Manufacturing sectors in the European Union Emissions Trading Scheme

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À Zoé

« Monsieur, j'ai cru qu'on pouvait définir l'aventure : un événement qui sort de l'ordinaire, sans être forcément extraordinaire. »

J.-P. Sartre
La Nausée

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Résumé

La thèse se concentre sur le secteur non-électrique agrégé couverts par le SCEQE. La contribution du secteur non-électrique aux variations des émissions de CO_2 pendant les deux premières phases du marché (2005-2012), tant du point de vue de la demande finale que de celui de l'offre, est comparée à celle du secteur électrique. Les implications du mode d'allocation gratuite de quotas au secteur non-électrique durant la troisième phase du marché (2013-2020) sont examinées, ce qui constitue l'une des premières évaluations approfondies des benchmarks institués en Phase 3. Il est montré que, tant du point de vue de la demande finale que de celui de l'offre, le secteur non-électrique, du fait de ses interdépendances et de son niveau d'activité, a davantage contribué aux variations des émissions de CO_2 que ne l'a fait le secteur électrique, au cours la période 2005-2012. Il est également montré que, en dépit de ses effets redistributifs, le mode d'allocation gratuite par benchmarks tel qu'il a été défini, demeure imparfait et n'est ainsi pas à la hauteur du rôle central du secteur non-électrique dans le fonctionnement du marché.

Mots clés : analyse entrée-sortie, analyse de décomposition, SCEQE, allocation gratuite de quotas, benchmarking, secteur manufacturier, émissions de CO_2

Abstract

The thesis focuses on the aggregated non-power sector covered under the EU ETS. First, the non-power sector contribution to CO_2 emissions changes in the first two phases of the Scheme (2005-2012), both from a final demand perspective and a supply perspective, is compared to that of the power sector at first. Then, the implications of the non-power sector specific free allocation methodology in the third phase of the Scheme (2013-2020) are scrutinized, which constitutes one of the first thorough assessment of Phase 3 benchmarking. It is showed that both from a final demand perspective and a supply perspective, the non-power sector, through its interrelated character and its activity levels, has contributed to changes in EU ETS CO_2 emissions more than the power sector did, over the 2005-2012 period. It is also showed that, despite its free allocation redistribution effects, benchmark-based Phase 3 free allocation remains flawed and may benefit from further improvements to be up to the central role of the non-power sector in the EU ETS dynamics.

Key words : input-output analysis, decomposition analysis, EU ETS, free allocation, benchmarking, manufacturing sector, CO_2 emissions

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Introduction

The Kyoto Protocol is the first legally binding international agreement on climate policy. In setting emissions reduction targets for countries listed in its Annex B, it has simultaneously laid down the principles for international trading of emission quotas among these countries over the 2008-2012 period, also referred to as the Kyoto Protocol commitment period. It was signed in December 1997 during the third Conference of Parties to the United Nations Framework Convention on Climate Change, and became effective in February 2005, once a large enough number of countries, accounting for a last 55 % of CO_2 emissions of developed countries in 1990, had ratified the Protocol. The target of the (at this time) EU 15 was to reduce its emissions by 8 % compared to 1990 levels by the 2008-2012 period, and varied national targets were agreed on following the burden-sharing agreement of 1998. Besides national initiatives considering emissions trading [1], a Green Paper by the European Commission (European Commission, 2000) pointed out the benefits that an EU-wide emissions trading scheme would bring, among which that of lower emissions reduction costs than national targets. This Green Paper prepared the ground for the EU ETS Directive, which has set the foundation of the European Union Emissions Trading Scheme (EU ETS), the largest market of tradable emission rights. A market-based instrument to reduce CO_2 emissions appeared the best option after the failure to introduce a carbon tax at the European level in the nineties. Indeed, and according to European Union statuses, fiscal measures proposed by the European Commission (such as a carbon tax), would have required to reach unanimity of Member States which, under the fear of progressively losing fiscal autonomy to the benefit of the Commission, was doomed to fail. As opposed to this, establishing a market of tradable emission permits entered the prerogatives of the Commission under the Single European Act of 1986 (Ellerman et al., 2010).

1. Domestic emissions trading schemes of Denmark, the U.K., Norway and the Netherlands, among others, are reviewed in (Boemare and Quirion, 2002).

In simplified terms, a market of tradable emission permits firstly consists in limiting the amount of CO_2 that can be released by market participants by setting what is referred to as an emission cap. Secondly, emission permits, which sum is equal to the pre-determined cap, are initially allocated following an also pre-defined methodology, which then allows market participants to trade these permits. The expected goal of the EU ETS is to allow the emergence of a single price associated with the right to emit a ton of carbon dioxide. This emerging carbon price results from the equilibrium between the supply and the demand in emission permits, which depends on several key factors among which : the activities entering the scope of the market (1), the behaviors of market participants according to the rules they are subject to (2), and the methodology for allocating emission permits (3). As stated by Trotignon (2012b), the ability to anticipate the dynamics of the market directly depends upon the knowledge and understanding of these three key factors.

The scope of the EU ETS is largely based on both Large Combustion Plant and Integrated Pollution Prevention and Controle Directives which, unlike the perimeter of the Regional Greenhouse Gas Initiative (most famously known under its acronym RGGI) - the emissions trading scheme of the Northeastern United States and Eastern Canada Region - gathered both the power sector and heavy industries (RGGI perimeter includes the power sector only). All in all, approximately two billion tons of CO_2 emissions, equivalent to about 40% and 50% of the EU greenhouse gases and CO_2 emissions respectively, entered the perimeter of the EU ETS. Said differently, two large aggregates could be distinguished among the almost twelve thousand plants having to comply with the newly implemented market rules : the power sector and the non-power sector, which could be assimilated to the EU manufacturing sector ; the power sector being twice as big as the non-power sector in terms of CO_2 emissions covered under the EU ETS. In particular, this dichotomy is justified upon criteria such as their yearly *ex post* net positions resulting from specific allocation decisions since 2005 based on the respective international competition exposures of the two aggregates. As an illustration of this dichotomy, the literature covers the power sector and the non-power sector separately on similar issues. To name two of these issues, Jouvet and Solier (2013) investigated the ability of the power sector to pass CO_2 cost onto wholesale electricity prices ; and short term emissions reduction through fuel switching in 2005 and 2006 which was examined by Delarue et al. (2010) in particular. On the other hand, the non-power sector is studied at the sectoral level i.e. at a disaggregated scale. Among others, the competitiveness issue due to international exposure and related to the introduction of the EU ETS has been examined, be it through the perspective of allocation methodology in the cement sector (Demailly and Quirion, 2006), border tax adjustment in the case of the cement, iron and steel and power sectors (Monjon and Quirion, 2011), or carbon cost pass-through in the iron and steel sector (Demailly and Quirion, 2008).

The thesis therefore proposes to enlighten on the respective roles of the power sector and the non-power sector, taken as an aggregate, in the functioning of the EU ETS, along the above mentioned three characteristics. First, the combined impact of the activity coverage of the Scheme and of EU-wide economy sectoral interrelations on EU ETS CO_2 emissions dynamics is assessed from a final demand perspective. Then, the respective contributions of both power and non-power sectors in the carbon price dynamics, as well as the nature of these contributions, are determined from a supply perspective. Finally, an extensive analysis of Phase 3 free allocation methodology to non-power installations, which has been implemented in 2013 under the Community-wide rules, is provided.

The frontier between the power and the non-power sector nevertheless remains floating. Indeed, power sector can be understood as electricity production only or include, along side with electricity generation, heat (and steam) production depending on the subject matter. The issue is more subtle in the case of the non-power sector as the nature of industry has evolved over time, mostly due to outsourcing allowed the liberalization of capitals, making it a concept with undefined borders (Colletis, 2011). To go round this potential semantic issue, a systematic approach consisting in making use of the NACE classification, the statistical classification of economic activities in the European Communities, which divides economic activities in a four-level hierarchical structure [2], is taken in each of the following three independent essays that constitute the three chapters of the thesis.

In chapter 2, a focus is made on the impact of final demand (hence growth) on the CO_2 emissions of both the power and non-power sectors. A traditional input-output framework is introduced in the first place in order to provide a description of the concept of interrelations in the economy, and their role in transmitting final demand stimuli to the productive system. Subsequent parts extend works by Alcántara and Padilla (2003) to CO_2 emissions. Indeed, the input-output framework is enriched with an environmental perspective as well as with the definition of the ETS perimeter, in order to draw a picture of both EU 27 and EU ETS CO_2 emissions flows, and how final demand affects their dynamics. By inserting the Scheme in the broader context of the European economic environment, this chapter

2. First levels are identified by an alphabetical code and named *Sections*. Second levels are identified by a two-digit numerical code and named *Divisions*. Third levels are identified by a three-digit numerical code and named *Groups*. Fourth levels are identified by a four-digit numerical code and named *Classes*. A thorough description of the NACE rev. 2 classification is available in (Eurostat, 2008b).

contributes to the debate on the relevance of the EU ETS perimeter.

In chapter 3, the contribution of the non-power sector to dynamics of carbon price is investigated. This result is obtained in three steps. In a first part it is suggested that, under given assumptions, sectoral contribution to price dynamics can be proxied by the contribution to emissions dynamics. In a second part, a two-factor decomposition is introduced to quantify the respective contribution to EU ETS CO_2 emissions of both power and non-power sectors. This decomposition analysis underlines the need for indicators specific to EU ETS activities. The use of NACE indicators as approximates for these activities is introduced and validated in the third part of the chapter, through a panel data econometric analysis. Chapter 3 allows envisaging the non-power sector as central in CO_2 emissions dynamics and therefore on carbon price.

In chapter 4, a thorough analysis of Phase 3 free allocation to non-power installations rules is provided. Benchmarking has been introduced in the third phase of the market to further encourage non-power sectors to mitigate their emissions, at the same time responding to the criticism that grandfathering encountered since the implementation of the market in 2005. This chapter constitutes one of the first detailed analysis of the Community-wide new rules, allowing, in a first part, to assess the implications of benchmarks compared to the first two Phases of the market, as well as to identify their structural flaws based on official Directive and Decision of the Commission. In a second part, the changes involved by benchmarking are concretely studied based on Member States free allocation provisional data. In both parts the cement sector is used as a case study of the sectoral impact of benchmarks. This chapter therefore provides materials to conclude on the merits of switching to benchmarking and the lessons that can be learned.

2

Industrial interlinkages and EU ETS CO_2 emissions

2.1 Introduction

Emissions of CO_2 result from the combustion of fossil fuels for the production of energy, from gas flaring, and from other industrial processes such as chemical reactions occurring in the production of cement (Forster et al., 2007). These latter emissions are also referred to as process emissions. Industry emits CO_2 due to its use of energy involved in its activity of production. It consists in the production of manufactured goods based on the transformation of raw materials (which are provided by either the *primary sector* or extractive industries [1]) or manufactured goods, to be used as intermediate products in other transformation processes, or directly for final uses [2]. Despite the fact that the eighties of the twentieth century saw the progressive externalization of activities of services that used to be internal to industry, these activities of services remain linked to industry making the frontier between services and industry not clear-cut. This has resulted in making industry a concept with blurred frontiers (Colletis, 2011). For these two reasons (the transformation of raw materials or manufactured products and the externalization of internal activities of services), industry is characterized by close interrelations in between all three sectors of the economy, be it from a production perspective or from a CO_2 emissions perspective. In other words, any sectoral activity entails direct CO_2 emissions and indirect CO_2 emissions that stem from other activated sectors.

At the end of the first decade of the twenty first century, global direct emissions stemming from industry are assessed at 7.2 Gt CO_2 and total (including indirect emissions)

1. Extractive industries may also be classified as belonging to the primary sector. In this chapter they are considered as belonging to the second sector of the economy.

2. Final uses are classified in three different kinds : exports, gross capital formation, and final consumption on expenditure. Gross capital formation includes changes in inventories and valuables, and gross fixed capital formation. Final consumption on expenditure is usually disaggregated in three kinds of end users : households, government and non-profit organizations serving households.

at 12 Gt CO_2 (Bernstein et al., 2007). Here, indirect emissions refer to emissions associated with the generation of electricity and other energy carriers. These emissions fall under the second scope as defined by Greenhouse Gas Protocol[3]. Yet, indirect emissions do not consist in the externalized production of electricity only (Minx et al., 2009). Indirect emissions should also gather all CO_2 emissions from the production of inputs that are used in the sectoral production process. These latter emissions correspond to scope 3 as defined by GHG Protocol. Unlike scope 2 emissions that have been widely covered (for instance by EPA (2008), which provides a guidance to assess scope 2 emissions in the frame of greenhouse gas emissions inventory) and identically to the aggregated non-power segment, indirect emissions other than from the purchase of electricity or steam (i.e. falling under scope 3) of the EU ETS have not been documented extensively. Yet, integrating CO_2 emissions flows (all three emissions scopes) into the systems of national accounts is in line with the recommendations of the Stiglitz report (Stiglitz et al., 2009), which aimed at proposing reforms to rethink the measurement of economic performance and to better assess social progress. This chapter therefore intends to develop the conceptual framework to study CO_2 emissions flows that are activated by final demand in the EU 27 economy and the EU ETS.

The EU ETS covers stationary industrial installations that contributed to approximately 40% only of the EU 27 total greenhouse gas emissions when first implemented in 2005. Appendix 1 of the EU ETS Directive (European Parliament Council, 2009) defines activities that are compelled to be included in the Scheme. They are manufacturing and energy activities since the EU ETS is meant to mitigate CO_2 emissions of Member States' heavy industries. Nonetheless, the fact that installed capacity or production thresholds have been introduced involves that only a restriction of EU 27 manufacturing sector may enter the scope of the Scheme. As stipulated by the European Commission, *performing an "industrial activity" is not the determining factor for deciding whether an installation falls under the scope of the ETS*, which is summarized by the statement : *activity is not a sector classification* (European Commission, 2010b). This unveils the fact that the scope of the

3. The definition of emissions scopes is provided on the GHG protocol website : "The GHG Protocol categorizes emissions into three broad scopes :
- Scope 1 : All direct GHG emissions ;
- Scope 2 : Indirect GHG emissions from consumption of purchased electricity, heat or steam ;
- Scope 3 : Other indirect emissions, such as the extraction and production of purchased materials and fuels, transport-related activities in vehicles not owned or controlled by the reporting entity, electricity-related activities (e.g. transmission and distribution losses) not covered in scope 2, outsourced activities, waste disposal, etc."

ETS does not coincide with the EU 27 industry perimeter, which suggests, under specific assumptions, the possibility for internal (within the EU 27 borders) carbon leakage. Indeed the frontier of sectors and parts of sectors covered under the EU ETS with those that are not has no reason to be hermetic.

The degree of sectoral interdependency can be measured in two different ways. A first descriptive approach consists in describing intermediate consumption patterns that conduct to the total output of the considered productive system (here the EU 27 economy), and what is made of this output (section 2.2). This approach provides a snapshot of existing structures and underlies the second approach, which is based on the Leontief model. The Leontief model assesses the impact of final demand variation [4] on the productive system given these structures. This approach allows to unveil the whole production chain in the sense that it highlights the solicited sectors of the economy for the satisfaction of final demand. Hence, the contributions to EU ETS CO_2 emissions of the power and non-power segments are assessed through the direct and indirect effects on the productive system of final demand in their respective products. The Leontief model requires assumptions on the productive system which may limit the conclusions that can be derived from it. These limits are developed in (Lenzen, 2003) and (Eurostat, 2008a). Among them, the fact that it assumes linear relationships between input and output involves that there are no fixed costs and thus constant returns to scale. Fixed proportions between inputs forbids input substitution, which is made possible by the absence of capacity scarcity. Products prices are therefore of no influence on the input mix. Despite these what seem to be far from reality assumptions, the Leontief production model offers to assess the sensitivity of production to marginal changes (i.e. from current production level and given production function) in final uses and their impacts on CO_2 emissions multipliers (section 2.3), and potential domestic carbon leakage under the perspective of the EU ETS perimeter (section 2.4).

4. Final use and final demand refer to the same concept, and are used without distinction in this chapter. Therefore final demand variation should be understood as aggregated variation from final consumption expenditures (F.C.E.), gross capital formation (G.C.F.) and exports (Exp.).

2.2 Power sector and industry in the EU 27 economy

2.2.1 A description of economic flows in the EU 27

2.2.1.1 A brief introduction to input-output tables

The input-output tables of Wassily Leontief Leontief credits Quesnay and its *Tableau économique*[5] for revealing the interdependences existing among parts of the economic system ; this idea having become "the very foundation of economic analysis" (Leontief, 1936). Revolutionary in theory, Leontief nevertheless points out the practical difficulties to gather the required data to represent national economic flows (reason for which Quesnay had to rely on fictitious national figures). Although different in their objectives and techniques, Leontief has renewed the principles of the *tableau économique* in his attempt to establish quantitative input and output relations in the economic system of the United States for the year 1919. Grounds for input-output tables, field of research that he is mostly known for, were provided in the same time. Indeed, given the nature of economic transactions in between firms and/or households, it was possible to represent flows in a single two-way table, where, from the perspective of the producer, rows represented revenues (output) and columns represented expenditures (input). And, similarly to what Quesnay did, Leontief gathered economic transactions of firms and/or households into aggregates (which nature depended on the investigated economic issue) as illustrated in table 2.1. Here, each element can be read in two ways : element D_c represents revenues for aggregate D from aggregate C, but also expenditures for aggregate C in the consumption of output from aggregate D. The diagonal of the table is empty as no transaction occurs within a same aggregate, should it correspond to a single account such as a firm. When single accounts are gathered to form an aggregate, the content of the table diagonal will depend on

5. The sense of economy functioning as a circular closed circuit was first introduced by Quesnay in the 18^{th} century. A French doctor, the intuition of Quesnay was inspired from the discovery of his colleague William Harvey, who unveiled blood circulation around the body and the associated role of the heart in the phenomenon (Harvey, 1628). Combining this intuition with the one of society being structured by classes (as Schumpeter puts it in his *History of Economic Analysis*), Quesnay developed a *tableau économique* with agricultural, manufactured products and money circulation in between three different social classes : the *classe des propriétaires* (landowners), the *classe productive* (the farmers) and the *classe stérile* (bourgeoisie). The *tableau économique* has brought three major breakthroughs in economic analysis (Schumpeter, 1954). It has first simplified millions of microeconomic interactions and flows into a limited number of aggregates. Secondly, it has explicited the nature of economic equilibrium. In order words, it has unveiled the fact that all economic transactions were related one to another and that partial and local equilibria actually constituted the economic system. Finally, and this is of major interest to us, the *tableau économique* has opened the doors to opportunities for quantitative applications. For instance, Quesnay took advantage of his work to derive national statistics such as annual production of France.

TABLE 2.1: Expenditures and revenues in an input-output table

Input/Output	A	B	C	D	E	Total
A		A_b	A_c	A_d	A_e	$\sum_{i=a}^{e} A_i$
B	B_a		B_c	B_d	B_e	$\sum_{i=a}^{e} B_i$
C	C_a	C_b		C_d	C_e	$\sum_{i=a}^{e} C_i$
D	D_a	D_b	D_c		D_e	$\sum_{i=a}^{e} D_i$
E	E_a	E_b	E_c	E_d		$\sum_{i=a}^{e} E_i$
Total	$\sum_{i=A}^{E} i_a$	$\sum_{i=A}^{E} i_b$	$\sum_{i=A}^{E} i_c$	$\sum_{i=A}^{E} i_d$	$\sum_{i=A}^{E} i_e$	S

Source : Leontief (1936)

the accounting principle : net accounting will involve the diagonal to be empty, as opposed to gross accounting.

Symmetric input-output tables Economic flows have finally been integrated in the input-output framework (Eurostat, 1995). The input-output framework consists in three types of tables : supply, use and symmetric input-output tables (SIOT) ; the latter being derived from the former two and a set of assumptions to the relationship between inputs and outputs. Broadly, supply and use tables serve statistical purposes (including the determination of gross domestic product and of value added), whereas SIOT are used for analytical purposes. The input-output framework focuses on the production in an economy as supply and use tables relate products to industrial activities [6]. On the one hand, a **supply** table provides the supply of products by industry, including imported products. Primary (secondary) activity of an industry corresponds to the production of products (not) characteristic for this industry. On the other hand a **use** table shows how supplied products are used by each industry as well as the value they add. Intermediate and final uses are also distinguished within the latter table.

As already mentioned, symmetric input-output tables result from the combination of use and supply tables [7] [8]. There exists several types of SIOT depending on the chosen input-output analytical approach. They can either be product by product or industry by industry tables. In the former case, supply and use tables are re-arranged so that inputs are allocated

6. The way industrial activities are organized depends on the classification that is chosen. The interested reader can find the list of existing classifications on the United Nations Statistics Division website (*http : //unstats.un.org/unsd/cr/registry/default.asp*).

7. Chapter 11 of Eurostat (2008a) provides a thorough description of the different methodologies to derive SIOT from use and supply tables, which is not of direct interest to us.

8. A description of the main elements of supply, use and symmetric input-output tables is provided in appendix 2.A of this chapter.

to homogeneous production units (or homogeneous branches). The underlying assumption to derive product by product tables is that each product is produced in its own specific way, irrespective of the industry where it is produced. In the latter case, it is assumed that each industry has its own specific sales structures, irrespective of its product mix. Therefore, supply and use tables are re-arranged so that inputs are allocated to industries (Eurostat, 2008a). Although industry by industry tables are closer to statistical sources and allow easier integration of other statistical databases, product by product ones tend to be favored in the literature as they are more homogeneous in their description of transactions (Rueda-Cantuche et al., 2009).

Whether they are product by product or industry by industry tables, it is possible to break the *total* SIOT of an economy up into a SIOT of domestic production and a SIOT of imported products. The choice of the SIOT (*total*, domestic, imports) relies on the research question that is investigated. In this chapter, the question about the power and the manufacturing sectors that is addressed concerns domestic CO_2 emissions exclusively, which therefore requires the use of the EU 27 SIOT of domestic production : given industrial interrelations in the EU 27, how does final demand affect domestic EU 27 and EU ETS CO_2 emissions ?

2.2.1.2 A focus on the power and manufacturing sectors

Defining input and output coefficients The way the power and the manufacturing sectors are inserted in the economy is provided by their respective input and output flows, which are summarized by both input and output coefficients. For a given homogeneous sector, input coefficients are the respective inputs shares in the total output of the sector. They are obtained from the SIOT, dividing intermediate consumptions of this given sector by its total output (i.e. SIOT intermediate inputs of a same column are divided by the column total). Input coefficients of a given homogeneous sector can be interpreted as its production function. Inversely, output coefficients are obtained dividing intermediate uses of a given product by the total output in this product (i.e. SIOT intermediate inputs of a same row are divided by the row total). They show how the product is consumed as intermediate input and for final uses. Used data, described in the following section, allow to isolate the power and the manufacturing sectors.

2.2.2 Data presentation

2.2.2.1 Symmetric input-output tables

The EU 27 aggregated SIOT is used to conduct this analysis. It is from Eurostat database available on the website of the organization [9], which provides SIOT of the EU 27 for the entire 2000-2007 period. They are product by product tables (for practical purposes, *homogeneous branches* will be referred to as *branches* in the remainder of the chapter). They have been generated by DG Joint Research Centre Institute for Prospective Technological Studies (JRC - IPTS) as a tool to support the development of European policies. The data is recorded in monetary measurement units (nominal Euros), and represent goods and services values (i.e. unit price multiplied with the quantity unit). Supply tables that were used to derive SIOT are measured in basic prices, that is, before the products are brought to the market. Hence, their valuation does not include trade and transport margins and are net of taxes. Use tables, on the other side, are measured at purchasers' prices, which include trade and transport margins as well as taxes. Same valuation (here in basic prices) is required to derive the EU 27 SIOT from both its use and supply tables. Consequently, the use tables have been adjusted so that both supply and use tables are measured in basic prices. This valuation allows input-output relations measured in monetary units to be interpreted as technical relations as distortions from trade and transport margins and taxes are eliminated (Rueda-Cantuche et al., 2009).

Two disaggregation levels for production units are available : they are either disaggregated into 6 or 59 (homogeneous) branches. Each branch of the 6-branch disaggregation corresponds to an aggregation of NACE rev. 1 sections, whereas each branch of the 59-branch disaggregation corresponds to NACE divisions [10]. The 6-branch disaggregation is defined as follows :

P1 : Products of agriculture, hunting and fishing. P1 gathers sections A (Agriculture, hunting and forestry) and B (Fishing) ;

P2 : Industrial products. P2 gathers sections C (Mining and quarrying), D (Manufacturing) and E (Electricity, gas and water supply) ;

P3 : Construction work. P3 gathers section F (Construction) ;

9. Accessed on June 30, 2012 at *http : //epp.eurostat.ec.europa.eu/ portal/page/portal/ esa95_supply _use_input _tables/methodology/symmetric_input_output_tables*

10. A thorough description of both NACE classification first and second revisions is provided in (Eurostat, 1996) and (Eurostat, 2008b) respectively.

P4 : Trade, transport and communication. P4 gathers sections G (whole and retail trade [...]), H (Hotels and restaurants) and I (transport, storage and communication) ;

P5 : Final services and business services. P5 gathers sections J (Financial intermediation) and K (Real estate, renting and business activities) ;

P6 : Other services. P6 gathers sections L (Public administration and defence [...]), M (Education), N (Health and social work), O (Other community, social and personal service activities) and P (Private households with employed persons).

In order to enable a comparison between power and manufacturing sectors, the 6-branch disaggregation is slightly modified in the remainder of the analysis. The power sector (section E) is separated from both the mining and quarrying and the manufacturing sectors (sections C and D). branch P2 is thus split into branch P2a (gathering sections C and D and later referred to as the *industrial branch* or *other industrial sectors* or *manufacturing sector*) and branch P2b (section E, later referred to as the power branch). The 6-branch disaggregation is thus transformed into a 7-branch disaggregation. Year 2007 is chosen as it corresponds to the first year where all EU 27 Member States participate in the EU ETS (as Romania and Bulgaria entered the Scheme in 2007 only).

2.2.3 Results : input and output coefficients matrices of the EU 27

2.2.3.1 Economic flows

Over the 2000-2007 period, it can be observed that the power sector (branch P2b) contributes only 2% on average to the EU 27 total output, whereas the contribution of other industrial sectors (branch P2a) reaches, on average, slightly less than a third (29%). Shares are stable over the period. Figures presented below are derived from the EU 27 domestic SIOT of 2007, which is provided in appendix 2.B of this chapter.

What are sectoral outputs made of ? A first difference between branches P2a and P2b lays in their respective production functions (table 2.2). In 2007, 61% of the output value of other industrial sectors (branch P2a) consists in intermediate consumption (i.e. the transformation of inputs from the same or other branches). As regards the power sector (branch P2b), 51% of its output value consists in intermediate consumption. Said differently, value added is more important in the power sector than in other industrial sectors (36% versus 29% respectively). The main inputs of both sectors are their own output. However the power sector has a more diversified input content : about 90% of its

Table 2.2: EU 27 domestic technical coefficients matrix in 2007 (in % of total output)

	P1	P2a	P2b	P3	P4	P5	P6
P1	13	3	0	0	1	0	0
P2a	18	34	14	20	10	4	6
P2b	2	2	21	1	1	1	1
P3	1	1	2	19	1	2	1
P4	9	11	5	7	18	5	5
P5	6	9	7	10	15	23	9
P6	1	1	2	1	2	2	7
Imports	3	9	11	2	3	2	2
Taxes less subsidies	2	1	2	1	2	2	3
Value added	46	29	36	39	48	60	65
Total output	100	100	100	100	100	100	100

Source : the author from Eurostat

Table 2.3: EU 27 domestic output coefficients matrix in 2007 (in % of total output)

	P1	P2a	P2b	P3	P4	P5	P6	F.C.E.	G.C.F.	Exp.	Total output
P1	13	45	0	1	6	1	2	26	4	4	100
P2a	1	34	1	6	7	3	3	19	9	16	100
P2b	1	23	21	2	10	6	7	29	0	1	100
P3	0	2	1	19	3	6	3	4	63	0	100
P4	1	15	1	3	18	5	4	44	3	6	100
P5	0	12	1	4	14	23	7	30	6	4	100
P6	0	2	0	0	2	3	7	84	1	0	100

Source : the author from Eurostat

inputs come from four different branches (itself and branches P2a, P4 and P5) whereas the same proportion of inputs of other industrial sectors comes from three branches only (itself and branches P4, P5). It is also to be noted that the output of other industrial sectors represents an important share of the power sector inputs, whereas power sector output is negligible in other industrial sectors inputs.

How are sectoral outputs consumed ? A second difference between the two branches concerns the ventilation of their output. They differ both in the intermediate and final uses of it (table 2.3). In 2007, 55% of the output of other industrial sectors was consumed as intermediate products, most of it by themselves and the sectors of construction and services (34%, 6% and 13% respectively). Interestingly, a larger share (70%) of the power sector output serves as input to other sectors. Furthermore, and as observed in previous paragraph, intermediate consumption of the power sector output is more diversified (23% of the power sector output is used by industrial sectors, 21% by the power sector itself and 24% by the sectors of construction and services). All of the power sector output final uses (30% of total output) is attributed to final consumption (of households, governments or non-profit organizations). The picture is different in the case of other industrial sectors. Final use of the output of industrial products other than energy (branch P2a) is split between final consumption (19%), gross capital formation (9%) and exports (16%).

Summary On the one hand, production functions show that the power sector is more diversified in terms of intermediate consumption of input than other industrial sectors are. The same comment applies when output ventilation inside intermediate use is considered : the power sector has more “inter-branch clients” than the industrial branch. Also a larger share of the power sector output is consumed in the production process by other branches [11]. On the other hand, the situation changes when it comes to final uses. The power sector output is exclusively concentrated in final consumption, which demand is rather inelastic (i.e. not sensitive to price variations) ; whereas other industrial sectors output is distributed among final consumption, gross capital formation and exports. The manufacturing sector (branch P2a) is therefore more exposed to the economic conjuncture, both at the domestic and international scales.

2.3 Sectoral interrelations impact on EU 27 CO_2 emissions

2.3.1 Defining backward linkage

Since the thirties of the twentieth century and its founding by Leontief, input-output analysis has developed in several directions thanks to SIOT. Indeed, they establish the mutual interrelationships among the sectors of the economy, be it “a nation, [...] the entire world economy, or as small as the economy of a metropolitan area or even a single enterprise” (Leontief, 1986). They thus allow to assess the impact of policies on specific variables of interest. More specifically, input-output analysis has been used to assess the impact of final demand on output. This impact is referred to as *backward linkage*. It indicates the

11. This picture is true at the domestic level but should be nuanced at the global level. Indeed, there is no indication of the use of EU 27 industrial sectors output exports : they might as well be used as intermediate products in other production processes abroad.

amount of output that is required from each sector to serve as input in a specific sector, which output has been affected by final demand. A positive description of economic sectoral interrelations using backward linkages was first proposed by Rasmussen (1956). Hirschman (1958) later introduced a causal relation, assuming that those "key sectors" with highest linkages values would drive economic growth through the effects of their multipliers on other smaller sectors. This implied that sectors targeted policies, known as "unbalanced growth" policies, would foster economic development. Such causal linkage has been the subject of a long lasting debate and several other approaches for the measurement of sectoral linkages were proposed and well summarized by Lenzen (2003).

The static input-output system of Leontief is recognized to measure backward linkage through the Leontief (or input) inverse matrix. The Leontief inverse matrix is composed of the input coefficients matrix, also known as the technical coefficients matrix, as described in section 2.2.1.2. Let X be the total output of an economic system. It follows the relation given in equation 2.1.

$$A^k X + Y^k = X \text{ with } k = d \text{ or } g \tag{2.1}$$

Where $A^k(N;N)$ is the technical coefficients matrix, with $a_{ij} = \frac{x_{ij}}{x_j}$ the technical coefficient of branch j for product i. $X(N;1)$ is the column vector of total output so that the matrix product $A^k X$ corresponds to intermediate consumption which, added to $Y^k(N;1)$, the column vector of final demand, corresponds to total output X. N is the number of economic branches that produce as many products. Superscript k indicates which intermediate matrix is considered : the domestic one ($k = d$) or the global one, which includes imports ($k = g$). Equation 2.1 can be re-written into :

$$\left(I - A^k\right) X = Y^k$$

Coefficients on the diagonal of the Leontief matrix $\left(I - A^k\right)$ are positive and lower than 1. They correspond to the net output of the branch of the considered column for a gross output of 1. Coefficients outside of the diagonal of the Leontief matrix are negative and same column coefficients correspond to input requirements of the considered branch. The impact of final demand on the productive system is then obtained by inverting the Leontief matrix (equation 2.2).

$$\left(I - A^k\right)^{-1} Y^k = X \tag{2.2}$$

The Leontief inverse matrix indicates the output multiplier effect that is required to satisfy final demand. Both direct and indirect intermediate input requirements are indicated, on and outside the diagonal of the Leontief inverse matrix respectively. Matrix coefficient indexed ij corresponds to the i^{th} input requirement for the production of one unit of product from branch j. The sum of output multipliers of a same column corresponds to the backward linkage of final demand in the sector of the considered column : it corresponds to the required total output involved by an increase of one unit in final demand in a specific sector product. Formally, backward linkage $L(1;N)$ is obtained multiplying the Leontief inverse matrix by the transpose of the unity vector $U(N;1)$:

$$L\left(1;N\right) = U^t \left(I - A^k\right)^{-1}$$

Elasticity in symmetric input-output tables In order to insert backward linkage in the context of the whole productive system, it is now expressed in percentage. Indeed, output multipliers per unit of final use inform on sectoral final use output intensity, but do no provide a sense of this intensity on the whole productive system. For instance, two branches may have similar output multiplier (i.e. per unit of output) but also have different weights in the total output of the economy. Therefore, the output multiplier derived from the Leontief inverse matrix would gain from being weighted by the relative sizes of branches [12]. Hence, and to rephrase Alcántara and Padilla (2003), "the disaggregated calculation of the production/demand elasticity" is introduced. It is later referred to as the *sensitivity* matrix of the EU 27 as it is the basis for the re-attribution model that is developed in the following section. The sensitivity matrix is derived from equation 2.2, assuming constant technical coefficients :

$$\left(I - A^k\right)^{-1} \Delta Y^k = \Delta X \tag{2.3a}$$

$$\Leftrightarrow \widehat{X}^{-1} \left(I - A^k\right)^{-1} \Delta Y^k = \widehat{X}^{-1} \Delta X$$

$$\Leftrightarrow \widehat{X}^{-1} \left(I - A^k\right)^{-1} \Delta Y^k \left(\Delta Y^{k^{-1}}\right)^t \widehat{Y}^k = \widehat{X}^{-1} \Delta X \left(\Delta Y^{k-1}\right)^t \widehat{Y}^k \tag{2.3b}$$

Where $\widehat{}$ denotes the diagonalization of the corresponding vector and superscript t the matrix transpose.

