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A LA RECHERCHE DU PRIX DU CARBONE

SYSTEME EUROPEEN D'ECHANGE DE QUOTAS DE CO_2 : DES ANALYSES *EX ANTE* ET *EX POST* A LA PROJECTION EN 2020

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IN SEARCH OF THE CARBON PRICE

THE EUROPEAN CO_2 EMISSION TRADING SCHEME: FROM EX ANTE AND EX POST ANALYSIS TO THE PROJECTION IN 2020

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Abstract in English

This thesis is an evaluation of the first two phases of the EU ETS. It is articulated around the progressive construction of a simulation model, ZEPHYR-Flex, which aims at being able to replicate the observed price and emissions trajectories between 2005 and 2012, and to project them until 2020 under different sets of assumptions. The *ex post* analysis of the first eight years of the system reveals that to understand its development, it is necessary to study in details the role played by three flexibility mechanisms: trading, spatial flexibility (offsets), and time flexibility (banking/borrowing). In a first stage, we build a technical-economic framework for the core trading mechanism of the model. The role of offsets is then scrutinized and a scenario for their use up to 2020 is calculated on this basis. Next, the time flexibility and the related banking and borrowing behavior are introduced into the model which can then replicate the past price and emission trajectory. The model and the lessons from the first two phases are then used in different prospective scenarios to 2020. Among the scenarios tested, only a strengthening of the cap in line with the 2050 European reduction target is able to restore confidence and anticipations, two factors needed for the efficiency of the EU ETS in the long term. The issue of correctly articulating the EU ETS with other climate-energy policies is also underlined.

Keywords: Ex post evaluation, emission trading, EU ETS, carbon offsets, climate policy

Résumé en français

Cette thèse est une évaluation des deux premières phases du Système Communautaire d’Echange de Quotas d’Emission (SCEQE). Il s'articule autour de la construction progressive d'un modèle de simulation, ZEPHYR-Flex, qui vise à reproduire les évolutions du prix et des émissions observés entre 2005 et 2012, et à les projeter jusqu'en 2020 sous différentes séries d'hypothèses. L'analyse *ex post* des huit premières années du système révèle que, pour comprendre son évolution, il est nécessaire d'étudier en détail le rôle joué par trois mécanismes de flexibilité: les échanges de quotas, la flexibilité spatiale (crédits carbone), et la flexibilité temporelle (*banking/borrowing*). Dans un premier temps, nous construisons un cadre technico-économique servant de base au mécanisme simulant les échanges de quotas dans le modèle. Le rôle des crédits carbone est ensuite examiné et un scénario pour leur utilisation jusqu'en 2020 est calculé sur cette base. Ensuite, la flexibilité temporelle est introduite dans le modèle qui, une fois les trois mécanismes de flexibilité réunis, peut reproduire la trajectoire passée du prix et des émissions. Le modèle et les leçons tirées des deux premières phases sont ensuite utilisés dans différents scénarios prospectifs à l'horizon 2020. Parmi les scénarios testés, seul un renforcement du plafond d’émission en ligne avec l'objectif européen de 2050 est en mesure de restaurer la confiance et les anticipations associées au système, deux facteurs qui conditionnent l'efficacité du SCEQE à long terme. La nécessité d’articuler correctement le SCEQE avec les autres politiques climat-énergie est également soulignée.

Mot clés: évaluation ex post, échanges de quotas, EU ETS, crédits carbone, politique climatique

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Introduction

"The EU ETS will be critical in driving a wide range of low carbon technologies into the market, so that the power sector itself can adapt its investment and operational strategies to changing energy prices and technology. For the EU ETS to play this role on the identified pathway to 2050, both a sufficient carbon price signal and long-term predictability are necessary."

European Commission, *A Roadmap for moving to a competitive low carbon economy in 2050*, March 2011

The economic literature opposes "command and control" policies, in which the public authority set up standards and rules to directly reduce environmental damages, with policies based on "economic tools" that aim at changing the behavior of economic agents through the modification or the introduction of prices, which reflect the cost of environmental damages in a context where traditional markets fail to account for environmental externalities.

There is a large consensus among economist to favor "economic tools" that aims at protecting the environment in the most efficient way, i.e. by minimizing the total cost of pollution abatement. Despite those recommendations, most of the environmental policies conducted in the real world continue to favor "command and control" policies. However since the adoption of the Kyoto protocol in 1997, climate change policy is a notable exception.

There are two ways of introducing a price which incorporates environmental externalities in the markets: price-based and quantity-based regulation. Price based policies generally consist of taxes or assimilated levies; quantity-based policies usually consist of cap-and-trade or baseline-and-credit programs, which create tradable emission rights. The economic literature has developed for the two branches since the founding work of A. C. Pigou (1920) and that of R. Coase (1960), and both types of policies have been put into practice into various fields. The evaluation of the conditions for their efficiency has also been carefully examined by economists like L. H. Goulder (the second dividend) or A. D. Ellerman (the US SO_2 cap-and-trade program). Since the intake of Weitzman (1974), a long literature has developed weighting the pros and cons of each of the methods. Facing this theoretical opposition, there is a need for more empirical evidence to feed the debate. The case of the European Union Emission Trading Scheme (EU ETS) provides to date the most complete experience of carbon pricing, and allows to draw lessons on the implementation of a cap-and-trade system and the conditions of its efficiency.

The European Union Emission Trading Scheme (EU ETS) is currently the largest greenhouse gas emissions trading system in the world, covering more than 12,000 industrial installations in 30 European countries, responsible for almost half of European CO_2 emissions. Originally created in 2005 to facilitate the achievement by European Member States of the targets set by the Kyoto Protocol for the period 2008-2012, it inherited three of it specificities. The first is its economic principle, emission trading, which allows the exchanges of allowances between participants. The second is the possibility to generate and use carbon offsets from project based mechanisms, linked to the general emission trading framework. The third is their initially short to medium term explicit timeframe, with only an implicit long term ground. In 2012, the EU ETS is considered by the European Commission as one of the core policies implemented to allow an almost complete reduction of European Union greenhouse gas emissions by 2050, but still the rules for the EU ETS after 2020 are not explicitly known.

The expected goal of the EU ETS is to allow the emergence of a single price associated with greenhouse gas emissions in the covered sectors by capping the total emissions covered with allowances called European Union Allowances (EUAs) and allowing the exchange of allowances between actors. The resulting carbon price depends on the actual and perceived scarcity of these allowances over time, and on the costs associated to emission reductions. This price has an important role to play, in that it will influence the decisions of economic players both in the short-term management of their existing assets, and in the longer term direction of their investments. By nature, the EU ETS aims at minimizing the cost of reaching a certain predefined target. The economic efficiency of the policy is dependent on the EU ETS capacity to establish rules that will modify the short term behavior of agents as well as their investments decision, which requires to act (for the second category) on their medium to long term anticipations.

The purpose of this thesis is threefold:

- It aims first at providing a complete assessment of Phase 1 and Phase 2 by a careful *ex post* observation of the market development and to what extent the initial goals have been reached. In so doing we will extend the work already done by Ellerman, Convery and De Perthuis (2011) on the first Phase.
- The second objective is to build a simulation model that will bring information on the compliance behavior of participants (abatement, trades, banking and borrowing), as well as the related compliance costs, and the impact of allowing the use of offsets. This will help us in our evaluation task mentioned above.
- The third objective is to enlighten the possible future of the EU ETS. This model, combined with the *ex post* analysis, will serve as a base for a prospective analysis to 2020.

The observation of the first two phases of operation, covering the period from 2005 to 2012, exhibits a carbon price which differs greatly from these theoretical expectations. Since its launch in 2005, the system has delivered a price which exhibited a certain level of unpredictability. It is not possible to understand properly the reasons for that and the possible consequences without looking more closely into the dynamics of the EU ETS, which is conferred by three provisions: the ability to trade allowances between participants, the possibility of using other types of allowances than EUAs for compliance under the scheme (namely the offsets generated by the Kyoto Protocol project-based mechanisms), and the ability to hold unused allowances for a later use, or borrow allowances in advance.

Two large families of economic models have been used to explain carbon price formation. The first category is that of macro models which represent global energy markets equilibirum, with a strong technologic-economic core such as the PRIMES model (developed by the E3Lab of the National Technical University of Athens) or the POLES models (LEPII and Enerdata). Those equilibrium models have the advantage of modeling the economical and technological impacts of economic scenarios or policies on most energy markets and all European countries at the same time. Nevertheless, it is difficult for them to isolate the scope of the EU ETS and to describe its detailed rules in order to represent the balance between supply and demand of allowances.

The second category is econometric models. An econometric model specifies the statistical relationship that is believed to hold between the various economic quantities studied, for example the relationship between oil and carbon prices, or the impact of meteorological conditions. Those models have been widely used to study the EUA price and its various links with other prices and markets. They can give interesting results when used for explaining the past relationships between price fluctuations on a specific timeframe. It is more difficult for them to be reliable in forecasting the future because it appears that the relevant variables explaining carbon price fluctuations differ according to the considered period.

The modeling tool we are going to build and use in this thesis, ZEPHYR-Flex, aims at representing the balance between supply and demand of allowances, based on a detailed representation of the EU ETS, its perimeter, and taking into account its precise rules and their evolution over the period. Our aim is to be able to replicate and explain the gap between *ex ante* expectations and *ex post* observations, and to better understand on this basis the possible future of the EU ETS.

Our thesis is structured in five chapters which gradually incorporate more information about the use and effects of the three flexibility mechanisms: trading, offsets, banking/borrowing.

The first Chapter is a historical review of the EU ETS, which allows to determinate the methodology followed in the rest of the thesis. In a first step, we remind the reader of the economic theoretical background and the historical debate on how climate change control should be integrated in the functioning of the economy. The European experience reveals that the supposed economic efficiency of allowance trading and the flexibility mechanisms associated to this system are at the core of its existence. Those mechanisms are necessary to explain the past, as will be shown by a detailed comparison between *ex ante* expectations and *ex post* observations. The better understanding of the use of the three flexibility provisions, along with the progressive construction of the ZEPHYR-Flex model, structures the following three Chapters of this thesis.

Chapter 2 focuses on building a technical-economic base represented by a counterfactual scenario, describing what could have happened in the absence of the EU ETS, and the underlying ex post marginal abatement cost curves. This technical-economic base will then be integrated into a prototype version of our model, which allows for only one level of flexibility: trading. At this point the actual observations will be not be replicated by the model, which will still highlight the potential savings related to trading. Replicating the price, as seen in Chapter 1, requires to incorporate the two other flexibility mechanisms: offsets and banking/borrowing.

Chapter 3 is an extensive analysis of the use of carbon offsets in the EU ETS. After describing the motivations and fears linked with the integration of offsets in a cap-and-trade system, the detailed rules for using offsets, as well as their availability over time, an analytical framework is build so as to explain the relationship between prices and uses of offsets compared to EUAs. Complementary ex post observation of the prices and of the use of offsets at the installation level will underline the effect of offsets in a cap and trade system, which comes to indirectly raise the internal cap (lower the constraint). The assessment of Phase 2 will allow for the construction of a scenario of offset use that will be an input of the ZEPHYR-Flex model.

Chapter 4 is a study of time flexibility in the EU ETS and leads to the complete integration of the three flexibility mechanisms (trading, offsets, banking/borrowing) into ZEPHYR-Flex. In a first part, the past banking and borrowing of allowances in the EU ETS is analyzed through the CITL data. Then, the link between anticipations and time flexibility is modeled and integrated into ZEPHYR-Flex along with the scenario for the use of offsets determined in Chapter 4. This version of the model is able to replicate the past price and emission trajectory, therefore allowing a complete ex post evaluation of Phase 1 and Phase 2 of the EU ETS: trades, banking/borrowing, abatement and costs, as well as the effect of offsets.

In Chapter 5, we will be using the model as a prospective tool to illustrate the possible futures of the EU ETS. The first step will be to incorporate in the emission counterfactual the effect of other climate and energy policies (renewable energy or energy efficiency policies), which tend to lower the need for internal EU ETS emission reductions over time. We will then run two simulations revealing the determining issues associated to the shift in Phase 3: the dynamics of past behavior and to the longer term anticipations of actors, in a context of economic stagnation and unforeseen policy interactions. The model will then be used to simulate three possible interventions on the EU ETS which could put it back on track: a reserve price at auctions, the back-loading of Phase 3 auctions, or the definition of a medium to long term cap trajectory. Among the scenarios tested, only a strengthening of the cap in line with the 2050 European reduction target is able to restore confidence and anticipations, two factors needed for the efficiency of the EU ETS in the long term.

Chapter 1 – Emissions trading: The key role of flexibility

"In any particular setting there may be important practical reasons for favouring either prices or quantities as planning instruments. These reasons might involve ideological, political, legal, social, historical, administrative, motivational, informational, monitoring, enforcing, or other considerations."

Martin L. Weitzman, *Prices vs. Quantities* (1974)

The need to integrate the cost of environmental damages into the functioning of the economy, so that these damages are controlled in an efficient way, is an idea largely shared among economists. To do so, several options are available to the public authority, such as setting standards and specific regulations, tax and subsidies, or tradable permits. The study of those options, in particular the mirroring relationship between price-based and quantity-based instruments, generated over the years a considerable economic literature. It is difficult to conclude whether one instrument is better than the other. In general, this question generates a normative debate on the relative cost functions for reducing the pollution against the costs associated with environmental damages, in conjunction with the nature of uncertainties to be faced. Quantity-based, price-based policies or even hybrid policies can all be proven best under certain conditions or in a particular context.

This theoretical debate is completed and influenced by practical experiences. Both price-based and quantity-based instruments have effectively been used to control environmental externalities, for example carbon taxes in Northern Europe or SO_2 emission trading system in North America in the beginning of the 1990s. The European Union, which was initially planning to establish a tax on carbon emissions in the same period, eventually favored an emission trading system after the negotiation of the Kyoto Protocol, in order to help the implementation of the Kyoto Protocol among European Member States. This led to the creation of the European Union Emission Trading System (EU ETS), to date the largest system in the world which effectively puts a price on the greenhouse gas emissions of energy intensive industries.

In this Chapter, we are going to present the theoretical principles of the EU ETS (section 1) and the historical construction of this emission trading system (section 2), along with a review of its functioning over the period from 2005 to 2012 (section 3). The comparison between what was expected before the start of the system and its actual realization will allow us to draw an analysis framework, detailed in section 4, in which the banking, borrowing and offsetting mechanisms play a determining role for both the acceptability and the formation of the carbon price. This allows us to structure the rest of the thesis around two pillars: the comparison between *ex ante* expectations and *ex post* realizations, and the sequential construction of ZEPHYR-Flex, a simulation model of the EU ETS.

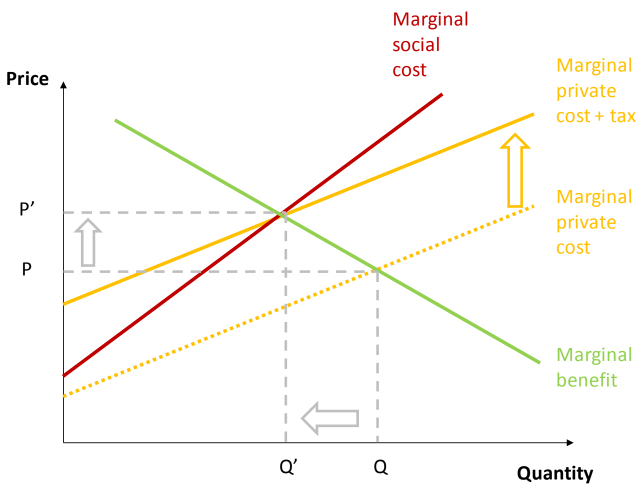
1. Integrating climate change in the economy: the Great Debate

1.1 The pigovian tax

The theory behind the integration of environmental damages in the economy dates back to the work of English economist Arthur C. Pigou (1920) which remains central to modern welfare economics and particularly to environmental economics. If an activity produces uncompensated damages to surroundings (externalities, i.e. social costs), the economy is not at its optimal state, that is not producing the "right" amount of goods at the "right" cost. In this situation, the production of an additional unit of good can induce an additional damage (marginal social cost) which value is much higher than the marginal benefit related to the production of the good. The society faces "net costs" related to this production, and the producer receives no economic signal to account for damages and over-produces the good.

Pigou shows that this problem can be efficiently corrected by making the activity which co-produces external damages pay for the damages it creates. In other words, Pigou advocates a tax on polluters, which raises the costs of production, so that the production level is automatically adjusted to the new optimum level accounting for the costs of damages. What is this optimum level? We can consider pollution acceptable in the economic sense as long as dealing with its consequences costs less than the benefit we get from producing it. Thus, if it is possible to evaluate environmental damages, the tax level should be fixed so that the producer's marginal production cost equalizes the marginal social costs.

FIGURE 1 - THE PIGOVIAN TAX



The lessons we can draw from Pigou is that public authority can intervene to correct market failures (such as environmental damages previously unaccounted for) through prices, if it can accurately gauge the social cost. In practice, economists have considerable difficulties in answering this question in regard to greenhouse gas emissions. When one would want to introduce a tax on carbon emissions, one would somehow estimate beforehand the tax level enabling emissions to be reduced by a certain amount. The advantage of a carbon tax lies in the visibility of the price which is know and taken into account by everyone and allows to control the levels of the costs implied; its disadvantage is that it is often difficult for the public authority to access data on reduction costs and anticipate the effects of this new price on the level of emissions and on the rest of the economy. Taxes are also difficult to adapt to a change of context and rather inflexible.

1.2 Property rights for environmental regulation

In later years, economists like the British-born, American-based Ronald H. Coase (1960) initiated a change of approach by putting into question the effects of a direct intervention of the public authority in the economy. Coase makes a strong case against Pigou, especially his view "in terms of a comparison between a state of laissez faire and some kind of ideal world, which inevitably leads to a looseness of thought". Coase thinks that the public authority may not always be the best judge, and that negotiation or bargaining (i.e. the market) could well deliver an optimal outcome by itself, if property rights (including limited rights to damage the environment) are well defined and if there are no transaction costs affecting actor's participation to the market.

The rather counterintuitive thesis of Coase is that as long as property rights are well defined and under zero transaction cost, the market and the corresponding exchanges of rights will naturally lead to the highest valued use of resources in total, no matter how the rights were initially allocated. Under these conditions, different initial allocations will lead to different wealth and transfers among actors, but they will all lead to the same optimal outcome for a same total quantity of rights.

Coase made clear the point that transaction costs, however, could not be neglected, and therefore, the initial allocation of property rights often mattered. One normative conclusion sometimes drawn is that property rights should initially be assigned to the actors gaining the most utility from them. Another is that government should create institutions that minimize transaction costs, so as to allow misallocations of resources to be corrected as cheaply as possible.

Coase's contribution laid the basis for the development of a new approach to economics and to environmental regulation in particular. If factors of production are thought of as rights, the right to do something which has a harmful effect (such as the creation of smoke, noise, smells, etc.) is also a factor of production. The right to damage the environment up to a certain point, seen as a limited factor of production, can be materialized as a tradable right. The public authority has to define the total number of rights (permits), ensure their legal force, and initially allocate them to the entities, but do not directly fix their price. The price of permits is determined by exchanges between entities on the market, which under perfect conditions, leads to the most efficient use of the permits. In this case, the environmental goal is obtained at the least possible cost, without the public authority having to evaluate *ex ante* the costs involved.

A few years later, Harold Demsetz (1964) extends and documents Coase arguments. He is followed by Crocker (1966) and Dales (1968) who propose examples of emission trading systems for air and water pollution control systems. Baumol and Oates (1971) and Montgomery (1972) build a detailed formalization of permit markets and analyse the conditions for their efficiency.

1.3 Prices versus Quantities

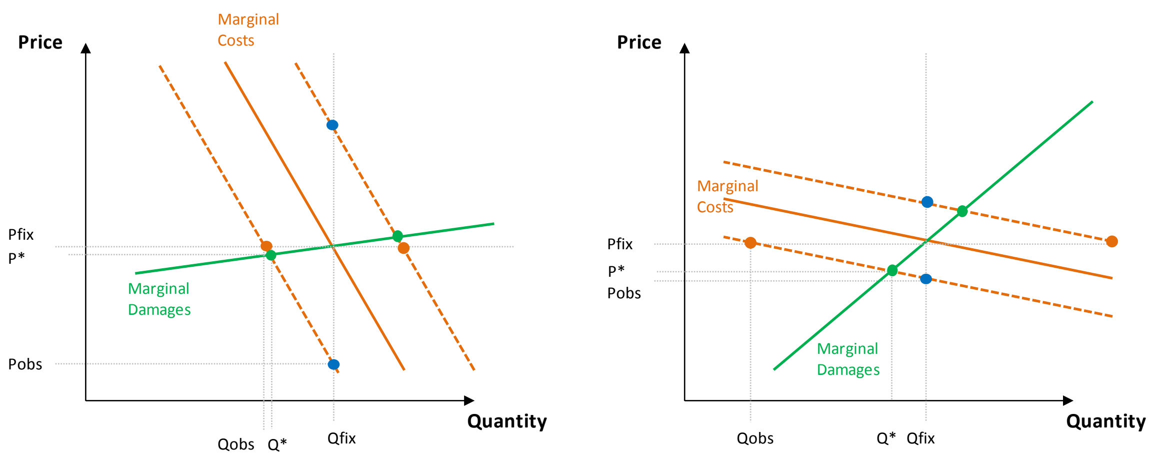
The famous paper *Prices vs. Quantities* of American economist Martin L. Weitzman (1974) proposes a prototype planning problem, attempting to characterize the situations in which one policy type (price-based policies or quantity-based policies) would be more preferable than the other, i.e. more efficient.

Resource allocation theory emphasizes the close connection between these two modes of control. No matter how one type of planning instrument is fixed, there is always a corresponding way to set the other that achieves the same result when implemented. From a strictly theoretical point of view, there is really nothing to recommend one mode of control over the other. Generally speaking it is neither easier nor harder to name the "right" prices than the "right" quantities, because in principle exactly the same information is needed to correctly specify either. Thus in an environment of complete knowledge and perfect certainty there is a formal identity between the use of prices and quantities as planning instruments.

If there is any advantage to employing price or quantity control modes, therefore, it must be due to inadequate information or uncertainty. Weitzman finds that, in order to determine which type of control will be the most efficient when faced with uncertainty, the relative slopes of marginal benefits and costs must be examined. In the case of pollution, marginal benefits are the avoidance of the marginal damages.

The major result from Weitzman is that the relative efficiency of price and quantity regulation depends upon the relative slope of costs and benefits functions. If costs are steep while benefits are flat, then price-type regulation is more efficient; conversely, if benefits are highly depending on quantities while the costs are close to flat, then quantity-type regulation is more efficient.

Figure 2 - Prices vs. Quantities (illustration)



Note: The two graphs represent the potential cost of error related to the choice of quantity or price instruments in the case where the public authority makes an error in assessing costs. Marginal costs (in red) are decreasing with quantities, whereas marginal damages (in green) are increasing. The continuous line represents costs as they are initially thought to be. Two additional dotted red lines represent two possible positions for the "real" cost curves (without errors). By choosing price or quantity as an instrument, the public authority will try to reach the point which equalizes marginal costs and marginal damages (intersection of the green and red lines). It can either fix the quantity at Q_{fix}*, thinking it will observe the price* P_{fix}*, or reciprocally. Two situations can arise depending on the relative slopes of marginal costs and damages.*

If marginal costs are sharper than damages (left-hand side), fixing the quantity Q_{fix} will, given the error on costs, induce a price P_{obs} which differs significantly from the theoretical optimum P. Inversely, if the public authority chooses to fix the price (at P_{fix}), the observed quantity will be Q_{obs}, which is close to the theoretical optimum (Q*). The solution that minimizes the cost of error is thus to use a price instrument. In the other situation (right-hand side), a quantitative instrument is preferable.*

In the case of climate change, what form of control should be favored? In general, the structure of the costs and damages in global warming gives a presumption to price-type approaches, see Newell and Pizer (2003a) or the description in Nordhaus (2007). The reason is that the benefits are related to the stock of GHGs, while the costs are related to the flow of emissions. This implies that the marginal costs of emission reductions are rather sensitive to the level of reductions, while the marginal benefits of emissions reductions are less directly dependent of the current level of emissions reductions.

Other argue that the presence of tipping points (irreversibility in damages related to climate change) gives an advantage to quantity based tools, by allowing the risk of catastrophic changes to be controlled directly with a quantitative threshold.

Nevertheless, because choosing between price or quantity tools requires to evaluate the damages of climate change impacts and of reduction costs, which are both uncertain and require aggregation over time (via a discount rate) and aggregation in space (equity weighting), this question has no real answer. The reader can refer to the explanations of Whitesell (2011). Documenting this question has generated over the years a considerable literature that built up into a normative and ethical debate on how much, when and where emissions should be reduced, see for example Newell and Pizer (2003b and 2004). Estimates of marginal damages at the world level have been published by many authors for example by Pearce (2003), Tol (2005), the most known from the public being the one of Stern (2007). Other have published studies focusing on certain regions, for example in the United States - Mendelsohn and Neumann (1999).

In fact, theory and practice of emission trading have always been intertwined, and actors in the real world did not wait for a definite answer from theoreticians to put ideas into practice.

2. A historical perspective on the emergence of the carbon price in Europe

In the early 1970s, emission trading was considered an academically intriguing, but ultimately impractical idea. Since the 1970s, the use of transferable permits to control pollution has evolved from an academic curiosity to practical experiments. Emissions trading has been tested in a lot of contexts: a program to phase out lead in gasoline - Nussbaum (1992) - reducing or eliminating ozone depleting chemicals - Stavins and Hahn (1993) and many other examples in diverse fields. But the real turning point happened in the mid-1990s with the American experience in reducing SO_2 emissions rather cost-effectively with the cap-and-trade system associated to the Acid Rain Program. This policy in turn had another great influence: laying the theoretical and experiential background for the discussions of the Kyoto Protocol and of the European Union Emission Trading System, this time to control greenhouse gas emissions.

2.1 The first experiments of emission trading

Prior to the adoption of the first emissions trading programs, the approach to pollution control relied primarily on "command-and-control" policies. Standards, which establish the highest allowable quantity or concentration of pollutant in the environment, represent the targets of this approach. To reach these targets, harmonized legal requirements are imposed on a number of specific sources and enforced using controls and penalties.

The political acceptability of quantity-based approach grew as the difficulties with the command-and-control approach, such as control and enforcement costs or the lack of flexibility to deal with heterogeneity of reduction costs or competitiveness among the sources, became more apparent. A pivotal point occurred when empirical cost-effectiveness studies confirmed that it was possible to reach the predetermined standards at a much lower cost than with the traditional command-and-control policies, but without having to rely on taxes; see for example Tietenberg (1973). This offered the politically satisfying prospect of either achieving the existing environmental objectives at a much lower cost or of obtaining a much higher level of environmental quality for the same expenditure.

A preliminary initiative which capitalized on these insights came in 1976 in the United States. By then it had become clear that a number of regions would fail to attain required ambient air quality standards by the deadlines mandated in the Clean Air Act. Prohibiting economic growth as the means of resolving air quality problems was politically unpopular among governors, mayors, and many members of Congress. The means for addressing the air quality problem while facilitating further economic growth involved the creation of an early form of emissions trading. Existing sources of pollution in the nonattainment area were encouraged to voluntarily reduce their emission levels below the legal requirements. Once the EPA certified these excess reductions as "emission reduction credits", they became transferable (sellable) to new sources that wished to enter the area. New sources were allowed to enter nonattainment regions providing they acquired sufficient emission reduction credits from other facilities in the region so that total regional emissions were lower after entry than before.

Known as the "offset policy" or the "EPA reduction credit program", this approach has been relatively successful, but case-by-case pre-certification of emission reductions were characterized by burdensome and time-consuming administrative approval processes that made trading difficult and transaction costs high. This limited the effectiveness of the program, as analyzed by Tietenberg (1985).

2.2 An inspiring experience: the United States SO_2 trading program

The EPA reduction credit program was run around the idea of ex-post certifications of reductions which would then be tradable. This was a first step towards a full cap-and-trade program: the SO_2 trading system. In this system, the total emissions are capped ex-ante by the creation of a corresponding limited number of rights. The units traded are not case-by-case verified reductions but rights to emit available in a limited quantity.

The U.S. SO_2 cap-and-trade program was established as a result of the enactment of the 1990 Clean Air Act Amendments under the authority granted by Title IV, which included several measures to reduce precursor emissions of acid deposition. The SO_2 component consisted of a two-phase, cap-and-trade program for reducing SO_2 emissions from fossil-fuel burning power plants located in the continental states of the United States. During Phase I, lasting from 1995 through 1999, electric generating units larger than 100 MWe in generating capacity with an annual average emission rate greater than 2.5 pounds of SO_2 per million Btu of heat input in 1985 were required to reduce emissions to a level that would be, on average, no greater than 2.5 pounds of SO_2 per million Btu of heat input.

In Phase II, beginning in 2000 and continuing indefinitely, the program was expanded to include fossil-fuel electricity generating units greater than 25 MWe, or virtually all fossil-fuel power plants in the United States. Emissions from these affected units are limited to an annual cap of 8.9 million tons, or about half of total electric utility SO_2 emissions in the early 1980s. The Phase II cap is equivalent to an average emission rate of 1.2 pounds of SO_2 per million Btu of heat input.

This cap on national SO_2 emissions was implemented by issuing tradable allowances—representing the right to emit one ton of SO_2 emissions—equal in total to annual allowed emissions from affected units in each year after 1995, and by requiring that the owners of these units surrender an allowance for every ton of SO_2 emitted. Allowances not used in the year for which they are allocated can be carried over or banked for future use by the original owner or by any party to whom the banked allowance is sold. Allowances are allocated to owners of affected units free of charge for the next thirty years, generally in proportion to each unit's average annual heat input during the three-year baseline period, 1985-87. A small percentage (2.8 percent) of the allowances allocated to affected units are withheld for sale through an annual auction conducted by the EPA to encourage trading and to ensure the availability of allowances for new generating units. The revenues from this auction are returned on a pro rata basis to the owners from whose the allowances were withheld.

A thorough *ex-post* evaluation of the first phase of the program is provided by Ellerman et al. (2000), a work that has since then been regularly updated by the authors and supplemented by other teams of researchers. An exhaustive summary of the lessons from a number of American initiatives in emission trading, including the SO_2 program, is provided in Ellerman et al. (2003):

- Emission trading has been successful in its major objective of lowering the cost of meeting emission reduction goals. Experience shows that emissions trading programs can reduce compliance costs significantly compared to command-and-control alternatives. While it is impossible to provide precise measures of cost savings compared to hypothetical control approaches that might have been applied, the available evidence suggests that the increased compliance flexibility of emissions trading yields costs savings of as much as 50 percent.

- While some skeptics have suggested that emission trading is a way of evading environmental requirements, the SO_2 experience indicates that emission trading helps achieve environmental goals in several ways.

- The achievement of required emission reductions is accelerated when emission reduction requirements are phased-in and firms are able to bank emissions rights. Moreover, giving firms with high abatement costs the flexibility to meet their compliance obligations by buying emissions allowances eliminates the underlying requests for special exemptions from emissions regulations based on "hardship" and "high cost".

- Banking has played an important role in improving the economic and environmental performance of emissions trading programs. Banking reduces the cumulative compliance costs. Moreover, it has been particularly important in providing flexibility to deal with many uncertainties associated with an emissions trading market—production levels, compliance costs, and the other factors that influence demand for credits or allowances.

- The initial allocation of allowances in cap-and-trade programs has shown that equity and political concerns can be addressed without impairing the cost savings from trading or the environmental performance of these programs. Because emissions allowances in cap-and-trade programs have a market value, their allocation has been perhaps the single most contentious issue. However, the ability to allocate this valuable commodity and thereby account for the economic impacts of new regulatory requirements has been an important means of attaining political support for more stringent emissions caps. There are many methods of allocating initial allowances—such as grandfathering, auctioning by the government and distributing on the basis of future information—that can affect cost savings and other overall impacts; but the major effects of the initial allocation are to distribute valuable assets in some manner and to provide effective compensation for the financial impacts of capping emissions on participating sources.

The lessons from the US SO_2 trading program were that emission trading could be an efficient, acceptable and flexible tool. Moreover it also proved that the design of the scheme was of crucial importance in providing the framework for trading and flexibility, thus cost-efficiency.

2.3 The European context: from tax to market[1]

As perfectly summarized by Convery (2009), the framework for the launch of the EU ETS was made possible by political cooperation, robust intellectual development and lessons from experience in the United States, with strong links with the Kyoto Protocol. But surprisingly enough, until the end of the 1990s European deciders were still strong opponents of emissions trading.

The Single European Act of 1986, which formally established European political cooperation and a single European market, provided the statutory basis for subsequent action to address climate change. It highlighted the need to address environmental challenges that transcended national frontiers on a community-wide basis, and to do so in a cost effective manner. These considerations combined to convince the European Commission to propose an EU-wide carbon energy tax in 1992, see European Commission (1992).

Opposition to the proposal came from two powerful sources. First, some Member States regarded a carbon tax as blow to their sovereignty that would be followed inevitably by other taxing initiatives that would incrementally leak fiscal autonomy to the Commission. Secondly, the main industry lobby also opposed the tax, with consistent and persistent case-making at Member State and EU levels (some industry interests at this time proposed emissions trading as a preferable option to taxation, a position that proved of relevance later on).

[1] This section draws heavily on the work of Franck Convery, his colleagues and the research team of *Pricing Carbon: the European Union Emission Trading Scheme* who I thank him gratefully for letting me reproduce part of this work.

The opposition proved too strong, and the carbon energy tax proposal was formally withdrawn in 1997. During the same period, The European Union was very active in the international climate negotiations that led to the Kyoto Protocol. Three features characterized the European Union's negotiating position: a commitment to mandatory caps on emissions by developed countries, an undifferentiated target of 15% below 1990 emissions levels, and an antipathy toward emissions trading as a mechanism for achieving this target. The Kyoto Protocol was signed in December 1997. Signatories agreed to caps, but the EU failed to achieve its 15% reduction or undifferentiated target goal.

In addition, at the insistence of the US delegation led by then-Vice President Al Gore, emission trading between countries was included as a flexible measure, together with the Clean Development Mechanism (CDM) and Joint Implementation (JI). The European negotiating team felt that it had failed to achieve most of what it had aimed for, and shortly after Kyoto most team members moved on to other assignments. Six months after Kyoto, new leadership at the Commission embraced emissions trading.

BOX 1 - EMISSIONS TRADING IN THE KYOTO PROTOCOL

In December 1997, industrial countries and countries with economies in transition agreed to legally binding emission targets for greenhouse gases at the Kyoto Conference, corresponding to a reduction of around 5% compared to 1990 levels by 2012, see UNFCCC (1997). The Kyoto Protocol became effective in February 2005 with the compliance period covering 2008-2012. The Kyoto Protocol authorizes three cooperative implementation mechanisms that involve tradable permits: Emission Trading (a cap and trade program), Joint Implementation and the Clean Development Mechanism (two emission reductions crediting mechanisms).

- "Emissions Trading" is a cap-and-trade program that allows the trading of Assigned Amount Units (AAUs, the national GHG quotas established by the Kyoto Protocol and corresponding to the volume of emissions authorized over the compliance period) among countries listed in Annex B of the Protocol (industrialized countries and economies in transition).

- Under "Joint Implementation" (JI), Annex B Parties can receive emissions reduction credit (ERUs) when they help to finance specific projects that reduce net emissions in another Annex B Party country. This "project-based" mechanism is designed to exploit opportunities in Annex B countries that have not yet become fully eligible to engage in the emission trading program described above.

- The "Clean Development Mechanism" (CDM) enables Annex B Parties to finance emission-reduction projects in non-Annex B Parties (developing countries) and to receive the corresponding certified emission reductions (CERs) in exchange.

The CERs and ERUs generated by those mechanisms can be used along AAUs against domestic emissions to fulfill the compliance obligations of the Protocol.

A key decision that enabled EU trading to emerge was the Burden-Sharing agreement of June 1998. In this agreement, each of the then-15 Member States agreed to a national target, the sum of which amounted to the overall Kyoto target of 8% below 1990 emissions levels.

These targets were subsequently made legally binding, see UNFCCC (2002). Also in June 1998 the Commission issued "Climate Change: Towards an EU Post-Kyoto Strategy" which stated that the Community could set up its own internal trading scheme by 2005, a move which would give the EU practical familiarity and even a leading edge in using this tool.

Member States were first to act on the potential that emissions trading seemed to offer. The UK had emerged during the 1990s as the European leader in mobilizing markets to address a range of environmental challenges. Denmark had a long tradition of using environmental taxes, and so was politically and temperamentally disposed to use markets to support environmental objectives. This early action by Member States convinced the Commission and others to move quickly at EU level. Otherwise, Europe would end up with a patchwork of schemes combining lack of scope and scale and probable incompatibilities to make the whole much weaker than the sum of the parts.

Momentum at the Commission quickly gathered force. Following the publication of a Green Paper in March 2000 and subsequent stakeholder consultations, the EU ETS draft proposal was submitted in 2001 for formal consideration. The European Parliament conducted its first reading of the draft Directive in October 2002, the Council of Ministers presented its position in December 2002, and an amended draft Directive was adopted and approved by the European Parliament and the Council of Ministers in July 2003. On October 13, 2003, emissions trading Directive 2003/87/EC came into effect, with a start in January 2005.

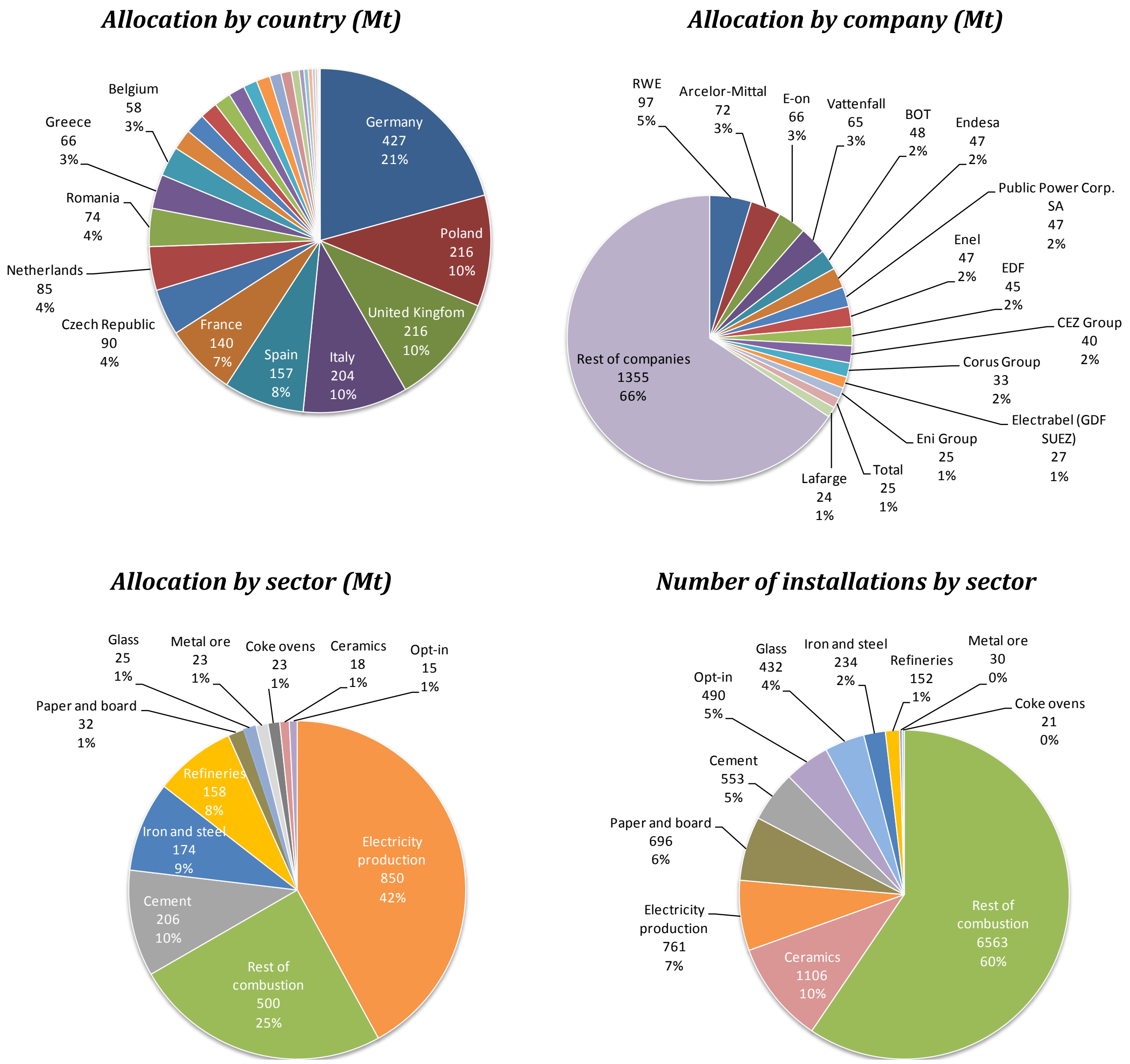
3. EU ETS: From expectations to reality

3.1 EU ETS: the rules and their evolution over time

Since 2005 the EU ETS has applied to around 12,000 energy-intensive industrial installations across the European Union, in sectors such as electric power generation, heating, steel, cement, refineries, ceramics, paper (see Figure 3). At the beginning of the year each of these industrial installations is allocated (or purchases through auctions) a certain number of allowances (also called permits or quotas), and known as European Union Allowances (EUAs). The sum of all allowances materializes the cap agreed by governments and the European Commission in the National Allocation Plans (NAPs). This cap sets an emissions reduction target for the system as a whole. At the end of each year, installations must surrender a quantity of allowances corresponding to their verified CO_2 emissions over the past 12 months, or be liable to penalties. EUAs are tradable on market exchanges or over the counter (OTC) as spot or derivative contracts. The price of an allowance is thus perceived by installations as a production cost associated with the emission of one tonne of CO_2.

While the market naturally attracts "compliance" actors (the industrial operators covered by the scheme), who have no choice as to whether or not they participate, it is also accessible to anyone who opens an account in a national registry, such as financial intermediaries, institutional actors, or speculators.

FIGURE 3 – EU ETS PERIMETER BY COUNTRY, SECTOR AND COMPANIES (2005-2011 AVERAGE)



Source: author from CITL (2012), Note: Figures are averages of CITL data for the year 2005 to 2011 (perimeter not constant). The combustion sector split and the company identification have been made by the author as described in McGuinness and Trotignon (2007) and Trotignon and Delbosc (2008). The figures attributed to companies are estimates and should be taken with caution.

Industrial installations are included in the EU ETS perimeter if they belong to one of sector listed in Annex I of the Directive and if their production capacity is superior to a certain inclusion threshold, set for example at 20MW in the combustion sector, 2,5 tonnes per hour in the steel production sector, 500 tonnes per day for clinker etc. – see European Parliament and the Council of the EU (2003), Annex I. Most installations in the EU ETS are small emitters in the combustion, ceramics, paper and glass sectors, totaling 80% of the total number of installations covered, but only 30% of emissions. On the contrary, a small number of energy intensive power plant, cement and steel plant, and refineries, which represent 20% of the total number of installations, make 70% of covered emissions. Emissions are also concentrated geographically, with more than 50% of covered emissions by the four most emitting countries (Germany, Poland, UK and Italy).

The implementation of the emission trading system is divided into three stages: Phase 1, the so-called trial phase (2005-07); Phase 2, which coincides with the period of the Kyoto Protocol

(2008-12); and Phase 3 (2013-20). Since the passing of the Climate and Energy Package in December 2008, the reduction target associated with the emissions trading system for 2020 (i.e. the planned decrease in the supply of allowances) is set at -21% compared to 2005. Rules define the validity of allowances over time and whether or not they can be used in advance or banked for a later use from one Phase to another.

The EU ETS was designed to be enlarged, through the inclusion of new countries, greenhouse gases and sectors. In 2007, Romania and Bulgaria were integrated into the European Union and consequently joined the Emissions Trading Scheme. These two countries account for an increase of approximately 5% in the emissions covered by the EU ETS. In 2008, three countries from the European Economic Area – Iceland, Liechtenstein and Norway – also joined the scheme. In addition, the ETS is also scheduled to include aviation emissions as from 2012, amounting to a significant expansion of the coverage (around 10% of 2005 ETS emissions).

With the shift to Phase 3 in 2013, new sectors and gases are covered by the scheme – such as CO_2 and PFC emissions from aluminum production, CO_2 and N_2O emissions from the production of various chemicals, and the capture, transport and storage of CO_2. All in all, the total coverage of the EU ETS has been extended by around 25% between 2005 and 2013, the main effect of which will be to broaden the range of potential emission reductions.

Another important feature of the ETS Directive for Phase 3 is setting the absolute quantity of allowances available up until 2020 (21% below 2005 levels) and the rate at which the cap decreases every year (-1.74% compared to 2010 per year). These changes entail more centralization in the allocation process, and a tightening of the cap compared to previous phases. The target figure could be subsequently revised. The European Commission is considering a possible move to a more restrictive medium-term cap, by raising the 2020 pan-European target to 25% or 30% below 1990 emissions, see European Commission (2010). Doing so would mean that the EU ETS cap would be also reduced.

Since the adoption of the so called Linking Directive in 2004, the use of carbon credits generated by the Kyoto Protocol's project based mechanisms is allowed under certain quantitative and qualitative limits, which will be detailed in the next Chapters. From 2013 onwards, one major change is the addition of qualitative restriction targeting HFC-23 and adipic N2O credits, which cannot be used for compliance after 2012.

TABLE 1 - CHANGES IN THE EU ETS SINCE 2005

	Phase 1 2005-07	Phase 2 2008-12	Phase 3 2013-20
	Directive 2003/87/CE, 2004/101/CE, and 2008/101/CE		*Same + Directive 2009/29/EC*
Countries	EU 25 + Romania and Bulgaria in 2007	EU 27 + Norway, Liechtenstein and Iceland	EU 27 + Norway, Liechtenstein and Iceland
Gases	CO_2 only	CO_2 + N_2O opt-in	CO_2, N_2O and PFC
Sectors	Electricity and heat, Refineries, Iron and steel, Cement, Glass, Ceramics, Paper	• Same sectors • Aviation from 2012 onward	• Same sectors • Chemicals • Aluminium • Capture, transport and storage of CO_2
Cap	~2,300 Mt annually including reserves	~2,100 Mt annually including reserves (non-constant perimeter)	From ~1,950 Mt in 2013 to ~1,700 Mt in 2020
Allocation	Minimum 95% free allocation Free allocation based on historical emissions (mostly)	Minimum 90% free allocation Auctions mainly in the UK and in Germany	• Auctioning of all allowances in the electricity sector beginning in 2013 • Progressive auctioning in other sectors • Free allocation based on benchmarks • Industries subject to carbon leakage receive free allowances
Banking Borrowing	Banking allowed between years inside the phase, not in 2007 Borrowing allowed between years inside the phase depending on free allocations, forbidden in 2007	Banking allowed between years inside the phase and into phase 3 Borrowing allowed between years inside the phase depending on free allocations, forbidden in 2012	Banking allowed between years inside the phase Borrowing allowed between years inside the phase, forbidden in 2013 (the possibility to use borrowing is dependent on free allocations and thus diminishes over time; in the electricity sector no borrowing from 2013 on)
Offsets	-	Authorized amount of ~1,450 Mt over the phase (~13.5% of total allocation)	Authorized amount: • Remaining from unused Phase 2 limits • + ~150 Mt added • HFC-23 and adipic N_2O credits not accepted anymore

Source: author, adapted from Trotignon and Solier (2011)

The shift to Phase 3 also marks a notable change in the way allowances are allocated. Up until 2013, the vast majority of allowances were allocated free of charge on the basis of historical emissions, corrected by an effort factor. From 2013 on, auctions become the main way of allocating allowances. A pure auctioning system means that covered installations have to buy all the allowances they need to cover their emissions, and no longer only the difference between free allocation and verified emissions. Secondly, allowances allocated free of charge will no longer be based on historical emissions, but on an emissions benchmark by sub-sector, meaning that installations will only receive free of charge a quantity more or less corresponding to the best performance of the sector. The electricity sector will be the first sector to shift to 0% free allocation as soon as 2013 (except a small number of plants under the special dispensation for new Member States). Other sectors will receive a proportion of free allowances and the remainder through auctions, with an increasing share by auction over time. Finally, sectors subject to carbon leakage will receive 100% free allowances.

The shift to more auctions also has the notable consequence of allowing public authorities to raise revenues from selling allowances. The approximate value of 2013 auctions will be around €10-20 billion. The Directive specifies how this amount to be subdivided among Member States, roughly equal to each Member State's proportion of total verified emissions in Phase 1 plus transfers toward certain Member States for solidarity and growth purposes.

3.2 The initial challenge: the lack of information

Ex post observations cannot be properly judged without taking into account the conditions under which the early years of the scheme were conducted. Before looking at the actual price and exchanges over the first two phases of the EU ETS, it is necessary to take a step back in time and analyze briefly what were the initial context and the expectations of participants (or observers) before or in the early stages of the scheme. Two aspects are important: the anticipated volume of required reductions, and the anticipated carbon price.

