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# Assessing the factors behind $CO_2$ emissions changes over the phases 1 and 2 of the EU ETS: an econometric analysis

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**Summary**

It has been repeatedly said that the economic slowdown that began in 2008 largely explains the fall in carbon emissions recorded in Europe since the introduction of the European Union Emissions Trading Scheme (EU ETS). In fact, the European Union stated this very clearly in its initial report on the operation of the EU ETS in November 2012. Using an econometric analysis based on a *business-as-usal* scenario, it is shown that reductions of around 1.1 $GtCO_2$ are likely to have been achieved within the scope of the 11.000 installations covered by the EU ETS. Of those reductions, between 600 and 700 million tonnes are said to have resulted from the two policies in the 2020 Climate & Energy Package, which aims to achieve a 20% renewable energy target (a decrease of around 500 million tonnes) and a 20% improvement in energy intensity (a decrease of between 100 and 200 million tonnes). The economic downturn also played a significant, although not dominant role in the decrease in $CO_2$ emissions, the impact of which was estimated at 300 million tonnes. Price substitution effects induced by coal and gas prices also seem to have affected emissions, within an order of magnitude of around 200 million tonnes. The study does not enable any impact created by the carbon price to be identified. It is important. However, to emphasize that the economic downturn and the development of RE were responsible for the decrease of the carbon price, and specifically marginalised its influence in terms of $CO_2$ emission reductions at the installations covered within the EU.

**Key words:** European Union Emissions Trading Scheme (EU ETS), Econometrics, panel

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This paper is a preliminary version and is currently undergoing a revision that incorporates the limits of econometric analysis and improves the choice of variables.

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## 1. Introduction

Phase 2 of the European Union Emissions Trading Scheme, or EU ETS, which lasted from 2008 to 201, 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[3].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[4], and covers over 45% of their overall greenhouse gas (GHG) emissions.

The first period was a learning phase: around 2.3 billion allowances were allocated every year, almost entirely free of charge. Annual $CO_2$ emissions amounted to 2.1 billion tonnes and generated an annual surplus of 160 million allowances. As this surplus could not be used in Phase 2, the price of Phase 1 allowances fell to zero. Between 2005 and 2007, the EU ETS' $CO_2$ emissions increased by 2.1%[5] at the level of the countries and sectors covered by the EU ETS, while European GDP increased by 5.8%. It should, however, be noted that total emissions at the EU-27[6] level rose by 1.9% between 1990 and 2007, although they declined by 4.7% at the EU-15 level[7].

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. For the record, we saw an overall 11.9% fall in emissions between 2008 and 2012 (-7.3% between 2005 and 2012), on a comparable geographical basis (and excluding the aviation sector), with a steep 11.4% fall in 2009 compared with 2008. 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 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*

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[3] 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,
[4] The 27 Member States, Croatia, Norway, Liechtenstein and Iceland,
[5] Verified emissions drawn from the EUTL database, excluding Bulgaria and Romania, which joined the EU ETS in 2007,
[6] US Energy Information Administration, total emissions relating to energy consumption; www,eia,gov/cfapps/ipdbproject/IEDIndex3,cfm?tid=90&pid=44&aid=8
[7] Anaïs Delbosc and Christian de Perthuis, *The carbon markets explained* (2009), page 13,

*of an increasing allowance surplus, primarily*[8] *due to the fact that the economic downturn has reduced emissions by more than was expected*"[9]. 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? In which case, can we then estimate the contribution that was due solely to economic activity where the trend in $CO_2$ emissions is concerned?

Other factors could also be have been involved and have played a certain 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 the European level, which resulted in the so-called "20-20-20"[10] targets, were implemented via a series of directives, including the directives on renewable energy and energy efficiency, which were combined with the domestic policies provided for in each Member State's action plans. These commitments were reflected by a "notable development of renewable energy"[11] 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[12].

The aim of this study is to provide quantitative answers to these questions, based on an econometric analysis of carbon emissions over the two phases of the EU ETS (between 2005 and 2011) for a panel of countries that are included in the EU ETS.

***This analysis therefore focuses on linking $CO_2$ emissions, the explained variable, to a series of explanatory variables, which we might believe had an impact on the trend in $CO_2$ emissions, and then subsequently on disproving or confirming the impact of each of these variables, before finally assessing their relative contributions.***

The approach is therefore as follows. Following a review of the published research, which is intended to guide our choice of the explanatory variables that may be initially suggested from an econometric

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[8] Capitalised by the author,

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

[10] 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,

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

[12] As will be explained in a later section of this report, the effect of the carbon price on investments will be captured indirectly by the variables that describe energy efficiency,

analysis will be performed in order to put forward and build a model that links the emissions and the explanatory variables selected. The robustness of this model will also be tested. A counterfactual scenario will then be put forward based on this model, in order to enable us to estimate the differences between the emissions recorded between 2005 and 2012 and the benchmark scenario.

## 2. Analysing the explanatory factors for $CO_2$ emissions: a new contribution to academic research

Up until now, the empirical academic research that has emerged on the subject of the EU ETS has primarily focused on an econometric assessment of the explanatory factors for the carbon price, rather than on an assessment of the factors behind $CO_2$ emissions. The initial period was the subject of several publications. the aim of which 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 fact there seem to be only a few econometric studies focusing on an ex-post analysis of the explanatory factors for $CO_2$ emissions within the EU ETS. The study that bears the closest resemblance to this paper is the one issued by Anderson *et al*. (2009) while Ellerman (2010) and McGuinness & Ellerman (2008) put forward several considerations regarding the explanatory variables that may be used.

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). As they had 25 groups and 251 observations, 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[13] and the cost of electricity were not significant. The authors underlined that the manufacturing sector was not actually affected by the EU ETS during Phase 1, due to the free allocation of a large quantity of carbon allowances.

[13] Eurostat Code: NACE D

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, 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. These studies focus solely on Phase 1 of the EU ETS.

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

In their book on the lessons learned from the European carbon market, which was published in 2010. Ellerman *et al.* dedicated one of the chapters to emission reductions and specifically to the portion attributable to the introduction of an allowance system relating to the carbon price, as well as to macro-economic factors. This issue is of interest for determining counterfactual scenarios and therefore for assessing the carbon emission volumes that were actually avoided. The authors underlined that the macro-economic strategies for estimating carbon emissions are primarily based on the principle that "*the level of economic activity is a key determining factor for $CO_2$ emissions*[14]" They also indicated that "*various factor, such as weather conditions, the price of energy and changes in the economic activity of the various sectors have an influence on the relationship between emissions and economic activity from one year to the next*[15]", while adding that the use of averages and aggregates tends to cancel out these annual variations and errors. The issue of fuel substitution as a reason for reductions is also addressed, including the role of relative energy pricing (especially gas and coal). Results obtained following the 2001 economic downturn (the Dot-Com Bubble) are highlighted, so as to show that trends in economic activity and emissions may be contradictory. Although a decrease in activity actually reduces emissions, we can expect an increase in emissions over the following years

[14] Ellerman *et al*, (2010), page 144,
[15] Ibid, page 145,

(for instance in the period between 2000 and 2004) due to the slowdown in efforts and investments aimed at improving carbon intensity.

McGuinness & Ellerman (2008) present an econometric study that focuses on the United Kingdom, and covers British power stations and their carbon emissions according to the price of energy and $CO_2$; the authors used a fixed-effect panel regression analysis. Lastly, 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.

Where assessing the reductions achieved via the introduction of the EU ETS is concerned, a series of studies have looked at the outcome for Phase 1 (2005 to 2007). Ellerman and Buchner (2008) found that emissions had been reduced by between 50 and 100 million tonnes, while Delarue *et al*. (2008a and 2008b) estimated that the reductions were between 34 and 88 million tonnes in 2005, and between 19 and 59 million tonnes in 2006; Ellerman and Feilhauer (2008) concluded that the reductions amounted to around 53 million tonnes in 2005 and 2006, and lastly. Ellerman *et al*. estimated that the reductions for the first period were between 120 and 300 million tonnes. It is interesting to note that the authors are obviously not unanimous to establish a relationship between the price of carbon to these emission reductions and mention the effects of energy substitution instead. Indeed, on the contrary. Widerberg and Wrake (2009) have shown that in some countries (like Sweden, it is "*unlikely that the EU ETS has generated significant reductions in $CO_2$ emissions*". Lastly Anderson and di Maria (2009) found that "*during the learning period. $CO_2$ emissions were approximately 113 million tonnes higher than they would have been in the absence of the EU ETS*".

## 3. Description of the variables and framework of the analysis

A review of the published research has highlighted a number of variables that have been regularly introduced in order to explain the changes in carbon emissions in Europe, either directly or indirectly (for instance. via the carbon price).

The choice of the explanatory variables has therefore been made in accordance with reasons that have been jointly admitted and identified as having a possible impact on $CO_2$ emissions in previous academic research. Institutional research and publications suggest that the change in carbon emissions may be linked to the following variables:

- economic activity. Industries produce more and the demand for energy is higher. which leads to higher emissions from power plants and industrial companies;

- the price of energy, especially the relative price of coal and gas. Power generators substitute either gas-fired or coal-fired power stations; both technologies have a different impact on $CO_2$ emissions;
- the $CO_2$ price. A high price leads to fuel-switching to use the energy that causes the least pollution;
- the policies implemented in Europe in order to begin the transition towards a low-carbon economy : the development of renewable energies and the improvement of the energy efficiency;
- the off-shoring of $CO_2$ emissions outside Europe;
- climate-related factors. For instance a particularly cold winter implies a higher demand for energy (heating) and therefore an increase in emissions.

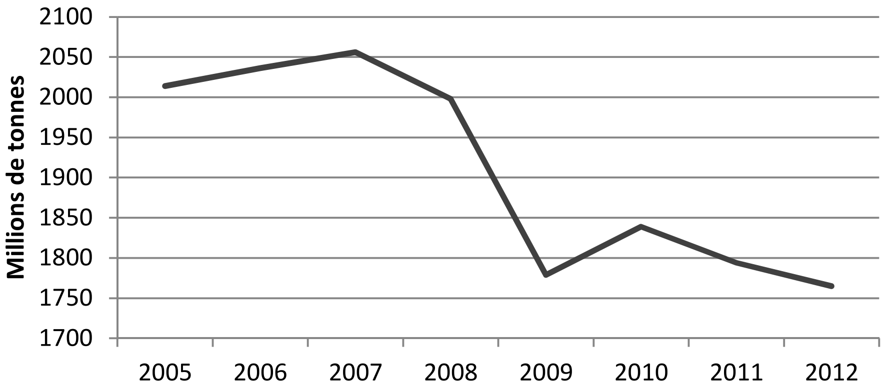
## 3.1 Carbon emissions: the explained variable

The industries included in the EU ETS must report their annual $CO_2$ emissions to a centralised registry, known as the European Union Transaction Log, or EUTL (formerly CITL), which is held by the European Union and is publicly accessible[16]. The EUTL provides access to the annual emissions reported by industrial companies and power generators, as well as to all the allowance transactions that have taken place within the EU ETS. The emissions for each country have been calculated over the period between 2005 and 2012 in millions of tonnes, using this database. The $CO_2$ emissions for countries therefore include the emissions of all the industrial sectors included in the EU ETS (Chart 1).