12. Providing the backward linkage of a given sector with reference to the interrelations of the whole economic system is an issue that was raised after Albert Hirschman came with his unbalanced growth strategy theory, and the attempts that were undertaken to test it. It was found necessary to weight the degree of linkage of each industry, with reference to the total degree of interdependence of all industries, in order to allow interindustry comparisons in between countries. It is well discussed by Laumas (1976) who warns about the same-sectoral-weight hypothesis on which is based the considered reference work of Yotopoulos and Nugent (1973) on Hirschmanian linkages.

By definition the "production-elasticity of final use" is given by :

$$\epsilon_{xy} = \frac{\Delta X}{\Delta Y^k}\frac{Y^k}{X}$$

Adapted to the use of vectors and matrices, the formulation becomes :

$$\epsilon_{xy} = \left(X^{-1}\right)^t \Delta X \left(Y^k\right)^t \Delta Y^{k-1}$$

Its disaggregated form is obtained diagonalizing the final use and output vectors.

$$\bar{\epsilon_{xy}} = \widehat{X}^{-1}\Delta X \left(\Delta Y^{-1}\right)^t \widehat{Y} \tag{2.4}$$

Thus, simplifying the left hand side term of the equation and replacing the right hand side one with the expression of "production-elasticity of final use", equation 2.3b becomes :

$$\bar{\epsilon_{xy}} = \widehat{X}^{-1}\left(I - A^k\right)^{-1}\widehat{Y}^k$$

Element $\bar{\epsilon_{ij}}$ of sensitivity matrix $\bar{\epsilon_{xy}}$ corresponds to the percentage increase in output in the product of branch i involved by an increase of 1% in final use in the characteristic product of branch j. Therefore, multiplying matrix element $\bar{\epsilon_{ij}}$ by the total output of branch i provides the required sectoral increase in production that will serve as input to allow an 1% increase in final use in the characteristic product of branch j.

2.3.2 Linking CO_2 emissions with backward linkages

2.3.2.1 The central model of input-output analysis

Central model The specific static input-output model of Leontief is derived from the more general *central model of input-output analysis* (Eurostat, 2008a). From a demand perspective, the central model generalizes the analytical capacity of input-output analysis to other variables than output (i.e. variable X in equation 2.1). These variables can either be endogenous or exogenous (see section 2.3.2.2). Direct and indirect impacts of final use/demand on these other economic variables can thus be considered. The general form of the central model is given in equation 2.5.

$$Z = b\left(I - A\right)^{-1}\widehat{Y} \tag{2.5}$$

Where b is either the *(1 ;N)* row vector of input coefficients of a given economic variable of interest (variable B), or its *(N ;N)* diagonalized form. Z is the variable gathering the direct and indirect impacts involved by final demand, here diagonalized vector $\widehat{Y}(N;N)$. It is either a *(1 ;N)* row vector (b being a vector), in which case both direct and indirect impact are summed up, and element z_j is the impact of final demand in product j on variable b of branch j. Or Z can be a *(N ;N)* matrix (b being a matrix - i.e. the above mentioned diagonalized vector), in which case direct and indirect impacts are disaggregated ; element z_{ij} is the impact on variable b of branch i, resulting from final demand in product j.

Remark Note that the sensitivity matrix of the economic system that has been evoked in section 2.3.1 underlies all variants of the central model, as they are linked through variable B, be it endogenous or exogenous. Indeed, $b(1;N) = B(1;N)\ \widehat{X}^{-1}(N;N)$ [13], which involves that equation 2.5 can also be re-written as follows :

$$Z = B\ \widehat{X}^{-1}(I-A)^{-1}\ \widehat{Y}$$
$$\Leftrightarrow Z = B\ \epsilon_{xy}$$

Satellite analysis Satellite analysis has been developed to expand the field of analysis from symmetric input-output tables. Its purpose is to go beyond the concept of production and to include social and environmental specific concepts. In this respect, the social accounting matrix and national accounting matrix including environmental accounts (NAMEA) frameworks have been developed following the same classifications of the traditional central framework of national accounts, which allowed integrated analysis through the central model. Combining NAMEA data with SIOT therefore enables to develop environmental input-output models (eIOT) [14]. Especially, it makes possible the determination of all “scopes” of CO_2 emissions activated by final demand.

2.3.2.2 The eIOT model for EU 27 CO_2 emissions

The central model can be split into several categories called re-attribution models (Moll et al., 2007), depending on whether the variable of interest is endogenous or exogenous. Endogenous variables are part of the symmetric input-output table (e.g. value added, imports) as opposed to exogenous variables which are not. Typically the latter have other units than monetary ones, among them environment related variables such as CO_2 emissions. Direct and indirect impacts on an exogenous variable are therefore referred to as

13. Or $b(N;N) = B(N;N)\widehat{X}^{-1}(N;N)$
14. Environmental input-output models enter the framework of environmentally extended input-output Analysis (EE-IOA), which was first developed by Leontief (1970) in order to analyze air pollution in the United States.

joint products. A re-attribution model of the EU 27 CO_2 emissions exogenous variable is introduced in this section.

Domestic activity related CO_2 emissions As our first interest lays in the production of CO_2 emissions within the EU 27 boundaries, final use of domestic activities is considered only, leaving imported products that are either used as intermediate products or for final consumption aside (nonetheless, superscript d is not indicated in subsequent equations in order to lighten the writing). Emissions are the variable of interest of the central model. Using equation 2.5, the domestic re-attribution model writes :

$$Em^t = e^t \ (I - A)^{-1} \ \widehat{Y} \tag{2.6}$$

Where e^t is the transpose of the CO_2 emissions intensity by branch vector. It is obtained dividing sectoral CO_2 emissions (vector E) by sectoral output (vector X). Em^t is the transpose vector of re-attributed EU 27 CO_2 emissions to final demand by product. Said differently, given sectoral CO_2 intensity (vector e^t) and sectoral interrelations embodied by the Leontief inverse matrix, vector Em provides final demand CO_2 content. Vector Em provides the impact *magnitude* and thus the weight of sectoral demand on the whole productive system. It also embeds sectoral direct and indirect emissions of final demand, hence the *location* of sectoral final demand CO_2 content. In order to disaggregate sectoral direct and indirect contributions of final demand, vector e is diagonalized (equation 2.7).

$$\bar{Em} = \widehat{e} \ (I - A)^{-1} \ \widehat{Y} \tag{2.7}$$

Where element $\bar{Em}_{ij}$ of matrix $\bar{Em}(N; N)$ corresponds to the CO_2 emissions stemming from branch i for the production of inputs for branch j. The re-attribution model thus provides the CO_2 emissions content of final demand (through vector Em) and its structure (through matrix $\bar{Em}$).

Remark Under the final demand perspective, total emissions that are re-attributed to final demand for a characteristic product of a given branch may either be greater or smaller than total emissions of the branch. Indeed :

A characteristic product may require inputs from other branches, involving indirect CO_2 emissions, and be dedicated to final consumption only. In this case total re-attributed emissions to final demand are greater than total emissions of the branch.

A characteristic product may also require inputs from other branches but may serve as an intermediary product primarily. In this case, most of total emissions of the considered branch cannot be re-attributed to final demand, and total re-attributed emissions to final demand are therefore lower than total emissions of the branch.

Hence, and this will be illustrated in section 2.3.4.3, not only should indirect emissions be considered to assess the real impact of growth (measured by final demand variation), but also, total emissions of a branch should be manipulated with caution as a share of it actually constitutes indirect emissions of final demand for products of other branches. The components of re-attributed emissions thus depend on the prism of the study. In this sense, what is referred to as scopes 1, 2 and 3 in the remainder of the chapter is different from the definition provided by GHG Protocol. Indeed, for a given product, scope 1 will refer to the share of re-attributed emissions to final demand that stem from the branch of the considered product. Scope 2 will refer to those that stem from the power branch and scope 3 to those that stem from remaining sectors (note that when considering energy products, scopes 1 and 2 correspond to the same scope) : they are emission scopes associated to final demand, whereas GHG protocol defined emission scopes associated to production.

Sectoral sensitivity of EU 27 CO_2 emissions to final demand The re-attribution model is extended with the introduction of the "elasticity" concept, evoked in section 2.3.1, in order to assess the sectoral CO_2 emissions sensitivity to final demand variation by product. It is based on a revisited version of the methodology that Alcántara and Padilla (2003) have developed to assess the changes induced by an increase by sector of energy final use on the final energy consumption of the Spanish economy in 1995. It is revisited in the sense that they assess the direct and indirect impacts of a 1% variation of final demand share in its respective sectoral output [15]. In the present section, it is the impact of a 1% variation of final demand by branch that is assessed, which better fits the definition of elasticity. Nonetheless, the model is still demand-oriented as it uses input coefficients [16].

Assuming constant CO_2 emission intensities, and diagonalizing the vector of CO_2 intensity by branch equation 2.3a becomes :

$$\Delta E = \widehat{e}\ (I - A)^{-1}\ \Delta Y \tag{2.8}$$

15. The share, as defined by Alcántara and Padilla (2003), is given by $s = \widehat{X}^{-1}Y$.

16. Alcántara et al. (2006) also developed a re-attribution model involving CO_2 emissions of Spain in 1995, but from a supply perspective in order to assess forward linkage (i.e. using output coefficients). Supply-oriented models have hardly been used in the literature as they lack proper theoretical grounds (Eurostat, 2008a). Further they require no oversupply issues and thus assume that supply creates its own demand.

Then, it directly comes :

$$\widehat{E}^{-1}\ \Delta E\ \left(\Delta Y^{-1}\right)^t\ \widehat{Y} = \widehat{E}^{-1}\ \widehat{e}\ (I-A)^{-1}\ \Delta Y\ \left(\Delta Y^{-1}\right)^t\ \widehat{Y}$$
$$\Leftrightarrow \bar{\epsilon_{ey}} = \widehat{E}^{-1}\ \widehat{E}\ \widehat{X}^{-1}\ (I-A)^{-1}\ \widehat{Y}$$

Finally, and as mentioned in the section introducing the central model[17] :

$$\begin{aligned}\bar{\epsilon_{ey}} &= \widehat{X}^{-1}\ (I-A)^{-1}\ \widehat{Y} \\ &= \bar{\epsilon_{xy}} \\ &= \bar{\epsilon}\end{aligned}$$

Element $\bar{\epsilon_{ij}}$ therefore provides the variation (in percentage) in CO_2 emissions of branch i following a 1% increase in final use in the product characteristic of branch j. As previously mentioned in the case of output sensitivity, multiplying element $\bar{\epsilon_{ij}}$ by 1% of direct emissions of branch i and summing the elements of a same column provides the total increase in CO_2 emissions involved by the final use increase in the product characteristic of branch j (equation 2.11) ; which allows revealing the impact (in tons of CO_2) on the EU 27 total emissions.

$$\Delta Em = \Delta E\ \bar{\epsilon} \tag{2.11}$$

Where ΔE is the row vector of sectoral emissions 1% variation.

Summary The model introduced in the above section enables the re-attribution of emitted CO_2 to the final use of a characteristic product of a branch. These CO_2 emissions,

17. This could have been also derived directly from the hypothesis of constant CO_2 intensities and the definition of demand "elasticity" of CO_2 emissions. Indeed, by definition :

$$\bar{\epsilon_{ey}} = E^{-1}\Delta E\left(\Delta Y^{-1}\right)^t\widehat{Y}$$

Output and CO_2 emissions are linked by emission intensity. Therefore, assuming constant emission intensities :

$$\begin{aligned}\Delta E &= \widehat{e}\ \Delta X \\ \widehat{E}^{-1} &= X^{-1}\ \widehat{e}^{-1}\end{aligned}$$

Substituting in demand "elasticity" of emissions, we obtain :

$$\bar{\epsilon_{ey}} = X^{-1}\ \widehat{e}^{-1}\ \widehat{e}\ \Delta X\ \left(\Delta Y^{-1}\right)^t\ \widehat{Y}$$
$$\bar{\epsilon_{ey}} = X^{-1}\ \Delta X\ \left(\Delta Y^{-1}\right)^t\ \widehat{Y} = \bar{\epsilon_{xy}} = \bar{\epsilon}$$

re-attributed to final demand, gather part of total emissions of a branch (measured in situ) - which correspond to direct emissions of final demand, as well as indirect emissions of final demand. Only part of total emissions of a branch are included in final demand direct emissions as some of them are re-attributed as indirect emissions of final demand in another branch product. Indeed, they are activated by the production of a given product to be used as input for another branch and are thus not dedicated to final use of this given product. The re-attribution to final demand model thus provides two major insights : the magnitude of re-attribution (i.e. how final demand emissions differ from in situ emissions - or production emissions) and its location (i.e. how final demand emissions are split in between scopes). Finally, the "elasticity" (or sensitivity) matrix also provides the re-attribution of CO_2 emissions to final demand with reference to total output.

2.3.3 Data presentation

Two types of data are used : symmetric input-output tables that have been described above in section 2.2.2, and EU 27 CO_2 emissions that are described below.

2.3.3.1 Eurostat CO_2 emissions

Eurostat CO_2 emissions correspond to emissions of production activities, that is, activities classified under the NACE classification. Emission data are available in both revisions (1 and 2), but only revision 1 is used (i.e. *env_ac_ainah_r1* database[18]) since EU 27 SIOT are available in NACE rev. 1 only. They are from the Eurostat Air Emissions Accounts. As such, they are net residual flows : they are CO_2 emissions crossing what is referred to as the *system boundary*. In other words CO_2 emissions going from the economy system to the environment system, and thus released into the atmosphere[19] (Eurostat, 2009). Air Emissions Accounts are updated every two year by Eurostat by sending electronic questionnaires to national statistics institutes. About thirteen air emission types are recorded (among which CO_2) by economic activity. The productive system is disaggregated at the NACE two-digit level (i.e. at the division level), which enables to organize the data at the 6-branch and at the 7-branch level. The data is expressed in thousand tons of CO_2. In 2007, CO_2 emissions from EU 27 NACE activities amounted to 3,535,519 thousand tons (table 2.4).

18. The database is available at *http : //epp.eurostat .ec.europa.eu/portal/page/portal/environmental accounts/data/database.*

19. Total residuals from the economy system are referred to as gross amount. Some of it is further processed and transformed in the system, and is thus not released into the atmosphere.

TABLE 2.4: EU 27 NACE activities CO_2 emissions in 2007 (thousand tons of CO_2)

Branches	P1	P2a	P2b	P3	P4	P5	P6
	89,425	1,135,112	1,435,003	64,296	618 ,614	64,831	128,237

Source : the author from Eurostat

TABLE 2.5: EU 27 Leontief inverse matrix in 2007

	P1	P2a	P2b	P3	P4	P5	P6
P1	1.16	0.05	0.01	0.02	0.02	0.01	0.01
P2a	0.38	1.60	0.32	0.44	0.23	0.11	0.14
P2b	0.05	0.05	1.27	0.02	0.03	0.02	0.02
P3	0.02	0.02	0.04	1.24	0.03	0.04	0.02
P4	0.19	0.24	0.14	0.18	1.28	0.10	0.10
P5	0.19	0.26	0.20	0.26	0.29	1.35	0.18
P6	0.03	0.03	0.04	0.02	0.03	0.03	1.08
Output multiplier	2.02	2.25	2.03	2.19	1.90	1.65	1.55
Of which (in %)							
Direct	57	71	63	57	67	82	70
Indirect	43	29	37	43	33	18	30

Source : the author from Eurostat

2.3.4 Results : direct and indirect effects disentanglement

2.3.4.1 Backward linkage of the power and other industrial sectors

The Leontief inverse matrix of the EU 27 in 2007 is provided in table 2.5. It serves as the basis for a description of sectoral interrelations and their impacts on output and CO_2 emissions with final demand variation. Last row of table 2.5 provides the backward linkage or output multiplier involved by a variation of one unit of final demand in a given product on the whole productive system. Backward linkage is composed of the direct (production of the product in which final demand increased) and indirect (production of other products that are required as inputs for the production of the product in which final demand increased) effects, which constitute the "production recipe". In other words, the Leontief inverse matrix "starts at the end of the production process, with an increase in final demand, and traces the effect backward through the system" (Jones, 1976).

Three groups of branches can be distinguished in terms of output multipliers. Branches P2a and P3 have the greatest ones (2.25 and 2.19 respectively). The increase of one unit of

TABLE 2.6: EU 27 CO_2 multipliers in 2007

Product	P1	P2a	P2b	P3	P4	P5	P6
CO_2 multiplier (t CO_2/M Euro)	449	431	3,074	205	280	89	133

Source : the author from Eurostat

final demand in other industrial sectors product requires an increase in output of more than 2 units from the productive system. Branches P1, P2b and P4 have intermediate values (2.02, 2.03 and 1.90 respectively ; the multiplier effect of the power sector is equivalent to that of the primary sector branch) ; and last two services branches, P5 and P6, have the lowest values (1.65 and 1.55 respectively). Leaving services branches (P4, P5 and P6) aside, direct effects are stronger in the industrial branch. This shows that interrelations for branch P2a occur within the branch mostly. This result should not come as a surprise since branch P2a gathers all divisions of both the mining and quarrying and manufacturing sections of the NACE classification. The fact that direct backward linkage of branch P2a reaches 71%, making it a more isolated branch than others, does not imply that its internal divisions hold such high direct backward linkage as well. And, as a matter of fact, going down to the 59-branch disaggregation shows the degree of interrelations occurring between these divisions (appendix 2.C of this chapter). The observed maximum direct backward linkage in the manufacturing section (i.e. section D) reaches 59%, making branch P2a a highly interdependent branch at least more than the power sector is (i.e. 63%). With regards to indirect backward linkage, the industrial branch represents the second largest input of other branches (not considering services ones). This involves that variations of final demand in the product of any branch will have an impact on the industrial branch output.

Backward linkage and CO_2 emissions in the EU 27 The fact that economic activities have different CO_2 contents changes the relative magnitude of the impact of final demand on CO_2 emissions compared to its effect on output. Data availability allows to determine EU 27 CO_2 emissions per unit of output at the 7-branch disaggregation level in 2007 (table 2.13 in appendix 2.D of this chapter). The amount of induced CO_2 emissions following an increase in final demand of one unit is given by equation 2.8 (ΔE). Results are provided in table 2.6 and should be read as follows : an increase by one unit in final demand in branch P1 product involves an increase of 449 tons of CO_2 in the EU 27. Despite its greater gross value added, branch P2b has, by far, the greatest CO_2 intensity of output (as

Table 2.7: Final demand sensitivity of EU 27 output and CO_2 emissions in 2007

Product	P1	P2a	P2b	P3	P4	P5	P6
Sensitivity of EU 27 output	0.012	0.287	0.015	0.118	0.208	0.158	0.210
Sensitivity of EU 27 CO_2 emissions	0.018	0.365	0.168	0.072	0.204	0.054	0.119

Source : the author from Eurostat

reported in table 2.13). Given that its output multiplier is similar to that of branch P2a and of others, CO_2 emissions backward linkage is more than seven times larger for branch P2b (3,074 tons of CO_2 compared to 431 for the branch of other industrial sectors).

2.3.4.2 Final demand *Elasticity* of CO_2 emissions in the EU 27

As mentioned above, the sensitivity matrix is the same whatever the variable of interest of the re-attribution model is. Nonetheless, final use variation by product is expected to have a different impact on total CO_2 emissions than it has on total output, since branches have different emissions to value added ratios as suggested in appendix 2.D.

As described in section 2.3.1, backward linkage is inserted in the context of the whole productive system with the use of the sensitivity matrix[20]. Combining it with the relative weight of each branch in EU 27 total output (i.e. matrix product $\frac{X^t\ \bar{\epsilon}}{X}$, where X at the denominator is total EU 27 output scalar) provides the total output percentage variation for a 1% variation in the use of a given product. Results are given on second row of table 2.7. It shows that an increase in final use of aggregated industrial products involves a greater impact on the EU 27 total output than the power sector. This is due to the large share in EU 27 total output of the former, despite the large output multiplier of the latter[21]. The fact that output is expressed in monetary value rather than physical output accounts for high value added divisions to be among those that have the greatest impact on total output. As a consequence two of the most emitting sectors in the EU ETS, namely the manufacture of other non-metallic minerals (D26) and basic metals (D27) are not among the ten divisions affecting the EU 27 output the most (see appendix 2.F).

The increase in total CO_2 emissions involved by a final demand increase of 1% in a

20. Matrix $\bar{\epsilon}$ at the 7-branch disaggregation level is provided in appendix 2.E of this chapter.
21. The picture is more balanced, and the power sector (branch P2b) appears as one among the NACE divisions having the most influence on the productive system output, when considering the 59-branch disaggregation level (appendix 2.F of this chapter).

branch product is then obtained combining the row vector of CO_2 emission multipliers (given in table 2.6) with the amount corresponding to a 1% increase of final demand of the associated product (i.e. $\frac{E^t\ \bar{\epsilon}}{E}$, where E at the denominator is total EU 27 emissions scalar). Results are provided on third row of table 2.7. As with output, using the sensitivity matrix tempers the large value of CO_2 emissions induced by a one unit final demand increase of branch P2b product, as it is now the impact of a change in 1% in final demand in a given product on total EU 27 CO_2 that is measured. It is showed that although the production of branch P2a is less intensive in carbon dioxide, the large size of the branch (in terms of output) involves that a variation of 1% of final demand in its products has a twice as large impact (0.365%) on the EU 27 CO_2 as branch P2b (0.168%).

2.3.4.3 Re-attributing CO_2 emissions to final demand

Above section dealt with the CO_2 multiplying effect of the EU 27 productive system, induced by final demand. This result is enriched by the use of the re-attribution model that provides the emission content of final use (magnitude) as well as its split between indirect and direct emissions (location). This further illustrates the impact of existing interrelations in between sectors.

The first form of the CO_2 emissions re-attribution model (equation 2.6) is used at the 7-branch disaggregation level in order to determine the amount of CO_2 that are embodied in final demand of a given product (i.e. the *magnitude* of re-attribution). This amount includes emissions of scopes 2 and 3 of final demand, added to the share of those of the branch measured in situ, that actually serve the production of the demanded product (and which correspond to scope 1 emissions of final demand). Three groups of branches emerge : those with lower final demand emissions than branch (or measured in situ) emissions (branches P1 and P2b), those with slightly greater (branches P2a and P4), those with several times their measured emissions as final demand emissions (branches P5 and P6, i.e. the activities of services), as reported on last row and last column in table 2.8. Second form of the re-attribution model (equation 2.7) details the *location* among branches of the CO_2 emissions re-attribution as reported in table 2.8.

The focus is made on the industrial and energy branches (P2a and P2b) corresponding to the non-power and power sectors of the EU ETS, which have two opposed patterns. On the one hand, final demand of products from the branch of other industrial sectors is attributed more (14%) CO_2 emissions than those stemming from the branch. On the other hand, final demand for energy products is much less (two and a half) intensive in CO_2 than

TABLE 2.8: Final demand re-attributed CO_2 emissions in 2007 (Mt CO_2)

	P1	P2a	P2b	P3	P4	P5	P6	Measured in situ
P1	34	34	1	5	8	2	5	89
P2a	9	811	10	93	100	39	73	1,135
P2b	15	340	580	69	175	81	175	1,435
P3	0	2	0	54	2	3	3	64
P4	3	92	3	29	423	28	41	619
P5	0	9	1	4	9	35	7	65
P6	0	3	0	1	3	2	119	129
Final demand	62	1,292	596	254	720	191	422	3,536

Source : the author from Eurostat

the branch is. This explains the lower impact of power sector final use increase on EU 27 total emissions despite its greater CO_2 intensity of output : most of its produced emissions are actually related to the activity of other sectors and the final demand of their products. This result should not come as a surprise as the power sector is an energy provider to the other productive sectors of the economy - branch P2a mostly. Furthermore, final demand of energy products does not involve much of indirect (here scope 3) emissions as direct emissions contribute 97% of its re-attributed emissions. With regards to branch P2a, 71% (811 out of 1,135 Mt CO_2) of its measured in situ emissions are related to the production of its own characteristic product to satisfy final demand. Furthermore, the branch requires more input from other branches and thus activates more indirect emissions than branch P2b (37%, i.e. 481 out of 1,292), which illustrates, even at the 7-branch disaggregation level, its CO_2 emissions interrelations with the rest of the economy. This interrelation is even more obvious when detailing the P2a branch at the NACE division level (appendix 2.G of this chapter). Indeed, the share of indirect CO_2 emissions, among the 28 divisions that the branch is composed of, reaches 70% on average with a median of 79% (minimum and maximum being 5% and 93% respectively).

2.4 Sectoral interrelations impact on EU ETS CO_2 emissions

2.4.1 Interrelations through the prism of the EU ETS scope

The EU ETS perimeter encompasses production activities as defined in the first appendix of the ETS Directive. These activities do not follow any sectoral classification and there exists thresholds for inclusion into the perimeter. Hence, for two installations performing identical activities, one may be included in the ETS while the other one may not, the former being above considered capacity of production thresholds and not the latter. Such thresholds have been introduced in order to reduce administrative complexity and costs for small installations. This calls for two comments. First one concerns the ETS coverage partial character, which leaves the possibility for a large aggregate of CO_2 emissions not to be covered by the ETS, as resulting from the sum of little installations that are not subject to comply with ETS rules[22]. Second, the direct implication of the ETS coverage partial character is the possibility for carbon leakage inside the EU 27 (later referred to as domestic carbon leakage). Carbon leakage consists in the withdrawal from regulated to unregulated areas of CO_2 emission sources. Carbon leakage reduces the efficiency of the emission mitigation policy originally set in the regulated area, since the emitter is not encouraged to reduce its emissions anymore. Carbon leakage may even counterbalance the mitigation policy effects should the unregulated area have a greater CO_2 intensity than the regulated one before the implementation of the mitigation policy. So far, the emphasis was put on the relocation of production activities outside the EU 27 that the implementation of the EU ETS would cause, and on the solutions that were put forward to reduce it, such as attributing free of charge emissions quotas to installations[23]. On the contrary, little has been said on domestic carbon leakage, that is on production activities that would be withdrawn for the ETS perimeter as perimeter inclusion thresholds would enable it. Yet, assuming free capital circulation and no return to scale (i.e. ignoring structural diversity within a given sector), potential for domestic carbon leakage exists as soon as CO_2 emissions of a given sector are split between being covered and not being covered under the Scheme. Therefore the potential for domestic carbon leakage would correspond to the

22. Such installations should be distinguished from those that have the possibility to opt out of the Scheme, because they recorded CO_2 emissions below 25 thousand tons, under the condition that they commit to achieve equivalent emission reductions.

23. Chapter 4 comes back on this topic with a focus of free allocation to non-power installations in Phase 3 of the EU ETS.

totality of CO_2 emissions of concerned sectors being withdrawn from the coverage of the Scheme. Of course, the above mentioned assumption is extreme and reality lays between free circulation of capital and sectoral full rigidity ; still enabling domestic carbon leakage.

Given the partial scope of the EU ETS, the dynamics of CO_2 emissions activated by final demand within the market may be different from when considering the whole EU 27 economy. Said differently, conclusions from observing the sectoral EU 27 emissions dynamics, as provided in previous section 2.3, may not be extrapolated to the EU ETS. Therefore, branches and parts of branches that enter the scope of the Scheme only are scrutinized according to the same re-attribution and sensitivity methodology. The combined use of the re-attribution model and of the sensitivity matrix under the prism of the EU ETS perimeter allows to differentiate the impact of final demand on the EU 27 CO_2 emissions, and those covered under the EU ETS. Hence, the objective is not to quantify domestic carbon leakage as data temporal dimension is reduced to one single observation, nor is an arbitrary sectoral rigidity threshold defined. The aim of the section is rather to quantify the partial EU ETS coverage at the sectoral level and its implication in terms of CO_2 emissions covered under the Scheme and activated by final demand. This section thus enlightens on the existence of potential domestic carbon leakage.

2.4.2 Linking the EU ETS scope with eIOT

Re-attribution and sensitivity analysis The shares of EU 27 emissions covered under the EU ETS by NACE divisions, are obtained comparing EU 27 emissions with EU ETS verified emissions for year 2007. This latter dataset is described below, in the second paragraph of this section. Let S_{in} be the shares of EU 27 emissions covered under the Scheme. Final demand sensitivity of EU 27 CO_2 emissions (given in table 2.7) can be split by ETS inclusion following equation 2.12 (as a reminder, superscript t indicates the vector transpose).

$$\bar{\epsilon}_{in} = \frac{1}{E} \; S_{in}^{t} \; \widehat{e} \; \widehat{X} \; \epsilon \tag{2.12}$$

The location (with regards to ETS inclusion) of CO_2 emissions re-attributed to final demand is derived from the re-attribution matrix (equation 2.7) and the share of EU 27 CO_2 emissions stemming from NACE activities that are covered under the Scheme (equation 2.13).

$$\bar{Em}_{in} = \widehat{S}_{in} \; \bar{Em} \tag{2.13}$$

TABLE 2.9: EU 27 CO_2 emissions covered under the EU ETS in 2007

Branches	P1	P2a	P2b	P3	P4	P5	P6	Total
Mt CO_2	0	745	1,382	0	< 1	0	27	2,154
%	0	66	96	0	< 1	0	21	61

Source : the author from Eurostat and CITL

Where $\widehat{S}_{in}$ is the diagonalized form of vector $S_{in}(1;N)$ above mentioned.

Finally, in order to compare EU ETS emissions dynamics with that of EU 27 emissions, final demand sensitivity of EU ETS emissions is obtained replacing parameter E in equation 2.12 by the total of ETS emissions E_{in} (equation 2.14).

$$\bar{\epsilon}_{ets} = \frac{1}{E_{in}} \; S_{in}^{t} \; \widehat{e} \; \widehat{X} \; \epsilon \tag{2.14}$$

EU ETS emissions data EU ETS emissions correspond to verified emissions of each installation participating in the Scheme. In 2007, they amounted to 2,166 million tons. Emissions are reported in what used to be the Community Independent Transaction Log (CITL) and what is, since August 2012, the European Union Transaction Log (EUTL). Each installation is characterized by a number of fields that are well described, as well as the reporting process, by Trotignon and Delbosc (2008).

As mentioned in the previous section, the Commission has attributed a NACE code to EU ETS covered installation in 2009 (European Commission, 2010a). NACE code attribution is done at the class level (i.e. four-digit code). This available granularity can not be fully exploited though, as the Eurostat *env_ac_ainah_r1* database offers division granularity only (i.e. two-digit code), which is the level the analysis is done at. Also, due to the complexity of the carbon leakage assessment, some installations could not be attributed a NACE code. The sum of these installations' emissions represented about 12 million tons, or 0.5% of total EU ETS emissions. The EU ETS encompasses 61% of EU 27 emissions entering the scope of the NACE classification. Emissions from non productive activities such as households consumption are not included in the NACE classification : emissions from NACE activities represent a subset of total EU 27 CO_2 emissions, which amounted to 4,407 Mt CO_2 in 2007 (from above mentioned Eurostat *env_ac_ainah_r1* database). Removing CO_2 emissions with no NACE code, the coverage by branch of NACE emissions by the EU ETS is reported in table 2.9.

It can be observed that the EU ETS scope indeed targets industrial sectors. There is a slight coverage of sectors categorized under *Other services* (branch P6), which mostly

TABLE 2.10: Final demand sensitivity of EU 27 CO_2 emissions in 2007 (ETS/non ETS)

branches	P1	P2a	P2b	P3	P4	P5	P6
P1	.00/.10	.00/.10	.00/.00	.00/.01	.00/.02	.00/.01	.00/.01
P2a	.02/.01	1.50/.79	.02/.01	.17/.09	.19/.10	.07/.04	.14/.07
P2b	.04/.00	.93/.04	1.58/.06	.19/.01	.48/.02	.22/.01	.48/.02
P3	.00/.00	.00/.01	.00/.00	.00/.15	.00/.01	.00/.01	.00/.01
P4	.00/.01	.00/.26	.00/.01	.00/.08	.00/1.19	.00/.08	.00/.11
P5	.00/.00	.00/.03	.00/.00	.00/.01	.00/.03	.00/.10	.00/.02
P6	.00/.00	.00/.01	.00/.00	.00/.00	.00/.01	.00/.01	.07/.27
Total	.06/.12	2.43/1.22	1.60/0.08	.36/.36	.66/1.37	.30/.24	.68/.51

Source : the author from Eurostat and CITL

corresponds to the activity of sewage and refuse disposal services (NACE rev. 1 code O90). These services are related to manufacturing activities. On the one hand, the power sector (branch P2b) is well covered since 92% of its emissions enter the Scheme. Note that activity under branch P2b is larger than just the production of electricity, as it also includes the manufacture of gas as well as steam and hot water supply. This may be one explanation for the whole branch not to be entirely covered by the Scheme. On the other hand, only about two thirds of other industrial sectors (branch P2a) emissions are covered. Going at the 59-branch disaggregation level shows that almost all NACE divisions are concerned with this ETS/non-ETS coverage split (as reported in appendix 2.H of this chapter). In other words, the 66% average EU ETS coverage of the P2a branch does not result from sub-branches being totally included and other totally excluded from the EU ETS. This confirms, and is an illustration of, the fact that the perimeter of the Scheme is not defined by sector or activity, but rather obeys installed capacity or production thresholds inclusion criteria.