As observers in the present, we must keep in mind that looking at 2012 from 2002 is the equivalent of looking at 2022 from now in 2012. Before the European Council's decision on 2020 reduction targets of March 2007, there was no certainty about a possible Phase 3 of the EU ETS running to 2020. The discussions in the years 2000 up to the start of the trading system in 2005 were thus focused on the context of Kyoto 2012 targets.

Three important facts marked the implementation and the launching of the scheme: the lack of reliable data to determine allocations at the Member State level and among installations; the time schedule of the decentralized National Allocation Plan (NAP) and registry system; the combination of the two previous points with the modest ambition of Phase 1 and the uncertainty about future emissions. The detailed story is exposed in Ellerman, Convery and De Perthuis (2010).

The task of determining the total number of allowances to be allocated by each Member State (setting caps) and building reliable emissions scenarios was made extremely difficult by the lack of data. The problem was that no Member State had a good idea of current and past emissions of installations within the EU ETS sectors. In most countries, good data had been developed and reported through the UNFCCC process, but the definitions of sectors and the inclusion threshold in the EU ETS introduced significant discrepancies, which often prevented to use these data. The problem has been even worse in the new Member States of Eastern Europe, where forecasting was made more difficult by the ongoing structural transformations of the economy. The result was a set of approximations of what EU ETS sector emissions were thought to have been in the recent past, and what they were expected to be in the first trading period. The problems created by poor data were not limited to cap-setting; they extended into the allocation of allowances to installations, which required installation-level emission data. Much more details and insights are provided by Ellerman, Buchner and Carraro (2007) including a description and analysis of the allocation process and individual experiences from Member States.

Another condition shaping the early years of the EU ETS was the demanding time schedule specified in the texts. The agreement of July 2003 between the 15 Member States required NAPs to be submitted by the end of March 2004. The ten new Member States which joined the European Union in May 2004 were to submit their NAPs by that date. The Commission was then expected to review each Member State's NAP within three months. The entire process would in theory be concluded by August 2004, i.e. five months before the start of the system scheduled on January 1st 2005. The same kind of delays had to be respected for the implementation of the reporting and trading infrastructures: the National Registries. Each separate Member State had to have, by the end of February 2005, a computerized registry system capable of tracking allowances, registering allocation, transfers and surrenders among installations and other account holders. Each registry should also be connected to every other in Europe and with the Community Independent Transaction Log (CITL), the central European registry gathering all information of participating Member States. This decentralized cap-setting, allocation and registry process has contributed to maintain a high degree of uncertainties in the first years of the system, because the cap (the total offer) is only fully determined when all separate allocation plans are accepted by the Commission and that registries are operational.

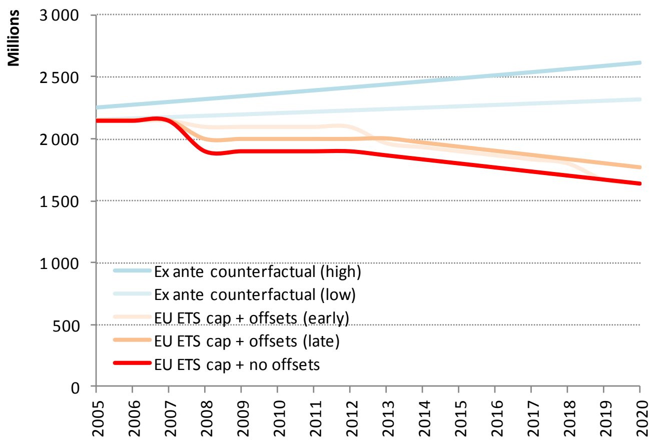
Finally, one must keep in mind that the objective of the trial period was not to achieve significant emission reductions but to establish the infrastructure, institutions and experience necessary to make the following period a success. The trial period was not part of the Kyoto Protocol and the cap for the first phase was a voluntary one, assumed by the European Union to prepare for the subsequent trading period. As a result, the criteria for setting individual Member State's cap were closely tied or slightly below expected business-as-usual emissions, at least as long as that would not jeopardize the individual achievements endorsed following the Burden Sharing Agreement – European Council (2002). But when combined with the inherent uncertainty of future emissions and the poor reliability of BAU scenarios due to lack of data, it was not clear at the beginning of the first phase if the need for reductions was to be quite modest or surprisingly demanding in Phase 1. This was even more the case for the second phase.

3.3 *Ex ante* expectations

Anticipations in the early stages of implementation can be of two kinds. The first consists of the assessment of the quantitative constraint on emissions, calculated as the difference between forecasted emissions and the allowance cap. This sub-section will detail what result would have been found given the information available at that time. The second kind of anticipation deals with the future allowance price. Those *ex ante* price expectations will be analyzed in a second step by looking at price forecasts published by various sources at the launch of the system.

Volume based anticipation. A simple calculation of the *ex ante* deficit expected over the first two phases can be drafted here. The cap for the 25 Member States over phase 1 is around 2,150 Mt/yr. We can thus build two counterfactual emission scenarios, one "low" scenario with initial expected emissions at the same level than the cap and a BAU emission growth of 0.5%/yr, and a "high" scenario with initial emissions 100 Mt/yr above the actual cap and a BAU emission growth of 1%/yr. This emission trajectory can then be compared with three cap scenarios (see Figure 4), the first one being the actual cap alone, the second the same cap with 500 Mt of Kyoto offsets available over Phase 2 and 1,1 Gt over Phase 3, and the third the same cap plus 1Gt of Kyoto offsets available over Phase 2 and 600 Mt over Phase 3 (since the vote of the Linking Directive – European Parliament and the Council of the EU (2004) – the use of offset is allowed in the EU ETS and they are supplemental to EUAs).

FIGURE 4 – COMPARISON BETWEEN *EX ANTE* EMISSION SCENARIOS AND THE CAP



Source: author

The difference between emissions scenarios and cap scenarios can give illustrative estimates of what were the initial expectations in terms of reduction efforts. Table 2 summarizes the results. On average, Phase 1 could be expected to be slightly in deficit (from 0.5% to 5% in the high estimate, 3% on average), but most of the effort was anticipated to manifest itself over Phase 2 with a difference between baseline emissions and the cap of around 1.4 Gt. The unknown future availability of Kyoto offsets makes the required reduction over Phase 2 more uncertain and the cumulated deficit ranges from 520 Mt to 2.3 Gt or 5 to 20% below BAU emissions.

TABLE 2 –ESTIMATES OF CUMULATED *EX ANTE* DEFICITS FOR EACH PHASE

Cumulated deficit anticipated (Mt and % of BAU)	Phase 1		Phase 2		Phase 3	
Min	32	0.5%	522	4.7%	3,107	17.1%
Avg	**200**	**2.9%**	**1,423**	**12.4%**	**4,625**	**23.9%**
Max	368	5.4%	2,325	19.7%	6,178	30.6%

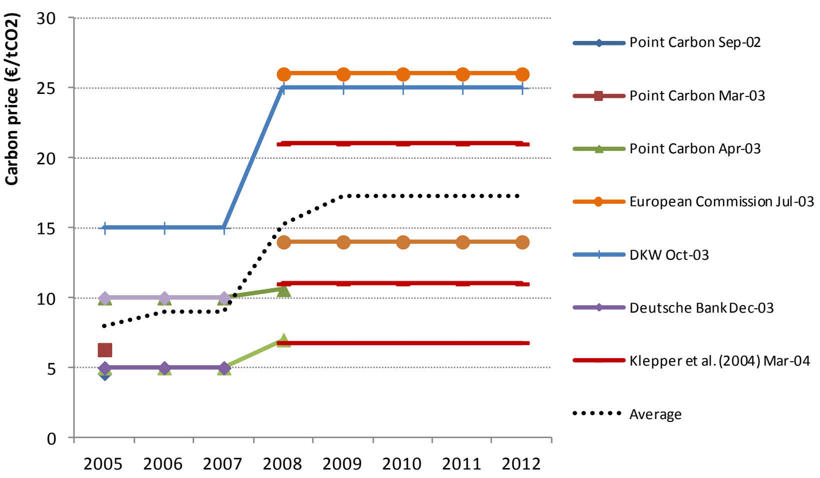
Source: author

This brief analysis reveals two important facts regarding the functioning of the EU ETS. First, the counterfactual scenario describing how emissions would evolve without a carbon price is crucial in quantifying the volume of required reduction, thus the effort or the constraint of the system. This discussion of counterfactual scenarios will be the center of Chapter 2. The second is the impact of offsets in this calculation and the related anticipations, which is going to be the focus of our attention in Chapter 3.

Price anticipations. Those anticipations in term of required reductions can be completed with a review of *ex ante* price forecasts. This review contains various kinds of studies published before the start of the first phase of the EU ETS, using different methods (polls, economic models etc).

One of the first sources of price forecasts on the EU ETS was Point Carbon and its publications "Carbon Market Analyst" and "Carbon Market Europe", which already regularly reported price forecast for the UK scheme before 2002, and started focusing on the EU ETS from early 2002. The results of their polls and forecasts reflect the sentiment of market actors at that time and the high uncertainty on the futures rules of the systems, with price forecast on average between 5 and 10€/tCO_2, and even high uncertainty regarding phase 2 – for more details refer to Point Carbon (2002, 2003a, 2003b). Other private analysts such as Deutsche Bank (2003) or Dresdner Kleinwort Wasserstein Research (2003) also published early forecasts of allowance price in the same range. The European Commission impact assessment of the EU ETS – European Commission (2003) - forecasted a price of 26€/tCO_2 over phase 2 and 14€/tCO_2 in case offsets are used by up to 6% of the cap. Those forecasts were based on the POLES model. Finally, Klepper et al. (2004) predicted an average price of 11€/tCO_2 over phase 2. This review is not exhaustive but gives an average *ex ante* expectation of around 8.5€/tCO_2 in Phase 1 and 17€/tCO_2 in Phase 2 (see Figure 5).

FIGURE 5 – REVIEW OF *EX ANTE* PRICE EXPECTATIONS



Source: author, compiled from cited sources (see References)

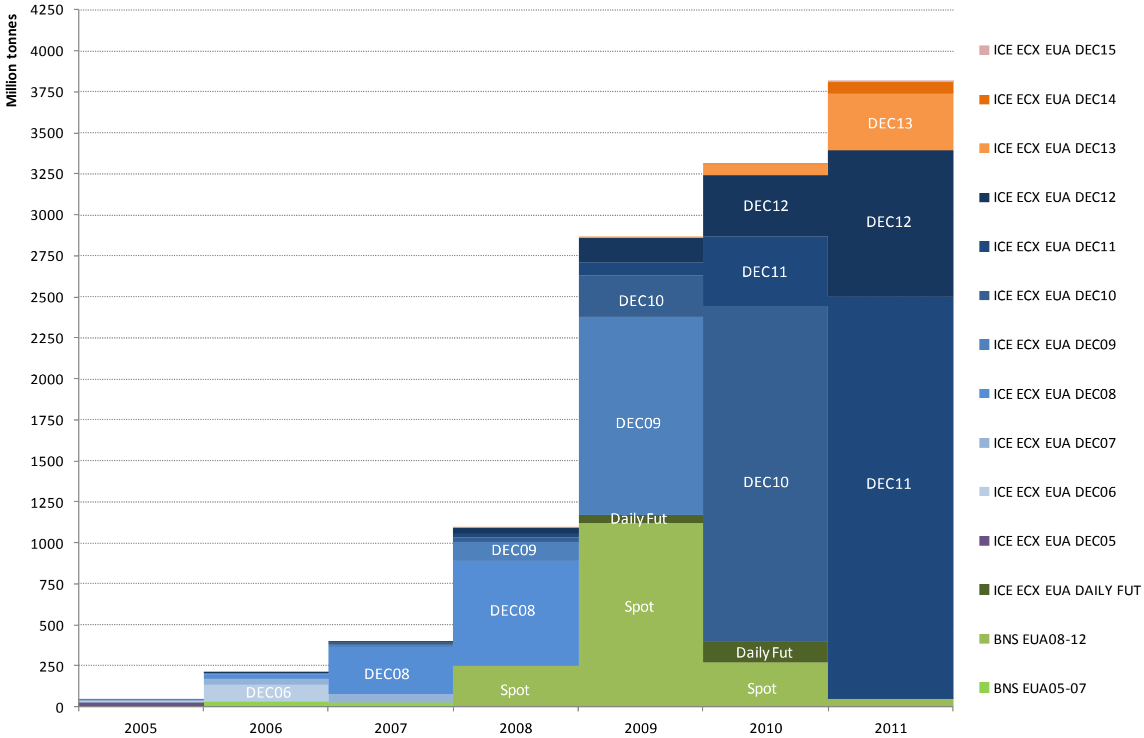
3.4 *Ex post* observations

Development of trading. European Union Allowances (or EUAs) can be bought and sold in different ways. Trades can happen on exchanges constructed for the purpose of facilitating and securing trades, such as Bluenext (ex- Powernext Carbon), Nordpool, European Energy Exchange (EEX), or European Climate Exchange (ECX, bought in 2010 by Intercontinental Exchange ICE); or trades can be concluded over-the-counter (OTC) that is in a bilateral way. In the later case it is very rare to get much public information concerning the trade, whereas on exchanges price and volume data are made available to the public. In this section, we will use the OTC price index of Point Carbon for futures trade happening before the start of trading platforms in mid-2005, and from 2005 onward we will focus on market exchanges data.

Two kinds of transactions are available to market actors: spot trades and derivatives. Spot trading consists of "physical" trades with almost immediate delivery of EUAs on registry accounts and payment, the reference contract being Bluenext Spot. Derivatives are contracts between two parties that specify certain conditions, especially the dates, or the price of the underlying asset – the spot EUA. In the case of Futures contracts, the delivery date is set at a distant point in time, the reference being the series of December contracts of ICE ECX. Other contracts like options are also available. We will focus on the main contracts, EUA spot and EUA

December Futures. Figure 6 shows the evolution of trading volumes in Mt over Phase 1 and Phase 2.

FIGURE 6 – VOLUMES BY CONTRACT ON MAIN TRADING PLATFORMS OVER 2005-2011



Source: author from Bluenext and ICE ECX Futures. Figures do not include options, CER/ERU contracts, nor volumes from OTC trades and other exchanges.

The trades experienced a continuous growth over time, from very few exchanges (39 Mt) in 2005 to 3.8 Gt in 2011, which is around twice the amount of one-year free allocation of Phase 2. The share of futures is predominant, like on other commodities markets such as oil where derivatives represent around 95% of exchanges. Of course all futures contract do not imply physical trades in the end because a significant part of them are terminated or rolled before maturity. After rising for four consecutive years, spot exchanges were less used from 2010 on due to frauds and security problems (this will be explained and discussed in Chapter 5).

Price development. Figure 7 summarizes the history of the selected carbon prices over 2003-2012. The price development over this 10 years period can be divided into six sub-periods. The first (see **I** in the Figure below) runs from January 2002 to the end of 2004. At this time, very little information is available on the potential offer and demand equilibrium of the coming phases, the first NAP submission from Member States confirming the *a priori* modest ambition of Phase 1. Trades during this first sub-period settles at around 10€/tCO_2, in line with analysts' early forecasts. Point Carbon indicates very few OTC volumes; a real liquid market for EUAs did not exist at that time.

The second sub-period runs from January 2005 to April 2006 (**II**). It is marked by the European Commission decisions on NAPs implying cuts in the expected supply of allowances, by the first issuance of allowances on operators accounts, and by the first trades on market exchanges (in April 2005 for ICE Futures and in June 2005 for Bluenext Spot). At that time, the covered entities expecting to be lacking allowances create a significant demand (in most Member States, electric utilities received allowances below baseline emissions), but the supply is apparently not willing to sell at price below 10€/tCO_2. Industrials discovering the system, the persistent uncertainty on the real level of emissions, and delays in the implementation of registries prevent them for engaging in trading. The price thus rises above 20€/tCO_2 and even up to 30€/tCO_2 when the harsh winter of 2005 over Europe increases the short term demand from utilities. On April 18th 2006, the EUA spot and the DEC12 contracts reach their highest observed value over 2003-2012, respectively 29.75€/tCO_2 and 34.85€/tCO_2.

(**III**) In April 2006, preliminary reports of verified emissions for the year 2005 are made public in certain Member States, before the Commission publishes the official aggregate figures for the EU ETS as a whole in May. Those reports seem to indicate that emissions are below expectations in many Member States, thus allaying the fear of a deficit of allowances over Phase 1 that would require costly reductions. Accordingly, the price dropped precipitously upon the release of this more accurate emissions data, decreasing by 63% in one week on the spot market and by 35% for the DEC12 contract. Between April 2006 and March 2007, both prices adapt themselves to the new equilibrium between supply and demand. The spot price progressively converges to zero as Phase 1 surplus becomes evident, because the banking of any unused allowances from Phase 1 to the second Phase has been forbidden by the Commission (despite Poland and France proposals). In the same time, the DEC12 price, corresponding to Phase 2 allowances, does not fall to zero but recalibrated itself to a value of around 17€/tCO_2. On February 20th 2007, the DEC12 price reaches its lowest value since the beginning of organized trades at 14.35€/tCO_2. At this time the Phase 1 spot price is 0.76€/tCO_2.

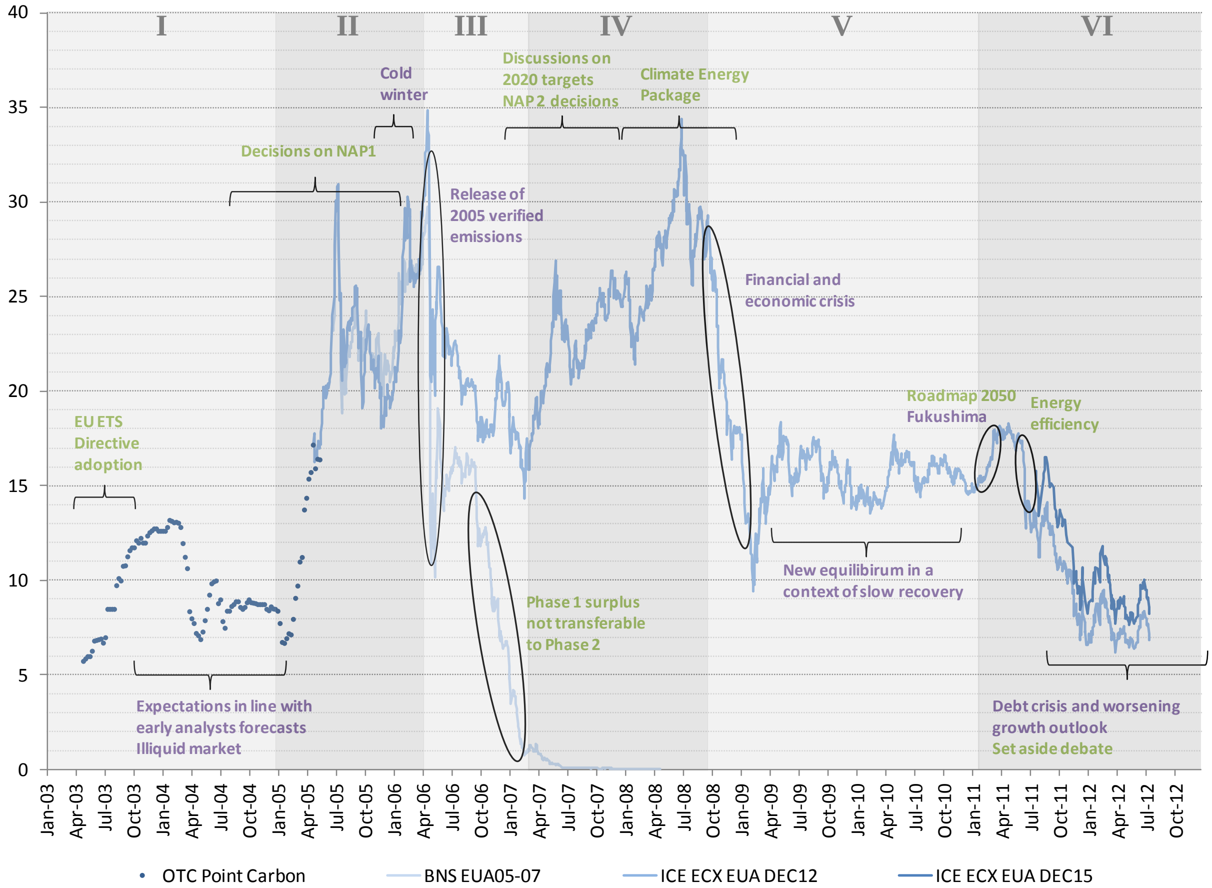
On March 9th 2007, an important decision is made by the European Council regarding international negotiations and the EU ETS, which opens the fourth sub-period (**IV**) in the carbon price history. The EU makes a firm independent commitment to achieve at least a 20 % reduction of greenhouse gas emissions by 2020 compared to 1990, a target which can possibly raised to -30% in case a global agreement is found. The Council also acknowledges the central role of emission trading in the EU's long-term strategy for reducing greenhouse gas emissions, European Council (2007). This signal has a direct impact on the carbon price because the probability of a third phase for the EU ETS increases. The DEC12 price thus rises to reach 25€/tCO_2 in January 2008. The Commission then makes a proposal for a Climate Energy Package, a set of Directives aiming at implementing the commitments taken by the Council earlier in the sub-period, including a Directive extending the EU ETS to 2020, a Directive on renewable energy, and a Directive on Carbon Capture and Storage (CCS). The DEC12 price rises to 34€/tCO_2. This sub-period is also marked by the European Commission cuts in the NAP2, the National allocation plans for Phase 2, reducing the expected supply of allowances to 2012. In this context, this sub-period could be named the "Carbon Fever", a year and a half of heavy bullish expectations on the market. This is well observed in the carbon price forecasts of that time, analysts shifting from an average forecast of 26€/tCO_2 for 2012 in the previous sub-period to an average of 32€/tCO_2 after mid-2007. The first forecasts for Phase 3 are highly bullish with average predictions climbing to 39€/tCO_2 for 2013 and to 48€/tCO_2 for 2020.

This "carbon fever" and bullish forecasts are rapidly contradicted by the economic and financial crisis starting end-2008. The fifth sub-period (**V**) is the longest of all and spreads from October

2008 to March 2011. It begins with the integration of the strong decline in energy prices, economic activity and financing conditions in the carbon price, which loses 65% of its value in four months to reach its lowest point since the start of the scheme, on February 12th 2009, at 7.96€/tCO_2 on the spot and 9.43€/tCO_2 for the DEC12 contract. Emissions in the EU ETS drop by 11% on average but certain sectors like cement and steel face a decrease of around 20%. The formal adoption of the Climate Energy Package in April 2009 and the following stagnation and slow recovery of the economy in the following year cause the price to float in the 15€/tCO_2 zone until March 2011.

(**VI**) March 2011 to end 2012. In March 2012, the Commission publishes a communication entitled « A Roadmap for moving to a competitive low carbon economy in 2050 » which contains informal targets by sector for greenhouse gas reduction up to 2050. The Fukushima event and the following debate on nuclear energy in some European countries, potentially raising business-as-usual emissions, added to the Roadmap discussion context, make the price gain 3€ in a few days. But the increase is momentary, as the Commission's plans also include a project for a Directive on energy efficiency, this time potentially lowering business-as-usual emissions in the EU ETS independently of the carbon price. This fact, is conjunction with the worsening of the crisis and its implications regarding debts in Europe, the degraded growth outlook in Europe, and the large supply of Kyoto credits, make the EUA price progressively plunge to a very low level, respectively 6.04€/tCO_2 and 6.21€/tCO_2 for the spot and DEC12 price on April 4th, 2012. The weakness of the carbon price and its interaction with other policy instruments, compared with the long term objectives of -80% reduction compared to 1990 (and more than -90% in the power sector) generated a fundamental debate in the beginning of 2012, questioning the existence of a surplus on the market and mentioning a possible allowance "set aside" supposed to raise prices. The DEC12 price has been continuously staying below 10€/tCO_2 since November 2011.

FIGURE 7 – EUA PRICE ON EXCHANGES OVER 2005-2012



Source: author from Point Carbon, Bluenext, ICE ECX – see Annexes A_1 to A_4 for details on the main NAP decisions, the vote of official texts and rules, as well as energy prices and growth.

General lessons on the determinant of carbon prices

There is a strong opposition between the *ex ante* expectations and the actual *ex post* observations. Whereas the initial vision was that price would increase over time as the constraint on emissions would grow, this is not what happened. Observations show a price which goes down, and quite volatile. We can distinguish two families of influences:

- The explicit external influences, such as the impact of temperature and weather conditions via short-term energy demand, the influence of primary energy prices, or the variations of the industrial production and growth in the longer term. These influences allow the price to adapt itself to external information and to the general economic context.

- The fundamental and intrinsic influences linked to the nature of cap-and-trade system, such as the provisions for banking and borrowing, for using offsets, or the change of targets or scope of the EU ETS. The experience of the carbon crash of April 2006 and the following "carbon fever" of 2007-2008 shows clearly that the flexibility rules and the anticipations of actors play a crucial role in explaining price dynamics.

Why no *ex ante* expectations had predicted this price trajectory? Two large families of economic models have been used to explain carbon price formation:

- The first category is that of macro models which represent global energy markets equilibirum, with a strong technologic-economic core such as the PRIMES model (developed by the E3Lab of the National Technical University of Athens) or POLES models (LEPII and Enerdata). Those equilibrium models have the advantage of modeling the economical and technological impacts of economic scenarios or policies on most energy markets and all European countries at the same time. Nevertheless, it is difficult for them to isolate the scope of the EU ETS and to describe its detailed rules in order to represent the balance between supply and demand of allowances.

- The second category is econometric models. An econometric model specifies the statistical relationship that is believed to hold between the various economic quantities studied, for example the relationship between oil and carbon prices, or the impact of meteorological conditions. Those models have been widely used to study the EUA price and its various links with other prices and markets. A thorough literature has developed on this topic, see for example the review of Chevallier (2011), or the papers of Convery and Redmond (2007), Mansanet-Bataller et al. (2007), Alberola, Chevallier and Chèze (2008a, 2008b, 2009), Bunn and Fezzi (2009), Hintermann (2010), and Solier and Jouvet (2011). Those models can give interesting results when used for explaining the past relationships between prices and some key drivers. It is more difficult for them to be reliable in forecasting the future because it appears that the relevant variables explaining carbon price fluctuations differ according to the considered time frame.

The modeling tool we are going to build and use in this thesis, ZEPHYR-Flex, aims at representing the balance between supply and demand of allowances, based on a detailed representation of the EU ETS, its perimeter, and taking into account its precise rules and their evolution over the period. Our aim is to be able to replicate and explain the gap between *ex ante* expectations and *ex post* observations, and to better understand on this basis the possible future of the EU ETS. The methodology used is described in the following section.

4. At the center of attention: the flexibility provided to firms

The flexibility provided by emission trading has been the major justification in the emergence of the EU ETS, which aim is to help reach a certain future emission target at minimum cost. This section details the conceptual framework and methodology used in the rest of the thesis to evaluate the economic efficiency of the EU ETS and the role played by the associated flexibility mechanisms.

4.1 The three levels of flexibility provided by the EU ETS

The appeal of emissions trading comes primarily from its ability to achieve a pre-specified target at minimum cost even in the absence of any public authority information on control costs. The lessons drawn from the study of how emissions trading emerged in the late 20th century, show that the choice of emission trading has also been motivated by the flexibility it offers, especially the EU ETS, which is our center of interest. Its potential adaptableness definitely played a major role in the acceptability and promotion of emission trading against other options.

The term flexibility can have different meanings and covers different aspects: for policy makers emission trading systems are flexible in terms of design because they do not require precise information on reduction costs, and allow accounting for competitiveness issues and acceptability by an adapted allocation of rights and without affecting the effectiveness of the system *a priori*. Emissions trading programs can be tailored to specific applications. To the extent that stakeholders can influence policy choice, using free allocation in general has increased the implementation feasibility of emissions trading systems.

For the covered entities, in comparison with tax or command and control, emissions trading can provide three kinds of flexibilities:

- **Trading**. This flexibility aspect arises from trading among firms subject to the cap and the extent to which they realize the full cost savings attainable through emissions trading. If a firm has high reduction costs, or is unwilling or unable to reduce emissions, it can always purchase allowances on the market, at a price which is in theory the lowest marginal abatement cost of covered entities.

- **Spatial flexibility**. Linking a cap-and-trade with an offset mechanism (reduction credits) is another way of giving flexibility to covered entities. In that case, the allowances associated to the cap are not the only accepted units to cover verified emissions, but credits or offsets corresponding to emission reductions outside the cap-and-trade perimeter can also be used for compliance. Specific rules or limits are often set by the regulator to control the quantity and quality of the credits allowed. There are two effects of linking. The first arises from the price difference between allowances and credits, which makes it financially interesting for entities to use the cheapest compliance unit and save the corresponding price spread. The second effect on price is due to a more global effect: linking with an offset mechanism raises the offer (diminishes demand) on the cap and trade by a certain amount, which tends to keep price at a lower level. The EU ETS is linked to the project based offset mechanisms associated to the Kyoto Protocol, CDM and JI, with qualitative and quantitative limits.

- **Time flexibility**. Emissions trading programs have to deal with participants' concern over volatile prices (large variation of price in a short period of time). Time flexibility, which is accounted for by the length of compliance periods as well as "banking" and "borrowing" provisions, can smooth price changes over time.

    - **Banking** of permits occurs when regulated entities are allowed to hold unused permits for future compliance. Banking thus diminishes the offer in the short term, but raises the offer in the future. Banking makes it difficult for the price of allowances to fall down to zero as long as the anticipation horizon is distant or highly uncertain. It is also an incentive for early action, which has been the case in the Acid Rain Program. In the EU ETS, year-to-year banking is allowed over 2005-2020 except in 2007 between Phase I and Phase II (the two phases are separated and the associated units are not fungible).

- **Borrowing** is symmetrical to banking. In this case, permits from future compliance periods can be used in advance. Borrowing thus diminishes demand in the short term, but raises demand in the future because the allowances used in advance have to be paid back. Nevertheless in case of price spike, borrowing can prove to be an efficient short term response. Borrowing is often not allowed (like in the Acid Rain Program) or limited because of the risk of future non-compliance it bears. In the EU ETS, entities receive free allocation in February each year, while permits must be surrendered before May. Hence, implicit borrowing is possible but limited by the amount of next year's free allocation, and impossible between phases.

4.2 Information sources: the central role of the allowance registry (CITL)

For the purpose of our ex post analysis and the construction of the ZEPHYR-Flex simulation model, we will use six categories of relevant information: the official texts and rules, data related to covered installations, information regarding the macroeconomic context, the CDM and JI project pipeline, market exchanges historical data and analysis from the private sector.

The rules consist of the set of official documents from the European Council, the European Commission or the European Parliament (communications, directives, regulations…), as well as national implementation documentations (e.g. National Allocation Plans, various evaluation reports). They are used to model as precisely as possible the set of rules which govern the market and their evolution over time. The national documents are used to get additional details on covered entities and a better representation of installations in our model.

The allocation, emission and surrender data of covered installations will be observed through the Community Independent Transaction Log (CITL) - the central allowance registry associated to the EU ETS. It records the allocation, verified emissions, surrendered units of all individual operators covered (available to the public within six month after the end of a year) and the transfers of allowances within all accounts (publicly disclosed after a five year delay). The CITL is the backbone of the EU ETS and is used as a primary source of verified information by all market players and analysts – see Box 2 below. The data contained in the CITL will be the basis of our *ex post* observation of trading, banking, borrowing and the use of offsets.

The macroeconomic context is of major importance for explaining and simulating price development. As demonstrated in the sections above, the EU ETS is integrated in the general macroeconomic European context. This context can be documented through various sources, among which we will use in particular the GDP growth and monthly industrial production index by NACE sector from Eurostat. This data will be used to build our counterfactual scenario. Other relevant indicators will be used, such as the primary energy prices (the Brent for oil, ARA for coal, NBP for gas), and the electricity prices on various regional markets (EEX, ICE).

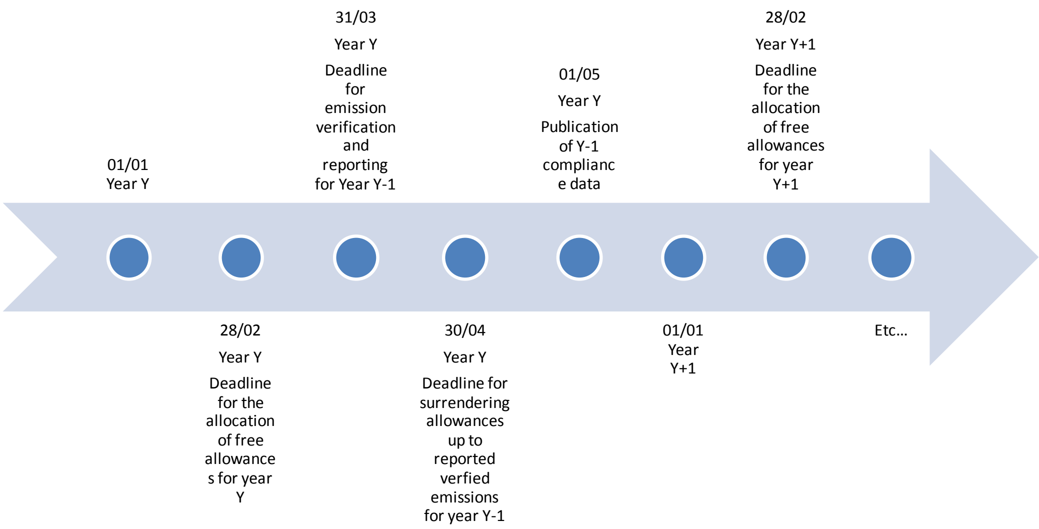
The Clean Development Mechanism's and Joint Implementation's pipeline consists of a list of all CDM/JI projects implemented or under implementation in the world. The UNEP Risoe lists and documents periodically all projects in the administrative process, and provides detailed statistics, among which the offset issuance, quantitatively and qualitatively. This data is used to forecast the offer of carbon offsets over time, and is also matched with EU ETS data when the offsets in question have been used in the EU ETS.

Very few data are available on OTC trades, with the exception of information provided by Point Carbon on OTC trades prior to 2005 which we used in the previous section. Nevertheless a significant share of trading happened on exchanges such as Bluenext (spot) or ICE ECX (futures) for which volumes and prices are public. **Market exchange historical data** will be used as a reference for the calibration of our model, in particular Bluenext Spot price.

Finally, **reports from the private sector** (Thomson Reuters' Point Carbon, Société Générale - Orbeo, Deutsche Bank etc.) can provide useful information. Publications from these sources are used in this thesis mainly as an indicator of market sentiment and anticipations, through a survey of around one hundred price forecast published between September 2002 and July 2012 (see Annex B2).

BOX 2 – CITL: THE BACKBONE OF THE EU ETS INFORMATION SYSTEM

For the environmental integrity of a cap-and-trade scheme, it is absolutely necessary to assure that one allowance always corresponds to one ton of greenhouse gas (GHG) emissions emitted by a single actor. To keep track of allowances, issuance (allocations) is recorded on a registry which also keeps track of all physical transfers of allowances between accounts. A registry thus serves as a carbon accounting book. In phase 1 and 2, each Member State has to maintain a registry in which the covered installations have to open an account. Other non-installations actors are also allowed to open accounts on national registries and to participate in allowances trades. All separate national registries are then connected to a central European registry maintained by the European Commission: the Community Independent Transaction Log (CITL). The CITL gathers in one place all the information from Member States' national registries, which is continually updated due to the constant dialogue between national registries and the CITL.



If the CITL was originally designed as a compliance and control enforcement tool, it has become in practice a very useful source of verified information for all market players. Accurate and reliable market information is essential. Three kinds of data are publicly available for each installation registered on the CITL database within one year of delay: (1) the number of allowances the installation was allocated through the Member State's National Allocation Plan;

(2) what the installation's emissions were in previous years; (3) What units (EUA/CER/ERU) were surrendered for compliance and in which quantity. This emissions data is collected through a monitoring, reporting and verification process which is performed by accredited private companies and then aggregated at the national level within national registries. The CITL thus gives market participants access to non-biased information on installation compliance by showing for example the balance of allocations to verified emissions each year, a quantification of the allowance potential scarcity on the market.

The CITL is the most valuable source of information on the EU ETS, but still it is not perfect. Among its limits analyzed in McGuinness and Trotignon (2007), we can highlight first the difficulty of determining an installation's precise activity through the CITL classification in ten sectors. This is notably the case for installations classified within the combustion sector, gathering nearly 70% of installations and allocations. Second, the CITL provides only installation-level data with very few information on holding firms. Real market players are most probably companies that may own many installations but which do not appear per se in the CITL. Final precision, the CITL only keeps tracks of physical transfers and does not reflect all transactions on the financial market, such as trades of financial derivatives like futures or options that do not necessarily lead to physical allowance movements.

4.3 Research method: construction of a simulation model reflecting the market equilibrium over time

The EU ETS is built in a cost-efficiency framework: reaching a pre-specified target at least cost. As noted by Ellerman (2003) referring to the US SO_2 trading program, "two aspects of economic efficiency need to be distinguished in evaluating cap-and-trade programs. The first concerns trading among firms subject to the cap and the extent to which they realize the full cost savings attainable through emissions trading. The second aspect of economic efficiency concerns the broader welfare effects from the tax and regulatory interactions resulting from the treatment of abatement costs and the scarcity rents generated by the environmental constraint".

Our thesis will be centered on this first aspect of efficiency. A full discussion of the second broader aspect of the economic efficiency would involve consideration of the practical likelihood of economically efficient recycling, of equitable concerns, and how public utility regulation is applied in practice: all those topics are beyond the scope of this thesis. Hence, all references to economic efficiency in the following pages refer to the conventional use in emissions trading, i.e. the cost savings resulting from emissions trading without regard to the larger welfare issues that may result from the existing regulatory and tax system.

We identified in the previous sections how determining the flexibility provisions were with regards to the market development (in terms of price and volumes) and the dynamics of actors' anticipations and behavior. In the following chapters of the thesis, we will investigate in detail the role played by those three levels of flexibility, each time by comparing *ex post* observation with a counterfactual scenario, and using the results to progressively build a simplified yet comprehensive EU ETS simulation model capable of replicating observations.

In Chapter 2, we will build a tailored counterfactual scenario describing how emissions would have evolved in the absence of a carbon price since 2005. By comparing this counterfactual scenario with actual observations from the CITL, we can derive estimates of emission reductions over time, and their relation with the market price. This simplified relationship between the price and emission reductions is then going to be modeled as a set of marginal abatement cost curves. Thoses MACCs and the associated counterfactual scenario are the first bricks allowing the construction of our simulation model. We build a first version of the model and run it without any flexibility provisions. We show that time flexibility, especially, is crucial to explain longer term anticipations' effect on the carbon price.

In Chapter 3, we start by setting an analytical framework for the analysis of the use of offsets in the EU ETS, with a focus on the quantitative and qualitative limits and their relationships with price observations. The actual use of offset over 2005-2011 will then be analyzed based on the CITL data, which will allow us to integrate and calibrate the impact of offsets in the ZEPHYR-Flex model, and to build a scenario for post-2012 offset use.

The fourth Chapter focuses on the different effects of time flexibility. First, it analyzes the banking and borrowing behavior of participants through an *ex post* analysis of the CITL data. Then we will build a more advanced version of the ZEPHYR-Flex model allowing for time flexibility. We will see that price can now be replicated, and that the dynamic anticipations of actors are determinant for explaining past price developments as well as for forecasting the future supply-demand equilibrium.

Finally in Chapter 5, we will use the most complete version of the model not to replicate the past, but to draw scenarios of possible futures for the EU ETS. We will focus our attention on the possible interactions between the EU ETS and other policies, on participants' banking behavior, and on the possible consequences of changes which could be made to the existing EU ETS framework in the future.

Chapter 2 – A prototype of ZEPHYR-Flex based on abatement and trading

"The essential task of any evaluation analysis is the construction of a credible counterfactual situation—a precise statement of what economic agents would have done in the absence of the policy intervention. Two counterfactuals are involved in assessing any emissions trading program: one to assess the amount and cost of the emission reduction and the other to assess the cost savings and other effects of trading (…). Estimates of cost savings are necessarily more subjective since they depend directly on the degree of inefficiency assumed in the imagined alternative regime."

A. D. Ellerman, *Ex Post Evaluation of Tradable Permits: The US. SO_2 Cap-and-Trade Program* (2003)

As reminded by Ellerman (2003) and advocated by Frondel and Schmidt (2001), the essential task for any evaluation analysis is the construction of a credible counterfactual situation – a precise statement of what economic agents would have done in the absence of the policy intervention. Those scenarios are purely fictive (not observable) and always questionable: we will never know if the assumptions in the counterfactual scenarios are correct or not. Nevertheless they are necessary for estimating the amount and costs of emission reductions, and the cost saving effects of trading among participants, which are determining the policy's cost-efficiency.

In our analysis of the EU ETS, we will use, along with the ***ex ante*** **counterfactual** presented in Chapter 1, an ***ex post*** **counterfactual "No Policy" scenario**, describing emissions as they would have been over the period if there had not been a carbon price. This Chapter describes, in a first section, how we build the counterfactual scenarios that will be used in this thesis, thanks to the past relationship between growth, production and CO_2 emissions. In a second stage, we will analyze the resulting emission reductions by comparison between verified emissions and the cap, and model a simple relationship between price and emission reductions in the form of marginal abatement cost curves. A first version of the ZEPHYR-Flex model is then built and run in the third section, using the constructed baseline and cost curves, but with only one flexibility enabled (trading), i.e. without banking/borrowing and offset provisions.

1. Construction of the counterfactual scenarios

The basic assumption underlying our analysis is that the existence of a carbon price is taken into account by operators as a production cost associated with the emission of greenhouse gases. At a given non-zero carbon price, observed emissions should be lower, even virtually, than emissions as they would have been if there had not been a carbon price. To estimate emission reductions, it is thus necessary to define a counterfactual scenario, a fictive emission path to compare real observations with.

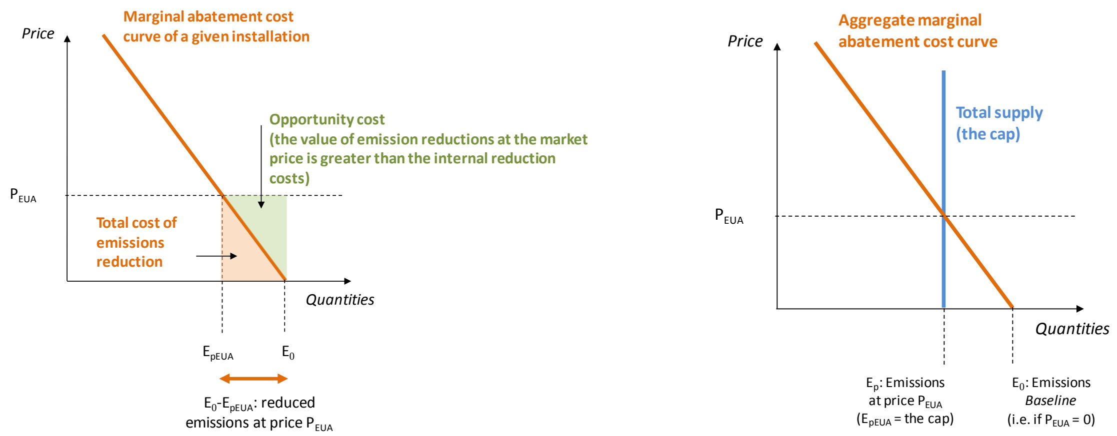
1.1 Emission reductions and how they relate to a counterfactual scenario

In a cap-and-trade system, the quantity of allowances is fixed over a specific period of time. In a perfect world, i.e. with perfect information and no transaction costs, it is expected that the allowance market price equals a certain value. This value is in theory the marginal abatement cost, i.e. the cost of the last (most expensive) emission reduction necessary to make total emissions diminish from "a certain value" down to the first that equals the predefined cap. This "certain value" represents emissions as they would have been in the absence of a price: the emission baseline. In Figure 8 below, it is represented as the quantity E_0 on the emission axis, at the intersection of the marginal abatement cost curve with the horizontal line P=0.

Emission reduction, also called abatement, is thus defined by the difference between emissions in the counterfactual scenario, the emission baseline, and the actual emissions of the installation under the market price P_{EUA}.

If installations can trade allowances without transaction costs, and if they perfectly recognize the opportunity cost attached to the value of emissions, this market price minimizes the total costs of achieving the given emission reduction target.

FIGURE 8 – STYLIZED RELATIONSHIP BETWEEN MARGINAL ABATEMENT COST AND ALLOWANCE PRICE



Source: author

The effect of the carbon price is to trigger certain emission reductions depending on their marginal cost. As a consequence, if the price is not zero, emission reductions should happen and the allowance market price should be an indicator of the costs involved.

There are two types of emission reductions which can be triggered by the carbon price:

- **Short term reductions**, which are the consequences of the carbon price on the **cost-optimization of existing production capacities/organizational practices of firms**. One basic example would be an electric utility owning two power plants in an isolated market (one gas-fired plant and a more carbon intensive coal-fired plant) and facing a capacity demand inferior to its installed capacity. In the absence of a carbon price and unless the price of coal reaches highly unusual level without the gas price rising at the same time, the utility will satisfy the demand by firing the coal plant, which generally produces the cheapest electricity. But as the carbon price rises, it may reach the value at which it becomes more profitable to satisfy the demand with the low-carbon gas plant instead of the coal plant, because the production costs (carbon included) associated to the production of the same quantity of electricity are now superior in the coal plant. No investment is needed; the reductions only depend on the integration of the carbon price in the firm's production costs and on the degree of optimality of production decisions.

- **Longer term reductions**, which are the consequences of the carbon price on the **return of investments in new capacities, technologies or practices**. Using the example situation from above, this would mean that demand in the market is now rising fast and that the utility has to invest in new capacities. The firm must choose between two alternative investments, gas or coal. Depending on the current and anticipated prices of coal, gas, electricity and carbon allowances in the long term, the two plants will yield different revenues. If the carbon price is high enough, the total revenues associated with the investment in the coal plant will be less attractive than those of the low-carbon gas plant.

Both types of reduction are inducing a change in emissions linked to the carbon price. Nevertheless in the case of short term reduction, the current price plays the major incentivizing role. On the contrary, in the case of longer term reductions, the anticipated price is more determining than the current price. Second difference: if the current price goes to zero, short term emission reductions will be undone and emissions will instantly rise back at their initial level; whereas after the decision of investment, longer term reductions are irreversible and emissions will not go back up to their initial level if the price incentive disappears. In practice, some mixed abatement can be obtained by additional investment on existing capacities. Later on, we will consider that on the 2005-2011 simulation period 10% of emission reductions are irreversible and that the remaining 90% are reversible, meaning that in the early years of the system and under a relatively low price, most emission reductions are assumed reversible.

1.2 The relationship between GDP growth, industrial production and CO_2 emissions

To build a credible counterfactual scenario, it is necessary to project emissions from 2005 onward as they would have been in the absence of the carbon price. There are two hypotheses to make: one on the initial level of emissions in 2005, the other on the annual growth of baseline emissions over time. We will start by explaining how we model the growth of baseline emissions.

We have seen in Chapter 1 that economic and industrial production growths were among the fundamental drivers of emissions, especially during periods of high energy demand and inversely during economic downturn like the one starting end-2008; this is observable on prices, see Annex A_3. In our stylized "No Policy" counterfactual scenario, we make the hypothesis that emissions, in the absence of a carbon price, are mainly driven by GDP and industrial production growth, thus neglecting the effect of other drivers such as meteorological conditions or energy commodities prices (excepting the part which indirectly impacts production). A more refined estimate accounting for the influence of energy prices is currently in development at the Climate Economic Chair but could not be included in the work presented here. As we are going to see, the past emission trend can already be approximated using GDP or industrial production growth.

Hence, we must identify the relationship between growth, production and emissions before the start of the EU ETS, and use this relationship from 2005 on by applying it to the chosen initial value.

Our aim is to estimate the reductions linked to the carbon price, so the counterfactual baseline must be free of any effect from the carbon price. There are two very important underlying assumptions in this way of reasoning. The first one is that the carbon price has no effect on production growth (otherwise we would not be able to use the observed EU ETS sector production growths to drive our baseline emissions). The second assumption is that other policies such as renewables' feed-in tariffs or energy efficiency credits, which effect is not linked to the carbon price but which effect is probably not or badly integrated through production indexes, have no effect on EU ETS perimeter's emissions. This last impact is neglected for now but will be integrated in some ways and discussed further in Chapter 5.

For EU27 growth, we use the GDP index (2005=100) published by Eurostat. The industrial production of EU ETS sectors is calculated separately by large sectors using Eurostat industrial production indexes (2005=100) by NACE code. We tried to use the NACE codes for which definitions were sufficiently large to match our EU ETS grouping (see Table 3). An aggregate EU ETS index is then calculated as a weighted average of sectors' index, where weights are the average share of sectors in EU ETS verified emissions.