Given the change in the scope of the countries covered by the EU ETS, due to the addition of new countries between 2005 and 2012, we have chosen to exclude these new countries. The scope has therefore been kept identical and so does not take into account the emissions generated by Bulgaria and Romania (which joined the EU ETS in 2007), and by Norway and Iceland (which joined the Scheme after 2008). These emissions account for around 4.5% of the total emissions identified in the EUTL database over both periods combined.

[16] www,eea,europa,eu/data-and-maps/data/european-union-emissions-trading-scheme-eu-ets-data-from-EUTL-1

**Chart 1 – Change in $CO_2$ emissions (constant scope)**



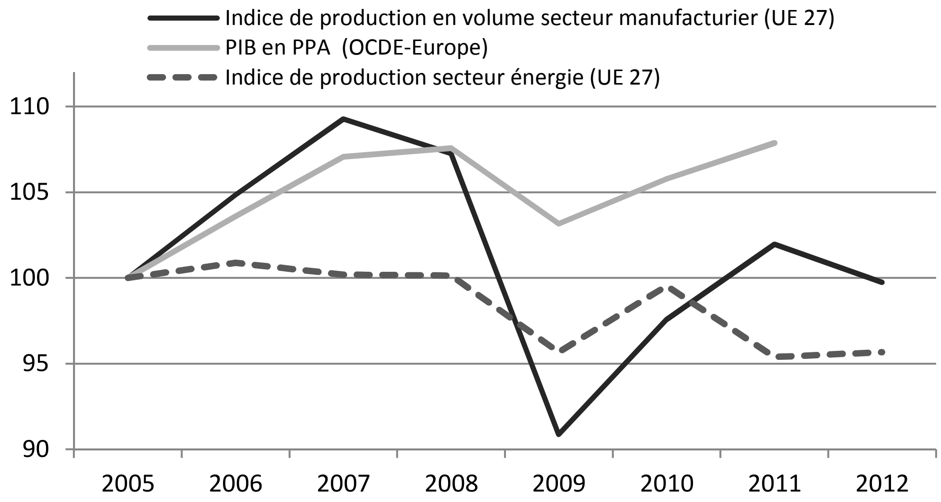

*Source: EUTL and CDC Climat*

### 3.2 Tested and selected explanatory variables

Three economic variables were selected (Chart 2), including GDP in billions of constant (2005) US dollars, calculated on the basis of purchasing power parity (PPP), as published by the International Energy Agency (IEA). GDP summarises the full range of economic activity, but covers many more sectors than industry alone[17]. GDP has been standardised and rebased to 100 (the base year is 2010). The output volume indicators for the industrial[18] and energy[19] sectors (in data adjusted for working days and standardised compared with the base year [2010]) were drawn from the Eurostat database. Both these indicators are much more accurate than GDP. as they are specific to the sectors concerned by the EU ETS.

[17] As will be specified in a later section, the GDP variable was also introduced to control the economic impact in the energy efficiency variables (TPES and ELEC) which have been standardised according to the respective GDP of the panel countries,
[18] NACE "Manufacturing" sector, Code C,
[19] NACE "Electricity, gas, steam and air conditioning supply" sector, Code D35,

**Chart 2 – Change in GDP and in the output indices for the manufacturing (M) and energy (E) sectors**
**Base year (100) = 2005 for the indices. OECD Europe for GDP**




*Source: Eurostat. IEA and CDC Climat*

Coal and gas (Chart 3) are the two main fuels that supply thermal combustion power plants in Europe. Their prices were drawn from the Thompson-Reuters database, using the API 2 CIF ARA Month Ahead contract for coal, and the TTF spot contract for gas. The annual averages were calculated and the prices converted into euros per MWh[20]. The conversion from the USD per tonne (coal) and GBP per therm (gas) measurement units were performed according to the methodology used by CDC Climat[21] namely:

$P_{gas}$ (€/MWh) = $\frac{Pgas\ (GBP/therm)}{100}$ $.FX_{(GBP\text{-}€)}.\ \theta$ Where θ: 1 Therm (GB) = 29.3071 kWh

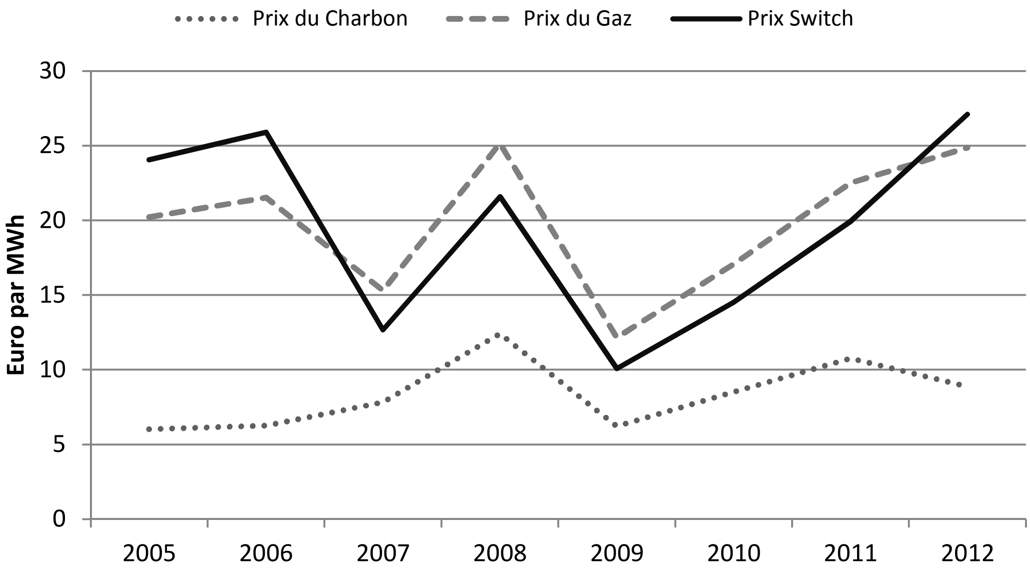
$P_{coal}$ (€/MWh) = $\frac{Pcoal\ (USD/t)/\varphi}{\omega}$ $.FX_{(USD\text{-}€)}.$ Where φ = 29.31 GJ/t
ω = 0.2777 MWh/GJ

The Switch Price indicator is then calculated. It indicates the fictional price that enables clean dark spreads and clean spark spreads to be equalised. It therefore represents the price of $CO_2$ above which it becomes attractive for a power generator to switch from coal to gas, and below which it is attractive to switch from gas to coal[22] in the short-term.

$$Switch\ Price = \frac{cost\ of\ gas - cost\ of\ coal}{tCO2\ (coal) - tCO2\ (gas)}$$

[20] EURO-GBP and EURO-USD conversions based on the average annual exchange rate,
[21] www,cdcclimat,com/spip,php?action=telecharger&arg=1300
[22] In this formula, the Cost of gas is the cost of producing one MWh of electricity on the basis of the net $CO_2$ emissions for gas expressed in € per MWh; and the Cost of coal is the cost of producing one MWh of electricity on the basis of the net $CO_2$ emissions for coal expressed in € per MWh; $tCO_2$ (gas) are the $CO_2$ emissions of a standard gas-fired power station per MWh of electricity (0,37); and $tCO_2$ (coal) are the $CO_2$ emissions of a standard coal-fired power station per MWh of electricity (0,96),

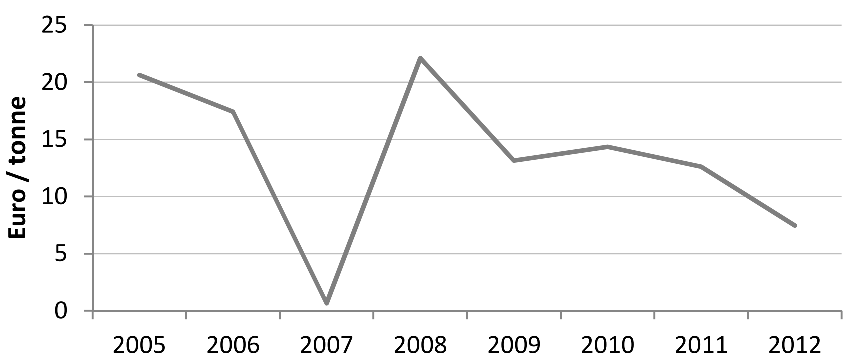
**Chart 3 – Average price of coal (Cprice) and gas (Gprice) and switch price in €/MWh**




***Source: Thompson Reuters and CDC Climat***

The price of a tonne of carbon (Chart 4) is based on the prices listed on the ECX market; the prices are reported on an average annual basis, and then converted into euros at the average annual exchange rate. We made a decision to use the spot market price, and not the carbon price on the futures market (typically one year forward), and especially not to use the Phase 2 market price for the period between 2005 and 2007 (although it existed)[23], as this variable seeks to capture the short-term substitution effects that may be created by the carbon price. The long-term effects of a carbon price that remains high over an extended period are reflected in investments in and the development of technologies that aim to reduce emissions by improving energy efficiency, an effect that is captured by the corresponding variables (see below).

**Chart 4 – Average annual spot price for a tonne of carbon**

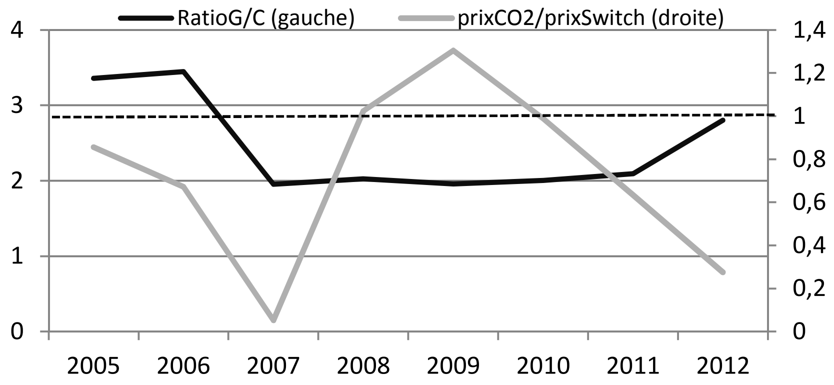



*Source: ECX and BNX. CDC Climat*

[23] As the Phase 1 allowances were not transferable to Phase 2, this amounted to the existence of two separate markets (Phase 1 and then Phase 2) and therefore to two different prices,

Two ratios were selected (Chart 5): the carbon price divided by the switch price and the energy (coal and gas) price ratio. The aim of both ratios was to capture the more short-term energy substitution effects. which were respectively due first to an incentive provided by the carbon price, and second to the relative cost of using both energies for power generation. The trend in these two variables is supposed to be identical for all the countries examined.