2.4.3 Results : potential domestic carbon leakage

Sensitivity : where do CO_2 emissions increases occur ? Final demand sensitivity of EU 27 emissions is differentiated by ETS inclusion. It is also disaggregated by branch in order to identify in which branches CO_2 emissions increases occur with final demand variation. Results are reported in table 2.10 [24], which is therefore a disaggregation of third row of table 2.7. Despite the fact that one third of attributed emissions to final use of P2a

24. Values are for a variation of 10% instead of 1% as in final demand sensitivity table 2.7.

branch product is outside the ETS, this aggregated branch product requires to activate the equivalent of 0.243% of EU 27 emissions within the ETS scope for an increase of 1% of final demand in its product, which corresponds to the greatest impact within the scope of the ETS. About 62% of this emission increase corresponds to direct (i.e. stemming from the P2a branch) emissions, remainder being indirect emissions, from scope 2 (i.e. branch P2b) exclusively. Final demand variation in branch P2b products has the second largest contribution to EU 27 emissions occurring within the EU ETS (0.160%). Although about one third lower than that of branch P2a, the contribution of the power sector appears exceptional as the sector weighted 2% only of the EU 27 output in 2007. High output CO_2 emissions intensity accounts for this, since 0.158% out of 0.160% corresponds to direct emissions.

Re-attributed CO_2 emissions Assuming that each branch through its consumption of output from other branches, involves a same proportion of ETS/non-ETS emissions (e.g. the CO_2 emissions resulting from the consumption, by any branch of branch P2a product occur within the boundaries of the Scheme for 66%) from these other branches, it is straightforward to derive the amount of ETS and non-ETS CO_2 emissions that are re-attributed to final demand. Results are provided in table 2.11, which is derived from further disaggregation by ETS scope of table 2.8.

On the one hand, most (95%) of CO_2 emissions that are attributed to final use of product of branch P2b are included in the EU ETS. Furthermore, of these 566 million tons of CO_2, 559 are direct emissions (i.e. measured in situ). On the other hand, only 67% of CO_2 emissions attributed to final use of branch P2a production (860 out of 1,292 million tons) fall under the EU ETS perimeter, with about the same direct/indirect emissions proportions inside and outside the ETS (532 out of 860 million tons, and 279 out of 431 [25]). All emissions from branches other than P2a and P2b occur outside the ETS. Although the EU ETS is meant to mitigate emissions from heavy industries, it is showed here that its fails to cover all branch P2a emissions scopes (production side) as well as about one third of CO_2 emissions re-attributed to final demand of the branch products, be it direct or indirect.

25. Note that, in 2007, the amount of avoided CO_2 thanks to imports and due to final demand in products from branch P2a is similar to the amount CO_2 occurring outside of the scope of the EU ETS and due to final demand in products from branch P2a. The former amount is estimated at 440 million tons, which is equivalent to the latter amount (i.e. 431 million tons). Appendix 2.I of this chapter provides the methodology to derive the former amount.

TABLE 2.11: Final demand re-attributed CO_2 emissions by ETS scope in 2007 (Mt CO_2)

	P1	P2a	P2b	P3	P4	P5	P6	Measured in situ
P1	34	34	1	5	8	2	5	89
ETS	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
non ETS	*34*	*34*	*1*	*5*	*8*	*2*	*5*	*89*
P2a	9	811	10	93	100	39	73	1,135
	6	*532*	*7*	*61*	*66*	*26*	*48*	*745*
	3	*279*	*3*	*32*	*34*	*13*	*25*	*390*
P2b	15	340	580	69	175	81	175	1,435
	14	*328*	*559*	*67*	*168*	*78*	*168*	*1,382*
	1	*12*	*21*	*2*	*7*	*3*	*7*	*53*
P3	0	2	0	54	2	3	3	64
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	0	*2*	*0*	*54*	*2*	*3*	*3*	*64*
P4	3	92	3	29	423	28	41	619
	0	*0*	*0*	*0*	*0*	*0*	*0*	*1*
	3	*92*	*3*	*29*	*423*	*28*	*41*	*618*
P5	0	9	1	4	9	35	7	65
	0	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	0	*9*	*1*	*4*	*9*	*35*	*7*	*65*
P6	0	3	0	1	3	2	119	129
	0	*1*	*0*	*0*	*1*	*1*	*25*	*27*
	0	*2*	*0*	*1*	*2*	*1*	*94*	*101*
All scopes	62	1,292	596	254	720	191	422	3,536
	20	*860*	*566*	*128*	*235*	*104*	*242*	*2,155*
	42	*431*	*30*	*126*	*458*	*86*	*180*	*1,381*

Source : the author from Eurostat

How do increases compare in between scopes ? Previous paragraph has reported the impact of final demand by branch on EU 27 emissions, and where the impact was located, by branch and by ETS/non ETS scope. The sensitivity of EU 27 emission is now compared to that of EU ETS emissions following the same stimulus in final demand. Final demand sensitivity of EU ETS emissions is obtained weighting ETS emissions increases by total ETS emissions in 2007 (as given in equation 2.14). Results are reported in table 2.12.

Given the coverage of both P2a and P2b branches by the Scheme, final demand variation results in greater percentage changes of emissions in the EU ETS perimeter than in the EU 27 perimeter. Nonetheless, although final demand in branch P2a product still has the greatest impact of the emissions of the Scheme, the gap with that of final demand in branch

TABLE 2.12: Final demand sensitivity of EU ETS emissions in 2007

	P1	P2a	P2b	P3	P4	P5	P6
P1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P2a	0.00	0.25	0.00	0.03	0.03	0.01	0.02
P2b	0.01	0.15	0.26	0.03	0.08	0.04	0.08
P3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P6	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Total	0.01	0.40	0.26	0.06	0.11	0.05	0.11

Source : the author from Eurostat and CITL

P2b product is reduced (ratio of 1.5 in the ETS versus 2.2 when considering the EU 27). The independence of branch P2b emissions is accentuated when considering the ETS perimeter only, since emissions increase following final demand variation in the product of the branch is composed of direct emissions only. On the contrary 60% of activated emissions by final demand in branch P2a product belong to the first scope, and 40% belong to the second scope. Interestingly, and although not entering the Scheme, the consumption of products of activities of services (P5, P6), transport and telecommunication (P4) and construction (P3) activates CO_2 emissions within the Scheme.

2.5 Conclusion : the EU ETS perimeter in perspective

In this chapter, the impacts of economic activity on CO_2 emissions of the EU 27 and of the EU ETS have been assessed from a final demand perspective. The focus was put on both the power sector (branch P2b) and manufacturing sectors (branch P2a) as they are the main two sectoral aggregates of the EU ETS. Their respective contributions to emissions variations have been determined through the consumption, by final users, of their products. This has been done using both input-output analysis and one of its extensions, namely environmental input-output analysis.

The predominant role of branch P2a among other branches has been demonstrated and quantified. Indeed, under input-output analysis assumptions, both EU 27 output and CO_2 emissions are more sensitive to variations of final demand in the products of branch P2a. This is also the case when considering CO_2 emissions covered under the EU ETS. Two factors account for this result. First the relative sizes of both sectors in terms of output :

branch P2a, assimilated to the non-power sector, represents about one third of the EU 27 economy in terms of output. Second, branch P2a shows larger interrelations with the rest of the economy, which involves that final demand in its products activates larger indirect emissions than the power branch. Hence despite the fact that the non-power segment of the EU ETS is about twice as small as the power segment, ETS emissions vary more with final demand in industrial products that in products of branch P2b.

With regards to the EU ETS perimeter, the input-output analysis also unveiled the fact that final demand in products from branch P2a generated CO_2 emissions outside the scope of the Scheme, due to existing interrelations (indirect effects) and partial inclusion of branch P2a (direct effects). This suggested, under specific assumptions, the possibility for carbon leakage within the EU 27, referred to as domestic carbon leakage in this chapter, and therefore raises the question of the relevance of current EU ETS perimeter.

2.A Input-output analysis framework three tables

Below tables are developed for the primary, secondary and tertiary sectors of the economy.

Products \ Industries	Industries			Imports	Total
	Agriculture	Industry	Service activities		
Agricultural products Industrial products Services	Output by product and by industry			Imports by product	Total supply by product
Total	Total output by industry			Total imports	Total supply

(a) Simplified supply table

Products \ Industries	Industries			Final uses			Total
	Agriculture	Industry	Service activities	Final consumption	Gross capital formation	Exports	
Agricultural products Industrial products Services	Intermediate consumption by product and by industry			Final uses by product and by category			Total use by product
Value added	Value added by component and by industry						Value added
Total	Total output by industry			Total final uses by category			

(b) Simplified use table

Products \ Products	Homogeneous units of production			Final uses			Total use
	Agricultural products	Industrial prodcts	Services	Final consumption	Gross capital formation	Exports	
Agricultural products Industrial products Services	Intermediate consumption by product and by homogeneous units of production			Final uses by product and by category			Total use by product
Value added	Value added by component and by homogeneous units of production						
Imports for similar products	Total imports by product						
Supply	Total supply by homogeneous units of production			Total final uses by category			

(c) Simplified symmetric input-output table

FIGURE 2.1: Input-output analysis framework three tables

Source : Eurostat (2008a)

2.B EU 27 domestic SIOT in 2007

Values in the table below are reported in current million Euros.

	P1	P2a	P2b	P3	P4	P5	P6	F.C.E.	G.C.F.	Exp.	Total uses
P1	54	189	1	3	24	4	7	108	16	15	419
P2a	78	2,281	84	379	477	195	221	1,287	633	1,076	6,709
P2b	9	135	125	8	59	35	45	188	0	6	609
P3	3	32	14	345	48	111	46	51	1,182	3	1,835
P4	36	727	30	121	869	258	187	2,130	157	287	4,803
P5	27	628	46	189	731	1,264	352	1,612	312	223	5,383
P6	5	73	11	12	73	108	257	3,129	26	17	3,710
Imported products	12	625	61	43	141	102	66	307	173	137	1,667
Taxes less subsidies	6	63	9	18	80	90	1036	803	204	-25	1,352
Value added	191	1,958	203	719	2,300	3,218	2,426	-	-	-	-
Output at basic prices	419	6,709	556	1,835	4,803	5,383	3,710	-	-	-	-

Source : the author from Eurostat

2.C Backward linkage of divisions C and D of NACE rev. 1

Division	Output multiplier	Direct (%)	Indirect (%)
Section C*			
10	2.22	47	53
11	1.50	71	29
12	2.75	37	63
13	2.43	44	56
14	1.98	54	46
Section D			
15	2.46	50	50
16	1.96	53	47
17	2.20	55	45
18	2.12	51	49
19	2.31	55	45
20	2.31	55	45
21	2.30	54	46
22	2.13	54	46
23	1.91	59	41
24	2.21	57	43
25	2.22	50	50
26	2.18	52	48
27	2.35	57	43
28	2.23	53	47
29	2.24	51	49
30	2.17	55	45
31	2.22	53	47
32	2.06	57	43
33	2.01	53	47
34	2.60	53	47
35	2.39	53	47
36	2.22	47	53
37	2.33	47	53

Source : the author from Eurostat

*. Name and description of each division is provided in Eurostat (1996).

2.D CO_2 intensity of EU 27 branches

TABLE 2.13: EU 27 CO_2 intensity of output by branch

Branches	P1	P2a	P2b	P3	P4	P5	P6
Emissions (Mt CO_2)	89	1,135	1,435	64	619	65	129
Output (G Euros)	419	6,709	609	1,835	4,803	5,383	3,710
Intensity (t CO_2/M Euros)	213	169	2,356	35	129	12	35

Source : the author from Eurostat

Last row of table 2.13 corresponds to vector e in equation 2.6. The validity of CO_2 intensity figures is controlled by comparing the CO_2 emissions to gross value added ratio by branch derived from EU 27 SIOT and emission data to figures provided by Luksch et al. (2006). Figures from both methodologies[26] are compared in table 2.14 below.

TABLE 2.14: Sectoral CO_2 intensity of value added comparison (t CO_2/M Euros)

Branches	EU 15 (2000)	EU 27 (2007)
E	6,776	7,072
DF	4,335	4,222
DI	2,753	3,139
DJ	1,062	964
AB	790	469
C	638	613
All productive sectors	350	320

Source : Luksch et al. (2006) and the author from Eurostat

The proximity of CO_2 emissions to gross value added ratios of both datasets is the criterion to feel secure about the validity of the CO_2 to output ratios reported in table 2.13.

26. Luksch et al. (2006) has provided the CO_2 intensity of sectoral gross value added for the EU 15 in 2000 at the NACE rev. 1 section and subsection levels. Subsections inside a section correspond to groups of NACE divisions.

2.E Final demand sensitivity matrix of EU 27

Branches	P1	P2a	P2b	P3	P4	P5	P6
P1	0.38	0.38	0.01	0.05	0.09	0.03	0.06
P2a	0.01	0.71	0.01	0.08	0.09	0.03	0.06
P2b	0.01	0.25	0.39	0.06	0.12	0.06	0.12
P3	0.00	0.04	0.00	0.83	0.04	0.04	0.04
P4	0.01	0.15	0.00	0.05	0.68	0.04	0.07
P5	0.00	0.14	0.01	0.06	0.14	0.54	0.10
P6	0.00	0.02	0.00	0.01	0.02	0.02	0.93

Source : the author from Eurostat

Reminder : the sensitivity matrix is defined by :

$$\bar{\epsilon} = \widehat{X}^{-1} (I - A)^{-1} \widehat{Y}$$

2.F Final demand sensitivity of EU 27 output by division

The ten divisions that affect EU 27 output the most are reported in the table below.

NACE division	NACE code	Output increase (%)	Output share (%)
Construction work	F45	0.116	7.8
Food products	D15	0.054	3.7
Motor vehicle	D34	0.049	3.0
Machinery	D29	0.040	2.8
Chemicals	D24	0.027	2.8
Electrical energy	E40	0.014	2.4
Furniture	D36	0.013	0.8
Other transport equipment	D35	0.014	2.4
Coke (etc.)	D23	0.011	1.5
Fabricated metal products	D28	0.011	2.1

Source : the author from Eurostat

2.G Re-attributed EU 27 emissions of branch P2a divisions

Divisions	C10	C11	C12	C13	C14	D15	D16	D17	D18
C10	1,699	11	0	4	12	668	11	69	56
C11	7	3,252	0	6	20	1,143	19	117	105
C12	0	0	410	0	0	0	0	0	0
C13	0	1	0	168	1	41	1	4	4
C14	1	1	0	1	1,047	178	2	12	10
D15	1	2	0	1	3	59,839	27	58	83
D16	0	0	0	0	0	0	338	0	0
D17	0	1	0	0	1	178	9	8,237	2,268
D18	0	0	0	0	0	9	0	7	1,728
D19	0	0	0	0	0	13	0	4	38
D20	2	1	0	0	3	255	7	19	19
D21	3	5	0	2	14	3,364	228	194	206
D22	1	1	0	0	2	198	8	17	31
D23	22	38	1	18	11	5,571	83	441	468
D24	13	18	0	8	54	4,806	84	1,142	638
D25	2	2	0	1	5	746	9	52	66
D26	29	38	2	26	343	8,243	65	479	430
D27	50	65	1	57	75	3,974	74	484	432
D28	6	7	0	2	8	564	8	43	51
D29	4	3	0	2	7	243	5	26	25
D30	0	0	0	0	0	5	0	1	1
D31	1	1	0	0	1	72	1	8	8
D32	0	0	0	0	0	15	0	2	2
D33	0	0	0	0	0	15	0	2	2
D34	0	0	0	0	1	77	1	7	8
D35	0	1	0	0	0	28	1	5	8
D36	0	0	0	0	1	71	2	13	21
D37	0	1	0	1	1	69	2	16	10
Re-att.	2,529	4,926	432	680	3,215	208,323	3,059	22,183	16,330
Indirect (%)	33	34	5	75	67	71	89	63	89

Source : the author from Eurostat

Divisions	D19	D20	D21	D22	D23	D24	D25	D26	D27
C10	27	31	94	71	634	496	71	104	418
C11	51	48	120	125	6,738	1,686	146	125	247
C12	0	0	0	0	0	0	0	0	0
C13	2	2	8	6	122	65	8	15	185
C14	6	7	28	15	22	242	22	319	68
D15	284	15	43	58	76	613	47	22	43
D16	0	0	0	0	0	0	0	0	0
D17	180	9	47	29	25	160	80	15	24
D18	6	0	1	1	1	4	1	1	2
D19	1,377	1	1	2	2	6	2	1	2
D20	13	1,890	63	36	20	97	30	29	36
D21	137	93	11,415	2,435	171	1,344	261	151	231
D22	13	7	26	3,325	27	122	20	12	21
D23	234	230	373	525	67,691	7,312	648	522	1,140
D24	430	307	730	760	2,199	84,627	2,540	418	839
D25	91	21	52	60	75	386	3,086	36	57
D26	207	462	305	432	631	3,716	777	46,647	1,607
D27	258	324	445	731	1,035	3,567	1,105	717	60,047
D28	35	40	36	46	87	262	82	50	232
D29	12	13	26	29	48	134	35	29	64
D30	0	0	1	3	1	4	1	0	1
D31	5	4	7	12	18	50	12	9	24
D32	1	1	1	5	3	11	3	1	3
D33	1	1	1	3	6	22	3	1	5
D34	4	4	6	8	12	36	13	7	19
D35	2	1	3	5	7	23	4	2	7
D36	7	5	6	14	15	44	11	6	49
D37	4	4	46	19	17	62	29	19	387
Re-att.	8,129	8,433	25,544	20,568	96,815	159,283	18,939	59,910	84,870
Indirect (%)	83	78	55	84	30	47	84	22	29

Source : the author from Eurostat

Divisions	D28	D29	D30	D31	D32	D33	D34	D35	D36	D37	In situ
C10	198	486	24	129	61	77	515	121	146	0	15,322
C11	210	633	48	173	101	125	706	169	239	0	31,924
C12	0	0	0	0	0	0	0	0	0	0	413
C13	65	124	4	30	10	16	117	26	38	0	1,738
C14	50	121	6	36	19	31	131	27	51	0	6,302
D15	59	230	26	57	46	56	249	64	107	0	82,220
D16	0	0	0	0	0	0	0	0	0	0	346
D17	42	145	10	41	28	47	514	74	438	0	15,231
D18	2	7	1	1	1	1	9	3	3	0	1,965
D19	3	12	1	3	1	4	35	5	44	0	1,747
D20	77	193	11	43	26	39	235	94	1,180	0	8,819
D21	271	1,069	100	312	231	299	972	235	619	3	40,128
D22	34	143	16	36	34	38	160	44	63	0	8,079
D23	890	2,722	235	711	420	554	3,137	761	1,170	2	159,609
D24	953	2,972	263	962	606	799	4,553	829	1,581	2	152,909
D25	125	751	35	222	127	164	1,681	185	290	0	13,507
D26	1,805	5,196	322	1,822	1,297	1,906	8,163	1,435	2,061	2	267,464
D27	16,112	30,559	662	7,518	2,185	3,416	30,929	6,542	5,344	19	243,976
D28	5,402	2,441	56	349	143	269	2,040	497	370	1	20,324
D29	102	11,782	12	83	42	75	562	168	93	0	16,168
D30	2	7	472	4	5	3	7	4	2	0	643
D31	44	445	38	2,878	127	105	509	78	34	0	6,450
D32	6	53	41	36	1,554	51	56	28	9	0	2,336
D33	7	53	8	17	35	2,156	61	63	7	0	3,105
D34	31	198	5	31	13	25	13,049	45	42	0	15,208
D35	10	57	10	12	12	15	41	3,568	10	0	4,887
D36	34	136	6	24	14	35	326	44	9,102	0	11,739
D37	141	252	7	59	19	30	247	54	57	22	2,554
Re-att.	44,771	115,869	6,650	29,651	16,166	20,754	132,405	29,796	43,411	84	-
Indirect (%)	88	90	93	90	90	90	90	88	79	74	-

Source : the author from Eurostat

2.H ETS coverage of divisions C and D of NACE rev. 1

Division	Eurostat emissions (Mt CO_2)	ETS coverage (%)
C (section)		
10	15	46
11	32	54
12	< 1	8
13	2	29
14	6	19
D (section)		
15	82	30
16	< 1	30
17	15	8
18	2	3
19	2	0
20	9	34
21	40	102*
22	8	11
23	160	105*
24	153	33
25	14	21
26	268	92
27	244	66
28	20	13
29	16	6
30	1	46
31	7	115*
32	2	9
33	3	5
34	15	38
35	5	11
36	12	5
37	3	26
Total	1,135	66

Source : the author from Eurostat and CITL

*. Coverage above 100% can be explained by the fact that Eurostat and CITL emissions are monitored according to two different and independent methodologies. NACE code attribution to installations participating in the Scheme may also suffer from inconsistencies since installations may perform several on site activities.

2.I Imports and avoided CO_2 emissions

Methodology Imports reach final demand through two distinct canals. First one consists in the direct import of final products. Second one consists in imported products that serve as intermediate and thus are processed domestically [27].

The amount of CO_2 emissions that imported products would have involved had they been produced domestically, referred to as avoided emissions, are estimated using EU 27 CO_2 input coefficients (i.e. matrix A^d in equation 2.15 [28]) instead of abroad ones. Note that production mix of the EU 27 trade partners, hence real production CO_2 intensity of imports, are therefore ignored.

$$E^{avoid} = e^t \left(I - A^d\right)^{-1} M \tag{2.15}$$

Where row vector $E^{avoid}(1; N)$ indicates the amount of domestically avoided emissions by branch and M the *(N;1)* vector of imported products. Final demand re-attributed avoided CO_2 emissions are derived diagonalizing both vectors e and M (equation 2.16).

$$\bar{E}^{avoided} = \widehat{e} \left(I - A^d\right)^{-1} \bar{M} \tag{2.16}$$

Results Total imports represent 7% of the EU 27 output in 2007. Especially, manufactured products (product of branch P2a) account for 81% of total imports, whereas product from the power sector (branch P2b) only account for 0.5% of the total, which illustrates the local dimension of electricity production (see table 2.15).

Given the average structure of the EU 27 economy and the profile of its imports (manufactured products principally), avoided domestic CO_2 emissions amount to 664 million tons in 2007. This is equivalent to about 19% of the emissions of the EU 27 productive activities emissions (table 2.16), which illustrates the high CO_2 intensity of imports.

As a consequence of its regional production nature and its little EU 27 final demand in imported branch P2b product, little emissions would be activated by final demand should the product be domestically produced. With regards to branch P2a, final demand in its product would have activated 440 million tons of CO_2, which is equivalent to the amount of CO_2 activated by final demand in the same product that occur outside of the scope of the EU ETS.

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27. As a reminder, the domestic SIOT of the EU 27 gathers the transactions between branches only for intermediates that are domestically produced.

28. Equation 2.15 is derived from a methodology developed in (Lenglart et al., 2010), where the estimation of imported CO_2 emissions is also described.

TABLE 2.15: EU 27 SIOT of imports in 2007 (M Euros)

	P1	P2a	P2b	P3	P4	P5	P6	F.C.E.	G.C.F.	Exp.	Total uses
P1	3	19	0	0	2	0	1	13	2	1	40
P2a	8	555	56	34	72	35	44	257	162	121	1,344
P2b	0	1	4	0	0	0	0	1	0	0	7
P3	0	0	0	1	0	0	0	0	1	0	3
P4	0	14	1	1	42	8	4	13	0	5	88
P5	1	34	2	5	22	57	12	12	7	9	160
P6	0	2	0	0	2	1	5	11	1	1	25
Total imports	12	625	62	43	141	102	66	307	173	137	1,667

Source : the author from Eurostat

TABLE 2.16: Final demand re-attributed avoided CO_2 emissions in 2007 (Mt CO_2)

	P1	P2a	P2b	P3	P4	P5	P6	Measured in situ
P1	4	15	0	1	2	1	2	26
P2a	3	265	8	23	33	14	27	374
P2b	3	120	12	12	20	10	16	193
P3	0	1	0	0	0	0	0	1
P4	1	34	1	4	12	3	5	59
P5	0	4	0	0	1	1	1	7
P6	0	1	0	0	0	0	1	3
Total	12	440	22	41	70	30	51	664

Source : the author from Eurostat

3

Industry contribution to EU ETS emissions

3.1 Preliminary remarks

Because it has represented in the first two phases (2005-2012) more than two thirds of verified emissions in the European Union Emissions Trading Scheme (EU ETS), the power sector has been considered as driving most of the variations of total CO_2 emissions of the Scheme, and therefore as being price maker on the market. This rationale implicitly establishes an existing relation between contributing to CO_2 emissions level and driving emissions permit price. In the present chapter, this suggested link is further investigated. First, it is provided with theoretical grounds, which enables defining what the work hypothesis of the chapter is : *establishing the respective sectoral contributions to EU ETS emissions variations of economic sectors will provide insights on their respective impacts on carbon price dynamics.* Section 3.2 therefore justifies the switch from behavioral (econometric analysis) to accounting (decomposition analysis) models to assess the sectoral activity impact on carbon price. As a result, section 3.3 develops a two-factor decomposition model that enables to determine the respective contributions of activity levels of both power sector and non-power sector on the variations of EU ETS CO_2 emissions that have been observed since its implementation. Although required by the decomposition analysis, no ETS-specific activity indicators have been developed for these two sectors under consideration. Therefore, the chosen alternative consists in making use of activity indicators that match the activity perimeters of these sectors the most. Section 3.4 develops the methodology and the panel model that have been used to validate chosen Eurostat activity indicators as right proxies for EU ETS power and non-power sectors activity levels.

3.2 From emission permits price to emissions dynamics

This section aims at justifying the work hypothesis that the analysis conducted in the following sections of this chapter is based upon. To do this a three-step reasoning is undertaken. In section 3.2.1, the main determinants of carbon price dynamics are reviewed. This review underlines the existence and the identification of a statistically significant link between carbon price and a measure of activity level. Although the research that led to the identification of this relationship could be considered pioneer, it is suggested that richer and more insightful conclusions on the link between carbon price and sectoral activity levels in the EU ETS could be drawn, provided different materials such as verified emissions data are used. The objective of section 3.2.2 is to provide theoretical grounds to the assertion that the evolution of overall monitored CO_2 emissions level in the EU ETS is a relevant proxy for carbon price dynamics. Indeed, the corollary of this assertion is that studying the link between sectoral activity and emissions levels is insightful with regards to the existing one between sectoral activity levels and that of carbon price. Finally, section 3.2.3 reviews research works that explicit and quantify the main determinants of CO_2 emissions in Europe through different methodologies. As expected, they show that the level of activity (embodied by gross value added for instance) remains a key determinant in the evolution of CO_2 emissions levels.

3.2.1 Sectoral contribution to carbon price

Determining the empirical factors that have an influence on carbon price has constituted a segment of the research on the EU ETS functioning since its implementation. As an *ex post* analysis, each year has brought its cortege of findings on the subject, allowed by the available material that increases with time. Models based on econometrics have made an important contribution in the studies on carbon price determinants. A review of some of these research works is provided in Chevallier (2011). Carbon price drivers, having an impact on either (or on both) the demand and the supply of emission permits, have been categorized in three different kinds that are the macroeconomic environment, the specificity of market participants, and the EU ETS institutional framework. The results of these empirical analysis are in line with what Christiansen et al. (2005) had anticipated before the market was effective.

3.2.1.1 Market participant specificity : energy markets and weather events

Mansanet-Bataller et al. (2007) and Alberola et al. (2008a) have identified both energy prices and weather conditions as two carbon price determinants. More specifically, their driving effects are transmitted through their influence on both electricity supply and demand, which potentially involves large variations in either emission permits supply or demand. Indeed, CO_2 emissions related to the production of electricity and heat, represent the greatest share in the total emissions of the Scheme, as described in the introduction of the thesis. On the one hand, absolute values of energy prices (more precisely of coal and natural gas), and mostly their relative values, affect the CO_2 content of produced electricity through the process of fuel-switching (briefly described in appendix 3.A of this chapter). The total level of emitted CO_2 and associated need in emission permits are thus a function of energy prices, which may vary for a same amount of electricity production, therefore affecting carbon price in return. On the other hand, weather events, especially departures from seasonal average temperatures, principally affect electricity demand from final consumers, either for cooling or heating uses. Electricity supply (in terms of electricity CO_2 content) can also be affected by weather conditions as higher rainfalls allow higher carbon free electricity production (hydro electricity), lowering the induced demand in emission permits of power producers.

3.2.1.2 EU ETS institutional framework

Obviously the EU ETS institutional design is key in setting the level of carbon price and has been identified as having long term effects by Carraro and Favero (2009). Especially the banking restriction that has been introduced in Phase 1 (2005-2007), which forbade the use of Phase 1 emission permits in Phase 2. Hence, should the *ex ante* cap be higher than *ex post* verified emissions and the price would collapse by the end of the phase ; should it be lower and carbon price would equal the penalty cost (Ellerman, 2008) [1]. *Ex post*, Alberola and Chevallier (2009) use an econometric approach to show that banking restrictions from Phase 1 to Phase 2 could contribute in explaining carbon price dynamics in Phase 1. They also show that the level of free allocation entitled to installations, and more precisely their *ex post* net positions, could play a role on carbon price variations.

1. Emission permit price obeyed to the first mentioned pattern in Phase 1. Indeed, the price collapsed as soon as mid 2006, after first compliance exercise revealed that the overall cap in Phase 1 was obviously too large.

3.2.1.3 Macroeconomic environment

As illustrated in chapter 2, productive sectors of the EU 27 as well as those activities falling under the perimeter of the EU ETS are highly interrelated. The EU ETS is therefore affected by the wider economic context through its impact on production levels of covered installations. Using the Stoxx Euro 600 financial index [2] as a proxy for economic activity, Schumacher et al. (2012) find a significant and positive effect of the Index on carbon price dynamics. Going from financial indices to real production, Alberola et al. (2008b) have demonstrated the impact of sectoral production levels on carbon price dynamics. Using EU 27 aggregated level data, they show that three activities covered under the EU ETS (combustion, iron and steel production and pulp and paper production) have had an impact on carbon price variations over the July 1^{st} 2005 - April 30 2007 period ; this period of time including the first two compliance exercises of the first phase, in April 2006 and 2007. These industrial effects are embodied in a first econometric model specification by their respective production indices. In a second econometric model specification, the industrial effects are embodied by three different dummies that are a) the sectoral net positions over the two compliance exercises (verification of 2005 and 2006 CO_2 emissions), b) production peak defined as the variation of 1% in absolute value of the considered sector production index, and c) the cross-product of the latter two dummies. In the first model specification, their results suggest that the coefficient estimates for production indices of the three activities are statistically significant although showing negative (and unexplained) signs. In the second one, the three kinds of dummies are statistically significant for combustion, whereas only the production peak dummy is for the remaining two activities.

3.2.1.4 Concluding remarks : extending existing work

As written in its introduction, this article “opens the *black box*” of industrial production impact on carbon price, especially that of non-power sectors (here iron and steel production and pulp and paper production). Nonetheless, while the sectoral production impact on emission permits price is what is aimed at, the use of emission permits price time series may not be the most relevant. Indeed, as much as emission permits price observations are

2. From the STOXX company website : The STOXX Europe 600 Index is derived from the STOXX Europe Total Market Index (TMI) and is a subset of the STOXX Global 1800 Index. With a fixed number of 600 components, the STOXX Europe 600 Index represents large, mid and small capitalization companies across 18 countries of the European region : Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

widely available due to continuous spot and forward contracts quotation on exchanges[3], the greatest release frequency for sectoral activity level indicators is monthly at best. To go round this sectoral activity data scarcity, Alberola et al. (2008b) use a re-sampling function. Daily production indices of each activity are linearly interpolated from monthly values provided by Eurostat to match the number of emission permits price observations. Although production activity is unlikely to encounter discontinuities (extreme variation rates at a daily frequency), the accuracy of linearly interpolated daily production indices from monthly values is nonetheless questionable ; as well as the use of linearly interpolated points instead of observations for an econometric analysis that originally aims at establishing whether a link between empirical observations of different kinds can be established. Emission permits price observations should thus be limited and coincide with the frequency of industrial production observations (i.e. twelve annually).

The limited number of observations may prevent from using large sample properties and thus from deriving results based on statistical inference. In order to go round these issues, the combined use of another methodology (decomposition analysis) and another set of data (EU ETS installations verified emissions), to assess and quantify the sectoral production impact on emission permits price is adopted. This constitutes a move from the use of behavioral models (econometrics models) towards accounting models (decomposition analysis). Given above mentioned limits, accounting models address the data scarcity issue as they do not require specific statistical properties. However they introduce the need for the use of a quantity that can be derived from activity levels, which is the case of verified emissions data. Section 3.2.2 therefore attempts to show that emissions levels variations is a relevant proxy for emission permits dynamics.

3.2.2 Emissions level to proxy carbon price

It has been suggested that assessing sectoral contributions to the overall level of CO_2 emissions in the EU ETS would inform on carbon price dynamics. In this section, it is first showed how carbon price and emissions level are theoretically linked in a cap and trade system. A focus is then made on the exercise of market power in the EU ETS and on flexibility mechanisms introduced by the ETS directive, which have the potential to alter this link. The purpose of the present section is thus to demonstrate that emissions level is

3. Spot contracts were exchanged on the French platform Bluenext, in Paris, which has closed in December 2012. Forward contracts are currently traded on The Intercontinental Exchange (ICE) in London. The European Energy Exchange (EEX) is the platform that auctions allowances the most.

a relevant proxy for carbon price under specific assumptions on market power and how EU ETS flexibility mechanisms are used.

3.2.2.1 Carbon price formation in a cap and trade system

Carbon price formation In simplified terms, the basis for an elementary cap and trade scheme is that a market supervisor provides an emission cap (i.e. the maximum amount of emissions that can be released into the atmosphere) for a given perimeter of participants and over a given period of time. The supervisor then allocates (e.g. through auctioning, grandfathering, benchmarking) emission rights, which sum corresponds to the cap. These emissions rights can be traded among participants. In a neoclassical perspective, market participants are knowledgeable about their marginal abatement costs (the cost involved by the reduction of the first ton of CO_2 from a given emission level. Said differently, it is the cost of the abated last ton of CO_2). Hence, in a competitive market, the price of emission permits will result from what is referred to as the *Walrasian tâtonnement*[4], where market participants permanently perform an arbitrage between their marginal abatement costs and the carbon price that is announced by the market secretary (figure 3.1). Consequently this market mechanism is expected to be Pareto efficient and to reach the emissions level target, set by the supervisor, at the lowest costs.

