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Risk Management in Carbon Trading

Managing the market risk of European CO_2 allowance trading

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Industrial Engineering and Management

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Managing the risk of European CO_2 allowance trading under the EU-ETS

Master's Thesis Financial Engineering and Management

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Abstract

In this study we tried to accomplish three things. First we aimed to give insight into the basic principles of emission mitigation. After explaining the theory of emission allowance trading we described the European emission market. We concluded that it is essential for the market to be fundamentally short. Recent reports that suggest the market is actually long resulted in an incredible price crash.

We identified the fundamental price drivers and described their dynamics. We found that particularly returns on British gas have shown periods of high correlation with CO_2 allowances (up to 70%). For other carbon emission related fuels we found no obvious correlations.

We used a GARCH(1,1) model to forecast the volatility of a CO_2 emission contract. The forecasts were then used in an advanced Value at Risk framework that is based on the empirical distribution. The out of sample back testing, revealed that the performance of the CHISVaR model is superior over the simple rolling Value at Risk. Based on the test results we concluded this approach deserves more attention, since it benefits both from the model free empirical distribution and the state of the art GARCH model.

Key words: Carbon allowance Trading, EU-ETS, Risk Management, Value at Risk

Acknowledgements

During my last year at the University of Twente I attended a course on financial derivatives. This was when I met Dominique. The enthusiasm with which he spoke about the subject was rather contagious. Therefore, the choice for my primary supervisor was easily made.

Dominique and I agreed that the focus of my study would be CO_2 emission trading. When I started working at Rabobank, the focus was directed towards the market risk management of emission trading. I offer Dominique my gratitude for providing me with encouragements and guidance throughout the project. His financial expertise in energy markets enabled him to motivate me and point out different interesting perspectives. The freedom to shape this study to my own judgment has been very valuable to me.

During the first few months of my research, I discovered that I lacked econometric skills that I would need to finish the study the way I had in mind. Laura was very kind in allowing me to join her course on financial econometrics without actually attending class. The charming contact and her professional background made her the ideal candidate for my second supervisor. Laura's suggestions have been invaluable for me in creating logical and consistent econometric analyses. The input Dominique and Laura gave me, but especially each other during our last meeting, was refreshing and made the last mile a little shorter.

My work further has been supervised by Wilma, market risk manager at Rabobank International. She offered me the possibility of conducting my research on the dealing room in Utrecht. Throughout the project Wilma has given me a lot of freedom to work on my studies. As she was soon to discover, my performance increases when under a little pressure. This enabled me to complete the study within seven months. For her professional focus, guidance and giving me the opportunity to experience working in such a dynamic environment, I owe her my gratitude.

Thanks also go out to my colleagues who have aided my research by creating a stimulating and productive environment. Their enthusiasm has been very inspiring to me.

This thesis concludes my time as a student at the University of Twente. I would like to take the opportunity to thank my parents. I cannot describe how thankful I am for the numerous ways in which they have always stimulated and supported me. Their unconditional support has made my student days something to remember!

Finally, my thoughts go out to Ilse, no words can confer adequate thanks for her affection and encouragements.

Duco Brouwers

Utrecht, May 2006

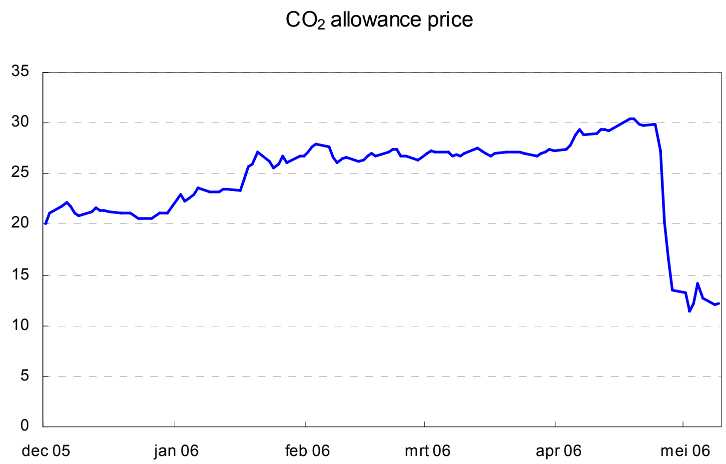
"Once the extreme is no longer feared or aimed at, it becomes a matter of judgment what degree of effort should be made; and this can only be based on . . . the laws of probability."

- Carl von Clausewitz -

I. Table of Contents

II. Introduction

There has been a lot of coverage recently in the papers, on the subject of the emission trading scheme in Europe. Reason for the fountain of articles and opinion is the recent market crash (at the end of April) when the price of a CO_2 allowance fell over 50%, from about 30€ to about 12€. The crash was ascribed to a number of countries that over the past year have emitted less than what the market expected.



This figure shows the recent market crash of emission allowances. The prices fell from the level of 30 euros to about 12 euros.
Source: European Climate Exchange

France reported its emissions to be 13% below cap, Belgium, 16% below its allocated amount and the Netherlands 7 % below its cap. Although Spain emitted more than the number of allowances it was allocated, the emissions turned out to be less above target than expected.