**Chart 5 – Gas to coal price ratio on carbon to switch price ratio**

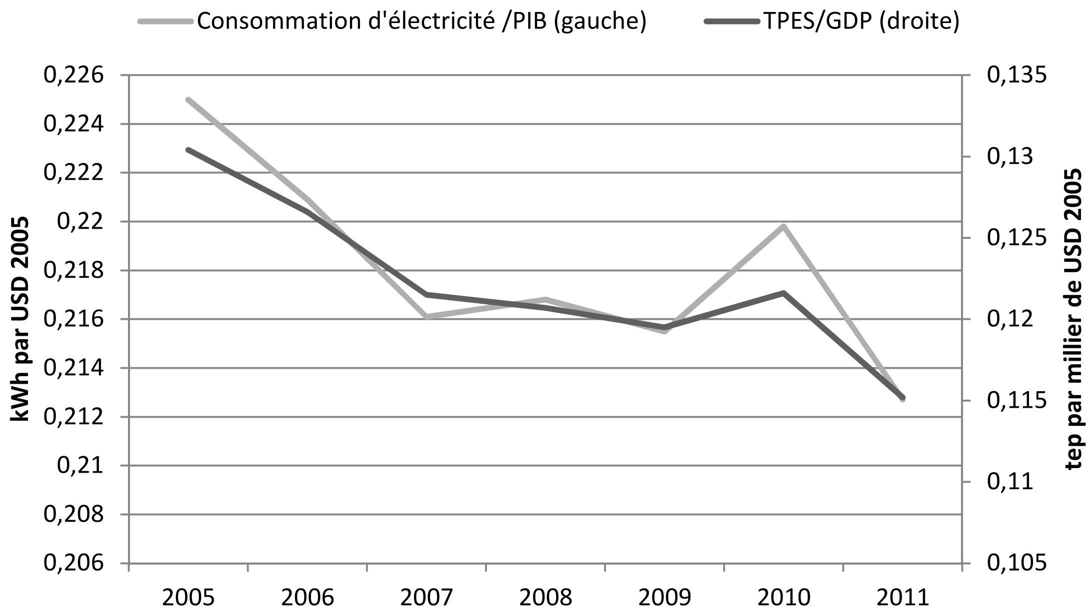



***Source: ECX and BNX. CDC Climat***

The policies implemented in Europe as part of the Climate & Energy Plans seek to develop sources of renewable energy, as well as to improve the energy efficiency of the economy (the famous “20-20-20” plans). It is legitimate to assume that these policies will have an impact on changes in emissions, with more of a long-term effect.

In terms of the magnitude of the energy efficiency efforts made, two variables were selected for each country (Chart 6), which were both drawn from the International Energy Agency database, i.e. the total primary energy supply, or TPES, standardised according to each country’s GDP (in constant 2005 dollars. calculated on a PPP basis), and electricity consumption, which was also rebased according to GDP. It would be more accurate to say that these variables capture the changes in the energy-intensity of the economy, rather than its energy efficiency. In fact, in addition to structural changes in the economy, these variables also capture the changes in the energy mix and even a potential carbon price effect, via investments in green technologies.

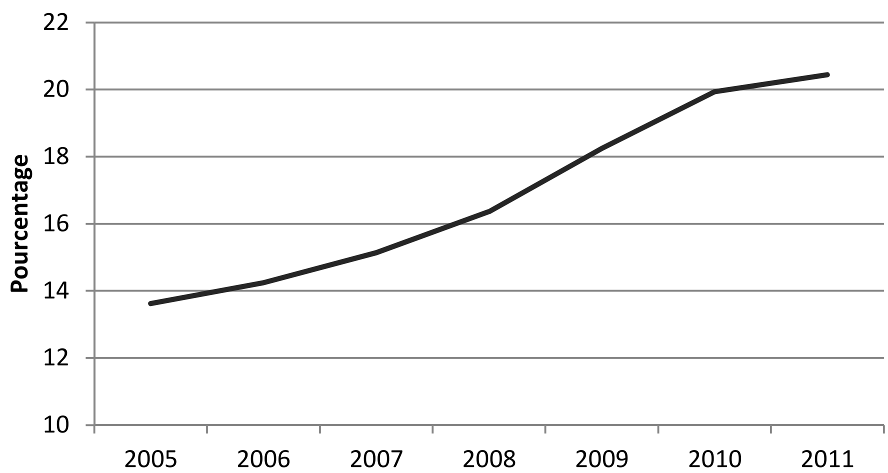
**Chart 6- Energy efficiency in the EU-27**




*Source: International Energy Agency*

One of the EU's three key policies in terms of combating carbon emissions is the binding target of achieving a 20% proportion of renewable energy in Europe's primary energy generation. This ambitious target implies a significant increase in RE in Member States' power generation. Given the importance of the power generation sector in the reported emissions in the EUTL database (around 60%). we selected the percentage share of renewable energy sources in each country's power generation (Chart 7). The data for the years between 2005 and 2011 were drawn from the Eurostat database. The direct impact of the development of renewable energy on emissions has been highlighted, in Germany at least, by the recent research carried out by Weigt *et al.* (2012).

**Chart 7 – Percentage of power generated from renewable sources in the EU-27**
*Source: Eurostat*




*Source: Eurostat*

Aside from current econometric research, observers often argue that a portion of the fall in carbon emissions in Europe can also be explained by the off-shoring of those emissions. To capture this potential effect, we explored two variables: the Direct Foreign Investment (DFI) Indicator published by the World Bank and the ratio between the volume of imports and domestic output. These variables were tested as part of various econometric analyses, although the results were not conclusive[24].

We also explored the option of including a variable that captures the impact of weather on power generation[25] in order to capture a possible climate-related effect. This indicator expresses the impact of weather conditions on power generation compared with the ten-year average for the period between 2000 and 2009. Unfortunately, the index is only available for a restricted number of countries, and was ultimately not included in the econometric research conducted on the panel as a whole. Two reasons support the decision not to include a climate-related effect. First, if we test this effect for the eight countries where it is available, it would appear that its impact is not significant. Obviously, given the very limited size of the panel, we cannot draw definitive conclusions. Second, given that the time unit for this study is one year, all the variables must be averaged over one year. We therefore assumed that the impact of the climate-related variable was not significant. as it typically changes over a period of one month. This choice is open to criticism, given that climatic conditions may have a certain impact on emissions, as observed by Ellerman *et al.* (2010)[26].

[24] It is unlikely that either of these variables actually captures the emission off-shoring impact that we are seeking, In fact, although the coefficients for DFI are still highly significant, regardless of the models examined, they tend to show that an average €1 billion increase in DFI outflows would result in a 10% increase in carbon emissions, We could initially have expected an opposite effect, as the DFI outflows would mean investments abroad, and the off-shoring of output and therefore of carbon emissions, Two factors enable us to reject this variable in order to capture the off-shoring effect, The first is that the indicator for DFI outflows is not a good proxy for capturing the off-shoring effect, In fact, the disadvantage of DFI outflows is that they record all intra-group flows, and therefore artificially over-value exchanges in the "real" economy (for instance, if a company pools its cash in one country, the result is various cash flows with other group subsidiaries that are recognised in DFI), The second explanation is said to be that DFI flows are strongly correlated to economic activity, Therefore, when economic activity increases, so do carbon emissions, along with DFI outflows, Likewise, the imports to output ratio was not significant in the various assessments performed, The idea behind the choice of this ratio was that, if off-shoring increases, imports of goods will rise, although domestic production is falling, The ratio between both factors should therefore increase sharply as business activities are off-shored,

[25] Climpact Metnext provides CDC Climat with temperature indices for a certain number of European countries, This national economy & climate index is defined as the average daily temperature in the regions that make up the country, weighted according to the population of those regions, which provides a good approximation for the size of a region's economic activity, Metnext calculates the weather factor impact on power generation based on this index,

[26] See page 151, among others,

**Table 1 – Explanatory variables studied**

| Name of the variable | Variable | Unit |
|---|---|---|
| Gross Domestic Product on a PPP basis | GDP | Index rebased to 100 in 2010 |
| Month-ahead CIF ARA coal price | Cprice | euro/MWh |
| TTF spot gas price | Gprice | euro/MWh |
| $CO_2$ price | pCO2 | euro |
| Percentage of renewable energy in power generation | pctRE | % |
| Electricity consumption per GDP point | ELEC[27] | kWh/ (2005) USD |
| Coal to gas switch price | switchp | euro/MWh |
| Manufacturing sector output volume index | outM | Rebased to 100 in 2010 |
| Energy sector output volume index | outE | Rebased to 100 in 2010 |
| Total energy consumption per GDP point | TPES[21] | TPE[28]/(2005) USD |
| Gas price to coal price ratio | G/C ratio | No unit |
| Carbon price to switch price ratio | CO2switch | $MWh^{-1}$ |

## 3.2 The geographical scope of the study

The data panel initially consisted of the variables observed for all the countries included in the EU ETS, namely the 28 European Union Member States and Norway, Iceland and Liechtenstein. It turned out to be necessary to reduce the size of the panel to 22 countries out of the 31 countries that made up the broadest panel possible. This was due to the fact that the data were not available for some countries, either because they joined the EU ETS after 2005 (Bulgaria, Romania, Norway, Croatia, Liechtenstein and Iceland), or because observations for some explanatory variables are simply not available (for Malta, Cyprus and even Belgium). These excluded countries account for a relatively small portion of total emissions, which amounted to around 7.3% for the second period as a whole, including 2.6% for Belgium and 2.7% for Romania. During the econometric analysis process (see Section 4 and the Appendix), it appeared that the inclusion of Estonia was skewing the estimates, so this country was subsequently withdrawn from the panel.

The final panel therefore included the 21 countries shown in Table 2, and the database covers the years between 2005 and 2011. 2012 was not included, as too many explanatory variables were missing (i.e. not published).

**Table 2 – Sample of the 21 countries monitored between 2005 and 2011**

| | | |
|---|---|---|
| Germany | Hungary | Poland |
| Austria | Ireland | Portugal |
| Denmark | Italy | Czech Rep. |
| Spain | Latvia | United Kingdom |
| Finland | Lithuania | Slovakia |
| France | Luxembourg | Slovenia |
| Greece | Netherlands | Sweden |

[27] There is a strong correlation between the ELEC and TPES variables (correlation factor of 0,86), which implies that these two variables should not be tested simultaneously within the same regression analysis,

[28] Tonne petroleum equivalent,

The database therefore includes 21 x 7 or 147 observations, which is a relatively low number to perform a panel regression analysis, but is, however, above the generally admitted empirical level of 120 observations.

## 4. Methodology and stress test

In keeping with the approach selected by Anderson *et al*. (2009a), we selected the fixed-effect panel regression model. Although analyses based on Hausman tests tend to show that a random-effect regression analysis is also possible[29], it seemed more appropriate to choose the fixed-effect panel regression analysis for economic justification purposes, although we remain aware that the estimators may not then be the most efficient ones that could be obtained. In fact, we can imagine that each country in the panel displays specific characteristic features, which the FE approach specifically enabled us to capture.