What the carbon price tells At the market level, *ex post* carbon price thus represents the degree of the "overall allowance shortage - marginal abatement cost" combination involved by the *ex ante* cap and illustrated by the *ex post* level of emissions. If one considers a single period market with a unique compliance exercise at the end of the period, having *ex post* overall emissions below the cap involves that, independently of the allocation mode and of the marginal abatement cost curves of market participants, carbon price is null. In such situation, market participants do not face any emission permits scarcity and observed emissions are baseline emissions, that is, the level of emissions to be expected when no emissions limitation is implemented. On the other hand, a strictly positive carbon price at the end of the period implies that abatement has occurred, and that baseline emissions would have been higher than the cap if the emission limitation had not been implemented.

4. In a market with perfect competition, the situation with a (*ex post*) carbon price resulting from the supply-demand equilibrium in emission permits in the frame of an *ex ante* cap is equivalent to setting, *ex ante*, a carbon tax at the level of the equilibrium price, which leads to an *ex post* amount of released emissions equal to the cap.

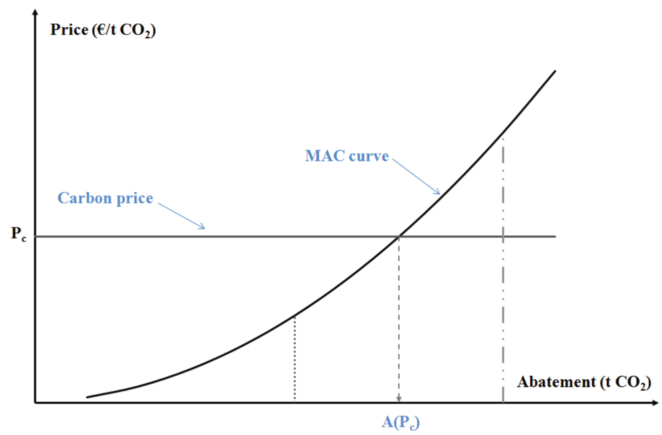
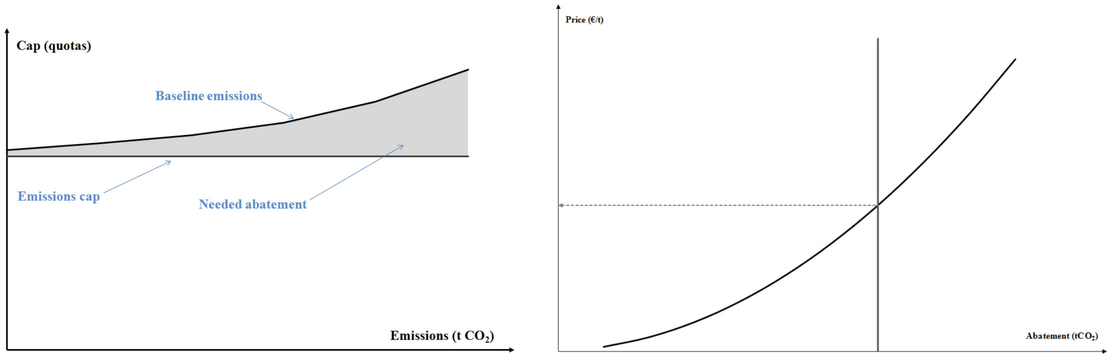


FIGURE 3.1: Installation operator carbon price - abatement cost arbitrage
Carbon price being given, its equalization with the marginal abatement cost of the installation operator corresponds to an *ex post* amount of abatement (dashed line).

An elementary cap and trade of emission permits system distinguishes from any other commodity market as, unlike the latter ones, supply (of emission permits) is static. Therefore, with a fixed cap, any departure from baseline emissions would be reported on the price of the emission permits : there is no overall supply adjustment as in any commodity market (e.g. the steel market) to support price in case of a drop in demand. The corollary of this being that the actual emissions trajectory departure from baseline emissions can be derived from the evolution of carbon price and vice versa. Note that a penalty is usually introduced for market operators unable to surrender as many emission permits as their verified emissions [5], so that it becomes prohibitive not to be compliant. It is therefore unlikely that the overall level of emissions exceeds the cap. As such the departure of actual emissions from baseline emissions is to be interpreted as the anticipated need for abatement, which is what is reflected in the price (figure 3.2) ; and vice versa, the evolution of the price suggests an evolution in the anticipated need for abatement. Therefore, assuming that marginal abatement cost curves are functions increasing with abatement, carbon price and anticipated abatement need are positively correlated.

In conclusion, in the framework of an elementary emission permits cap and trade with a fixed cap, and under a realistic assumption on marginal abatement costs, it has been showed that emissions variations (i.e. the variation of abatement need) is a relevant proxy

5. EU ETS market operators that do not cover their total emissions are "held liable for the payment of an excess emissions penalty" of 100 Euros for each tonne of CO_2 that is not covered by an emission permit (European Parliament Council, 2009).



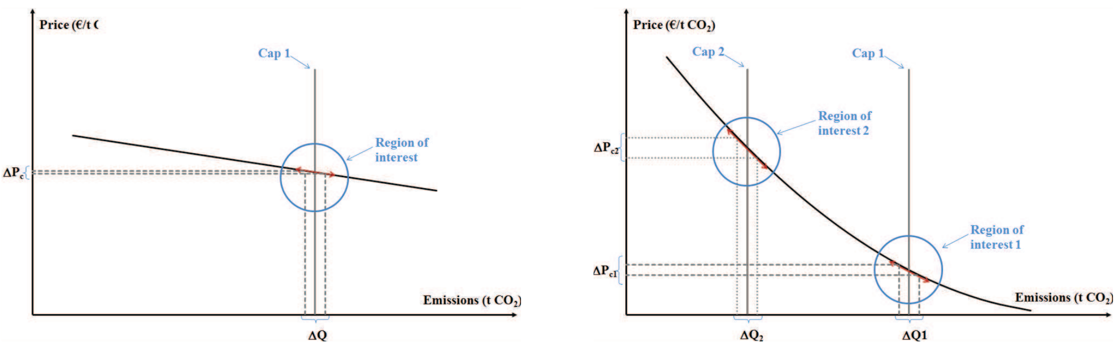
(a) (b)

FIGURE 3.2: Baseline emissions, abatement need and carbon price
For a given cap, the need for abatement increases with baseline emissions (a). Required amount of abatement for a given cap-baseline emissions combination involves a given carbon price, which also increases with abatement assuming increasing marginal abatement cost curve (b)

for carbon price dynamics. Nonetheless, flexibility mechanisms allowed by the ETS directive and the exercise of market power to manipulate the price of emission permits could question this conclusion. These two cases are evoked below.

3.2.2.2 Market power

Conditions to exert market power For a market participant, exerting market power consists in having the ability to influence the transaction price of emission permits - against market fundamentals such as energy prices, the macroeconomic environment and its institutional design - whether as a monopolistic seller or a monopsonistic buyer. Exerting market power in the EU ETS would therefore make void the positive correlation between carbon price and baseline emissions (or need for abatement), and involve carbon price not to reflect market conditions. Two parameters are involved in determining whether market power can be exerted in the EU ETS. First one is the price-elasticity of emission permits demand that an installation (or a coalition of installations) faces. Second one is the ability to artificially create an emission permits scarcity or abundance, through permits purchase or sale. Should price-elasticity of emission permits demand be elastic (i.e. approaching that of a competitive market), exerting market power appears unlikely as artificial scarcity or abundance of emission permits would have little impact of carbon price. On the contrary, should it be inelastic, carbon price could potentially be influenced by sales or purchases of emission permits, as long as they are large enough. In other words, the "size require-



(a) *Elastic* demand of emission permits (b) *Inelastic* demand of emission permits

FIGURE 3.3: The impact of abatement cost curve on market power

ment" (i.e. the ability to withdraw large amounts of emission permits from the market) is necessary, but not sufficient (Hahn, 1984).

The price-elasticity of emission permits demand is given by the aggregated abatement cost curve, which summarizes that of all installations of the EU ETS. The region of interest (ROI) of the aggregated abatement cost curve is given by the cap set by the market supervisor : the impact of an artificial addition or withdrawal of emission permits by an installation (or a coalition of installations) is determined from this region of interest. This is illustrated in figure 3.3. For an aggregated abatement cost curve displaying a rather elastic demand for emission permits (figure 3.3a), the impact of having an installation artificially remove (or add) emission permits from total supply (the cap) has little impact on emission permits price. On the contrary, for an aggregated abatement cost curve displaying a rather inelastic (or less elastic) demand for emission permits (figure 3.3b) the situation is different.

The importance of the cap level is obvious as the impact of an emission permits artificial withdrawal is not the same when the abatement cost curve does not have a constant slope (see ROI 1 and ROI 2). Hence, the resulting two questions are : what is the EU ETS aggregated abatement cost curve ? Are there market participants that have the ability to withdraw or add large enough amounts of emission permits so that, in combination with the aggregated abatement cost curve ROI, they can exert market power ?

Ability to withdraw emission permits The magnitude of a potential allowances withdrawal (or addition) can be derived from initial allocation of allowances. When trying to identify the countries that could potentially exercise market power in a global market of tradable CO_2 quotas, Westskog (1996) mentions the United States, Russia and China, which respective shares of global emissions were above 10% each in 1987 (assuming their allocation is equal to their emissions). At this date, the ten biggest emitters represented about 70% of total emissions (Cline, 1992). In the EU ETS, Trotignon and Delbosc (2008) showed that, within the first phase of the market (2005-2007), in the case of allocation pooling of installations belonging to a same company, the first ten most allocated companies held one third of total allocation (most allocated company held 6% of total allocation). This is less than the 70% evoked by Cline.

The Herfindahl Hirschman Index (HHI - named after economists Orris Herfindahl and Albert Hirschman) can be used as well. It indicates the degree of concentration of a given market derived from the respective market shares of firms. Values of the HHI below 0.1 generally indicate a not concentrated market. The values of this index for the most allocated ten companies in Phase 1 have been calculated by Convery and Redmond (2007) [6]. Figures are reproduced in table 3.1. Based on the Index values, they conclude that no company has had the ability to exert market power in Phase 1, nor had the power sector as most of the first ten companies were electricity producers.

In addition to this, allocation in the first two Phases of the market have been based on grandfathering mainly (i.e. in relation to historical emissions levels), so that installations have received either slightly larger or smaller amount of their reference emissions in allowances. This would involve, at least, that the existence of a situation with large hot air [7] (amount of available allowances not corresponding to abatement) should not occur in the EU ETS. Further, Ellerman et al. (2000) have suggested that installation operators may benefit from keeping a given amount of emission permits aside in prevision of unexpected emissions variations (also called convenience yield). This would result in reduced opportunities to manipulate either supply or demand of emission permits [8].

EU ETS aggregated abatement cost curve The EU ETS aggregated abatement cost curve (level of emitted CO_2 for a given carbon price) can be approached using models that describe the perimeter of EU ETS, integrate carbon price as an input, and output CO_2 emissions levels. The PRIMES model corresponds to this type of models although not exactly matching the EU ETS in terms of geographical and technological coverage. This EU-wide energy model has been developed by the E3Lab of the National Technical

6. They also assess the allocation share of these companies to amount to 20% approximately.
7. As described in Ellerman and Decaux (1998).
8. Carrying an in-depth analysis of transaction data would help support these intuitions. At the time of writing, this was on-going work at the Climate Economics Chair.

TABLE 3.1: Market power in the EU ETS

Company	Share of total EU ETS allocation in Phase 1	HHI
RWE	5.9	0.0035
Vattenfall	3.6	0.0013
Enel	2.2	0.0005
E.ON	1.7	0.0003
EDF	1.6	0.0003
Corus	1.4	0.0002
Endesa	1.3	0.0002
E.ON	1.3	0.0002
Shell	0.9	0.0001
Arcelor Mittal	0.9	0.0001
Total	20.8	0.0065

Source : Convery and Redmond (2007)

University of Athens. It outputs CO_2 emissions from energy related uses and industrial processes of all EU 27 Member States, the Western Balkans countries, the European Free Trade Association (EFTA) countries and Turkey. The model has been run for several values of carbon price in the framework of a contribution to a study for the European Commission DG Environment on CO_2 emission reduction opportunities in the European Union in 2001 (Blok et al., 2001). It uses 1995 as the base year which may account for the observed difference in 2010 emissions for the EU 27 between PRIMES projection and verified emissions in the EU ETS. The linearly interpolated abatement cost curve [9] derived from the PRIMES model and concerning a similar perimeter as the one of the EU ETS is provided in figure 3.4. A focus is made on the area of carbon price values that have already been observed (i.e. up to 30 Euro/t CO_2). Table 3.2 provides the abatement cost curve slope (line 2), which corresponds to the marginal abatement cost (MAC), the abatement-elasticity of carbon price (line 3) and the carbon price variation in Euro (2010) for an emission permits withdrawal of ten million (line 4). The table is to be read as follows : for a cap set at 1,550 million tons of CO_2, an artificial scarcity (addition) of five million emission permits would entail a carbon price increase (decrease) of two Euro. Consequently, being able to affect carbon price on a large scale (above two Euros) would require an installation operator to withdraw from the secondary emission permits market the equivalent of more than

9. A description of a methodology to obtain a more elaborated abatement cost curve is provided in appendix 3.B of this chapter.

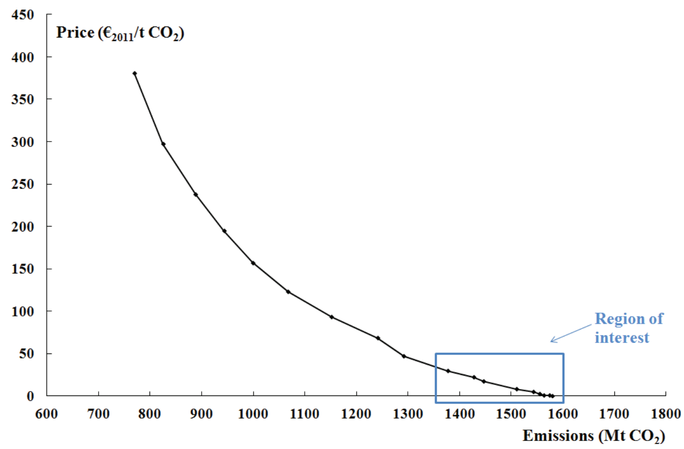


FIGURE 3.4: Abatement cost curve from PRIMES model

TABLE 3.2: abatement-elasticity of carbon price

Initial cap ($Mt\ CO_2$)	1,580	1,570	1,560	1,550	1,530	1,480	1,440	1,400
Slope ($Euro/Mt\ CO_2$)	-0.08	-0.03	-0.17	-0.19	-0.09	-0.15	-0.23	-0.16
Elasticity	-526	-78	-185	-87	-23	-18	-17	-8
Price variation (Euro)	0.8	0.3	1.7	1.9	0.9	1.5	2.3	1.6

Source : the author from Blok et al. (2001)

ten million quotas. This seems unlikely as no installation has been allocated an amounts of emission permits that would allow it to perform such market manipulation and at the same time keep emission permits aside in prevision of unexpected emissions variations [10].

3.2.2.3 Flexibiliy mechanisms

The EU ETS has been promoted as the economic instrument to reduce CO_2 at least costs, and the built-in flexibility it offers to market participants has contributed to this. As mentioned in Trotignon (2012b), the offered flexibility can be declined in three different ways : trading (mentioned and described in previous section), spatial (the authorization to import Kyoto Protocol credits) and temporal flexibility (the ability to bank allowances to

10. This would benefit from being illustrated by an analysis of emission permits transactions that the EUTL allows to perform.

be used in future periods, and that of borrowing allowances from next period for a present use). Nonetheless, they allow a dynamic modification of emission permits supply that could involve carbon price and abatement need not to be correlated as it should be expected in a basic ETS design (and as described in section 3.2.2.1).

Spatial flexibility The introduction of spatial flexibility by the Linking Directive (European Parliament Council, 2004), added to that of trading, further reduces the cost of compliance for market participants. Indeed, unlike trading which does not modify the overall cap, the import of Kyoto Protocol credit does increase the amount of emission permits that can be used for compliance. The need for abatement can thus be reduced, lowering the level to which marginal abatement costs and carbon price equalize, or verified emissions could increase without any observed effects on carbon price. The limit for Kyoto credits imports is country and industry dependent. In almost all countries, operators have the choice to decide when to use their Kyoto credits for compliance. The import limit is therefore at the Phase scale and not annual. It is estimated at 1.45 billion credits which is equivalent to 13.5% of Phase 2 allocation approximately [11]. Given the above comments on carbon price sensitivity and the limited authorized import of Kyoto Credits, it seems unlikely that spatial flexibility provides a single market actor with the possibility to manipulate the transaction price.

Temporal flexibility With regards to temporal flexibility, banking or borrowing enables an allowance transfer from one compliance period (one year) to another : it reduces (respectively increases) the cap of the considered period and thus modifies its supply and demand balance such that emissions could grow (respectively diminish) to such extent that it would not affect carbon price. Nonetheless the overall cap (the sum of all periods caps) is left unchanged by these two temporal flexibility mechanisms. Rather than reducing the sub-period compliance costs of operators, banking and borrowing allow to smooth the compliance costs over time and all the consecutive sub-periods, or to constitute precautionary saving in a context of uncertainty (see also Ellerman et al. (2000)). As such, it seems unlikely that an extreme use of temporal flexibility by a single market operator (either banking of total allocation of a given year or borrowing of total following allocation) causes emission permits price not to behave according to market fundamentals.

11. An in-depth analysis of the use of Kyoto credits for compliance in 2008 and 2009 can be found in Trotignon (2012a). After Phase 2 last compliance exercise, it was estimated that 1.06 billion credits had been surrendered by installation operators in Phase 2.

On Phase 2 allowances surplus It has been mentioned above that it was doubtful that any single market operator could influence carbon price. Nonetheless, the aggregation of the individual uses of these mechanisms in Phase 2 have resulted in an emission permits surplus which raises the possibility that the positive correlation between carbon price and the need for abatement is made void. Indeed, the surplus magnitude involves larger emission permits addition than a single installation could potentially introduce. The evidence of Phase 2 allocation surplus to be brought into Phase 3 (i.e. the fact that Phase 2 is "long") has been ramping up right after the economic crisis spread into the carbon market in autumn 2008 (Capoor and Ambrosini, 2009). Several estimations of Phase 2 surplus are gathered in IETA (2012b), and all converge to around 1.5 billion of emission permits, which represents 75% of an annual allocation level in Phase 2. What has prevented carbon price from dropping [12] to the same levels it witnessed in Phase 1 is the allowed partial inter Phase temporal flexibility. Indeed, the banking of Phase 2 allowances into Phase 3 (that has started on January 1^{st}, 2013) has been authorized, as opposed to the borrowing of Phase 3 allowances for use in Phase 2. Therefore, the observed level of carbon price in Phase 2 has to be interpreted as the integration of Phase 3 characteristics in the anticipations of market participants, and especially the expectation of a potential and progressive allocation shortage as Phase 3 develops. This has resulted in the "freezing" (or artificial withdrawal) of emission permits by market participants. This surplus can theoretically be used to temper carbon price variations, eventually leading to a commodity market with variable supply.

Two assumptions are thus necessary for the positive correlation between carbon price and need for abatement to hold. First, it is assumed that market participants have anticipated the cap enlargement involved by Kyoto Credits imports. Second, it is assumed that the use of the emission permits surplus tempers carbon price variations and does not reverse nor prevent them. Carbon price volatility is attenuated and the positive correlation with abatement need is kept positive. This assumption seems reasonable since, as mentioned previously in (Carraro and Favero, 2009), banking (as well as borrowing) is a long term mechanism which involves that the release of banked allowances into the market, if occurring, should be progressive over time. Hence, although market participants have "modified" Phase 2 annual emission caps (through the building of Phase 2 allowances surplus), currently leading to an artificial support of carbon price, this collective retention of emission allowances is used to cushion the observed downward momentum of carbon price.

12. Emission allowance price hit a record low at 2.81 Euros (40% drop) after the European Parliament voted against a legal amendment on the timing of EU carbon auctions on January 24, 2013.

3.2.2.4 Concluding remarks : proxying carbon price with emissions level

In conclusion, the aim of this section was to show that the level of overall emissions in the EU ETS could be used as a proxy for carbon price dynamics. This result was desired as it has been showed that the use of annual verified emissions was more convenient to study the sectoral impact on EU ETS CO_2 emissions (see section 3.2.1.4). Although the cap and trade system design involves a positive correlation between carbon price and CO_2 emissions dynamics, potential flaws in the reasoning may have been introduced by built-in flexibility mechanisms or the potential exercise of market power by dominant operators. It has been showed that under two specific assumptions it could be concluded that, under the EU ETS, the need for abatement (or departure from baseline emissions) is a relevant proxy for carbon price. This allows to assert that determining the sectoral impact on the need for abatement enlightens on its impact on carbon price.

3.2.3 Sectoral contributions to CO_2 emissions

Having established that emissions could be used as a proxy for carbon price, the attention is now focused on the determinants of CO_2 emissions. This topic has been widely covered in the literature under several modeling approaches. Some can be found in (Greening et al., 2007) which provides a compendium of studies on the modeling of energy consumption from different backgrounds. The diversity of modeling approaches (e.g. econometrics, decomposition analysis, use of top-down and bottom-up models) that is reflected in this special issue of *Energy Policy* is explained by the variety of questions about industrial energy consumption that these studies attempt to answer. Among them, research works investigating the questions of the attribution of changes in energy consumption to different types of factors, as well as the question of decoupling CO_2 emissions with industrial growth are of direct interest to us. Through decomposition methods they point out the existing relation between CO_2 emissions and energy consumption in the manufacturing sector in some European OECD countries.

Decomposition analysis has mostly been developed in the eighties. It has been applied to better understand the changes occurring in energy consumption patterns in industry mostly, through the identification of the factors that influenced this changes. Growing concern about climate change issues involved the application of this methodology to energy related greenhouse gas emissions [13]. Decomposition methods consist in a two-step process.

13. As an example, under the Kaya identity, CO_2 emissions can be accounted for by the contribution of

They first require the establishment of an accounting identity, or *governing function*, that relates an aggregate with a number of factors. A decomposition method is then chosen to quantify the respective impacts of the governing equation factors on the changes of the aggregate. Several methods have been developed and two have been used more extensively : decomposition based on the Divisia index (Park, 1992) and based on the Laspeyres index [14]. Through a Laspeyres index method, Liaskas et al. (2000) show that the industrial output level has caused the emissions of CO_2 in the studied 13 European countries to increase over the 1973-1993 period, despite the dramatic improvements in energy efficiency and changes in towards less CO_2 intensive fuel mixes that have followed the energy crisis in the seventies. Identically, Diakoulaki and Mandaraka (2007) have demonstrated that economic growth, although progressively decoupling [15] over the 1990-2003 period remains the main determinant for energy related CO_2 emissions in the manufacturing sector of 14 European countries. This is embodied by the predominant role of the “output effect” (i.e. industrial output growth) in increasing emissions. The European Environment Agency has provided insights on the annual determinants of CO_2 emissions from energy combustion in the EU 27 in 2008 and 2009 (European Environment Agency, 2010, 2011). In both studied years, growth is the factor that has contributed the most to their variations, whether negative or positive.

Above studies unveil several drivers for CO_2 emissions. Not only do they confirm the fact that activity level affects CO_2 emissions, they show that it is the most influential one. To our best knowledge, few studies have attempted to unveil and quantify the determinants of EU ETS emissions, whereas those that provide either descriptive statistics or in depth analysis of the state of the market from Community Independent Transaction Log (CITL) data are quite numerous [16]. Next section develops the theoretical model that is used to

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four human factors (Kaya and Yokobori, 1997) :

$$F = P \, \frac{G}{P} \, \frac{E}{G} \, \frac{F}{E} = P \; g \; e \; f \tag{3.1}$$

Where F are global anthropic CO_2 emissions, P is global population, G is global GDP and E is global consumption of primary energy. Human factors accounting for global CO_2 emissions are therefore, global population (P), GDP per capita (g), energy intensity of GDP (e) and CO_2 intensity of consumed primary energy (f).

14. No general consensus on the preferred method exists. Criteria for assessing which method is more appropriate are discussed in (Ang, 2004).

15. The notion of decoupling has first been introduced by von Weizsäcker (1989).

16. Among these studies, Trotignon (2012b); Trotignon and Ellerman (2008); Ellerman and Buchner (2008) are considered reference works on the use of CITL data for the analysis of, for instance, compliance positions of installations or Member States, cross-border allowances transfers and *ex post* estimated abate-

assess the contribution of economic activity on CO_2 emissions covered under the EU ETS. More precisely, the sectoral impact is assessed. It will shed light on the sectoral contribution to carbon price variations. Indeed, it has been showed in this section that the level of CO_2 emissions, or rather the need for abatement, could be used as a proxy for carbon price.

3.3 A decomposition analysis of EU ETS emissions

This section aims at presenting the model that has been developed to assess the sectoral contribution to CO_2 emissions covered under the EU ETS. This is done in two steps. First the intuition behind and the relevance of the modeling approach is provided. The economic recession has involved different responses from economic sectors that justify a sectoral disaggregation when focusing on the impact of activity levels on CO_2 emissions variations in the EU ETS (section 3.3.1). Second, the theoretical model is described in details (section 3.3.2). It is showed in this latter section that the absence of specific EU ETS activity indicators requires the definition and the validation of activity indicators from other sources, in order for the decomposition analysis to be undertaken. This is developed in section 3.4.

3.3.1 Economic activity and the EU ETS in Phase 2

3.3.1.1 Sectoral activity in the EU 27

Although the decoupling of CO_2 emissions with economic activity has occurred in Europe in the last decades, the ouput effect remains a significant driver of CO_2 emissions growth (see studies mentioned in section 3.2.3). The economic and financial crisis, which became manifest on the macroeconomic environment mid-2008 (Banque de France, 2010), has involved emission reductions due to lower economic activity. In the EU ETS, this has resulted in lower demand for emission permits, consequently leading to a drop in carbon price. At the same time it has been observed different responses to the crisis. Indeed, some industrial sectors being more affected (whether in output variation or falling output duration) than others as it is showed in (European Commission, 2011a). This has resulted in heterogeneous emission levels decreases among sectors (figure 3.5a). Especially, industries belonging to the manufacturing sector, although showing different reactions to the economic downturn, did encounter a sharper decrease than the power sector. At a more aggregated

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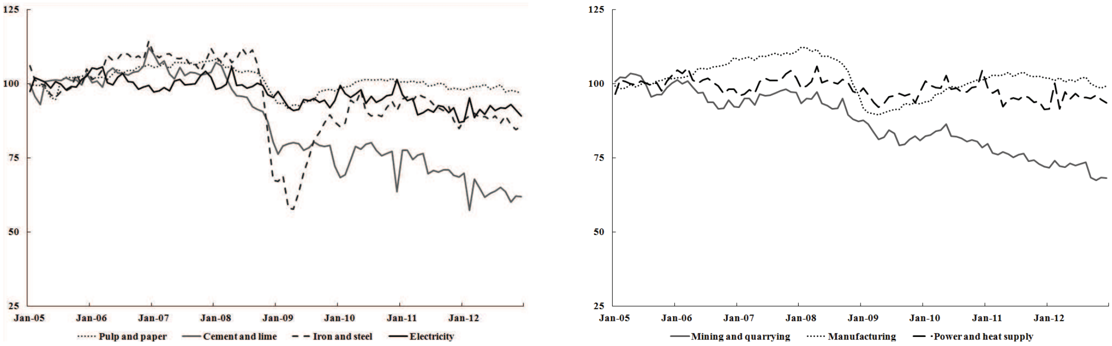


(a) Selected non-power sectors (b) NACE rev. 2 divisions B, C and D

FIGURE 3.5: EU 27 sectoral activity and GDP variations (2005 = 100)

Source : Eurostat

level, the manufacturing and power sectors show dramatically dissimilar patterns : the former amplifies the gross domestic product downwards momentum, whereas the latter is hardly affected (figure 3.5b). From the first quarter of 2008 until the fourth quarter of 2010, the production index of the aggregated manufacturing sector has a correlation of 0.99 with gross domestic product index ; over the same period the production index of the power sector shows a correlation of 0.32 only.

Two main reasons can account for this differentiated reaction to the larger economic environment. First when considering the aggregated manufacturing sector (section C of NACE rev. 2), the "size effect" plays. Indeed, it represents a greater share of the EU 27 gross domestic product than the power sector (section D of NACE rev. 2). Hence, it is expected to witness larger activity variations in the manufacturing sector than in the power sector with gross domestic product variations. Diving at the NACE division level, the second accounting factor lays in existing connections in between industries, known as interlinkages, as well as in the way final output is employed, be it in terms of investments, final consumption, or exports. The impacts of these interlinkages are measured by backward and forward linkages (see chapter 2). Manufacturing industries show higher backward linkages than the power sector, which involves that an economic downturn caused by a drop in final demand will be disseminated through interlinkages and thus affect manufacturing industries harder than electricity producers.

TABLE 3.3: EU ETS Phase 2 CO_2 emissions and EU 27 GDP variations (in %)

Variation (%)	2008	2009	2010	2011	2012
CO_2 emissions	-3	-11.4	3.2	-1.8	-2.1
GDP	0.3	-4.3	2.1	1.6	-0.3

Source : CITL and Eurostat

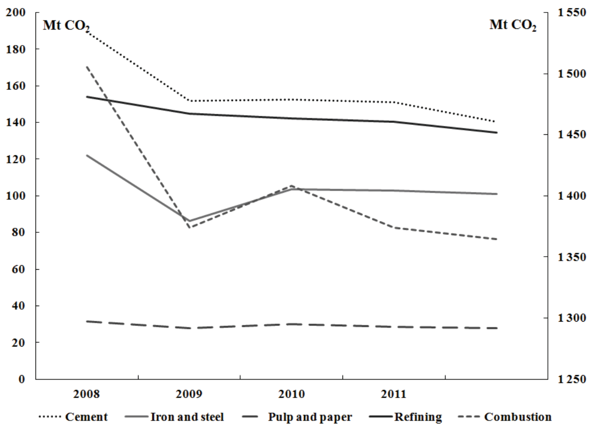


FIGURE 3.6: EU ETS emissions by CITL activity over 2008-2012
Right hand side axis is for the emissions of the combustion sector only.

Source : CITL

3.3.1.2 Sectoral CO_2 emissions and carbon price

The absence of full decoupling between economic activity and energy related emissions has induced a fall in EU ETS CO_2 emissions that has been captured by the 2009 compliance (table 3.3). Similarly to the heterogeneous patterns of sectoral activity levels that contribute to the fluctuation of gross domestic product, the aggregated level of emissions covered under the EU ETS results in the contributions of sectoral emissions patterns, which have also witnessed heterogeneous (in terms of magnitudes) breaks from their 2008 levels (figure 3.6). All sectoral emissions show variations that have affected aggregated emissions levels.

Interestingly, it can also be observed that carbon price evolution over the same above mentioned period (first quarter of 2008 until fourth quarter of 2010) is more correlated with the production index of the manufacturing sector (0.90), than it is with the production index of the power sector (0.68). All in all, industry appears in its heterogeneity, as illustrated by the diversity of responses to the macroeconomic downturn of its sub-sectors. Its capability to affect the level of carbon price has also been suggested by the synchronous

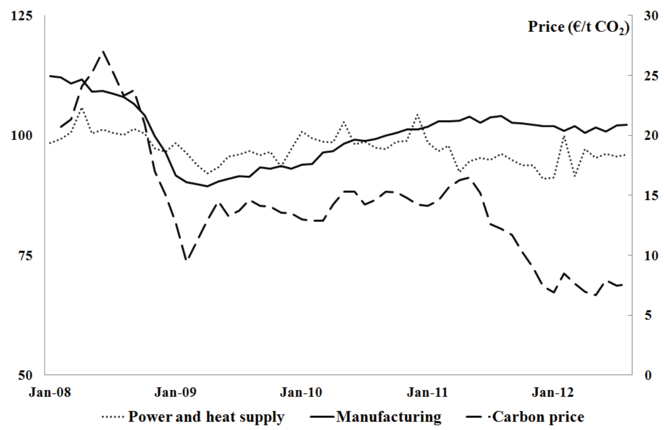


FIGURE 3.7: Carbon price and industry activity level (2005 = 100)

Source : Eurostat and Bluenext

and ample movement of the latter with the aggregated activity level of the manufacturing sector (figure 3.7). This role that is attributed to industry is well summarized by the statement of the International Emissions Trading Association in a brief of April 2012 :

> With the economic recession, there is less demand for allowances than when the EU-wide cap was established. Also, not only has the amount of electricity sold forward dropped as power prices have been impacted by the deteriorated economic environment thereby further reducing demand for emission allowances, but also selling by industrial installations to monetize their allowance surplus in times of cash constraints adds to the downward trend. (IETA, 2012a)

Next section describes the model that is used to disentangle the contribution of sectoral activity to the variations of CO_2 emissions covered under the EU ETS.

3.3.2 Decomposition model

3.3.2.1 Governing equation : a two-factor decomposition

The impact of activity on CO_2 emissions covered under the EU ETS is modeled through a decomposition analysis. Indeed, CO_2 emissions and activity level are linked by an identity relation involving the CO_2 emissions intensity of activity (equation 3.2).

$$E^{ets} = \frac{E^{ets}}{P^{ets}} \times P^{ets}$$
$$\Leftrightarrow E^{ets} = I^{ets} \times P^{ets} \qquad (3.2)$$

Where P^{ets} is the EU ETS aggregated activity level. This decomposition involves the introduction of the emission intensity factor I^{ets}, thus resulting in a (simple) two-factor decomposition. Sectors are the attributes of both factors so that equation 3.2 is re-written in equation 3.3 introducing subscript i to differentiate attributes.

$$E^{ets} = \sum_{i=1}^{n} P_i^{ets} \cdot I_i^{ets} \qquad (3.3)$$

Where subscript n is the number of sectors that are covered under the EU ETS.

3.3.2.2 Refined Laspeyres index and Divisia index methods

The choice of the decomposition methodology follows the recommandations of Ang (2004). It is stated that the logarithmic mean Divisia method I (LMDI I), linked to the Divisia index approach, fits best the desirable attributes that should be expected from a decomposition method. These criteria are : theoretical foundation, adaptability, ease of use and ease of result interpretation. Since the above decomposition involves two factors only, the Sun method can also be used. It was proposed by Sun (1998) and corresponds to the additive form linked to the Laspeyres index approach (also referred to as the refined Laspeyres index method). Therefore both Sun and LMDI I (in its additive form) are chosen to decompose CO_2 emissions covered the EU ETS. Additive forms are retained against multiplicative forms as results are easier to interpret [17]. Furthermore, both methods provide perfect decomposition (i.e. no unexplained residual term remains).

