1093)	(952.6465)
coal	734998.8	1359552***	1351504***
	(561656.5)	-198236	(196785.9)
oil	-3730313***	-368349.6	-366854.8
	(561557.9)	(233104.4)	(231252.8)
constant	1262917***	-529339.7 ***	-552405.8***
	(357360.5)	(198496.2)	(197174.3)
FE	Yes (installation)	-	-
RE (FGLS estimator)	-	Yes (installation)	Yes (installation)
Number of observations	8887	8887	8887
Number of groups	1405	1405	1405
F test for FE	76.69	-	-
(P-Value)	(0.0000)		
Breusch & Pagan LM test for RE	-	22108.34	22103.04
(P-Value)		(0.0000)	(0.0000)
Hausman test	-	571.21	574.09
(P-Value)		(0.0000)	(0.0000)

Unfortunately, it is not possible to include all variables in the "*whole*" sample model because of the major differences between power plants acording to their primary fuel. To test other other technical data, the "*whole*" sample is thus divided into a coal power plant sub-sample, a gas power plant sub-sample and a oil power plant sub-sample.

4.2.2. Results for the Coal power plant sample

Table 2 column 1 presents result for the reduced model estimated by fixed-effect. Colum 2 presents the same model estimated by random effect whereas column 3 presents the reduced model estimated by random effect.

In the Coal sub-sample model, as for the whole sample none of the technical variables tested are significant in the fixed-effect reduced model. In the random effect reduced form the year of commissioning (*com_year*) becomes statistically significant at the 10 % significance level. Its estimated coefficient is negative as the youngest power plants emit less CO2 than the older ones as they are less energy efficient. Other technical variables tested, the percentage of CHP units (*Cogen_perc*), the percentage of supercritical units (*supercritical_perc*) and dummies for lignite power plants are not statistically significant.

The rest of the reduced model is the same. The CO_2 price becomes statistically significant at the 1% level. We can note that all estimated coefficient have a higher absolute value than in the whole model: CO2 price coefficient is -10,702 whereas it was -2,311 in the whole sample, *GDP* one is 20,152 when it was 6,410, or other renewable production is -25.30 when it was -10.18. It shows that all this variables affect primarily CO_2 emissions of coal power plants as they are more CO_2 intensive.

Table 2 – Regression results for coal plants - Model (2)

	(1) Verified emissions (reduced model)	(2) Verified emissions	(3) Verified emissions (reduced model)
mw	1634.298**	4052.725 ***	4150.539***
	(660.9942)	(517.1173)	(487.0468)
lcpd	-460495.3 ***	-438431.6***	-437669.9 ***
	(176426.4)	(168982.3)	(169647.2)
production_rnw	-25.77502***	-7.152497***	-7.050067***
	(4.699848)	(1.698468)	(1.687005)
production_hydro	-25.3014***	-18.45899***	-17.38966***
	(8.618928)	(6.951189)	(6.152004)
production_nuke	-19.19519 ***	.318306	-
	(4.25639)	(1.180179)	
GDP	20152.91 ***	16900.06***	17754.88***
	(4507.511)	(4434.938)	(4481.33)
gas_moy	39507.05***	42201.05***	42929.81***
	(5301.882)	(5978.373)	(6103.128)
coal_moy	-78457.86 ***	-94321.45***	-96980.57 ***
	(15057.72)	(16109.58)	(16285.25)
co2_moy	-10702.12***	-13215.23***	-13256.03***
	(2729.843)	(2794.696)	(2825.066)
com_year	-	-	-19230.53*
			(10515.8)
constant	1995322 ***	-903900.1*	3.70e+07*
	(658443.3)	(540530.2)	(2.09e+07)
FE	Yes (installation)	-	-
RE (FGLS estimator)	-	Yes (installation)	Yes (installation)
Number of observations	2322	2322	2273
Number of groups	350	350	343
F test for FE	53.91	-	-
(P-Value)	(0.0000)		
Breusch & Pagan LM test for RE	-	5008.58	4912.66
(P-Value)		(0.0000)	(0.0000)
Hausman test	-	299.90	311.34
(P-Value)		(0.0000)	(0.0000)

4.2.3. Results for the Gas power plant sample

Table 3 column 1 presents result for the reduced model estimated by fixed-effect. Colum 2 presents the same model estimated by random effect whereas column 3 presents the reduced model estimated by random effect.