The first stage consisted in studying the homoskedasticity assumption. To do so, we used the test suggested by Wiggins and Poi[30]. It seems that the homoskedasticity assumption should be rejected (LR chi2 = 229.54). Therefore, all the regression analyses that we subsequently performed used the robust configuration in order to take the heteroskedasticity of the variables into account. It was then possible to perform a series of regressions that enabled us to determine which variables were significantly different from zero, and then to perform regressions on a model that was pared down to just the significant variables. Lastly, a regression approach using indicative variables (dummies) for each country, equivalent to a FE approach, was performed in order to access the fixed effects for each country in the panel. All the regressions were performed using the Stata 12.0 software package.

The robustness of the models was checked via various tests[31], including a Hausman test, a heteroskedasticity test, an autocorrelation test, and an analysis of the observations that usually have a disruptive effect on regression[32]. This last analysis was performed by calculating the DfBetas. It appeared that Estonia had an abnormally disruptive effect on the estimates, so the country was therefore removed from the panel. The robustness of the model was also ensured via controls including certain variables – even if they were not significant, i.e. typically controls using the GDP variable when including the energy efficiency variables that are both measured against GDP[33], as well

[29] See Appendix,
[30] Vince Wiggins and Brian Poi (StataCorp), *Testing for panel-level heteroskedasticity and autocorrelation*, June 2001, revised in December 2003; www,stata,com/support/faqs/statistics/panel-level-heteroskedasticity-and-autocorrelation/,
[31] See the Appendix for the results of the tests performed on Model 1,
[32] Observations that show a material residual error during a regression analysis, i.e., observations that have an abnormal influence on the coefficient estimators and their accuracy,
[33] In fact, the aim of the ELEC and TPES variables is primarily to capture the "energy efficiency" effect, i.e., the country's energy consumption, which corresponds to the measurement chosen by the European Commission in its third target, namely to reduce energy consumption by 20% by 2020, Standardisation via economic activity enables variables with comparable orders of magnitude to be obtained, However, the introduction of GDP implies that the new variable may capture a certain

as via multiple regressions with a lower number of variables (in order to confirm the potentially insignificant nature of any one of the key variables).

## 5. Models, results, and analysis

The first model (Model 1) that we tested included all the variables that may play a role in determining the explained variable. All the variables are expressed as decimal logarithms[34], so the estimated coefficients can therefore be interpreted as elasticities.

Several preliminary conclusions appear immediately (Table 3). Three variables appear to be particularly significant, namely the percentage of RE and the manufacturing output index, together with the TPES energy efficiency variable. The energy sector *outE* output index is not particularly significant in either case. This may be explained by the relatively limited change in the output volume of this sector over both periods compared with that of the manufacturing sector, for instance (see Chart 2). It seems that the energy output volume in Europe was only moderately affected by the slowdown in economic activity (5% difference between the highest and lowest points over the period observed. compared with a 20% difference for the manufacturing sector). Likewise, the GDP variable was not significant, doubtless due to the fact that it covers much broader sectors than those covered by the EU ETS[35]. The ratio for the $CO_2$ price to the switch price did not seem to be significant, which already led us to believe that the $CO_2$ price only has a limited impact on the explained variable. Meanwhile, the energy price variable was not significant in the model that includes the TPES variable, but may have been significant in the model that includes the ELEC variable.

effect of economic activity (see 2010 in Chart 6, for example), although this effect should preferably be captured by the output indices, The inclusion of the GDP variable – even if it is not significant, enables us to control for this economic activity effect and simplifies the interpretation of the TPES and ELEC variables,

[34] The ratios (price of gas to price of coal, and price of CO2 to switch price), and energy efficiency variables are all multiplied by 100 before using the log,

[35] However, it may be necessary to keep this variable, in order to control the GDP effect among the energy efficiency variables (see previous notes),

**Model 1 and its two alternatives**

$$em_{it} = \beta_1 GDP_{it} + \beta_2 pctRE_{it} + \beta_3 outM_{it} + \beta_4 outE_{it} + \beta_5 GCratio_{it} + \beta_6 CO2switch_{it} + \beta_7 TPES_{it} / ELEC_{it} + u_i + \varepsilon_{it}$$

**Table 3**

| Model | 1 with TPES | | | 1 with ELEC | | |
|---|---|---|---|---|---|---|
| | Coefficient | Standard error | P>\|t\| | Coefficient | Standard error | P>\|t\| |
| $GDP_{it}$ | 0.0772 | 0.3824 | 0.842 | -0.2589 | 0.3347 | 0.449 |
| $pctRE_{it}$ | -0.0801 * | 0.03128 | 0.019 | -0.1368 ** | 0.0479 | 0.010 |
| $outM_{it}$ | 0.4709 *** | 0.1091 | 0.000 | 0.4486 *** | 0.1354 | 0.004 |
| $outE_{it}$ | 0.1851 | 0.1604 | 0.263 | 0.2965 | 0.2002 | 0.155 |
| $G/Cratio_{it}$ | -0.00895 | 0.02732 | 0.747 | 0.04397 | 0.02928 | 0.150 |
| $CO2switch_{it}$ | -0.00384 | 0.00481 | 0.435 | -0.00606 | 0.006175 | 0.338 |
| $TPES_{it}$ | 0.8512 * | 0.3468 | 0.024 | - | - | |
| $ELEC_{it}$ | - | - | - | 0.2566 | 0.2931 | 0.392 |
| *Intercept* | -0.73492 | 1.0856 | 0.507 | 0.4399 | 1.0506 | 0.680 |

Number of observations = 140; number of groups = 20
Notes: *** indicates a variable that is significantly different from zero at a 1% threshold; ** at a 5% threshold and * at a 10% threshold
For Model (1 TPES): joint nullity test for the variables F(7.22) = 13.96
Prob > F = 0.00%
For Model (1 ELEC): joint nullity test for the variables F(7.22) = 12.20
Prob > F = 0.00%

The significant or potentially significant coefficient estimators are in line with the assumptions. As expected. an increase in the percentage of RE used in power generation reduces emissions, while an increase in manufacturing activity increases them, as does an increase in the ELEC or TPES variables, which corresponds to a decrease in the economy's energy efficiency. Lastly, in Model 1 with ELEC. the coefficient estimator for the ratio of the gas price over the coal price is positive, which is consistent with the following interpretation: an increase in this ratio (i.e. 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[36].

Based on Model 1, it is possible to focus on the pared down model, by removing the variables that are clearly not significant, but retaining variables where we want to control the effect (GDP[37]), or where we are more specifically looking to examine the impact (CO2switch). The results are shown in Models 2 and 3.

[36] 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,

[37] See Appendix for the results of the regressions performed without controlling for the GDP variable, The estimators differ slightly for the TPES variable,

**Table 4**

| Model | (2) | | | (3) | | |
|---|---|---|---|---|---|---|
| | Coefficient | Standard error | P>\|t\| | Coefficient | Standard error | P>\|t\| |
| $GDP_{it}$ | -0.04987 | 0.3368 | 0.884 | 0.2271 | 0.4205 | 0.595 |
| $pctRE_{it}$ | -0.1758 *** | 0.04095 | 0.000 | -0.1175 *** | 0.03995 | 0.008 |
| $outM_{it}$ | 0.4429 *** | 0.1359 | 0.004 | 0.4467 *** | 0.1203 | 0.001 |
| $GCratio_{it}$ | 0.05794 * | 0.03095 | 0.076 | - | - | - |
| $CO2switch_{it}$ | -0.005811 | 0.006214 | 0.361 | -0.00358 | 0.003925 | 0.373 |
| $TPES_{it}$ | - | - | - | 0.8656 ** | 0.3273 | 0.016 |
| $ELEC_{it}$ | 0.3415 | 0.27409 | 0.227 | - | - | - |
| *Intercept* | 0.41436 | 0.96701 | 0.673 | -0.6807 | 1.1725 | 0.568 |

Number of observations = 147; number of groups = 21
Notes: *** indicates a variable that is significantly different from zero at a 1% threshold; ** at a 5% threshold and * at a 10% threshold
For Model 2: joint nullity test for the variables F(7.22) = 15.34
Prob > F = 0.00%
For Model 3: joint nullity test for the variables F(7.22) = 22.25
Prob > F = 0.00%

**Model 2**

$$em_{it} = \beta_1 GDP_{it} + \beta_2 pctRE_{it} + \beta_3 outM_{it} + \beta_4 GCratio_{it} + \beta_5 CO2switch_{it} + \beta_6 TPES_{it} + u_i + \varepsilon_{it}$$

**Model 3**

$$em_{it} = \beta_1 GDP_{it} + \beta_2 pctRE_{it} + \beta_3 outM_{it} + \beta_4 CO2switch_{it} + \beta_5 TPES_{it} + u_i + \varepsilon_{it}$$

It seems clear from Models 2 and 3 that the $CO_2$ price to switch price ratio does not explain the change in carbon emissions in the EU ETS sector, or only explains them to a very limited extent. To support the robustness of this analysis, which tends to disprove any contribution of the carbon price as such to reducing emissions, a fourth model (Model 4) was tested. This model includes the price of $CO_2$ directly, but not the energy efficiency variables, which we could assume may capture a certain carbon price effect via long-term investments in green technologies. Although all the variables included are significant, at least at the 5% threshold, the only variable that is not significant is the price for a tonne of carbon (Table 5).

**Model 4**

$$em_{it} = + \beta_1 pctRE_{it} + \beta_e outM_{it} + \beta_e CO2switch_{it} + \beta_4 GCratio_{it} + u_i + \varepsilon_{it}$$

**Table 5**

| **Model** | (4) | | |
|---|---|---|---|
| | Coefficient | Standard error | P>\|t\| |
| $pctRE_{it}$ | -0.1811 *** | 0.03849 | 0.000 |
| $outM_{it}$ | 0.3669 *** | 0.1033 | 0.002 |
| $pCO2_{it}$ | -0.00317 | 0.00255 | 0.228 |
| $GCratio_{it}$ | 0.09096 ** | 0.3857 | 0.029 |
| *Intercept* | 0.8549 *** | 0.1918 | 0.000 |

Number of observations = 147; number of groups = 21
Notes: *** indicates a variable that is significantly different from zero at a 1% threshold; ** at a 5% threshold. and * at a 10% threshold
For Model 4: joint nullity test for the variables F(7.22) = 25.43
Prob > F = 0.00%

The pared down Models 2 and 3, and Model 4 enable us to draw a number of conclusions. First, in terms of the changes in emissions observed over the two periods, the analysis confirms the role of the economic downturn, through industrial activity, but not through the activity of the energy sector. It also shows that the increased use of renewable energy in electricity production has certainly played a role. Both Models 2 and 3 show elasticities of 0.12 to 0.17 for the percentage of RE used in annual power generation, and of 0.44 for the manufacturing sector output index in volume terms. These values are very close, and even identical for both models, which increases their robustness. This means that a 1% increase in the RE share results in a decrease of between 0.12 and 0.17% in the emissions covered by the EU ETS sectors, while a 1% fall in the manufacturing sector output index implies a 0.44% decrease in emissions.