In additive decomposition, the aggregate variations from year 0 to year T is given by equation 3.4 and decomposed into the variation of each factor as in equation 3.5.

17. The multiplicative decomposition is given by :

$$DE^{ets} = \frac{E_T^{ets}}{E_0^{ets}}$$
$$\Leftrightarrow DE^{ets} = DI^{ets}\ DP^{ets}$$

.

Table 3.4: Factor formula by decomposition method (additive form)

Method	LMDI I (Divisia index)	Sun (Laspeyres index)
ΔP^{ets}	$\sum_{i=1}^{n} \frac{E_{i,T}^{ets}-E_{i,0}^{ets}}{\ln\left(E_{i,T}^{ets}\right)-\ln\left(E_{i,0}^{ets}\right)} \ln\left(\frac{P_i^T}{P_i^0}\right)$	$\frac{1}{2}\sum_{i=1}^{n}\left(P_i^T - P_i^0\right)\left(I_i^T + I_i^0\right)$
ΔI^{ets}	$\sum_{i=1}^{n} \frac{E_{i,T}^{ets}-E_{i,0}^{ets}}{\ln\left(E_{i,T}^{ets}\right)-\ln\left(E_{i,0}^{ets}\right)} \ln\left(\frac{I_i^T}{I_i^0}\right)$	$\frac{1}{2}\sum_{i=1}^{n}\left(I_i^T - I_i^0\right)\left(P_i^T + P_i^0\right)$

Source : Ang (2004)

$$\Delta E^{ets} = E_T^{ets} - E_0^{ets} \tag{3.4}$$

$$\Leftrightarrow \Delta E^{ets} = \Delta I^{ets} + \Delta P^{ets} \tag{3.5}$$

The formulas to compute the variation of both factors (P and I) then depends on the adopted methodology. Table 3.4 provides the formulas for the additive forms of both LMDI I and Sun decompositions.

3.3.2.3 Sectoral focus and need for EU ETS activity indicators

The above decomposition analysis provides the contribution of each of the two factors on CO_2 emissions covered under the EU ETS, from a reference point to another point in time. This constitutes the primary purpose of decomposition analysis and what is reflected in research works that use it : the contributions of attributes (i.e. sectors) to a factor are combined but not individually assessed. In order to assess the sectoral activity impact on EU ETS emissions, the analysis is therefore brought a step further by comparing the sectoral contributions of both factors. Nonetheless, as the formulas to compute the variation of both production and intensity factors show, activity and intensity indicators of sectors covered under the EU ETS are needed. As showed in chapter 2, the coverage of the Scheme is not sectoral. Therefore these ETS sectoral indicators do not exist as ETS sectoral activity has not been monitored explicitly. Closest activity indicators are sectoral production indices provided by Eurostat. In order to use them in the above described decomposition analysis instead of (non existent) ETS activity indicators, they should be statistically validated as adequate substitutes. The methodology and results are described in following section 3.4.

3.4 Eurostat production indices as EU ETS activity indicators proxies

3.4.1 Testing Eurostat indicators : motivations

The decomposition model that has been introduced in section 3.3 requires three types of datasets : EU ETS emissions (E^{ets}), production indices of activities covered under the EU ETS (P^{ets}), and CO_2 intensity of these activities (I^{ets}). EU ETS verified CO_2 emissions data at the installation level are available from the CITL. Verified emissions data could be aggregated at the activity level as defined by Annex 1 of the ETS Directive, however no production indices data corresponding to such activities have been developed so far [18]. Closest available activity indicators are Eurostat production indices, which are organized by NACE activity. Hence, taking advantage of the carbon leakage assessment performed by the European Commission in 2009, which led to associate a NACE rev. 1 code to almost each installation participating in the Scheme (European Commission, 2010a), verified emissions data are re-organized by NACE code.

As underlined in chapter 2, CO_2 emissions of most of NACE activities are partially covered by the EU ETS only (see appendix 2.H of chapter 2), which involves that production indices of NACE sections and divisions do not accurately correspond to activity levels under the EU ETS. Consequently, in order to be able to use the production indices of NACE divisions provided by Eurostat in the decomposition analysis described in section 3.3, their values are tested against the theoretical values of production indices that would correspond to the activity levels of EU ETS covered activities. The employed methodology to validate Eurostat NACE sections and divisions production indices as proxies for production indices of EU ETS activities is described in section 3.4.2. This validation is a three-step process. First, the theoretical relation existing between total EU ETS emissions and (what would be) the production indices of EU ETS activities (should they be defined) must be determined. Second, the relation that actually exists between total EU ETS emissions and production indices of Eurostat NACE sections and divisions are estimated. Finally, the estimated actual relations are tested against their theoretical values, which enables validating production

18. It is to be noted that a production index for the EU ETS activity has been developed at (former Mission Climat and now) CDC Climat Recherche of Caisse des Dépôts et Consignations. This index is based on a combination of production indices (from Eurostat) of activities, which descriptions are the closest match to those of the EU ETS, with ad hoc weights corresponding to the shares in total Phase 2 allocation of these EU ETS activities. This aggregated index is used in CDC Climat Recherche monthly publication *Tendances Carbone*.

indices of Eurostat NACE sections and divisions as relevant proxies for activities in the EU ETS.

3.4.2 Theoretical ETS CO_2 emissions/production indices relations

Total EU ETS emissions and corresponding sectoral production indices are linked by the relation given in equation 3.3. From this relation, variations of EU ETS emissions are given by equation 3.6.

$$\begin{aligned} \Delta E^{ets} &= \sum_{i=1}^{n} \Delta \left(P_i^{ets} \cdot I_i^{ets} \right) \\ \Leftrightarrow \Delta E^{ets} &= \sum_{i=1}^{n} \left(I_i^{ets} \Delta P_i^{ets} + P_i^{ets} \Delta I_i^{ets} \right) \end{aligned} \tag{3.6}$$

Translated into variation rates, equation 3.6 becomes equation 3.7.

$$\begin{aligned} \frac{\Delta E^{ets}}{E^{ets}} &= \sum_{i=1}^{n} \left(\frac{I_i^{ets} \Delta P_i^{ets}}{E^{ets}} + \frac{P_i^{ets} \Delta I_i^{ets}}{E^{ets}} \right) \\ \Leftrightarrow \frac{\Delta E^{ets}}{E^{ets}} &= \sum_{i=1}^{n} \left(\frac{E_i^{ets}}{E^{ets}} \frac{\Delta P_i^{ets}}{P_i} + \frac{E_i^{ets}}{E^{ets}} \frac{\Delta I_i^{ets}}{I_i^{ets}} \right) \\ \Leftrightarrow \frac{\Delta E^{ets}}{E^{ets}} &= \sum_{i=1}^{n} \alpha_i \left(\frac{\Delta P_i^{ets}}{P_i^{ets}} + \frac{\Delta I_i^{ets}}{I_i^{ets}} \right) \end{aligned} \tag{3.7}$$

Where α_i is the sectoral share in total EU ETS emissions (i.e. $\frac{E_i^{ets}}{E^{ets}}$). Coefficient α_i is the theoretical value linking EU ETS activity i with its production index and associated CO_2 intensity. It is against this theoretical value that the estimated one that links EU ETS activity with NACE section and/or division production index is tested.

3.4.3 Estimated ETS CO_2 emissions/NACE production indices relations

3.4.3.1 What is estimated ?

The restricted to Eurostat dataset production indices availability involves that the decomposition analysis is based on the relations given in equations 3.8 and 3.9.

$$E^{ets} = \sum_{i=1}^{n} P_i^{nace} \cdot I_i^{nace} \tag{3.8}$$

$$\frac{\Delta E^{ets}}{E^{ets}} = \sum_{i=1}^{n} \beta_i \left(\frac{\Delta P_i^{nace}}{P_i^{nace}} + \frac{\Delta I_i^{nace}}{I_i^{nace}} \right) \tag{3.9}$$

Where superscript *nace* indicates production indices and resulting CO_2 intensities derived from Eurostat NACE production indices database. Coefficients β_i are estimated regressing EU ETS emissions variation rates on Eurostat production indices variation rates. Coefficients β_i are then tested against coefficients α_i. The econometric model is described and specified in following sections.

3.4.3.2 Econometric model

A panel model is built in order to get round EU ETS emissions data scarcity. Indeed, under annual only mandatory emissions reporting [19] and as of September 2013, the EU ETS has recorded eight emissions compliance exercises, corresponding to each year of the first two Phases (from 2005 to 2012 included). Annual Member States emissions observations are therefore used, which can conveniently be coupled with their respective annual activity observations, so that a panel dataset is constituted.

Coefficients β_i are thus estimated through Ordinary Least Square regressions applied to panel models, where observations are Member States over time. This modeling approach is inspired by and extends the research works by the European Environment Agency (European Environment Agency, 2010, 2011) as it introduces the period dimension. It allows the use of larger data sets, which provides more degrees of freedom and more efficiency (Baltagi, 2005) ; estimations of coefficients are thus closer to their real values (Pirotte, 2011). This methodology is particularly suited to the present work where time dimension covers a limited period. Further, the present analysis differs from the European Environment Agency studies as it focuses on EU ETS emissions exclusively and second, aims at decomposing the gross domestic product determinant into industrial sectors, using industrial production indices variations. The general form of the model is given in equation 3.10.

$$CO_2 = Prod \times \beta + \epsilon \tag{3.10}$$

19. Although sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emissions compliance from coal fired power plants is annual under the US Acid Rain Program, installations operators are nevertheless responsible for providing quarterly reports that include emissions data to the US Environmental Protection Agency (EPA, 2009).

Where $CO_2(N;1)$ is the vector of emissions variation rates (i.e. $\frac{\Delta E^{ets}}{E^{ets}}$) of N Member States, $Prod(N;K+1)$ is the matrix of activity indicators variation rates ($\frac{\Delta P_i^{nace}}{P_i^{nace}}$) of K different sectors, $\beta(K+1;1)$ is the vector of estimated constant and sectoral production "elasticities" of CO_2 emissions, and $\epsilon(N;1)$ is the vector of independent and normally distributed random error. Note that, given the general form of the model, the random error term includes the sectoral CO_2 intensity variation rates ($\frac{\Delta I_i^{nace}}{I_i^{nace}}$).

3.4.3.3 Econometric specification

Data availability allows to test for a panel specification use in the model, which consists in combining both temporal and cross sectional (or cross country) dimensions of the dataset. Panel data analysis assumes that slope coefficients (i.e. coefficients β) are homogeneous for all individual observations (i.e. constant over time and across Member States). Depending on datasets, this assumption may not hold and lead to biased estimations (Hurlin, 2002). The specification of above model thus has to be determined. Three configurations can be envisaged :

1. Model homogeneity ; both slope ("elasticity") and constant coefficients are identical across Member States and over time. Panel data analysis can be applied and one model only is required (equation 3.11) ;
2. Model partial heterogeneity ; slope coefficients are identical across Member States but constant terms are not. Panel data analysis can be applied and one model only is required, but Member States specific effects are introduced (equation 3.12) ;
3. Model (full) heterogeneity ; slope coefficients are not identical for all Member States. Panel data analysis cannot be applied and as many models as Member States must be specified (equation 3.13).

$$y_{i,t} = \eta + x_{i,t}^K \times \beta^K + \epsilon_{i,t} \tag{3.11}$$

$$y_{i,t} = \eta_i + x_{i,t}^K \times \beta^K + \epsilon_{i,t} \tag{3.12}$$

$$y_{i,t} = \eta_i + x_{i,t}^K \times \beta_i^K + \epsilon_{i,t} \tag{3.13}$$

In the above three equations, $y_{i,t}$ is the dependent variable, $x_{i,t}^k$ is the k th independent variable of the model (that includes K independent variables), $\beta^{\,k}$ is the estimated k th sectoral production "elasticity", η is the vector of estimated constant, and ϵ is the vector of independent and normally distributed random error. Subscripts i and t correspond to the cross sectional and period dimensions, referring to Member State and year respectively. To determine the specification of each of the model, a procedure of embedded homogeneity tests is performed, as proposed by Hsiao (2003). The procedure is detailed in appendix 3.C of this chapter.

3.4.3.4 Validating Eurostat indicators as EU ETS activities proxy

Estimations obtained from the procedure above described are compared with theoretical values to validate Eurostat sectoral production indices as right proxies of activities covered under the EU ETS. A one sample t-test is performed is this respect, where the hypothesis that both the estimated and theoretical values are equal ($H_0 : \beta_i = \alpha_i$) is tested against the hypothesis that they are different ($H_1 : \beta_i \neq \alpha_i$). The t-statistic that is computed is given in equation 3.14.

$$t = \frac{\beta_i - \alpha_i}{S.E._i} \tag{3.14}$$

Where β_i is the estimated value of the link between EU ETS emissions and Eurostat production index of sector i, α_i is the theoretical link between EU ETS emissions and production index of sector i, which corresponds to sector i share in EU ETS emissions (see equation 3.9). Scalar $S.E._i$ is the standard error of coefficient β_i estimation.

3.4.3.5 Data presentation

Eurostat activity levels indicators Activity levels data are industrial production indices extracted from the Eurostat *sts_inpr_a* database. Values range from 2005 to 2012 for all Member States participating in the EU ETS and are adjusted by working days. The data is organized using the NACE rev. 2 statistical classification and is more complete at the section and division levels [20]. Chosen economic sectors are those belonging to the *mining and quarrying* sector (section B), the *manufacturing* sector (section C) and the *electricity, gas, steam and air conditioning supply* sector (section D). The manufacturing sector is disaggregated into 15 sub-sectors. Most of them correspond to a NACE division, some other encompass two or three NACE rev. 2 divisions (see appendix 3.D of this chapter).

20. Second revision of the NACE classification is to be used since 1 January 2008 for statistics referring to economic activities. As of August 2013, Eurostat production indices data are solely available under the NACE second revision. This accounts for the shift from the use of NACE rev. 1 in chapter 2, which focuses on year 2007, to the use of NACE rev. 2 in chapter 3.

EU ETS emissions data EU ETS emissions data correspond to the sum of annual verified emissions of installations participating in the Scheme as reported in the CITL (now EUTL). Emissions data are available for eight years, from 2005 to 2012, for most of EU 27 Member States. The data is organized both at the NACE rev. 2 section and division levels. Originally organized under the NACE rev. 1 classification, following the carbon leakage assessment conducted by the European Commission, EU ETS emissions data have been re-organized under the NACE rev. 2 classification to match Eurostat production indices data. The EU ETS emissions transposition from first to second NACE revision is detailed in appendix 3.E of this chapter. Only a subset of EU ETS verified emissions from the CITL is used as only emissions from NACE rev. 2 sections B, C and D are used.

Dataset balancing The dataset consists in 27 country observations times 7 years (time period running from 2006 to 2012 as variation rates are used), which totals a maximum of 189 observations by variable (i.e. CITL CO_2 emissions and sectoral production indices). The econometric analysis is performed at two disaggregation levels : first at the section level where NACE rev. 2 sections B, C and D activity indicators are tested, then at the division level where section C is further disaggregated so that activity indicators of 19 sub-sectors are tested. A balanced dataset is required to perform the specification tests procedure. Therefore, since data availability varies depending on the disaggregation level, the number of observations of the balanced dataset varies with the disaggregation level. Balancing the dataset also prevents individual (Member States) fixed effects from being introduced in not all variable series. Complete datasets descriptive statistics are provided in appendix 3.F of this chapter.

Temporal and individual variability Differencing variables smooths the size effect of Member States and makes the period dimension and thus the economic conjuncture more apparent. Hence, the individual variability of variables is dominated by intra-individual variability. In other words, considering a given variable (e.g. CO_2 emissions), the spread between the average variation rate of a Member State shows a larger variance with its annual variation rates than with the average variation rate of all Member States. Temporal variability is also dominated by intra variability although to a smaller degree (table 3.5). Especially, the manufacturing sector (variable C) stands out as its inter-temporal variability is greater than its intra-temporal variability. This feature illustrates temporal specific effects i.e. that the variations rates for a given year of this variable is smaller across Member States than from one year to another.

TABLE 3.5: Balanced dataset temporal and individual variability (% of total variability)

	EU 15				EU 25			
	CITL	B	C	D	CITL	B	C	D
Individual								
Intra	97	86	91	89	96	90	87	91
Inter	3	14	9	11	4	10	13	9
Temporal								
Intra	70	80	21	74	70	84	33	79
Inter	30	20	79	26	30	16	67	21

Source : the author from Eurostat and CITL

3.4.4 Results : Eurostat production indices validation

3.4.4.1 Activity to CO_2 emissions link : theoretical values

The proportional relation that links EU ETS emissions variations with EU ETS sectoral activity variations is the ratio between sectoral and total EU ETS CO_2 emissions (see equation 3.9). Theoretical values are provided in table 3.6. They correspond to the average *sectoral to total EU ETS emissions* ratio over the 2005-2012 period for the EU 25 and EU 15.

3.4.4.2 Activity to CO_2 emissions link : estimated values

At the NACE section level The results of the Hsiao procedure are given in table 3.7 for both EU 15 and EU 25 EU ETS emissions [21]. Reported models (1a, 1b, 2a and 2b) are those for which the hypothesis of full homogeneity can not be rejected at the significance level of 1%. Cross section data can be pooled and the homogeneity specification thus applies (equation 3.11) for all four models. They are all used to estimate the link between EU ETS emissions of EU 15 and EU 25 Member States and Eurostat production indices. Results are provided in table 3.8 for all four models. Robust standard errors were used to take heteroskedasticity into account, which presence was suggested by the White test in all four model specifications.

At the NACE division level The estimation at the NACE division level brings more difficulties, both at the EU 15 and EU 25 scales. First, the homogeneous and semi homogeneous panel specifications cannot apply with model specifications involving variables B,

21. There are missing data for Portugal (section B) and Ireland (section D), hence the number of cross sections are equal to 14 and 24 instead of 15 and 25.

TABLE 3.6: EU ETS emissions and production index theoretical link (in %)

Section	Division	β - EU 25	β - EU 15
B		1.3	1.3
C		34.4	36.7
	C10 - C12	1.2	1.4
	C13 - C15	0.1	0.1
	C16	0.1	0.1
	C17 - C18	2.0	2.3
	C19	9.0	10.0
	C20	3.0	3.6
	C22	0.1	0.1
	C23	10.7	11.1
	C24 - C25	7.4	7.5
	C26	0.0	0.0
	C27	0.2	0.2
	C28	0.0	0.0
	C29 - C30	0.3	0.2
	C31 - C32	0.0	0.0
	C33	0.0	0.0
D		64.3	61.9

Source : the author from CITL

TABLE 3.7: Hsiao tests procedure results at the section level

Model	Area	Regressors	Cross section	Period	p-value
1a	EU 15	B - C	14	7	0,779
1b	EU 15	C - D	14	7	0,012
2a	EU 25	B - C	24	7	0,835
2b	EU 25	C - D	24	7	0,024

Source : the author from Eurostat and CITL

TABLE 3.8: EU ETS emissions and production index empirical link

	Model 1a	Model 1b	Model 2a	Model 2b
β_B	0.187		0.118*	
β_C	0.429***	0.354***	0.473***	0.337***
β_D		0.680***		0.783***
η	-1.97*	-2.119**	-2.295***	-2.034***
R^2 adjusted	0.20	0.36	0.26	0.49
Obs. (#)	98	98	168	168
VIF	1.23	1.05	1.08	1.09
LM test	0.40	0.15	0.85	0.23

*** : 1% level ; ** : 5% level ; * : 10% level

D and any of the following divisions of the manufacturing section : C23, C24-C25, C28, C29-C30, C31-C32 and C33. Indeed, the Hsiao tests procedure rejects both null hypothesis H_0^1 and H_0^2. Second, although the Hsiao tests procedure does not reject the null hypothesis H_0^1 for model specifications involving variables C and D and one of the remaining variables of the manufacturing section, their estimations are not satisfying. Indeed, the addition of another manufacturing division variable to the model specification reduces the R^2 adjusted parameter. Therefore the validation of Eurostat indicators at the division level as proxies for EU ETS sectors production indices is stopped here. This area of research may benefit from the use of other NACE indicators, such as at the group level (3-digit NACE code) or at the class level (4-digit NACE code), provided data is available - which is not the case or at least not comprehensively. Narrowing the activity of chosen indicators would help get closer to performed activities under the EU ETS.

3.4.4.3 Validation at the NACE section level

The null hypothesis that the estimated value of the link between EU ETS emissions and Eurostat production index is equal to the theoretical value is not rejected at the significance level of 10% for all variables of each of the four models (table 3.9). These results thus allow to use Eurostat production indices indicators at the section level in the two-factor decomposition analysis that has been presented in section 3.3 and which results are reported in section 3.5.

TABLE 3.9: Validation of NACE production indices at the section level

Model #	Regressor	Estimated value	Standard Error	Obs. #	Theoretical value	t stat	p-value
1a	B	0.187	0.140	98	0.013	1.245	0.216
1a	C	0.429	0.119	98	0.367	0.525	0.601
1b	C	0.354	0.104	98	0.367	-0.126	0.900
1b	D	0.680	0.193	98	0.619	0.315	0.753
2a	B	0.118	0.069	168	0.013	1.513	0.132
2a	C	0.473	0.080	168	0.344	1.621	0.107
2b	C	0,337	0,061	168	0,344	-0,124	0,902
2b	D	0,783	0,134	168	0,642	1,048	0,296

3.5 Decomposition analysis results : industry contribution to CO_2 through activity

3.5.1 Decomposition analysis : data presentation

Eurostat production indices Activity level data are industrial production indices extracted from the Eurostat *sts_inpr_a* database, with a reference point in 2010 (i.e. production index of each sector equals 100 in 2010). Time period ranges from 2005 to 2012 and production indices are adjusted by working days. Geographical coverage of selected sectors (NACE rev. 2 sections B, C and D) concerns the EU 27 and EU 15, as Eurostat production indices for the EU 25 are no longer available. The EU 15 area has been introduced as this country aggregate does not vary over the time period in the EU ETS, as opposed to enlarged EU, where Romania and Bulgaria enter the Scheme in 2007 only. Production indices data remain aggregated at the NACE section level as NACE division level indicators cannot be used as proxies of EU ETS activities (see section 3.4.4).

EU ETS emissions data EU ETS emissions data correspond to the sum of annual verified emissions of installations participating in the Scheme as reported by the CITL (now EUTL). Emissions data are available for eight years (from 2005 to 2012) for most of EU 27 Member States. Only a subset of the data provided in the CITL is used. Indeed, sectoral and geographical restrictions are applied. Firstly, sectoral emissions are limited to the above mentioned three NACE rev. 2 sections (i.e. B, C and D). Secondly, the analysis is conducted on the EU 25 and the EU 15 so that CO_2 emissions data perimeter remains constant over the period. Emissions data remain representative of the EU ETS as 94%

TABLE 3.10: Decomposition analysis EU ETS emissions coverage

Year	2005	2006	2007	2008	2009	2010	2011	2012
Total EU ETS ($Mt\ CO_2$)	2,014	2 ,036	2,165	2,120	1,880	1,939	1,904	1,864
Analysis - EU 25 ($Mt\ CO_2$)	1,963 (98%)	1,985 (99%)	2,003 (94%)	1,928 (92%)	1,711 (92%)	1,755 (92%)	1,704 (91%)	1,679 (91%)
Analysis - EU 15 ($Mt\ CO_2$)	1,616 (80%)	1,632 (80%)	1,644 (76%)	1,585 (75%)	1,395 (74%)	1,428 (74%)	1,376 (72%)	1,364 (73%)

Source : the author from CITL

(respectively 76%) of the emissions of the Scheme in Phase 1 and Phase 2 are included in the analysis (table 3.10). Identically, emissions data is aggregated by NACE section at both the EU 25 and EU 15 levels.

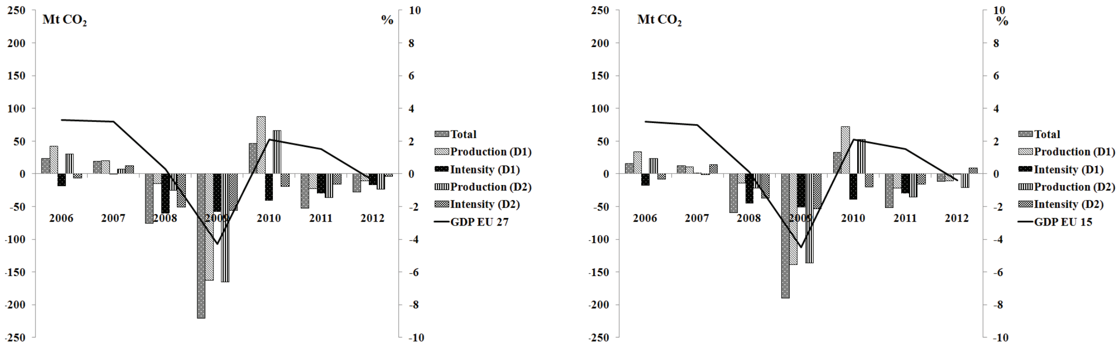
3.5.2 Factor contributions to changes in EU ETS emissions

The decomposition is performed at the NACE section level at first (D1 in figure 3.8). Although it has been showed that Eurostat production indices could not be used at the division level, the decomposition is performed with a manufacturing sector (section C) disaggregated into sub-sectors (at the division level, D2 in figure 3.8). This is done for comparison purposes. Results are given in table 3.11 for the EU 25 and in table 3.12 for the EU 15. Figures are rounded in both tables so may not add up exactly. Results for the decomposition with disaggregated manufacturing sector are summarized in both tables in brackets and are detailed for the EU 15 in appendix 3.G of this chapter. As expected with a two-factor decomposition, both LMDI I and Sun decomposition methods provide identical results, so that ony results of the LMDI I decomposition method are reported.

Be it at the EU 25 or EU 15 scale, two main results about factor contributions can be derived from the *aggregated* decomposition :

1. The activity factor has a greater or similar contribution to that of the intensity factor in changes in EU ETS emissions (except in 2008) stemming from NACE rev. 2 sections B, C and D ; and follows gross domestic product trend (figure 3.8).
2. The intensity factor contributes to reducing EU ETS emissions. This can be accounted by sectoral contributions to the intensity factor.

The *aggregated* decomposition shows that activity has been the main factor contributing to CO_2 emissions changes in years 2006, 2007, 2009 and 2010, whether these changes are



(a) EU 25 (b) EU 15

Figure 3.8: Factors contributions to EU ETS emissions changes
D1 : *aggregated* decomposition ; D2 : *disaggregated* decomposition.

Source : the author from Eurostat and CITL

Table 3.11: EU ETS decomposition analysis - EU 25 (Mt CO_2)

Year	2006	2007	2008	2009	2010	2011	2012
Activity	**42 (30)**	**20 (7)**	**-15 (-25)**	**-163 (-165)**	**88 (66)**	**-22 (-36)**	**-11 (-24)**
B	-1	-0	1	-3	-0	-2	-1
C	32 (20)	28 (15)	-13 (-23)	-106 (-108)	43 (21)	27 (13)	-13 (-26)
D	11	-9	-1	-54	45	-47	3
Intensity	**-19 (-7)**	**-0 (13)**	**-60 (-51)**	**-58 (-56)**	**-41 (-19)**	**-30 (-16)**	**-17 (-4)**
B	0	4	3	2	0	-0	-0
C	-21 (-9)	-20 (-7)	16 (25)	-10 (-8)	-7 (14)	-41 (-26)	-18 (-5)
D	2	16	-79	-50	-34	11	1
Total	**23**	**19**	**-76**	**-221**	**47**	**-52**	**-28**

Source : the author from Eurostat and CITL

positive or negative. Intensity has contributed the most to emissions changes in 2008 and both factors have rather equivalent contributions (that of intensity being greater than that of activity though) in 2011 and 2012. The *disaggregated* decomposition provides a greater contribution of the activity factor in emissions changes except for year 2007, where the relation between the two factors is inverted compared to the *aggregated* decomposition. As a general rule, contributions of the activity and intensity factors are slightly smaller and greater respectively than in the *aggregated* decomposition. Although not too distant from the *aggregated* decomposition results, the fact that NACE division production indices cannot be used as EU ETS activities proxies should account for these differences.

TABLE 3.12: EU ETS decomposition analysis - EU 15 (Mt CO_2)

Year	2006	2007	2008	2009	2010	2011	2012
Activity	**33 (23)**	**10 (-1)**	**-14 (-22)**	**-138 (-136)**	**72 (53)**	**-22 (-36)**	**-11 (-21)**
B	-1	-0	1	-3	-0	-2	-1
C	25 (14)	21 (10)	-13 (-20)	-93 (-91)	36 (16)	22 (8)	-13 (-23)
D	10	-11	-1	-42	37	-42	3
Intensity	**-18 (-8)**	**2 (14)**	**-45 (-36)**	**-51 (-53)**	**-40 (-20)**	**-30 (-16)**	**-1 (9)**
B	0	4	3	1	0	-0	0
C	-19 (-9)	-15 (-3)	17 (25)	-4 (-6)	-3 (17)	-39 (-25)	-13 (-3)
D	1	13	-66	-49	-37	9	12
Total	**15**	**12**	**-59**	**-190**	**33**	**-52**	**-12**

Source : the author from Eurostat and CITL

TABLE 3.13: Section D contribution to *intensity* factor and elec. mix changes - EU 25

Year	2006	2007	2008	2009	2010
Contribution	+	+	-	-	-
Fossil fuels based electricity	↗↗	↗	↘	↘↘	↘
Non emitting electricity	↗	↘	↗	↘	↗

Source : the author from the World Bank Databank

3.5.3 Sectoral contribution to factors

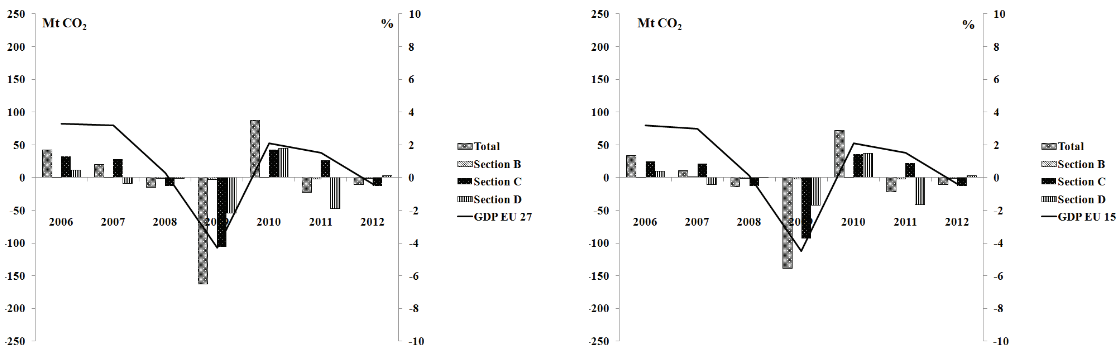
Intensity factor The contribution of NACE section D to the intensity factor results from the evolution of the electricity production mix. The contribution sign is indeed directly linked to the parallel evolutions of fossil fuel based electricity production and non emitting electricity production as reported in table 3.13 for the 2006-2010 period (the latest available data from the World Bank databank is 2010). In year 2006, the contribution to CO_2 emissions of NACE rev. 2 section D in the EU 15 is positive although the contrary could have been expected given that non emitting electricity production increases more than fossil fuels based. This unexpected result is nonetheless tempered by the fact that the positive contribution amounts to 1 million as opposed to that of section C which reaches minus 19 million tons (in the *aggregated* decomposition).

NACE rev. 2 section D has the greatest contribution to the intensity factor in years 2008, 2009 and 2010 (tables 3.11 and 3.12), enabling reductions in CO_2 emissions. This

TABLE 3.14: Section D contribution to *intensity* factor and elec. mix changes - EU 15

Year	2006	2007	2008	2009	2010
Contribution	+	+	-	-	-
Fossil fuels based electricity	↗	↗	↘	↘↘	↗
Non emitting electricity	↗↗	↘	↗	↘	↗↗

Source : the author from the World Bank Databank



(a) EU 25

(b) EU 15

FIGURE 3.9: Sectoral contributions to the *activity* factor

Source : the author from Eurostat and CITL

coincides with electricity production mix being less intensive in CO_2 in both the EU 27 and EU 15 (tables 3.13 and 3.14). In other years, the manufacturing sector contributes the most to emissions reduction.

Activity factor In both *aggregated* and *disaggregated* decompositions, and for both geographical coverages, the manufacturing sector is the main contributor to activity changes, except in year 2011. Figure 3.9 gathers the sectoral contributions to the activity factor for the *aggregated* decomposition. The *disaggregated* decomposition shows that two divisions of the manufacturing sector contribute to the same scale as section D : the manufacture of other non-metallic minerals (division C23) and the manufacture of basic metals and of fabricated metal products (which gathers divisions C24 and C25) as illustrated for the EU 15 in appendix 3.G of this chapter.

3.6 Conclusion

Sectoral contribution to CO_2 emissions under the EU ETS The purpose of this chapter was to provide a quantified picture of sectoral weights in EU ETS carbon price dynamics. To achieve this stated goal it was decided to assess the sectoral activity impact on CO_2 emissions variations through a two-factor decomposition analysis. Indeed, the limits of research works using carbon price data has motivated the shift towards the assessment of sectoral impact on emissions rather than on carbon price. The shift in data nature has resulted in a change in methodology i.e. switching from an econometric (behavioral) to a decomposition (accounting) analysis. The results of the decomposition analysis first confirm that the activity factor contributes to changes in EU ETS CO_2 more than the intensity factor. Secondly, they show that the manufacturing sector is the main contributor of the activity factor. Therefore, it has been showed that, while being twice as small as the power sector, in terms of emissions share in the Scheme, the manufacturing sector contributes to a larger extend to the changes in emissions than the power sector does.

One side-product of this research work is that it was demonstrated that Eurostat production indices indicators, at the section level, could be used as EU ETS activities proxies. On the contrary, production indices at the division level appeared embracing too large activities to depict those covered under the Scheme. Nonetheless, this result is encouraging with regards to activity level quantitative analysis in the EU ETS provided two requirements are fulfilled. First NACE rev. 2 codes should be attributed to all installations participating in the Scheme and/or be made publicly available ; second, efforts to fill Eurostat data at the 4-digit NACE code should be sustained.