In the Gas sub-sample model, some technical variables become significant in the fixed effect reduced form. The year of commissioning (*com_year*) is statistically significant at the 10 % significance level. Its estimated coefficient is negative as the youngest power plants emit less CO_2 than the older ones as they are less energy efficient. The CHP units percentage (*cogen_perc*) is statistically significant at the 10 % significance level. Its estimated coefficient is positive which is coherent with the hypothesis that CHP units tends to emit more CO_2 all other things being equal as they produce also heat. Combined-cycled power plant units dummy of first (*GT_C*) and second (*CC*) generation are respectively statistically significant at 10 % and 1 %, which means that this units emits more CO_2. It can be explained because CCGT units are generally used on semi-base level, longer times than other gas units. Small units using internal combustion (*IC*) emits significantly less than steam turbines whereas gas turbine (*GT*) doesn't differ much to steam turbine.

The rest of the reduced model is almost the same. Coal price is dropped has it is not statistically significant for gas price which is a little surprising. Gas price is statistically significant at the 1 % significance level, and its coefficient is contrarily to the whole sample positive. It makes complete sense has gas price is the fuel used in this sample, any increase of it would reduce the incentive to produce from these power plants.

Table 3 – Regression results for gas plants - Model (3)

	(1) Verified emissions (reduced model)	(2) Verified emissions	(3) Verified emissions (reduced model)
mw	844.2287***	1268.154***	1262.792 ***
	(192.52)	(77.41443)	(76.72037)
com_year	-11802.89 *	-324.9677	-
	(6281.832)	(1970.766)	
cogen_perc	5353431*	24687.97	-
	(3313247)	(40270.4)	
production_rnw	-5.715859***	-2.390569***	-2.340893***
	(.9125659)	(.3861576)	(.3757776)
production_hydro	-9.058272***	-3.37493***	-3.386875***
	(2.154996)	(.8031818)	(.8009635)
production_nuke	-3.821899***	.325439***	.3257812***
	(.7077747)	(.1117418)	(.109551)
GDP	6536.066 ***	6552.168***	6596.153***
	(1609.641)	(1556.338)	(1554.358)
gas_moy	-3578.894***	-3439.366***	-3439.223***
	(1231.129)	(1216.097)	(1208.954)
co2_moy	3125.892***	2365.812***	2363.125***
	(777.008)	(717.5411)	(713.9035)
cc	1758226***	114423.5*	93462.01*
	(451310)	(64906.25)	(55478.21)
gt_c	408018.4*	178730.2	163855.2***
	(221071.8)	(50399.33)	(37186.19)
ic	-5057545*	-37034.69	-40707.02
	(2975990)	(74583.31)	(56431.03)
gt	220165.4	-3433.632	-10795.37
	(244734)	(74148.2)	(59418.75)
constant	2.17e+07*	106868.8	-520863***
	(1.18e+07)	(3854844)	(165390.1)
FE	Yes (installation)	-	-
RE (FGLS estimator)	-	Yes (installation)	Yes (installation)
Number of observations	4046	4046	4107
Number of groups	645	645	655
F test for FE	10.94	-	-
(P-Value)	(0.0000)		
Breusch & Pagan LM test for RE	-	3835.77	3981.16
(P-Value)		(0.0000)	(0.0000)
Hausman test	-	37.33	38.18
(P-Value)		(0.0000)	(0.0000)

4.2.4. Results for the Oil power plant sample

Table 4 column 1 presents result for the reduced model estimated by fixed-effect. Colum 2 presents the same model estimated by random effect whereas column 3 presents the reduced model estimated by random effect.

In the Oil sub-sample model, some technical variables become significant in the fixed effect reduced form. The year of commissioning (*com_year*) is statistically significant at the 1 % significance level. Its estimated coefficient is positive contrarily to the case of gas and coal samples. The youngest power plants emit more CO2 than the older ones. We would explain that because the only place where oil power plants are still commissioned is in islands (Malta, Cyprus), where they serve as baseload generation. Compared with other onshore oil power plants, used as peak units they tend to emit more even if they are younger. We will test a dummy in the future to identify this. The CHP percentage (*cogen_perc*) is not statistically significant in this sample. Small units using internal combustion (*IC*) and gas turbine (*GT*) emits significantly less than steam turbines.