The second conclusion is that the energy price and energy efficiency ratios are probably also variables that contribute to explaining the change in carbon emissions. Although this aspect will be discussed at greater length in the last section, we may, however, question the relevance of the electricity consumption and total primary energy consumption per GDP point variables as a measurement of the efforts made to improve European countries' energy efficiency.

Lastly, Models 2 and 3, supported by Model 4 do not enable us to identify any potential impact of the $CO_2$ price on the change observed in carbon emissions within the EU ETS. Given that the ELEC/GDP and TPES/GDP variables are not included in Model 4, this result also includes the possible effect of the carbon price via the energy efficiency variables that could capture the impact of investments in green technologies. This final result tends to support the assumption that the carbon price remained too low throughout both periods (except perhaps in the first year of each phase) to lead to investments in low-carbon technologies. This does not, however, mean that we should conclude that the setting up of a carbon market does not enable a reduction in $CO_2$ emissions. In fact, what the analysis shows, is that the economic downturn and the development of RE were specifically behind the fall in emissions. However, by generating substantial allowance surpluses, both these factors (among others) led to a permanently depressed carbon price[38].

## 6. Counterfactual model and estimates for the impact of each variable

The econometric analysis has enabled us to build two models (one including an electricity consumption to GDP[39] variable. and the other including total primary energy consumption per GDP point[40]), with robust coefficient estimates and orders of magnitude for the joint variable estimators that are mutually similar.

The consistency of these models has been checked by calculating the total volume of carbon emissions for all the countries in the panel, and for each year, based on the data for the manufacturing sector output, the roll-out of RE and the energy efficiency for each country, as well as on the energy price ratio. Total emissions were calculated as the sum of the predicted emissions for each State in each year (Chart 8) on an individual basis.

The difference[41] between the observed amounts and the amounts predicted by the model was small in both cases[42]. It amounted to 184 and 134 million tonnes for the entire period covered for Model 2 and Model 3[43]. Model 3 shows a slight propensity to estimate emissions more accurately: not only is the aggregate difference 50 million tonnes lower, but it also provides a more accurate forecast of changes in the emission trend, especially over the period between 2009 and 2011. Both these amounts (184 and 134 million tonnes respectively) were used to estimate the error in the models' predictive abilities. In fact, they enabled us to estimate the order of magnitude for the error in theoretical emissions on an overall basis for the period between 2005 and 2011, regardless of the level of emissions[44]. The error for Model 2 was therefore ± 90 Mt. and ± 65 Mt for Model 3. The errors may be estimated by calculating the percentage difference between the theoretical and observed values for each year (see Appendix 9). Lastly, one solution, which we did not use in this instance, would be to calculate the

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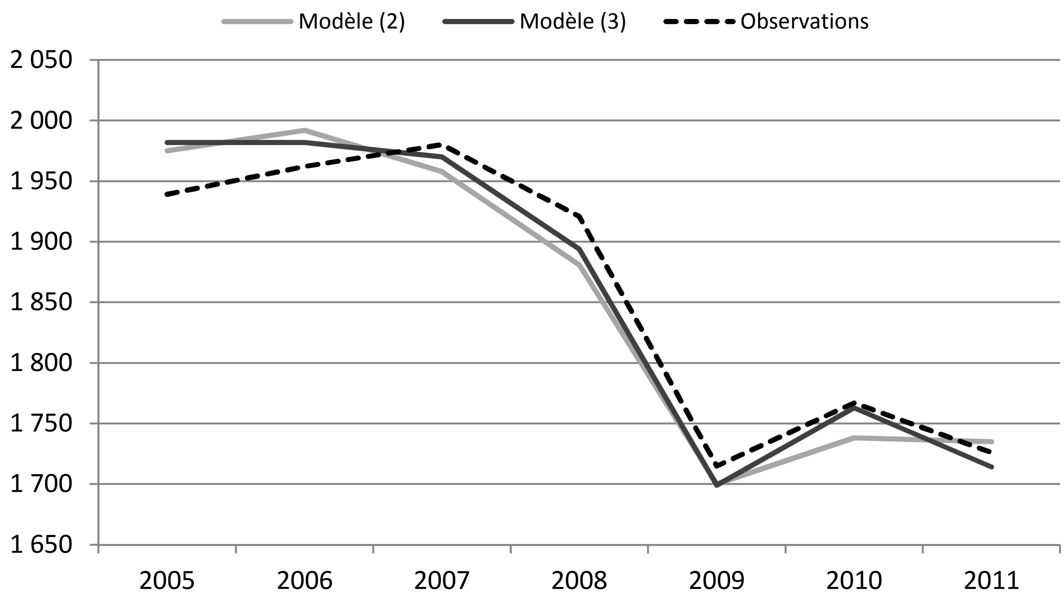
[38] Currently around 1,7 $GtCO_2$, which were generated in Phase 2 and have been deferred to Phase 3,
[39] "ELEC" variable,
[40] "TPES" variable,
[41] Aggregate difference: the sum of the absolute amounts of the differences between the amounts predicted by the models and the emissions observed,
[42] See Appendix 9 for the data table that corresponds to Chart 7,
[43] As a reminder: Model 2 includes the ELEC (electricity consumption per GDP point) variable, while Model 3 includes the TPES variable (total primary energy consumption per GDP point), The GDP variable was not included in the regression analysis,
[44] In a continuous model, this order of magnitude would correspond to the area between the theoretical and observed emission curves,

error based on the error ranges for each of the coefficient estimators obtained via the regression analysis.

**Chart 8 – Observed emissions and their theoretical amounts arising from the models drawn up using econometric analysis. The amounts are in $MtCO_2$**




The econometric analysis therefore enabled us to build two models that were able to track the observed emissions with a small margin of error. Both models were subsequently used to determine the counterfactual emissions that would have been observed under the conditions of an alternative scenario known as the "business-as-usual" (BAU) scenario. This BAU scenario served as a benchmark to estimate the reductions achieved between 2005 and 2011, as well as to assess the importance of the explanatory factors that were identified in the previous section. As Ellerman *et al*. (2010) underline, "*since the reductions depend on the counterfactual emissions, which must be estimated, the amount of emissions avoided cannot be known with any certainty*[45]". The results obtained in this section must therefore always be read, interpreted or used by comparing them with this BAU scenario and its assumptions.

The methodology adopted was as follows. First, the fixed effects were estimated for each of the countries in the panel[46] for both models. Counterfactual data that corresponded to the BAU scenario were then drawn up, again for each country in the panel. At this point, by using the two models that have been validated by econometric analysis, it was possible to estimate the emissions for all the countries, and to aggregate them for each year. It is important to note that the $CO_2$ price to switch price

[45] Ellerman *et al*, (2010), page 143
[46] See Appendix 3, which sets out the estimated coefficients, including the fixed effects for each country, used for the two counterfactual models,

ratio was retained (despite the fact that it was not significant) in order to enable Models 2 and 3 to be used to predict $CO_2$ emissions in a BAU scenario where the carbon price is virtually nil.

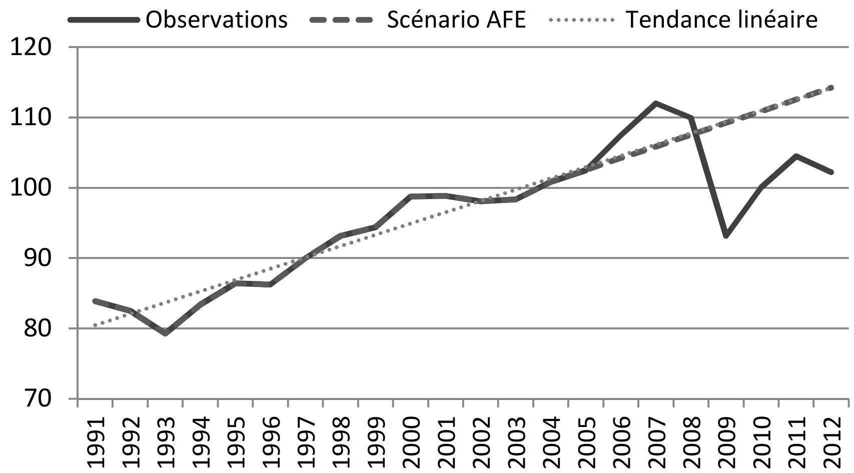
## 6.1 The counterfactual scenario known as the "business-as-usual" (BAU) scenario

Drawing up a counterfactual scenario, which offers an alternative path to the one actually observed between 2005 and 2011. is undoubtedly based on a series of assumptions and estimates that may be open to criticism. The following alternative variables were drawn up *(i)* for all the countries (see Table 6). and include the percentage of RE used in power generation, energy efficiency (electricity consumption to GDP. and total energy consumption to GDP) and the manufacturing output index; *(ii)* while the following variables were common to all the countries: the carbon price to switch price ratio, and the energy price ratio. The general approach that was adopted in this instance was to prolong the major trend or the average development observed over one or two decades prior to the period between 2005 and 2011, for each of the variables. *(i)* and for each of the 21 countries in the panel. Conversely, in the case of the data *(ii)* shared by the States, we decided to select an energy ratio that was kept constant, at its 2005 level, and a constant carbon price of €1.00 per tonne, i.e. a very low price[47]. The following charts illustrate the counterfactual data included in the BAU scenario for the EU-27.

**Table 6 – Summary of the assumptions for the alternative BAU scenario**

| Variable | Observed | Counterfactual (BAU) |
|---|---|---|
| Economic (manufacturing) activity | Sudden fall in 2009 | Growth of 1.6% per year |
| Development of RE | Accelerating increase | Limited |
| Energy efficiency | Increase | Less marked increase |
| Carbon price | Varies between €3 and €23 per tonne | Constant at €1 per tonne |
| Energy ratio | Varies | Constant at the 2005 level |

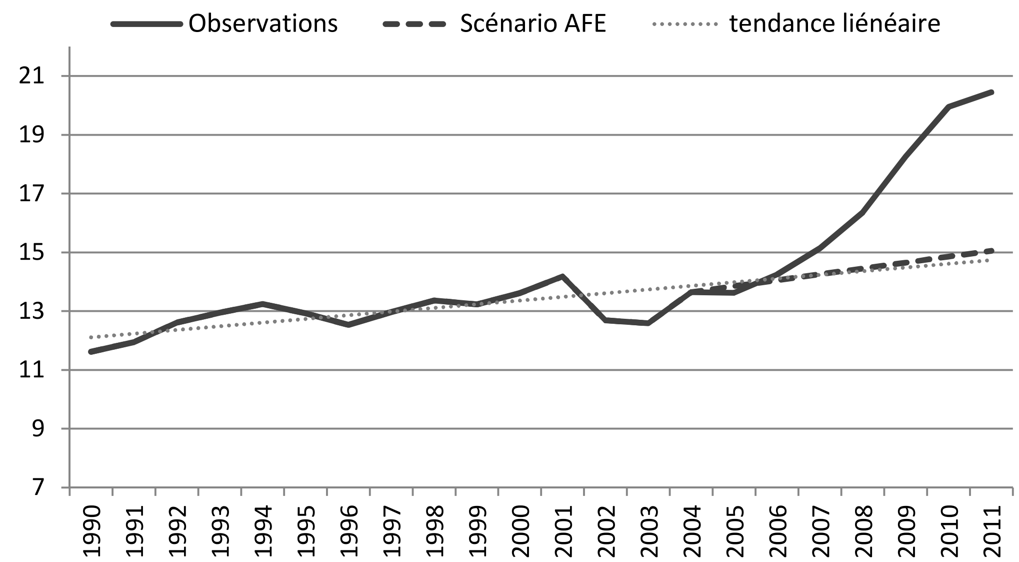
**Chart 9- Manufacturing output index (2010 = 100)**




[47] For practical reasons, it was not possible to simply use a carbon price amounting to zero,

The alternative trend suggested for the manufacturing sector output index (Chart 9) applies a constant growth rate for each year, in line with the trend prior to 2005, which is not as high as the rate during the period between 2005 and 2008. This means that, in the BAU scenario, the economic downturn, which began in 2008, did not take place, and that the output level in 2011 was 11.6% higher than in 2004 (although it was actually 3.6% higher).