Back to sectoral impact on carbon price For all that, can a clear cut conclusion on the sectoral impact on carbon price be drawed ? The analysis was conducted starting from the work hypothesis that assessing the sectoral impact on EU ETS emissions variation could inform on the sectoral impact on carbon price dynamics in the market, i.e. that aggregated emissions changes were a reasonable proxy for carbon price dynamics. It was showed in this chapter that this work hypothesis was valid under a couple of assumptions. Among them, the assumption of increasing marginal abatement costs with required abatement and the absence of market power. Implied here is that the just mentioned increasing with abatement marginal abatement cost function corresponds to the aggregation of marginal abatement curves of market participants. Should they all be identical, making any sector representative of all other as in standard microeconomics theory of competitive market (i.e. no exercise of market power), and the extension from sectoral impact on emissions to sectoral impact on carbon price is straightforward : the manufacturing sector contributes to carbon price variation at least as much as the power sector does.

3.A Energy prices and fuel-switching

The amount of CO_2 emissions that is released in the atmosphere from the production of electricity depends on the carbon content of the primary energy source that has been transformed. Electricity production obeys to the merit order ranking : power plant operators that have a diversified production mix portfolio choose to produce electricity with electricity production options in order of increasing variable costs. Coal (including lignite) and natural gas (including derived gas) have accounted for 26.3% and 23.6% [22] of electricity production in the EU 27 in 2008 respectively. They are the main two primary energy sources that are substitutable one another within a power plant, in a process called fuel-switching. Where technically possible, fuel-switching occurs when the economic conditions involve a change in the electricity production merit order involving these two energy sources.

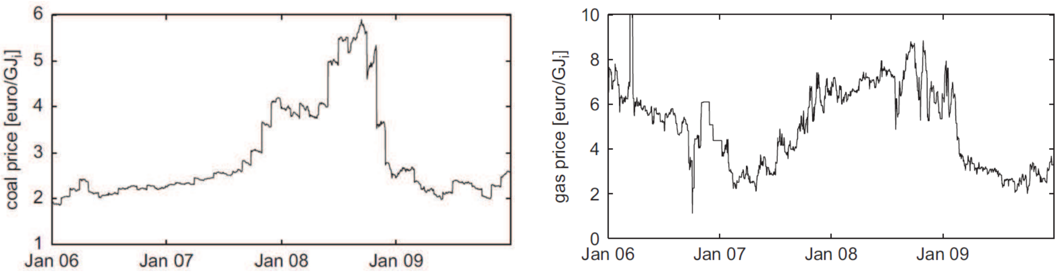


FIGURE 3.10: Coal and natural gas prices over 2006-09

Source : Declercq et al. (2011) from DataStream, Thomson/Reuters

Energy prices (EP) and power plants efficiency (η) are the main two factors accounting for fuel switching. In Europe, coal price is on average lower than that of natural gas as illustrated in figure 3.10 ; as well as coal based electricity CO_2 content (EI) is higher than that of natural gas (0.812 versus 0.236 tons of CO_2 per megawatt hour respectively in Europe in 2010 (IEA, 2012)). As a consequence, the combustion of coal ranks first in the merit order and generates more CO_2 emissions for an identical volume of electricity than from the combustion of natural gas. The introduction of carbon pricing involves the possibility that, from and above a given level of carbon price, natural gas based electricity becomes cheaper to produce. This given level is the switching price i.e. the price of an emission allowance from which running a natural gas power plant is more economic (equation 3.15). Switching from coal to gas leads to what is referred to as short term abatement. The coal

22. EEA database : share of electricity production by fuel type in 2008. Accessed on January 28, 2013.

to gas price ratio is thus key in the CO_2 intensity of produced electricity, which therefore drives the price of emission permits through the need to cover emitted CO_2.

$$Switch = \frac{\eta_{coal} \times EP_{gas} - \eta_{gas} \times EP_{coal}}{\eta_{gas} \times EI_{coal} - \eta_{coal} \times EI_{gas}} \tag{3.15}$$

Delarue et al. (2010) provide an estimation of short term CO_2 emissions abatement through fuel switching in the European power sector over the years 2005 and 2006.

3.B Deriving MAC curves from PRIMES model

Methodology The determination of a more elaborated than a linearly interpolated abatement cost curve requires two elements :

1. A parametric functional form for the abatement cost curve, which gives the abatement trend as a continuous function of carbon price ;
2. Discrete levels of emissions for a given carbon price, which allow the calibration of the function parameters.

The marginal abatement cost (MAC) curve is the slope (or first derivative) of the abatement cost curve.

Functional form of the abatement cost curve The functional form of the abatement cost curve is taken from De Cara and Jayet (2011) and is given in equation 3.16.

$$E(p) = E_0 (1 - \alpha(p)) \tag{3.16}$$

Where E_0 is the reference level of emissions of a given sector, that is the level of emissions with no carbon price (or baseline emissions), and $\alpha(p)$ the abatement rate as a function of carbon price, which is explicated in equation 3.17.

$$\alpha(p) = \overline{\alpha} \left(1 - e^{-\left(\frac{p}{\tau}\right)^{\beta}}\right) \tag{3.17}$$

Where parameter $\overline{\alpha}$ represents the maximum abatement rate technically achievable by the sector as it is assumed that there are incompressible emissions. Parameter τ indicates the carbon price for which abatement reaches approximately two thirds of achievable abatement (63% of $\overline{\alpha}E_0$). Parameter β indicates whether the abatement cost curve has an inflexion point : β strictly greater than 1 implies the presence of one, that is an increasing abatement rate variation first (accelerating returns), then a decreasing one (diminishing returns). The three parameters are determined using the data provided by the PRIMES model.

PRIMES outputs PRIMES output are from Blok et al. (2001). They provide the level of CO_2 emissions with respect to carbon price. Abatement, then abatement rate are derived from these data (table 3.15). Below values concern an aggregation of PRIMES

TABLE 3.15: PRIMES non-power sector abatement in 2010

Carbon price (Euro/t CO_2)	0.3	0.5	3	5	14	19	30	44	60	79	125	191
Abatement (Mt CO_2)	0	3	14	31	59	74	105	126	156	191	240	280
Abatement rate (%)	0	0	2	4	8	10	14	17	21	26	33	38

Source : the author from Blok et al. (2001)

defined sectors that is the closest to the non-power sector of the EU ETS [23]. The reference level of emission E_0 is equal to 737 million tons of CO_2, and reference year is 2010 (i.e. derived abatement is for different values of carbon price in 2010).

Results

Calibration procedure and results The methodology to calibrate the three parameters (α, β and τ) is derived from Tufféry (2007). It is a two-step process, both of which consisting in a learning phase and a test phase. Learning phase consists in determining the values of the parameters with a learning sample. The obtained values are then tested with the test sample which, here, is different from the learning one. The learning sample is a partition of the data provided by the PRIMES model, the test sample is the complementary of the learning sample. As said above, both learning and testing phases are applied to the two calibration steps : first step aims at determining the best size of the sample, second step outputs the best parameter set obtained with the learning and testing samples of previously determined sizes.

Choice of the learning and test samples The size of the learning sample may range from 8 to 14 elements, as 17 elements are available from the PRIMES model. The size of the testing sample is simply the difference between the total available data and the size of the learning sample. Elements of the learning sample are randomly chosen. Elements composing the testing sample are those not in the learning sample (both samples are complementary). One hundred samples are generated for each size of the learning sample (i.e. ranging from 8 to 14 elements, that is seven sample sizes). An optimization is performed

23. Gathered PRIMES sectors are those classified under *Industry* added to that of *industrial generators* in Blok et al. (2001).

for each of the 700 learning samples : the values of the parameters of the abatement cost functional form are optimized to minimize the error with PRIMES data ; this is the learning phase. Then the obtained parameters are tested with the testing sample : the error these parameters involve (with PRIMES data which have not been used to calibrate them) is calculated. This is the testing phase. An average error is provided for each learning sample size (the average error is weighted by the sample size). The chosen size is 10.

Results : choice of the parameters set One hundred of ten-element learning samples are randomly generated and each is tested with the corresponding test samples. The chosen parameter set is the one which minimizes the averaged learning and testing sum. The obtained parameter set indicates that 45% of baseline emissions can be abated (parameter $\overline{\alpha}$), that two thirds of this abatement will occur at a carbon price of 97 Euro/t CO_2 (parameter τ) and that abatement has a diminishing return (β equal to 0.85 and thus below 1).

3.C Hsiao homogeneity tests procedure

The procedure proposed by Hsiao consists in up to three tests. The first one tests the hypothesis of a homogeneous structure of the model (H_0^1), against either constant α or elasticity β heterogeneity (H_a^1).

First test : global homogeneity test

$$\begin{cases} H_0^1 : \forall i \in [1, N], \beta_i = \beta \ and \ \alpha_i = \alpha \\ H_a^1 : \exists (i, j) \in [1, N] / \beta_i \neq \beta_j \ or \ \alpha_i \neq \alpha_j \end{cases}$$

The Fisher statistic of the global homogeneity test is given in equation 3.18, where SCR_1 is the square sum of residuals of the heterogeneous model (equation 3.13), and $SCR_{1,c}$ is the square sum of residuals of the homogeneous model (equation 3.11).

$$F1 = \frac{SCR1_{1,c} - SCR_1}{(N-1)(K+1)} \times \frac{NT - N(K+1)}{SCR_1} \tag{3.18}$$

If H_0^1 is not rejected, the model has a homogeneous panel structure (equation 3.11) and the specification tests procedure ends. If H_0^1 is rejected, the panel structure is rejected and a second test is performed to test the hypothesis of elasticity homogeneity (H_0^2), against elasticity heterogeneity (H_a^2), assuming constant heterogeneity.

Second test : elasticity homogeneity test

$$\begin{cases} H_0^2 : \forall i \in [1, N], \beta_i = \beta \\ H_a^2 : \exists (i, j) \in [1, N] / \beta_i \neq \beta_j \end{cases}$$

The Fisher statistic of the elasticity homogeneity test is given in equation 3.19, where SCR_1 is the square sum of residuals of the heterogeneous model (equation 3.13), and $SCR_{1,c'}$ is the square sum of residuals of the partially heterogeneous model (equation 3.12).

$$F2 = \frac{SCR1_{1,c'} - SCR_1}{(N-1)K} \times \frac{NT - N(K+1)}{SCR_1} \tag{3.19}$$

If H_0^2 is rejected, the model is fully heterogeneous (equation 3.13). The specification tests procedure ends and panel data analysis can not be applied : there are as many models as cross country dimensions. If H_0^2 is not rejected, a third test is performed to determine whether constants have an individual dimension. The hypothesis of constant homogeneity (H_0^3) is tested against elasticity heterogeneity (H_a^3), assuming elasticity homogeneity.

Third test : constant homogeneity test

$$\begin{cases} H_0^3 : \forall i \in [1, N], \alpha_i = \alpha \\ H_a^3 : \exists (i, j) \in [1, N] / \alpha_i \neq \alpha_j \end{cases}$$

The Fisher statistic of the elasticity homogeneity test is given in equation 3.20.

$$F3 = \frac{SCR1_{1,c} - SCR_{1,c'}}{(N-1)} \times \frac{N(T-1) - K}{SCR_{1,c'}} \tag{3.20}$$

If H_0^3 is rejected, the model is partially heterogeneous (equation 3.12). If H_0^3 is not rejected, the model has a homogeneous panel structure (equation 3.11). This test thus confirms or invalidates the results obtained in the first test (global homogeneity test). It is more powerful than the first test as it involves less linear restrictions (restrictions of H_0^3 concern the constant term only, whereas those of H_0^1 concern both the constant and elasticity terms).

3.D Tested NACE rev. 2 divisions for the decomposition analysis

Section	Division	Description
B		Mining and quarrying
C		Manufacturing
	C10 - C12	Manufacture of food products, beverages, tobacco products
	C13 - C15	Manufacture of textiles, wearing apparel, leather and related products
	C16	Manufacture of wood and of products and of cork, except furniture (...)
	C17 - C18	Manufacture of paper and paper products Printing and reproduction of recorded media
	C19	Manufacture of coke and refined petroleum products
	C20	Manufacture of chemicals and chemical products
	C22	Manufacture of rubber and plastic products
	C23	Manufacture of other non-metallic mineral products
	C24 - C25	Manufacture of basic metals, fabricated metal products, except machinery and equipment
	C26	Manufacture of computer, electronic and optical products
	C27	Manufacture of electrical equipment
	C28	Manufacture of machinery and equipment n.e.c.
	C29 - C30	Manufacture of motor vehicles, trailers and semi-trailers Manufacture of other transport equipment
	C31 - C32	Manufacture of furniture, and other manufacturing
	C33	Repair and installation of machinery and equipment
D		Electricity, gas, steam and air conditioning supply

3.E EU ETS emissions : from NACE rev. 1 to NACE rev.2

Transposition definition Transposition of EU ETS emissions from NACE rev. 1 to NACE rev. 2 is performed from the division level (i.e. 2-digit NACE code). In this sense, the transposition is approximate since there exists some NACE rev. 1 classes (i.e. 4-digit NACE code) that correspond to more than one NACE rev. 2 classes. For instance the NACE rev. 1 class 1010 (*Mining and agglomeration of hard coal*) is transposed into three different NACE rev. 2 classes that are 510 (*Mining of hard coal*), 990 (*Support activities for other mining and quarrying*) and 1920 (*Manufacture of refined petroleum products*). These three classes belong to three different divisions of three different sections. The choice to transpose this NACE rev. 1 class into a given section and division is purely arbitrary, hence the approximate character of the EU ETS emissions transposition to the second NACE revision.

TABLE 3.16: EU ETS emissions : from NACE rev. 1 to NACE rev.2 (kt CO_2)

rev. 1 division	EU ETS emissions	rev. 2 division
C10 - C14	22,280	B (section)
D15 - D16	24,814	C10 - C12
D17 - D19	1,320	C13 - C15
D20	2,936	C16
D21 - D22	40,282	C17 - C18
D23	173,617	C19
D24	48,245	C20
D25	2,792	C22
D26	220,968	C23
D27 - D28	148,212	C24 - C25
D29	996	C28
D30, D32 - D33	621	C26
D31	2,109	C27
D34 - D35	6,637	C29 - C30
D36	615	C31 - C32
D37	675	C33
E40	1,285,827	D35

Source : the author from Eurostat and CITL

Only EU ETS emissions belonging to NACE rev. 1 sections C, D and E are transposed into NACE rev.2 as indicated in table 3.16. Reported values are for year 2005. Norway, Bulgaria and Romania are not included as not participating in the Scheme in 2005.

Transposition assessment The validity of this approximate transposition can be estimated by assessing its impact on Eurostat CO_2 emissions that have been classified by Eurostat in both NACE revisions for year 2008, at the division level. Figures are reported in table 3.17.

Table 3.17: Eurostat CO_2 emissions in both NACE revisions in 2008 (kt CO_2)

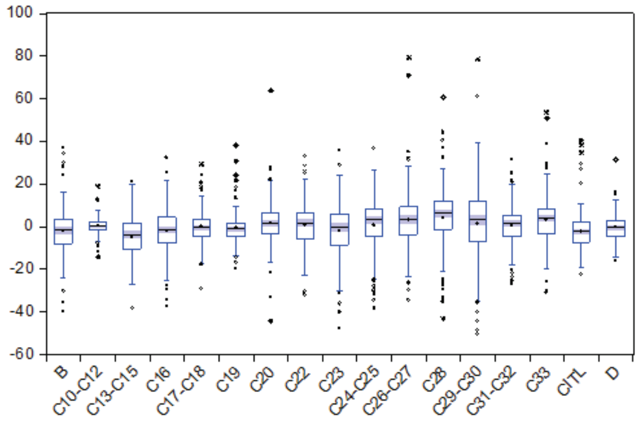
rev. 1 division	rev. 1 EU 27 emissions	rev. 2 division	rev. 2 EU 27 emissions
D15 - D16	80 874	C10 - C12	63 778
D17 - D19	18 379	C13 - C15	14 034
D20	8 508	C16	6 079
D21 - D22	45 600	C17 - C18	43 970
D23	159 246	C19	164 274
D24	149 737	C20	151 628
D25	12 923	C22	17 446
D26	251 655	C23	233 996
D27 - D28	251 777	C24 - C25	244 217
D29	15 176	C28	13 497
D30, D32 - D33	5 404	C26	5 573
D31	6 413	C27	7 131
D34 - D35	19 501	C29 - C30	19 157
D36 - D37	13 804	C31 - C33	15 410
C (section)	53 368	B (section)	50 360
D (section)	1 038 996	C (section)	1 011 515
E (section)	1 358 372	D (section)	1 361 970
Total Rev. 1	2 450 736	Total Rev. 2	2 423 845

Source : the author from Eurostat

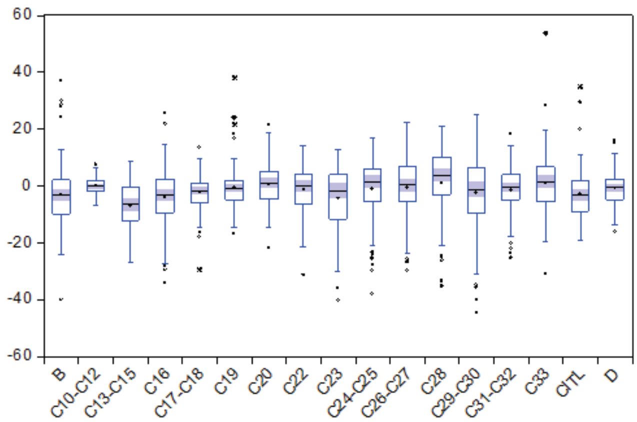
3.F Datasets descriptive statistics

Considering sections B, C and D, Ireland and Portugal have missing data in section D and section B (in 2009) respectively. Romania and Bulgaria have missing CO_2 data for at least one year over the 2006-12 period. These two countries are hence removed from the dataset.

At the division level Descriptive statistics and box plots are provided for the EU 25 and the EU 15 in table 3.18 and figure 3.11. Reported figures are derived from balanced variables.



(a) EU 25



(b) EU 15

FIGURE 3.11: Box plot of unbalanced dataset at the NACE division level

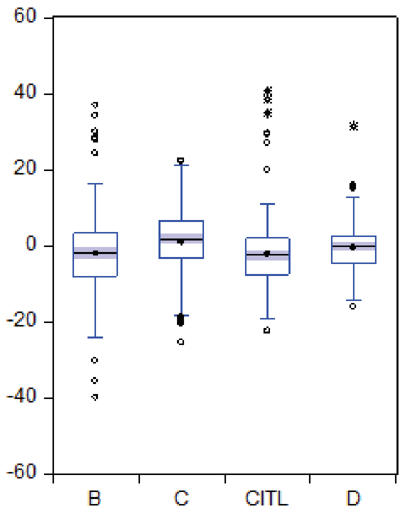
Source : Eurostat and CITL

Table 3.18: Dataset descriptive statistics - EU 15 (above) and EU 25 (below) division level (in %)

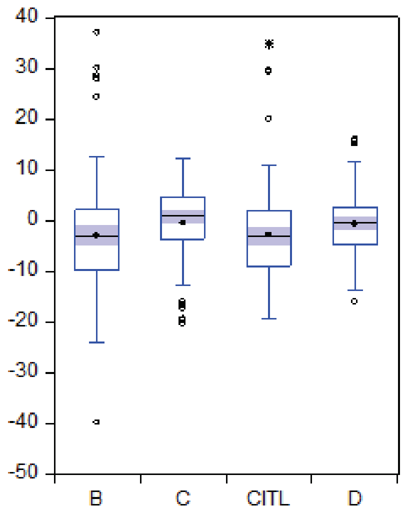
Division	10-12	13-15	16	17-18	19	20	22	23	24-25	26-27	28	29-30	31-32	33
Mean	0.2	-6.7	-3.9	-2.1	-0.4	0.5	-1.1	-4.2	-1.0	-0.7	1.1	-2.4	-1.4	1.2
	0.6	-5.1	-1.7	-0.0	-0.5	1.9	0.9	-2.2	0.7	3.1	4.0	1.3	0.4	3.2
Median	0.0	-6.4	-3.0	-1.5	-0.7	1.2	0.0	-1.5	1.7	0.5	4.0	-1.1	-0.3	1.7
	0.20	-3.6	-1.4	-0.3	-1.0	1.6	1.8	-0.3	3.3	3.6	6.2	3.3	1.8	4.0
Max.	7.8	8.7	25.6	13.6	38.2	21.8	14.3	13.1	17.2	22.4	21.3	25.0	18.4	53.8
	19.2	21.2	32.5	29.3	38.2	63.9	33.2	36.0	36.8	79.3	60.8	78.5	31.5	53.8
Min.	-6.7	-26.9	-34.0	-29.2	-16.7	-21.6	-31.2	-40.1	-37.9	-29.8	-35.2	-44.5	-25.4	-30.9
	-14.1	-38.4	-37.5	-29.2	-19.7	-44.2	-32.1	-47.8	-38.6	-34.3	-43.1	-50.1	-27.0	-30.9
Std. Dev.	2.7	8.7	10.6	6.2	8.9	8.1	8.2	10.8	11.6	10.8	13.0	14.6	9.0	11.1
	4.2	10.0	11.5	8.1	8.4	11.3	10.8	13.7	13.6	14.9	15.5	17.4	10.5	12.7
Skew.	0.3	-0.4	-0.3	-1.0	1.5	0.0	-0.8	-1.0	-1.2	-0.8	-1.2	-0.6	-0.9	0.9
	0.4	-0.3	-0.2	0.4	1.4	0.6	-0.2	-0.6	-0.8	1.2	-0.4	0.1	-0.3	0.4
Kurtosis	3.4	2.5	3.6	6.2	7.3	3.4	3.9	3.7	3.9	3.4	3.8	3.4	3.9	8.0
	6.2	3.3	3.8	4.9	7.5	9.5	4.0	4.0	3.7	9.2	4.8	5.9	3.9	5.5
Sum	21	-560	-382	-205	-34	44	-103	-413	-92	-54	107	-238	-121	109
	98	-783	-299	-5	-68	303	152	-386	113	477	704	221	69	536
Obs. (#)	98	84	98	98	77	84	91	98	91	84	98	98	84	91
	168	154	175	168	126	161	168	175	161	154	175	168	154	168

Source : the author from Eurostat and CITL

At the section level Descriptive statistics and box plots are provided for the EU 25 and the EU 15 in table 3.19 and figure 3.12. Reported figures are derived from balanced variables .



(a) EU 25



(b) EU 15

FIGURE 3.12: Box plot of balanced dataset at the NACE section level

Source : Eurostat and CITL

TABLE 3.19: Dataset descriptive statistics - section level (in %)

	EU 15				EU 25			
	B	C	D	CITL	B	C	D	CITL
Mean	-2.50	-0.51	-0.41	-2.59	-1.60	1.09	-1.92	-0.30
Median	-2.40	1.30	-0.40	-2.97	-1.40	2.00	-2.20	-0.20
Max.	30.10	12.40	16.10	34.88	37.10	22.50	40.63	31.60
Min.	-23.90	-20.30	-13.60	-19.23	-39.80	-25.40	-22.32	-14.00
Std. Dev.	10.51	7.55	6.20	9.61	11.91	9.10	9.68	6.37
Skew.	0.62	-0.97	0.46	1.27	0.19	-0.57	1.63	0.93
Kurtosis	4.45	3.37	3.21	6.51	4.60	3.41	8.41	6.40
Sum	-227.80	-46.30	-36.90	-235.82	-257.20	176.00	-308.67	-47.80
Obs. (#)	91	91	91	91	161	161	161	161

Source : the author from Eurostat and CITL

3.G Sectoral contributions to EU ETS emissions - EU 15

The following table gathers the results of the *disaggregated* decomposition of EU ETS emissions in the EU 15, with the use of the LMDI I method, for the activity factor. Figures are expressed in thousand tons of CO_2.

	2006	2007	2008	2009	2010	2011	2012
Total	23,329	-1,238	-22	-136,265	52,736	-35,628	-20,628
B	-815	61	-911	-2,565	-102	-1,896	-1,284
C10 - C12	241	288	-244	-291	289	326	-349
C13 - C15	-11	-6	-87	-138	28	-30	-39
C16	63	5	-175	-297	24	29	-77
C17 - C18	706	466	-1,005	-3,122	897	-442	-1,378
C19	-1 313	245	1 509	-12 287	-3 419	-2 653	-2 154
C20	1,668	1,381	-1,709	-7,962	5,861	727	-1,159
C22	64	76	-109	-287	114	48	-62
C23	6,850	1,357	-14,404	-36,003	2,118	3,128	-12,796
C24 - C25	5,723	5,367	-4,003	-28,773	9,232	6,070	-4,486
C28	37	34	5	-125	38	43	1
C26	46	45	4	-123	35	33	-10
C27	190	109	-41	-1,015	403	151	-101
C29 - C30	117	172	-147	-784	488	326	-72
C31 - C32	20	9	-21	-90	25	10	-13
C33	51	26	20	-63	11	27	-15
D	9,689	-10,873	-594	-42,339	36,694	-41,524	3,364

Source : the author from Eurostat and CITL

4

Benchmarking in EU ETS Phase 3

Note This chapter is based on two articles. More precisely, section 4.2 is adapted from a first article published in *Economics of Energy & Environmental Policy* (volume 2, issue 2). Section 4.3 is adapted from a second one which has been accepted and is forthcoming at *Climate Policy*. The latter article has been co-authored.

4.1 Introduction

In a market configuration with no transaction costs, Montgomery (1972) showed that, for a given cap, initial allocation of emission permits had no impact on the efficiency nor on the abatement incentive of the market : be initial allocation derived from auctioning, *ex ante* benchmarking or *ex ante* grandfathering, performed abatement is identical and reached at least cost. Indeed, the arbitrage is in theory made between internal abatement cost and emission permits price, which is imposed to all market participants[1]. On the contrary, welfare resulting from the price attributed to emission permits depends on initial allocation *a priori*. Auctioning is considered more efficient as it allows to use generated revenues to cut distortionary taxes (or to produce public goods), whereas these revenues are captured by regulated private entities with grandfathering (Goulder et al., 1999).

As the first international carbon market for mitigating carbon dioxide emissions, the European Union Emissions Trading Scheme (EU ETS) is also the first emissions trading scheme that has implemented, on a large scale, initial allocation based on both grandfathering and benchmarking (the latter has been implemented in Phase 3 in 2013 for the first time). In light of initial allocation mode theoretical implications, a substantial literature has developed since the creation of the EU ETS and based on lessons learned from 2005 to 2012. Focusing on the question of incentive to perform abatement, Abrell et al. (2011)

1. On the longer term though, Milliman and Prince (1989) showed that environmental innovation would be slowed down because reducing the value of grandfathered emission permits.

showed through an econometric analysis that high levels of free allocation in the first two phases of the Scheme seem to have masked the carbon price signal to installations or, in other words, that the decision to abate was not based on the carbon price / internal abatement cost arbitrage, thus invalidating what could theoretically be expected in terms of abatement incentive in the short term. These high levels of free allocation were underlined by Trotignon and Delbosc (2008) in Phase 1 and by Pearson (2010) in Phase 2, before the economic downturn cut emissions levels down. Not performing the arbitrage between carbon price and internal abatement cost directly results in reducing the efficiency of the Scheme, as least cost abatement opportunities are not systematically exploited, making demand for emission permits, and thus carbon price, greater than its expected theoretical value. Over allocation has often been used to qualify these high levels of initial free allocation, although Ellerman and Buchner (2008) has nuanced this statement suggesting that these high levels of free allocation could as well result from *ex post* abatement. Such initial free allocation levels originated from the decentralized National Allocation Plan (NAP) approach that was chosen in both Phase 1 and Phase 2, as a political compromise (or policy second best alternative) for the implementation of the Scheme (Ellerman et al., 2010; Boemare and Quirion, 2002). A side effect of such compromise is the non-harmonization of free allocation to installations at the EU level. This has left the possibility for sectoral competitiveness distortion in final product markets (Betz et al., 2004, 2006; González, 2006) [2], advantaging some market operators of a country over others from another Member State.

Given the field experience provided by the first two phases of the EU ETS, the European Commission amended the emission permits allocation principles in Phase 3, which has started in 2013 : auctioning has become the standard allocation mode, but free allocation is expected to continue until 2027 for installations considered non-electricity generators. Nonetheless, benchmarking has replaced grandfathering to address above mentioned issues : the observed lack of incentive of grandfathering leading to reducing the efficiency of the Scheme, and the potential sectoral distortion involved by NAPs. The EU ETS therefore offers the best opportunity to assess the merits of benchmarking with regards to lessons learned from the first two periods (2005 to 2012) where grandfathering, as initial allocation mode, ruled. Benchmarking rules are gathered in (European Parliament Council, 2011a), and constitute what is referred to as transitional Community-wide rules. It is by scrutinizing this reference document that benchmarking, the way it has been defined and

2. Market distortion resulting from NAPs should certainly be put in front of socio-productive structures as developed by Lordon (2009).

implemented, is assessed in terms of enabling to reach the objectives set by the Commission. Section 4.2 aims at providing materials to feed the discussion on the *incentive* objective of benchmarking. Indeed, it suggests that, based on both theoretical rules and the concrete examples of their application at the Scheme's aggregated level, switching from grandfathering to benchmarking in Phase 3 should not dramatically change the conditions prevailing in the first two phases, therefore questioning the overall economic efficiency of the newly introduced allocation mechanism. The two factors accounting for this are to be found in the *grandfathering dimension* that remains in the definition of benchmarks combined with the economic downturn that has affected emissions levels downwards, and the carbon leakage provision that has been introduced to protect non-electricity generators that are identified as exposed to international competition. Section 4.3 focuses on the objective of harmonized allocation that benchmarking is expected to bring. Based on an original database gathering provisional Phase 3 free allocation and an elementary econometric model, it is suggested that part of the variation of free allocation to cement clinker producing installations results in the mitigation of the NAPs distortion as well as Phase 1 and Phase 2 over allocation.

4.2 Phase 3 free allocation : introducing benchmarks

The EU ETS, the largest emissions allowances cap and trade market in the world (Ellerman and Buchner, 2007), has undergone a radical change in Phase 3 (2013-2020). Allocation methodology has shifted from grandfathering to a combination of auction-based allocation and free allocation now taking place within the framework of the "Community-wide and fully harmonised Implementing Measures" (CIMs). Broadly speaking, electricity generators are not to be allocated free emission quotas (European Union Allowances) except for activities other than the production of electricity [3] ; free allocation, based on benchmarking, now applies mainly to non-electricity generators and is transitional. Non-electricity generators will receive a decreasing amount of free allowances throughout the phase, with a target of no free allocation by 2027, as stated in article 10a(11) of the Consolidated ETS Directive (European Parliament Council, 2009). Consequently, Phase 3 inaugurates a new market configuration where the value of emission permits is redistributed among market participants and public authorities : allowance auctioning is progressively becoming the allocation standard, and both primary and secondary emission permits markets now coexist. This shift changes the emissions allowance supply and demand structure and thus permits

3. The case of preliminary amounts of electricity generators is briefly explained in appendix 4.A of this chapter.

transfers between actors, as installation operators are now expected to manage their free allocation entitlement more strictly than they used to in the first two phases (Brockmann et al., 2012).

The shift from free allocation to auctions has been adopted as the main change in allowance allocation. In fact, the allowances to be auctioned in Phase 3 are those that will not be allocated free of charge. Transitional free allocation associated with the move from grandfathering to Community-wide rules therefore merits special attention. This section aims to take the analysis conducted by Pauer (2012) a step further by quantifying the changes that these transitional Community-wide rules involve and by identifying their potential flaws. Phase 3 free allocation rules are described in section 4.2.1. The main two changes that they imply in Phase 3 compared to Phase 2 are presented in section 4.2.2 and illustrated using Member States free allocation data. Section 4.2.3 explains why these Community-wide rules, and the way they have been defined by the European Commission, are possibly flawed.

4.2.1 Community-wide transitional free allocation rules

In the first two phases of the EU ETS, each Member State participating in the Scheme was allocated an envelope of free allowances that it could distribute at its discretion. Detailed allocation at installation level was embodied in the NAP of the Member State, and the overall allocation amount had to be in line with its Kyoto Protocol target and validated by the European Commission. The amount of allowances to be allocated free of charge remains capped in Phase 3 but, unlike in Phase 1 and Phase 2, Member States do not have a pre-determined free allowances envelope. Phase 3 final free allocation involves a three-step process, which is described in the following subsections. The free allocation entitlement of an installation, referred to as the preliminary amount, is determined by the operator of the installation, following benchmarking rules. Simultaneously the European Commission determines annual free allocation caps in Phase 3, referred to as maximum amounts, in accordance with article 10a(5) of the Consolidated ETS Directive. The Phase 3 final free allocation entitlement process ends once two different correction factors are applied to preliminary amounts : the Cross Sectoral Correction Factor (CSCF), ensuring that the sum of preliminary amounts does not exceed annual maximum amounts ; and the Carbon Leakage Exposure Factor (CLEF), which is intended to make free allocation in Phase 3 transitional.

4.2.1.1 Installation level-derived preliminary amounts : the use of benchmarks

Put simply, an installation preliminary amount is the multiplication of a specific benchmark by the associated Historical Activity Level (HAL). Should the installation carry out different activities on-site, its preliminary amount would consist of the sum of different benchmark/HAL multiplications.

Product benchmarks A product benchmark corresponds to the average of the 10% most efficient installations for the manufacture of the product in question in 2007 and 2008 among countries participating in the Scheme. Efficiency here is to be understood as the amount of CO_2 emissions emitted per unit of output (e.g. grey cement clinker, coated fine paper). It therefore focuses on the output intensity in order to have the CO_2 intensity mitigation incentive apply to the whole production chain. Where either the number of installations producing a specific good was insufficient or data unavailable, it was made use of existing technical literature such as Best Reference documents (BREF) from the European Integrated Pollution Prevention and Control bureau.

Historical Activity levels The HAL corresponds to the highest median production level between the 2005-2008 and 2009-2010 periods of the installation. The use of the median and the freedom to choose between two periods has been justified on the grounds that it would allow to compensate for the potential activity decrease of an installation.