Table 4 – Regression results for oil plants - Model (4)

	(1) Verified emissions (reduced model)	(2) Verified emissions	(3) Verified emissions (reduced model)
com_year	13639.95***	7481.73***	5873.895**
	(3323.232)	(2307.78)	(2698.331)
production_rnw	-3.012168***	-1.760466**	-1.81211**
	(.9594707)	(.7627691)	(.7677708)
production_hydro	-5.002656***	-3.120531***	-3.579584***
	(1.746086)	(1.155013)	(1.328299)
production_nuke	-2.920791***	-.3783321**	-.3121724*
	(.7240825)	(.1821173)	(.1914463)
GDP	6206.458***	6792.222***	7082.012***
	(2387.436)	(2419.115)	(2463.911)
gas_moy	4944.473***	4015.289***	4052.689***
	(1598.642)	(1557.36)	(1529.804)
coal_moy	-22551.97***	-22337.34***	-23138.71***
	(5525.52)	(5787.495)	(5693.939)
co2_moy	1682.76*	1829.295**	1851.552**
	(902.3907)	(891.2932)	(899.3179)
ic	-194457.5***	-448265.3***	-283736.2**
	(32110.3)	(98700.93)	(145823.4)
gt	-466340.4***	-398390.7***	-319516.2**
	(99286.38)	(64771.52)	(157824.5)
mw	-	-	607.4868**
			(295.9391)
constant	-2.67e+07***	-1.48e+07***	-1.18e+07**
	(6585481)	(4587680)	(5292430)
FE	Yes (installation)	-	-
RE (FGLS estimator)	-	Yes (installation)	Yes (installation)
Number of observations	1501	1501	1501
Number of groups	232	232	232
F test for FE	74.76	-	-
(P-Value)	(0.0000)		
Breusch & Pagan LM test for RE	-	3890.44	3691.69
(P-Value)		(0.0000)	(0.0000)
Hausman test	-	20.94	28.90
(P-Value)		(0.0039)	(0.0002)

5. Conclusions

Although the European Commission has launched a debate on options for structural reform of the EU emissions trading system (EU ETS) to address the growing surplus of emission allowances that is building up, identifying that the main cause is largely the economic crisis, this paper provides a new analysis on factors behind the CO2 emissions reductions in the EU ETS. These results show that CO_2 emissions abatements in the power sector come to a large extent from the development of renewable energy production, as it reduces the emission level of individual fossil-fuel power plants. Although the carbon price is still presented by the European Commission as the number one tool to decarbonise the economy, its impact has been marginalised in the power sector due to the strong deployment of renewable energy. Most of these new renewable production capacities are put in place at a national level in the form of feed-in tariffs or green certificates, without connection to the carbon price. Still, the CO_2 price emerging from the EU ETS appeared also effective in our analysis in reducing CO_2 emissions in the power sector, but to a smaller scale than renewable energy deployment. Other environmental regulation also influences CO_2 emissions of power plants as shown in the case of the Large Combustion Plant (LCP) Directive. Finally, it also shows that at least for coal and gas power plants, older plants less energy efficient emits on average more CO_2 than younger one. The replacement of ancient units will therefore allow reducing CO_2 emissions to some extent.

These results suggest that coordination of energy, climate and other environmental policies has to be thought carefully. Interaction between policies where a low carbon price has now emerged from the economic crisis that swept away most of the demand for EU allowances but is also the result of how the Climate and Energy package was designed in Europe, with a fixed cap for the EU ETS and fixed renewable energy targets, has to be taken into account. During the studied period, most of overlapping emissions reduction comes from renewable policies, but other regulations would need to be assessed as shown by the LCP Directive. For example, policies fostering energy efficiency tends to reduce energy demand and their results in terms of CO_2 emissions in the power sector should be assessed to avoid making the price of CO_2 redundant.

Overall, our results suggests, based on the European experience until 2011, that more timely adjustment of policies between each other in the face of changing conditions have to be considered, which can be relevant in the future design of climate and energy policies in Europe but also in other parts of the world. A further analysis based on estimations with "business-as-usal" scenarios could confirm the contribution of each variable in the decrease of CO_2 emissions of the power sector during the period 2005-2011.

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7. Annexes

7.1. Databases matching methodology

The power plants included in the EU ETS were identified using the following two databases:

- the European Union Transaction Log (EUTL), formerly the Community Independent Transaction Log (CITL), which lists the CO2 allocation and emission levels for EU ETS operators12. These data enable an installation to be identified on the basis of various information items (name of the installation, account holder, and region etc.).

- the World Electric Power Plants (WEPP), edited by Platts, which sets out the technical specifications for power generation units. The database specifically enables us to find out the technology used by the unit, its theoretical capacity, the primary fuel used, and the year when it was first commissioned. It also enables us to find out about the type of operator, i.e. whether they generate power for their own use, or are a private or public service company.