Growth is quite easily observable, the question is how to monitor emissions of EU ETS sectors before the perimeter was even created? No emission data that can take into account the specific threshold and sector definitions of the EU ETS are available before 2006. Hence, we make the assumption that, at the European level, EU ETS emissions (or at least their variations over time) can be approximated by the CO_2 emissions reported to the UNFCCC under the Fuel Combustion category, excluding transport. This is equivalent to isolating the "1.A.1-Energy industries" and "1.A.2-Manufacturing industries and construction" sectors. Doing so, we neglect the process emissions of the cement and steel sectors and some other sources. Nevertheless, we consider for the moment that the variations of UNFCCC emissions can be a good proxy of EU ETS baseline variations.

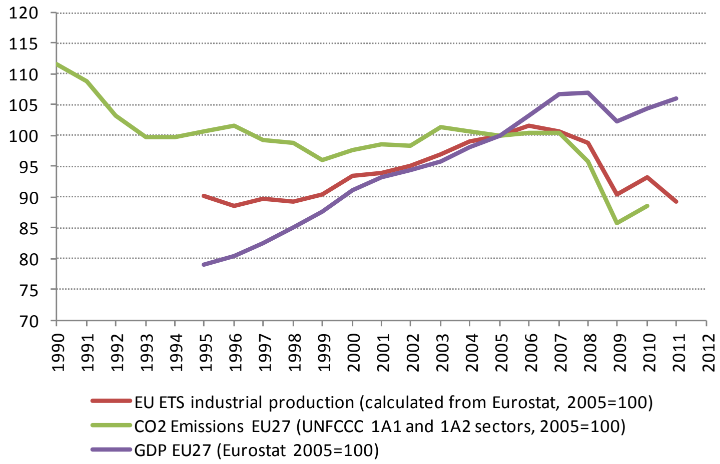
TABLE 3 – DEFINITIONS OF SECTORS USED TO CALCULATE THE EU ETS PRODUCTION INDEX

Large sector used in this thesis	Corresponding CITL sectors	NACE codes used	Average share in EU ETS emissions
Electricity production	1a-Electricity production	D351	51.9%
Rest of combustion	1b-Rest of combustion	MIG_NRG_X_E	21.0%
Refineries	2-Refineries	C192	7.6%
Iron and steel	5-Iron and steel+4-Metal ore+3-Coke ovens	C241	7.9%
Cement	6-Cement	C235	8.6%
Rest of industry	7-Glass+8-Ceramics+9-Paper and board+99-Opt-in	B-D_F	2.9%

Source : author, CITL

Figure 9 below shows the observed relationship between GDP, industrial production and CO_2 emissions growth between 1995 and 2010. We see that the GDP growth has been sustained between 1995 and 2007, and that at the same time the industrial production growth was less pronounced, and the emissions again even less. The period from 1999 to 2004 presents a positive growth trend for all three indexes; we will thus focus on this period to identify some basic relationships between them.

FIGURE 9 - EVOLUTION OF EUROPEAN GDP, INDUSTRIAL PRODUCTION AND CO_2 EMISSIONS

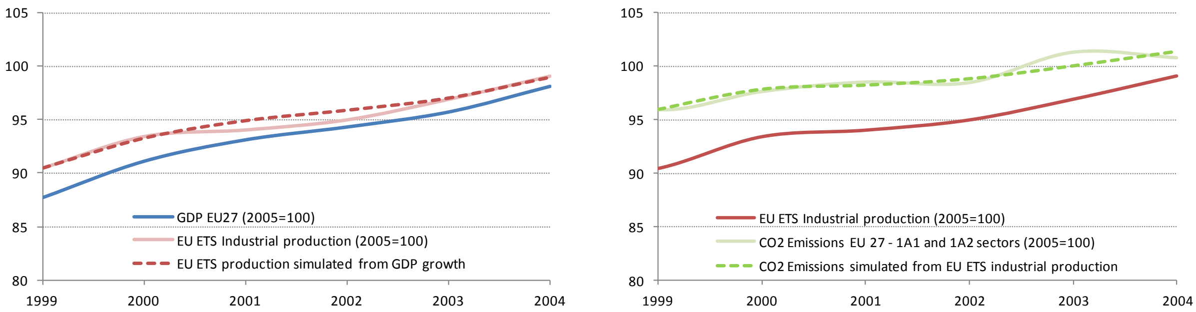


Source: Eurostat GDP index, Eurostat annual industrial production index by NACE sectors, EU27 GHG inventory submissions to the UNFCCC

The basic method we are going to use is to suppose a constant elasticity of industrial production to GDP growth, and a constant elasticity of emissions to industrial production growth. We then calibrate the elasticites by choosing the value that allows the best replication of observed production and emissions series. Those basic relationships should be completed by specific econometric studies; for now our interest here is to find a simple way of representing this interaction, even if it is not perfect. There is ongoing work at the Climate Economics Chair to refine those estimates, see Stolyarova (2012).

On the 1999-2004 period, we find that among all possible values, an elasticity of industrial production to GDP equal to 0.8 gives the best fit (see below, left-hand side), reflecting the structural change of the economy (decreasing importance of industry in the GDP). On the same period and using the same identification method, we determine that an elasticity of emissions to industrial production equal to 0.6 gives the best fit (see below, right-hand side), reflecting the effect of efficiency gains in the industry which partially disconnects production growth from emissions.

FIGURE 10 – STYLIZED RELATIONSHIP BETWEEN EMISSIONS, GROWTH AND PRODUCTION (1999-2004)



Source: author from Eurostat GDP index, Eurostat annual industrial production index by NACE sectors, European GHG inventory submissions to the UNFCCC

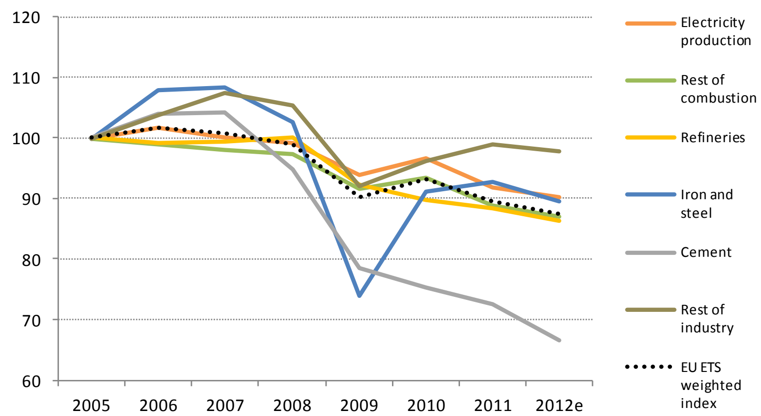
We keep that on general over the past few years before 2005, 1% GDP growth lead to an industrial production increase of 0.8%, and a CO_2 emission increase of 0.5% (0.8*0.6). This relationship does not allow explaining entirely the observed variations, but this back-of-the-envelope calculation is rather appropriated on a period of continuous growth like this one. It is probable, in case of economic chocks and especially downwards like in the case of the economic crisis starting in end-2008, that the elasticity of emissions to growth is more pronounced. As a matter of fact, carbon intensive industries will tend to cut production first from the oldest/less efficient/more costly installations, including carbon intensive plants.

Since we are building a counterfactual scenario to estimate abatement, we must take into account the decrease of emission due to the crisis in the emission scenario. For this reason, we will use the elasticity of emissions to production of 0.6 identified above for all years except in 2009 (the year in which most of the industrial crisis hit emissions), for which we will double this value, e.g. an elasticity of 1.2 (downward).

1.3 The set of *ex post* "No policy" counterfactual scenarios

Using the sector-matching criteria from Table 3, we can get to the annual industrial production change by large EU ETS sectors since 2005 and to the aggregate EU ETS production index. Figure 11 below shows graphically how the industrial production indexes evolved over the first two phases of the EU ETS. The value for 2012, not available at the time of writing, is estimated based on monthly indexes trend over the first month of 2012.

FIGURE 11 –EU ETS INDUSTRIAL PRODUCTION BY SECTOR OVER 2005-2012 (2005=100)



Source: author from Eurostat industrial production index. Note: 2012 value were not available at the time of writing and are estimated based on the monthly indexes available for the first months of 2012.

Over 2005-2012, the sectors covered by the EU ETS experienced different economic context. In all sectors, the industrial production in 2012 is still lower than 2005 level, because of the strong decline of production in end-2008 and 2009 and the slow recovery which followed. After experiencing a relatively stronger growth until 2007 compared to other sectors, the cement, steel, paper, glass and ceramic producers experienced stronger declines than the others in 2009. In the steel and cement sector, this decrease leads production to fall about 20% below 2005 levels. Since 2012, the production levels stabilized in almost all sectors except the cement sector for which the first monthly indicators of 2012 show a continuing decline. The EU ETS index, which is a weighted average of sectoral indexes, presents only two years of growth, 2006 and 2010. In 2009, the weighted index looses ten points compared to 2005. In 2012 the index reached a value 12 points below 2005 levels. We derive from the variations of EU ETS production the series of variations for baseline emissions.

Determination of emissions' initial level

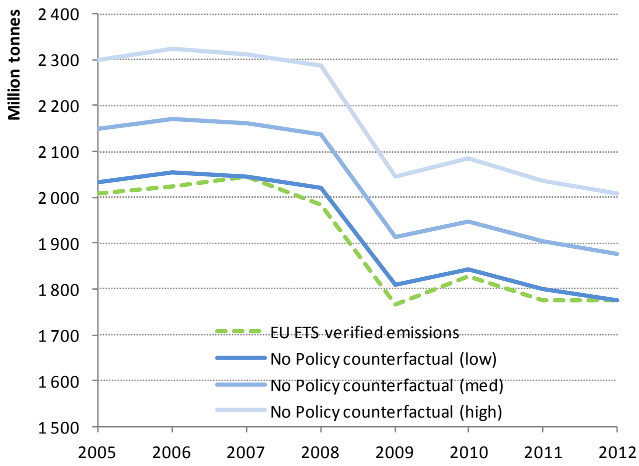
Now that we determined the variations of our baseline emissions as the variations of the production indexes multiplied by the elasticity of emissions to production, we still need to make an assumption on the initial level of emissions, as they would have been in 2005 without a carbon price. A carbon price existed all along the year 2005, which implies we cannot use the observed ex post emissions of that year as the starting point for the baseline.

To stay coherent with our assumption that the existence of the carbon price will make emissions go below the baseline, the counterfactual baseline has to always be above or equal to verified emissions, so that the carbon price and estimated abatement, be they virtually null, are positive at the same time.

Verified emissions are taken from the CITL. We chose to focus on the EU25 so that the emission perimeter is constant over time (the inclusion of Romania and Bulgaria in 2007 and of Norway, Liechtenstein and Iceland in 2008 is not accounted for). The verified emissions for installations in this perimeter are plotted in Figure 12 below. They start in 2005 at around 2,000 Mt and arrive in 2012 at around 1,780 Mt.

For the starting point, we choose to consider three possibilities: the most conservative is set at the lowest possible level (2005 baseline at 2,035 Mt), a second (med) scenario starts at 2,150 Mt, and a third (high) which begins at 2,300 Mt. The three scenarios end up in 2012 at respectively 1,780 Mt, 1,880 Mt, and 2,000 Mt. Later on in the thesis, we will determine only one emission baseline which will serve as the counterfactual scenario in our model.

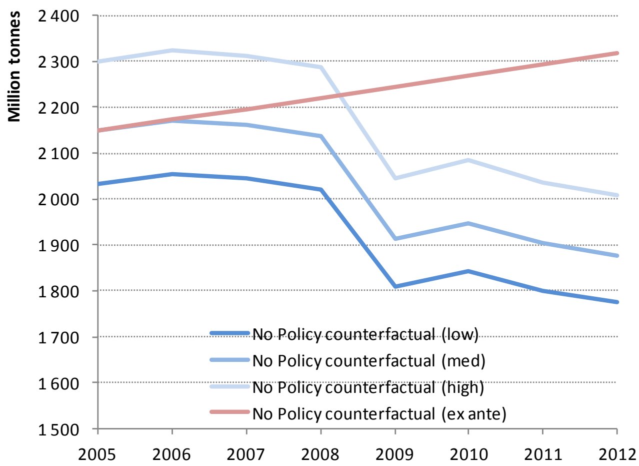
FIGURE 12 –EU ETS VERIFIED EMISSIONS AND POSSIBLE INITIAL LEVELS FOR THE COUNTERFACTUAL



Source: author, CITL

An *ex ante* version of this counterfactual can also be drafted, which will allow comparing expectations with actual observations. This scenario derives baseline emissions from the medium initial value identified previously, but using a production growth scenario based on the average past year-to-year growth over the 1999-2004 period (1.8%). It corresponds to a counterfactual scenario as it could have been represented in early 2005 not knowing what actually happened afterwards.

FIGURE 13 –COMPARISON WITH AN *EX ANTE* "NO POLICY" SCENARIO



Source: author

2. Emission reductions and marginal abatement cost curves

Emission reductions are going to be estimated for each year as the difference between baseline emissions and observed CITL emissions. Then we will suppose that the price of carbon on the market for that year is responsible for the decrease of emissions, and we will estimate the total costs of reductions on this base. This will allow us to construct an approximated EU ETS abatement curve. A sector based estimate completes this analysis by letting us identify possible shapes of sectoral MACCs and refine the initial baseline starting point.

2.1 Emission reductions: an initial assessment

The counterfactual baseline has been built so that it represents emissions as they would have been without a carbon price. Hence by definition emission reductions are corresponding, each year, to the difference between baseline emissions and the verified emissions reported in the CITL. They can be visualized on Figure 12, and the results are presented in the Table 4 below.

Using the *ex ante* counterfactual scenario, we find an annual abatement of around 150Mt/yr in Phase 1 and 500Mt/yr in Phase two, for a total reduction of 2.6 $GtCO_2$ over 2005-2012. This represents the abatement we would find by sticking to our belief that emissions, in the absence of a carbon price, would have increased continuously on the pace observed over the 1999-2004 period. The volumes identified are thus huge, and manifestly do not account for emissions reductions linked to production decrease, especially the effect of the crisis and the general slowdown of European economies since end-2008.

TABLE 4 – ESTIMATE OF EMISSION REDUCTION AT THE EU LEVEL

$MtCO_2$	2005	2006	2007	2008	2009	2010	2011	2012	Phase 1	Phase 2	2005-2012
Emission reduction (ex ante)	142	149	153	235	477	443	517	544	445	2,216	2,661
Emission reduction (high)	292	300	269	301	278	258	260	233	861	1,330	2,190
Emission reduction (med)	142	148	118	152	145	122	127	102	408	648	1,056
Emission reduction (low)	25	30	0	35	40	16	23	0	55	115	171

Source: author

The three other estimates are based on the *ex post* counterfactual scenario built in the first section of this Chapter. Those are net of (at least part of) emissions reduction not linked to the carbon price, and especially those related to growth and production variations. The three are offset by around 150 Mt around their initial baseline value. The high scenario gives estimates superior to the ex ante version in Phase 1 (300 Mt/yr) and inferior in Phase 2 (around 250 Mt/yr) for a total reduction of 2.1 Gt over 2005-2012.

The medium scenario has the same initial starting point than the *ex ante* scenario. It forecasts an abatement of 400 Mt over Phase 1 and 650 Mt over Phase 2. The main differences with the ex ante version of the estimates are in 2007 (40Mt difference) but above all in 2009. Instead of increasing from 470 Mt in 2009 to 540 Mt in 2012, emissions reductions netted of the crisis effect are now at 145 Mt in 2009 and decreasing to 100 Mt in 2012. It's a significant result: over 2005-2012, netting of reductions not linked to the carbon price leads to a reduction of estimates by 60% if the initial value is set at around 2,150 Mt. But it can be set lower.

The low scenario is the lowest possible counterfactual giving a positive abatement for all years. We see that when we account for the effect of production, almost all the previously estimated emission reductions fall to zero: the low counterfactual almost perfectly fits the observed emissions, so that an initial baseline close to observed emissions gives only 55 Mt abatement over Phase 1 and 115 Mt over Phase 2, for a total of 171 Mt. That is only a 1% reduction of baseline emissions over the entire period.

The first lesson is that accounting for the *ex post* variation of growth in the emission baseline eliminates a large share of what was the *ex ante* anticipated deficit. Secondly, those scenarios highlight the importance of the initial starting point in the establishment of the emission baseline.

2.2 The cost of emission reductions and the resulting marginal abatement cost curve

Longer term reductions have an effect on future emissions independently of the actual future carbon price. To account for this would require to progressively lower the baseline because of the persistence of reductions. This will be done in simulations with our model in the next section.

Total costs can be approximated by considering that marginal abatement cost curves are linear. In this simple case, the total cost of reduction equals the volume reduced times half the marginal cost. This is graphically shown on Figure 8, page 48. The Table 5 below summarizes the costs resulting from our four scenarios. The medium scenario gives a total reduction cost of about 7.6 billion euros over 2005-2012.

TABLE 5 – MARGINAL AND TOTAL COST OF REDUCTIONS

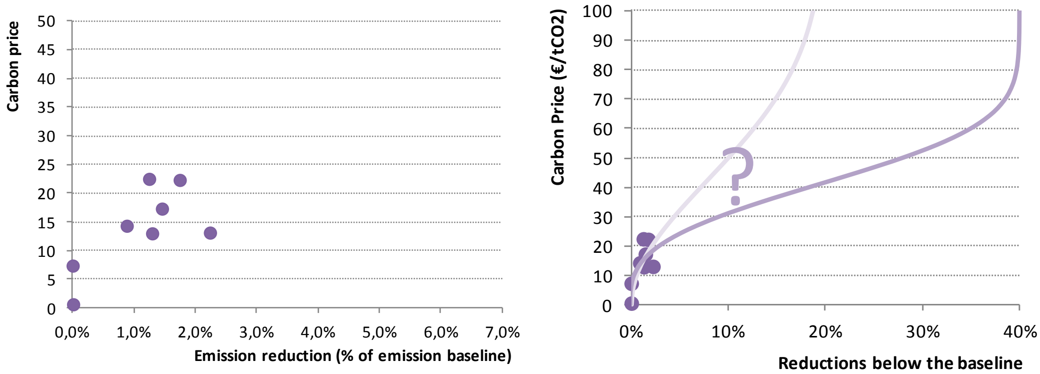
	2005	2006	2007	2008	2009	2010	2011	2012	Phase 1	Phase 2	2005-2012
Marginal cost (€/tCO_2)	22.51	17.33	0.66	22.33	13.15	14.34	13.02	7.40	13.50	14.05	13.84
Total cost (ex ante, M€)	1,603	1,295	50	2,627	3,137	3,174	3,366	2,012	2,949	14,316	17,264
Total cost (high, M€)	3,292	2,596	89	3,356	1,827	1,852	1,691	862	5,977	9,588	15,565
Total cost (med, M€)	1,603	1,284	39	1,692	950	877	826	378	2,926	4,724	7,650
Total cost (low, M€)	285	259	0	394	266	116	152	0	544	928	1,472

Source: author, BlueNext spot price

The relationship between marginal costs and annual abatement can be plotted. Abatement is supposed to be an increasing function of the price. A low price will trigger no or low abatement, a higher price will tend to increase this amount, even by a small bit. The shape of the actual curves is completely unknown to us and complicated to estimate given the underlying production processes, even for the operators themselves. On the left-hand side of Figure 14, each point represents the couple (abatement, price) of a given year in the low scenario. The other curves would just be translation on the right of roughly the same curve.

There effectively seem to be an increasing relationship between both. However, the errors are in the range of 5€/tCO_2 which is quite high. Moreover the number of observation is small and does not go beyond the range of 2% reduction below the baseline. Projecting a relationship from this scatter plot is very uncertain, especially beyond 5% reduction as shown on the right-hand side.

FIGURE 14 – RELATIONSHIP BETWEEN EMISSION REDUCTION AND THE CARBON PRICE



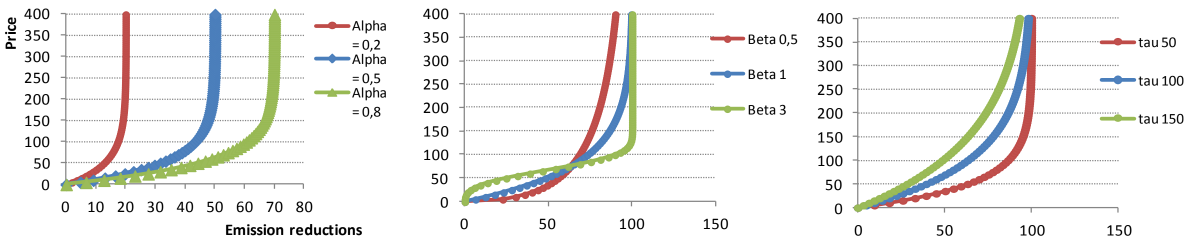
Source: author. Note: parameters of example curves on the rhs are alpha = 0.2; beta = 2; tau = 60 / alpha = 0.4; beta = 3; tau = 47; see Box 3 the for details about the modeling of abatement cost curves

BOX 3 – MODELING ABATEMENT CURVES

MACCs are commonly approximated as linear functions, which are easy to manipulate analytically, see for example Newell and Stavins (2003). Here, we propose to use the alternative, non-linear representation for MACCs used in De Cara and Jayet (2011) for modeling reduction costs in the agricultural sectors. This form has several advantages, mainly to allow approximating MACCs with a few parameters (three) which can quite easily be estimated and interpreted. The equation linking emissions with the price of carbon is shown below, with E_p the emissions at price p, E_0 the baseline emissions (emissions at p=0), and the three parameters α, β and τ.

$$E_p = E_0\left(1 - \alpha\left(1 - e^{-\left(\frac{p}{\tau}\right)^{\beta}}\right)\right)$$

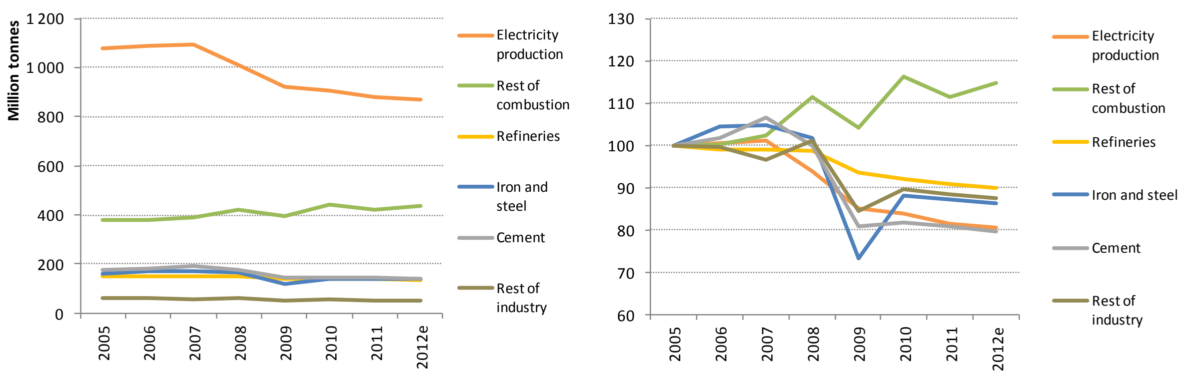
Under the assumptions that 0<α<1, β> 0 and τ> 0, this equation ensures that the abatement is positive and increasing with the price p. If β>1, the abatement supply function has an inflexion point (which horizontal position depends on τ). When the price tends to infinity, the abatement proportion tends to α. Therefore, α represents the maximum share of baseline emissions which can technically be reduced, and (1-α) represents the amount of incompressible emissions. All other parameter being equal, τ describes the relative position of costs functions to attain the same reduction.



2.3 Introducing diversity between sectors

Reasoning at the EU level can net out different situations among sectors. A growth of emission in a certain sector can be offset by the decrease in another. The construction method of a counterfactual emission scenario that we just used can also be applied separately to each sector's industrial production indexes. Unfortunately it is not possible to estimate a disaggregated set of emissions by CITL sector before 2005. Therefore we have to use the same average elasticity of emissions for each sector than previously (0.6 and 1.2 in 2009). By determining separately each sector initial baseline, we can get another estimate of the resulting total EU ETS initial baseline. We also want to access information about possible differences in reduction costs among sectors, because this difference is at the core of the trading mechanism which we eventually want to simulate.

FIGURE 15 – VERIFIED EMISSIONS BY SECTOR IN VOLUME AND INDEX (EU25, 2005=100)



Source: author from CITL, estimates for 2012

The verified emissions, which evolution are shown in Figure 15 for each sector since 2005, are individually compared with each sector's counterfactual emission scenario. For each sector, the initial baseline is fixed to the first value inducing non-negative abatement in each of the years, like in the low scenario used in previous pages. *Ex ante* versions of scenarios are also presented (see Annex D_1). The resulting initial baseline is 2,180 Mt, close from the value used in the previous medium EU ETS scenario.

We also have access to approximation of emission reductions for each sector (Annex D_2). The new estimate is, once aggregated, close from the previous medium scenario. Emission reductions are estimated a little above 150 Mt/yr on average over Phase 1 and between 185 Mt and 125 Mt/yr in Phase 2. The cumulated reductions over 2005-2012 represent around 1.3 $GtCO_2$. Again, using the same process than previously in matching the annual reductions with the observed carbon price, we can try to identify basic relationships between abatement and the carbon price for each sector (Annex D_3).

3. A prototype version of ZEPHYR-Flex allowing for trading, without time-flexibility nor offsets

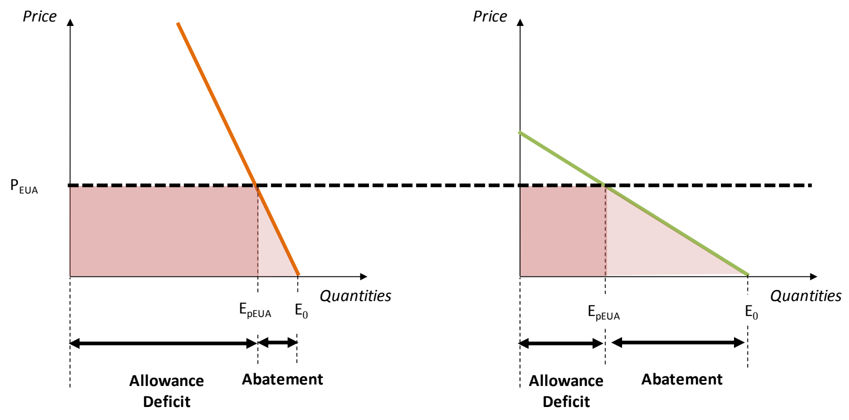
In the previous section we established a set of assumptions on the baseline emissions and the reduction cost of each sector. Those two elements are the ground for trading among operators. Installations with low reduction costs are supposed to reduce more emissions than those with high reduction costs, and trading among them is the source of the EU ETS' economic efficiency, by equalizing marginal abatement costs. Our aim in the following pages is to build the first block of our ZEPHYR-Flex model, to simulate the trades between operators over the first two trading periods. In this last section, we will concentrate on simulating trading as if there was no other flexibility instrument available: no banking or borrowing between years, and no Kyoto offsets.

3.1 The opportunity to trade

Trading opportunities arise from the existence of differences in reduction costs among actors. In theory, the market price and the total reductions achieved by the system do not depend on the distribution of allowances among actors, because exchanges on the market will in the end lead to the most efficient repartition of rights (again, with rational actors, perfect information and perfect trading). However the quantity of exchanges and the nature of transfers (who buys and who sells, which quantities) is indeed influenced by the way allowances are distributed among actors.

The most simple situation is that represented on Figure 16 of two installations with different abatement curves. The red one, on the left-hand side, is sharper than the green one (right-hand side) so that attaining the same reduction compared to the baseline is more costly for the red installation than the green. We consider that they are holding no allowances, i.e. they received no free allocation and made no previous purchase of allowance. Those two installations are in a larger market of many other installations so that they can be considered price taker. In that case, at the price P_{EUA} observable on the market each installation will reduce emission as long as the marginal cost is inferior to the market price (recognition of opportunity costs). Because the slope of their MACC is different, each will reduce a different proportion of baseline emissions. Abatement is entirely determined by the market price and the abatement curves, and installations now know their verified emissions. At the end of the year, installations must surrender as many allowances as verified emissions. This is where the demand for allowances comes from. If they do not hold any allowances, those installations will need to buy as much allowances as verified emissions on the market (primary or secondary). Each installation has a deficit equal to its verified emissions. No installation has a surplus.

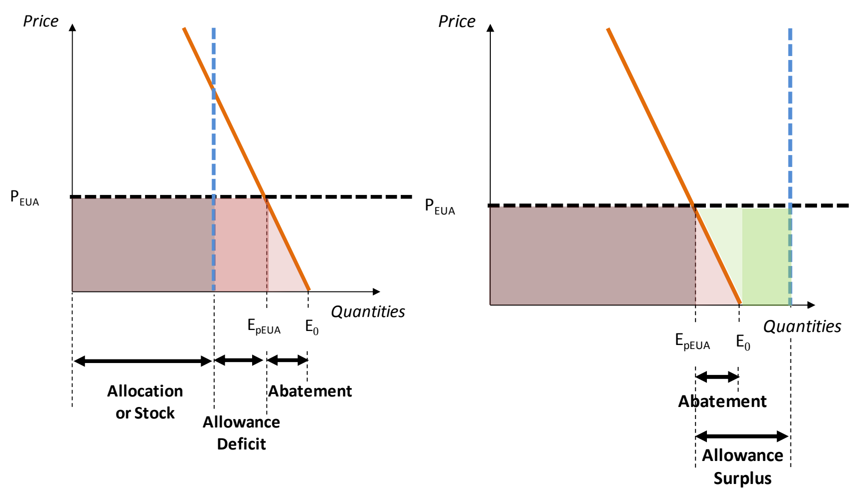
FIGURE 16 – SURPLUSES AND DEFICITS WITHOUT INITIAL STOCKS



Source: author

In a second step, we consider that installations can hold allowances, which is in reality almost always the case (even with full auctioning of allowances because actors can buy/sell allowances all along the year and that they can make errors in anticipations). In this situation - and under the same assumptions regarding opportunity costs, information, rationality and transaction costs - two possibilities can be represented. In the first case, the amount of allowance held by an actor (its EUA stock), is inferior to its verified emissions (two graphs at the top) which results in an allowance deficit; in the other case, the amount in the stock is superior to verified emissions, or even superior to baseline emissions (see Figure 17 below) which results in an allowance surplus.

FIGURE 17 – SURPLUSES AND DEFICITS WITH INITIAL STOCKS



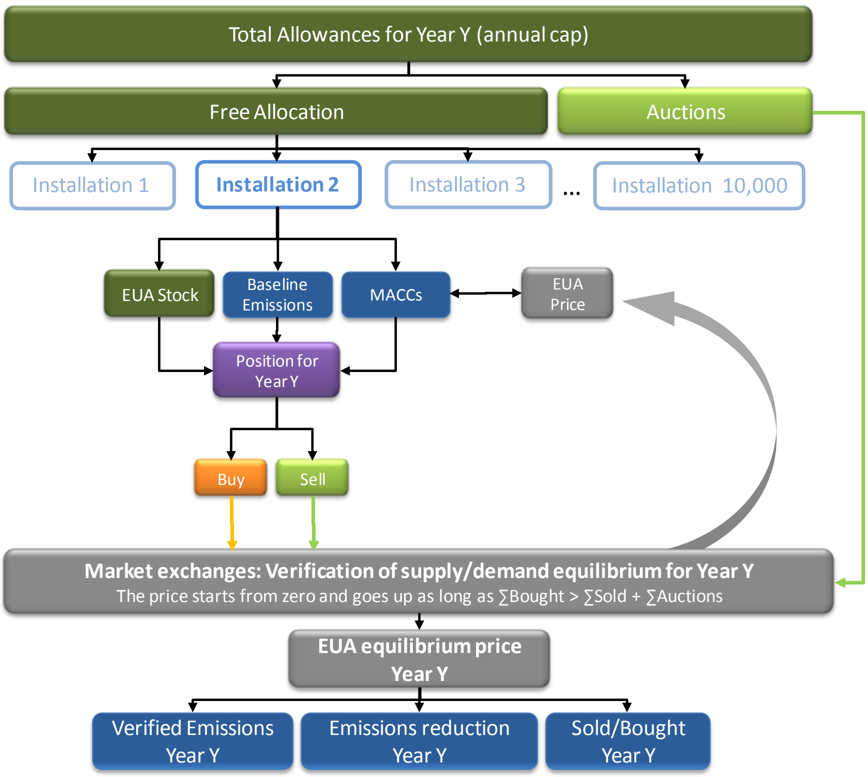
Source: author

In both cases, the quantity of allowance held by actors, the EUA stock, can be viewed as compensation against the cost of acquiring all allowances (verified emissions) on the primary or secondary market. This stock has been either received at the beginning of the year (free allocation) or acquired on the market and banked for this purpose, or both. The only source of supply in the market, apart from primary auctions and Kyoto offsets, in this situation, is installations holding more allowances than their verified emissions. Inversely, installations holding fewer allowances than their emissions face a deficit of allowances. They have to find at least the complementary amount on the market, or be subject to penalties. Those installations are the source of demand on the market.

3.2 Simulating trades without other flexibilities

Supply and demand on the market, hence the price, is determined by the separate condition of each installation. More precisely the price is, starting from zero and going up, the first price which equalizes supply and demand. If the cap is superior to baseline emissions, there may exist individual demand on the market because of the distribution of allowance, but there is no need for emission reductions and all the demand can be satisfied at p=0 (still under the same hypotheses of zero transaction costs allowing quotas to flow between participants); if the cap is constraining (inferior to baseline emissions), the price will not be zero. Demand will initially exceed supply. By rising, the price will trigger more and more reductions, which will in turn either diminish demand and/or augment supply (depending on how allowances are distributed), until the price reaches the value that allows the cap to be met.

FIGURE 18 – ZEPHYR-FLEX: A FIRST VERSION WITH TRADING ONLY



Source: author

The ZEPHYR-Flex model is a simulation model at the installation level. The behavior of 10,000+ installations is going to be simulated on the basis of real CITL observation and assumptions on baselines and reduction costs. The detailed simulation process we are going to use is described in Figure 18 above. It consists of several steps: the determination of annual caps and the share of free allocation/auctions; free allocation to individual installations; determination of supply and demand at any price; computation of market equilibrium.

Annual caps and share of free allocation/auctions: The annual allowance cap is determined by the National Allocation Plans for Phase 1 and Phase 2. In both phases and for the EU25, the cap can be considered constant over time (we neglect the new entrants/closures). The total cap for Phase 1 amounts to approximately 2,175 $MtCO_2$/yr and 2000 $MtCO_2$ in Phase 2. This annual cap is then divided in two parts. One will be distributed to installations as free allocation, the other will be auctioned. Annual caps with their respective share of auctions are inputs to the model.

Free allocation to installations: The share of allowances to be allocated free of charge is distributed, at the beginning of each year, to every installation on the basis of its real allocation's share in the total observed CITL allocation of its sector. With this assumption, it is possible to modify the cap parameter without changing proportions/concentration between installations in the model compared to real observations. The fact that the allocation of an installation depends on its sector is not used for the moment but will be necessary to account for changes in the way allowances are allocated from 2013 on. More details will be given in Chapter 5.

Supply and demand, at any given price: At this point we use the results from this Chapter, baseline variations of emissions for each sector since 2005, and parameterized abatement curves for each sector. Each installation is given a baseline emissions scenario and a marginal abatement cost curve in function of its sector (every installation in the same sector have the same MACC). We consider for now that emission reductions are non-definitive, so that emissions can instantaneously come back at the baseline level as soon as the carbon price is null. For each installation we know its EUA stock, emission baseline, and reduction costs. We can thus calculate for any given price the surplus or deficit of allowances as shown in Figure 17. These are aggregated at the EU ETS level on a market exchange.

Market equilibrium: For now, we consider that provisions for banking, borrowing and offsets do not exist. As a consequence, surpluses have to be sold or they will become unusable at the end of the year, and deficits have to be bought because borrowing is forbidden. The model starts by calculating supply and demand on the market at the price p=0. If supply exceeds demand at this stage, the verified emissions are exactly the baseline emissions and the model goes to the next year. If at the price p=0 the demand exceeds supply, the model increments the price and recalculates supply and demand until the first value which equalizes supply and demand is reached. Verified emissions are then the sum of the intersection of the market price with the individual installations' abatement curves. Exchanges allow all installation to comply with their obligation to surrender allowances, and the model goes to the next year.

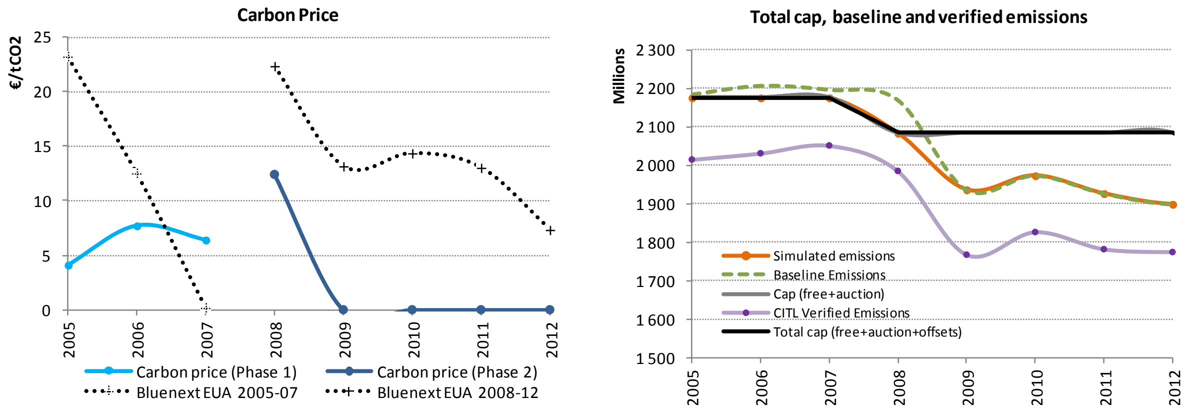
3.3 Simulation results: not replicating the past at all

The simulated carbon price is between 5 and 10€/t in Phase 1, 12€/t in 2008 and then null until the end of Phase 2. The resulting emission trajectory is shown on the right-hand side of Figure 19 below. Without banking and borrowing, allowances are like vintages only working for the current year, so that surpluses have to be sold and deficit have to be bought immediately. As a consequence, verified emissions can either be at the cap (with the help of a corresponding carbon price) or at the baseline level (in that case there is no need of a carbon price – under no transaction costs).

From 2005 to 2008, the EU ETS cap is slightly below the emission baseline. The corresponding carbon price (from 5 to 12€/t) allows to meet this cap by reducing around 150 Mt in total over this time period.

After the economic crisis of 2008, the baseline falls down below the cap, meaning that even without a carbon price, growth would not be enough to make emissions rise over the cap (the level of the cap was decided two years before the crisis). In this situation and without banking, the price stays at zero and emissions follow the baseline. An annual surplus of approximately 150 Mt/yr is lost from 2009 on.

FIGURE 19 – SIMULATION RESULTS WITH TRADING ONLY: CARBON PRICE AND VERIFIED EMISSIONS

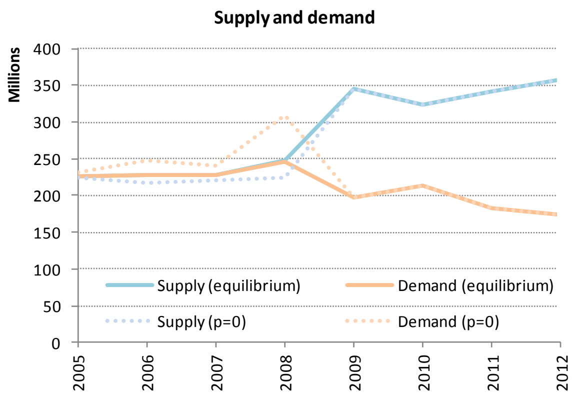


Source: author

This development can be described more precisely with the help of Figure 20 and Table 6. We see that although the emission baseline is close to the cap at the EU ETS level, the initial repartition of allowances creates a much wider gross deficit of allowances among installations (calculated as the sum of the deficits of all installations for which the allocation is below the baseline), which varies between 170 and 310 Mt/yr over 2005-2012. The need for allowances from short installations amounts to a total of 720 Mt over Phase 1 and 1,100 Mt over Phase 2, whereas the need for reduction at the EU ETS level is only 140 Mt in total. Inversely, installations for which allocation is superior to baseline emissions own a surplus of 662 Mt in Phase 1 and 1.6 Gt in Phase 2. This reveals well how allocation influences the potential transfers between actors independently of the overall EU ETS target.

Nevertheless we also see that the total cap (17 Gt) is superior to the total baseline emissions (16.5 Gt), so that with perfect anticipation of the crisis and full banking/borrowing, no price would have been necessary to meet the 2012 emission target. In the end, the simulated verified emissions amount to a total of 16.3 Gt, which is 200 Mt reduced for nothing given that the cumulated baseline emissions are already 500 Mt below the cap.

FIGURE 20 – SIMULATION RESULTS WITH TRADING ONLY: SUPPLY AND DEMAND



Source: author

TABLE 6 –ZEPHYR-FLEX RESULTS WITH TRADING ONLY

	2005	2006	2007	2008	2009	2010	2011	2012	Phase 1	Phase 2	2005-2012
Annual cap (free+auctions)	2,176	2,176	2,176	2,084	2,084	2,084	2,084	2,084	6,528	10,421	16,949
Baseline emissions	2,183	2,206	2,196	2,169	1,936	1,973	1,926	1,899	6,585	9,904	16,488
(cap-baseline)	-7	-30	-20	-85	148	111	158	185	-57	517	460
Gross demand (p=0)	231	247	240	309	197	213	183	173	718	1,075	1,793
Gross supply (p=0)	224	217	220	224	345	324	341	359	662	1,592	2,253
Carbon price	4.1	7.7	6.4	12.4	0.0	0.0	0.0	0.0	6.1	2.5	3.8
Emission reductions	8	30	20	86	0	0	0	0	58	86	144
Volumes traded	227	228	227	246	197	213	183	173	682	1,012	1,694
Verified emissions	2,176	2,175	2,175	2,083	1,936	1,973	1,926	1,899	6,527	9,818	16,344

Source: author

The major lesson of this simulation is that trading continues, even with a zero price, to ensure the compliance of every participant. This allows the total costs to be drastically reduced.

3.4 The cost of reductions and the savings from trades

The ZEPHYR-Flex model can calculate the costs of reductions, purchase and sales of allowance for each installation. These are calculated in our scenario with trading only and summarized in Table 7. Given the uncertainty of our assumptions, we are far from saying that this is what would have really happened if that scenario had come true. However it is a good example of what the ZEPHYR-Flex model can do and the orders of magnitude involved in this particular setting of the EU ETS.

TABLE 7 –ZEPHYR-FLEX COMPLIANCE COSTS WITH TRADING ONLY

(M€)	2005	2006	2007	2008	Phase 1	Phase 2	2005-2012
Total reduction cost	24	181	99	827	304	827	1,130
Purchases value	929	1,756	1,456	3,052	4,140	3,052	7,192
Sales value	930	1,727	1,431	2,287	4,088	2,287	6,375
Total compliance cost (reduction+purchase-sale)	23	210	123	1,592	356	1,592	1,948
Auctions value	0	33	28	775	61	775	836

Source: author

The total abatement cost of the simulated 150 Mt reduction is estimated at 1,130 M€, i.e. on average 7.5€/tCO_2. The value of purchased allowances amounts to about 7 bn€ over the two phases. In 2009-2012, there are exchanges but they happen at zero cost because of the assumption on perfect competition and transaction costs. The value of sales is 6.3 bn€, less than the purchases, because part of the allowances have been sold by Member States via auctions. In total, Member States' auctions raised around 830 M€ in total over the simulation period. All in all, the net compliance cost is calculated as the sum of the reduction costs and purchase cost, minus the value of sales. For the EU ETS as a whole and under this setting (no flexibility other than trading), it amounts to 2bn€.

4. Conclusion

This first run of ZEPHYR-Flex allows us to verify that the equilibrium calculation module works according to the theoretical framework adopted. This simulation highlights first of all that the trading provision (the basis of market-based policies) is very efficient to lower compliance costs, by allowing the market to re-distribute allowances from where reductions are cheap to where reductions are expensive. Trading thus represent high savings compared to the cost of seeing all installations reduce emission to their own allocation level. Secondly, under our assumptions and especially zero transaction costs, trading happen even if the price is null because of the compliance needs of some participants.

The major limit is that the model does not replicate the past. At this stage it is perfectly normal because we know that the other flexibility provisions (spatial and time flexibility) have determinant implications on the price and emission trajectories. This was one of the lessons from the *ex ante*/*ex post* comparison of Chapter 1. Our goal is now to implement those two missing flexibility mechanisms in the ZEPHYR-Flex model. The following Chapter will analyze the offsetting provision, its influence on the observed price, and establish a scenario for the future use of offsets on this basis. Chapter 4 will focus on the banking/borrowing provisions and their link with the anticipations and behavior of participating firms, allowing the reunion of the three flexibility mechanisms in a complete version of ZEPHYR-Flex.

Chapter 3 –The use of carbon offsets: Good or Evil?

"In summary the proposal is economically beneficial, as it is expected to reduce compliance costs for companies in the Community emissions allowance trading scheme by €0.5 bn or more than 20% and lower allowance prices by almost 50%. The proposal is expected to result in an annual "outsourcing" of emission reductions from covered installations to third countries of close to 100 million tonnes of CO_2 (editor's note: 500 Mt over Phase 2)*"*

European Commission, *Extended Impact Assessment of the Linking Directive* (2003)

One of the major characteristic of the EU ETS is its articulation with the Kyoto Protocol's flexibility mechanisms: the emission trading system between Annex B Parties of the Protocol and especially the two associated project-based mechanisms. In the same way Annex B Parties can use emissions credits from project mechanisms in the emission trading system associated to the Kyoto Protocol (Article 6 and 12), industrial installations covered by the EU ETS are allowed, since the vote of the "Linking Directive" in 2004, to meet part of the emission reduction target with Kyoto offsets, e.g. Certified Emissions Reductions (CERs) from the Clean Development Mechanism (CDM) or Emissions Reductions Units (ERUs) from the Joint Implementation (JI), with some qualitative and quantitative restrictions.

In 2005, it was anticipated that Kyoto offsets would be accepted and demanded by various sources: Parties to the Kyoto Protocol, EU ETS installations, emerging emission trading schemes in other Annex I Parties, and various voluntary markets. Offsets in this context would be a great tool to indirectly link different markets in different region of the world, strengthening the efficiency of international action against climate change. These initial expectations triggered the development of a large number of projects and, once emission reductions have been verified, a substantial supply of offsets.

Unfortunately, international demand didn't follow a comparable growth path. The large availability and the low price of Kyoto units (AAUs) limited demand from Annex I Parties, and no large scale demand for offsets emerged in other regions of the world, which made the EU ETS almost the only possible destination of offsets. In this context, the attitudes towards international offsets seem to have changed; initially worshiped like goddesses enlarging the scope of abatement potentials, Kyoto offsets became like evils aggravating disequilibrium on the EUA market.

In this chapter, we are going to study in detail this articulation between the EU ETS and the Kyoto market, which will allow us calibrating the use of offsets in the ZEPHYR-Flex model, as well as drawing more general lessons regarding the integration of offsets in a cap-and-trade system. The first section presents our analytical framework. Section 2 describes the rules for using offsets in the EU ETS and their possible consequences on the distribution of offset use over time. Section 3 focuses on the observed evolution of Kyoto offset supply as well as their probable future availability. Section 4 analyses the past price patterns of offsets compared to that of EUAs.

Section 5 is a detailed observation of the use of offsets at the installation level, which will serve as a basis for the calibration of the integration of offsets in the ZEPHYR-Flex model in Section 6.

1. The use of offsets: an overview

1.1 Using offsets: brief review of literature

As analyzed in the economic literature – see for example Flachsland et al. (2009) - there are advantages and disadvantages that arise when establishing a link between a cap-and-trade and project based mechanisms. From a global design point of view, this link extends the price signal of the cap-and-trade in other sectors and in other regions of the world. The expected consequence is to trigger transfers of low carbon technologies and good practices outside the cap and trade boundaries as long as the reductions obtained are less expensive than EUAs.

Another advantage of linking a cap-and-trade with offset mechanisms is to lower the compliance cost of installations inside the cap-and-trade. This direct effect on compliance cost benefits only to installations using offsets, but induces another cost-saving effect for all installations, because it lowers the demand for cap-and-trade allowances and thus their price. Reducing cost was one of the argument for establishing a link between the EU ETS and Kyoto's project based mechanisms. This was clearly stated, prior to the decision of linking, in the European Commission's impact assessment; see European Commission (2003).

Linking a cap-and-trade with offset mechanisms is also feared to induce negative effects. As summarized by Olander and Murray (2008), there are many concerns associated with the incorporation of offsets into a cap-and-trade system: damage to the integrity of the cap (if offsets are not real, i.e. additional emissions reductions), money flows to foreign countries, negative co-effects in host countries, and outsourcing emission reductions (because emission reductions occur first where they are least expensive, the cap could be met without any participants reducing emissions domestically).