**Chart 10 – Percentage of RE used in power generation (EU-27)**




We observe a very clear acceleration in the contribution of RE to power generation as from 2005-2006 (Chart 10). The BAU scenario suggests a modest increase of 0.2 points per year, in line with the trend that began in the early 1990s, so as to reach a 10.2% increase in 2011 compared with the 2004 level (versus the 49.7% increase observed).

**Chart 11 – Electricity consumption per GDP point (kWh/ 2005 USD) at the OECD-Europe level**

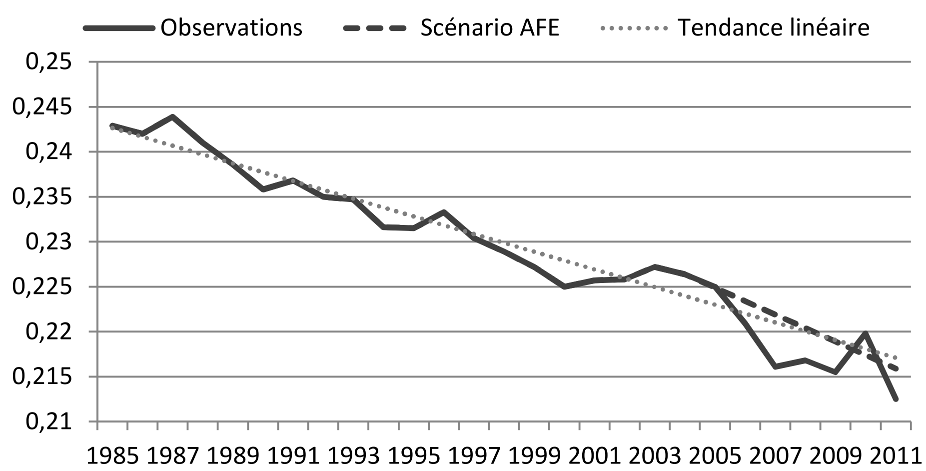
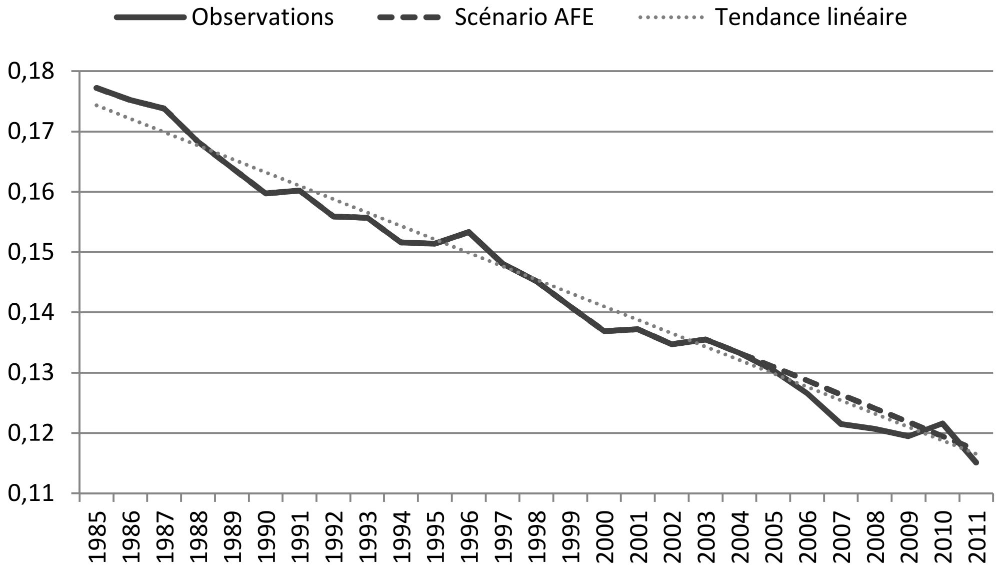


**Chart 12 – Total primary energy consumption per GDP point (TPE/ 2005 USD '000s) at the OECD-Europe level**




The amounts suggested as part of the BAU scenario for the two variables that capture energy efficiency (electricity consumption and total primary energy consumption per GDP point) are close to those observed, although they remain on the high side (i.e. suggesting lower energy efficiency).

As a reminder, the energy price ratio was supposed to remain constant at the 2005 level (3.36), while the $CO_2$ price was fixed at a constant level of €1 per tonne for the entire period between 2005 and 2011, which changed the carbon price to switch price ratio as a result.
The validity of all these assumptions may be discussed. For instance, is it valid to assume that economic growth would continue at the rate seen prior to 2005 without a significant development of RE? Indeed, an economic situation that was relatively favourable to public and private investment would imply an expansion in green energy, which is not the BAU assumption. Likewise, is it compatible to consider that the gas to coal price ratio would remain permanently at the 2005 level, at a time when industrial activity in Europe was growing at a rate of 1.6% per year? Drawing up counterfactual data that take such issues into account would imply using much more complex economic equilibrium models, which we were unable to do for this study. Lastly, as a reminder, the European Commission has based most of its targets and assumptions on a scenario drawn up before 2008 (the PRIMES model), which does not take the economic downturn into account, and is therefore banking on a GDP growth assumption of 2.2% per year.

## 6.2 Estimated reductions compared with the BAU benchmark scenario

Models 2 and 3, which include the data that correspond to the BAU scenario for each country in the panel, therefore enable us to predict the aggregate counterfactual emissions. These emissions serve as a benchmark to determine the reductions achieved during the period between 2005 and 2011 for the sector covered by the EU ETS. The model that uses the electricity consumption to GDP (ELEC) variable estimated the reductions over both periods combined at 1.324 million tonnes (± 90 million tonnes). while the model that uses the total energy consumption per GDP point (TPES) variable estimated that the total reductions compared with the BAU scenario amounted to 1.151 million tonnes ((± 65 million tonnes). Details of the $CO_2$ emission reductions for each year are provided in Table 7. Model 3 is the model with the lowest margin of error.

**Table 7 - Estimated $CO_2$ emission reductions for each model compared with the BAU scenario (in millions of tonnes)**

| | Model 2[48] | Model 3[49] |
|---|---|---|
| **2005** | 60 | 68 |
| **2006** | 52 | 65 |
| **2007** | 109 | 68 |
| **2008** | 175 | 138 |
| **2009** | 321 | 300 |
| **2010** | 295 | 236 |
| **2011** | 312 | 275 |
| **Aggregate** | **1.324** | **1.151** |

The aggregate reduction in Phase 1 (2005-2007), which amounted to between 200 and 220 million tonnes, was relatively modest, while the reduction in Phase 2 is estimated at between 950 and 1.100 million tonnes. It is already possible to observe the impact of the economic downturn, due to the particularly substantial reduction in emissions in 2009, which corresponds to the worst year of the economic recession.

The published research has identified a number of studies by various authors, which estimate the reductions achieved at the EU ETS level during Phase 1. The figures range between 300 and 500 million tonnes, but most often between 50 and 120 million tonnes. The model in this study is therefore putting forward estimates of the same order of magnitude, which increases our confidence in the validity of the model.

## 6.3 Origin of the fall in emissions

The analysis can be refined in order to assess the origin of the $CO_2$ emission reductions estimated by the models. Given the linearity of Models 2 and 3, it is possible to isolate the impact of each of these variables on a stand-alone basis[50]. The detailed results are shown in Appendix 10. Table 8 summarises the reductions generated for each sector as a percentage of the total and as an amount.

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[48] Model with the electricity consumption per GDP point variable (ELEC variable),
[49] Model with the total primary energy consumption per GDP point variable (TPES variable),
[50] Emissions are predicted by the model by introducing only one of the variables and its counterfactual data from the BAU scenario, while retaining the other variables and their actual data,

**Table 8 –Estimated reductions generated by each variable over the two periods as a whole. in millions of tonnes and as a percentage of the total reductions**

| | | RE | Economic activity | Energy efficiency | $CO^2$ price | Energy price substitution |
|---|---|---|---|---|---|---|
| **Model 2** | % | 48.6 | 22.4 | 10.3 | -1.0 | 19.8 |
| | Mt | 643 | 296 | 136 | -13 | 262 |
| **Model 3** | % | 39.5 | 30.0 | 20.4 | 10.1 | - |
| | Mt | 454 | 346 | 235 | 116 | - |

*The error is around ±90 Mt for Model 2. and ±65 M t for Model 3.*

Compared with the benchmark BAU scenario, it appears that the main cause of the fall in emissions observed over the period between 2005 and 2011 was the contribution of renewable energy to power generation, which accounted for an aggregate reduction of around 500 Mt (40 to 50% of all the reductions), followed by the economic downturn due to the fall in manufacturing sector output. which led to a reduction of around 300 million tonnes (i.e. around 20 to 30%) and then. probably at the same level. the improvement in the economy's energy efficiency. which resulted in a reduction of between 100 and 200 million tonnes (i.e. between 10 and 20%). along with a reduction of around 200 million tonnes (i.e. around 20%) in $CO_2$ emissions via the fuel-switching The impact of the carbon price is apparently small or non-existent (between 0 and 10%) and of the same order of magnitude as the model’s range of error. which does not enable us to reach more accurate conclusions.

## 6.4 Comments on the results and their limitations

The estimates obtained are solely the result of formalising a BAU scenario and the related assumptions. This means that it is their order of magnitude that needs to be retained first and foremost. as well as the ranking of the importance and impact of each variable.

The variable used to capture the “RE policy” effect, namely the percentage of renewable energy used in domestic power generation, does not enable us to distinguish between hydropower (around 15%[51] of total power generation in the European Union) and other sources of renewable energy (especially wind power. solar power. and biomass), which account for less than 7% of power generation in the European Union, and must be the main source of the growth required to achieve the 2020 targets (European Commission. 2013). A future extension of this study could focus on breaking down and distinguishing between the origin of the reductions due to RE according to the type of renewable energy.