The research focuses on the EU ETS installations which primarily supply the power that they generate to the electrical grid, and covers 1,453 installations. Sites owned by autoproducers, and those owned by a private company outside the energy industry, i.e. that are not included in the "power generators" or "energy brokers" categories in the WEPP database, were excluded from the research. Conversely, all public service companies were included in the sample.

The linking of a CITL operator account with the corresponding power generation units in the WEPP database was performed based on three criteria which are found in both databases13: the name of the site, the name of the company that owns the site and the city where the installation is located. Where the three criteria correspond, the accounts were linked. Where the name of the company did not correspond, an internet search was performed in order to identify a potential change of owner. In the event that this difference could be explained, the accounts were linked and the owner company selected was the one in the WEPP database.

The unit or units recorded as being operational in the WEPP database were then linked to the CITL emission data. In the event of multiple units on one site:

- The installed capacities of different unites were added together;
- The commission year was weighted according to the generation capacity of each unit;
- In the event of different primary fuels on the same site, the fuel selected was the one used by most of the generation capacity;

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[12] For further information on the CITL, see Trotignon and Delbosc (2008)

[13] The CITL database does not include explicitly the name of the company; however the companies were identified by Trotignon and Delbosc (2008) in a previous version that corresponded to Phase 1 of the EU ETS, based on Internet contact addresses, which are no longer available. In some cases, the name of the company appears in the account name for sites that were added in Phase 2.

CHP plants were identified based on the type of unit provided by the WEPP database. A site is considered as a CHP site if over 90% of its generation capacity corresponds to CHP units.

In some cases, a site in the WEPP database corresponded to several accounts in the CITL. In this case, the generation units were divided based on the information included in the account name or in the National Allocation Plan. In eight cases, there was either a change of account, or one account was being used to receive allocations while the other was being used to return them. Both accounts were therefore merged. Lastly, it was impossible to identify the units in three cases. Due to the significance of the verified emissions, it was decided to merge the installation's various accounts into a single account.

7.2. CO_2 emissions from power and CHP plants by primary fuel in Europe

In $MtCO_2$	**PHASE I**			**PHASE II**				
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Power	**922**	**928**	**983**	**923**	**833**	**835**	**826**	**830**
Bituminous Coal	373.8	391.5	392.2	345.4	307.6	311.3	306.6	351.3
Lignite Coal	199.9	194.3	231.6	221.5	211.6	207.2	225.2	225.8
Other Coal	43.6	39.9	41.3	33.3	26.1	20.4	29.0	32.4
Gas	202.9	211.4	228.5	240.0	218.9	221.9	194.0	152.6
Oil	64.7	55.8	48.7	46.0	41.9	37.6	33.5	33.6
Blast-furnace gas	23.6	22.6	24.2	22.6	14.7	20.8	21.9	20.2
Oil Shale	10.0	9.2	12.1	10.3	8.3	12.2	12.1	10.9
Peat	2.7	3.1	3.3	3.4	3.3	3.2	2.9	3.0
Combined Heat and Power	**297**	**305**	**323**	**307**	**294**	**306**	**298**	**289**
Bituminous Coal	111.4	118.6	121.8	108.7	102.7	109.3	104.4	99.5
Lignite Coal	133.7	131.5	142.4	142.0	136.6	136.1	138.2	138.8
Other Coal	4.3	4.4	5.7	5.4	4.7	5.0	4.3	4.2
Gas	26.1	28.3	31.6	31.1	31.2	33.0	29.7	27.4
Oil	5.0	4.1	4.5	4.3	4.4	4.3	3.8	3.9
Blast-furnace gas	9.1	8.9	8.3	8.1	7.1	9.4	9.4	8.9
Oil Shale	0.7	0.7	0.8	0.7	0.7	0.7	0.9	0.9
Peat	3.7	4.7	4.5	4.1	3.8	4.8	4.1	3.3
Total Power/CHP	**1 219**	**1 233**	**1 306**	**1 230**	**1 127**	**1 141**	**1 124**	**1 120**

Source: EUTL, WEPP (Platts)