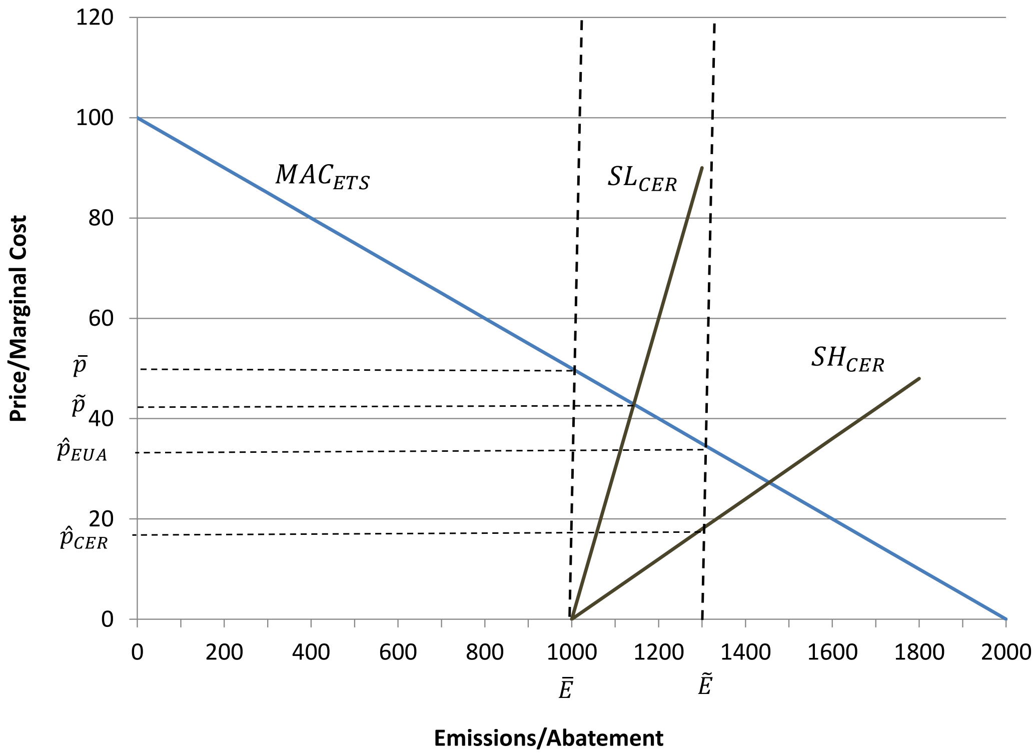
The last one, outsourcing emissions reductions, has clearly been a concern when designing both the Kyoto market and the EU ETS. In both cases it is stated that the majority of the emission reduction effort has to be reached domestically. To account for this, it has been agreed to establish a limit on the authorized use of offsets for Annex B Parties and EU ETS installations, so that cap-and-trade participants could benefit partially from the cost reduction effect of offsets without preventing the implementation of domestic actions (emissions trading was agreed to be "supplemental" to domestic action, see UNFCCC Kyoto Protocol, Article 17).

It is an interesting fact because the underlying assumption is that offsets would be naturally much less expensive than allowances and would be used on a very large scale. Secondly it supposes that, even if the imposed limit is entirely used, the undermining effect on EUA price is controlled.

1.2 An analytical framework

Subject to the restrictions of the Linking Directive and the later implementing rules in approved National Allocation Plans, CERs and ERUs are supposed to be perfect substitutes for EUAs in meeting the compliance requirements of the EU ETS. This would imply a market price close to that of EUAs. However, the existence of a constraint on aggregate offset use (quantitative and qualitative limits described in section 1) suggests that offsets would sell at a discount if the constraint were binding. The potential effect of this constraint can be illustrated by the following diagram and is discussed below.

FIGURE 21 – THEORETICAL RELATIONSHIP BETWEEN EUA AND OFFSETS PRICE



Source : Trotignon and Ellerman (forthcoming)

Figure 21 is a classic diagram showing the relationship between emissions, a cap, marginal abatement costs, and price. In this instance, a cap at 1000 ($\bar{E}$) produces a price of $\bar{p}$, when abatement is restricted to the system. When offsets are allowed within the system, emissions may be greater than the level of the cap to the extent that offsets are submitted for compliance. Figure 21 illustrates the case of offsets for which the only market is the ETS. Thus, the supply schedule originates at the cap level and the quantity supplied at a given price is the difference between the value indicated on the horizontal axis minus the cap. When an aggregate limit on offset use is imposed, such that within the system, emissions could be as much as $\tilde{E}$, two pricing (and use) possibilities arise depending on the supply curve for offsets, such as illustrated above by S_L and S_H.

Situation 1. If the supply of offsets is relatively low, the aggregate limit will not be constraining and the price for EUAs and offsets somewhat less ($\tilde{E}$), reflecting the supply of cheaper offsets. In this case, where the aggregate limit on offset use is non-constraining, the price of EUAs and CERs would be expected to be equal.

Situation 2. If the supply of offsets is relatively high or abundant, such that the limit on aggregate offset use is binding, the price of EUAs and offsets will not be equal and the latter will be priced at a discount. The limit on aggregate offset use means that within system emissions can be no greater than $\tilde{E}$, which implies an EUA price of $\hat{p}_{EUA}$. Although suppliers of offsets would be willing to supply more than allowed by the aggregate limit, they cannot do so and competition among them would be expected to drive the price of CERs or offsets to $\hat{p}_{CER}$, that is, at a discount to the price of EUAs. This discount reflects the shadow price of the constraint on aggregate offset use and it has the potential of reducing compliance costs by an amount equal to the discount times the quantity of offsets allowed, and leads to a complete utilization of limits.

This analytical framework is going to be the ground for analyzing the pattern of offset use described later in Section 5. Before looking at the actual use of offsets by installations, it is necessary to specify the detailed rules (Section 2), the availability of Kyoto offsets accepted on the European market (Section 3), as well as the observed prices of CERs compared to EUAs (Section 4).

2. The use of offsets in the EU ETS: the rules

As long as the price of an offset is below the price of an EUA, all installations have an incentive to use as many offsets as possible over the time period, either as a cheaper alternative to buying EUAs, or to free up EUAs that can then be sold or banked. The gain in both cases is the difference (spread) between EUAs and offsets prices. Offsets can be bought on the market (secondary CERs) or directly by financing a CDM project (primary CER market). Since the beginning of the secondary market for CERs, offsets have always been cheaper than EUAs, so that in theory all installations have had an incentive to surrender as many offsets as they are allowed to. According to the analysis presented in section 1, this suggests that the limits imposed on the use are binding.

2.1 Qualitative and quantitative limits to the use of offsets

The rules for using Kyoto offsets in the EU ETS are stated in the so-called Linking Directive of 2004. Two kinds of restrictions which are going to be described hereafter apply to the use of offsets: qualitative restrictions and quantitative restrictions.

Qualitative limits. In phase 2, all types of offsets are accepted in the EU ETS, except CERs and ERUs generated from nuclear facilities and temporary offsets resulting from land use, land use change and forestry activities. There are also restrictive criteria for large hydro projects; see European Parliament and the Council of the EU (2004 and 2009). As will be discussed later, those project types represent a very small share of the supply potentially available for the EU ETS in Phase 2. But the 2011 restrictions on industrial gases credits, which will only apply in Phase 3 but concern a very large share of offsets available to the EU ETS, have had consequences on the use of offsets in Phase 2. This issue will be discussed further.

Quantitative limits to the use of offsets. The majority of emissions reductions induced by the Kyoto Protocol and the EU ETS has to be realized domestically. To account for this, the amount of offsets which can be used by operators is limited to a certain percentage of the conventional free allocations. On average, installations can surrender offsets from Kyoto's project mechanisms up to 13.5% of free allocations, which represents around 1,450Mt over 2008-2012. The limits are specified in the different National Allocation Plans for Phase 2 and vary from 0% (in Estonia) to 20% (Germany, Spain, Norway, and Lithuania) of allowances allocated to installations. Because limits of use are expressed as a share of allocations, the quantity of offset allowed is larger in the major emitting Member States. Installations from Germany can use a total of 450 million offsets over the phase, more than a fourth of the total volume of offsets allowed in Europe. Seven Member States (Germany, Spain, Italy, France, Poland, the United Kingdom, and Czech Republic) account for more than 75% of total limit of use. Annex E_1 summarizes the limits for each participating State and the corresponding amount of offsets.

2.2 Variability of the authorized use of offsets over time

The limit of 1450 Mt is set over the phase, but Member States can decide to establish annual limits of use. Limits can also vary inside a country depending on sectors. In the UK for example, the percentage allowed for Large Electricity Producers (LEP) is slightly higher than for other sectors. The limit in the UK is set annually, but installations may bank any unused limit to the next year; see DEFRA (2007).

The rules differ significantly among countries. As a consequence there is a great amount of spatial and temporal variability in the potential demand for offsets in the EU ETS. Three factors have an impact on determining the maximum quantity of offsets that can be used every year: differences of treatment between industries, banking of unused annual limit of use, and borrowing of next year's annual limit. In 16 countries representing 160Mt (56%) of average annual potential offset use, installations have full flexibility (i.e. one limit for the phase as a whole). Annex E_1 summarizes those specifications for each participating country. As will be explained later, this decentralized flexibility can be a source of uncertainty regarding the cap and the related price and emission trajectory adopted by participants.

2.3 Post-2012 rules and implications in Phase 2

In order to give covered entities more flexibility, the revised Directive for Phase 3 enables them to bank any unused portion of their Phase 2 limit into Phase 3. This will be added to any additional Phase 3 limit decided by Member States and the European Commission with regards to international negotiations and to the level of the European economy-wide reduction target for 2020. Installations of the EU ETS are thus free to spread the use of their Phase 2 limit of use however they like over 2008-2020, but it will not be allowed to borrow possible offsets limits of use from Phase 3 to Phase 2. The quantity of offsets accepted for compliance in Phase 3 will thus be around 1450 Mt minus limits used in Phase 2 plus any new limit accepted by then (mostly in Member States that had a low limit of use in Phase 2, for new entrants and aviation for an approximated amount of 200 Mt). Given the analysis presented in the following pages, we estimate the authorized used of offsets in Phase 3 at around 850 Mt.

In 2011, the European Commission also added qualitative restrictions to the use of offsets in Phase 3; see European Commission (2011b). From 2013 on, offsets corresponding to emission reductions from HFC-23 and N_2O from adipic acid production will not be authorized anymore for use in the EU ETS. One immediate consequence is to incentivize the use of those offsets in Phase 2, while there are valid, to bank EUAs in Phase 3. Those types of offsets represent a large majority of offsets issued up to 2012. The first communication about this restriction was a statement by Commissioner Connie Hedegaard in August 2010, eight month before the compliance deadline of EU ETS installations for the year 2010 (end of April 2011). As a consequence the 2010 and 2011 compliance data can show the effects of those restrictions in Phase 2. We will see next in great details that the restrictions on HFC-23 and adipic N_2O credits generated a substantial increase in the use of offsets from 2010 onward.

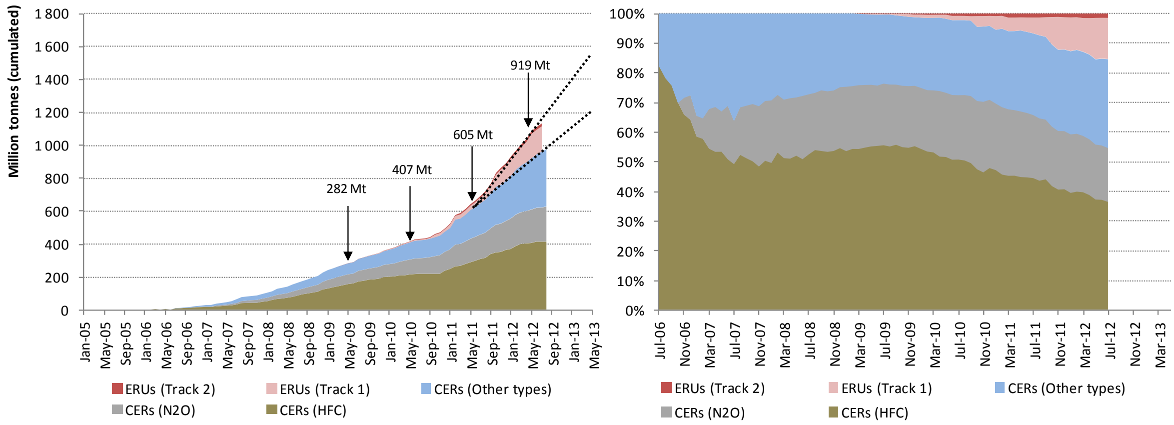
3. The availability of Kyoto offsets

There can be no use of offsets without offsets. Information on existing projects and offsets issuance is made available every month from the United Nations and a summary table is made available by the UNEP Risoe; see UNEP Risoe (2012). At the end of 2012, there were more than 10,000 different projects in the pipeline, among which nearly 1,800 are implemented and regularly issuing offsets. Most offsets come from industrial gases activities (reduction of HFC and N_2O represents more than 50% of the cumulated offsets issued up to 2012), and renewable energy projects (wind and hydro offsets represent 10% of the cumulated issuance). In terms of location, most CERs come from emerging countries: China (nearly half of it), India, South Korea, and Brazil make 90% of the cumulated issued CERs.

The amount of CER issued does not directly indicate CERs available for compliance in the EU ETS, because there are other sources of demand for offsets: Kyoto's international market (for Annex B Parties), and regional or voluntary markets. Real offset demand from Kyoto international market is hard to estimate because CERs are substitute to AAUs, which can be less expensive and are largely available (global surplus of Kyoto international market). Demand from regional and voluntary systems is also very difficult to quantify, hence the figures presented hereafter must be considered as maximum possible values for offsets available to the EU ETS. Figure 22 below summarizes the quantities of CERs and ERUs generated by projects and potentially available for EU ETS installations in each month of April, the yearly deadline for surrendering allowances and offset against previous year's emissions.

The cumulated supply of offsets (without accounting for those used previous years, shown on Figure 22) amounts to 280 Mt in 2009, 410 Mt in 2010, 600 Mt in 2011 and more than 900 Mt in 2012. The share of industrial gases in the supply of offsets has always been above 50%, even though their share in total offsets created diminishes over time, due to the arrival of JI projects and new CDM projects in the renewable and energy efficiency sectors. In May 2012, 600 Mt of the 900 MCERs issued up to this date came from HFC or N_2O project types, as well as 53 MERUs.

FIGURE 22 – SUPPLY OF KYOTO CREDITS OVER 2005-2012



Source: UNEP Risoe CDM and JI Pipelines

It is projected that a cumulated offset supply of around 1,300 Mt will be available before end April 2013, which is nearly the amount initially allowed for use in Phase 2 of the EU ETS. After this date, projects already existing will continue to generate credits and new projects will enter the pipeline. As a consequence the supply of offsets, if not stopped for other reasons, will continue to grow. Details on the possible methodologies used to simulate offset supply can be found in Trotignon and Leguet (2009), Cormier and Bellassen (2012) and Bellassen, Stephan and Leguet (2012). The UNEP Risoe publishes in the end of 2012 an estimated cumulated supply of 5.6 GCERs over the 2013-2020, which is largely superior to the EU ETS limit of approximately 1600 Mt, even if we subtract the post 2012 supply from banned project types.

4. *Ex post* price observation

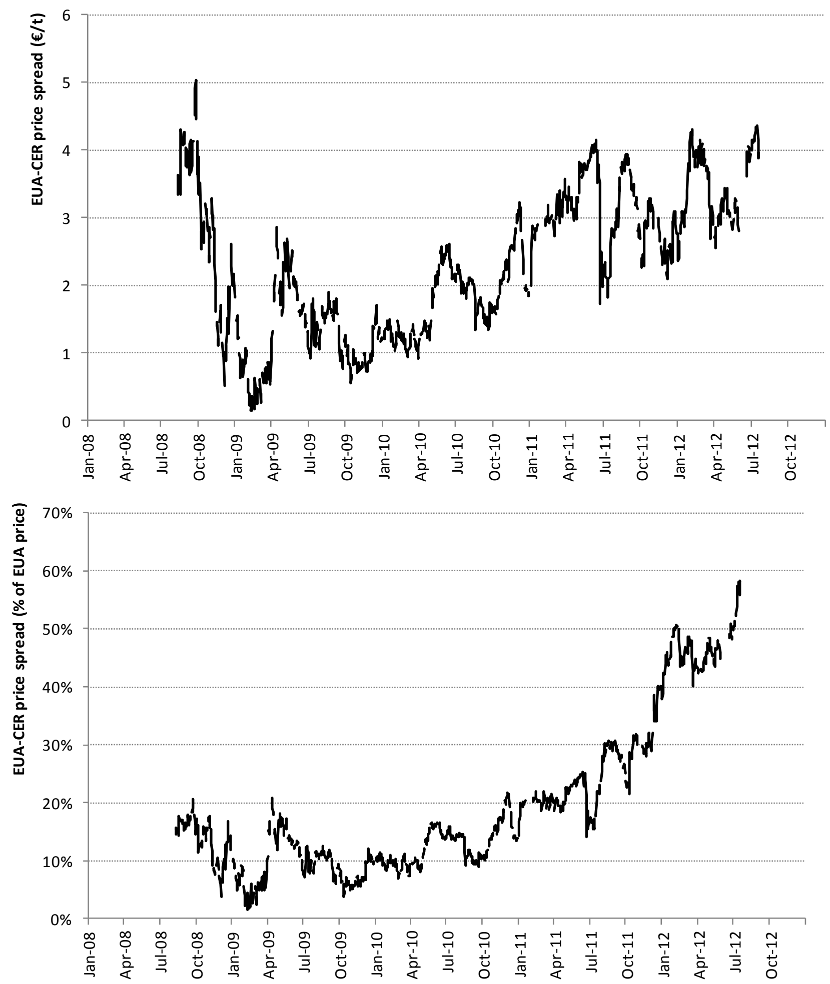
Here we focus on the pricing of these offsets and in particular with explaining what appears to be a pricing anomaly, namely, that these offsets have been consistently priced at a discount to European Union Allowances (EUAs), for which they are perfect substitutes as compliance instruments, notwithstanding a non-binding constraint on aggregate offset use.

This section will first explain the discount of offsets on the spot market as depending on actor's anticipations regarding whether a limit to the use of offsets exists and whether it is binding; and second will question the time profile of offset price compared to EUAs. As a matter of fact, in theory, EUA and offsets should have equal rates of discount over time, unless there is some reason to question whether offsets would be future compliance instruments fully equivalent to EUAs.

4.1 Variable but persistent spot discount

Figure 23 below shows the observed price spread between EUAs and offsets over 2008-2012. Prices of CERs and ERUs do not differ significantly so that we use the CER price as a proxy of both Kyoto offsets' prices.

<u>FIGURE 23 – EUA AND OFFSETS PRICE SPREAD OVER 2008-2012</u>



Source: author from Bluenext and ICE ECX

The price spread between EUAs and offset has always existed. In absolute value (graph at the top), it rapidly decreased from 4-5€ to less than 2€/t at the time the EUA price fell down due to the start of the economic and industrial crisis. It then stayed in a band around 3€/t over 2010-2012. But this picture is distorted by the price of EUAs: a 5€ discount does not have the same effect when the EUA price is high and when it is low. Hence to complete the picture, we also express the price spread in relative value (as a discount percentage relative to EUAs). The relative spread then stays in a band of about 10% until the end of 2010. From this date, an increasing trend seem to appear which progressively drives the relative price spread above 50% in 2012, levels never reached before. At the same time, the absolute price spread is almost constant, because both EUA and CER price are very low. In mid 2012, the EUA spot price is about 7.5€/t and the CER spot price about 3€/t. What changed to induce this increasing relative spread since end-2010?

The first explanation would be that from this date, two years before the end of Phase 2, it became more and more certain that the supply of offsets would be sufficient to cover most of the offset needs in the EU ETS over Phase 2, and to generate largely enough offsets after 2012 compared to the probable unused Phase 2 limits (bankable into Phase 3). Simulations of CER issuance can be computed on the basis of the CDM pipeline and allow estimating month after month the probable future availability of offsets; see for example Trotignon and Leguet (2009). It is reasonable to posit that actors on the market had quite precise information on the future, and quite certain anticipations regarding the timing of offsets' supply.

The second factor explaining this increasing trend starting in end 2010 is the announcement of qualitative restrictions for offsets originating from HFC-23 and adipic N_2O projects, made in August 2010 by Commissioner Connie Hedegaard. Plenty of warnings were given and the final regulation was voted in June 2011. Starting from this date, the spread increases even more and doubles in relative value in less than one year.

This review of past prices suggests that market participants have always had the anticipation of a binding constraint, i.e. a supply of offset sufficient to meet to actual demand from EU ETS installations. However these expectations have varied in intensity over time: they were quite strong in the beginning of Phase 2, then decreased due to economic crisis and the perturbation of global anticipations it induced, and rose again afterwards, especially as soon as it became clear that the abundant offset supply, added to the fact that large amounts of industrial gases offsets would be used while they are still valid, was significantly above the actual demand from installations.

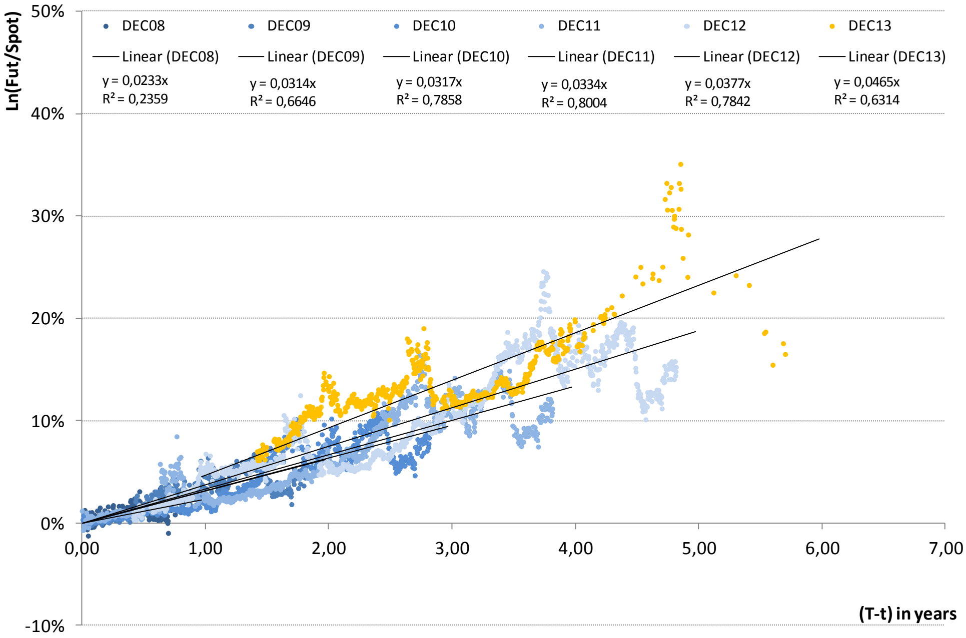
4.2 Different time discounts

The EUA and offset prices also differ in time discounts: for the same delivery date, a CER contract will account for a larger discount compared to spot prices than that of an EUA contract. The classic theoretical relationship between the spot and the future price over time (for a delivery at the date T) is given by the following equation: $F_{t,T}^{EUA} = S_t^{EUA} e^{r^{EUA}(T-t)}$

This relationship represents perfectly arbitraged markets where the difference in price at the date t is a function of an interest rate r. In the perfect case (with no storage costs), r is supposed to be the risk free interest rate. The observed relationship between distance to delivery and the time discount for EUAs is shown in Figure 24 below.

The different linear trends give us a set of different values for r_{EUA} (the slope of regressions, one for each contract). The results are pretty much consistent with the theory and in line with our expectations. The interest rate takes value from 2.3% for the DEC08 contract, between 3.1% and 3.8% for DEC09 to DEC12 contracts. The DEC13 contract presents a premium compared to other contracts (at the same distance to delivery), and its slope is steeper at 4.6%.

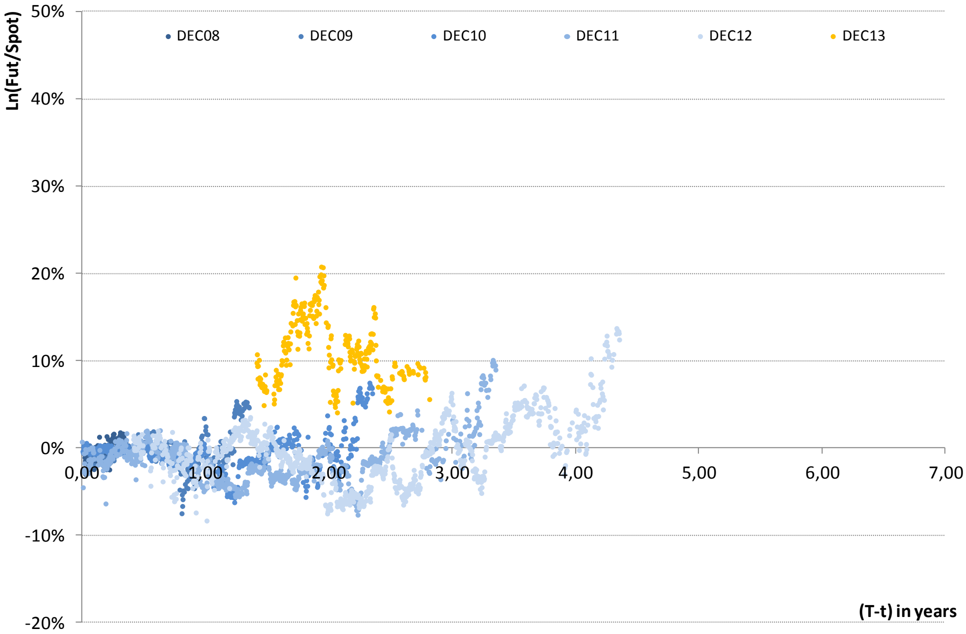
FIGURE 24 – EUA TIME DISCOUNT OVER 2008-2012



Source: author from Bluenext and ICE ECX

EUAs and CERs are perfect substitutes, and CERs are not more expensive to hold on an account than EUAs, so that CERs should present the same time discount profile than EUAs. Figure 25 presents the relationship between distance to delivery and the time discount for CERs.

FIGURE 25 – CER TIME DISCOUNT OVER 2008-2012

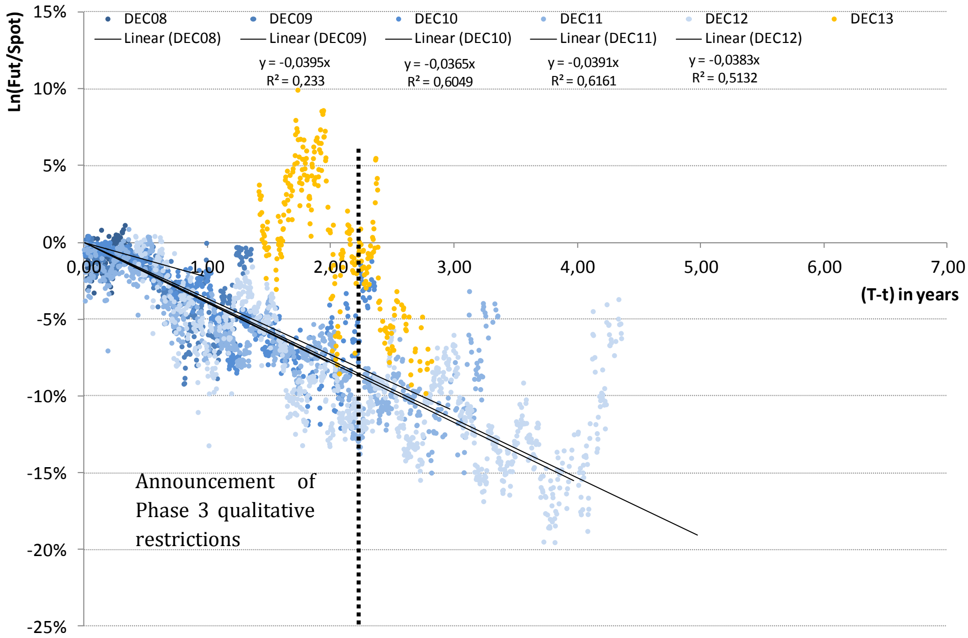


Source: author from Bluenext and ICE ECX

The pattern of CERs is very different from that of EUAs. For most contracts (DEC08 to DEC12) there seems to be a very small or even negative interest rate. On the contrary, the DEC13 contract presents a pattern rather similar to that of EUA. It seems clear that the time profile of CERs is impacted by the different risks associated to holding or being able to use offsets: DEC13 contracts are somehow recognized by operators as closer substitute to EUAs than Phase 2 CERs.

The difference between the two interest rates r_{CER} and r_{EUA} can be seen as a negative convenience yield, a compensation for holding CERs up to the delivery date. The observed CER convenience yield can be calculated from the formulas above, and is represented below in Figure 26. It is estimated at around -3.8% for DEC09 to DEC12 contracts. Once again, the DEC13 contract stands out, especially from 2011 onwards, showing an underlying interest rate closer to that of EUAs. The prices tell us that holding DEC13 CERs is less risky than holding other contracts with earlier delivery dates, which is coherent with the actual rules.

FIGURE 26 – CER CONVENIENCE YIELD OVER 2008-2012



Source: author from Bluenext and ICE ECX

4.3 Explanations for the observed differences

Differing time discounts are not so surprising. Even if offsets and EUAs are fully equivalent at time of use, some doubt is inevitable about their future acceptability given qualitative restrictions, controversies, etc. In the case of the EU ETS, the HFC and N_2O offsets' ban is a clear demonstration of the existence of this risk, even for projects certified by the United Nations. Many other reasons could explain why offsets are not fully equivalent to EUAs: higher transaction costs, reluctance to use due to reputational concerns, continuing controversy of specific types of projects or host countries etc. It is always possible to see future use of an offset as more in question than that of an allowance. For this reason, the holders of CERs are being compensated for bearing more risks. They hold CERs hoping for larger future discount; the discount may in fact be larger or smaller than expected, but the observed prices are always in equilibrium given expectations.

A persistent spot discount suggests that the offset limit is binding. But what limit are we talking about? A *de facto* limit other than the *de jure* limit? Assuming that both are the same implies that all parties are exploiting all cost saving opportunities. If not, then that potential use is withdrawn and the *de facto* limit is lower. Also, those parties are not present in the market on the demand side, implying lower prices, and offset suppliers find they cannot get a fully equivalent price. The next section will focus on this issue by characterizing the past use of offset at the EU ETS and at the installation level.

5. *Ex post* use of offsets in the EU ETS over 2008-2011

A persistent discount should favor the use of offsets against EUAs by making swapping profitable. But despite the persistent discount identified in previous pages, the analysis provided in this section reveals that offsets have not yet been used up to the limits.

5.1 Main characteristics of the use of offsets at the EU ETS level

Between 2008 and 2011, 550 million CERs and ERUs have been surrendered for compliance in the EU ETS, which represents around 7% of all units surrendered over 2008-2011. The main figures relative to the use of offsets on this period are summarized in Table 9. CERs represent 85% of surrendered offsets, with a use of around 80 Mt in 2008 and 2009, rising to 120 Mt in 2010 and 175 Mt in 2011. The rest is made by ERUs, which issuance started to be significant in the end of 2010 and have been used increasingly since (20 Mt in 2010 to 75 Mt in 2011). The quantity of offsets used was significantly below the average annual limit authorized (280Mt) in 2008, 2009 and 2010 with between 4 and 7% of surrendered units. In 2011, the quantity of offset used rose sharply to 13% of units surrendered, close to the authorized annual average of 13.5%.

TABLE 8 – USE OF OFFSETS IN THE EU ETS OVER 2008-2011

	2008	2009	2010	2011
Total offset used (Mt)	83	80	136	251
CER used (Mt)	83	77	116	175
ERU used (Mt)	0.05	3	20	75
Cumulated offsets used (Mt)	83	163	299	550
Share of offsets in surrendered units	4%	4%	7%	13%
Cumulated share of offsets in surrendered units	4%	4%	5%	7%

Source: author from UNEP Risoe and CITL

The offsets which are used once in the EU ETS become unusable and are transferred on States' accounts to be surrendered in the Kyoto Protocol framework. We can thus calculate for every year the total quantity of offsets which has been created up to this date, and subtract from this total the amount already used in the EU ETS (the main source of demand for Kyoto offsets). By doing so, we see that approximately 30% of available offsets in a given year have been purchased by EU ETS operators and used for compliance (24% in 2009 and 32% in 2011).

TABLE 9 – SHARE OF THE EU ETS IN THE USE OF AVAILABLE OFFSETS OVER 2008-2011

	2008	2009	2010	2011
Offsets cumulated supply – offsets used in the EU ETS in the previous years (Mt)	283	331	479	788
Offsets used / (supply - already used)	29%	24%	28%	32%

Source: author from UNEP Risoe and CITL

Savings can be attributed to offsets. The major impact of using CERs is to lower the demand for EUAs, thus lowering the equilibrium price on the EUA market. Those savings are theoretically spread across all installations. The total cost saving resulting from this effect will be estimated by the ZEPHYR-Flex model in Chapter 4.

The second cost saving due to offsets is the benefit from the EUA-CER spread when surrendering CERs instead of EUAs. This saving is more direct, but benefits only to installations using offsets. A back of the envelope calculation consists of multiplying the volume of offsets used in a certain year by the average EUA-CER spread over the period. Table 10 gives a total estimate of 1.5 billion euros saved over the first four years of Phase 2, half of it happening in 2011. This method supposes installations bought CER on the secondary market (savings would probably be higher for installations which got the offsets from financing a project).

TABLE 10 – ESTIMATE OF DIRECT SAVINGS DUE TO OFFSETS

	2008	2009	2010	2011
Average EUA spot price	22.3	13.1	14.3	13.0
Average CER spot price	17.1	11.9	12.5	9.9
Spread	5.3	1.2	1.8	3.1
Savings (M€)	438	100	247	772
Cumulated savings (M€)	438	538	785	1,557

Source: author from CITL and Bluenext

Different behavior of use, evolving with the context. Another important aspect of the use of CERs is the ability, for most operators, to choose the timing and intensity of their offset use. In 2011, the authorized amount of offset had been used at 39%. It nearly doubled between 2009 and 2010, and doubled again in 2011, showing the sharply rising supply of offsets over this period, and the change of anticipations of actors following the qualitative restrictions for Phase 3. The Table 11 summarizes the progress of the use of offsets among installations between 2008 and 2011.

The participation of installations has been growing over time. At the end of 2008, only 14% of installations had used at least one offset. This number rose to 44% in 2011, i.e. almost one installation out of two. In 2011 alone, one installation out of three used at least one offset. The use of offset is also increasing in terms of intensity (the relative use of the authorized limit). In 2008 and 2009, around a third of the annual average limit has been used. Operators using offsets, considered alone, used around 100% of the annual average limit. In 2011, the situation has dramatically changed and the use of offsets is much more intense.

TABLE 11 –GENERAL FIGURES ON THE PROGRESS IN THE USE OF OFFSETS AMONG INSTALLATIONS

	2008	2009	2010	2011
Cumulated use of offsets/total limit of use	6%	12%	21%	39%
Share of installation having used at least one offset since 2008	14%	21%	31%	44%
Frequency of use (share of installations using offsets)	14%	15%	22%	30%
Intensity of use (offsets used / average annual limit of use)	31%	30%	51%	95%
Specific intensity of use (offsets used / average annual limit, only for installation using offsets)	98%	97%	136%	173%
Share of installation having reach 100% of limit	0%	1%	2%	4%
Share of installation having reach 75% of limit	2%	3%	6%	18%
Share of installation having reach 50% of limit	2%	4%	13%	24%
Share of installation having reach 25% of limit	4%	11%	21%	35%
Share of installation which did not use any offsets	87%	80%	70%	58%

Source: author from CITL

To complete this description we also looked at the evolution in the use of limits among installations. In 2008, 87% of installations did not use any offset, and none of them had reach the limit of use. Comparatively in 2011, the share of installations not using offsets decreased to 58%, and almost one installation out of four has used at least 25% of the authorized amount of offsets. Nevertheless, only 4% of installations have already reached the 100% limit over Phase 2.

These figures reveal what seems to be an anomaly, which is that the use of offset, in spite of a strong and intense progress over Phase 2, is far from being completely used and that a high potential of use remains for subsequent years, whereas at the same time the price spread has been persistently incentivizing the use of offsets. The important point we need to investigate is the nature of this *de facto* limit of use, inferior to the *de jure* limit, which would explain this apparent anomaly and allow us to project the future use of offset in the EU ETS. This is the purpose of the next paragraphs.

5.2 Installation level analysis

A complete utilization of the authorized amount of offsets would in theory induce a high frequency and intensity of use among installations, because of the decentralized rules. In this subsection the use of offsets is analyzed at the installation level by category of installation (sector, size, position) in terms of frequency, intensity, and specific intensity.

The "frequency" of offset use is calculated as the number of installations in the category (sector, size or position) that surrendered at least one offset for compliance, divided by the total number of installations in that category. It describes the awareness of a category for project based mechanisms and compliance cost minimization. The "specific intensity" of offset use is calculated as the sum of offset surrendered by category (sector, size or position), divided by the annual average authorized use of offsets of installations which surrendered at least one offset. It describes the average importance of CER use for installations which surrendered offsets. From the specific intensity and the frequency indicators, we can derive the average "intensity" of use for all installations (taking into account installations which surrender no offsets at all). The "intensity" represents the average level of offset use among installations relative to the authorized amount, and is equal to the frequency times the specific intensity of a category. Note that intensity and specific intensity can be above 100% because the limit of use is fixed on the phase whereas our indicators are compared to the average annual limit.

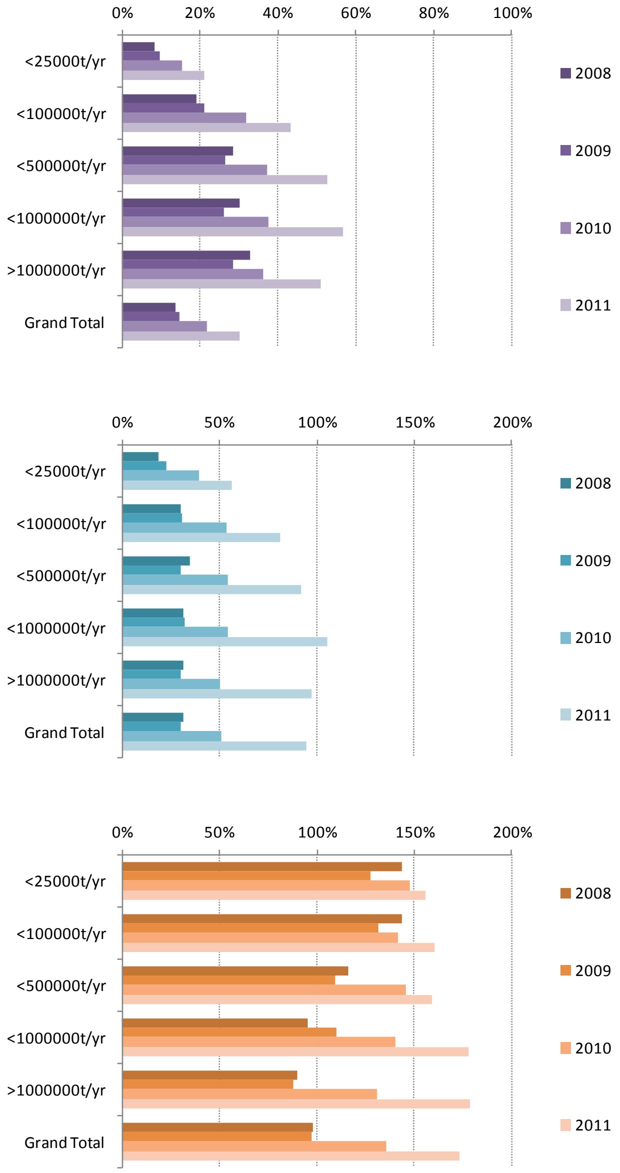
Intensity and frequency of the use of offsets, by size. It appears from Figure 27 below that the size of installations does matter in term of frequency. Smaller installations are clearly using offsets less frequently than the others. One third to half of installations > 500,000t/yr surrendered at least one CER, against one out of ten to one out of five for installations <25,000t/yr. These differences can be explained by market awareness, the relative size of benefits which depend on the total volume of offsets surrendered, and potential transaction costs associated. Smaller installations, because the limit of use depends on allocation and is thus very small in volume, will have an incentive to surrender as many offsets as possible to get a reasonable benefit. This confirms the findings of Jaraite et al. (2010) that small installations can face significant barriers when willing to participate in trading.

In terms of intensity however, the differences are less visible, although smaller installations seem to use offset less intensively than larger ones. But in terms of specific intensity, it seems that the smaller installations are consistent in using a high share of authorized amounts (close to 150% every year) without strong changes in 2010-2011. In the other sectors comparatively, the specific intensity is smaller in 2008 and 2009 in large installations, but rises significantly after 2009.

Intensity and frequency of the use of offsets, by sector. Considering the use of offsets by industries, our analysis shows that offset use is quite frequent in all sectors. Most frequent uses of offsets are in the Electricity production, Cement and Refinery sectors. In 2008 and 2009, the intensity is relatively small and constant across sectors (25% on average) but rises strongly from 2010, especially in the Iron and steel and Cement sectors where it goes beyond 100% of the annual average limit of use. This is confirmed by the specific intensity indicator, close to an average of 100%, and clearly above 100% in all sectors in 2011. Nevertheless, despite the discrepancies among sectors, no clear pattern appears which would indicate a behavior specific to a certain sector. The sharp rise in the use of offset is the result of both an increase in frequency and in intensity of use. The complete graphs are reproduced in Annex E_2.

Intensity and frequency of the use of offsets, by position. Installation's position (emissions > or < to allocation) does not seem to matter much, as show in Annex E_3. This may be surprising given the possible asymmetry between the long and the short installations (short installations have to find allowances or offsets to be compliant, when long installations only have the possibility but not the obligation of selling surplus). Long installations even surrendered more offsets in term of intensity than the short. Apparently installations did not use offset as a way to be compliant but as a way of minimizing the total cost of compliance, which is what is expected in theory. In terms of frequency of offset use, position does not make a difference either. This clearly shows that installations swapped out offsets in order to bank or sell EUA surpluses, benefiting from the EUA-CER spread, whatever their actual need of compliance units was.

FIGURE 27 – FREQUENCY, INTENSITY AND SPECIFIC INTENSITY OF OFFSET USE, BY SIZE CATEGORY



Source: author from CITL

This installation level analysis reveals that the use of offset is relatively well understood and used by operators across sectors, whatever their compliance needs. Among the factors tested, the size of installations is by far the strongest driver for the use of offsets in the EU ETS, even though in terms of intensity uses are more or less equally spread whatever the factor considered (sector, size or position). The change of behavior between 2008-2009 and 2010-2011 is clear, leading to think that the large availability of offsets and the qualitative restrictions had a significant impact on installation behavior and compliance costs. Nevertheless, none of the analysis would suggest a probable complete utilization of limits, at least in the short term. The next paragraph introduces a classification of installations by behavior of offset use to study this question.

5.3 Use of offset limits: the exercise of time flexibility by operators

Installations can be classified into groups depending on how frequently they have used offset over time. This will allow us to characterize the use of time flexibility by operators. There are four years of data available, thus 16 different possible patterns of use. The following graphs are all based on the same structure. Each line represents a unique surrender pattern, at the top we find installations using at least one offset in each of the years (called the constant users) and at the bottom installations which never used offsets (called the absent users). In between, we find the rest of possible combinations (installations using offsets only in one of the four years, in all years except one etc). The green and red symbols in the left columns indicate in which years offsets have been used by each category. This structure can be filled with different information. The following graphs (Figure 28, Figure 29 and Figure 30) show respectively the number of installations by category, the volume of offsets surrendered by each category, and the specific intensity of offset use for each category.

The first reveals that the most frequent behavior among installations, apart from those not using offsets at all, are those which used offsets only in 2011. Those 1,600 installations represent 12% of installations. The next category is that of operators which did not use offsets in 2008 and 2009 but used offsets since (10% of all installations). The installation consistently using offsets is the next category, which represent 5% of installations. This clearly shows that a changed in behavior regarding offsets occurred from 2010 onward, which favored their use at least in terms of frequency.

FIGURE 28 – NUMBER OF INSTALLATION IN EACH CATEGORY OF BEHAVIOR

	2008	2009	2010	2011	Number of installations in the category	Share in total number of installations
Constant users	✓	✓	✓	✓	607	5%
All except 2011	✓	✓	✓	✗	83	1%
All except 2010	✓	✓	✗	✓	72	1%
	✓	✓	✗	✗	192	1%
All except 2009	✓	✗	✓	✓	139	1%
	✓	✗	✓	✗	72	1%
	✓	✗	✗	✓	171	1%
Only in 2008	✓	✗	✗	✗	429	3%
All except 2008	✗	✓	✓	✓	392	3%
	✗	✓	✓	✗	162	1%
	✗	✓	✗	✓	114	1%
Only in 2009	✗	✓	✗	✗	272	2%
	✗	✗	✓	✓	830	6%
Only in 2010	✗	✗	✓	✗	542	4%
Only in 2011	✗	✗	✗	✓	1593	12%
Absent users	✗	✗	✗	✗	7325	56%

Source: author from CITL

In terms of quantity, the second graph below shows that the category of installations having used offsets only in 2011 is the largest contributor to the global offsets used, with 22% of the total offsets surrendered over 2008-2011. Once again this highlights the shift of behavior happening in 2010 and 2011. The constant users, although being a small number of installations, arrive in second position, with 19% of the cumulated offset use over 2008-2011. Categories which include a late or consistent use of offset are logically big contributors to the general effect.

FIGURE 29 – USE OF OFFSETS OVER TIME BY CATEGORY OF BEHAVIOR

	2008	2009	2010	2011	2008	2009	2010	2011	Share in total cumulated use of offsets
Constant users	✓	✓	✓	✓	25 784 062	22 417 435	28 319 039	30 204 784	19%
All except 2011	✓	✓	✓	✗	4 353 080	4 769 653	5 130 386		3%
All except 2010	✓	✓	✗	✓	3 042 651	2 477 943		3 307 198	2%
	✓	✓	✗	✗	6 021 191	4 880 226			2%
All except 2009	✓	✗	✓	✓	8 411 518		13 735 358	13 597 253	6%
	✓	✗	✓	✗	1 884 547		3 444 341		1%
	✓	✗	✗	✓	8 777 238			18 769 762	5%
Only in 2008	✓	✗	✗	✗	24 857 958				5%
All except 2008	✗	✓	✓	✓		19 989 245	19 729 136	17 793 939	10%
	✗	✓	✓	✗		7 384 753	4 137 234		2%
	✗	✓	✗	✓		4 984 105		5 741 644	2%
Only in 2009	✗	✓	✗	✗		13 415 252			2%
	✗	✗	✓	✓			37 966 071	41 129 936	14%
Only in 2010	✗	✗	✓	✗			23 362 440		4%
Only in 2011	✗	✗	✗	✓				120 220 487	22%
Absent users	✗	✗	✗	✗					0%

Note: Figures in tonnes. Source: author from CITL

Those two graphs can be completed by one on specific intensity (the use of the annual average limit of use, which can go up to 500% if the entire limit is used at once). It underlines the fact that operators are very aware of the rules and the associated time flexibility, and very reactive to changes made to these rules. The constant users show a pattern of relatively constant intensity of use around 100%. By contrast, it is clear that the less frequent is the use of offset, the more intense it will be. For example installations which used offsets in 2008 but not in 2009, increased their use of offsets to 150% or higher after 2009 instead of around 90% in 2008. At the bottom of the graphs, installations using offsets only in 2011 have used nearly three times the average annual limit authorized, as did the installations using offsets only in 2010.

FIGURE 30 – USE OF OFFSET LIMIT BY CATEGORY OF BEHAVIOR

	2008	2009	2010	2011	2008	2009	2010	2011	Average use of annual limit
Constant users	✓	✓	✓	✓	83%	73%	92%	98%	86%
All except 2011	✓	✓	✓	✗	108%	118%	127%		118%
All except 2010	✓	✓	✗	✓	118%	96%		128%	114%
	✓	✓	✗	✗	86%	70%			78%
All except 2009	✓	✗	✓	✓	91%		148%	147%	129%
	✓	✗	✓	✗	83%		151%		117%
	✓	✗	✗	✓	85%			182%	133%
Only in 2008	✓	✗	✗	✗	133%				133%
All except 2008	✗	✓	✓	✓		116%	115%	104%	112%
	✗	✓	✓	✗		127%	71%		99%
	✗	✓	✗	✓		95%		109%	102%
Only in 2009	✗	✓	✗	✗		135%			135%
	✗	✗	✓	✓			171%	186%	179%
Only in 2010	✗	✗	✓	✗			281%		281%
Only in 2011	✗	✗	✗	✓				256%	256%
Absent users	✗	✗	✗	✗					0%

Source: author from CITL

This combination of facts shows that the increase in the use of offsets in the last years of Phase 2 is much more due to a rise in frequency than a rise in the intensity of use. Installations which were already using offsets on a regular basis did not significantly raised their intensity of use, because they were already on track to use to authorized amount over Phase 2. The sharp increase in the use of offset is by contrast due to the fact that much more installations shifted from never using offsets to using them, and joined the others by surrendering three times more offsets than the average annual limit in one or two years.