Fall-back approach Fifty-two product benchmarks have been defined. They are estimated to account for 75% to 80% of emissions from non-electricity generators in the EU ETS (European Commission, 2011d). The remaining emissions from non-electricity generators are covered variously by a heat benchmark, a fuel benchmark and a process emissions benchmark. Product benchmarks are prioritized over other benchmarks. The fall-back approach is applied when a product benchmark is not defined for a given manufactured product, and involves using the heat benchmark, or the fuel benchmark (if heat is not measurable), or the process emissions benchmark (if the emissions do not result from fuel combustion) (European Commission, 2011c). Process emissions are accounted for in product benchmark but not in heat and fuel benchmarks. A process emission benchmark (rather a process emission coefficient) has thus been determined to accompany the fuel and heat ones when the fall-back approach applies. This coefficient is equal to 0.97, and has to be multiplied with historical process emissions to determine the amount of free allowances to be allocated to cover process emissions in case the fall-back approach is employed. Heat and fuel benchmarks values have been derived using a reference efficiency of natural gas.

4.2.1.2 EC-derived annual maximum amounts : setting aggregated free allocation caps

Article 10a(5) of the Consolidated ETS Directive stipulates that the amount of allowances to be annually allocated free of charge in Phase 3 should not exceed the annual maximum amount. The latter is composed of two quantities, reformulated as follows [4] :

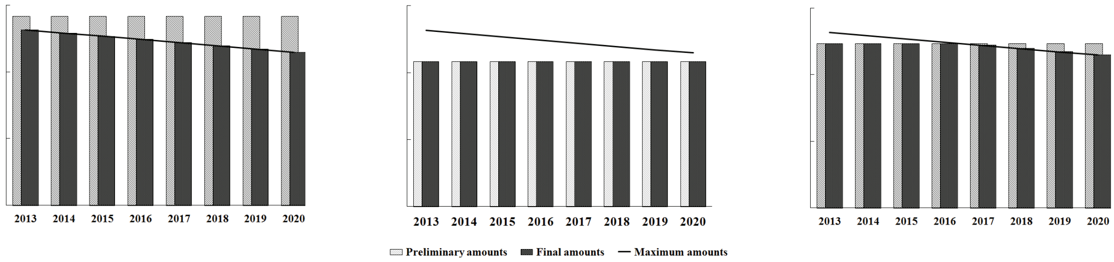
1. The non-extended EU ETS cap in Phase 3 (i.e. excluding sector and gas coverage extension that has become effective in 2013) multiplied by the share of emissions from installations covered in Phase 2 and not considered to be electricity generators, in Phase 1 average verified emissions ;
2. The amount of allocations corresponding to the emission coverage perimeter extension adjusted by the linear factor as referred to in article 9 of the Consolidated ETS Directive.

As opposed to the first two trading periods of the Scheme, where the respective caps were constant, the cap of Phase 3 linearly decreases over the 2013-2020 period. From 2013 onwards, it is annually reduced by a linear factor equivalent to a constant amount of allowances (article 9 of the Consolidated ETS Directive). This reduction amounts to about 37 million quotas (European Parliament Council, 2010), representing 1.74% (the linear factor) of average allowances issued in Phase 2. Annual maximum amounts, as defined by the European Commission, are therefore decreasing quantities throughout Phase 3.

4.2.1.3 Concluding remarks : reaching the final free allocation entitlement

The final allocation entitlement to non-electricity generators is obtained after the application of annual CSCFs and CLEFs, which respective roles are to ensure the integrity

4. The definitions of the two quantities have been simplified for ease of understanding. They are formulated as follows in article 10a(5) of the Consolidated ETS Directive :
  - the annual Community-wide total quantity, as determined pursuant to article 9, multiplied by the share of emissions from installations not covered by paragraph 3 in the total average verified emissions, in the period from 2005 to 2007, from installations covered by the Community scheme in the period from 2008 to 2012 ;
  - the total average annual verified emissions from installations in the period from 2005 to 2007 which are only included in the Community scheme from 2013 onwards and are not covered by paragraph 3, adjusted by the linear factor, as referred to in article 9.



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3

FIGURE 4.1: Final amounts scenarios

Source : the author

of free allocation annual caps (or annual maximum amounts) as defined by the European Commission and to provide a smooth transition to full auctioning by 2027. A CSCF is determined by comparing the sum of Member States preliminary amounts of installations not considered electricity generators with the corresponding annual maximum amounts. It is uniformly applied to the preliminary amounts of all non-electricity generators if their sum exceeds the annual maximum amounts. The fact that the preliminary amounts sum and the annual maximum amounts are respectively constant and decreasing quantities means that the probability of the former to exceed the latter increases as Phase 3 develops. Three scenarios for CSCFs can thus be anticipated, depending on the date when the CSCF is first required, as displayed in figure 4.1 :

1. The sum of the preliminary amounts exceeds the maximum amounts as soon as the first year of Phase 3 in 2013. In this case, a CSCF is applied annually and preliminary amounts are reduced to the upper limit over the entirety of the Phase ;
2. The sum of the preliminary amounts is below the maximum amounts all Phase 3 long. No CSCF is applied ;
3. The sum of the preliminary amount exceeds the upper limit at a later stage in Phase 3. A CSCF is applied from this date only.

Configurations 2 and 3 clearly show that although annual maximum amounts of free allowances are defined, they may not be allocated in their entirety.

Article 10a(11) of the consolidated ETS Directive indicates that free allocation to both electricity and non-electricity generators in Phase 3 is transitional, steadily decreasing from preliminary amounts values. Coefficients (i.e. Carbon Leakage Exposure Factors) are further applied to preliminary amounts to ensure free allocation transitional character.

TABLE 4.1: Factor ensuring the transitional character of free allocation to non-electricity generators in Phase 3 (in %)

Year	2013	2014	2015	2016	2017	2018	2019	2020
CLEF	80	73	66	59	51	44	37	30

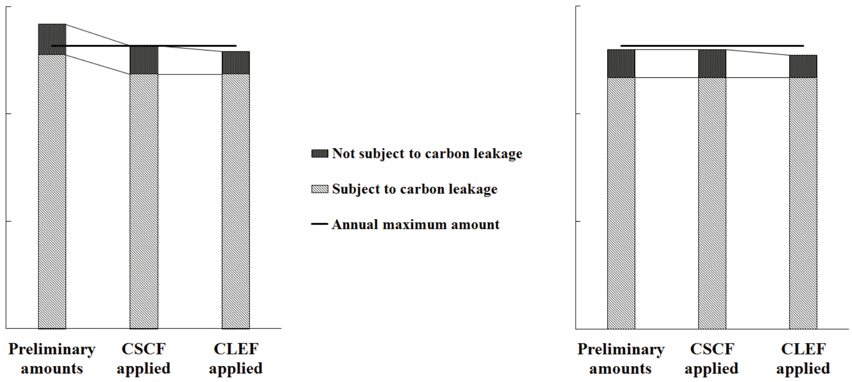
Year	2021	2022	2023	2024	2025	2026	2027
CLEF	26	21	17	13	9	4	0

Source : Annex VI of benchmarking Decision (European Parliament Council, 2011a) up to and including 2020, estimation of the author from 2021

They are provided in Annex VI of the benchmarking Decision and reported in table 4.1 : 80% in 2013 to 30% in 2020,"with a view to reaching no free allocation in 2027". To address competitiveness issues of industries covered by the EU ETS, a provision has been introduced for activities that are identified as deemed to be exposed to significant risk of carbon leakage. The proportion of preliminary amounts corresponding to these activities is exempted from the application of decreasing CLEFs and is instead applied a CLEF equal to 100% in each year of Phase 3 (as indicated in article 10a(12) of the consolidated Directive). Products deemed at risk of carbon leakage are included in a carbon leakage list drawn up by the European Commission. The current list (unless sector additions) runs up to and including 2014 and a new carbon leakage list for the 2015-2019 period is currently being defined through stakeholders meetings. It should be ready by the end of 2014. Non-EU trade intensity and the sum of direct and indirect additional costs associated with carbon pricing are the two criteria used to determine whether a sector or sub-sector is included in the list (European Parliament Council, 2011b).

CSCF and CLEF application sequence The sequence below is given for a random year between 2013 and 2020. Two preliminary amounts sum scenarios are tested : one beyond annual maximum amount (horizontal line) (case 1) and one below (case 2).

1. Preliminary amounts sum is first compared to annual maximum amounts (first column) ;
2. In case 1, a CSCF applies to bring the sum back to the maximum amount level (second column). In case 2, preliminary amounts sum remains idle as already below maximum amount (no CSCF applies) ;



(a) Case 1 (b) Case 2

FIGURE 4.2: From preliminary amounts to final amounts of free allowances

Source : the author

3. Then the CLEF is applied given the year of the phase (third column). For 2013, CLEF is equal to 80%. This last column represents the final amount of allocated free allowances.

4.2.2 non-power installations allocation interdependence

The interdependence of non-power installations in terms of Phase 3 allocation, which results in the design of Phase 3 free allocation rules, comes out in two ways : first through allocation redistribution, second through the determination of the annual CSCF. Indeed, both allocation variation and reduction through annual CSCFs at the installation level account for the performances (in terms of CO_2 emitted per unit of output) of all other installations. The dataset based on which the analysis is conducted is described in section 4.3.1.

4.2.2.1 Free allocation is redistributed among installations

As mentioned in the previous section, free allocation entitlement to installations in the first two phases of the market was decided at the national level. It thus could lead to market distortion within a given sector across Member States. Benchmark-based free allocation is expected to eliminate any national level-derived distortion in the internal market by allocating permits to installations in a given industrial sector on the same grounds of efficiency. Switching from grandfathering to benchmarking means that installations which are less efficient than their benchmarks will have their free allocation entitlement reduced in Phase 3. For those that are more efficient, there is an increase in allocation levels compared to Phase 2, thus leading to sectoral "allocation redistribution". As mentioned in the previous section, free allocation entitlement to installations in the first two phases of the market was decided at the national level. It thus could lead to distortion within a given sector across Member States. Benchmark-based free allocation is expected to eliminate any national level-derived distortion in the internal market by allocating permits to installations in a given industrial sector on the same grounds of efficiency. Switching from grandfathering to benchmarking means that installations which are less efficient than their benchmarks will have their free allocation entitlement reduced in Phase 3. For those that are more efficient, there is an increase in allocation levels compared to Phase 2, thus leading to sectoral "allocation redistribution". Based on available National Implementation Measures (NIMs) of Member States, it is estimated that, among the identified 6,196 non-power installations, net reduction in free allocation amounts to 108 million quotas. This net reduction underlies a redistribution of 84 million quotas, which represents 13.6% of Phase 2 average free allocation of these installations. The analysis of Member States NIMs [5] allows this redistribution of emission quotas among the main non-electricity sectors of the EU ETS to be characterized in section 4.3.

4.2.2.2 Preliminary amounts to be further cut down by adjustment factors

Another change resulting from the introduction of Community-wide rules in Phase 3 is that annual CSCF can be uniformly applied to preliminary amounts, so that Phase 3 free allocation is further reduced, adding to the reduction induced by benchmarks. As of September, 2013, all required NIMs have been submitted to the European Commission for the determination of annual CSCFs. However, the final free allocation distribution to non-electricity generators remains unknown, despite the fact that the third phase of the EU ETS started on 1 January, 2013. Initially expected by end of February 2013, it has been postponed to September 2013 as communicated by the European Commission on 30 July 2013. Nonetheless an estimate of annual CSCFs is provided below. Indeed, annual CSCFs are determined by comparing the sum of preliminary amounts of non-electricity generators (based on Member States NIMs) to annual maximum amounts. Since the latter have not been made publicly available either, their values are estimated following the guidelines in article 10a(5) of the Consolidated ETS Directive. The results suggest that annual CSCFs

5. Apart from NIM of Slovenia, which is not publicly available at the time of writing.

TABLE 4.2: Annual CSCFs estimations (in %)

Year	2013	2014	2015	2016	2017	2018	2019	2020
Low	3.3	5.1	6.9	8.6	10.4	12.2	14.0	15.7
High	6.7	8.4	10.1	11.8	13.5	15.2	16.9	18.7

Source : the author

will be required in Phase 3 as soon as 2013 (table 4.2), corresponding to the first scenario in figure 4.1 [6]. This requirement (in annual CSCFs as soon as 2013) implies that the overall amount of allowances to be freely allocated to non-electricity generators in Phase 3 does not depend on benchmarks, i.e. that the purpose of benchmarks is solely to redistribute free allowances among market participants, in line with the European Commission's stated aims of "(...) avoid[ing] distortions in the internal market (...)" and "ensur[ing] that allocation takes place in a manner that provides incentives for reductions in greenhouse gas emissions (...)" (article 10a(1) of the Consolidated ETS Directive).

4.2.3 Benchmarks potential flaws

4.2.3.1 Persisting grandfathering in Phase 3 benchmarking

At the non-electricity installations aggregate The first potential flaw that can be identified in the Community-wide rules lies in the methodology to determine preliminary amounts at the installation level. Indeed, although benchmarks target installations with higher efficiency, the "historical dimension" that has been criticized in grandfathering remains in Phase 3 with the use of HALs. Where allocation was directly derived from the historical emissions level under grandfathering, the preliminary amount of an installation is derived from its HAL multiplied by the benchmark value : the preliminary amount will be proportionate to the output level of the installation in a past reference period, as grandfathering was. Therefore underlying benchmarking there is still the notion of grandfathering, but now associated with the production level rather than the emissions level. This becomes more evident in a situation of economic downturn.

All other things being equal (production levels identical to HALs, physical capital, carbon price feedback, etc.), benchmark-based allocation has led to the expectation that most non-electricity installations (and thus the non-electricity aggregate) would be allocated fe-

6. The annual CSCFs estimation methodology is provided in appendix 4.B of this chapter. A sensitivity analysis is provided in appendix 4.C as well.

wer free allowances than the emissions corresponding to their activity levels, due to most installations having CO_2 intensities above benchmark values. However, the economic recession has strongly affected EU activity levels since 2008, making the current levels lower than those from which HALs were defined. This fall in activity led to a 16% decrease in CO_2 emissions from non-electricity generators [7] from 2008 to 2012. During the same period, free allocation to non-electricity generators has decreased to a smaller extent, with 2013 levels being 14% below the Phase 2 average.

The net position can be measured *ex post* only (using the allocation level of a given year and the verified emissions of the same year), but the *ex ante* net position of aggregated non-electricity generators can be assessed, by comparing 2012 emissions levels with 2013 free allocation, in order to put current emissions levels and the changes in free allocation into perspective. It can be seen that the non-electricity generators aggregate enters Phase 3 with an *ex ante* net long position of 17%, which is certainly below the observed 24% average net long position in Phase 2, but definitely not negative and thus far from the challenging picture that Community-wide free allocation rules have led one to expect (figure 4.3). It should be kept in mind that the just mentioned 17% *ex ante* net position does not include the application of a CSCF in 2013, although it was shown in previous section that the CSCF estimate magnitude would not change it dramatically. Furthermore, the *ex ante* net position does not in principle say anything about the *ex post* net position as, unlike the latter, it does not integrate carbon price feedback on emissions levels.

At the non-electricity installations level : the case of the cement sector The grandfathering character of benchmarking can be further illustrated at the installation level. The focus is put on the cement sector for its simple production chain and the homogeneity of the final product, which only required the definition of one product benchmark ; that of grey cement clinker [8]. In the case of French cement producing installations (i.e.installations located in France), it can be observed that, due to the economic downturn, installations with larger CO_2 emission intensity than benchmarks will receive more allowances than their actual emission levels and than their anticipated 2013 emissions levels. To reach to this result the following methodology has been followed. First the CO_2 intensity $i_{clinker}$ of each installation has been determined so they could be compared to the grey clinker

7. As identified in the NIM database.

8. A product benchmark for the production of white cement clinker has been defined as well. However, its production volume is estimated to be small and the distinction between white and cement clinker productions is difficult to make as reported in the PRODCOM classification (Ecofys, 2009).

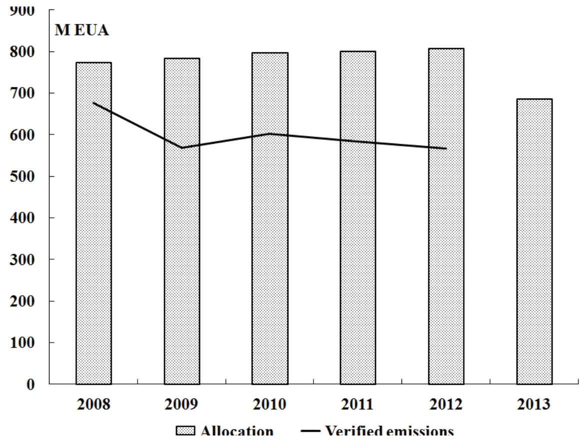


FIGURE 4.3: Non-electricity generators CO_2 emissions and allocation levels

Source : the author from CITL and NIM database

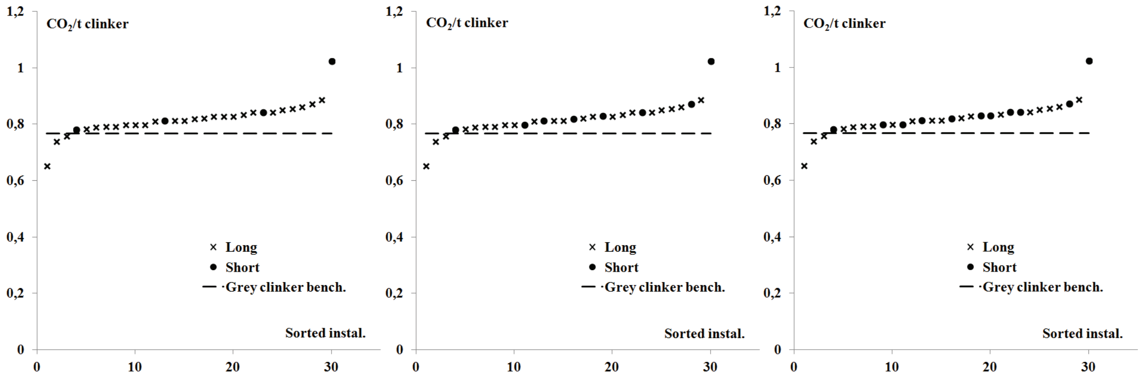
product benchmark value (equation 4.1) .

$$i_{clinker} = \frac{Em_{ref}}{PA} \times BM_{clinker} \tag{4.1}$$

Where Em_{ref} is the historical activity level (HAL) corresponding level of CO_2 emissions. These HAL corresponding emissions levels have been defined as the highest of the two emission level medians over the 2005-2008 and 2009-2010 periods, which therefore assumes that the CO_2 intensity of cement installations has remained the same over these two time periods. Respective CO_2 intensities of French cement producing installations are reported in figure 4.4. These installations are sorted by CO_2 intensity and compared to the grey cement clinker benchmark value (horizontal line). Their *ex ante* net positions (full circle for short net positions and cross for long ones) are derived from their preliminary amounts values first (figure 4.4a), which are then corrected by the low (figure 4.4b) and high (figure 4.4c) estimated values of the 2013 CSCF (as reported in table 4.2). It is showed that the CSCF will not correct much of the grandfathering character of benchmarking.

4.2.3.2 The carbon leakage provision trap

The transitional character of free allocation to non-electricity generators in Phase 3 is challenged by the provision for installations deemed at risk of carbon leakage, which constitutes the second potential flaw of the Community-wide new rules. Indeed the study of Member States NIMs shows that 96% of non-electricity generators sum of preliminary



(a) No CSCF (b) CSCF Low (c) CSCF High

FIGURE 4.4: Cement installations *Ex ante* net positions with CSCF

Source : the author from CITL and NIM of France

TABLE 4.3: Proportion of PAs sum exposed / not exposed to carbon leakage (M quotas)

Free allocation to non-elec. generators	2013	2020	2013	2020
Total	**686**	**671**	**100**	**100**
Risk of carbon leakage	661	661	96	99
Transitional	25	9	4	1

Source : the author from NIM database

amounts is composed of allocations to installations deemed at risk of carbon leakage (table 4.3). This figure makes void, at the EU ETS level, the transitional character of Phase 3 free allocation that was to be ensured by the CLEFs. Indeed CLEFs will involve a decrease of slightly more than 2% only in free allocation to non-electricity generators from 2013 to 2020 (686 to 671 million quotas), resulting from their application to just 4% of non-electricity generators sum of preliminary amounts. This amount is less than the much publicized 62.5% decrease that would have occurred without the introduction of the carbon leakage provision. Although free allocation levels through to 2027 are well indicated for sectors and sub-sectors not deemed at risk of carbon leakage, allowing them to anticipate the shift towards full auctioning in 2027, this is not the case for sectors and sub-sectors deemed at risk of carbon leakage. Indeed, no indication on how the question of free allocation to these sectors will be addressed after 2020 has been given by the European Commission, therefore preventing them from anticipating their allocation entitlement beyond the end of Phase 3. Will it be kept constant in Phase 4 ? Will it decrease from 2020 levels to zero in 2027 ? What will it be in 2021 ? This issue is all the more important in that, as reported in table 4.3, it concerns almost all the allowances to be allocated free of charge to non-electricity generators.

4.3 Phase 3 free allocation : an empirical assessment

While previous section assessed the impacts of benchmarks on Phase 3 by comparing the newly introduced free allocation design and pursued objectives, the following section assesses these impacts with a backward perspective, i.e. with reference to Phase 2, by diving at the sectoral and installation levels. Free allocation variations in Phase 3 compared to Phase 2 are quantified at first in section 4.3.2. Then, an attempt to determine the factors that should account for observed variations in the cement sector is done in section 4.3.3. The focus on the shift in free allocation methodology from Phase 2 to Phase 3 therefore allows to enlighten on Phase 2 free allocation. Previous to this, the original database that enables the analysis, and which has been constituted following the progressive publication of Member States NIMs, is described in section 4.3.1. Note that the analysis is based on data from preliminary amounts, that is no cross sectoral correction factor is applied to Phase 3 free allocation data submitted by Member States in their respective NIMs.

4.3.1 NIM database description

The NIM database is composed of Phase 3 free allocation to all installations included in the NIM of Member States that have been gathered. Twenty-five of them are complete and one (that of Belgium) partially covers the installations of the country (i.e. those of Wallonia only). Two NIMs are therefore missing : those of Slovenia and Croatia. About 11,500 installations constitute the database, including installations entering the Scheme for the first time in 2013. Member States NIMs provide Phase 3 free allocation with CLEF. In other words, the preliminary amount of each installation is applied a CLEF for each year of Phase 3 (as reported in table 4.1). Some NIMs provide an electricity generator indicator that takes values *yes* or *no*. Where missing, and when possible, a value is manually added. When possible, preliminary amounts are determined by dividing 2013 free allocation by CLEF of year 2013 (80%). The share of each preliminary amount that is exposed to carbon leakage is also added. The applied methodology in above cases in described in appendix

4.B of this chapter. For installations that were already participating in the Scheme before Phase 3, Phase 2 CITL data (verified emissions and allowance allocation) are added.

4.3.2 From Phase 2 to Phase 3 : allocation pattern changes

What previous section has put the emphasis on is the fact that maximum amounts to be allocated for free, as determined by the ETS Directive, have the greatest impact on the overall level of free allocation to the non-electricity sector in Phase 3, requiring the application of annual CSCFs. This leaves one with the wrong impression that free allocation would not have been reduced from Phase 2 to Phase 3 without this 1.74% annually decreasing upper limit. This would however be inaccurate and leaving aside the fact the maximum amounts already involve a reduction in free allocation to non-electricity generators compared to Phase 2. Allocation reduction induced by benchmarks is detailed in the following paragraphs.

4.3.2.1 Free allocation reduction in Phase 3

Overall free allocation reduction Based on the NIM database above described, the reduction of free allocation involved by benchmarks, for installations in place in Phase 2 and continuing in Phase 3, reaches 54% (from 1,759 to 811 million quotas). Average Phase 2 allocation is used, and chosen reference point in 2013 is the preliminary amount with applied CLEF (i.e. as provided by Member States in their respective NIM) [9]. Observed free allocation reduction is heterogeneous between Member States, ranging from 100% in Malta to 5% in Austria (table 4.4). A notable free allocation increase of 31% in Sweden can be accounted by the fact that Union-wide allocation rules has forced Sweden to allocate free allowances to installations of the electricity, gas, steam and hot water sector that were not allocated in Phase 2 under the Phase 2 NAP of the country.

Allocation variation and power sector As expected by benchmarking rules, free allocation reduction is highly correlated with the size of the power sector. The size of the power sector is measured by its share of total emissions for each Member State. Two sizes are determined, first one (M1) including and second one (M2) not including installations

9. Using 2013 allocation as provided by Member States NIMs allows to include installations which allocation patterns prevents their preliminary amounts from being determined (see appendix 4.B). Installations with void or incomplete Phase 3 free allocation fields are removed, as well as those considered closed in both Phase 2 and Phase 3. Mentioned allocation reduction of 54% therefore refers to 9,222 installations.

TABLE 4.4: Phase 2 to Phase 3 (2013) free allocation variation by Member State

Member State	**Instal.** (#)	**Phase 2 alloc.** (M quotas)	**2013 alloc.** (M quotas)	**Variation** (%)
Austria	153	23	22	-5
Belgium	83	16	14	-10
Bulgaria	125	38	11	-72
Cyprus	12	5	1	-81
Czech Rep.	323	79	21	-74
Denmark	349	25	9	-45
Estonia	50	13	3	-76
Finland	442	35	24	-31
France	886	131	82	-37
Germany	1,405	365	153	-58
Greece	100	26	16	-39
Hungary	160	22	10	-55
Ireland	96	20	5	-75
Italy	1,012	200	89	-55
Latvia	70	5	3	-25
Lithuania	92	8	7	-13
Luxembourg	13	2	1	-43
Malta	2	2	0	-100
Netherlands	353	84	44	-48
Poland	768	203	59	-71
Portugal	168	32	12	-63
Romania	206	58	32	-44
Slovakia	136	32	17	-46
Spain	805	91	69	-25
Sweden	564	22	29	+31
United Kg.	849	222	73	-67
Total	9,222	1,759	811	-54
Std. dev.				28

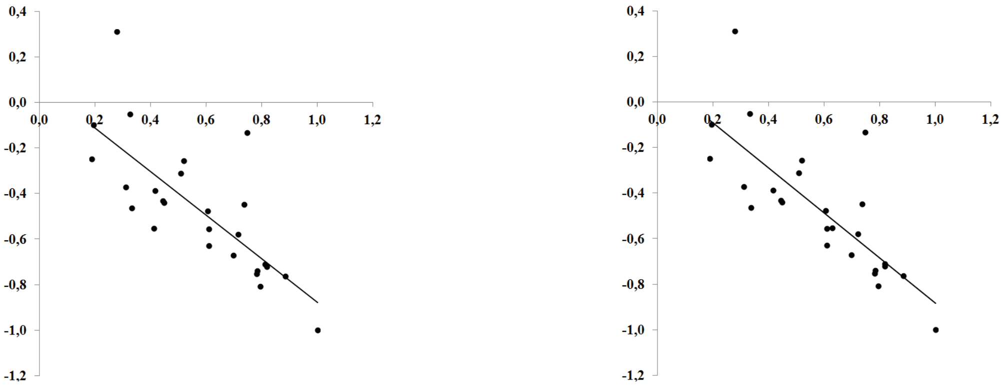
Source : the author from NIM database

TABLE 4.5: Phase 2 to Phase 3 (2013) free allocation variation and power sector

	M1	M2
Intercept	0.08	0.11
β	- 0.96***	- 0.99***
R^2	0.58	0.61
Obs.	26	26

*** : 1% level ; ** : 5% level ; * : 10% level

Source : the author from CITL and NIM database



(a) M1 (b) M2

FIGURE 4.5: Free allocation variation vs. power sector size

Source : the author from CITL and NIM database

that are considered *unclassified*[10] among those that are identified electricity generators. Regressing free allocation variation from Phase 2 to Phase 3 on the size of the power sector, where observations are Member States, shows that on average, free allocation is reduced by almost 1% when the size of the power sector increases by 1% (table 4.5 and figure 4.5). Both regressions bring similar results. The value of the power sector size elasticity of free allocation variation closely corresponds to what should be expected with a shift from Phase 2 to Phase 3, where electricity generators are not freely allocated.

Allocation variation and non-electricity sectors Now turning to the non-electricity aggregate only, allocation variation shows smaller variability (standard deviation is equal

10. An *unclassified* installation is one for which it has not been possible to determine whether it should be considered an electricity generator or not despite two possibilities to do so. These two possibilities are detailed in appendix 4.B of this chapter.

TABLE 4.6: Phase 2 to Phase 3 (2013) free allocation variation and largest non-electricity sub-sectors

NACE rev. 1 (Instal. #)	D21 (697)	D23 (148)	D24 (398)	D26 (1 697)	D27 (273)
Avg. size (%)	5	18	8	31	22
Correlation	0.37	-0.10	0.24	-0.23	0.03
Obs.	26	26	26	26	26

Source : the author from CITL and NIM database

to 0.18%) than when considering both electricity and non-electricity aggregates (see table 4.4). Overall reduction in 2013 for non-electricity aggregate amounts to 108 million quotas, or 13.6% [11] of their average Phase 2 free allocation (table 4.7).

Furthermore, the relative sizes (expressed in average shares of Phase 2 CO_2 emissions) of the largest sub-sectors of the non-electricity aggregate appear uncorrelated to the observed free allocation variation (table 4.6). This absence of correlation seems to indicate heterogeneous variation distributions between Member States for each of the largest non-electricity sub-sectors. This is investigated in the following section by diving at the installation level.

4.3.2.2 Free allocation redistribution in Phase 3

Sectoral redistribution The non-electricity sectors studied are unevenly affected by the change in free allocation methodology in Phase 3. Although they all undergo net free allocation reduction, two major allocation redistribution patterns can be observed. Sectors can be distinguished between those for which net allocation reduction underlies both large gross reduction and large gross addition of free allocation (the pulp and paper sector, the iron and steel sectors and, at a more aggregate level, the basic metals sector), and those for which net allocation is principally composed of gross allocation reduction. The latter group includes the glass, lime and cement manufacturing sectors and, at a more aggregate level, the other non-metallic minerals manufacturing sector. Also included are the food sector and the oil refining and coke ovens products industries (columns 3 and 4 of table 4.7).

On the one hand, the second allocation pattern is intuitive, because, in accordance with the definition of benchmarks, CO_2 intensities of most installations are above benchmark values, thus leading to a reduction in free allocations : benchmarks involve a downward

11. The requirement for a CSCF as soon as 2013 therefore implies that maximum amounts involve a reduction in free allocation greater than 13.6%.

TABLE 4.7: Sectoral free allocation variation from Phase 2 to 2013 at the installation level (thousand quotas)

	No. of instal.	Total reduction	Total addition	Median	Average	Median (%)	Average (%)
Non-electricity generators	6,196	-191,938	83,913	-3	-17	-21	307
Among which							
Food	534	-6,210	1,262	-5	-9	-27	2
Pulp and paper	697	-13,937	8,648	-3	-8	-19	2,068
Other non-metallic min.	1,697	-42,210	4,587	-5	-22	-17	-13
Cement	*243*	*-23,354*	*1,685*	*-61*	*-89*	*-11*	*-11*
Lime	*216*	*-6,902*	*753*	*-11*	*-29*	*-19*	*-18*
Glass	*338*	*-6,629*	*1,085*	*-10*	*-16*	*-21*	*-20*
Basic metals	274	-34,304	25,205	-3	-33	-12	69
Iron and steel	*129*	*-19,587*	*15,018*	*-8*	*-35*	*-12*	*5*
Oil Refining & Coke Ovens	148	-36,337	6 048	-39	-205	-17	-11

Source : the author from CITL and NIM database

momentum to the allocation level. On the other hand, the first allocation pattern is mainly accounted for by the rule change in the allocation for emissions related to heat exchanges. Under this new rule (as part of the transitional Community-wide rules in Phase 3), free allocation is now given to heat producers under specific circumstances only and, as a general rule, allowances are allocated to heat consumers to ensure that the amount they receive is independent from the heat supply structure (European Commission, 2011b). Therefore high heat consumer industries such as the pulp and paper manufacturing sector include some installations whose average Phase 2 allocation is several times greater in 2013.

Finally, the impact of allocation redistribution at the installation level can be assessed by both the allocation variation median and mean, expressed as an absolute value and as a percentage. All sectors shown in table 4.7 have a smaller negative allocation variation median than the average when expressed in volume change. They also have a greater allocation reduction median than the average when expressed in percentage change. This suggests that, on average, large reductions in volumes concern installations with larger allocation levels in Phase 2 (hence low allocation variation percentages), and that large additions in percentage concern installations with lower allocation levels in Phase 2. In a nutshell, benchmarks unevenly affect sectors and involve strong redistribution within them.

These results corroborate the previous result, which stated that free allocation variation of the non-electricity aggregate did not depend on its sub-sector structure. Two factors could account for this conclusion. First, sectoral structure can differ from one country to another for different motives such as sectoral historical development and/or sectoral regulation. Such national structural bias feature ought to be unveiled by the switch from a national sectoral reference for allocating emission permits, such as grandfathering was, to a EU-wide sectoral reference, as implied by benchmarks. Second accounting factor could be found in national free allocation bias that was enabled by NAP. Focusing on the cement sector, these two factors are tested as free allocation variation determinants in a econometric analysis as detailed in the following section.

4.3.3 Accounting for free allocation variations in the cement sector

A focus is made once again on the cement sector, this time to test the factors that have been put forward in the previous section, as accounting for observed allocation variation pattern at the installation level : installation CO_2 intensity combined with nationally biased over allocation. Again, uniqueness and homogeneity of the benchmark product (clinker) is the justification for the choice of the sector. Also, the sector has negligible cross-boundary heat flows and does no produce electricity (Ecofys, 2009), which therefore involves that they should not be a determinant for free allocation variation for any cement clinker producing installation. A simple econometric analysis is undertaken in this purpose.