7.3. Number of installations by primary fuel in Europe

Primary fuel used by the installation	2005-2012	2007	2012	2007-2012 Change	% of CHP installations in 2012
Natural gas	671	587	653	+ 66	42 %
Coal (total)	352	342	336	- 6	45 %
- ***bituminous coal***	223	217	210	-7	42 %
- ***lignite coal***	87	83	86	+3	50 %
- ***other coal***	42	42	40	-2	45%
Oil	248	232	227	-5	12%
Peat	22	20	21	+1	71%
Bituminous shale	7	6	6	0	67%
Blast furnace gas	14	11	13	+2	46%
Other (total)	139	83	129	+46	60%
- ***biomass***	76	60	75	+15	81%
- ***solar power***	27	0	27	+27	0%
- ***waste***	11	7	10	3	100%
- ***methane***	6	6	4	-2	50%
- ***unknown***	19	10	13	+3	31%
TOTAL	**1,453**	**1,281**	**1,385**	**+104**	**40%**

Source: EUTL, WEPP (Platts)

7.4. Variables in the database

Variables family	Description of variables	Variables	Type of variable	Unit	Source
General data					
	Year	Year	Quantitative	Year	EUTL
	Identification of the power plant	Installationnumber	Quantitative		EUTL
	If the power plant emitted didn't retire or has not enter the EU ETS between 2005 and 2012	Permanent_A	Binary (=1 if 'true'; 0 else)		EUTL
Emission and restitution under EU ETS data					
	Free allocation of EUAs to the power plant	Allowancedistributed	Quantitative	tCO2	EUTL
	Surrendered EUAs for compliance by the power plant	Surrenderedallowances	Quantitative	tCO2	EUTL
	Surrendered CERs for compliance by the power plant	Surrenderedcers	Quantitative	tCO2	EUTL
	Surrendered ERUs for compliance by the power plant	Surrenderederus	Quantitative	tCO2	EUTL
	Sum of surrendered EUAs, CERs and ERUs by rhe power plant	Totalofallowancessurrendered	Quantitative	tCO2	EUTL
	Verified emissions of the power plant	Verifiedemissions	Quantitative	tCO2	EUTL
Tecnical data					
	Technical maximum production capacity of the power plant	Mw	Quantitative	Mw	WEPP(Platts)
	Commission year of the power plant	Com_Year	Quantitative	Year	WEPP(Platts)
	Percentage of the production capacity coming from combined heat and power units	Cogen_Perc	Quantitative	% of Mw	WEPP(Platts)
	Percentage of the production capacity coming from supercritical units	Supercritical_Perc	Quantitative	% of Mw	WEPP(Platts)
	Percentage of the production capacity submitted to restricted utilization starting from 2008 under the Large Combustion Plant Directive	Lcpd	Quantitative	% of Mw	European Environmental Agency
Fuel data					
	Gas power plant using gas as primary fuel	Gas	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas power plant using coal as primary fuel	Coal	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas power plant using lignite coal as primary fuel	Coal_Lignite	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas power plant using bituminous coal as primary fuel	Coal_Bituminous	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas power plant using undifined coal as primary fuel	Coal_Undifined	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas power plant using oil as primary fuel	Oil	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas power plant using peat as primary fuel	Peat	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas power plant using blast-furnace gas as primary fuel	Bfg	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Other primary fuel	Other	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
Type of production unit					
	Combined-cycle gas turbine powerplant	CC/GT/C	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	2nd generation Combined-cycle gas turbine powerplant	CC	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	1st generation Combined-cycle gas turbine powerplant	GT/C	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Gas turbine	GT	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Internal combustion engine	IC	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
	Steam Turbine	ST	Binary (=1 if 'true'; 0 else)		WEPP(Platts)
Activity/Energy data					
	Electric renewable gross production in the country (except. Hydro)	Production_Rnw	Quantitative	GWh	Eurostat
	Hydro gross production in the country (except. Hydro)	Production_Hydro	Quantitative	GWh	Eurostat
	Nuclear gross electric production in the country	Production_Nuke	Quantitative	GWh	Eurostat
	Gross electricity production in the country	Production_Elec	Quantitative	GWh	Eurostat
	Final electricity consumption in the country	Final_Cons_Nrj	Quantitative	GWh	Eurostat
	Gross domestic product	Gdp	Quantitative	Index base 100 in 2005	Eurostat
Price data					
	Average annual Zeebrugge gas month ahead price	Gas_Moy	Quantitative	€/Mwh	Reuters
	Average annual API 2 coal month ahead price	Coal_Moy	Quantitative	€/Mwh	Reuters
	Average annual EUA next december price	Co2_Moy	Quantitative	€/tCO2	ICE exchange
	Theoretical switching price of CO2	Switch_Moy	Quantitative	€/tCO2	Reuters, ICE exchange