As underlined at the beginning of the study, it is not obvious that the variables selected (total primary energy consumption per GDP point and electricity consumption per GDP point) can be directly

[51] CDC Climat, *Tendances Carbone,*

interpreted as a reflection of energy efficiency, as they are actually more correlated to the economy's energy intensity. However, we should note that the European Commission mentions both "a 20% reduction in the annual consumption of primary energy in Europe by 2020[52]" and "increasing energy efficiency by 20% by 2020[53]". There does not seem to be a precise and consensual definition of what is understood by "improving energy efficiency in the EU". In the econometric model, the two variables selected probably capture a broader series of effects than just "energy efficiency". In addition to the structural changes in the economy, they also capture the changes in the energy mix (e.g. the shutdown in nuclear power stations in Germany that resulted in an increase in the primary energy to GDP ratio. as nuclear power generation has a lower thermal efficiency than combined-cycle gas-fired power plants. for instance[54]). Lastly, these variables could also, apparently, capture one possible impact of the carbon price via investments in green technologies, which specifically improve energy efficiency. However, as indicated above. Model 4 tends to contradict this assumption. Lastly, these variables probably capture something of the economic crisis, through standardisation via GDP, which means that the impact of the crisis may have been slightly underestimated in the results in Section 6.3.

## Conclusion

The econometric analysis, which includes a panel of 21 countries and covers around 93% of the carbon emissions included in the European Union Emissions Trading Scheme., enables us to provide several explanations for the possible causes of the downward trend in the carbon emissions generated by the installations covered by this regulation (-7.3% between 2005 and 2012). Overall, therefore, between 600 and 700 million tonnes (i.e. between 50 and 70%) of the 1.1 or 1.2 $GtCO_2$ in estimated $CO_2$ emission reductions between 2005 and 2011 apparently resulted from the policies implemented in connection with European targets. which include reaching a 20% contribution by renewable energy to energy end-consumption in 2020 (a reduction of around 500 million tonnes). and improving energy efficiency by reducing primary energy consumption by 20% by 2020 (reduction of between 100 and 200 million tonnes). The economic downturn played a significant role, although not a dominant one, in the fall in $CO_2$ emissions, and its impact was estimated at 300 million tonnes, i.e. between 20 and 30%. Price substitution effects between coal and gas also seem to have affected emissions, in an order of magnitude of around 200 million tonnes. These estimates are based on the estimates in the benchmark scenario, known as the "business as usual" scenario, set out in this study.

The econometric analysis and the models do not enable us to identify a possible carbon price impact, and conclude that the price of carbon played a small role in the recorded fall in emissions. However, it

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[52] http://ec,europa,eu/energy/efficiency/index_fr,htm,
[53] http://ec,europa,eu/energy/efficiency/eed/eed_fr,htm,
[54] The ratio between the power generated and primary energy is around 33% for nuclear power, and 60% for combined-cycle gas-fired power plants, Switching from nuclear power stations to gas-fired power stations leads to a fall in primary energy consumption per GDP point, and therefore to an improvement in energy efficiency,

is important to underline that the economic downturn, which is linked to the development of RE, is responsible for the fall in said carbon price and specifically marginalises its influence in terms of the $CO_2$ emission reductions at the installations covered by the European Union. The $CO_2$ price posted by the EU ETS also contributed to a 1.048 $MtCO_2$ reduction in emissions beyond the European Union, via the use of international carbon credits arising from the CDM and JI mechanisms by EU ETS installations between 2008 and 2012.

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# Appendices

## 1. $CO_2$ emissions for the EU ETS countries. in millions of tonnes

| | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | Total |
|---|---|---|---|---|---|---|---|---|---|
| **AT** | 33.4 | 32.4 | 31.8 | 32.1 | 27.4 | 30.9 | 30.6 | 29.6 | **248.1** |
| **BE** | 55.4 | 54.8 | 52.8 | 55.5 | 46.2 | 50.1 | 46.2 | 43.8 | **404.7** |
| **BG** | 0.0 | 0.0 | 39.2 | 38.3 | 32.0 | 33.5 | 40.0 | 0.3 | **183.3** |
| **CY** | 5.1 | 5.3 | 5.4 | 5.6 | 5.4 | 5.1 | 4.6 | 0.0 | **36.3** |
| **CZ** | 82.5 | 83.6 | 87.8 | 80.4 | 73.8 | 75.6 | 74.2 | 69.3 | **627.2** |
| **DE** | 475.1 | 478.1 | 487.1 | 472.7 | 428.3 | 454.9 | 450.3 | 463.3 | **3 709.7** |
| **DK** | 26.5 | 34.2 | 29.4 | 26.5 | 25.5 | 25.3 | 21.5 | 18.3 | **207.1** |
| **EE** | 12.6 | 12.1 | 15.3 | 13.5 | 10.4 | 14.5 | 14.8 | 13.6 | **106.9** |
| **ES** | 183.6 | 179.7 | 186.6 | 163.5 | 136.9 | 121.5 | 132.7 | 139.9 | **1 244.3** |
| **FI** | 33.1 | 44.6 | 42.5 | 36.2 | 34.3 | 41.3 | 35.1 | 30.7 | **297.8** |
| **FR** | 131.3 | 127.0 | 126.6 | 124.1 | 111.1 | 115.2 | 105.1 | 89.1 | **929.5** |
| **GB** | 242.5 | 251.2 | 256.6 | 265.1 | 231.9 | 237.4 | 220.9 | 247.0 | **1 952.5** |
| **GR** | 71.3 | 70.0 | 72.7 | 69.9 | 63.7 | 59.9 | 58.8 | 62.3 | **528.5** |
| **HU** | 26.2 | 25.8 | 26.8 | 27.2 | 22.4 | 23.0 | 22.5 | 21.1 | **195.0** |
| **IE** | 22.4 | 21.7 | 21.2 | 20.4 | 17.2 | 17.4 | 15.8 | 26.2 | **162.3** |
| **IS** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 | **0.4** |
| **IT** | 225.6 | 227.4 | 226.4 | 220.7 | 184.9 | 191.5 | 189.9 | 181.2 | **1 647.6** |
| **LI** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| **LT** | 6.6 | 6.5 | 6.0 | 6.1 | 5.8 | 6.4 | 5.6 | 5.8 | **48.8** |
| **LU** | 2.6 | 2.7 | 2.6 | 2.1 | 2.2 | 2.3 | 2.1 | 2.0 | **18.5** |
| **LV** | 2.9 | 2.9 | 2.8 | 2.7 | 2.5 | 3.2 | 2.9 | 3.0 | **23.1** |
| **MT** | 2.0 | 2.0 | 2.0 | 2.0 | 1.9 | 1.9 | 1.9 | 2.3 | **16.0** |
| **NL** | 80.4 | 76.7 | 79.9 | 83.5 | 81.0 | 84.7 | 80.0 | 80.1 | **646.3** |
| **NO** | 0.0 | 0.0 | 0.0 | 19.3 | 19.2 | 19.3 | 19.2 | 0.0 | **77.1** |
| **PL** | 203.1 | 209.6 | 209.6 | 204.1 | 191.2 | 199.7 | 203.0 | 196.2 | **1 616.6** |
| **PT** | 36.4 | 33.1 | 31.2 | 29.9 | 28.3 | 24.2 | 25.0 | 25.2 | **233.3** |
| **RO** | 0.0 | 0.0 | 69.6 | 64.1 | 49.0 | 47.3 | 51.2 | 47.8 | **329.1** |
| **SE** | 19.4 | 19.9 | 19.0 | 20.1 | 17.5 | 22.7 | 19.9 | 18.3 | **156.7** |
| **SI** | 8.7 | 8.8 | 9.0 | 8.9 | 8.1 | 8.1 | 8.0 | 7.7 | **67.3** |
| **SK** | 25.2 | 25.5 | 24.5 | 25.3 | 21.6 | 21.7 | 22.2 | 17.9 | **184.1** |
| **Total** | **2 013.7** | **2 035.7** | **2 164.7** | **2 119.8** | **1 879.5** | **1 938.5** | **1 903.8** | **1 842.3** | **15 898.1** |

*Source: base EUTL*

## 2. Statistical data for the observations

| Variable | Obs. | Average | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| **emission** | 147 | 88.50 | 111.55 | 2.05 | 487.15 |
| **pCO2** | 147 | 14.41 | 6.57 | 0.66 | 22.11 |
| **pctRE** | 147 | 20.11 | 16.54 | 2.64 | 67.69 |
| **CO2/switch** | 147 | 0.79 | 0.37 | 0.052 | 1.31 |
| **Gas/Coal price** | 147 | 2.41 | 0.63 | 1.95 | 3.45 |
| **outM** | 147 | 103.14 | 10.67 | 65.54 | 129.51 |
| **outE** | 140 | 99.33 | 6.83 | 81.79 | 118.42 |
| **TPES/GDP** | 147 | 0.13 | 0.032 | 0.08 | 0.22 |
| **ELEC/GDP** | 147 | 0.28 | 0.11 | 0.12 | 0.55 |

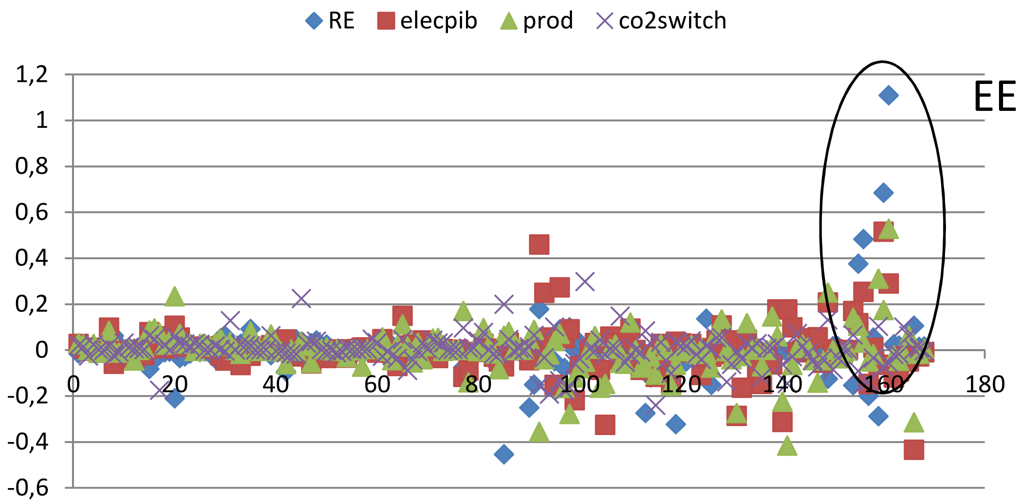
3. **Models 2 and 3 with the fixed-effect amounts for each country in the panel. Data used to estimate the counterfactual emissions**