Nevertheless, there remains at least one installation out of two that did not use any offset over the 2008-2011 period. Those installations represent a potential use of offset of around 320 Mt, which is around 40% of the unused share of the EU ETS limit at the end of 2011. Figure 31 below summarizes the unused limits at the end of 2011 and how they are distributed among categories of users. It shows that most of the unused limit is in the hands of operators that never used offsets (40% of the unused potential). The rest of the unused limit is in the hands of operators having used offsets only in one year. Operators using offsets only in 2011 have 15% of the remaining potential. The constant users have 6% of the unused limits.

FIGURE 31 – OFFSET LIMITS REMAINING UNUSED AT THE END OF 2011

	2008	2009	2010	2011	Unused limit end 2011 (Mt)	Share in total (%)
Constant users	✓	✓	✓	✓	48	6%
All except 2011	✓	✓	✓	✗	6	1%
All except 2010	✓	✓	✗	✓	4	1%
	✓	✓	✗	✗	24	3%
All except 2009	✓	✗	✓	✓	11	1%
	✓	✗	✓	✗	6	1%
	✓	✗	✗	✓	24	3%
Only in 2008	✓	✗	✗	✗	69	9%
All except 2008	✗	✓	✓	✓	28	4%
	✗	✓	✓	✗	18	2%
	✗	✓	✗	✓	16	2%
Only in 2009	✗	✓	✗	✗	36	5%
	✗	✗	✓	✓	32	4%
Only in 2010	✗	✗	✓	✗	18	2%
Only in 2011	✗	✗	✗	✓	115	15%
Absent users	✗	✗	✗	✗	322	41%

Source: author from CITL

6. Scenario for the use of offsets in the ZEPHYR-Flex model

Because the limits to use offsets have been changed to cover the 2008-2020 instead of the originally planned 2008-2012 period, the complete calibration of the use of offsets in ZEPHYR-Flex requires making assumption until 2020. As seen previously, the supply of offset is most probably going to be sufficient to meet the demand from EU ETS installations over 2008-2020, explaining the discount of CERs relative to EUAs. Moreover, the theoretical limit accepted by the Commission is going to be reduced by a certain amount due to the existence of a *de facto* limit, inferior to the *de jure* limit, because some installations will not be able or want to capture this opportunity.

The previous section showed that a significant share of offset limits is still unused, despite higher and more frequent use since the decision on Phase 3 qualitative restrictions. In this section, we are going to use the previous results to build a scenario of offset use in the EU ETS in 2012, and expend it on Phase 3.

Use of offsets in 2012. We base our projection on three assumptions, each one used for a family of behavior categories identified in the previous section. The projection method is described below and a more detailed table is made available in Annex E4.

- **Constant users**. The constant users are the easy ones and we posit that they will continue to use an average 86% of annual limit in 2012, for an amount of 31 Mt. This is equivalent to say that they will conserve around 15% of Phase 2 limits for a later use in Phase 3.

- **Intermediate users**. We cannot really know what share of installation in each category will continue, discontinue or resume using offsets in a given year. We are thus going to posit that each category in 2011 is split in two, with half of the potential not using offsets, and the other half using offsets in 2012, with the average intensity of its previous category. In total, intermediate categories add 150 Mt to the probable use of offsets in 2012.

- **Absent users**. Since 2008, the share of installations shifting from "never used offsets" to "using offsets" in a given year has been on average 12% before 2010, and 16% after. We are going to posit that an average of 15% of installations will shift from never using offset to using offsets in 2012. We then make the assumption that their intensity of use will be proportional to that of installations in the same situations as them in 2011, which was 260% after four years not using offsets. The intensity used in thus 325%. In total, new users in 2012 surrender in our scenario around 155 Mt.

As a result, the use of offsets in 2012 is estimated at 335 Mt. This is very compatible with the offer of HFC and N_2O offsets, which historically represented 75% of offsets surrendered in the EU ETS – see Trotignon (2012). Applied to our amount of 335 Mt, this is equivalent to a use of 250 Mt of HFC and N2O offsets in 2012, which is more or less equal to the 230 million of those offsets already issued but still not used before 2012. This 2012 figure would make a total cumulated use of offset over Phase 2 of about 900 Mt.

Use of offsets post 2012. In Phase 3, installations are left with an unused Phase 2 limit of about 550 Mt, to which must be added the probable additional 200 Mt (for more details refer to Article 11a of the EU ETS Directive). From this potential total Phase 3 use of 750 Mt, we assume that 20% (or 150 Mt) will never be used, which is equivalent to 10% of the total 2008-2012 cap, decomposed as follows:

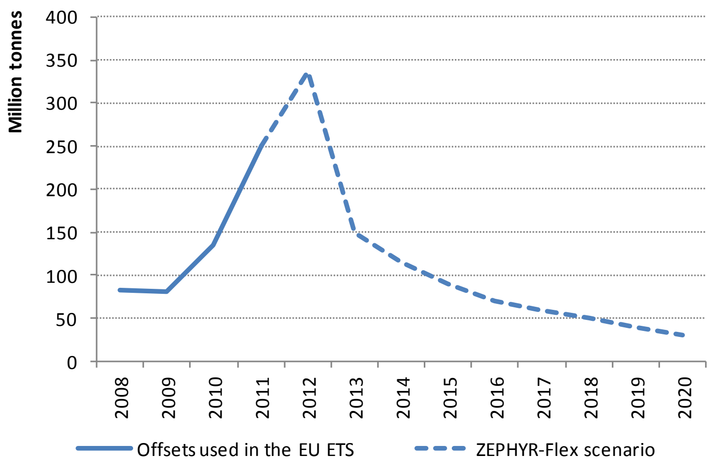
- Consistent users are supposed to use entirely the limits

- The use of offsets from the rest of installations is assumed to culminate at 85% of their limits of in 2020, leaving 15% or 90 Mt unused.

- Installations which never used offsets represent in our estimation 10% of the total number of installations in 2020, with a total unused offset limit of 60 Mt. This may happen for various reasons (for example too small amounts, transaction costs, or reputational concerns).

Those numbers are coherent with the observed trends presented previously in Table 11. However the precise way those 600 Mt will be spread over 2013-2020 is difficult to determine. We assumed a progressive diminution of use, from 150 Mt to 30 Mt in 2020. The final scenario for the use of offsets in the EU ETS from 2012 to 2020 is shown in Figure 32 below.

FIGURE 32 – SCENARIO FOR THE USE OF OFFSETS IN THE EU ETS OVER 2012-2020



Source: author

7. Conclusion

The first thing to keep in mind is that the supply of offsets appears to be large because no other significant demand for offsets has been appearing since 2005, contrary to what was initially expected by many actors in the 2005-2008 years. It is unfortunate because offsets were expected to play a strong role in linking indirectly various trading initiatives in Annex I countries, while incentivizing low carbon technologies in the rest of the world.

In 2012, there is a complete disconnection between what offsets were supposed to be and what they have become. The price of offsets can become very low because there is no substitute demand apart from the EU ETS. Moreover the participants' behavior of offset use does not show a perfect substitutability as initially expected, and offsets are discounted differently than EUAs over time, reflecting the perception of some risks associated with holding offsets which validity and value may be put into question in the future.

Given the level of the offset supply and the consequent supply for the coming years, we go towards a situation with a persistent spot discount accompanied by a maximum limit of use which will never be reached. This perception is consistent with observations of the past, which suggest the existence of a de facto limit to the use of offsets that is inferior to the amount authorized by the rules. It is also confirmed by empirical studies made by other researchers, see for example the answers from German EU ETS operators to the ZEW CO2 Barometer questionnaires (Loeschel et al.). Those factors are taken into account and allow us to build a consistent scenario for the use of offset post 2012, which will be used in the following simulations from the ZEPHYR-Flex model.

Chapter 4 – The calibration of ZEPHYR-Flex and its results on the first two trading periods

"When allowed in cap-and-trade programs, banking can be expected to produce more abatement and higher allowance prices in the early phases of the program in what can be seen as voluntary "early action." This implication will be particularly important in designing CO_2 cap-and trade programs. Since the level of the counterfactual is inherently uncertain and the initial CO_2 caps are likely to be relatively undemanding, the expectation (or the reality) of later, more stringent caps will tend to produce a positive price and early abatement even if the initial cap is non-binding"

A. D. Ellerman and J-P. Montero, *The Efficiency and Robustness of Allowance Banking in the U.S. Acid Rain Program*, The Energy Journal (2007)

In Chapter 2, we have built the core of our simulation model with a technical-economic block representing baseline emissions and reduction costs, along with a trading mechanism and a market equilibrium determination process. This prototype showed that trading, without other flexibilities, was not sufficient to replicate EU ETS observations. In Chapter 3 we clarified the role of offsets, which represent additional allowances compared to the internal cap, and determined a scenario for the use of offsets up to 2020.

In this Chapter, we are going to introduce into ZEPHYR-Flex the two remaining flexibility mechanisms which were not included in the prototype version: space flexibility (the use of offsets) and time flexibility (the provisions for banking and borrowing). The introduction of offsets uses the results of Chapter 3. The introduction of time flexibility mechanisms implies to represent the anticipations of installations which play an essential role in our calibration exercise.

In the first section of this chapter, we describe the framework used to analyze the impacts of time flexibility. In the second section, we observe the *ex post* evidence of banking and borrowing over 2005-2011 from the CITL data. In a third section, we explain how the anticipations of individual participants are represented in the ZEPHYR-Flex model. In the forth section we calibrate the model to replicate as well as possible observed prices and quantities. Finally in the third section, we calculate with this new version of ZEPHYR-Flex the main results of the EU ETS over Phase 1 and Phase 2.

1. Banking and borrowing in a cap-and-trade: an analytical framework

Emissions trading programs have to deal with participants' concern over price volatility. We have just seen that without time or space flexibility, there remained high risk of seeing the price fall to zero or jump back rapidly at high levels because of the relationship between the inelastic cap of allowances and potential high variations of the demand in the short term.

Time flexibility, which is accounted for by "banking" and "borrowing" provisions, can smooth those price changes over time. It has the property to make longer-term anticipations participate to the price formation mechanism, and to influence transfers among firms participating to the market.

From the theoretical point of view, economist provide a comprehensive treatment of emission trading, banking, and borrowing – see for example Rubin (1996) which uses an inter-temporal continuous-time model, under assumptions of perfect trading and full certainty. Using optimal-control theory, he shows that the decentralized behavior of firms leads to the least-cost solution attainable under joint-cost minimization from covered sources. The solutions for an optimal time paths of emissions and permit prices can be derived from those kind of models.

In this chapter, we are going to use a different method. We will model the banking and borrowing behavior with a more empirical method, i.e. without calculating optimum inter-temporal paths. Our goal is to simulate the individual anticipations and decisions of covered installations.

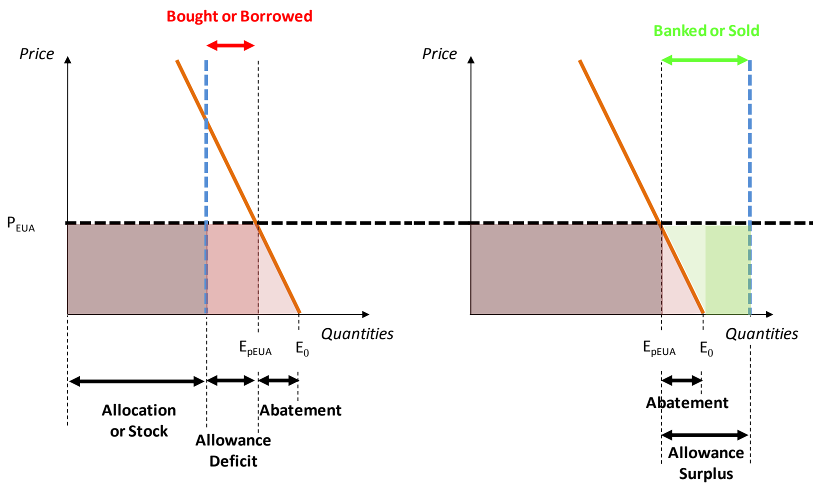
Banking of permits occurs when regulated entities are allowed to hold unused permits for future compliance. In the EU ETS, year-to-year banking is allowed over 2005-2020 except in 2007 between Phase I and Phase II (the two phases are separated and the associated units are not fungible).

Borrowing is symmetrical to banking. In this case, permits from future compliance periods can be used in advance. In the EU ETS, entities receive free allocation in February each year, while permits for the past year must be surrendered before May. Hence, implicit borrowing is possible but limited by the amount of next year's free allocation, and impossible between phases (forbidden in 2007, 2012, and 2020).

In the previous chapter, we considered that surpluses had to be sold and that deficits had to be met by purchasing allowances on the market. There were no other alternatives, because without time-flexibility allowances are only valid during the current year.

With time-flexibility, there are other alternatives to trading: banking and borrowing. Figure 33 presents the usual graphs with the option of banking and borrowing. The surpluses, defined as the difference between the allowance stock and the verified emissions (if positive), can now be carried over to the next year. Reciprocally, deficits can be borrowed from future year.

FIGURE 33 – BANKING AND BORROWING AS ALTERNATIVES TO TRADING



Source: author

It is the aggregation of individual operators' choices which makes the actual supply and demand on the market, choices that now depend on their various anticipations. The share of deficits/surpluses, which is actually going to be bought/sold on the market is decided by each operator on the basis of various possible "internal" (own-compliance related) and "external" (price-change related) anticipations. We will try to detail and then to model these decisions in the following section.

Allowances are emission permits. The fact that they can be accumulated or consumed in advance is going to have an impact on the price trajectory. Banking is suppose to lower supply because of operators hoarding allowances for future use. Whether they are right or wrong to do so, the hoarded allowances will eventually come back on the market, then as additional supply. Inversely, operators borrowing allowances from future years will tend to lower demand in the short term, because operators bypass the market. But the borrowed allowances have to be paid back eventually (at least in 2007, 2012, and 2020 in the case of the EU ETS), which raises demand in the longer term and bares a risk of future non compliance.

Of course, the influences of banking and borrowing on the price trajectory are going to have an impact on the emission trajectory. Banking and borrowing effectively allow operators to shift emissions through time. For example, banking can be an incentive for early reduction if prices are expected to become higher in the future. This effect has been clearly identified in the case of the US SO2 system where banking has been recognized as playing a determinant role in early abatement and price development. In particular, Ellerman and Montero (2007) evaluated the efficiency of observed temporal pattern of abatement and banking based on the aggregate data from the first eight years of the Acid Rain Program. They find that, contrary to the general opinion that banking in this program has been excessive, it has been reasonably efficient. Their evaluation shows that firms used banking provisions in a rational and predictable way, and that the banking provision accordingly produced more abatement and higher allowance prices in the early phases of the program.

2. Ex post observation throughout 2005-2012

Observing banking and borrowing through the CITL data is not easy. At the installation level, we can only observe verified emissions and free allocations, not the dynamic EUA stock with purchases, sales, banking and borrowing accounted for. We can observe the difference between allocation and emissions at the installation level, but it will not be the "true" amount, which should be calculated as the difference between the EUA stock and verified emissions. We don't know if surpluses are banked or sold, we don't know either if deficits are borrowed or bought on the market, which would impact next year EUA stock.

The CITL transaction data, which is available with a five year delay, should provide additional information on movement of allowances between accounts, in particular who holds the allowances that are not surrendered for a given year, or on installations using forward year allocation for present compliance. The data for Phase 1 is not entirely available yet but a thorough analysis of this data is under way, see Martino and Trotignon (2012).

2.1 Estimate of net banking over the two periods

At the global EU ETS level however, the installation-level deficits and surpluses net out as a global EU ETS position, which indicates a net banking or a net borrowing, depending on the sign. We can calculate the net surplus or deficit of the initial year (2005 and 2008 because of the non-banking constraint in 2007). Because of the rules we know that unused allowances are "banked" in some ways, even in an involuntary way; or respectively that deficits are fulfilled by drawing from next year allocation, because the penalty for non-compliance is discouraging and is not discharging the operator from surrendering as many allowances than required. We can then add (or remove) from next year calculation the corresponding banking (respectively borrowing).

Table 12 presents the net banking for each year based on the CITL data. Banking or borrowing is identified as the EU ETS dynamic position, defined for each year as the annual cap minus emissions, plus or less the net position of previous year if banking and borrowing are allowed (not in 2008).

TABLE 12 –ESTIMATE OF AGGREGATE BANKING AT THE EU ETS LEVEL

(Mt)	2005	2006	2007	2008	2009	2010	2011	2012e
Free allocation	2,088	2,063	2,139	1,950	1,966	1,990	2,008	2,002
Reserves	*28*	*57*	*85*	*60*	*60*	*60*	*60*	*60*
Auctions	*0*	*4*	*4*	*62*	*83*	*83*	*83*	*83*
Surrendered CERs	0	0	0	83	77	116	175	*224*
Surrendered ERUs	0	0	0	0	3	20	75	*112*
VerifiedEmissions	2,008	2,024	2,153	2,107	1,867	1,926	1,892	*1,904*
Net banking	108	209	284	49	372	715	1,225	*1,802*

Source: author's calculations. Note: italicized numbers are estimates.

The net banking is estimated at around 110 Mt in 2005, growing to 280 Mt at the end of Phase 1. Because those allowances cannot be carried over to the next phase, this represents the amount of unused EUAs expiring worthless at the end of the period. It represents approximately 4% of the total EUAs distributed. The net banking in 2008 is relatively small at 49 Mt, reflecting the tightening of the cap and the still high level of emissions. From 2009 on, the decrease of emissions compared to the unchanged cap induces a net banking of 370 Mt the first year growing to 1.8 Gt at the end of 2012 (the last year is based on estimated 2012 emissions).

The role of offsets (as supply that is additional to original EUA allocation) is very important in this global cumulative banking. The offset provision is responsible for half of the detected banking in Phase 2. In the same scenario but without accounting for offsets, the EU ETS is in a position of net borrowing in 2008. It means that the risk of price spikes was real, and that high prices in 2008 could have been even higher, if there had not been any borrowing or offsets provisions.

The net banking observed here results in fact from individual behavior of gross banking and borrowing, for which we don't have many direct information –although this could be improved by an analysis of Phase 2 transactions data which will be gradually available over the course of 2013. Theses gross banking and gross borrowing values can nevertheless be approximated as presented in the next subsection.

2.2 A disaggregated estimate of banking/borrowing using the CITL surrender data

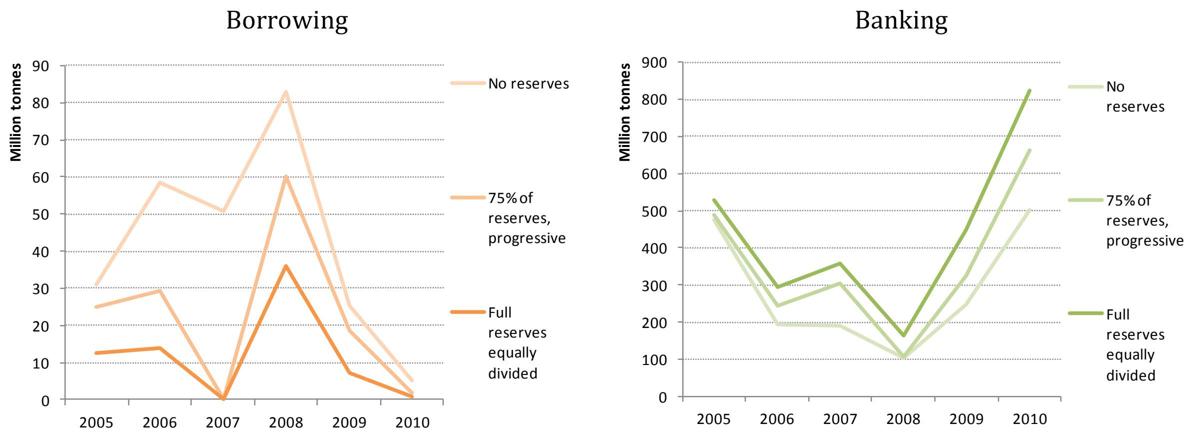
There is another way of estimating banking and borrowing over time. This method is based on the CITL surrender data, which is the part of the central registry giving details on surrendered units (EUA, CER and ERU) and particularly the country of origin (issuance) for all surrendered units. This method has already been used to estimate banking and borrowing in Phase 1 of the EU ETS, see Trotignon and Ellerman (2008) and Ellerman and Trotignon (2009).

We already know (from allocation, reserves and auction data), the amounts that enter the market annualy in each of the Member States. Those allowances are marked with a sort of tag allowing to track their Member State of original issuance. Thanks to the surrender data, we also have access to the number of those Member States' allowances which have been surrendered by installations in each of the years (wherever they might be). The difference between the two numbers has to indicate the quantity of allowances, originally issued, which have not been surrendered yet (thus which have to be banked or hoarded). In the case where the allowances from a given registry that have been surrendered exceed the amount allocated, then it means that the difference had to come from borrowing. This analysis is thus done at the Member State level, not at the EU ETS level like previously. The results are then aggregated separately, which allows estimating a gross banking and a gross borrowing instead of just the net results. Readers can refer to Trotignon and Ellerman (2008) for details on the use of surrendered units data and examples of analysis at the Member State level (borrowing in the UK for example) or at the installation level. Because of their very difficult extraction process, we only have the data corresponding to the 2005-2010 years at the time of writing.

Figure 34 shows the results of those calculations under different sets of assumptions for the use of reserves, aggregated at the EU ETS level. First we see that borrowing, when not netted out with banking, has effectively been used, especially in 2005, 2006 and 2008, in quantities around 20 Mt in Phase 1 and 60 Mt in 2008 (between 1.5 and 3% of surrendered units were borrowed from future years). After the economic crises, borrowing seems to be much less used (around 5Mt in 2010).

Our analysis shows a significantly high value for banking in 2005, around 500 Mt. It is in fact due to late surrender of installations in certain Member States in countries such as France, Italy, or Czech Republic, because of technical and administrative problems in the first year. The "debt" contracted by installations in those Member States has been recovered entirely in 2006, and the amount of banking identified are around 250 Mt, to finish in 2007 at 275 Mt. In 2008 the gross banking detected amounts to 150 Mt, and grows following the economic crisis to around 650 Mt in 2010. The different estimates given by this method seem also to be coherent with the estimate of banking from the previous subsection (370 Mt in 2009, 715 Mt in 2010).

FIGURE 34 – BANKING AND BORROWING FROM THE SURRENDER DATA (2005-2010)



Note: Reserves are allowances from the cap which are initially set aside and progressively distributed over time to new entrants in the system. The most probable situation is that all the reserves will enter the market eventually (Full reserve scenario).

Source: author

Those observations show that banking and borrowing have been used and played a role in the market development over the first two phases. Borrowing seems to have been rather small, but banking is found to be massive. It is quite logical to have a resulting net banking in a cap and trade system, because the inverse situation is uncomfortable or unsustainable because of the risk of non compliance, which rises quickly. It is not surprising to observe installations holding allowances, especially if their value is expected to increase, and all the more in a context where allowances are almost entirely granted free of charge and banking is somewhat passive. But the change of allocation rules with the shift to auctions in Phase 3 is giving much importance to the future of banked allowances, which depends on operator anticipations regarding the available information.

The accumulation of surpluses and its use over time is determining the emission and price path. It is thus crucial to be able to capture this effect in our simulation model. Because the aggregated effect results from the individual decisions of covered participants, we chose to simulate the individual behavior of every installation in the ZEPHYR-Flex model. The simulation method is the purpose of next section.

3. Modeling the link between anticipations, banking and borrowing

There are two categories of anticipations to consider, which are intertwined in many ways. The first category concerns how operators anticipate their own compliance need in the future years, in terms of volumes (how much allowances will they need in which situation). Secondly, actors on the market have anticipations of the total EU ETS situation (the aggregate of all operators' compliance strategy plus the behavior of non-compliance traders), which is linked to the anticipation of a price trajectory. As a matter of fact, prices reflect an implicit anticipation of the market position as it is anticipated by actors. In its simplest form, this corresponds to anticipating bullish or bearish prices over a certain period, that is whether the emissions targets are binding and costly to meet or not.

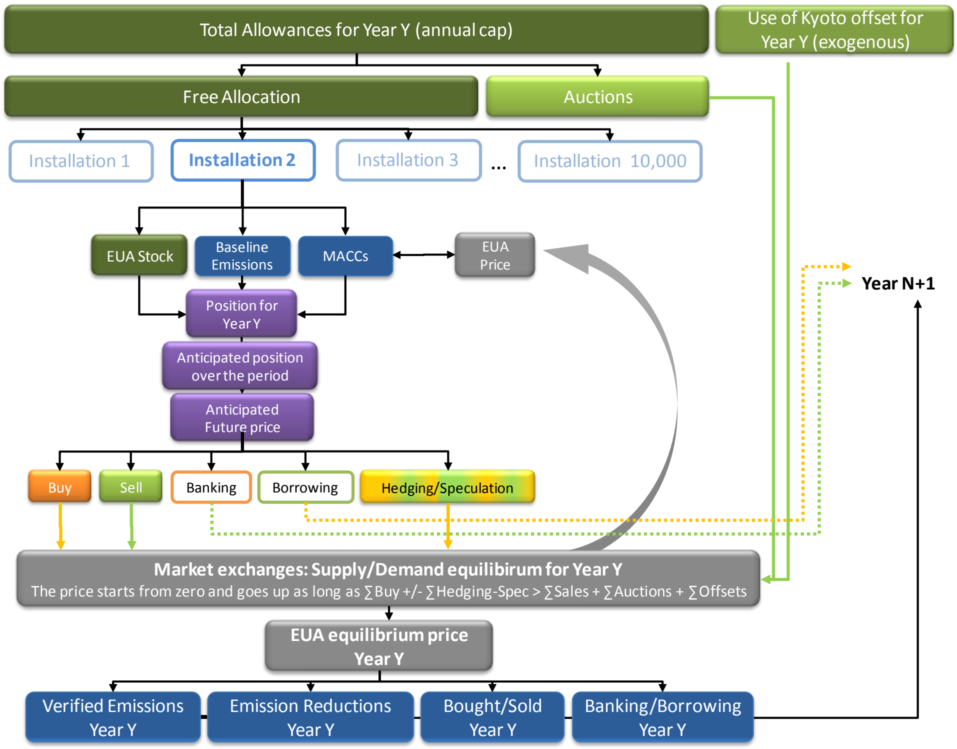
In our model, the anticipation periods are defined as follows: in the three years of Phase 1, anticipations are over Phase 1 only (because the two phases are separated); from 2008 to 2012, anticipations are based on the following five years (rolling); from 2013, anticipations are based on the following seven years (rolling). For example in 2008, actors will anticipate up to 2013; in 2012 up to 2017; in 2013 up to 2020; and in 2020 up to 2027.

Once installations have anticipations of their own situation and the general EU ETS context in the future years, they can choose what seems to them as the optimal behavior on the market, given the information available at that time. The process will be repeated every time new information becomes available (in our model, every year).

3.1 Introduction of banking and borrowing in the ZEPHYR-Flex model

Compared to the previous version of ZEPHYR-Flex presented in Chapter 2, we are introducing several new features: two levels of anticipations (position, price); three new market behavior enabled by anticipations (banking, borrowing, hedging/speculation); and the introduction of offsets as exogenous supply to the market. The new state of the model is represented on Figure 35.

Figure 35 – A new version of ZEPHYR-Flex with banking, borrowing, hedging and speculation



Source: author

There are now three criteria for the determination of each installation's behavior on the market (in purple on the Figure above): the annual position, the anticipated position, and an anticipated price trajectory. Two behaviors are going to be described below: compliance banking/borrowing (management of current stocks and free allocations), and banking/borrowing related to hedging or speculation (shift to auctions and price anticipations).

3.2 Banking and borrowing for pure compliance

We consider first that installations have no price anticipation and only pure "quantity" or compliance anticipations. In that case, to quantify their future "internal" need/surplus of allowances, installations must forecast on the one hand the future amount of free allocation they could receive, and on the other hand their projected emissions, both over the same anticipation period. This anticipation quantifies the future need/surplus of allowances regarding internal compliance.

The free allocation stream can be anticipated by actors. It depends on the total annual caps (determined by the different reduction targets) and the corresponding annual share of auctions. The part which is not auctioned is distributed among installations based on the observed share of each installation in the allocations of its sector in 2005. The figures for 2013 on are estimated based on current preliminary amounts' analysis; see for example Lecourt (2012).

Concerning emissions, we posit that operators do not have perfect anticipations and thus that they have their own desired emission trajectory in mind. We model this by assuming that, every year, operators quantify their future emissions by applying a certain annual average growth rate to their current emission level. This growth percentage is divided in two, one for the electricity sector and the other for the rest of sectors, and both are revised every year.

Installations' anticipations of future allowance needs/surpluses, later called Qb, thus depend, directly or indirectly, on the following parameters: the annual caps, the annual share of auctions, and the two anticipated average growth rates of emissions. With those hypotheses, we can represent the behavior of installations depending on the position they expect to be in on the market.

The annual position is thus defined, for each installation, as the difference between its EUA stock at the beginning of the considered year minus its verified emissions at the current market price p. In the following explanations, it will be noted Qa. It is either a surplus (Qa>0) or a deficit (Qa<0). Table 13 below summarizes the choices faced by an installation in the two situations. If the installation yields a surplus, this quantity will be either banked or sold, or partially both. Hence we write in the table Qa times x, the share of allowances sold if holding a surplus in the Sold column, and (1-x) times Qa in the Banking column. Reciprocally, an installation in deficit will either buy or borrow allowances. If we note y the share of allowances purchased on the market, the quantity bought is y|Qa|, and the complementary is (1-y) times |Qa|.

TABLE 13 – BEHAVIOR TABLE IN FUNCTION OF ANNUAL POSITION (QA) ONLY

	Banking (compliance)	Borrowing (compliance)	Selling (compliance)	Buying (compliance)
Qa>0	(1-x)|Qa|	0	x|Qa|	0
Qa<0	0	(1-y)*|Qa|	0	y|Qa|

Source: author

The second criterion is the expected position over the anticipation period Qb, calculated as explained in the first paragraphs of this subsection. It can either be positive or negative. Each installation is going to estimate Qb and take it into account in addition to Qa. Our table is thus going to become a sort of decision tree, the first two columns on the left representing the different possible combination of signs for Qa and Qb.

For the moment we consider that installations do not have price anticipations and think only in terms of quantities, for compliance purposes. In that case, the previous table can be transformed into Table 14. Installations for which Qa>0 and Qb>0 do not expect to be in need of allowances, and will sell the entire surplus they own, Qa. Installation in the other extreme will buy their entire deficit |Qa| on the market.

In contrast, installations with different signs for current and expected positions will have interest in banking and borrowing, for instance to avoid having to buy later the allowances they have now. We consider that those installations will bank (resp. borrow) as much allowances as needed for the future compliance (resp. current compliance) if the rules allow for it. For example, an installation currently long (Qa>0) but expecting to become short (Qb<0), will bank the amount it expects to be needing (Qb). If this quantity is superior to its current surplus, it will only bank Qa. If |Qb| is smaller than the current surplus, it will only bank the amount needed |Qb|. The "banking" cell of the table is thus Min(|Qa|,|Qb|) and the "selling" cell is the complementary in |Qa|.

TABLE 14 – BEHAVIOR TABLE: ANNUAL POSITION AND EXPECTED POSITION, WITHOUT PRICE ANTICIPATION

		Banking (compliance)	Borrowing (compliance)	Selling (compliance)	Buying (compliance)
Qa>0	Qb>0	0	0	|Qa|	0
	Qb<0	Min(|Qa|,|Qb|)	0	|Qa|-Min(|Qa|,|Qb|)	0
Qa<0	Qb>0	0	Min(|Qa|,|Qb|)	0	|Qa|-Min(|Qa|,|Qb|)
	Qb<0	0	0	0	|Qa|

Note: Qa: annual position, Qb: expected position over the anticipation period

Source: author

3.3 The introduction of price expectations in compliance banking and borrowing

The second step consists in introducing participants' price expectations. Because we don't really know what could be the general expectations of each and every participant over time, we choose to simulate them as random functions, which output can either be "+" or "-", meaning "believe in bullish prices" or "believe in bearish prices". To be able to build different scenarios, we use an annual parameter to control the frequency of either "+" or "-" among installations. This method allows introducing another level of diversity in behavior among installations. Without this random variable, nothing would differentiate a long installation willing to sell from a long installation not willing to do so (for instance). Here we can change the parameter to change the willingness to sell/bank or borrow/buy of certain operators but not all, without choosing which. Participants can also change their mind, because the random variable is different for every year and so is the control parameter.

The expectation of higher or lower price to come is going to have two impacts on the possible behaviors. First it is going to change the compliance banking and borrowing behavior. Secondly it is going to introduce new possibilities of behavior, independently of the compliance positions, which are hedging and speculation.

We focus first on the first effect of price anticipation on compliance banking and borrowing. Table 15 shows the effect of price anticipation in case those are fully trusted by operators. In this situation, the price anticipation "bypasses" the expected position criteria (Qb). As a matter of fact, if the expected price movements are fully trusted, the best decision is always to sell when prices will be lower in the future or to buy if prices are going to be higher in the future.

TABLE 15 – BEHAVIOR TABLE: ANNUAL POSITION, EXPECTED POSITION AND FULL PRICE ANTICIPATION

<table>
<tr><th></th><th></th><th></th><th>Banking (compliance)</th><th>Borrowing (compliance)</th><th>Selling (compliance)</th><th>Buying (compliance)</th></tr>
<tr><td rowspan="4">Qa>0</td><td rowspan="2">Qb>0</td><td>-</td><td>0</td><td>0</td><td>|Qa|</td><td>0</td></tr>
<tr><td>+</td><td>|Qa|</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Qb<0</td><td>-</td><td>0</td><td>0</td><td>|Qa|</td><td>0</td></tr>
<tr><td>+</td><td>|Qa|</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td rowspan="4">Qa<0</td><td rowspan="2">Qb>0</td><td>-</td><td>0</td><td>|Qa|</td><td>0</td><td>0</td></tr>
<tr><td>+</td><td>0</td><td>0</td><td>0</td><td>|Qa|</td></tr>
<tr><td rowspan="2">Qb<0</td><td>-</td><td>0</td><td>|Qa|</td><td>0</td><td>0</td></tr>
<tr><td>+</td><td>0</td><td>0</td><td>0</td><td>|Qa|</td></tr>
</table>

Note: Qa: annual position, Qb: expected position over the anticipation period
"-": bearish price expectations, "+": bullish price expectations

Source: author

This way of doing is not really satisfying as it reduces the heterogeneity of behavior and eliminates the influence of expected positions: only the price counts and operators have no more considerations relative to their future expected positions. Therefore we choose to introduce a parameter noted i ($0<i<1$) which is going to allow weighting the integration of price anticipations in behavior. The resulting pattern is shown in Table 16.

TABLE 16 – BEHAVIOR TABLE: ANNUAL POSITION, EXPECTED POSITION AND PRICE ANTICIPATION

<table>
<tr><th></th><th></th><th></th><th>Banking (compliance)</th><th>Borrowing (compliance)</th><th>Selling (compliance)</th><th>Buying (compliance)</th></tr>
<tr><td rowspan="4">Qa>0</td><td rowspan="2">Qb>0</td><td>-</td><td>0</td><td>0</td><td>|Qa|</td><td>0</td></tr>
<tr><td>+</td><td>i*|Qa|</td><td>0</td><td>(1-i)*|Qa|</td><td>0</td></tr>
<tr><td rowspan="2">Qb<0</td><td>-</td><td>(1-i)*Min(|Qa|,|Qb|)</td><td>0</td><td>|Qa|-(1-i)*Min(|Qa|,|Qb|)</td><td>0</td></tr>
<tr><td>+</td><td>i*|Qa|+(1-i)*Min(|Qa|,|Qb|)</td><td>0</td><td>(1-i)*(|Qa|-Min(|Qa|,|Qb|))</td><td>0</td></tr>
<tr><td rowspan="4">Qa<0</td><td rowspan="2">Qb>0</td><td>-</td><td>0</td><td>i*|Qa|+(1-i)*Min(|Qa|,|Qb|)</td><td>0</td><td>(1-i)*(|Qa|-Min(|Qa|,|Qb|))</td></tr>
<tr><td>+</td><td>0</td><td>(1-i)*Min(|Qa|,|Qb|)</td><td>0</td><td>|Qa|-(1-i)*Min(|Qa|,|Qb|)</td></tr>
<tr><td rowspan="2">Qb<0</td><td>-</td><td>0</td><td>i*|Qa|</td><td>0</td><td>(1-i)*|Qa|</td></tr>
<tr><td>+</td><td>0</td><td>0</td><td>0</td><td>|Qa|</td></tr>
</table>

Note: Qa: annual position, Qb: expected position over the anticipation period
"-": bearish price expectations, "+": bullish price expectations

Source: author

It is a mix of the two previous tables. If $i=0$, price anticipations are taken entirely into account and the table is similar to Table 14; if $i=1$ price anticipations are not taken into account and the table is similar to Table 15. The parameter i quantifies how the current stock management takes into account price anticipations; it can be set between 0 and 1.

3.4 The introduction of hedging and speculation in the banking and borrowing behavior

The price anticipations have a second effect: allowing for hedging/speculation. Those terms can have a wide range of meanings. In the following pages, they are used with the sense of actors buying allowances to bank them (when they expect prices to go up), or borrowing allowances to sell them directly (when they expect prices to go down). We thus create a new table with four columns containing the distinct effects of hedging/speculation (Table 17).

It is necessary to quantify the intensity of hedging among installations and to implement parameters to be able to build different behavior scenarios. In any situation, we consider that actors will engage in hedging with an intensity that depends on their expected average annual shortage/surplus of allowances (Qb) over the anticipation period, which consists of N years. We also introduce two parameters *j* and *k,* which control the intensity of hedging/speculation so that the behavior resulting in borrowing and sales in the current year are controled by j, and the behavior resulting in purchases and banking in the current year are controled by k. Both j and k can be interpreted as the share of annual average future surplus/deficit over the anticipation period which is going to be banked in advance or sold in advance.

This way of modeling actors' decisions allows representing the behavior of non-compliance actors such as financial players, without creating dedicated actors in the model. Their behavior is integrated by installations as a behavior related to price anticipations.

TABLE 17 – BEHAVIOR TABLE: HEDGING AND SPECULATION

	Banking (hedging/speculation)	Borrowing (hedging/speculation)	Selling (hedging/speculation)	Buying (hedging/speculation)
-	0	j*|Qb|/N	j*|Qb|/N	0
+	k*|Qb|/N	0	0	k*|Qb|/N

Note: Qb: expected position over the anticipation period, N: number of years in the anticipation period
"-": bearish price expectations, "+": bullish price expectations

Source: author

3.5 The general behavior table

We now have two complete sub-tables, one for stocks-based behavior and one for hedging/speculation behavior. The two sub-tables are re-united in the general behavior table below (Table 18), which is going to be the core of ZEPHYR-Flex market behavior module.

TABLE 18 – BEHAVIOR TABLE: GENERAL CASE IMPLEMENTED IN ZEPHYR-FLEX

<table>
<tr><th></th><th></th><th></th><th>Banking (compliance)</th><th>Banking (hedge)</th><th>Borrowing (compliance)</th><th>Borrowing (hedge)</th><th>Selling (compliance)</th><th>Selling (hedge</th><th>Buying (compliance)</th><th>Buying (hedge)</th></tr>
<tr><td rowspan="4">Qa >0</td><td rowspan="2">Qb> 0</td><td>-</td><td>0</td><td>0</td><td>0</td><td>j*|Qb|/N</td><td>|Qa|</td><td>j*|Qb|/N</td><td>0</td><td>0</td></tr>
<tr><td>+</td><td>i*|Qa|</td><td>k*|Qb|/N</td><td>0</td><td>0</td><td>(1-i)*|Qa|</td><td>0</td><td>0</td><td>k*|Qb|/N</td></tr>
<tr><td rowspan="2">Qb< 0</td><td>-</td><td>(1-i)*Min(|Qa|,|Qb|)</td><td>0</td><td>0</td><td>j*|Qb|/N</td><td>|Qa|-(1-i)*Min(|Qa|,|Qb|)</td><td>j*|Qb|/N</td><td>0</td><td>0</td></tr>
<tr><td>+</td><td>i*|Qa|+(1-i)*Min(|Qa|,|Qb|)</td><td>k*|Qb|/N</td><td>0</td><td>0</td><td>(1-i)*(|Qa|-Min(|Qa|,|Qb|))</td><td>0</td><td>0</td><td>k*|Qb|/N</td></tr>
<tr><td rowspan="4">Qa <0</td><td rowspan="2">Qb> 0</td><td>-</td><td>0</td><td>0</td><td>i*|Qa|+(1-i)*Min(|Qa|,|Qb|)</td><td>j*|Qb|/N</td><td>0</td><td>j*|Qb|/N</td><td>(1-i)*(|Qa|-Min(|Qa|,|Qb|))</td><td>0</td></tr>
<tr><td>+</td><td>0</td><td>k*|Qb|/N</td><td>(1-i)*Min(|Qa|,|Qb|)</td><td>0</td><td>0</td><td>0</td><td>|Qa|-(1-i)*Min(|Qa|,|Qb|)</td><td>k*|Qb|/N</td></tr>
<tr><td rowspan="2">Qb< 0</td><td>-</td><td>0</td><td>0</td><td>i*|Qa|</td><td>j*|Qb|/N</td><td>0</td><td>j*|Qb|/N</td><td>(1-i)*|Qa|</td><td>0</td></tr>
<tr><td>+</td><td>0</td><td>k*|Qb|/N</td><td>0</td><td>0</td><td>0</td><td>0</td><td>|Qa|</td><td>k*|Qb|/N</td></tr>
</table>

Note: Qa: annual position, Qb: expected position over the anticipation period
N: number of years in the anticipation period, "-": bearish price expectations, "+": bullish price expectations

Source: author

4. Calibration of the ZEPHYR-Flex model

4.1 Replicating the observed prices: first run

The model is first run with the following set of assumptions for the different context variables and anticipation behavior. The annual caps and the share of auctions are defined pursuant to the rules governing Phase 1 and Phase 2 of the ETS as explained previously. The emission baseline initial levels and annual growth by sector, as well as the marginal abatement cost curves and the partial irreversibility of reductions, are those determined previously in Chapter 2. Offsets are introduced as exogenous supply to the market and incorporated in the annual caps according to the information provided in Chapter 3.

To calibrate anticipations, we are going to fix the parameters as what could be a coherent set of assumption given what we have learned from the ex post analysis in the first Chapter. We will then see if prices are replicated or not, and how those assumption should be corrected to replicate observations.

Three anticipations have to be parameterized: the anticipated average growth of emissions over the anticipation period for the electricity sector and the industrial sectors (annual); the share of actors believing in bullish prices (short market) or bearish prices (long market) for each year; and the values for parameter i, which quantifies how the current stock management takes into account price anticipations, and (j_1, j_2, k_1, k_2) which govern the intensity of hedging/speculation behavior compared to the average expected deficit/surplus over the anticipation period.

Average expected growth of emissions. We consider that the covered installations project the probable emission growth based on the observation of the past growth. Based on linear projection of industrial production growth, for each sector and using only "past" information (meaning without knowing what actually happened afterwards), we find that the probable expected growth in 2005 and 2006 was around 2% in the electricity sector and 1% in the other sectors. In 2007 and 2008, the figure is revised down to 1% in the electricity sector. The year following the crisis, a linear trend would give a value largely too pessimistic, hence we choose to limit the parameter to zero in both sectors in 2009. From 2009 on, the GDP and industrial production stagnates. The different situations across Member States and sectors make it difficult to estimate the average expectations. It is considered to be around 1% per year, in both sectors (the anticipation period are five years long starting from 2008). The values for these parameters used in this first run are summarized in Table 19 below.

TABLE 19 – ANNUAL GROWTH EXPECTATIONS OVER THE ANTICIPATION PERIODS

Year	2005	2006	2007	2008	2009	2010	2011	2012
Anticipation period	2006-7	2007		2009-13	2010-14	2011-15	2012-16	2013-17
Expected annual average growth over the period								
Electricity sectors	2.0%	2.0%	1.0%	1.0%	0.0%	1.0%	1.0%	1.0%
Rest of sectors	1.0%	1.0%	1.0%	1.0%	0.0%	1.0%	1.0%	1.0%

Source: author

Belief in bullish/bearish prices. Once again it is difficult to posit a priori what is the expectation of actors over time. It is nevertheless possible to use the information contained in the evolution of various price forecasts published by various analysts or economic centers over 2005-2012. The summary of the hundred forecasts studied are shown in Annex B_2. If we look at the average forecast over each of the sub-periods identified in Chapter 1 (noted I, II III etc, see Figure 7 page 40), we see that the message is always the same: price are going to go up, because current price and emission trajectory are not estimated consistent with the long term targets associated to the scheme (see Annex B_2). This is also true after the 2008-9 crisis.

The situation in which a majority of actors would believe in bearish prices is reserved to cases like the end of Phase 1, where a constraint on banking and the information available clearly reveals a surplus without any value. Following this observation we could simply consider that all installations always believe in bullish prices, whether this is confirmed in reality or not. But this could reduce the diversity of behavior among installations. Moreover, there has to be a few actors on the market who don't believe like the others. As a consequence we make the assumption that, even if the share of installations having positive expectations should always be high, it is slightly influenced by new information such as the release of 2005 verified emissions in 2006, the effects of the economic crisis in 2009 and the following stagnation, and the energy efficiency/set aside debate in 2012. The values used for the first run of the model are shown in Table 20.

TABLE 20 – POSITIVE AND NEGATIVE PRICE EXPECTATIONS AMONG INSTALLATIONS

Probability among installations	2005	2006	2007	2008	2009	2010	2011	2012
Negative expectations	15,0%	25,0%	50,0%	10,0%	15,0%	15,0%	15,0%	20,0%
Positive expectations	85,0%	75,0%	50,0%	90,0%	85,0%	85,0%	85,0%	80,0%

Source: author

Accounting for price anticipation in EUA stock management. The parameter *i* is comprised between 0 and 1 and quantifies the intensity with which operators take into account their price expectations to decide whether they should bank or sell current surplus, respectively buy or borrow deficits, compared to the situation where they only take into account their own compliance need over the anticipation period (i=0). It seems quite logical to us that operators take price anticipations into account for taking this kind of decisions. Again to avoid having extreme behavior, we choose for now to give this parameter the value of 75%.

Intensity of hedging/speculation. For now we consider that those parameters can be constant over time, as if the need for hedging was constant in time once expressed as a share of the annual expected position over the anticipation period. The parameter j quantifies the intensity with which actors will borrow allowances from future years to immediately sell them on the market. We consider that this parameter is probably around 5% given the observed low borrowing levels observed on the first years. It is a behavior strictly driven by speculation. The parameter k quantifies the intensity with which actors will buy EUAs on the market to bank them, for hedging or speculation purposes. For now we take a constant value equal to 40% of the expected annual deficit/surplus over the anticipation period.

TABLE 21 – FIRST SET FOR THE PARAMETERS I, J, AND K

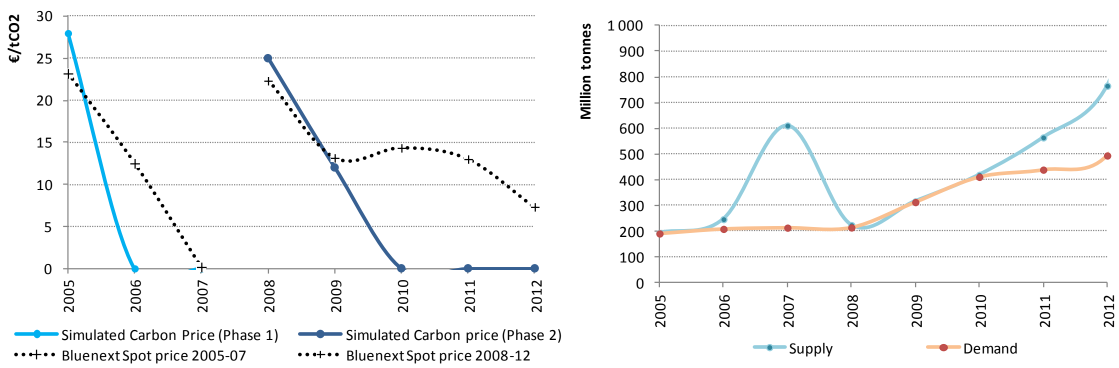
Parameters	2005	2006	2007	2008	2009	2010	2011	2012
i **(importance of price anticipations in stock related banking/borrowing)**	75%	75%	75%	75%	75%	75%	75%	75%
j **(intensity of speculative borrowing)**	5%	5%	5%	5%	5%	5%	5%	5%
k **(intensity of hedging/speculative banking)**	40%	40%	40%	40%	40%	40%	40%	40%

Source: author

We run the model using all the parameters described above. The resulting equilibrium price and the related supply/demand are shown on Figure 36. The model forecasts a price close to the observed price in 2005, 2008 and 2009. However, in 2006 and 2010, the demand is too low to trigger a non-null price (40 Mt surplus in 2006 and 8 Mt in 2010). From 2011 on, the net market surplus extends gradually to 265 Mt.