4.3.3.1 Econometric model

Sectoral structure and potential allocation bias due to Phase 2 NAPs are measured by two variables that are the CO_2 intensity (I) and the average net position in Phase 2 of a considered clinker producing installation (P). This is illustrated by equation 4.2. The former variable is built as given in equation 4.1. It is thus expressed in tons of CO_2 per ton of clinker. The latter variable corresponds to the allocation to verified CO_2 emissions ratio in 2008. This year is chosen to get rid of the impact of the economic crisis on production levels, which was not accounted for when defining Phase 2 NAPs. This variable is therefore expressed in percentage of 2008 verified emissions.

$$\Delta A_i = \alpha + \beta_1 P_i + \beta_2 I_i + \epsilon_i \tag{4.2}$$

Where A_i is the average Phase 2 to Phase 3 (preliminary amount) free allocation variation divided by the preliminary amount of the i^{th} clinker producing installation. This way defined, the estimated coefficients β_1 and β_2 represent the net position elasticity and CO_2 intensity elasticity of allocation variation from Phase 2 to Phase 3, expressed in percentage of the preliminary amount quantity [12]. Finally, ϵ the vector of independent and normally distributed random error, and α the constant term. Such model specification should therefore capture any allocation bias thanks to variable P. Indeed, should free allocation in Phase 2 be accurately based on grandfathering, then allocation variation, involved by switching from grandfathering to benchmarking in the cement sector, should be explained by installation CO_2 intensity (variable I) only. On the contrary, having installation 2008 net position (variable P) as a statistically significant variable would involve the presence of Phase 2 free allocation bias. To determine whether the bias can be considered national, a dummy variable (C) that embodies country specific effects is added to the previous specification. A second model specification is thus elaborated (equation 4.3).

$$\Delta A_i = \alpha + \beta_1 P_i + \beta_2 I_i + \sum_{j=1}^{N} (\beta_j C_{ij}) + \epsilon_i \tag{4.3}$$

Where N indicates the number of Member States included in the analysis, and C_{ij} equals 1 when installation i belongs to Member State j, 0 if it does not.

4.3.3.2 Results

Clinker producing installations are those with NACE rev. 1 code equal to 2651. They are 243 installations, scattered among 24 Member States (those in table 4.4 except Malta). The dataset is slightly amended removing two installations : the one (and only) from Latvia which has not been allocated nor has provided verified emissions in 2008 ; one installation from Ireland for which the value of variable I is an outlier. Indeed, its preliminary amount indicates a free allocation decrease of 92%. Without any further considerations, and given the HAL corresponding emissions level, equation 4.2 provides a CO_2 to clinker ratio of 8.78

12. Since cement clinker production has been determined as deemed at risk of carbon leakage, the CLEF value that applies to the preliminary amount of cement clinker producing installation throughout Phase 3 is equal to 1 throughout Phase 3. Therefore, 2013 free allocation amounts are equal to preliminary amounts for each installation of the sector.

where the benchmark value is 0.766 and the average value of the dataset is 0.859. Results are provided in table 4.8. Robust standard errors were used to take heteroskedasticity into account, which presence was suggested by the White test in model specifications 2, 3 and 4. Values in brackets correspond to standardized coefficients.

First model specification shows that the CO_2 intensity factor is statistically significant at the 1% level as expected. Nonetheless this first specification solely accounts for 23% of the variance of free allocation variation in the cement sector. This suggests that Phase 2 grandfathering deviated from its original definition. Second model specification includes variable P and shows that both variables P and I are found to be statistically significant at the 1% level. As expected, variable I shows a negative relation with allocation variation from Phase 2 to Phase 3 : the greater the CO_2 intensity, the greater the free allocation reduction. More precisely, for every CO_2 intensity increase of 0.1 ton of CO_2 per ton of clinker produced, Phase 2 free allocation decreases by 8.56% of the installation preliminary amount. The presence of an allocation bias in Phase 2 seems likely as variable P also shows a negative relation with allocation variation from Phase 2 to Phase 3 ; the longer the net position, the greater the free allocation reduction. More precisely, for any net position size relaxation corresponding to 0.1% of verified emissions, Phase 2 free allocation decreases by 5.35% of the installation preliminary amount. As variables are measured in different units, their associated coefficients are standardized (divided by their standard errors) in order to determine the variable that has the greatest impact. It appears that, on average, the impact of free allocation bias has the greatest impact, although that of CO_2 intensity is almost equivalent.

Third model specification shows that, added to an average allocation bias in Phase 2 that remains statistically significant, a national character of Phase 2 allocation bias is also statistically significant for thirteen out of the twenty-four tested Member States. Introducing Member States specific effects involves coefficients β_1 and β_2 to be better estimated as their standard errors are smaller : the magnitude of the former is slightly reduced (-0.483), the one of the latter is slightly increased (-0.881). When looking at "national" coefficients, three of them are positive (for Austria, Denmark and Spain), the other ten being negative. The sum of coefficient β_1 with the national coefficient provides the national free allocation bias. The sum is negative for all thirteen Member States, which involves that they all biased free allocation "upwards", leading to what can be referred to as over allocation. The bias of Austria, Denmark and Spain is lower than the average bias though (-0.483). Results suggests that Cyprus and Romania performed the greatest allocation bias (-0.292

Table 4.8: Phase 2 to Phase 3 free allocation variation in the cement sector

Model specification	1	2	3	Model specification	4
α	0.559***	1.16***	1.15***	α	1.05***
β_1	-	-0.535*** (-0.615)	-0.483*** (-0.555)	β_1	-0.510*** (-0.585)
β_2	-0.843*** (-0.484)	-0.856*** (-0.491)	-0.881*** (-0.506)	β_2	-0.844*** (-0.484)
β_{AT}		-	0.042* (0.047)	β_{AT}	0.134*** (0.150)
β_{BG}		-	-0.059** (-0.045)	β_{BE}	0.090*** (0.077)
β_{CY}		-	-0.292*** (-0.112)	β_{CY}	-0.205*** (-0.079)
β_{DK}		-	0.051*** (0.020)	β_{DK}	0.143*** (0.055)
β_{ES}		-	0.036* (0.076)	β_{ES}	0.134*** (0.279)
β_{FR}		-	-0.045*** (-0.089)	β_{FR}	0.049*** (0.097)
β_{LT}		-	-0.087*** (-0.034)	β_{CZ}	0.081*** (0.069)
β_{NL}		-	-0.059*** (-0.023)	β_{NL}	0.039** (0.015)
β_{PL}		-	-0.077*** (-0.096)	β_{DE}	0.091*** (0.197)
β_{RO}		-	-0.270*** (-0.272)	β_{RO}	-0.171** (-0.172)
β_{SE}		-	-0.100*** (-0.067)	β_{GR}	0.090*** (0.097)
β_{SK}		-	-0.139** (-0.106)	β_{IE}	0.090** (0.060)
β_{UK}		-	-0.125*** (-0.174)	β_{IT}	0.101*** (0.248)
				β_{LU}	0.062*** (0.024)
				β_{PT}	0.073*** (0.068)
R^2-adj.	0.23	0.61	0.74	-	0.73
Obs. (#)	241	241	241	-	241
VIF	-	1.00	< 2	< 2	
LM test	-	0.50	0.26	0.23	

*** : 1% level ; ** : 5% level ; * : 10% level

Source : the author from NIM database

and -0.270 respectively), more than 50% over the average one. The national bias could not be precisely measured for the other eleven Member States, which however does not mean that it does not exist.

Fourth model specification gathers another combination of Member States dummy variables, which makes statistically significant some dummy variables that were not in the third specification. This new set of dummy variables gathers those of the first four cement producers in the EU 27 : Germany, Italy, Spain, and France respectively.

4.3.3.3 Abatement potential

The analysis conducted in the previous section has showed that free allocation variation in the cement sector, from Phase 2 to Phase 3, due to the change in free allocation methodology, could be explained by the relative performances of cement clinker producing installations compared to the cement clinker benchmark. Since the latter has been defined as the average CO_2 intensity of the ten best performing cement clinker producing installations across Member States, the observed overall free allocation reduction in the cement sector [13], which amounted 21.0 million quotas (from 171.1 to 150.1 million allocated quotas), was expected. The analysis also showed that installations' CO_2 intensities were not the only factor accounting for this allocation variation, and that the amounts of grandfathered quotas in Phase 2 "beyond pure grandfathering" partially explained such allocation variations in 2013 as well. In other words, switching from grandfathering to benchmarking enabled to correct "over allocation" bias that occurred in Phase 2, and which extent differed from one Member State to another.

The free allocation variation that can be attributed to the CO_2 intensity factor represents the amount of emissions that would be abated should all installations be as efficient as the cement clinker benchmark. Said differently, the just mentioned amount of hypothetical abatement (i.e. that could attributed to the CO_2 intensity factor) could be considered the least abatement that could be expected in the cement sector throughout Phase 3, given the benchmark value. Indeed, and as mentioned above, the cement clinker benchmark is defined as the average CO_2 intensity of the ten most efficient cement clinker producing installations over the years 2007 and 2008. It is therefore, as much as other product benchmarks, considered achievable ("The achievability of the benchmarks in practice has been carefully evaluated by the Commission services." - European Commission website) none-

13. Here, the cement sector is to be understood as the 241 installations entering the above econometric analysis.

theless challenging ("Being set at the level of the best performers, as required by the ETS Directive, they may represent a challenge for some installations [...]" - European Commission website). This amount of abatable emissions can be derived from the results of the above econometric analysis.

Given the definition of coefficient β_2, the theoretical amount of free allowances that would have been allocated based on pure grandfathering to cement installation k, GF_k, is given in equation 4.4.

$$GF_k = PA_k + PA_k \ \beta_2 \, (BM_{clinker} \ - \ i(k)_{clinker}) \tag{4.4}$$

Where, for installation k, PA_k is its preliminary amount and $i(k)_{clinker}$ is its CO_2 intensity. The amount of CO_2 emissions that can be abated by the cement sector should all installations reach the benchmark intensity is obtained by subtracting the preliminary amounts sum of cement installations to their theoretical grandfathered Phase 2 free allocations sum. Abatable emissions should therefore range from 6.2 to 9.0 million tons of CO_2, when using confidence interval at 95% boundaries of β_2 value from fourth model specification [14]. These amounts represent 4.0% and 5.9% respectively of 2008 CO_2 emissions of the sector, which reached 150.1 million tons.

Such low figures of abatable emissions illustrate the fact that cement clinker producing installations are "piled up" not too far from benchmark value (see figure 4.4). Not questioning the challenge that may represent achieving the cement clinker benchmark for installations above it, one cannot help notice that business as usual efficiency improvements in the cement sector would outperform cement clinker benchmark value by 2020, should they keep on their observed historical trend throughout Phase 3. Indeed, based on the Getting the Numbers Right (GNR) database [15], the EU 28 cement sector had an intensity of 0.772 tons of net [16] CO_2 per ton of clinker in 2011. Over the 1990-2000 period, that is before the implementation of the EU ETS, the cement sector CO_2 intensity annually im-

14. The boundaries of β_2 value from model specification 4 are chosen, since the latter specification provides the best estimation of the coefficient. Indeed, its associated standard error is the lowest (0.15 in first specification, 0.10 in second specification, 0.09 in third specification, 0.08 in fourth specification).

15. The GNR database gathers CO_2 and energy performance information on the global cement industry. It is available on the World Business Council of Sustainable Development at $http://www.wbcsdcement.org/index.php/key-issues/climate-protection/gnr-database$.

16. From GNR database glossary : gross CO_2 emissions are direct CO_2 emissions (excluding on-site electricity production) minus emissions from biomass fuel sources. Net CO_2 emissions are gross CO_2 emissions minus emissions from alternative fossil fuels. Alternative fuels are fuels used for fossil fuel substitution in clinker production. They are derived from waste (excluding biomass waste).

proved by 0.57% on average[17], from 0.904 to 0.854 tons of CO_2 per ton of clinker. Under a business as usual scenario (i.e. without emissions mitigation policy), the cement sector would therefore reach a CO_2 intensity of 0.733 in 2020, which is below 0.766, the cement clinker benchmark value.

Remark : comparing the NIM and the GNR databases The cement sector intensity in 2008 can be estimated from the NIM database. It was showed in section 4.2.3 how to determine CO_2 intensity of each cement clinker producing installation. Cement clinker production in 2008 is obtained dividing each installation's 2008 verified emissions by its associated CO_2 intensity. The sum of 2008 verified emissions is then divided by total 2008 cement clinker production to derive the average intensity of the cement sector, which is estimated at 0.824 tons of CO_2 per ton of clinker in 2008. This value is close to that of the GNR database, which provides an intensity of 0.814 tons of net CO_2 emissions per ton of clinker in 2008.

4.4 Conclusion

Auctioning is supposed to become the basic principle for allocation in Phase 3 of the EU ETS. Yet transitional free allocation remains for non-electricity generators and benchmarking has replaced grandfathering. The analysis of Member States (except Slovenia) National Implementation Measures has shown that benchmarks have only involved redistributing free allocation among non-electricity generators. The analysis has also shown that the application of Cross Sectoral Correction Factors (CSCF) to preliminary amounts will be enforced by 2013, as confirmed by the the Commission's Decision on transitional free allocation on September 5, 2013 (European Parliament Council, 2013). This has revealed the fact that, at the ETS level, the Phase 3 cap provides greater scarcity than benchmark-based free allocation. All in all Phase 3 free allocation decreases thanks to the application of annual CSCFs, i.e. at the same rate as the overall EU ETS, since CSCFs are applied all phase long. This result suggests that the introduction of benchmarks have a local impact (free allowances redistribution among installations and allocation variation at the installation level) rather than a global impact on the overall amount of allowances to be allocated for free such that, in Phase 3, aggregated free allocation to non-electricity generators follows a business as usual reduction, which magnitude is not involved by benchmarks. Furthermore,

17. Over the 1990-2005 period, the CO_2 intensity improvement compound annual growth rate (CAGR) is similar and equal to 0.58%, from 0.904 to 0.828 tons of CO_2 per ton of clinker.

two suspected inherent flaws have been confirmed by the analysis. First, free allocation amounts remain static and derived from historical reference values, hence do not address the "over allocation" criticisms of grandfathering ; despite the fact that it was also showed that benchmarks did provide a certain form of allocation harmonization across Member States, thus reducing free allocation national bias that occurred in Phase 2. Second and finally, the provision to protect some European industries from international competition and carbon leakage has made the transitional character of Phase 3 free allocation void and brought about uncertainty as to the post-2020 allocation entitlement to these industries.

4.A A word on preliminary amounts of electricity generators

Electricity generators may be entitled free allocation in Phase 3 through the modernization of electricity generators in some Eastern Europe countries (European Parliament Council, 2009) or through benchmarks for activities other than electricity production. In the latter case, electricity generators have to determine preliminary amounts. These preliminary amounts are not taken into account for the determination of annual CSCF. Hence, they are not applied any annual CSCFs. Instead, they are applied a Linear Reduction Factor (LRF), which values are determined so that preliminary amounts of electricity generators decrease at the same rate as the ETS cap in Phase 3 (table 4.9). Note that carbon leakage exposure factor (CLEF) applies to both non-electricity and electricity generators preliminary amounts.

Table 4.9: LRF values applied to electricity generators preliminary amounts

Year	2013	2014.	2015	2016	2017	2018	2019	2020
LRF	1	0.9862	0.9652	0.9478	0.9304	0.9130	0.8956	0.8782

Source : (European Parliament Council, 2009)

4.B Annual CSCFs estimation methodology

Determining annual CSCFs is a three step process. Firstly and secondly, both the preliminary amounts sum and annual maximum amounts have to be estimated. Thirdly, annual CSCFs are obtained by comparing the preliminary amounts sum with annual maximum amounts.

Note that at the time of writing this chapter, annual CSCFs had not been communicated by the European Commission yet. These values have finally been published on September 5, 2013 in (European Parliament Council, 2013). They are compared to the estimated values that have been obtained following the methodology introduced in this appendix.

Estimating the preliminary amounts sum

A comment on NIM data In the frame of transitional benchmark-based free allocation (i.e. excluding the case of free allocation for the modernization of electricity generation as indicated in article 10c of the consolidated ETS Directive), both non-electricity and electricity generators are eligible to free allocation although not for the production of electricity (article 10a of the consolidated ETS Directive). Nonetheless and according to article 15(3) of the benchmarking Decision, only preliminary amounts of non-electricity generators are to be considered in order to determine annual CSCFs.

Although the benchmarking Decision required to explicitly distinguishing electricity generators from non-electricity generators, some publicly available NIMs of Member States do not include this information. Determining the preliminary amounts sum thus involves performing the missing non-electricity/electricity generators distinction in the concerned NIMs. This is done by making use of two other indications that NIMs contain : annual preliminary allocation pattern throughout Phase 3 and installation NACE codes [18].

The identification cannot be performed entirely though. Some installations are left *unclassified* when the above two indicators (i.e. annual preliminary allocation pattern and NACE codes) cannot be used. Concerned installations are new entrant in Phase 3 mostly. Two preliminary amounts sums can thus be estimated, whether one assumes these installations are considered electricity generators or not. In the former case their preliminary amounts are discarded from the preliminary amounts sum, in the latter one, they are included.

18. See (European Commission, 2010a) for more details on the attribution of NACE rev. 1 code to installations participating in the EU ETS.

TABLE 4.10: Sectoral disaggregation of PAs (thousand quotas)

Range	Total	Elec. gen.	Non-elec. gen.	Unclassified	Atypical	Non-elec. gen. PAs sum
Low	890,732	80,017	717,886	50,386	42,443	724,887
High	890,732	80,017	768,272	0	42,443	776,360

Source : the author

A range for the preliminary amounts sum Free allocation entitlement in 2013 amounts to 891 million quotas according to the NIMs (excluding the NIM of Belgium, which consists in the NIM of Wallonia only, and that of Slovenia). It is split in four categories (table 4.10) : installations that have been identified either as electricity or non-electricity generators ; installations that could not be identified ; installations with atypical allocation patterns (i.e. not corresponding to either that of electricity or non-electricity generators).

The preliminary amounts sum that is used to determine annual CSCFs is thus obtained summing preliminary amounts of non-electricity generators ; the share of these 2013 preliminary amounts that is deemed at risk of carbon leakage being divided by the 2013 CLEF value as defined in article 15(3) of the benchmarking Decision *"[Cross Sectoral Correction Factor] shall be determined by comparing the sum of the preliminary total annual mounts of emission allowances allocated free of charge to installations that are not electricity generators in each year over the period from 2013 to 2020 without application of the [Carbon Leakage Exposure] factors with the annual [maximum] amount of allowances that is calculated in accordance with article 10a(5) of Directive 2003/87/EC".* The preliminary amounts sum low and high values of non-electricity generators are eventually estimated at 725 (7,454 installations considered) and 776 million (8,350 installations considered) quotas. The preliminary amounts sum is one single value, to which annual maximum amounts are compared.

Atypical installations show a stronger allocation decrease between 2013 and 2020 than any of the two standard allocation patterns ; or show increases in allocation. It is likely that these allocation patterns have to do with allocation to anticipated capacity reduction or addition in the course of Phase 3. Most of these installations are identified as electricity generators when their NACE codes are available and would thus not have been included in annual CSCFs determination, should their Phase 3 allocation patterns coincide with that of electricity generators. Therefore, removing atypical installations from the computation of annual CSCFs should have a negligible impact.

Estimating annual maximum amounts

Non-electricity emissions share Article 10(a)5 of the consolidated ETS Directive introduces three elements that are required to determine annual maximum amounts. They are, 1) the cap of the non-extended perimeter and 2) the new coverage extension in 2013. Third element is the share of emissions from installations covered in Phase 2 and not considered electricity generators (later referred to as "non-electricity emissions share"), in Phase 1 average verified emissions.

The availability of all but two (i.e. Belgium and Slovenia) Member States NIMs makes possible an estimation of the non-electricity emissions share from NIMs. It is obtained summing average Phase 2 emissions of installations that are included in NIMs and not considered electricity generators. The average is then divided by the average emissions of all but two (i.e. Belgium and Slovenia) in Phase 2. Two estimates of non-electricity emissions shares can thus be provided depending on whether emissions of *unclassified* installations are included or not. These values are 31.6% and 32.8% [19], associated to the low and high values of preliminary amounts sum respectively (table 4.11 [20]). It is to be noted that Phase 2 emissions (instead of Phase 1 emissions) are used so that Bulgarian and Romanian installations are included in the computation. The estimation obtained thus does not exactly match the definition given in the consolidated ETS Directive ; it is thus assumed that it is still a good proxy for the non-electricity emissions share.

Derivation of annual maximum amounts Low and high estimations of Phase 3 annual maximum amounts are directly derived from the estimated non-electricity emissions shares. The cap of the non-extended perimeter in 2013 is set at 1,931 million quotas and the new coverage extension concerns 107 millions quotas in 2013. The annual maximum amount of year i is determined using equation 4.5.

$$MA_i = (Cap_{NE} \times S + Cap_E) \times \left(1 - \frac{Red(i - 2013)}{Cap_{NE} + Cap_E}\right) \tag{4.5}$$

Where MA_i is the maximum amount in year i, Cap_{NE} is the non-extended cap, S the non-electricity emissions share, Cap_E the cap extension and Red the constant annual reduction

19. An anterior estimation of the non-electricity emissions share is provided by Lecourt (2012). Following a different methodology the estimated value is 35.5%.

20. Belgium and Slovenia emissions data are not included.

TABLE 4.11: Non-electricity emissions share estimation (Mt CO_2)

Year	2008	2009	2010	2011	2012	Avg.	Non-elec. share (%)
Total ETS	2,036	1,806	1,861	1,831	1,795	1,866	-
Non-elec. gen. (Low est.)	664	560	595	574	558	590	31.6
Non-elec. gen. (High est.)	688	580	617	598	581	613	32.8

Source : the author from NIM database

TABLE 4.12: Estimation of annual maximum amounts in 2013 (M quotas)

Year	2013	2014.	2015	2016	2017	2018	2019	2020
MAs								
Low	718	704	691	678	665	652	639	625
High	741	727	714	700	686	673	659	646

Source : the author from NIM database

of the EU ETS cap in Phase 3, which is set at 37,435,387 quotas. The corresponding 2013 maximum amount low and high values reaches 718 and 741 million quotas. Phase 3 subsequent maximum amounts are reported in table 4.12.

Estimating annual CSCFs

Keeping Belgium aside In the end, the determination and application of annual CSCFs to non-electricity generators preliminary amounts in a given year will occur in the case where the preliminary amounts sum exceeds the maximum amount of the year in question. According to the low and high value of preliminary amounts sum (table 4.10) and their associated annual maximum amounts (table4.12), annual CSCFs are required by the first year of Phase 3, in 2013. Annual CSCFs values in both low and high scenarios are reported below in table 4.13.

The inclusion of *unclassified* installations has a greater impact on the preliminary amounts sum (7.1% increase in 2013 from low to high estimates) than on the annual maximum amounts (3.2% increase in 2013 from low to high estimates). Indeed, most ins-

Table 4.13: Annual CSCFs estimations (in %)

Year	2013	2014	2015	2016	2017	2018	2019	2020
Low	1.0	2.8	4.6	6.5	8.3	10.1	11.9	13.7
High	4.6	6.3	8.1	9.8	11.6	13.3	15.1	16.8

Source : the author

tallations now included in the computation of both the preliminary amounts sum and annual maximum amounts are new entrant in Phase 3 that, although allocated in Phase 3 (about 50 million quotas in 2013), had no verified emissions in previous phases. As a result, the increase in the preliminary amounts sum is not fully compensated by the increase in annual maximum amounts and annual CSCFs are greater with high preliminary amounts sum and annual maximum amounts values, thus providing the upper range of annual CSCFs estimation.

Including Belgium The partial preliminary amount of Belgium has been discarded in the above process in order to not distort the non-electricity share estimation. It should however be included in the total preliminary amounts sum as the cap of the non-extended perimeter accounts for the emissions of both Belgium and Slovenia. Hence the estimation of annual CSCFs is closer to their expected values with the inclusion of Belgian non-electricity installations preliminary amounts. Values reported in table 4.2 in section 4.2.2 account for this adjustment.

Comparing to official CSCFs values *Ex post*, the above described methodology proved correct. Indeed annual values of CSCF provided by the European Commission fall in between the low and high CSCF estimates obtained with the inclusion of Belgium as reported in table 4.14.

Note that two institutions had also estimated annual CSCFs before official values were published. The Dutch consultancy Ecofys provided on July 11, 2013, a CSCF value in 2013 of 15% [21], while the germany-based consultancy Tschach Solutions provided, on July 12, 2013, a low value of 1% and a high value of 5% [22].

21. See Ecofys website : $http : //www.ecofys.com/en/news/eu-ets-industry-will-receive-fewer-free-emission-allowances-than-expected/?utm_source= buffer\&utm_campaign = Buffer\&utm_content = buffer4229c\&utm_medium = twitter$

22. See ICIS website : $http : //www.icis.com/heren/articles/2013/07/12/9687387/emissions/edcm/commission-to-slash-free-euas-requests-0xe2-0x80-analysts.html$

TABLE 4.14: Comparison of annual CSCF estimations (in %)

Year	2013	2014	2015	2016	2017	2018	2019	2020
Low estimate	3.3	5.1	6.9	8.6	10.4	12.2	14.0	15.7
Commission value	5.7	7.4	9.0	10.7	12.4	14.1	15.8	17.6
High estimate	6.7	8.4	10.1	11.8	13.5	15.2	16.9	18.7

Source : the author and (European Parliament Council, 2013)

4.C Annual CSCFs sensitivity analysis

The CSCF value in year i is determined following equation 4.6.

$$CSCF_i = 1 - \frac{MA_i}{PA} \tag{4.6}$$

Variation can either come from the preliminary amounts sum PA (annual maximum amounts MA) held equal) or the annual maximum amounts (preliminary amounts sum held equal). An increase in the preliminary amounts sum involves an increase in annual CSCFs, whereas an increase in annual maximum amounts (or in the non-electricity emissions share S) involves a decrease in annual CSCFs (as illustrated in equation 4.7).

$$dCSCF_i = \frac{MA_i}{PA^2}\partial PA - \frac{1}{PA}\partial MA_i \tag{4.7}$$

The variation in annual maximum amounts is involved by a variation in non-electricity emissions share S, which is defined in equation 4.5. Therefore, equation 4.7 can be re-written now considering a variation in the non-electricity emission share (equation 4.8).

$$dCSCF_i = \frac{MA_i}{PA^2}\partial PA - \frac{Cap_{NE}}{PA}\left(1 - \frac{Red(i-2013)}{Cap_{NE} + Cap_E}\right)\partial S \tag{4.8}$$

The sensitivity analysis, performed from the lower range estimate, shows that a 1% increase in the preliminary amounts sum involves a CSCF increase of 0.97 in 2013 ; a 1% increase in the non-electricity emissions share involves a CSCF decrease of 2.60 in 2013 (table 4.15).

TABLE 4.15: Annual CSCFs variations with PAs sum and non-electricity share (in %)

Year	2013	2014	2015	2016	2017	2018	2019	2020
PAs sum	0.97	0.95	0.93	0.91	0.90	0.88	0.86	0.84
Share (S)	-2.60	-2.55	-2.51	-2.46	-2.41	-2.36	-2.31	-2.27

Source : the author

5

General conclusion

The thesis has unveiled how the power and the non-power sectors were different in their respective structures, both from a demand perspective (chapter 2) and from a supply perspective (chapter 3). The non-power sector has been identified as contributing as much as, if not more than, the power sector in the dynamics of CO_2 emissions, despite the fact that the latter has represented about two thirds of the EU ETS CO_2 emissions since its implementation in 2005. In light of these results, it was suggested in chapter 4 that benchmark-based Phase 3 free allocation to non-power sub-sectors may therefore not be up to the central role of the non-power sector in the EU ETS functioning.

Through an environmental input-output analysis, chapter 2 showed that, given existing EU 27 production structures, sectoral interrelations involve a twice as big sensitivity of EU 27 CO_2 emissions to final demand in products from the non-power sector than to final demand in products from the power sector. This is true when considering EU ETS CO_2 emissions as well, although the ratio between sensitivities is reduced to about one and a half. More developed interrelations in the non-power sector account for such result as final demand in non-power sector products activates more indirect CO_2 emissions. The reduced ratio between both sensitivities when considering EU ETS CO_2 emissions results in the partial coverage, by the EU ETS, of non-power sub-sectors, which may be accounted for by production and capacity thresholds inclusion rules as stipulated in the ETS directive. Under specific assumptions of capital circulation, such partial coverage, which has been outlined in chapter 2, unveiled the possibility for potential domestic carbon leakage, that is to say within EU 27 borders but outside of the EU ETS scope, as most of non-power sub-sectors share their CO_2 emissions between outside and inside the perimeter of the Scheme.

Chapter 3 investigated the relation of sectoral activity with carbon price in the EU ETS over the first two Phases of the Scheme (2005-2012). To do so, it studied the link between sectoral activity and EU ETS CO_2 emissions, after having demonstrated that the former relation could be enlightened by the latter one. A two-factor decomposition analysis was thus undertaken in order to disentangle the respective sectoral contributions on EU ETS CO_2 emissions variations, with regards to the two activity level and intensity accounting factors. The absence of EU ETS specific activity levels indicators required to choose Eurostat production indices because of their nearness to activities covered under the EU ETS firstly, and to statistically validate them as proxies for EU ETS activities. The decomposition analysis showed that activity level was the main factor driving CO_2 emissions changes, and that the non-power sector contribution to the activity factor was greater than that of the power sector. Chapter 3 also showed that the intensity factor contributed to reduce CO_2 emissions in the EU ETS (except in 2007), and that the power sector, through its electricity mix, contributed the most to the intensity factor.

By scrutinizing the benchmark-based free allocation mechanism that has shaped Phase 3 allocation to non-electricity generators, chapter 4 has first unveiled its relative complexity because of the numerous rules benchmarks embody and the amount of data from installations' operators they require to be operational. Secondly, the analysis of benchmarks showed that they do not address part of the criticisms they were expected to, as aggregated free allocation level will remain above verified emissions levels of the aggregated non-electricity sector. More problematic is also the fact that some less efficient than benchmarks non-electricity generators should be allocated more emission permits than their current activity levels would required, which has been demonstrated in the case of the cement sector. The analysis of benchmarks also showed that the structural design of the mechanism was flawed because of its stated aim of pursuing two opposed targets. Indeed the European Commission has publicized their transitional character throughout Phase 3, targeting free allocation phase out in 2027, while at the same time has introduced a carbon leakage provision that affects most of non-electricity generators [1] and involves that Phase 3 free allocation decreases not because of benchmarks but thanks to annual cross sectoral correction factors only. Thirdly, and because benchmarks merits should be underlined as well, chapter 3 has demonstrated that the shift to Phase 3 and the use of benchmarks have

1. In its Communication on a 2030 policy framework for climate change and energy (European Commission, 2014), the European Commission made clear that criteria that were used to define the first carbon leakage would be kept so that there is "continuity in the composition of the list". The carbon leakage list for 2015-2019, is currently under development and is expected to be adopted by the Commission by end of 2014. Sectors that will be included in the draft document should be known by end of March 2014. Note also that Clò (2010) has suggested that the existing criteria to determine whether a sector is deemed at risk of carbon leakage tend to overemphasize trade-intensity as a measure of carbon leakage risk.

involved large free allocation redistribution among installations across Member States, within and in between sectors. It was also suggested that this redistribution, by correcting Phase 2 national bias, led to an harmonization of free allocation.

Should mitigation incentive be embodied by the intensity factor, its effectiveness (or, in other words, the response to carbon price) should therefore be translated into a contribution to the intensity factor to reduce CO_2 emissions. As chapter 3 has showed, the mitigation incentive seems to have been perceived by the non-power sector to a lesser extent, compared to the power sector, over the 2005-2012 period. Two accounting factors may be suggested : partial EU ETS coverage of the non-power and its associated allocation methodology.

Approaching CO_2 emissions through an environmental input-output analysis has shed a new light on their interrelations, and raised the question of the Scheme's perimeter relevance in the case of the non-power segment due to its partial coverage. Although this policy tool seemed well suited to the power sector as most of its direct and indirect emissions activated by final demand were covered under the Scheme, this appeared not to be the case with regards to the non-power sector. The compromise that required an as large coverage of EU heavy industries as possible while keeping the Scheme administratively manageable for market participants resulted in having some indirect emissions of the non-power sector to not be covered, as well as one third of its direct emissions. Treating partially covered and highly interrelated CO_2 emissions differently from clear cut partitioned emissions may therefore be an option to consider, such as final demand orientated mitigation policy ; although the implementation of such mitigation policy appears daunting.

Allocation methodology was identified as a key determinant, in the design of the market, to encourage CO_2 emissions mitigation. Phase 3 has introduced a brand new mode of allocating emission quotas to the non-power segment, which aim is to strengthen the mitigation incentive in the non-power sector while protecting it from international competition (as stated by the European Commission). The question seems all the more crucial to the EU ETS functioning and its capability in participating in driving the EU towards a low carbon economy that both chapter 2 and chapter 3 demonstrated the central role of the non-power sector in the EU ETS emissions dynamics. While not demonstrating whether the emission mitigation incentive of market operators has been changed by the shift in free allocation methodology from Phase 2 to Phase 3 or not, above mentioned results still contribute to the open debate on the ETS structural reforms that the European Commission initiated in December 2012. Indeed, while *ex ante* benchmark-based allocation now targets the most efficient installations and have provided a greater degree of allocation harmonization across

Member States, the fact that they remain linked to historical activity levels involves that they still enable over allocation and calls for the need to improve benchmarks, or to go beyond them in Phase 4 and to develop other policy tools (Knudson, 2009). Output-based allocation coupled with benchmarking would keep less efficient installations net short and vice versa, thus providing a better incentive for structural emissions reductions in the European Union. Hence, it would also prevent from having a market configuration where the emission mitigation incentive of market participants is based on an outdated historical reference, once considered ambitious since, as suggested in the case of the cement sector, benchmarks may be surpassed by business as usual CO_2 emissions intensity improvements.

Hence, it is debatable whether protection from international competition and carbon leakage issues should be addressed by the EU ETS through constant *ex ante* free allocation alone. Indeed, it this implies that there is no logical reason for free allocation to end since there is no logical reason for international competition to end, therefore limiting the emissions reduction incentive and the efficiency of the Scheme, since it adds a second pursued aim to the ETS instrument, which is opposed to the first one that consists in CO_2 emissions mitigation. It is even debatable whether protection from international competition and carbon leakage issues should be addressed by the EU ETS at all. The reduction of CO_2 emissions from energy intensive industries is part of a broader EU ambition to become a highly energy-efficient low-carbon region, thus concerning all the sectors of the economy. As such, international competition issues will concern sectors other than those covered by the EU ETS, and hence might better be addressed by wider measures.

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