| Model | (2) | | (3) | | Country |
|---|---|---|---|---|---|
| | Coefficient | Standard error | Coefficient | Standard error | |
| $pctRE_{it}$ | -0.1746 *** | 0.04216 | -0.1249 *** | 0.04269 | - |
| $outM_{it}$ | 0.4314 *** | 0.10522 | 0.5001 *** | 0.6890 | - |
| $GCratio_{it}$ | 0.0607 * | 0.03141 | - | - | - |
| $CO_2switch_{it}$ | -0.00589 | 0.00626 | -0.00386 | 0.03987 | - |
| $TPES_{it}$ | - | - | 0.7488 *** | 0.1776 | - |
| $ELEC_{it}$ | 0.3684 | 0.2348 | - | - | - |
| $u_2$ | 0.6263 | 0.0119 | 0.6496 | 0.0101 | Germany |
| $u_3$ | 0.1434 | 0.0119 | 0.2099 | 0.0157 | Spain |
| $u_4$ | 0.2917 | 0.0184 | 0.3434 | 0.0195 | Italy |
| $u_5$ | 0.0916 | 0.0590 | 0.1647 | 0.0192 | Poland |
| $u_6$ | 0.3276 | 0.0486 | 0.3911 | 0.0387 | United Kingdom |
| $u_7$ | -0.1530 | 0.0329 | -0.1635 | 0.140 | Netherlands |
| $u_8$ | -0.3355 | 0.0759 | -0.2959 | 0.0202 | Czech Rep. |
| $u_{10}$ | -0.4464 | 0.0297 | -0.4252 | 0.0256 | Austria |
| $u_{11}$ | -0.5449 | 0.0772 | -0.5946 | 0.0448 | Finland |
| $u_{12}$ | -0.2911 | 0.0120 | -0.1840 | 0.0238 | Greece |
| $u_{13}$ | -0.8124 | 0.0467 | -0.7499 | 0.0156 | Hungary |
| $u_{14}$ | -0.5656 | 0.0291 | -0.4754 | 0.0184 | Portugal |
| $u_{16}$ | -0.7459 | 0.0656 | -0.7516 | 0.0367 | Sweden |
| $u_{18}$ | -0.6929 | 0.0632 | -0.6205 | 0.0426 | Ireland |
| $u_{19}$ | -1.4382 | 0.0594 | -1.13747 | 0.0153 | Lithuania |
| $u_{20}$ | -1.7880 | 0.0358 | -1.7459 | 0.0336 | Luxembourg |
| $u_{21}$ | -1.6158 | 0.0751 | -1.5543 | 0.0247 | Latvia |
| $u_{22}$ | -0.7791 | 0.0889 | -0.7306 | 0.0223 | Slovakia |
| $u_{23}$ | -0.5145 | 0.0501 | -0.5218 | 0.0190 | Denmark |
| $u_{25}$ | -1.1554 | 0.0584 | -1.1094 | 0.0170 | Slovenia |
| *Intercept* | 0.7661 | 0.4543 | 0.03544 | 0.335 | France (Bmk.) |

Number of observations = 147; number of groups = 21
Notes: *** indicates a variable that is significantly different from zero at a 1% threshold; ** at a 5% threshold. and * at a 10 % threshold

The reference country ($u_1$) is France and the other $u_i$ are therefore expressed as a difference with this benchmark. All the $u_i$ estimators are significant at a 1% threshold (except for $u_5$ and the constant. which are significant at a 10% threshold for Model 2. and for the constant in Model 3. which is only significant at a 29% threshold).

**4. DfBeta analysis for Model 2**




The DfBeta analysis shows the disruptive effect of the observations for Estonia on the estimated regression coefficients. We made the decision to withdraw this country from the panel, in order to improve the model's accuracy.

5. Hausman test performed on Model 1 with the TPES/GDP variable

Ho assumption test (non-systematic difference between the RE and Fen coefficients)

Chi 2 = 10.53

Prob > Chi2 = 16.06%

The probability is higher than 5%, so authorises the use of a random-effect regression analysis (with a risk threshold of 5% and even 10%).

## 6. Error autocorrelation test

The presence of error autocorrelation was tested by adding the estimated residual for period t-1 (variable lag_residu) to the t regression.

| **Model** | **(1 with ELEC)** | | | **(1 with TPES)** | | |
|---|---|---|---|---|---|---|
| | Coefficient | Standard error | P>\|t\| | Coefficient | Standard error | P>\|t\| |
| $pctRE_{it}$ | -0.0965 | 0.0587 | 0.115 | -0.0668 | 0.0569 | 0.253 |
| $outM_{it}$ | 0.409 | 0.0972 | 0.00 | 0.445 | 0.0748 | 0.00 |
| $GCratio_{it}$ | 0.0880 | 0.0288 | 0.006 | 0.037 | 0.0351 | 0.301 |
| $ELEC_{it}$ | 0.605 | 0.226 | 0.014 | - | - | - |
| $TPES_{it}$ | - | - | - | 0.862 | 0.293 | 0.008 |
| $CO_2switch_{it}$ | -0.0115 | 0.00639 | 0.085 | -0.00827 | 0.00528 | 0.132 |
| $Lag\_residu_{it-1}$ | **0.186** | **0.189** | **0.336** | **0.0994** | **0.139** | **0.481** |
| *Intercept* | -0.477 | 0.627 | 0.455 | -0.425 | 0.545 | 0.443 |

## 7. Heteroskedasticity test performed on Model 1

The test applied is the one suggested by Wiggins and Poi[55]. The Ho assumption tested was the homoskedasticity assumption**.**

LR Chi2 = 229.54

Prob > Chi2 = 0.0 %

Rejection of the Ho homoskedasticity assumption

[55] Vince Wiggins and Brian Poi (StataCorp), *Testing for panel-level heteroskedasticity and autocorrelation*, June 2001, revised in December 2003; www,stata,com/support/faqs/statistics/panel-level-heteroskedasticity-and-autocorrelation/,

## 8. Regression analysis for Models 2 and 3 excluding the GDP variable. which is not significant

**Table 3**

| Model | 2 | | | 3 | | |
|---|---|---|---|---|---|---|
| | Coefficient | Standard error | P>\|t\| | Coefficient | Standard error | P>\|t\| |
| $GDP_{it}$ | - | - | - | - | - | - |
| $pctRE_{it}$ | -0.1746 *** | 0.04216 | 0.001 | -0.1249 *** | 0.04269 | 0.008 |
| $outM_{it}$ | 0.4314 *** | 0.10522 | 0.001 | 0.5001 *** | 0.6890 | 0.000 |
| $GCratio_{it}$ | 0.0607 * | 0.03141 | 0.067 | - | - | - |
| $CO_2switch_{it}$ | -0.00589 | 0.00626 | 0.358 | -0.00386 | 0.03987 | 0.344 |
| $TPES_{it}$ | - | - | - | 0.7488 *** | 0.1776 | 0.000 |
| $ELEC_{it}$ | 0.3684 | 0.2348 | 0.132 | - | - | - |
| *Intercept* | 0.2709 | 0.4351 | 0.54 | -0.0998 | 0.3069 | 0.748 |

Number of observations = 147; number of groups = 21
Notes: *** indicates a variable that is materially different from zero at a 1% threshold; ** at a 5% threshold and * at a 10% threshold

For Model 2: joint nullity test for the variables $F(7.22) = 17.43$
Prob > F = 0.00%

For Model 3: joint nullity test for the variables $F(7.22) = 26.29$
Prob > F = 0.00%

## 9. Predictions of the models generated by the econometric analysis. and differences with the data observed. The amounts are in $MtCO_2$

| | **Model 2**[56] | | **Model 3**[57] | | Observations |
|---|---|---|---|---|---|
| | Prediction | Diff. from obs. | Prediction | Diff. from obs. | |
| **2005** | 1 975 | 1.9 % | 1 982 | 2.2 % | 1 939 |
| **2006** | 1 992 | 1.5 % | 1 982 | 1.0 % | 1 962 |
| **2007** | 1 958 | -1.1 % | 1 970 | -0.5 % | 1 980 |
| **2008** | 1 881 | -2.1 % | 1 894 | -1.4 % | 1 921 |
| **2009** | 1 700 | -0.9% | 1 699 | -0.9 % | 1 715 |
| **2010** | 1 738 | -1.6 % | 1 763 | -0.2 % | 1 767 |
| **2011** | 1 735 | 0.5 % | 1 714 | -0.7 % | 1 726 |
| **Aggregate difference**[58] | 184 | - | 134 | - | - |

[56] Model including the electricity consumption per GDP point variable (ELEC variable),
[57] Model including the total primary energy consumption per GDP point variable (TPES variable),
[58] Sum of the absolute amounts of the differences between the emission volumes predicted by the model and the emissions observed,

### 10. Estimated origin of the reductions compared with the BAU scenario

The reductions were calculated compared with the emissions predicted by the model based on the data observed over the period between 2005 and 2011. CF indicates that the counterfactual data estimated using the assumptions of the BAU scenario were used for this variable only. The observed data were used for all the other variables.

**Model 2**

| | Prediction | % of RE (CF) | OutM (CF) | ELEC/GDP (CF) | CO2/switch (CF) | G/C ratio (CF) | Aggregate |
|---|---|---|---|---|---|---|---|
| **2005** | 1 975 | 10 | 42 | 2 | 7 | 0 | 60 |
| **2006** | 1 992 | 36 | 3 | 13 | 4 | -3 | 52 |
| **2007** | 1 958 | 56 | -29 | 29 | -32 | 85 | 109 |
| **2008** | 1 881 | 83 | -2 | 28 | 7 | 59 | 175 |
| **2009** | 1 700 | 125 | 126 | 27 | -2 | 46 | 321 |
| **2010** | 1 738 | 153 | 89 | 13 | 2 | 39 | 295 |
| **2011** | 1 735 | 182 | 68 | 25 | 1 | 36 | 312 |
| **Aggregate** | - | 643 | 296 | 136 | -13 * | 262 | 1 324 |
| **%** | - | **48.6** | **22.4** | **10.3** | **-1.0** | **19.8** | 100 |

* The error for Model 2 is estimated at ± 90 Mt. As a result, the reduction calculated for the CO2 price/switch price variable is not significantly different from zero (in accordance with the econometric results).

**Model 3**

| | Prediction | % of RE (CF) | Out M (CF) | TPES/GDP (CF) | CO2/switch (CF) | G/C ratio (CF) | Aggregate |
|---|---|---|---|---|---|---|---|
| **2005** | 1 982 | 6 | 49 | -10 | 23 | - | 68 |
| **2006** | 1 982 | 25 | 3 | 14 | 22 | - | 65 |
| **2007** | 1 970 | 40 | -34 | 65 | -3 | - | 68 |
| **2008** | 1 894 | 59 | -3 | 58 | 23 | - | 138 |
| **2009** | 1 699 | 88 | 147 | 50 | 16 | - | 300 |
| **2010** | 1 763 | 109 | 105 | 5 | 18 | - | 236 |
| **2011** | 1 714 | 126 | 79 | 54 | 17 | - | 275 |
| **Aggregate** | - | 454 | 346 | 235 | 116 | - | 1 151 |
| **%** | - | **39.5** | **30.0** | **20.4** | **10.1** | **-** | 100 |

The error for Model 3 is estimated at ± 65 Mt.