The price is already best replicated here than without flexibility mechanisms, but it seems that something prevents the surplus to be adequately banked by actors over time, which creates a price of zero too early in Phase 1 and from 2010 to 2012 in Phase 2, contrary to observations.

FIGURE 36 – ZEPHYR-FLEX INITIAL RUN: CARBON PRICE, SUPPLY AND DEMAND OVER 2005-2012



Source: author

4.2 The calibration: a version of ZEPHYR-Flex replicating history

The model needs to be calibrated so that it replicates the observed prices. Consequently we must adjust the parameters to absorb part of the surplus on the market, because observation tells us that they have not been sold. We make the assumption that all parameters are more or less representative of the actual situation, except the *k* parameter which should account for more hedging/speculation/banking. Therefore we can calibrate the model by gradually adjusting the *k* parameter in each of the years, until annual prices are correctly forecasted by the model. Note that all other parameters are kept fixed, so that the calibration of parameter k gives one solutions among the multiples possibilities allowing replicating observations.

The resulting "calibrated" set of parameter *k* is presented in Table 22, instead of a constant 40% adopted in the initial run. Because there was accumulated surplus to compensate in the initial run, the value of k is increasing with time on each of the separate phases, from 30% to 90% in Phase 1 and from 30% to 70% over Phase 2. This adjustment accounts for growing supply-demand disequilibrium observed in the initial run.

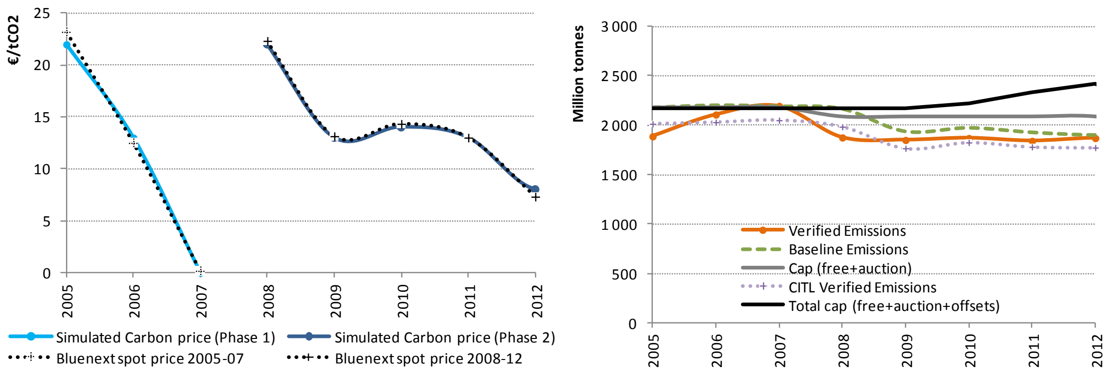
TABLE 22 – CALIBRATED SET FOR THE PARAMETER K

Parameter	2005	2006	2007	2008	2009	2010	2011	2012
k	30%	90%	0%	30%	36%	48%	62%	69%

Source: author

The annual prices are better replicated thanks to the calibration. The resulting emission trajectory is rather similar to observed emissions, although it is clearly not perfect (see Figure 37). In 2005, the relatively high price lowers emissions below the observed level, and the same phenomenon happens in 2008. Inversely, emissions in other years are overestimated. These discrepancies can be due to many approximations in our model, which remain to be clarified and explained but will naturally appear in any modeling exercise. It is thus not surprising that emissions are not perfectly replicated, and the results can on the contrary be considered surprisingly coherent given the cumulated uncertainties for the number of assumptions made.

FIGURE 37 – ZEPHYR-FLEX RESULTS: CARBON PRICE AND EMISSION TRAJECTORY OVER 2005-2012



Source: author

5. The ex-post evaluation of the EU ETS with the ZEPHYR-Flex model

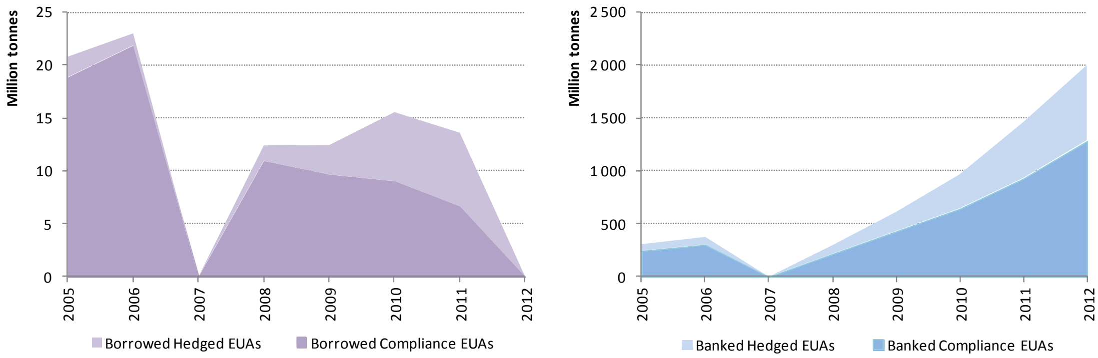
5.1 Banking, borrowing and trades

Borrowing and banking. The simulated banking and borrowing can be observed in Figure 38. Two subtypes of banking/borrowing are shown on the graphs. For banking, it shows the cumulated banking resulting from actors' decisions to hold surplus allowances that they already own before trading (noted "Banked Compliance EUAs"); and the banking resulting from purchases on the market (noted "Banked Hedged EUAs") that will become EUA stock at the beginning of the next year and thus will then be probably included in the "Banked Compliance EUAs" sub-type. For borrowing, it shows the borrowing from actors having current deficits to fill in ("Borrowed Compliance EUAs") and borrowing from actors immediately selling the amounts borrowed on the market ("Borrowed Hedged EUAs").

Borrowing is estimated at around 20 Mt in the first two years of Phase 1 and 15 Mt/yr in Phase 2, which is roughly the same order of magnitude as the net borrowing observed through the CITL at the country level (see Figure 34 page 92). Speculation through borrowing is very limited due to the parameter chosen (j=5%). The parameter could be adjusted slightly over time to replicate more precisely our previous estimates, but the effect on prices and trades would be very small.

On the other side, the annual cumulated banking is simulated at around 250 Mt in 2005 and 350 Mt in 2006, then rising from 300 Mt in 2008 to reach 2 Gt in 2012. We clearly see that, in order to absorb the surplus of Phase 2 (difference between the cap plus offsets minus baseline emissions) and to avoid a price collapse from 2009 on, it is necessary that banking rises exponentially over time. This is coherent with observation from Section 1 of this chapter and is rendered through calibration of the model. More and more hedging is necessary to hold the price above zero, from 25% of the annual banking in 2008 up to 35 % in 2012. This kind of setting is necessary to maintain emissions below the cap in a context of short term abundance of allowances, but should not hold long if perspectives of future deficits disappear. The impact on the market is then potentially massive, with an equivalent volume of more than one year of emissions held by actors in the form of allowances bankable to at least 2020. This mechanism will be analyzed in details in the last Chapter of this thesis.

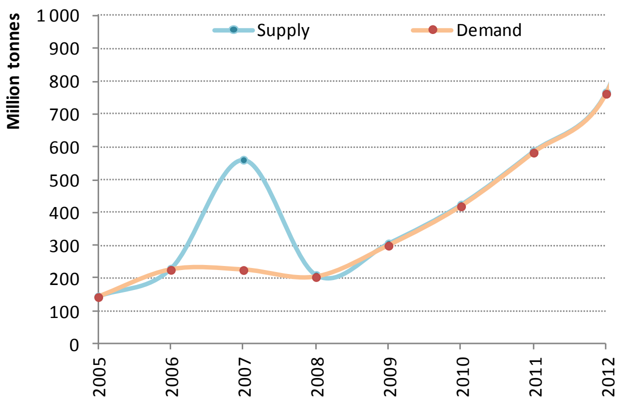
FIGURE 38 – ZEPHYR-FLEX RESULTS: ALLOWANCES BORROWING AND BANKING OVER 2005-2012



Source: author

Purchases/sales. In Phase 1, the simulated trades amount to 150 Mt in 2005, rising to 220 Mt in 2006. In 2007, the price is zero and the phase ends with a net surplus of around 300 Mt, but still around 200 Mt of demand are met with costless allowances. Without the assumption on perfect trading (no transaction costs, full participation, no market power etc.), a non-zero price would be necessary to transfer those allowances. Over phase 2, the annual exchanges rise progressively from 200 Mt to around 800 Mt (Figure 39). It should be kept in mind that those trades are physical trades and do not include financial transactions which may not induce physical exchanges of allowances. Hedging in reality would probably happen in Futures market; those hedging behavior are simulated in ZEPHYR-Flex as if actors were buying spot allowances and were holding them on their account for later use. Another factor limiting traded volumes is the fact that prices are annual and trades happen all at once in our model.

FIGURE 39 – ZEPHYR-FLEX RESULTS: SUPPLY AND DEMAND ON THE MARKET OVER 2005-2012



Source: author

5.2 Emission reductions and compliance costs

Emission reductions. Emission reductions are dependent on the same assumptions evoked above. They are estimated at around 400 Mt over Phase 1, 75% of which happened in the first year (simulated 2005 verified emissions are below observed levels). In Phase 2, the model forecasts 600 Mt reductions, 50% of which happened in 2008 (also probably overestimated). In total over 2005-2012, 1 $GtCO_2$ emission have been reduced, in line with what was expected to happen given the baseline and costs used (see Chapter 2). These ranges of estimates are coherent with measures obtained with other methods, see for example Delarue, Ellerman and D'Haeseleer (2008). As seen in Chapter 2, the dependency of emission reductions to the counterfactual scenario is determinant. It must hence be underlined here that part of the identified emission reductions in this Chapter may be over-estimated because of lowering factors that are unaccounted for in the counterfactual scenario used up to now, such as the effect of renewable energy and energy efficiency policies on baseline emissions. The integration of this effect will be done in the next chapter.

Compliance costs. The ZEPHYR-Flex model calculates, for each installation covered by the scheme, the annual amount of money spent/earned on emission reductions and trades. Those are summarized in Table 23 below, and will be compared to other cost estimates in the following subsection of this chapter.

TABLE 23 –ZEPHYR-FLEX RESULTS: REDUCTION COST AND TRADING COSTS

(M€)	2005	2006	2007	2008	2009	2010	2011	2012	Phase 1	Phase 2	2005-2012
Reduction cost	4,965	981	0	4,925	862	1,115	857	176	5,946	7,935	13,881
Purchases value	3,140	2,933	0	4,482	3,892	5,868	7,578	6,099	6,074	27,920	33,994
Sales value	3,185	2,924	0	1,417	1,854	2,877	3,294	2,780	6,109	12,222	18,331
Total compliance cost (reduction+purchase-sale)	4,921	990	0	7,991	2,901	4,106	5,140	3,495	5,911	23,633	29,544
Auctions value	0	57	0	1,375	1,083	1,167	1,083	667	57	5,375	5,431
Offsets value	0	0	0	1,829	1,044	1,902	3,260	2,688	0	10,722	10,722

Source: author

The reduction cost can be viewed as the area below the marginal abatement cost curve between the baseline and emissions at the observed price. At the EU ETs level, reduction costs amounts to 6 billion euro in Phase 1 and 8 billion euro in Phase 2. The purchase/sales value is the quantity bought/sold in each year multiplied by the market price. Total purchases amount to 6 billion euro in Phase 1 to 28 billion euro over Phase 2, whereas the sales amount to 6 billion euro in Phase 1 but only 18 billion euro in Phase 2. The difference between the value of sales and the value of purchases is explained by the existence of other sources of supply than actors selling allowances: auctions and offset. In the first case, the value is captured by the public authorities; in the second the value goes to offset sellers (primary market actors, financial intermediary, funds for example). The value of auctions over Phase 2 is estimated at 5.3 billion euro and offsets at 10 billion euro.

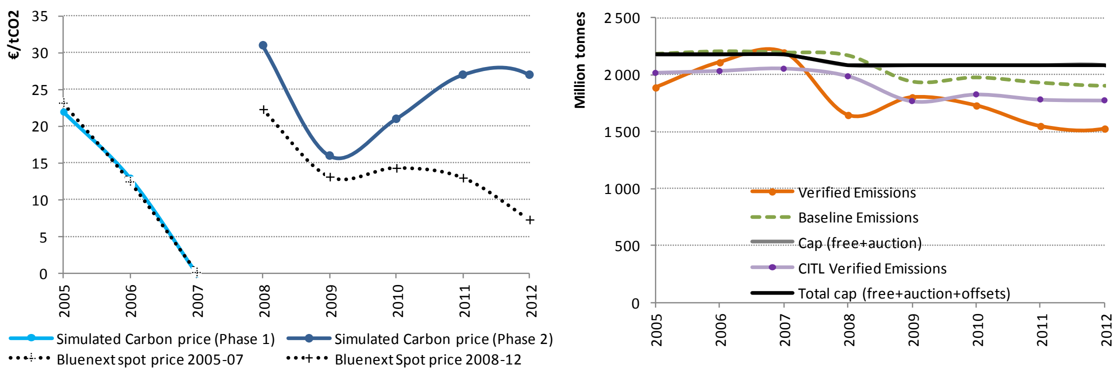
The total (net) compliance cost it the sum of reduction and purchases costs (positives) with sales benefits (negatives), it is equivalent to the cost of reductions plus the cost of buying EUAs in auctions, plus the cost of buying offsets. It amounts to 5 billion euro in Phase 1 and 24 billion euro in Phase 2.

5.3 The specific impact of offsets

One third of the allowances purchased by actors over 2005-2012 are offsets. What would have happened, all other things being equal (including banking), if there were no offset allowed over this time period? The ZEPHYR-Flex model can simulate this configuration. Keeping all parameters at their value, we only remove the exogenous supply of offset from the market. We must keep in mind that this is a rather conventional exercise, because in a reality without offsets, anticipations would have been changed. The resulting price and emission trajectories are shown on Figure 40.

In this scenario, the price would have been significantly higher, reaching 30 €/t in 2008, decreasing to 15 €/t in 2009, and rising again to 27 €/t in the end of Phase 2. The corresponding emission trajectory ends far below observed emissions, but is subject to high variations over time. This clearly shows the limit of certain of our assumptions, such as the full recognition of opportunity cost, the fact that only short term reductions are simulated, and the shape of MACCs. Concerning MACCs, the associated uncertainty may not be negligible because when prices go above historically observed price, we are in a zone of MACCs that has not been "calibrated", because there are no observation of emission reduction available at such prices. This probably explains why emissions are simulated at such a low level.

FIGURE 40 – ZEPHYR-FLEX RESULTS: REMOVING OFFSETS



Source: author

6. Conclusion

We now have three different series of output from ZEPHYR-Flex, the first build in Chapter 2 which accounts only for trading without any flexibility mechanism, and the two scenarios with banking and borrowing built in this chapter, one with offsets and the other without. We can thus compare the results from those three different versions. Table 24 presents for each version the simulated carbon price along with verified emissions, emission reductions, traded volumes, the cumulated banking and the total compliance cost.

TABLE 24 –ZEPHYR-FLEX RESULTS: COMPARISON BETWEEN THE THREE SCENARIOS

	2005	2006	2007	2008	2009	2010	2011	2012	Phase 1	Phase 2	2005-2012
ZEPHYR-Flex (trading only)											
Carbon price	4	8	6	12	0	0	0	0	6	2	4
Verified emissions	2,176	2,175	2,175	2,083	1,936	1,973	1,926	1,899	6,526	9,817	16,343
Emission reductions	8	30	20	86	0	0	0	0	58	86	144
Traded volumes	227	228	227	246	197	213	183	173	682	1,012	1,694
Cumulated banking	0	0	0	0	0	0	0	0			
Total cost	23	210	123	1,592	0	0	0	0	356	1,592	1,948
ZEPHYR-Flex (banking, borrowing w/o offsets)											
Carbon price	22	13	0	31	16	21	27	27	12	24	20
Verified emissions	1,888	2,108	2,196	1,646	1,801	1,729	1,550	1,526	6,192	8,252	14,444
Emission reductions	296	97	0	523	135	244	377	372	393	1,652	2,045
Traded volumes	143	226	225	163	266	348	451	590	594	1,819	2,413
Cumulated banking	307	375	0	436	729	1,084	1,604	2,164			
Total cost	4,921	990	0	13,472	2,984	5,586	9,416	9,608	5,911	41,068	46,979
ZEPHYR-Flex (banking, borrowing and offsets)											
Carbon price	22	13	0	22	13	14	13	8	12	14	13
Verified emissions	1,888	2,108	2,196	1,876	1,851	1,870	1,841	1,870	6,192	9,308	15,500
Emission reductions	296	97	0	293	86	103	85	28	393	595	988
Traded volumes	143	226	225	204	299	419	583	762	594	2,268	2,861
Cumulated banking	307	375	0	297	610	965	1,457	1,994			
Total cost	4,921	990	0	7,991	2,901	4,106	5,140	3,495	5,911	23,633	29,544

Source: author

At this stage, we now have a simulation model that is able to replicate observation under a set a different assumptions. Price and emissions trajectories are not calculated using optimization nor econometric relationships, they are simulated from a series of annual market equilibrium between supply and demand, in which three flexibility mechanisms play a determinant role.

The trading provision alone, established in Chapter 2, do not allow replicating the past at all but is the core of the cost minimization module. With banking and borrowing but without offsets, prices and emissions are not replicated either. Offsets thus had a major influence in the formation of the cumulated surplus at the end of 2012.

With the three flexibility mechanisms reunited, it is possible to simulate Phase 1 and Phase 2. Because of the conjunction of a decreased baseline (due to the crisis), large offset use and emission reductions, the cumulative banking in the end of 2012 is estimated at around 2.0Gt, which is more than a year of baseline emissions. In this context our model highlights that the dynamics of banking and the future anticipations are determinant for the third phase of the EU ETS, which is going to be the subject of Chapter 5.

Chapter 5 – Looking ahead: a multi-level regulation challenge

"Undoubtedly, errors will be made in climate policy as well, especially in the early years of policy formulation and implementation. Unless timely adjustments are made to correct such errors when they become evident, the consequences could be harrowing. On one hand, weak and ineffective policies could mean extreme climate change in the future and great damage to society. On the other hand, poorly designed climate policies could cause an enormous waste of resources and substantial impairment of economic prospects".

William C. Whitesell, *Climate Policy Foundations: Science and Economics with Lessons from Monetary Regulation* (2011)

At the end of Chapter 4, we have a simulation model capable of replicating the evolution of the carbon price and of emissions from 2005 to 2012. In this last chapter, we are going to shift from an *ex post* use of the model which allowed for a better understanding of the past, to an *ex ante* use of the tool, simulating the development of the market until 2020, given the information available up to the end of July 2012.

In this simulation, we consider as fixed the technical-economic framework built in the first chapters (the abatement behaviors of companies and the assumptions on growth leading to baseline emissions), as well as the assumptions on the use of offsets and the banking/borrowing framework determined in Chapter 3 and 4, except that we are introducing a modification in the baseline previously unaccounted for.

The calculation of the baseline, projected to 2020, must take into account the effects of other climate-energy related policies. This will be reducing the future baseline emissions, and increase the anticipated supply of allowances if participants' anticipations are not changed, as will be shown with the two preliminary simulations presented in the first section of this chapter.

We then test, in the second section, three possible scenarios of an intervention of public authorities regarding the future of the EU ETS, which have been publicly discussed since the publication of the European Commission Roadmap for moving to a competitive low carbon economy in 2050:

- The introduction of a reserve price of 20€/t at auctions
- A back-loading (or set-aside) of allowances to be auctioned in Phase 3 following the propositions made by the Commission on July, 25th 2012
- A reevaluation of the allowance cap to 2020 and 2030 compatible with the long term trajectory advocated by the European Union for 2050.

The main result from these simulations is that only the third scenario leads to a sustainable enhancement of the market because it is the only one to allow for a change of participants' anticipations and confidence over the long term. The conditions for the implementation of such a scenario are then reviewed in the last section of the chapter.

1. The introduction of the post 2012 rules in the ZEPHYR-Flex model

In this section we are going to parameterize the ZEPHYR-Flex model in order to simulate the third trading period of the EU ETS, up to 2020. Based on the rules as they exist in July 2012, we can build estimates of the future cap and allocations. The amount of offsets which will be added to the cap has been calculated at the end of Chapter 3, and is considered as an input that doesn't change from one simulation to another.

The baseline emissions are projected over the 2013-2020 period on the basis of growth assumptions which are derived from standard projection of European GDP growth by the OECD and using the methodology described in Chapter 2. Nevertheless, they will be modified to account for a previously ignored effect: the interactions of the EU ETS with other climate-energy policies. The scenarios used in this Chapter will all be based on this new "Policy interaction" counterfactual scenario.

1.1 The general rules after 2012

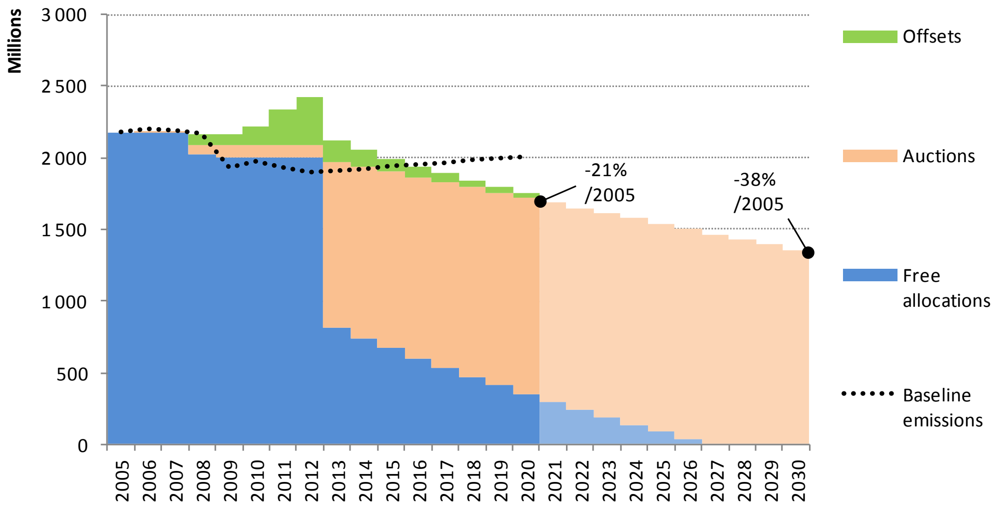
Along with the texts relative to the Climate Energy Package of April 2009, particularly the directive on renewable energy and the texts on energy efficiency which will be the topics of the next subsection, the EU ETS Directive details the rules for the 2013-2020 period.

The cap for Phase 3 of the EU ETS, covering the period from 2013 to 2020, is decreasing annually by a certain amount, called the linear reduction factor, which equals to 1.74% of average Phase 2 emissions (see the EC website for a detailed explanation). From 2013 and onwards, the cap is thus reduced each year by an approximate amount of 37 Mt, which puts the cap to a value of around 1,720 Mt in 2020, i.e. -21% compared to 2005 emissions. This is what is implemented in ZEPHYR-Flex.

Due to the anticipation periods of the simulated installations (which goes up to 2027 in 2020) it is necessary to simulate the cap beyond 2020. In the 2009 EU ETS Directive, there is no mention of a Phase going beyond 2020, nevertheless it is implicitly accepted that the EU ETS is not stopped in 2020 and continues beyond this date, with a continuously decreasing cap along the same linear reduction factor. This assumption takes the annual cap down to a value of 1,360 Mt in 2030, i.e. around -38% compared to 2005 emissions. The representation of the cap in ZEPHYR-Flex is extended to 2030 to reflect this framework. It corresponds to what participants could anticipate at the end of 2012.

Allocations to installations are simulated on the basis of their sector: installations in the electricity sector receive no free allowances from 2013 and onward (the exemptions to full auctioning for certain electricity plants in new Member States are neglected); the share of free allocation is progressively decreasing in the other sectors and disappears completely in 2027. In 2012 the exact amounts and distribution keys for free allowances are not entirely determined, so we based our assumption on the latest analysis of Member States preliminary amounts available, see for example Lecourt (2012). The quantity of free allocations is considered to be at around 810 Mt in 2013 (40% of the annual cap), decreasing to 350 Mt in 2020 (20% of the annual cap). Figure 41 details the assumptions implemented in ZEPHYR-Flex for the post-2012.

FIGURE 41 – CAP, FREE ALLOCATION, AUCTIONS AND OFFSETS AFTER 2012



Source: author

The quantity of offset which comes in addition of the cap up to 2020, has been calculated in Chapter 3. Because of the huge uncertainties, we don't take into account the implications of the inclusion of aviation in the scheme. This could be done by reducing the projected cap by the anticipated amount of net purchases of EUAs by aviation operators. Given the anticipated order of magnitude of these purchases over the period -see Boutueil, Solier and Russo (2011) - their inclusion in the simulations would not significantly change their results.

Baseline emissions also need to be projected after 2012. We base our assumption on a GDP growth scenario similar to the average observed over the 1996-2004 period, which is around 2.4% per year. This level which is slightly higher than the 2010 and 2011 growth is compatible with the medium term forecasts of the OECD. Based on these assumptions, we derive a corresponding set of industrial production growth by sector after 2012. Baseline emissions are calculated by applying the elasticity of emissions to production used in Chapter 2.

The baseline emission growth applied after 2012 is supposed constant and varies from 0.5% in the electricity sector to 1.1% in the rest of industry. On average for the EU ETS, emissions without a carbon price would rise from 1,900 Mt in 2013 to 2,010 Mt in 2020.

This is already substantially less than initially expected as mentioned in Chapter 1, because of the strong decrease of production in certain sectors and to the global slowdown of European economies since the beginning of the crisis. But another factor is going to reduce the level of baseline emissions.

1.2 Accounting for the interactions with other policies in the emission baseline

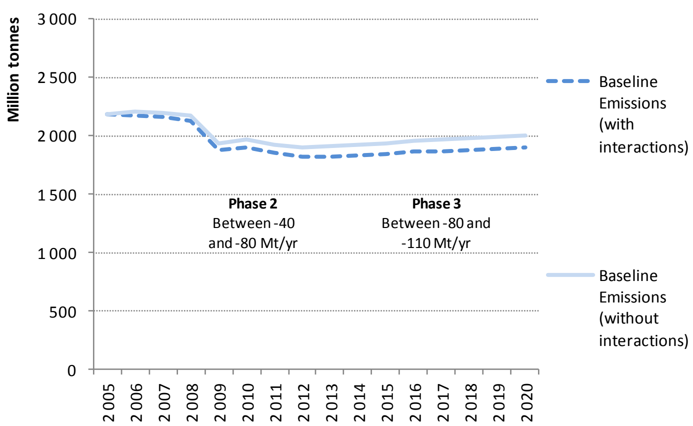
Along with the decision of the Council to reduce CO_2 emissions by 20% compared to 1990 in 2020, two other targets have been adopted during the course of Phase 2. The first regards the inclusion of more renewable energies in Member States' energy mix (with a target of 20% of energy consumption at the EU level); and the second deals with the improvement of energy efficiency, with a goal of 20% reduction in primary energy use compared with projected levels. At the time of the discussion, it was anticipated that those three targets were complementary and would "help" each other. But the practical consequences had not been clearly foreseen.

As a matter of fact, if a mandatory target exists on energy efficiency, with possibly specific economic tools or incentive to achieve this target, a share of the savings will be either made directly in the EU ETS perimeter, or indirectly by inducing a decrease in energy demand (which is carbon based, at least on average). As a consequence of energy efficiency measures, demand for allowances would be reduced, implying a lower carbon price than what would have happened in the absence of the energy efficiency target. This interaction effect has been widely discussed and has been the source of an intense debate at the end of 2011 and in 2012, following the Commission proposal for a new energy efficiency Directive in June 2011, which included mandatory targets – see for example the description of Berghmans (2012).

The effect is the same for the renewable energy Directive: more renewable energy in the consumption means somehow substituting fossil fuel based plants by hydro, biomass, wind and solar energy, thus diminishing the demand for CO_2 emitting electricity or energy. The effect on the carbon market is the same, reducing demand for allowances and thus the price. Weigt, Delarue and Ellerman (2012) estimated the actual reduction in demand for European Union Allowances that has occurred due to renewable energy deployment focusing on the German electricity sector, for the five years 2006 through 2010. Based on a unit commitment model, they estimate that CO_2 emissions from the electricity sector are reduced by 33 to 57 Mt, or 10% to 16% of what estimated emissions would have been without any renewable energy policy.

In ZEPHYR-Flex, this type of policy interactions is going to be integrated in the baseline emissions scenarios, and the previously used "No Policy" scenario is going to be replaced by a new "Policy interaction" scenario used in the rest of the chapter. The policy interactions will be schematically accounted for by assuming that other policies are progressively reducing emissions independently of the EU ETS. Compared to the previous scenario, the annual baseline emission growth is now progressively reduced by up to 25% in 2020. The resulting trajectory is shown in Figure 42 and corresponds to an annual reduction of the baseline from 60 Mt/yr in Phase 2 to 100 Mt/yr in 2020.

FIGURE 42 – THE STYLIZED EFFECT OF POLICY INTERACTIONS ON THE BASELINE IN ZEPHYR-FLEX



Source: author

All the parameters described in this section along with the rules of abatement determined in Chapter 2 will not be changed in all the ex-ante simulations that are going to be described in this chapter. But despite these common rules, it appears that the story that is told by the ZEPHYR-Flex model can differ fundamentally as showed in our two stylized scenarios presented next.

2. Two stylized scenarios

In this section we introduce two stylized scenarios, both using the "Policy interaction" counterfactual, but which differ by the the anticipations of actors in the market:

- A "Naïve" scenario in which participants continue to increase the accumulation of banked allowances at the pace observed in Phase 2, well above their medium term compliance needs.
- An "Adapted" scenario in which covered entities react to the interaction of other policies by changing their expectations, and doing so, reduce the amount of allowances banked over the period.

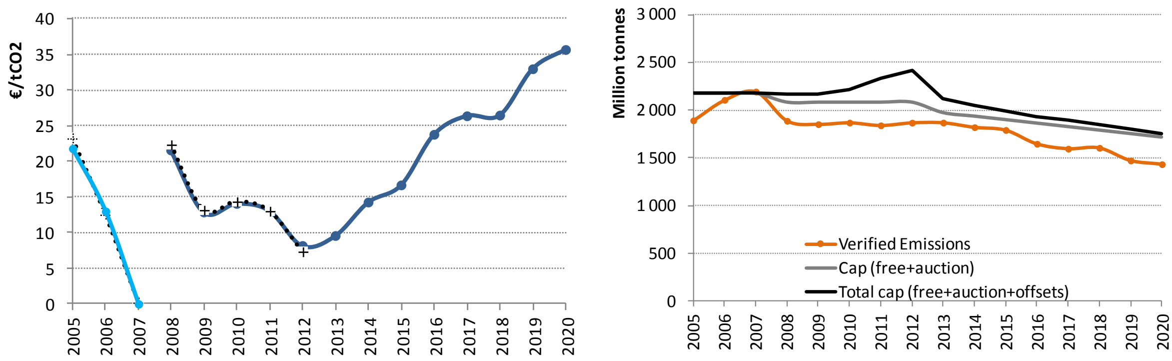
2.1 A "Naïve" scenario: the continuity of banking behavior

To simulate the EU ETS after 2012 it is necessary to make assumptions on participants' behavior, and in particular on their banking behavior. Chapter 4 demonstrated that, to explain the non-null price in end 2012, it was necessary that participants hold an increasing amount of allowances on their accounts. In the calibrated scenario, the k parameter is multiplied by 2.3 between 2008 and 2012.

The first scenario we are testing is a scenario in which participants continue to bank allowances at an increasing pace, above the quantity strictly "necessary" for compliance purposes in the medium term. The parameter k is thus set to progressively rise from 70% in 2012 to the double in 2020. The resulting price and emission trajectories are shown on Figure 43.

Under this set of assumptions, the carbon price is projected to rise from 10 €/tCO_2 in 2013 to 35 €/tCO_2 in 2020. Consequently, the simulated verified emission decrease and dive strongly below the actual cap, to reach an emission level of 1,500 Mt/yr in 2020, 200 Mt below the cap.

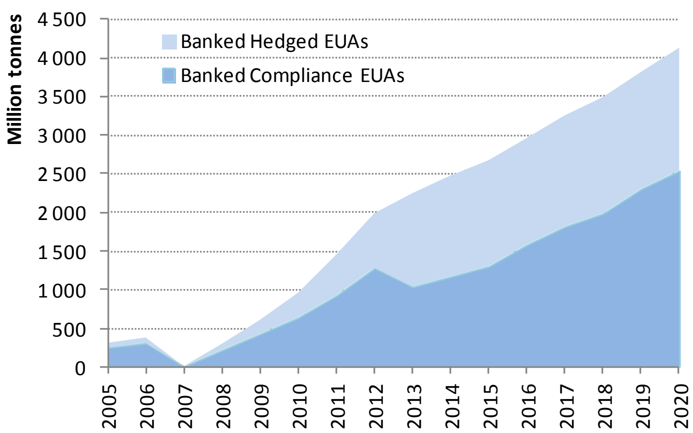
FIGURE 43 – ZEPHYR-FLEX POST 2012: "NAÏVE" SCENARIO RESULTS



Source: author

In this scenario, the high levels of banking can be interpreted as very high anticipations of allowance shortage after 2020. By simulating these anticipations, we see that participants, by hoarding allowances, create a shortage on the market which incentivizes emission reductions "in advance" compared to a situation where participants would not anticipate the future shortage. The corresponding banking behavior, shown in Figure 44, leads to a volume of 4 Gt banked in 2020. It represents potentially between two and three years of baseline emissions.

FIGURE 44 – ZEPHYR-FLEX POST 2012: BANKING IN THE "NAÏVE" SCENARIO



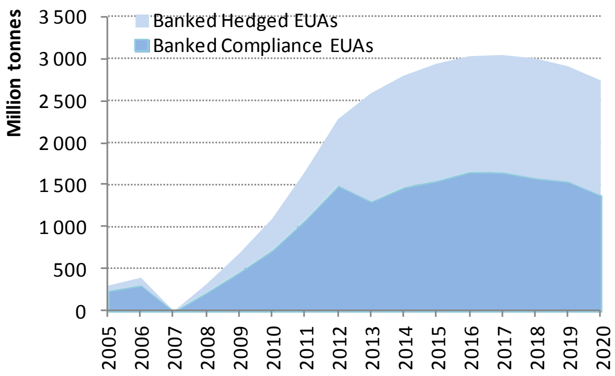
Source: author

This run is called the "Naïve" scenario because it implies that participants expect a high future allowance shortage, whereas observations tell us that this is not really the case (due to the cumulated banking, the slowed down growth and the reductions from other policies). This scenario is not really credible in the current situation, but is shows that strong anticipations can lead to a high price even in the presence of a "surplus" in the form of large amounts of banked allowances.

2.2 An "Adapted" scenario accounting for a stabilization of banking

In the "Adapted" scenario, a correction is made to anticipations, which now account for the reduction of demand due to other policies. We consider in this scenario that the cumulated banking achieved at the end of 2012 is a satisfying amount given the participants visibility on the 2020 target and that it is going to stabilize over the course of Phase 3, and finish at a level equivalent to that of the end of Phase 2. The parameter *k* is hence capped and stabilized over Phase 3 to reach a value of 82% in 2020, equal to that of 2012. The related banking behavior is shown in Figure 45.

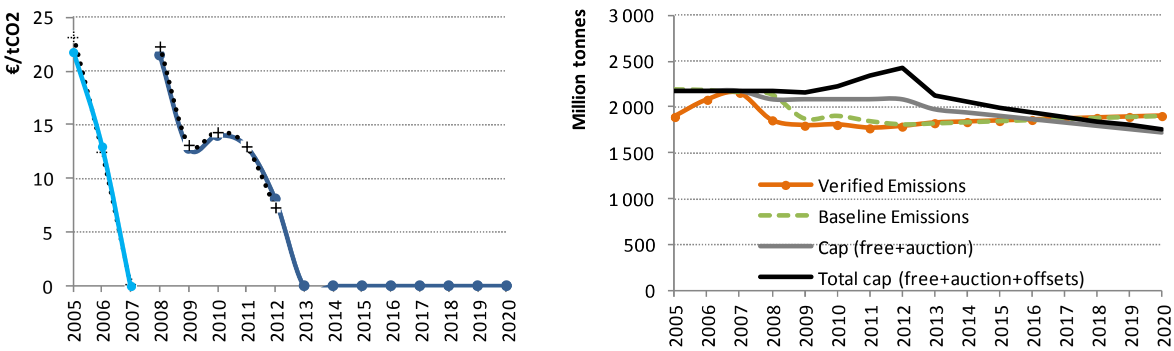
FIGURE 45 – ZEPHYR-FLEX POST 2012: BANKING IN THE "ADAPTED" SCENARIO



Source: author

The resulting price and emission trajectories are shown on Figure 46 and are pretty clear: under these conditions, there is no need for a carbon price over the entire Phase 3. The ZEPHYR-Flex model simulates a price of zero over the entire 2013-2020 period. Exchanges of allowances are still needed (transfer from short to long installations) but because there are no transaction costs, it does not prevent the price from being exactly equal to zero. If there were transaction costs in the model, the price would be forecasted at this new level and not at zero.

FIGURE 46 – ZEPHYR-FLEX POST 2012: "ADAPTED" SCENARIO RESULTS



Source: author

The corresponding emission trajectory simply follows the emission baseline. The actual reduction need over Phase 3 is very limited, and is largely inferior to the total allowances distributed over 2008-2020 plus offsets. The hypothesis of banking stagnation means that there is no early anticipation of the future constraint. In other words, under this set of assumption, the EU ETS has no role to play between 2013 and 2020 and a very small price is sufficient for reaching the 2020 target at the lowest cost. In the model, this is represented by a null price. In reality, this could manifest as a price hovering at very low levels (around 5€/t) until 2020.

At the end of Phase 2, nobody can predict with certainty which one of the two scenarios will prevail in the future. Nevertheless, the second scenario clearly shows that the policy interactions and their impact and the anticipative behavior of participants are determining the future emission path and the corresponding cost of reaching a longer term target. This fact generated in late 2011 and 2012 a thorough debate on the role the EU ETS should play in the set of climate and energy policies, and if it should be modified to account for possible present and future interactions. The more profound question is how to deal, in a cap and trade system, with the "advance" on the cap which can be induced by recession, policy interactions but also past emission reductions?

3. Intervention on the EU ETS: analysis of various proposals

Since the end of 2011, various proposals have been made regarding an intervention on the EU ETS, which original aim was to account for the effect of the new Energy Efficiency Directive, but end-up as a global questioning of the "surplus" and the advance on the actual cap induced by other policies and the economic recession, not foreseen at the time of implementation. This section will use the ZEPHYR-Flex model to assess the possible consequences of three families of interventions. The first would be to fix a sort of floor price by setting a reserve price to auctions from 2013 on, above the theoretical equilibrium market price. The second would be to set aside allowances, i.e. to backload part of the volumes to be auctioned over phase 3, by removing 400 Mt, 900 Mt or 1,200 Mt from auctions over the first three years and re-injecting them over the rest of the Phase. The third option would be to change the 2020 target and to augment the implicit 2030 target for the EU ETS, which is the equivalent of progressively setting away allowances compared to the actual situation.

3.1 Price floor through auctions' reserve price

The transition to the third phase is accompanied by a sharp increase in the amount of allowances auctioned. The way auctions are organized was designed by a regulation, which main objective is to ensure that the auction system, which will introduce a genuine primary market into the scheme, does not disturb the equilibrium on the secondary market. In other words, auctions must be "neutral" in relation to market prices that reflect the balance between supply and demand on the secondary market. The proposal to establish a reserve price at a level well above the current price has been advanced by some economists – see Grubb and Laing (2009) – and advocated by some stakeholders like CDC-Climat. In this alternative approach, the aim would be to use the auction system in order to act directly on the equilibrium price. The ZEPHYR-Flex model allows us to analyze its possible implications.

Establishing a reserve price at an auction means that a sale is not concluded unless the price reaches a value determined *ex ante* by the public authority. In our simulation, the reserve price is set at 20 €/tCO_2.

In such an awkward situation of setting a reserve price at more than the double of the price on the secondary market, we can imagine the following sequence happening:

- At 20€/tCO_2 nobody is buying allowances because of the wide gap between the reserve price and the "real" price given by the secondary market.

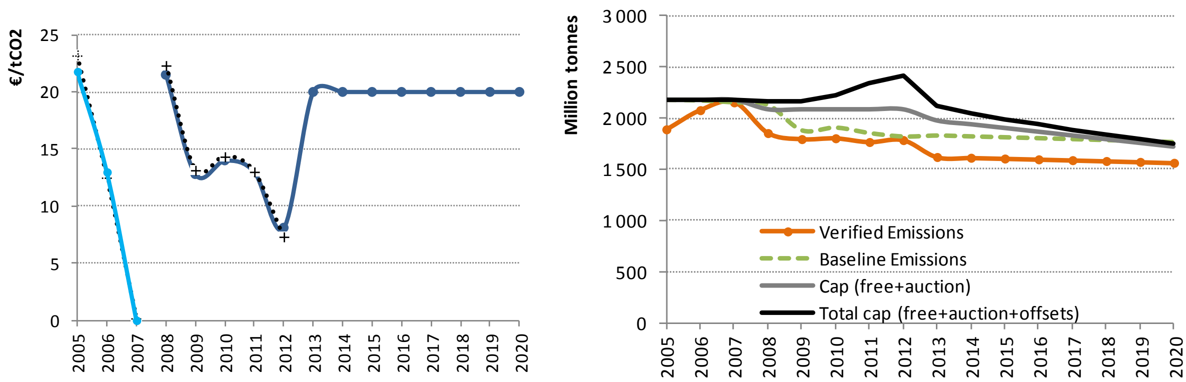
- The EUA sellers cease to sell at less than 20€/t, by wanting the secondary price to rise at the level of the reserve price

- The market is frozen: potential EUA sellers and the auction adjudicators are face to face. At this stage probably the private sellers would accept selling EUAs at just a little below 20€/t and thus prevent the adjudicator to sell part of his.

In ZEPHYR-Flex, that level of detail is not available. If this option is implemented from 2013, the first consequence is that half the allowances do not enter the market in 2013 (because the market price is below 20€/t), which immediately raises the allowance price to 20 €/t. A gap is created between the reserve price that will prevail due to the removal of allowances by the allocating authority and the price that theoretically would appear on the market in the absence of this intervention.

The difference between the new price and the theoretical market price spontaneously tends to grow: the floor price of 20€/tCO_2 "forces" emissions reductions that were not necessary to attain the environmental objective, which remains unchanged because the cap has not been altered. This pseudo-tax lowers CO_2 emissions below the limit represented by the total number of allowances and credits available (Figure 47).

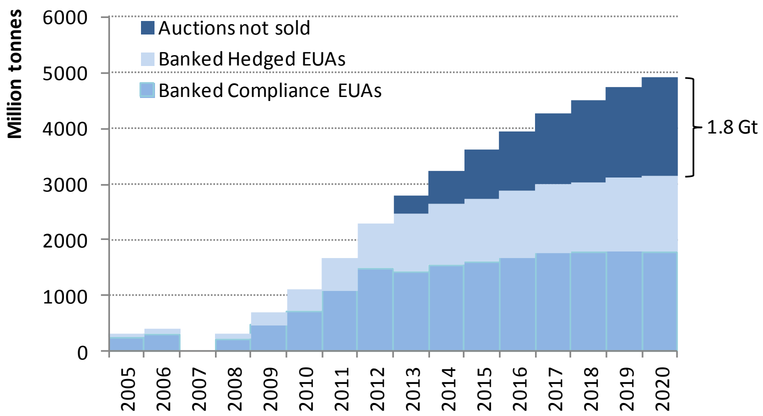
FIGURE 47 – ZEPHYR-FLEX POST 2012: "RESERVE PRICE" SCENARIO RESULTS



Source: author

The decrease in emissions resulting from a price that is above the level dictated by supply/demand equilibrium automatically leads to additional emissions reductions and hence a reduced demand for allowances. But as the private sellers sell allowances at a price just below the reserve price, the auctions remain tied to the reserve price throughout Phase 3. The authority auctioning allowances is thus forced to accumulate an ever-increasing amount of allowances that it is unable to sell. Our simulation puts this quantity at about 350Mt in 2013, increasing to a total of 1.8 Gt unsold over Phase 3 (see Figure 48).

FIGURE 48 – ZEPHYR-FLEX POST 2012: BANKING IN THE "RESERVE PRICE" SCENARIO



Source: author

It is not possible to access a level of detail allowing to specify the real impact of this situation in the current version of ZEPHYR-Flex. Nevertheless we can highlight three important lessons. First, the uncertainty on the share of auctions that will be actually sold and the share taken on banked allowances will create an additional risk of instability on the market. Second, it would be difficult anyway to figure what the evolution of actors' anticipations would be in such a situation. Finally, establishing a reserve price at more than twice the secondary market price level would induce additional emission reductions because of the artificially high price imposed through the reserve price, which would in turn result in an augmented accumulation of surplus.

The direct intervention in the price of allowances by establishing a reserve price at auctions thus leads to the "freezing" of allowances. The great unknown in so acting is the future of those allowances that have not been put onto the market. Here the ZEPHYR-Flex model recalls a key mechanism: as soon as the auctioning authority places these quantities back on the market without reserve clause, the price immediately tends to zero.

In short, setting a reserve price of €20/t means removing allowances from the market, but without deciding in advance the quantity withdrawn. If maintained throughout the period, this reserve price gives actors a temporary visibility on the price thus "forced", but totally clouds their medium-term perspective in that it has not been clearly decided what would happen to these allowances in the succeeding period. If the fixed reserve price is abandoned during the period, it causes a collapse of market prices because the imbalance between supply and demand for allowances has been widened by the price floor that generated additional reductions. Many such lessons may be found in the following analysis of different variants of set-aside.

3.2 Setting allowances aside or back loading auctions

For institutional reasons, if an intervention by the public authorities is agreed, it would probably involve a set-aside or auctions back-loading decision. Specifically, the European Commission envisages going ahead with such a withdrawal, made all the more necessary in the European legislator's thinking in that the implementation of the other policies from the Climate and

Energy Package could have a further depressive effect on the carbon market, see European Commission (2012a) and (2012b).

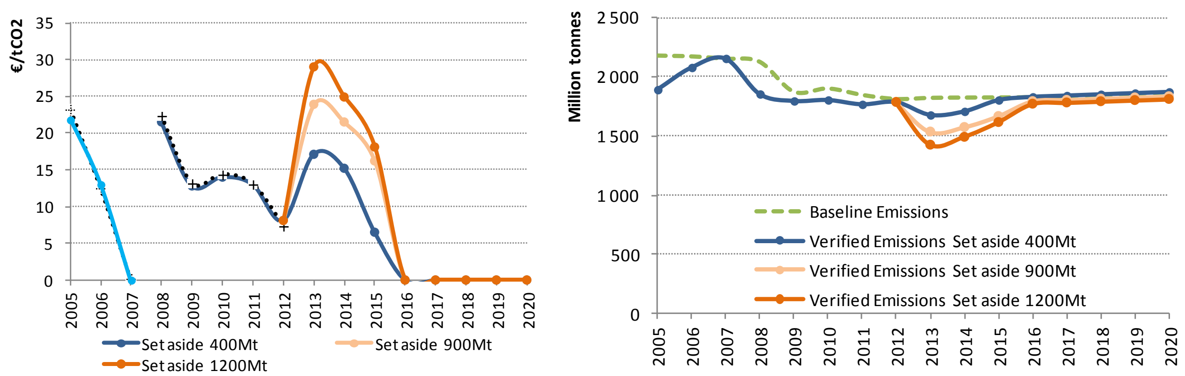
Such a measure is actually not as distant as it first seems from the introduction of a reserve price. It consists simply in setting *ex ante* the quantity of allowances that will be withdrawn from the market and then observing the resulting price. The simulations carried out using ZEPHYR-Flex lead to the same kind of conclusion: in both cases, the impact of intervention by the public authorities in the medium term depends primarily on what happens to the allowances that were set aside.

If the set aside allowances are put back into the market, the cap is not changed (the total number of allowances over the Phase is not changed) and only the distribution of allowances over time is impacted. If those changes are perfectly anticipated there is simply no effect on the price, with the condition that enough allowances can be made available from borrowing or "un-banking". In our scenarios, the underlying assumption is that anticipation of actors are similar than those in the "Adapted" scenario. In other words, they are taken by surprise by the Commission's decision to set aside allowances, so that it creates a choc on prices, but their global anticipation of the cap is not changed. This is a bit unrealistic but allows for the first results to stand out clearly.

We tested the three amounts of set aside as they are described by the European Commission (2012a). The first consists in progressively setting aside 400 Mt over the first three years of Phase 3, and reintroducing them equally over the five remaining years. The second and the third work on the same principle but with amounts of 900 Mt and 1,200 Mt.

All three interventions cause a fairly rapid rise in the allowance price, which reaches 17, 24 or 30 €/t in 2013 depending on the scenario, as shown in Figure 49 below. The rise generates additional emissions reductions from companies, which proportionally reduce their demand for allowances, thereby accelerating the fall in the price of allowances following their return to the market from 2016 onward. The effect is quite similar to what would occur in the case where the auction authority introduces a reserve price of 20 €/t at the start of the period and then drops it in 2016. In both cases, the removal of allowances at the start of the period drives the price up, which leads to more emissions reduction. The price then falls dramatically when the allowances are put back on the market, because the cap has not change.

FIGURE 49 – ZEPHYR-FLEX POST 2012: "SET ASIDE" SCENARIOS RESULTS

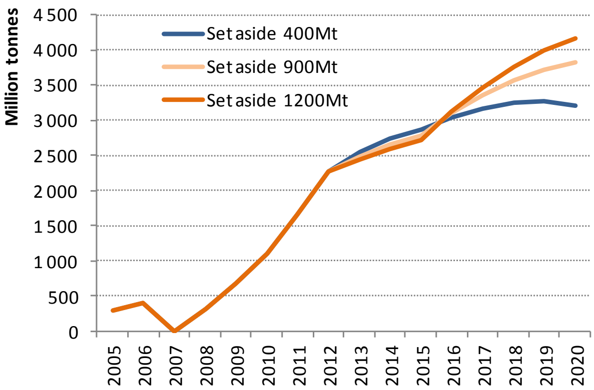


Source: author

As a consequence, the three scenarios lead to the same final emission level in 2020, which is the baseline level. The additional reductions induced by a non-zero price induce higher compliance costs than when simply following the emission baseline, and higher levels of cumulated banking in 2020 (Figure 50). In these scenario, there isn't very much interest in inducing reductions in the early years of the phase if it is to get to the same emission level in 2020.

One exception would be the situation in which the EU ETS cap is revised in the meantime. It would not be a set aside but a set away of allowances. In this case, participants would need to revise their expectations for the future years, which probably would lead to a non-zero price over the rest of Phase 3. But why would it be necessary to proceed this way when there already exists a process for revising the cap and changing EU ETS target, without involving a set aside becoming a set away? Playing with expectations has already proven to be dangerous given the weight of participants' anticipations and confidence in the price (see Chapter 1 and Chapter 4).

FIGURE 50 – ZEPHYR-FLEX POST 2012: BANKING IN THE "SET ASIDE" SCENARIOS



Source: author

Hence, the main lesson from these simulations is that any set-aside action, if it is to avoid blurring the signals given to industry, must be very explicit on the future allowances withdrawn from the market. Rules that are unclear or inappropriate in this area would be likely to disrupt industry's medium-term outlook and trigger undesirable shocks in the market.

3.3 Renewed confidence and visibility on the longer term constraint

The third possible type of intervention would be to lengthen the time horizon of the market, and quickly decide on the amount of allowances available until 2030 so as to change the long-term expectations of participants. For now, the total allowance cap is determined only up until 2020. The planned reduction of the cap is set by the Directive and represents an annual decrease of 1.74% compared to the average cap for the period 2008-12. According to the text of the Directive, if the cap's linear reduction factor is not changed in Phase III, it automatically continues to apply after 2020, and constitutes an implicit reduction target of -38% in 2030 compared to 2005.

Since the adoption by the European Council of a long-term objective for the European Union leading to a reduction in emissions of at least 80% in 2050 compared to 1990, the public authorities have been discussing the inclusion of this new target in official documentation. The trajectory aimed for is detailed in the European Commission's Roadmap 2050 published in March 2011 – European Commission (2011a). On the basis of impact studies carried out for the Commission, the implementation of the roadmap would require emissions reductions of 43-48% in 2030 compared to 2005 in the sectors covered by the EU ETS.

One of the solutions proposed to restore market confidence in Phase III is to immediately ensure that the cap's linear reduction factor is consistent with the long-term European objective by establishing the amounts of allowances that will be available until at least 2030. This intervention would entail revising the cap's linear reduction factor from 2013 by raising it from 1.74% to about 2.15%. This change would have an impact on the 2020 reduction target, increasing it to 25% below the 2005 figure as against 21% currently.

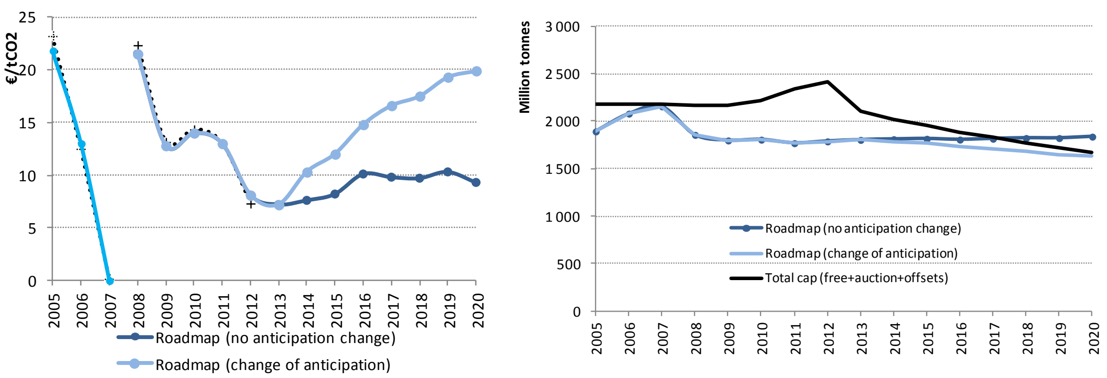
The ZEPHYR-Flex simulation shows that this reassessment of reduction targets would in fact raise the allowance price from 2013 and throughout Phase III. Taking into account the expectations of market participants ensures that the price increase is smoothed out over time. Nevertheless, everything depends on the nature of the actors' expectations, particularly the element of surprise that this measure may have in a context of imperfect forecasts. Two scenarios are tested, both implying a revision of the EU ETS cap in line with the Roadmap targets.

- The first run considers the same anticipations as the "Adapted" scenario above, implying a stabilization of banking throughout Phase 3. The k parameter culminates at 100% and stabilizes progressively at a level of 82% (equal to that of 2012).

- The second run considers an adaptation of anticipations by augmenting the parameter k from 82% in 2012 to a value of 105% in 2020, leading to match 2020 emissions with the target.

The simulations show that if anticipations are not changed, the revision of the cap only leads to a carbon price of around 10€/t over Phase 3, meaning that participants consider in this case an emission trajectory that does not decrease significantly before 2020. In the second scenario, anticipation are changed to account for the need of a lower emission trajectory, preparing for the compliance with the 2030 target. Under those assumptions, the price is forecasted to rise progressively to 20€/t.

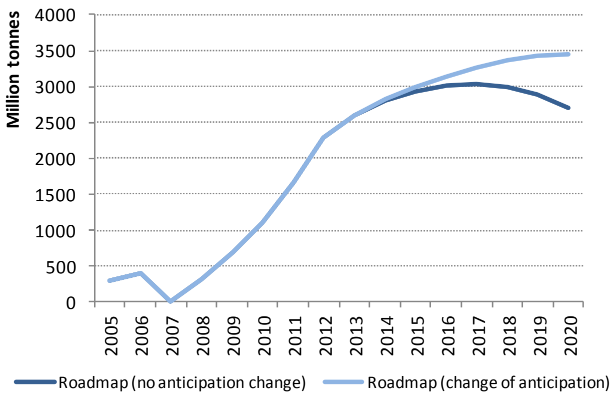
FIGURE 51 – ZEPHYR-FLEX POST 2012: "ROADMAP" SCENARIOS RESULTS



Source: author

As a consequence, the two scenarios have two resulting banking behaviors that differ in the end by around 1 Gt. The scenario in which anticipation are changed entails more banking than the other, so that emissions are maintained below the 2020 cap in advance (Figure 52).

FIGURE 52 – ZEPHYR-FLEX POST 2012: BANKING IN THE "ROADMAP" SCENARIOS



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3.4 A back-loading turning into a revision of the target: the "Gamble" scenario

The Roadmap scenario seems to be the only one to lead to a sustainable enhancement of the market, because it allows for a change of participants' anticipations and confidence over the long term. However, the discussions regarding the adoption of a strengthened 2020 target or a 2030 target are not, currently in 2012, leading to a consensus among Member States.

A scenario which imagined by some market players given the state of negotiations would be a shift to an EU ETS longer term target using auctions back-loading as a transitory measure. This is the scenario we are going to represent now.

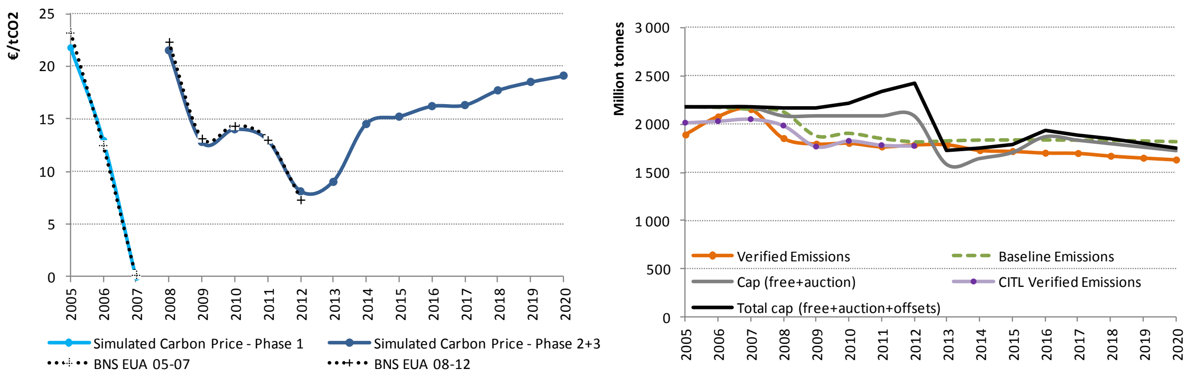
We assume the following sequence of events:

- In 2013, a set aside or back-loading of 900 Mt is implemented, leading to the reduction of auctions of 400 Mt in 2013, 300 Mt in 2014 and 200 Mt in 2015 in line with the European Commission proposal.
- As a reaction to this measure, installations "un-bank" a volume equivalent to 75% of allowances set aside in 2013, i.e. 300 Mt, which prevents the price to rise sharply contrary to the previous scenarios testes.
- Progressively realizing that the Commission is thinking about revising the EU ETS cap and that the volumes set aside may never come back to the market, installations "un bank" only 50% of the set aside volume in 2014, and 25% of the set aside volume in 2015.
- In 2016, the EU ETS cap is revised so that the 900 Mt set aside are never re-injected in the market, corresponding to a revision of the 2020 target from -21% to a little less than -30% compared to 2005.

- Installations anticipations are then considered in the model similar to those in the Roadmap scenario from 2016 and onwards.

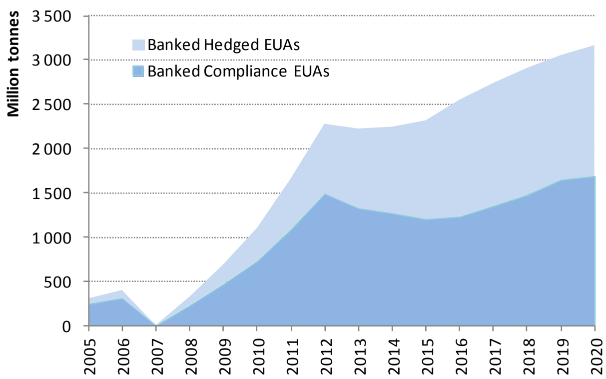
Figure 53 and Figure 54 present the simulation results under this set of assumption. The increase in price due to the set aside is smoothed over time because of actors drawing from banked allowances to replace the missing auctions, so that the price stays below 10€/t in 2013 and rises progressively to 15€/t in 2015. Once installations are convinced that the cap will be changed, they resume their banking behaviour which allows the price to rise to 20€/t in 2020.

FIGURE 53 – ZEPHYR-FLEX POST 2012: RESULTS IN THE "GAMBLE" SCENARIO



Source: author

FIGURE 54 – ZEPHYR-FLEX POST 2012: BANKING IN THE "GAMBLE" SCENARIO



Source: author

This scenario is one of the possibilities which is envisaged by participants to the market. Nevertheless there are many limits to the results presented here. We called it the "Gamble" scenario because it is very risky and relies on playing voluntarily with participants expectations. It would require actors to "un-bank" allowances, thinking the set aside allowances will be re-injected in the market, when this will not be the case. It requires also that the Commission and the Member States agree to shift from a set aside to a set away, which is not allowed explicitly by the current EU ETS rules. So even if the results of our simulation may lead to think that this would be a satisfying solution, it is one of the most risky and probably one which can lead to an enormous loss of confidence in the EU ETS regulation.

Conclusion on the measures tested

It is apparent that measures such as a reserve price at auctions or a set aside can cause the price to rise within the 2020 time horizon. But they significantly alter the quantities by increasing the amount of allowances carried over to the future, which potentially can generate market disruption. Although market actors acquire a better perception of prices in the short term, their long-term outlook becomes considerably less clear. Interventions by the public authority carried out in a hurry risk further weakening the scheme. Among the measures tested, only the revision of the cap accompanied by a renewed confidence in a longer term constraint can put back the allowance price on a "natural" path, meaning not forced artificially and not playing with actors expectations.

After eight years of operation, the EU ETS has not yet fully established its credibility. Although the courses of action currently under discussion may be able temporarily to increase price visibility, they risk further clouding the medium and long-term confidence required by market actors. As the simulations using the model ZEPHYR-Flex show, establishing a reserve price in allowances auctions or creating a set-aside system simply defers the problem to the future. On the other hand, setting an ambitious goal now for 2030 would not suffer from this disadvantage – but its impact on the market would depend on participants' expectations and on the credibility of the public authority, which in the current market governance context has been weakened.

4. How to coordinate climate related policies?

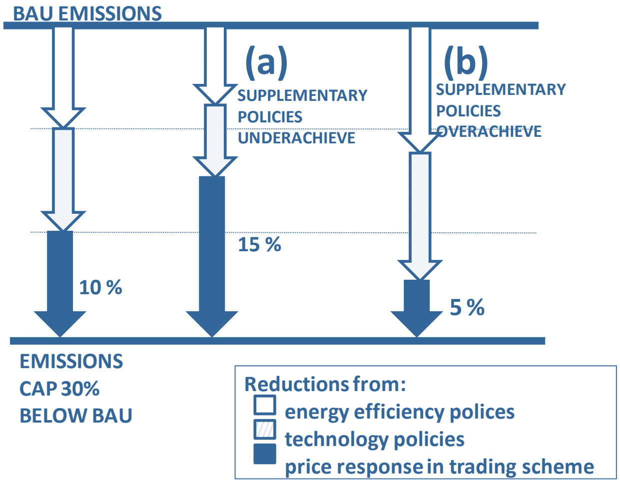
As shown in the previous sections, one major political issue for the future of EU ETS is the kind of articulation that should be found between different instruments of European climate policy. According to economic literature, the efficiency is obtained in using one instrument for each goal. This would lead in theory to recommend using one single instrument, i.e. the carbon price, for reaching all the climate policy goals. However, in the real world the European Union decided to use several tools. Therefore, this raises two questions: How to coordinate these instruments to reduce possible overlaps which could reduce the global efficiency of the policy? What is the specific function of carbon price in this coordination?

4.1 The necessary coordination of policies in the long term

The real question raised by the 2012 debates deals with the long term reduction goal, but also deals with the role given to the carbon price to reach this target among other tools. The past experience of the EU ETS suggests that forecasts and anticipations made at the beginning of a period may be disappointed later, thus casting doubt on the idea that the public authorities can permanently put allowance prices on the "right" path given the number of interactions between the EU ETS, other climate energy policies, and the general macroeconomic context. For this reason it seems to us that an intervention determining a 2030 ETS cap alone would not be sufficient, and that enhanced governance is needed to deal with the change of the economic and social context over time, in particular interactions with other policies.

There is a trade-off between the benefits of early action in reducing the cost of the transition to a low carbon economy, and the potential to undermine the carbon pricing policy. The long term relationship between these two effects is the key issue. Figure 55 illustrates how an energy efficiency policy impacts an emission trading system if the cap is not changed.

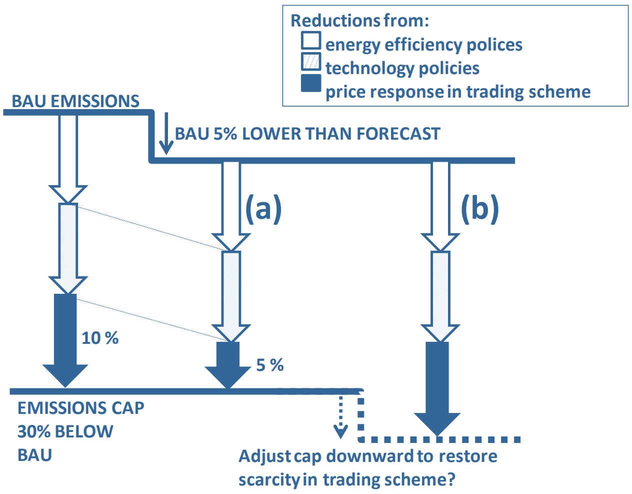
FIGURE 55 – STYLIZED INTERACTIONS BETWEEN TWO RELATED POLICIES



Source: Baron (2012)

To restore a level of constraint similar to that without policy interactions, it is necessary to adapt dynamically the cap as a function of how other policies deliver or not. This way of compensating interactions is represented in Figure 56 below.

FIGURE 56 – POLICY INTERACTION AND DYNAMIC MANAGEMENT OF THE TARGET



Source: Baron (2012)

One of the main recommendations to reduce inefficiencies which could be brought by overlap between instruments of climates policies is therefore to take into account the anticipated effect of other policies when setting up the cap. As those effects cannot be estimated with certainty at the beginning of the scheme, this imply to build up a political framework that takes into account ex-post information resulting from the implementation of these policies, in order to correct the cap when actual abatements resulting from other policies differ substantially from anticipated ones.

4.2 Can one price do everything?

Carbon pricing supplemented by energy efficiency and renewable energy policies are supposed to be the core tools in a least-cost package to fulfill the transition to a low carbon economy, as advocated in the Commission's Roadmap 2050. The choice of instruments represents a real challenge, because other policies may deliver or not and the total cost may be greater than with the market only.

Economic theory tells us in general that a single price is the most efficient way to induce reductions where they are less costly, thus minimizing the total cost of the reductions. But it supposes that the carbon price can effectively be transmitted to every agent, and that agents will react as expected to this signal.

For many reasons, this would not be the case in reality. For example in end uses, the potential for energy efficiency may not respond to the price signal because the final consumer does not always follow a rational path, or due to the presence of market failures (asymmetric information etc).

In other cases, a different price is needed because the market alone cannot deliver immediately a sufficient price. The case of early prototypes is a good example. Those additional prices are not in line with market price but are necessary to launch a learning process leading eventually to costs comparable to market prices. Those additional prices are not made to be sustained over a long period.

5. Conclusion

In this last chapter, we shifted from an *ex post* use of the model which allowed for a better understanding of the past, to an *ex ante* use of the tool, simulating the development of the market until 2020, given the information available up to the end of July 2012.

The calculation of the baseline, projected to 2020, has been adapted to simulate the effects of other climate-energy related policies, by reducing the future baseline emissions, and increasing the anticipated supply of allowances if participants' anticipations are not changed, as shown with the two preliminary simulations presented of this chapter. Of course, anticipations are indeed going to change in the future, and the question is how, why and when?

The main result from the proposals of intervention tested in our simulations is that only the strengthening of the cap to 2020 and its prolongation to at least 2030 leads to a sustainable enhancement of the market, because it is the only simulation to allow for a coherent support to the needed change of participants' anticipations and confidence, over the medium to long term.

Our analysis is not an attempt to forecast the future with a high level of details, which would be difficult given the current limits of our model, for example the projection of the counterfactual scenario and of the marginal abatement cost curves to 2020. However, the ZEPHYR-Flex model enlightens the market mechanisms behind price formation and their link with the precise rules of the EU ETS and the evolution of participants' anticipations over time. It allows testing the compatibility of different sets of assumptions. The results obtained in our simulations are relevant in this sense.

The simulations of this chapter may seem too stylized but they are revealing the determining weight of participants' anticipations and behavior on the medium term price trends. Especially, they reveal that those anticipations must be solid and coherent with all the other relevant information regarding the scheme (future rules, growth outlook etc). We have seen in Chapter 1 that most of these influences were variable over time, by nature. When considering an intervention from the public authority on the market to change participants' anticipations, our results suggest that those changes risk undermining the system credibility. The question raised at the end of 2012, treated or not, will come back eventually, because it is the nature of the scheme to adapt itself to unforeseen changes in context. As an example of how EU ETS rules allow for adaptation to the context but also change over time, we can point the rules for using offsets (time flexibility, addition of the 2013-2020 period in 2009, industrial gases restrictions in 2010, etc) which, as seen in Chapter 3, have induced a large amount of unpredictability regarding the actual allowance cap since 2008.

This fact, along with the existence of interactions with other policies and "shadow" carbon prices which effect is variable and can only be observed ex-post, poses a real governance problem, which we think would not be solved by any of the proposals of interventions studied in this chapter, and should be solved as soon as possible. If not, our simulations show that the EU ETS risks gradually losing its credibility and its role as a core policy to reach Europe 2050 goals in the most efficient manner, with a carbon price hovering at very low prices up to 2020. The necessary adaptations of the scheme over time and the induced change of anticipations of participants will determine the overall cost-efficiency of the EU ETS, and deserve more than adjustments made in a hurry.

Conclusion

As seen in the introduction, there is a large consensus among economist to favor economic tools which aims at protecting the environment in the most efficient way, i.e. by minimizing the total cost of pollution abatement. Despite those recommendations, most of the environmental policies conducted in practice continue to favor “command and control” policies. Since the adoption of the Kyoto protocol in 1997, climate change policy is a notable exception.

The European Union Emission Trading Scheme (EU ETS) is in 2012 the largest greenhouse gases emissions trading system in the world and a “living experiment” for studying the effect of such economic tool applied to the issue of climate change. Originally created in 2005 to facilitate the achievement by European Member States of the targets set by the Kyoto Protocol for the period 2008-2012, it inherited most of it specificities. The work presented in this thesis can provide lessons on the design and achievements of the EU ETS given its Kyoto heritage, with three main results.

The first result of this thesis is to provide a complete assessment of the two first phases of the EU ETS by a careful *ex post* observation of the market development and to what extent the initial goals have been reached. In doing so, we extend the work already done by Ellerman, Convery and De Perthuis (2011) on the first Phase. The observation of the first two phases of operation done in Chapter 1 exhibits a carbon price which differs greatly from *ex ante* expectations. Since its launch in 2005, the system has delivered a price with a great level of unpredictability. We show that it is not possible to understand the observed developments without looking more closely into the dynamics of the EU ETS, which are conferred by the three flexibility provisions: the ability to trade allowances between participants examined in Chapter 2, the possibility of using other types of carbon assets than EUAs for compliance under the scheme scrutinized in Chapter 3, and the ability to hold unused allowances for a later use, or borrow allowances in advance studied in Chapter 4.

The second result of our thesis is the construction of the ZEPHYR-Flex model. The model differs from existing models: macro models which represent global energy markets equilibrium, with a strong technologic-economic core such as the PRIMES model or the POLES models; and econometric models. The ZEPHYR-Flex model represents the balance between supply and demand of allowances, using a detailed representation of the EU ETS, its perimeter, and its rules over the period. In its last version, it is able to replicate historical prices and quantities trajectories, and explain the gap between *ex ante* expectations and *ex post* observations from Chapter 1. The model allows us to access information on the compliance behavior of participants (abatement, trading, banking and borrowing), as well as the related compliance costs, and the impact of allowing the use of offsets.

Those first two results lead to conclude that the EU ETS induced a cumulated amount of emission reduction of about 1540 Mt over the first two Phases. Among those reductions, 35% have been obtained outside the scheme’s perimeter through the use of carbon offsets (550 Mt). With those internal emission reductions and the use of offsets we estimate that, given the level of the allowance cap, the cumulated net banking of allowances at the end of 2012 is close to 2,000 Mt. The total compliance costs are estimated at 30 bn€, 14bn of which are related to emission reductions inside the scheme, 11bn€ for reductions outside the schemes (offsets), 5bn to buy allowances at auctions. The exchange of allowances between participants represents a value of 18 bn€ over the first two phases. As seen in the end of Chapter 3 and 4, the offset provision generated substantial economies.

However, the accuracy of our results depends on the data used to parameterize the model, in particular in two domains. The first is the technical-economic block consisting of the marginal abatement cost curves and how they relate to the counterfactual scenario, as well as their behavior over time in relation to past abatement and economical/technological changes. This is a wide research topic which would allow a better representation of the economy in our model. The second is related to the availability of CITL data. The transactions data detailing the exchanges of allowances between all participants to the market is only disclosed after a five year delay, meaning that the complete Phase 1 and Phase 2 data will be available from 2017. That information can reveal a lot on the trading, banking and borrowing behavior of participants, thus allowing for a better calibration of the model. In these two fields, further research could bring more insights on the functioning of the European carbon market. Studies have already been launched at the Climate Economic Chair to improve our understanding of abatement and the related costs, as well as on the relationship between growth and baseline emissions. The transaction data made gradually available for Phase 1 is also under investigation.

The third result from this thesis is to draw lessons from *ex post* observations and a set of simulations to enlighten the possible future of the EU ETS. The ZEPHYR-Flex model is used as an *ex ante* assessment tool on a selection of possible stylized scenarios to 2020. It showed that the measures currently discussed to restore market confidence by 2015 have very low relevance if they don't integrate measures that define with credibility the future cap after 2020. The simulations presented in Chapter 5 show that these measures, without long term outlook and foundation, could induce more uncertainty and instability, because they would not allow the firms to set up "correct" anticipations by themselves.

The lesson is that it is very difficult to send the "right" incentives to market players in the absence of explicit long term targets that are connected with the current and medium term cap. From this standpoint, it is interesting to notice that the US SO_2 trading program included a 30 years cap. The results from this thesis show that in the absence of such a foundation, it is very difficult to establish a price which translates adequately the actions required from the short to the long term. The unforeseen evolution of the macro-economic context, the state of international negotiations and the link with an offsetting mechanism are factors which can be extraordinarily stimulating but also dangerous if not anticipated correctly.

This leads us to remind the third main rules that underpin any environmental market: integrity, transparency, credibility.

Integrity. Integrity is a condition required by market players for participating to the market and undertaking concrete efforts to reduce emission in the short and the long term. A regulating authority is required to allocate permits and verify emission, assure that emissions are properly monitored and reported, manages a permit registry to guarantee that each permit is surrendered only once so that the overall cap on emissions is not exceeded, traces transactions in a registry which is the repository of property rights, and enforces compliance (imposes a penalty) on non-compliant entities.

Transparency. Liquidity and transparency reduce transaction costs and facilitate the efficient exchange of permits between participants. The market must be free of any abuse or strategic behavior influencing the price, it must also be liquid so that it is easy to find counterparty, and all entities should have access to the same information.

Credibility. Actors need to be able to anticipate and trust the probable changes of rules or market conditions over time. The price of allowances only exists because the quantity of permits is limited (scarcity rent). A permit can be considered as a pure artificial construction. Its existence relies on the political will to effectively guide the economy on a certain emission path. Secondly, the market price takes into account the current conditions, but it also takes into account the effect of actors' anticipations via the flexibility mechanisms.

If one of these pillars cannot play entirely its role, the system could simply disappear over time. This is the main risk affecting the EU-ETS in its current turmoil. The work presented in this thesis advocates the implementation of a renovated governance framework which would guarantee the emergence of the conditions needed by participants to correctly form their anticipations given the long term goal set by society, and would ensure that the policy and context risks are controlled whatever the situation, always in the same way, from the short term market conditions to the system's long term credibility.

It is difficult given the situation in the end of 2012 to take a few steps back and look at the situation objectively. We can nevertheless think that those lessons are limited to the current knowledge and could be revised for many reasons in the future. For example, a memorandum of understanding has recently been signed for a possible linking with the Australian trading system from 2015. Such changes, as well as the future economic and technologic developments, or the evolution of international negotiations could change many things we think today are definitively acquired. Let us not reproduce the same subjective patterns from the past when looking to the future.

At the end of this thesis, one could ask whether, given all the issues identified in this thesis, it would not be simpler to introduce a tax instead of an emission trading scheme. The results from this thesis indicate that no matter the tool chosen, the set of issues remain the same: assuring the integrity and the environmental effectiveness, access to transparent information, and credibility in the articulation between the short term constraints and the long term goals associated to any public policy. Given where we stand now, it would be appropriate not to abandon what has been started to shift to a tax system, but to strengthen the EU ETS regarding those three pillars and to extend the economic signal outside the EU ETS perimeter, whether by taxes or other quantitative tools adapted to the remaining sectors currently out of the set of climate policies. The coordination of all those policies is a crucial governance challenge, which requires a serious debate and probably innovative regulation frameworks, ensuring their overall consistency and cost-efficiency over time.

References

Alberola, E., Chevallier, J., Chèze, B. (2008a), Price Drivers and Structural Breaks in European Carbon Prices 2005-07, Energy Policy 36(2), 787-797

Alberola, E., Chevallier, J., Chèze, B. (2008b), The EU Emissions Trading Scheme: the Effects of Industrial Production and CO2 Emissions on European Carbon Prices, International Economics 116, 93-126

Alberola, E., Chevallier, J. (2009), European Carbon Prices and Banking Restrictions: Evidence from Phase I (2005-2007). The Energy Journal 30(3), 51-80

Alberola, E., Chevallier, J., Chèze, B. (2009), Emissions Compliances and Carbon Prices under the EU ETS: A Country Specific Analysis of Industrial Sectors, Journal of Policy Modeling 31(3), 446-462

Baron, R. (2012), Energy efficiency policies and the carbon price: what logic?, Presentation at the workshop "Carbon market interventions and climate-energy policies coordination", February 2012

Baumol, W. J. and Oates, W. E. (1971), The Use of Standards and Prices for Protection of the Environment, Swedish Journal of Economics 73: 42-54

Bellassen, V., Stephan, N. and Leguet, B. (2012), Will there still be a market price for CERs and ERUs in two years time?, CDC Climat Research, Climate Brief n°13, May 2012

Berghmans, N (2012), Coordinating the Climate & Energy Package with the EU ETS: more to be done, Tendances Carbone n°71, July 2012

Boutueil, V., Solier, B. and Russo, R. (2011), The inclusion of air transport in the EU ETS, in De Perthuis and Jouvet (eds., 2011)

Bunn, D. W., Fezzi, C. (2009), Structural interactions of European carbon trading and energy prices, Journal of Energy Markets 2(4), 53-69

Chateauneuf, A., Eichberger, J., and Grant, S. (2007), Choice under Uncertainty with the Best and Worst in Mind: NEO Additive Capacities, Journal of Economic Theory, 137, 538-567, 2002.

Chevalier, J-M., Derdevet, M. and Geoffron, P. (2012), L'avenir énergétique : Cartes sur table, Folio Actuel ; Gallimard, February 2012

Chevallier, J., Ielpo, F., Mercier, L. (2009), Risk Aversion and Institutional Information Disclosure on the European Carbon Market: a Case-Study of the 2006 Compliance Event, Energy Policy 37(1), 15-28.

Chevallier, J. (2009), Carbon futures and macroeconomic risk factors: A view from the EU ETS, Energy Economics 31(4), 614-625

Chevallier, J. (2011), Carbon Price Drivers: An Updated Literature Review, Working Paper, Paris-Dauphine University, April 2011

Coase, R. H. (1960), The Problem of Social Cost" Journal of Law and Economics 3: 1-44, October 1960

Convery, F. J., Redmond, L. (2007), Market and Price Developments in the European Union Emissions Trading Scheme, Review of Environmental Economics and Policy 1(1), 88-111

Convery, F. J., Ellerman, A. D., De Perthuis, C. (2008), "The European Carbon Market in Action: Lessons from the first Trading Period", Interim report, MIT CEEPR Working Paper n°2008-002

Convery, F. (2009), Origins and development of the EU ETS, Environmental and Resource Economics, 43, 391–412, 2009

Cormier, A. and Bellassen, V. (2012), The risks of CDM projects: how did only 30% of expected credits come through?, CDC Climat Research, Working Paper n°2012-11, January 2012

Criqui, P. and Mima Silvana (2001), The European greenhouse gas tradable emission permit system : some policy inssues identified with the POLES-ASPEN model, ENER Bulletin, (23), p. 51-55, 2001

Criqui P., Kitous A., Stankeviciute L. (2005), Climate policies and the implementation of emission trading in Europe, IFE - LEPII-EPE/ENERDATA, Grenoble, 2005

Crocker, T.D. (1966), Structuring of Atmospheric Pollution Control Systems, In: The Economics of Air Pollution, H. Wolozin (Editor), W. W. Norton, New York, pp. 61-86

Dales, J. H. (1968), Pollution, property and prices: An essay in policy-making and economics. University of Toronto Press

De Cara, S., and Jayet, P.-A. (2011), Marginal abatement costs of greenhouse gas emissions from European agriculture, cost effectiveness, and the EU non-ETS Burden Sharing Agreement, Ecological Economics, 70(9), 1680-1690

Delarue, E. D., Ellerman, A. D. and D'Haeseleer, W. D. (2008), Short-term CO_2 Abatement in the European Power Sector, MIT CEEPR Working Paper n°08-008, June 2008

Demsetz, H. (1964), The Exchange and Enforcement of Property Rights, Journal of Law and Economics, Vol. 7, pp. 11-26, The University of Chicago Press, Oct. 1964

Declercq, B., Delarue, E., D'Haeseleer, W. (2011), Impact of the economic recession on the European power sector's CO2 emissions, Energy Policy 39, 1677-1686

DEFRA (UK Department for Environment, Food and Rural Affairs), 2007, EU Emissions Trading Scheme Approved Phase II National Allocation Plan, published on 16 March 2007

De Perthuis, C. and Jouvet, P-A., eds. (2011), Climate Economics in Progress 2011, Economica, October 2011

De Perthuis, C. and Trotignon, R. (2012), EU ETS: issues in the transition to Phase 3, Climate Economics Chair, Paris-Dauphine University, Information and Debates n°14, March 2012

Deustche Bank (2003), Current Issues - EU trade in CO_2 emissions: 2005 launch deadline at risk, Deutsche Bank Research, December 2003

Dresdner Kleinwort Wasserstein Research (2003), Emission Trading – Carbon Derby Part II: And they're off, October 2003

Ellerman, A. D., Schmalensee, R., Joskow, P. L., Montero, J-P., and Bailey, E. (2000), Markets for Clean Air: The U.S. Acid Rain Program. Cambridge, UK: Cambridge University Press

Ellerman, A. D. (2003), Ex Post Evaluation of Tradable Permits: The U.S. SO_2 Cap-and-Trade Program, MIT CEEPR Working Paper 03-003, February 2003

Ellerman, A. D., Joskow P. L. and Harrison, D. Jr. (2003), "Emissions trading in the US: Experience, Lessons, and Considerations for Greenhouse Gases", prepared for the Pew Center on Global Climate Change

Ellerman, A. D., Montero J. P. (2007), The Efficiency and Robustness of Allowance Banking in the U.S. Acid Rain Program, The Energy Journal, Vol. 28, No. 4, pp. 67-92, 2007

Ellerman, A. D., Buchner, B. K., Carraro, C. (2007), Allocation in the European Emissions Trading Scheme: Rights, Rents and Fairness, Cambridge University Press, April 2007

Ellerman, A. D. and Trotignon, R. (2009), Cross Border Trading and Borrowing in the EU ETS, The Energy Journal, Volume 30 (Special Issue 2), Climate Change Policies After 2012, 2009

Ellerman, A. D., Convery, F. J., De Perthuis, C. (2010), "Pricing Carbon : the European Union Emissions Trading Scheme", Cambridge University Press, March 2010

Elsworth, R., Worthington, B. (2010), International Offsets and the EU 2009, Sandbag, July 2010

European Commission (1992), Proposal for a Council Directive introducing a tax on carbon dioxide emissions and energy, COM(92) 226 final, Brussels, 30 June 1992

European Commission (1998), Climate Change: towards an EU post-Kyoto strategy, Communication from the Commission to the Council and the European Parliament, COM(98)353

European Commission (2001), Proposal for a Directive of the European Parliament and of the Council establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC, COM(2001) 581 final

European Commission (2003), Extended impact assessment on the Directive of the Parliament and of the council amending Directive establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of Kyoto Protocol's project based mechanisms, SEC(2003) 785, July 23, 2003.

European Commission (2010), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Analysis to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage, COM(2010) 265 final

European Commission (2011a), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Roadmap for moving to a competitive low carbon economy in 2050, COM(2011) 112 final, March 2011

European Commission (2011b), Commission Regulation n° 550/2011 of 7 June 2011 on determining, pursuant to Directive 2003/87/EC of the European Parliament and of the Council, certain restrictions applicable to the use of international credits from projects involving industrial gases, June 2011

European Commission (2012a), Commission Staff Working Document, Information provided on the functioning of the EU Emissions Trading System, the volumes of greenhouse gas emission allowances auctioned and freely allocated and the impact on the surplus of allowances in the period up to 2020, SWD(2012) 234 final, July 2012

European Commission (2012b), Proposal for a Decision of the European Parliament and of the Council amending Directive 2003/87/EC clarifying provisions on the timing of auctions of greenhouse gas allowances, COM(2012) 416 final, 2012/0202 (COD), July 2012

European Parliament and the Council of the EU (2003), Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC

European Parliament and the Council of the EU (2004), Directive 2004/101/EC of the European Parliament and of the Council of 27 October 2004 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms, Official Journal of the European Union L338, 18–23

European Parliament and the Council of the EU (2008), Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community

European Parliament and the Council of the EU (2009), Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, Official Journal of the European Union I.140, 63–87

European Council (2007), Presidency Conclusions of the Brussels European Council, 8/9 March 2007, 7224/1/07 REV1 CONCL 1

European Council (2002), Council Decision of 25 April 2002 concerning the approval, on behalf of the European Community, of the Kyoto Protocol to the United Nations Framework Convention on Climate Change and the joint fulfilment of commitments thereunder, 2002/358/EC

Flachsland, C., Marschinski, R., and Edenhofer, O. (2009), To Link Or Not To Link: Benefits and Disadvantages of Linking Cap-and-Trade Systems, Climate Policy 9 (4), p.358-372, July (2009), Special Issue on "Linking emissions trading schemes"

Frondel, M., and Schmidt, C., M. (2001), Evaluating Environmental Programs: The Perspective of Modern Evaluation Research, ZEW Discussion Paper No. 01-59, Centre for European Economic Research, 2001

Grubb, M., and Laing, T. (2009), Price Floors – Getting Some Perspective, CEPS/IETA Workshop: Pushing and Pulling: What has the EU learned about the efficient combination of carbon market and low-carbon investment support, September 2009

Goulder, L. H. (1994), Environmental Taxation and the "Double Dividend:" A Reader's Guide, NBER Working Paper No. 4896, October 1994

Goulder, L. H. and Pizer, W. A. (2006), The Economics of Climate Change, NBER Working Paper No. 11923, January 2006

Heindl, P. and Loeschel, A. (2012), Designing Emissions Trading in Practice: General Considerations and Experiences from the EU Emissions Trading Scheme, ZEW Discussion Paper No. 12-009, Centre for European Economic Research, March 2012

Hintermann, B. (2010), Allowance price drivers in the first phase of the EU ETS, Journal of Environmental Economics and Management 59, 43-56

Hotelling, H. (1931), The Economics of Exhaustible Resources, The Journal of Political Economy, Volume 39, Issue 2, 137-175, Apr. 1931

Jouvet, P-A., Chevallier, J. and Etner, J (2011), Bankable Pollution Permits under Uncertainty and Optimal Risk Management Rules, Research in Economics, 2011

Jouvet, P-A., Creti, A. and Mignon, V. (2012), Carbon price drivers: Phase 1 versus Phase 2, Energy Economics, 2012

Klepper, G., Peterson, S, (2004), The EU emissions trading scheme: allowance prices, trade flows, competitiveness effects, FEEM Working Papers No. 2004-49

Lecourt, S. (2012), The EU ETS Phase 3 preliminary amounts of free allowances, Climate Economics Chair, Information and Debates Series n°16, June 2012

Loeschel, A. et al. (2009, 2010, 2011 and 2012), KFW/ZEW CO2 Barometer: Annual report on the activities and expectations in European emissions trading, KFW Bankengruppe and Center for European Economic Research (ZEW).

Mansanet-Bataller, M., Pardo, A., Valor, E. (2007), CO_2 Prices, Energy and Weather, The Energy Journal 28, 73-92

Martino, V. and Trotignon, R. (2012), For the Record: Uncovering Market Behavior in Phase 1 of the EU ETS, Climate Economics Chair Working Paper, forthcoming

McGuinness, M. and Trotignon, R. (2007), Technical Memorandum on Analysis of the EU ETS Using the Community Independent Transaction Log, MIT Center for Energy and Environmental Policy Research, Working Paper 07-12, December 2007

Mendelsohn, R. O. and Neumann, J. E., (Eds.) (1999) The Impact of Climate Change on the United States Economy, Cambridge: Cambridge University Press

Montgomery, D., W. (1972), Markets in Licenses and Efficient Pollution Control Programs, Journal of Economic Theory, n°5, 395-418, May 1972

Montero, J. P., Sanchez J. M. et al. (2002), "A Market-Based Environmental Policy Experiment in Chile", Journal of Law and Economics 45(1, Part 1): 267-287

Newell, R. G. and Stavins, R., N. (2003), Cost Heterogeneity and the Potential Savings from Market Based Policies, Journal of Regulatory Economics, 23:1, 43-59, 2003

Newell, R. G. and W.A. Pizer (2003a), "Regulating Stock Externalities under Uncertainty", Journal of Environmental Economics and Management, vol. 45 (2003), pp. 416-432

Newell, R. G. and W.A. Pizer (2003b), "Discounting the Distant Future: How Much Do Uncertain Rates Increase Valuations?", Journal of Environmental Economics and Management, vol. 46 no. 1 (2003), pp. 52-71

Newell, R. G. and W.A. Pizer (2004), "Uncertain Discount Rates in Climate Policy Analysis", Energy Policy, vol. 32 no. 4 (2004), pp. 519-529

Nordhaus W. D. (2007), To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming, Review of Environmental Economics and Policy, Volume 1, Issue 1, pp. 26–44

Nussbaum, B. D. (1992), "Phasing Down Lead in Gasoline in the U.S.: Mandates, Incentives, Trading and Banking"

Olander, L. and Murray, B. (2008), Offsets: An Important Piece of the Climate Policy Puzzle, Nicholas Institute for Environmental Policy Solutions, Duke University, August 2008

Pearce, D. (2003), "The social cost of carbon and its policy implications", Oxford Review of Economic Policy, Vol 19, No 3, Nov 2003

Pigou, A. C. (1920), The Economics of Welfare, Macmillan, London, 1920

Point Carbon (2002), Lessons learned in 2002, Carbon Market Analyst of 23 December 2002, citing forecasts from Carbon Market Analyst of 26 September 2002.

Point Carbon (2003a), What price for EU allowances?, Carbon Market Analyst of 26 March 2003

Point Carbon (2003b), Viewpoint: What price for EU allowances?, poll published in Carbon Market Europe of 25 April 2003

Ramseur, J. (2008), The Role of Offsets in a Greenhouse Gas Emissions Cap-and-Trade Program: Potential Benefits and Concerns, Congressional Research Service, Report for the US Congress, April 2008

Rubin, J. D. (1996), A Model of Intertemporal Emission Trading, Banking, and Borrowing, Journal of Environmental Economics and Management 31, 269-286, Article No. 0044, 1996

Solier, B. and Trotignon, R. (2010), Comprendre les enjeux énergétiques, Collection Comme un expert, Pearson, September 2010

Solier, B. and Jouvet, P-A. (2011), An overview of CO2 cost pass-through to electricity prices in Europe, Climate Economics Chair Working Paper n°2011-08, July 2012

Stankeviciute, L. and Criqui, P. (2008), Energy and climate policies to 2020: the impacts of the European "20/20/20" approach, International Journal of Energy Sector Management, Vol. 2 Iss: 2, pp.252 - 273

Stavins, R. and R. Hahn (1993), "Trading in Greenhouse Permits: A Critical Examination of Design and Implementation Issues", Cambridge, MA, John F. Kennedy School of Government, Harvard University

Stern N. (2007), The Economics of Climate Change: The Stern Review, Cambridge University Press, Cambridge, UK

Stolyarova, E., (2012), Observed and modeled relationships between GDP growth, energy production, and CO_2 emissions in the World, Climate Economics Chair Working Paper Series, forthcoming

Tietenberg, T. H. (1973), "Controlling Pollution by Price and Standard Systems: A General Equilibrium Analysis", Swedish Journal of Economics 75: 193-203

Tietenberg, T. H. (1985), "Emissions Trading: An Exercise in Reforming Pollution Policy", Washington DC, Resources for the Future

Tietenberg, T. (2006), "Emissions Trading: Principles and Practice", 2nd ed., Resources for the Future, Washington

Tietenberg, T. (2008), "The Evolution of Emissions Trading", 2008 AEA Conference Papers

Tol, R. S. J. (2005), The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties, Energy Policy, Vol. 33,No. 16, pp. 2064-2074

Trotignon, R. and Delbosc, A. (2008), Allowance Trading Patterns During the EU ETS Trial Period: What does the CITL reveal?, Climate Report n°13, CDC Climat Research, June 2008

Trotignon, R. and Ellerman, A. D. (2008), Compliance Behavior in the EU-ETS: Cross Border Trading, Banking and Borrowing, MIT CEEPR Working Paper n°08-012, September 2008

Trotignon, R. (2009), Comprendre le réchauffement climatique, Collection Comme un expert, Pearson, November 2009

Trotignon, R. and Leguet, B. (2009), How Many CERs by 2013?, Mission Climat of Caisse des depots, Working Paper n°2009-5, August 2009

Trotignon, R. and Solier, B. (2011), The European Market on the Road to Phase 3, in De Perthuis, C. and Jouvet, P-A., eds. (2011), Climate Economics in Progress 2011, Chapter 2, Economica, October 2011

Trotignon, R (2012), Combining cap-and-trade with offsets: lessons from the EU-ETS, Climate Policy, Vol. 12, Iss. 3, 2012

UNEP Risoe (2012), Clean Development Mechanism and Joint Implementation Databases, www.uneprisoe.org

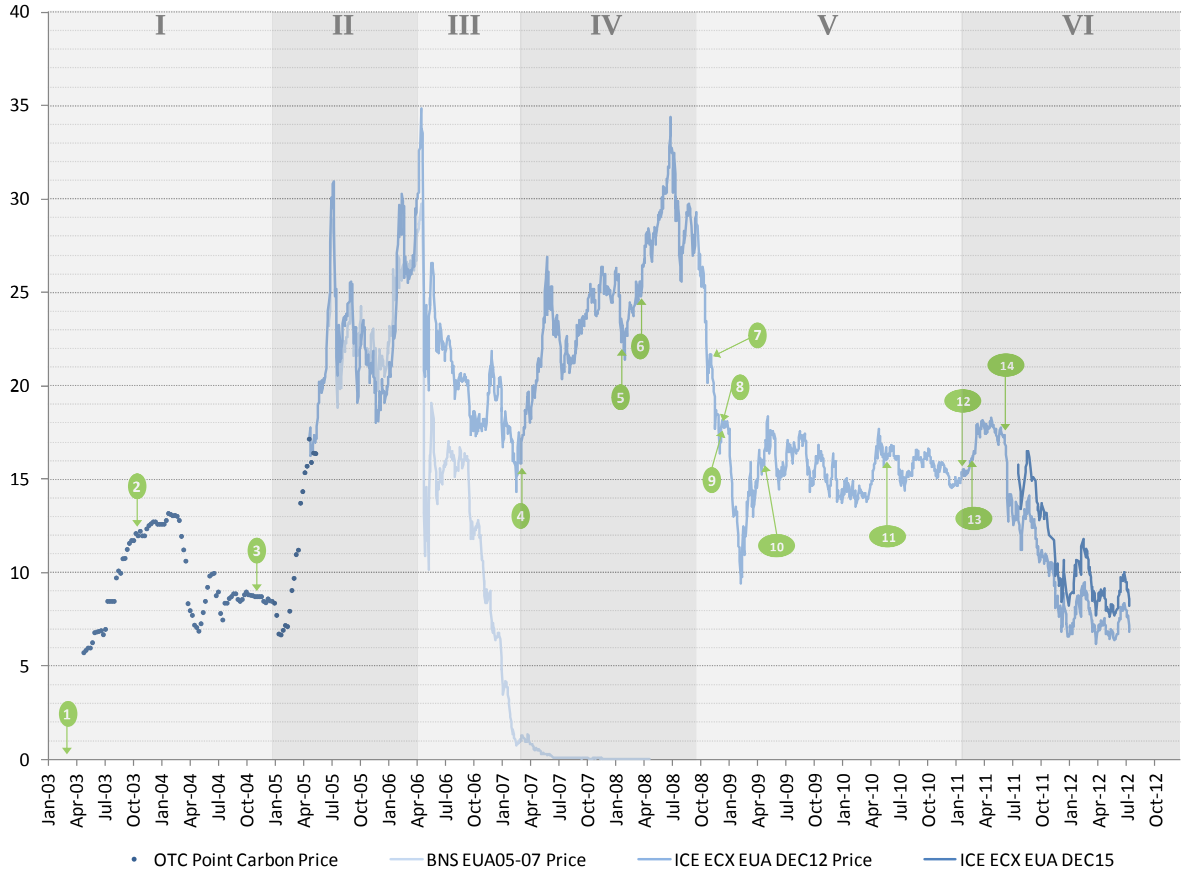
UNFCCC (1997), "Kyoto Protocol to the United Framework Convention on Climate Change"

UNFCCC (2002), "Agreement between the European Community and its Member States under article 4 of the Kyoto Protocol", Conference of the Parties, Eighth session, FCCC/CP/2002/2, 12 June 2002

Weitzman M. L. (1974), Prices vs. Quantities, The Review of Economic Studies, Vol. 41, No. 4 (Oct., 1974), pp. 477-491

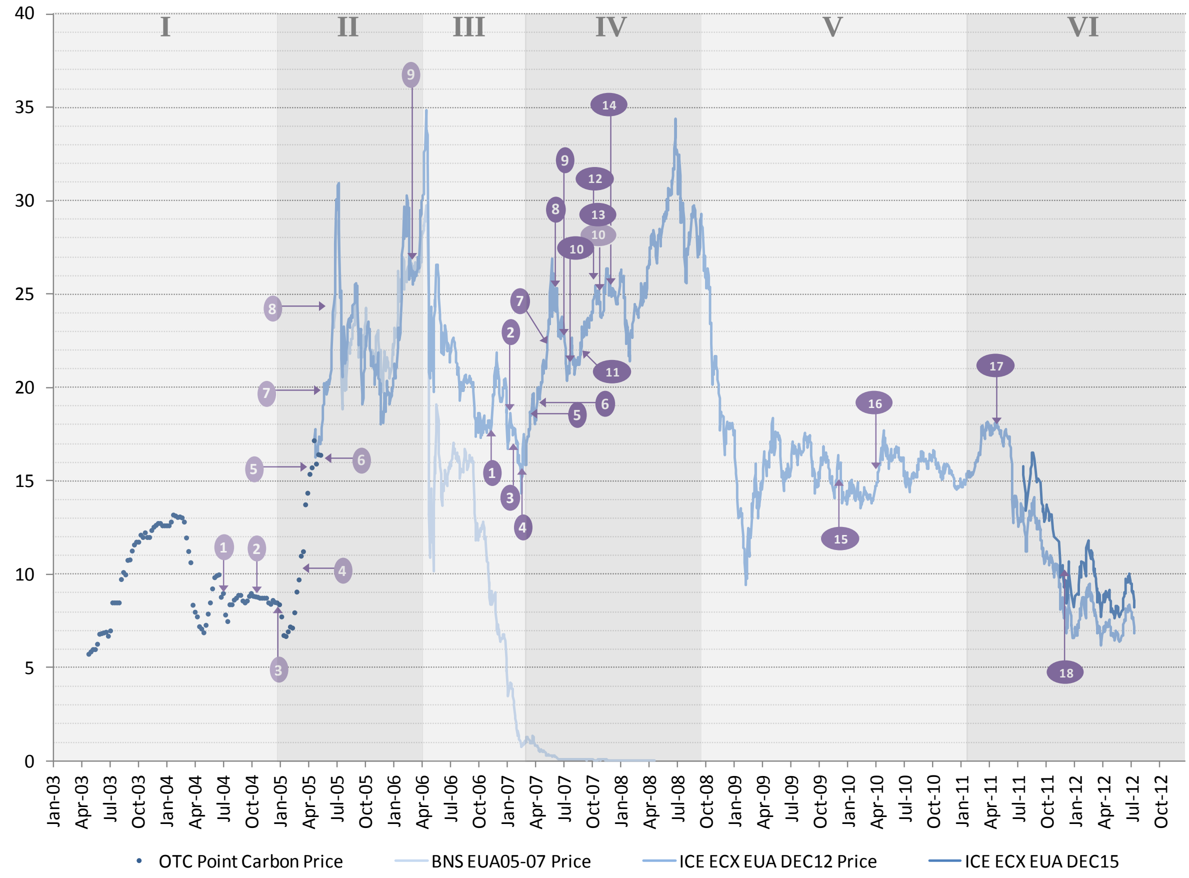
Whitesell, W., C. (2011), Climate Policy Foundations - Science and Economics with Lessons from Monetary Regulation, Cambridge University Press, 2011

Annex A$_1$: Adoption of official texts



1	18/3/2003	EU ETS: Common Position (EC) No 28/2003 adopted by the Council
2	13/10/2003	EU ETS Directive 2003/87/EC
3	27/10/2004	EU ETS Linking with CDM/JI (Directive 2004/101/EC)
4	08/3/2007	EU Council Decision on 2020 targets
5	23/1/2008	Commission proposal for a Climate Energy Package COM(2008)30
6	13/3/2008	Council Decision on a Climate Energy Package
7	19/11/2008	EU ETS Inclusion of aviation in 2012 (Directive 2008/101/EC)
8	11/12/2008	Council Adoption of the Climate Energy Package
9	17/12/2008	Parliament Adoption of the Climate Energy Package
10	23/4/2009	Climate Energy Package: Directive 2009/29/EC (EU ETS), Directive 2009/31/EC (CCS), Directive 2009/28/EC (Renewables)
11	26/5/2010	Commission analysis of options to move beyond 20% reductions
12	04/2/2011	EU Council on the Roadmap 2050
13	08/3/2011	Commission communication « A Roadmap for moving to a competitive low carbon economy in 2050 » and « Energy Efficiency Plan 2011 »
14	22/6/2011	Commission proposal for a Directive on energy efficiency

Annex A2: Decisions on NAP 1 and NAP 2

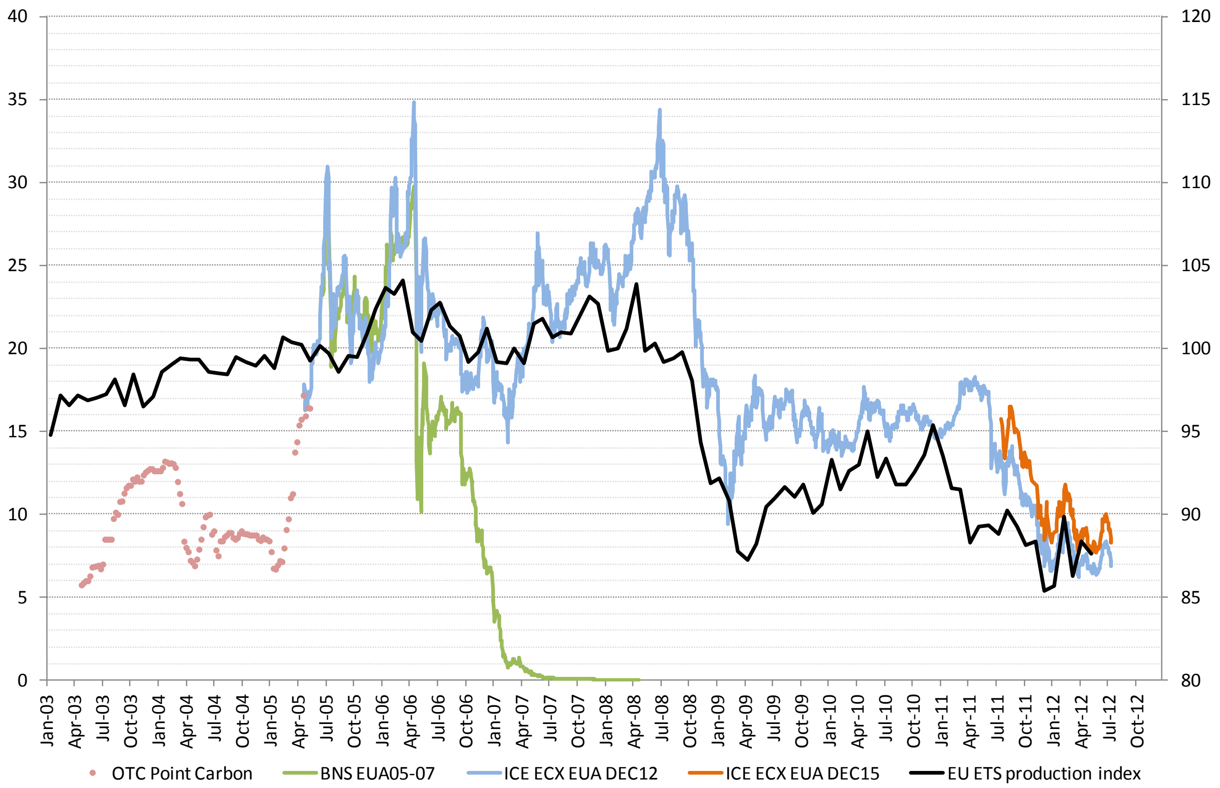


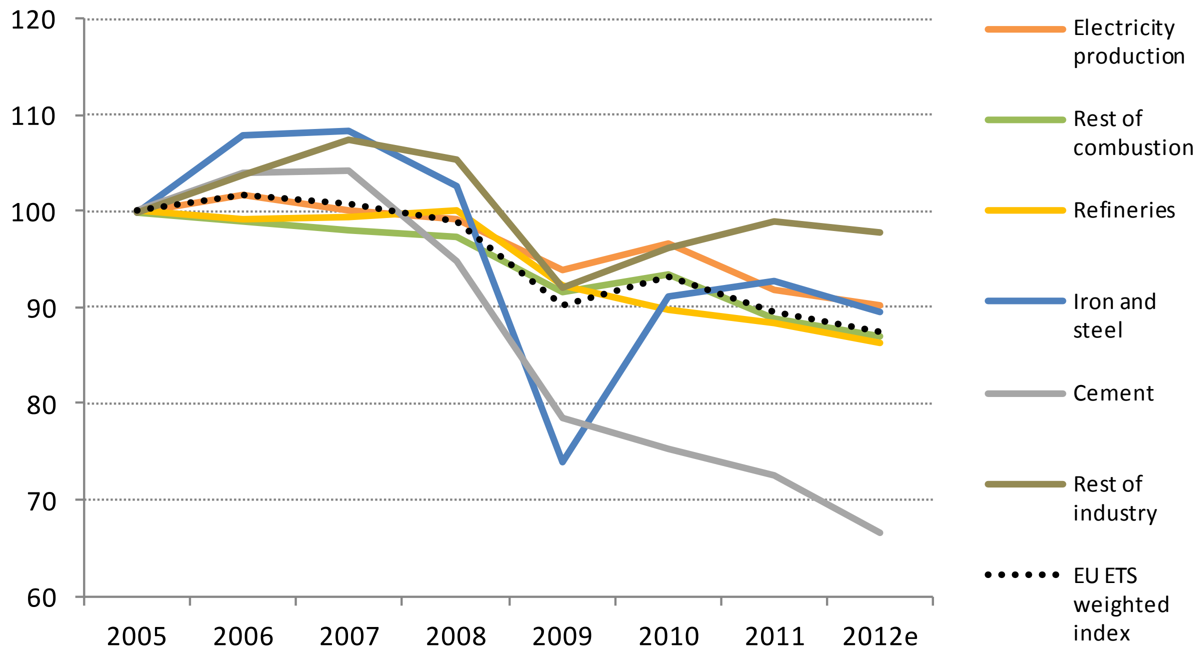
1	07/7/2004	**ECNAP1 Decision** AT, DK, DE, IE, NL, SE, SI, UK
2	20/10/2004	**ECNAP1 Decision** BE, EE, FI,FR,LV, LU, PT, SK
3	27/12/2004	**ECNAP1 Decision** CY, HU, LT, MT, ES
4	08/3/2004	**ECNAP1 Decision** PL
5	12/4/2005	**ECNAP1 Decision** CZ
6	12/4/2005	**ECNAP1 Decision** UK (2)
7	25/5/2005	**ECNAP1 Decision** IT
8	20/6/2005	**ECNAP1 Decision** GR
9	22/2/2006	**ECNAP1 Decision** UK (3)
10	26/10/2007	**ECNAP1 Decision** BG, RO

1	29/11/2006	**ECNAP2 Decision** DE, IE, SE, UK, LV, LU, SK, LT, SK, LV, MT, GR
2	16/1/2007	**ECNAP2 Decision** NL, BE
3	05/2/2007	**ECNAP2 Decision** SI
4	26/2/2007	**ECNAP2 Decision** ES
5	26/3/2007	**ECNAP2 Decision** FR, CZ
6	2-16/4/2005	**ECNAP2 Decision** AT, HU
7	15/5/2007	**ECNAP2 Decision** IT
8	04/6/2007	**ECNAP2 Decision** FI
9	13/7/2007	**ECNAP2 Decision** IE (2), SE (2), LV (2), LU (2), LT (2)
10	18/7/2007	**ECNAP2 Decision** CY

11	31/8/2007	**ECNAP2 Decision** DK
12	18/10/2007	**ECNAP2 Decision** PT
13	26/10/2007	**ECNAP2 Decision** BG, RO, DE (2)
14	07/12/2007	**ECNAP2 Decision** SK (2)
15	11/12/2009	**ECNAP2 Decision** EE
16	19/4/2010	**ECNAP2 Decision** PL
17	29/4/2011	**ECNAP2 Decision** EE (2)
18	05/12/2011	**ECNAP2 Decision** EE (3)

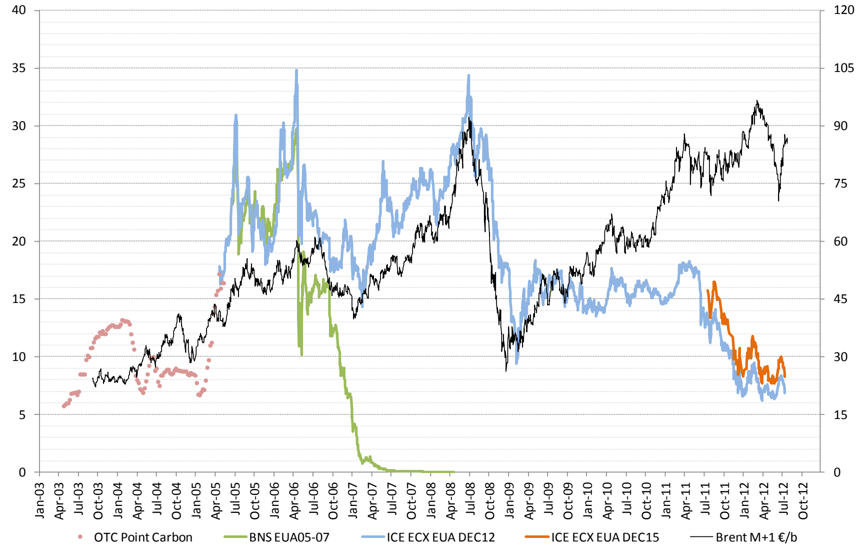
Annex A3: EU ETS industrial production index

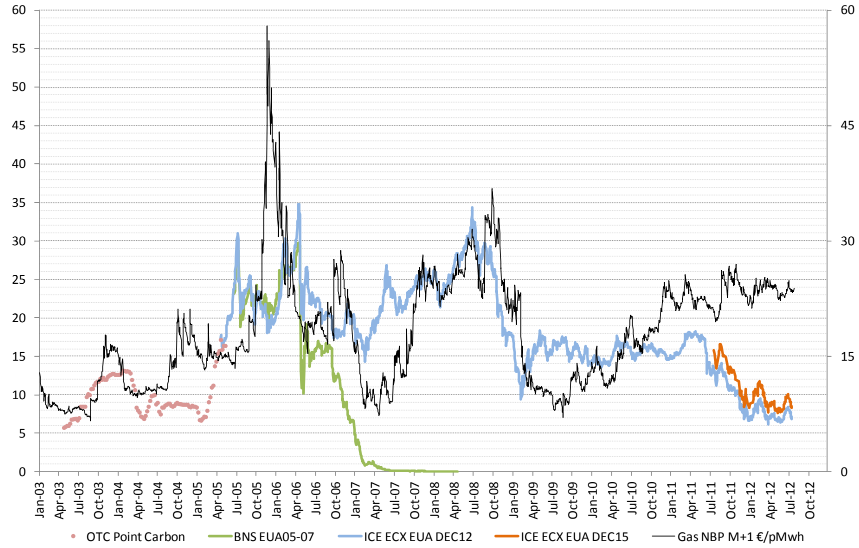


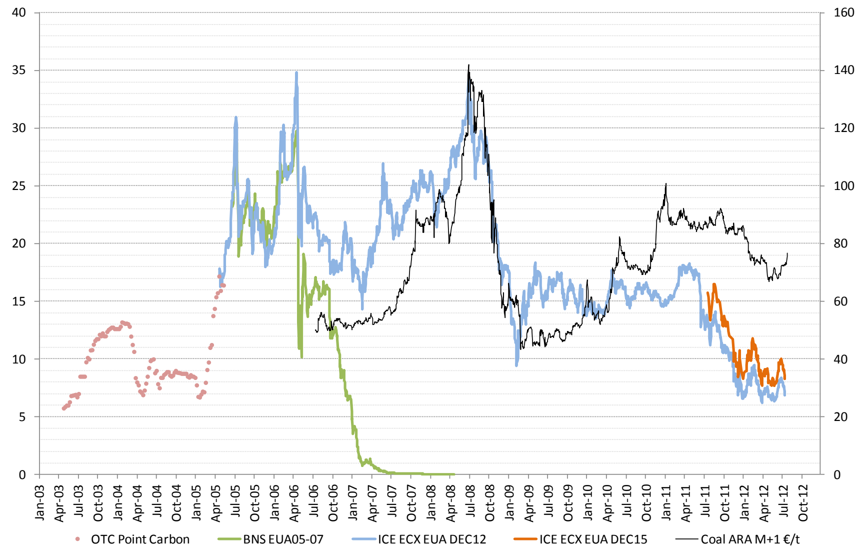


Source: author from Eurostat industrial production index. Note: 2012 value is an estimate.

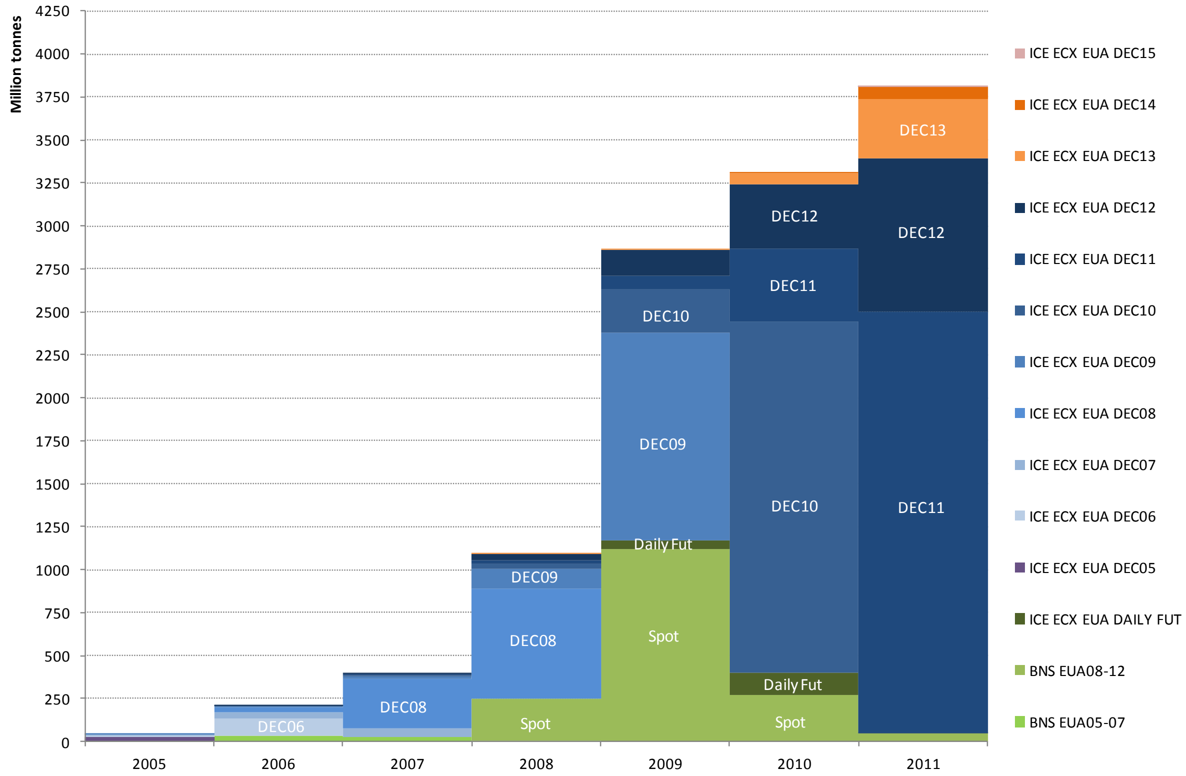
Annex A4: Energy prices



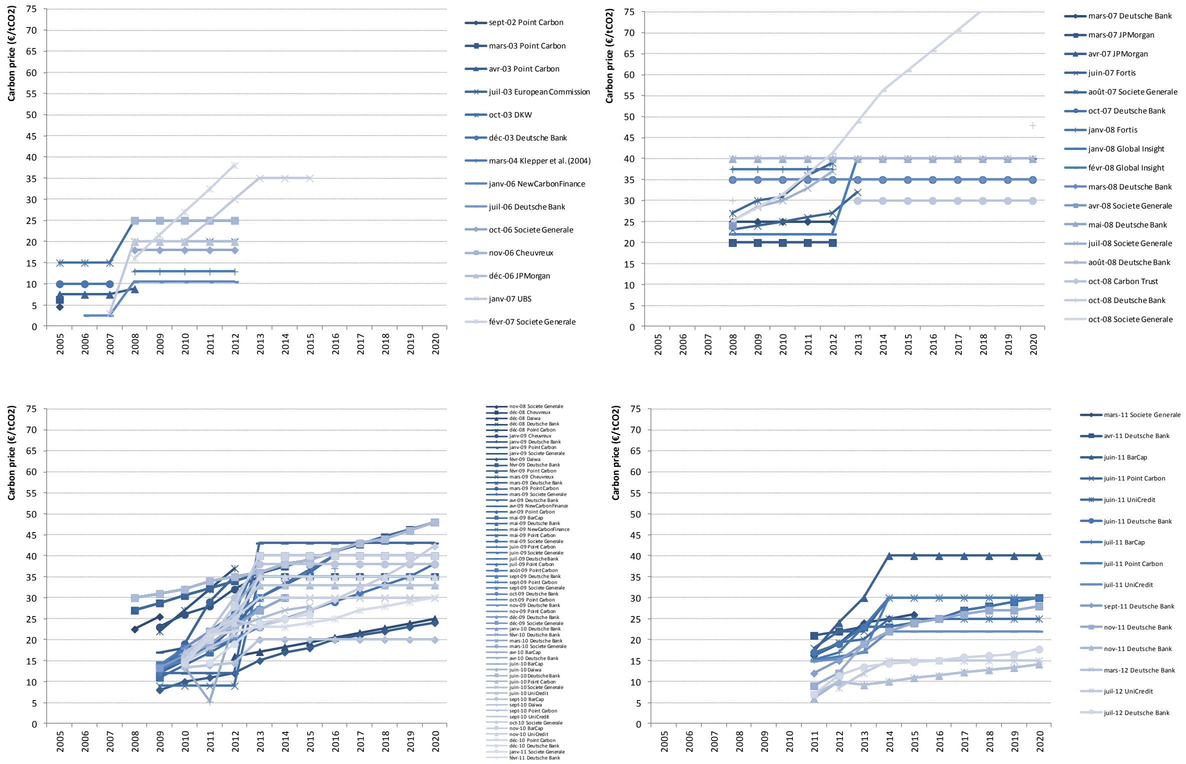


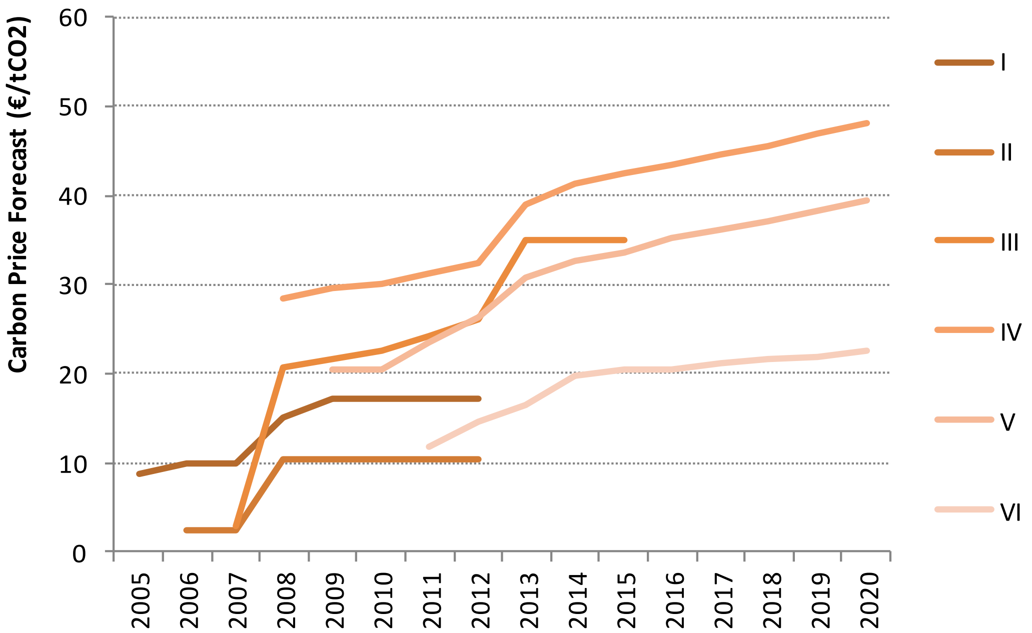


Annex B_1: Carbon market prices and volumes



Annex B₂: Review of Carbon Price Forecasts





Note: The roman figures represent the sub-period identified in the market development, see Figure 7 page 40

Annex C1: Example of CITL data – an installation in Germany

Operator Holding Account Information - DE 1649

General Information

Account Identifier	Holding Registry	Account Type	Account Holder	Installation Number	Account Status
1649	Germany	120-Operator Holding Account	Stadtwerke Gießen AG	1631	open

Details on Contact Information

Type	Name	Main Address Line	Secondary Address Line	Postal Code	City	Country	Main Phone Number	Alternate Phone Number	Fax Number	E-Mail Address
Account holder	Stadtwerke Gießen AG	Lahnstraße 31		35398	Gießen	Germany	00496417081330	00491718652394	00496417083104	mfunk@stadtwerke-giessen.de
Primary authorised representative of the account holder	Funk Matthias	Lahnstraße 31	Stadtwerke Gießen AG	35398	Gießen		00496417081466	00491718652398	00496417083421	mfunk@stadtwerke-giessen.de
Secondary authorised representative of the account holder	Paul Reinhard	Lahnstraße 31	Stadtwerke Gießen AG	35398	Gießen		00496417081330	00491718652394	00496417083104	rpaul@stadtwerke-giessen.de

Installation Information

Installation General Information

Installation Number	Installation Name	Permit Number	Permit Date	Subsidiary Company	Parent Company	EPER Identification
1631	14310-1126	14310-1126	2005-04-19			

Installation Address Information

Main Address Line	Secondary Address Line	Postal Code	City	Country	Latitude	Longitude	Main Activity
Versailler Str. 8		35394	Gießen	DE	0	0	1-Combustion installations with a rated thermal input exceeding 20 MW

Installation Contact Information

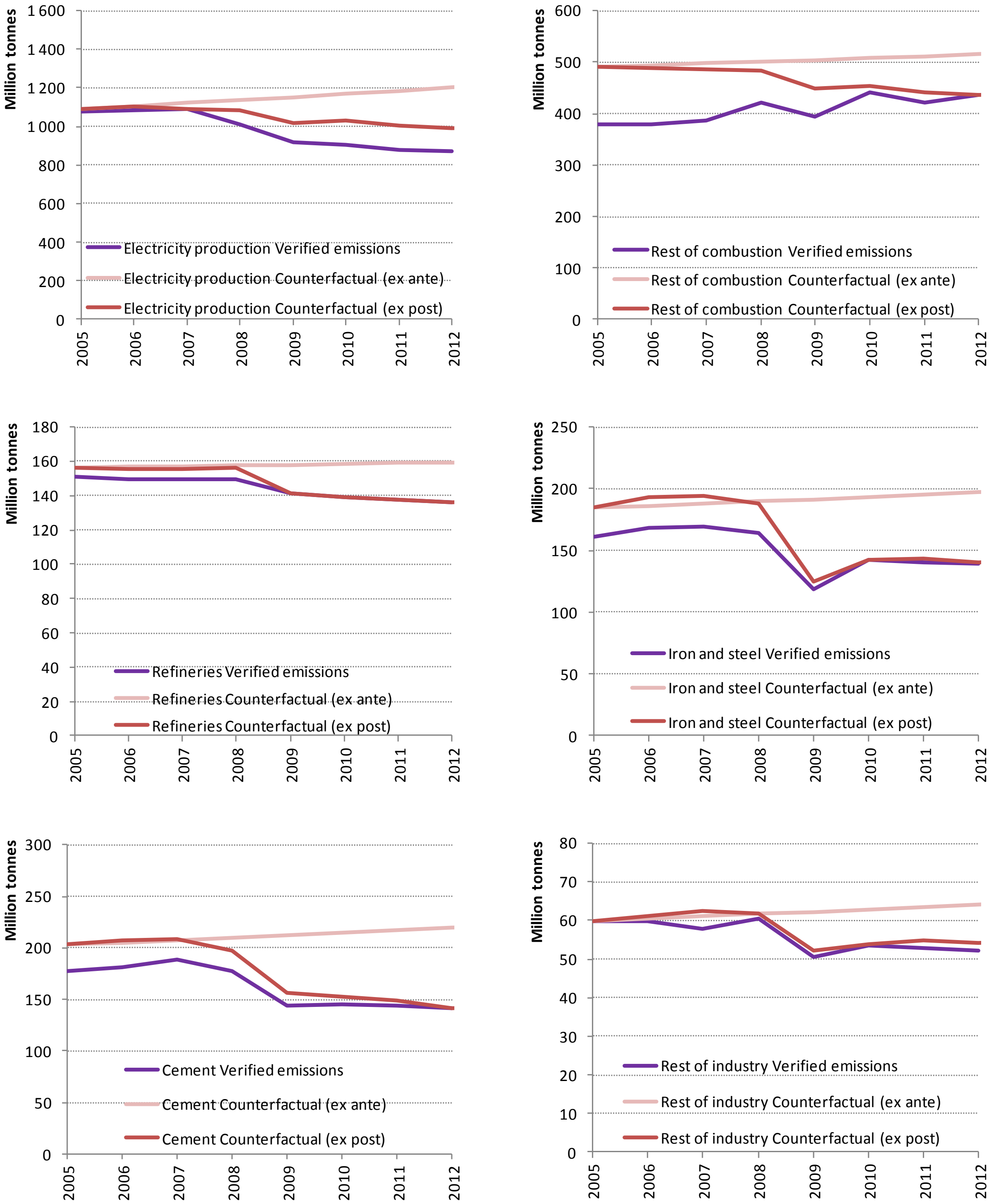
Name	Main Address Line	Secondary Address Line	Postal Code	City	Country	Main Phone Number	Alternate Phone Number	Fax Number	E-Mail
Matthias Funk	Lahnstraße 31	Stadtwerke Gießen AG	35398	Gießen		00496417081466	00491718652398	00496417083421	mfunk@stadtwerke-giessen.de

Compliance Information

ETS Period	Year	Allowances in NAP table	Verified Emissions	Units Surrendered	Total of units surrendered*	Total verified emissions**	Compliance Code	Options	
2005-2007	2005	14833	12314	12314	12314	12314	A	History	Details on Surrendered Units
2005-2007	2006	14833	13618	13618	25932	25932	A	History	
2005-2007	2007	14833	14469	14469	40401	40401	A	History	
2008-2012	2008	13435	12675	12675	12675	12675	A	History	Details on Surrendered Units
2008-2012	2009	13435	11670	11670	24345	24345	A	History	
2008-2012	2010	13435	11473	11473	35818	35818	A	History	
2008-2012	2011	13435	9420	9420	45238	45238	A	History	
2008-2012	2012	13435						History	

Source: CITL (random choice), German installation n°1631 (Permit Number 14310-1126)
Accessible at www.ec.europa.eu/environment/ets

Annex D₁: Comparison between counterfactual and verified emissions by sector



Source: author

Annex D₂: Emission reduction and reduction costs by sector using the counterfactual scenario

EMISSION REDUCTION BY SECTOR AND EU ETS AGGREGATE, COMPARED WITH PREVIOUS ESTIMATE

($MtCO_2$)	2005	2006	2007	2008	2009	2010	2011	2012	Phase 1	Phase 2	2005-2012
Electricity production	10	15	0	72	94	126	122	122	25	536	561
Rest of combustion	112	108	97	61	54	14	18	0	317	147	464
Refineries	5	6	6	7	0	0	0	0	17	8	25
Iron and steel	23	25	25	24	6	0	3	1	73	34	108
Cement	26	27	19	19	13	7	6	0	72	45	116
Rest of industry	0	2	5	1	2	0	2	2	6	7	13
EU ETS (sectoral)	**176**	**182**	**152**	**185**	**170**	**147**	**151**	**125**	**511**	**777**	**1,288**
EU ETS (med)	142	148	118	152	145	122	127	102	408	648	1,056

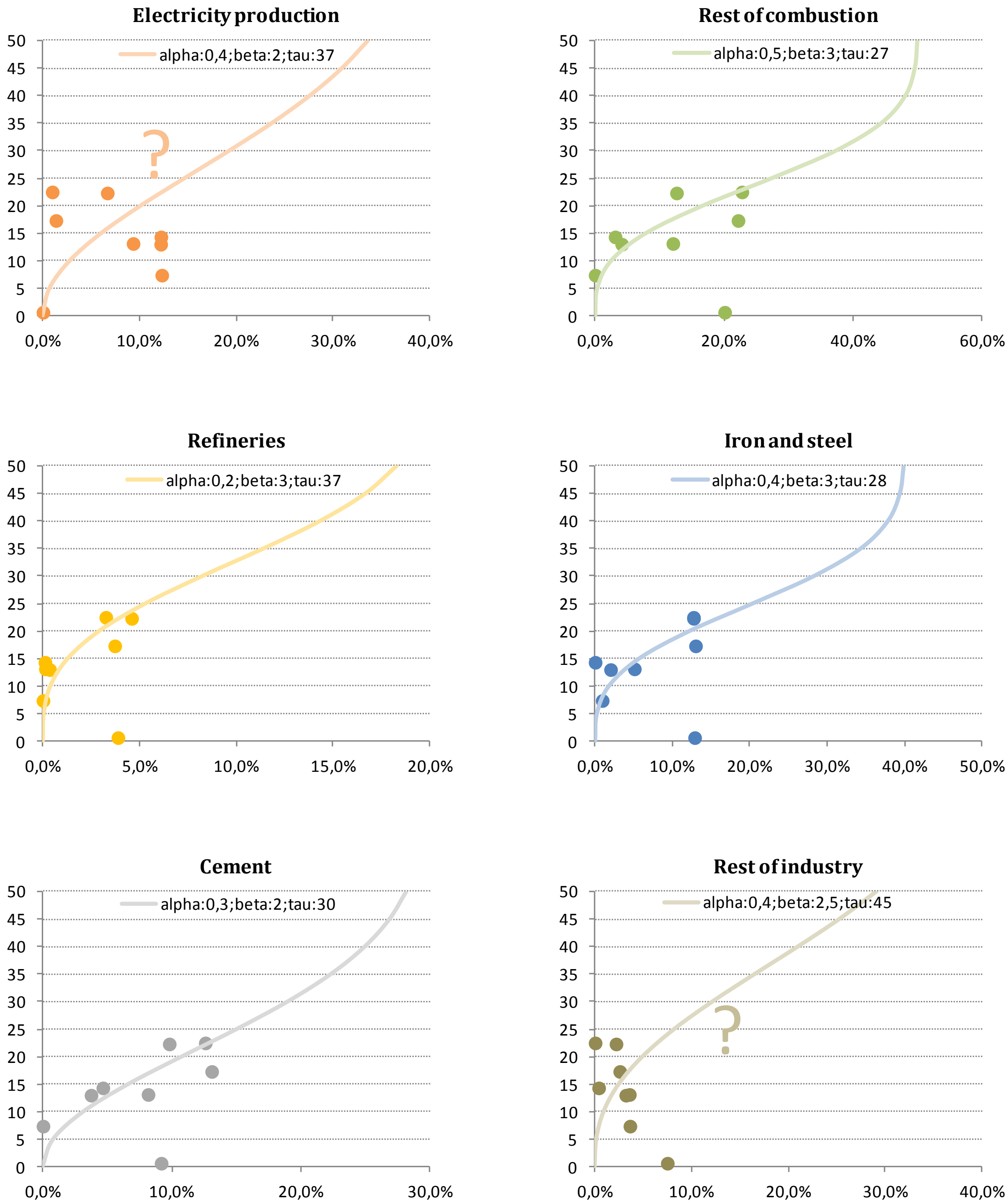
Source: author

REDUCTION COSTS BY SECTOR AND EU ETS AGGREGATE, COMPARED WITH PREVIOUS ESTIMATE

(M€)	2005	2006	2007	2008	2009	2010	2011	2012	Phase 1	Phase 2	2005-2012
Electricity production	117	128	0	805	621	902	793	450	245	3,572	3,816
Rest of combustion	1,256	936	32	680	355	101	118	0	2,225	1,254	3,479
Refineries	57	50	2	80	1	1	3	0	109	85	194
Iron and steel	264	217	8	266	41	0	19	5	490	331	821
Cement	288	235	6	215	84	51	36	0	529	386	915
Rest of industry	0	13	2	15	12	1	11	7	15	47	62
EU ETS (sectoral)	**1,982**	**1,580**	**50**	**2,061**	**1,115**	**1,056**	**981**	**462**	**3,612**	**5,675**	**9,287**
EU ETS (med)	1,603	1,284	39	1,692	950	877	826	378	2,926	4,724	7,650

Source: author

Annex D3: Approximation of MACCs by sector



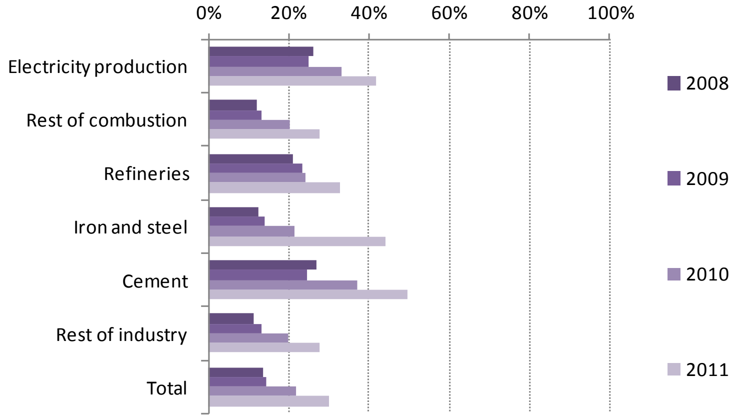
Source: author

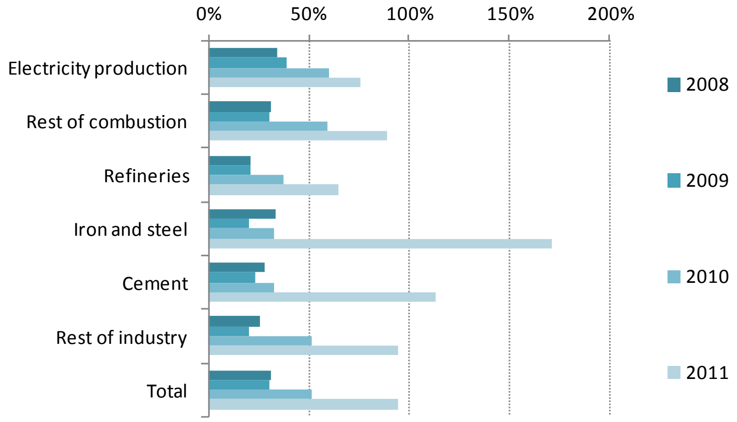
Annex E_1: Rules for using offsets in Member States

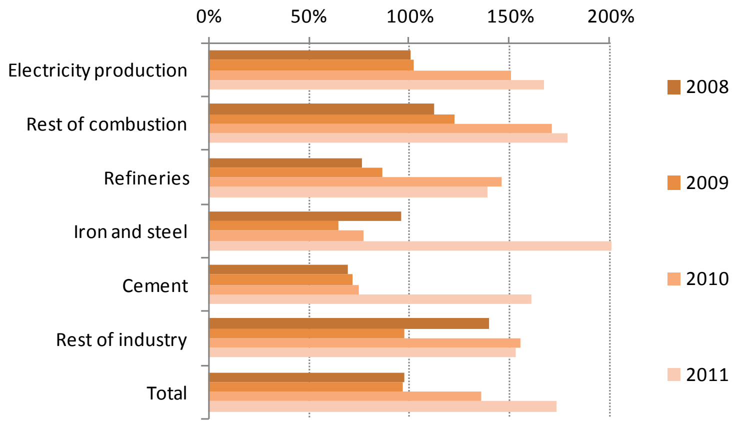
Country	Authorized use (in % of allocation)	Corresponding amount over the phase (in Mt)	Banking the limit	Borrowing the limit
Austria	10.0%	15.4	Yes	Yes
Belgium	9.1%	24.6	-	-
Bulgaria	12.5%	26.5	-	-
Cyprus	10.0%	2.7	Yes	Yes
Czech Republic	10.0%	43.4	Yes	Yes
Denmark	17.0%	20.8	Yes	Yes
Estonia	0%	0.0	-	-
Finland	10.0%	18.8	Yes	Yes
France	13.5%	89.6	Yes	Yes
Germany	20.0%	453.1	Yes	Yes
Greece	9.0%	31.1	Yes	Yes
Hungary	10.0%	13.5	No	No
Iceland	0	-	-	-
Ireland	10.0%	11.1	Yes	Yes
Italy	15.0%	151.2	Yes	No
Latvia	10.0%	1.7	No	No
Liechtenstein	0	-	-	-
Lithuania	20.0%	8.8	No	No
Luxembourg	10.0%	1.3	Yes	Yes
Malta	10.0%	1.1	-	-
Netherlands	10.0%	42.9	Yes	Yes
Norway	20.0%	15.0	Yes	No
Poland	10.0%	104.2	Yes	No
Portugal	10.0%	17.4	Yes	Yes
Romania	10.0%	38.0	Yes	Yes
Slovakia	7.0%	11.4	Yes	Yes
Slovenia	15.8%	6.6	Yes	Yes
Spain	20.6%	156.8	Yes	No
Sweden	10.0%	11.4	Yes	Yes
United Kingdom	8.0%	98.5	Yes	No
Total	13.5%	1416.9		

Source: National Allocation Plans, Member States' communications

Annex E2: Frequency, intensity and specific intensity of offset use, by sector

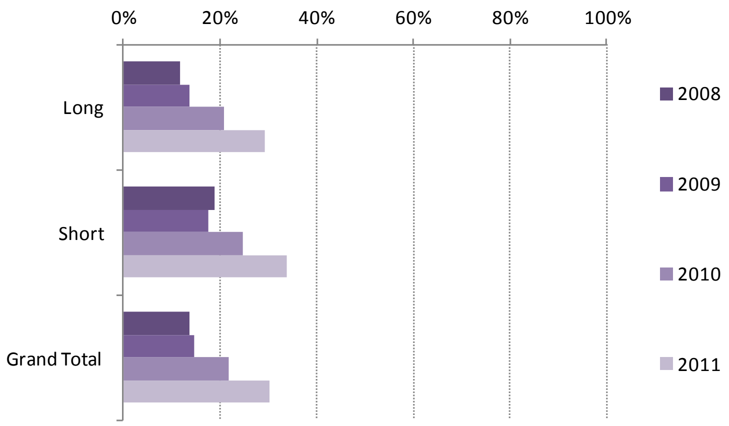


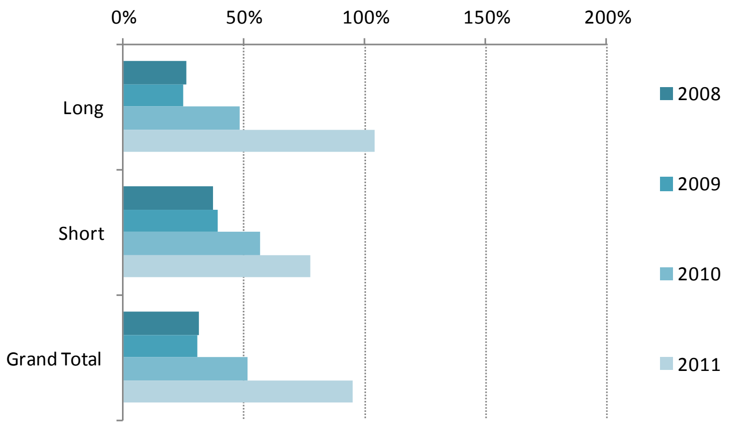


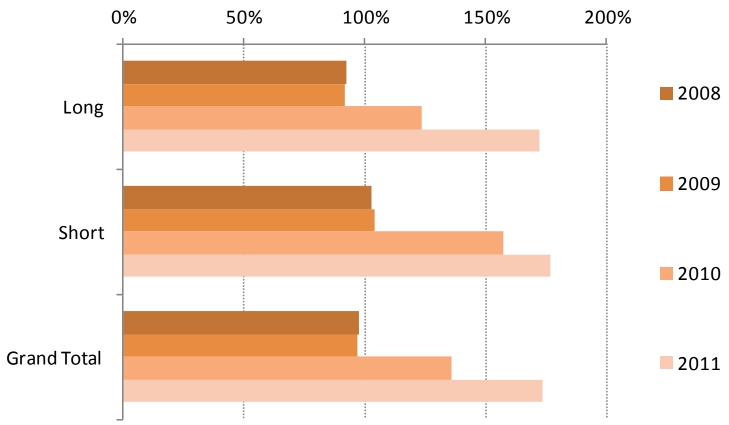


Source: author from CITL

Annex E3: Frequency, intensity and specific intensity of offset use, by position







Source: author from CITL

Annex E4: Projecting the use of offset in 2012 using past behavior

2008	2009	2010	2011	2012	Use of offsets in 2012 (Mt)	Estimation method
✓	✓	✓	✓	✓	31	Constant use compared to past
✓	✓	✓	✓	✗	0	
✓	✓	✓	✗	✓	2	Previous category split in two, and continuity of average intensity of use (118%)
✓	✓	✓	✗	✗	0	
✓	✓	✗	✓	✓	1	Previous category split in two, and continuity of average intensity of use (114%)
✓	✓	✗	✓	✗	0	
✓	✓	✗	✗	✓	3	Previous category split in two, and continuity of average intensity of use (78%)
✓	✓	✗	✗	✗	0	
✓	✗	✓	✓	✓	6	Previous category split in two, and continuity of average intensity of use (129%)
✓	✗	✓	✓	✗	0	
✓	✗	✓	✗	✓	1	Previous category split in two, and continuity of average intensity of use (117%)
✓	✗	✓	✗	✗	0	
✓	✗	✗	✓	✓	7	Previous category split in two, and continuity of average intensity of use (133%)
✓	✗	✗	✓	✗	0	
✓	✗	✗	✗	✓	12	Previous category split in two, and continuity of average intensity of use (133%)
✓	✗	✗	✗	✗	0	
✗	✓	✓	✓	✓	10	Previous category split in two, and continuity of average intensity of use (112%)
✗	✓	✓	✓	✗	0	
✗	✓	✓	✗	✓	3	Previous category split in two, and continuity of average intensity of use (99%)
✗	✓	✓	✗	✗	0	
✗	✓	✗	✓	✓	3	Previous category split in two, and continuity of average intensity of use (102%)
✗	✓	✗	✓	✗	0	
✗	✓	✗	✗	✓	7	Previous category split in two, and continuity of average intensity of use (135%)
✗	✓	✗	✗	✗	0	
✗	✗	✓	✓	✓	20	Previous category split in two, and continuity of average intensity of use (179%)
✗	✗	✓	✓	✗	0	
✗	✗	✓	✗	✓	12	Previous category split in two, and continuity of average intensity of use (281%)
✗	✗	✓	✗	✗	0	
✗	✗	✗	✓	✓	60	Previous category split in two, and continuity of average intensity of use (256%)
✗	✗	✗	✓	✗	0	
✗	✗	✗	✗	✓	157	15% of installations which did not used offset before shift to using offsets (observed in 2010 and 2011), with an intensity of 325% (proportional to the 260% of those in the same situation in 2011)
✗	✗	✗	✗	✗	0	
Total					335	