This is an outstanding example of the business of market risk. Market risk is concerned with quantifying and managing the risks of such price movements.

Background

In 1998 the Kyoto Agreement was established in order to reduce the global emission of GHG. The agreement has been ratified by many countries around the world, hence committing them to reducing CO_2 emissions. Constraints on GHG emissions have significant implications on businesses in the near future.

Companies have several choices if their emission levels are going to be too high. The first is internal emission reduction. But there is also a possibility of buying additional allowances on the market. On default a fine will be imposed for the lacking allowances. Excessive allowances can be sold, or be saved for future years. Thus the right to emit a certain amount of CO_2 becomes a tradable commodity.

Structure

In this paper we will study the market risk of carbon trading under the EU-ETS. To determine how risk managers should manage the market risk associated with carbon allowance trading, chapter 2 will give an introduction to the different aspects of market risk that are of interest.

The global warming raised concern to the international community. To understand the background of the CO_2 allowance market of the European Union we then discuss the Kyoto Protocol and its origin in chapter 3.

In line with the Kyoto Protocol the European Union created the European Emission Trading Scheme (EU-ETS). It is the largest international emission trading scheme worldwide. In chapter 4 we start by explaining the theoretical framework behind emission trading. The marginal abatement costs indicate emission trading is supposed to lead to cost efficient emission reductions. Next, the European trading scheme is described from an economic point of view. It provides insight in the market dynamics by identifying and describing the sellers and buyers, the affected sectors and the national allocation plans.

In chapter 5 our focus will be on the actual allowance market. This chapter begins with summarizing the different instruments that in theory can be traded. As becomes clear in the chapter on market risk management it is essential to know what moves the market. To obtain this knowledge the fundamental price drivers are identified. Based on these drivers a correlation analyses is performed. To illustrate the maturity of the market, this chapter concludes with an analysis of the market liquidity.

Where, in chapter 5 we learned what factors move the market, chapter 6 will take a more econometric approach in looking at the changes in the carbon allowance price. Based on the time series of a CO_2 allowance contract, the volatility of the returns is modelled. To illustrate the capabilities of such a model it is used to forecast the day ahead volatility and applied for Value at Risk calculations (as discussed in chapter 2).

Chapters 7 and 8 will discuss the final conclusions and recommendations respectively.

III. Market Risk Management

Crouhy, Galai et al. (2001) remark that the answer to the question: *How much can I lose on my portfolio over a given period of time?* should be: *"Everything"*.

Market risk, as Crouhy et al define it as the risk, that changes in financial market prices and rates will reduce the value of a security or a portfolio. For financial institutions market risk management has and in the future will have high priority.

The first thing that is essential for a proper market risk framework is to understand the risk factors in play. These are the factors that should be monitored by market risk management. They will form the basis for analyzing the market structure and the observed correlations in the later chapters.

The next section deals with the concept of Value at Risk, a popular way of quantifying risks. Conventional approaches in calculating the VaR are mentioned. The concept of Value at Risk is nuanced with regard to diversification effects. Finally, the state-of-the- art CHISVaR method is introduced.

Risk factors

Politics and Policy

- Size and changes of NAPs
  The main item that creates political uncertainty is the size of the National Allocation Plan. The NAPs (which are assumed constant within trading periods) are the fundamental tools by which the market scarcity is created. Changes (or rumors about changes) in the allocated amount for the next period can have impact on the market price and volatility.

- Banking of allowances between trading periods
  Rules governing the possibility of banking allowances between trading periods can pose structural changes in the market. When not allowed the allowances become worthless when a period ends. When allowed, the value of the allowance doesn't evaporate upon expiring periods; this will have a big impact on the forward curve.

- Agreement on a follow-up for the Kyoto Protocol
  Negotiations on a successor for the Kyoto Protocol have yet been futile. Note that the 2nd Kyoto period ends in 2017. This implies uncertainty for the long term. Typically strategies regarding large investments are evaluated with a long horizon in mind. Profitability calculations often use minimum operating periods of 20 years. Large investments in abatement technology like low emission installations can suddenly become profitable when there is more certainty about the post Kyoto era.

- Aviation and transportation
  There is an ongoing discussion about whether aviation and transportation have to be included in future trading periods.

CO_2 Production

- Emission to Cap
  The output level of CO_2 is of course of major influence on the scarcity on the market. The more CO_2 emitted, the more allowances needed. Although the cause of fluctuations in CO_2

production can be various, the impact on the market can be tremendous. The price crash observed in April 2006, due to the lower emissions reported than expected from France, Belgium, Holland and Spain, is illustrative of this fact.

- Temperature (demand)
  As we showed temperature levels are indicative for electricity demand. The electricity demand in turn influences CO_2 output.

- GDP (demand)
  The macro economic growth will probably increase CO_2 emissions, not only of the most dominant factor: power production, but also of the other emitting sectors. The reverse is also true: Economic downfalls will probably result in large emission reductions as was illustrated by the disintegration of the former Soviet Union.

- Weather (supply)
  Since in the EU a significant proportion of energy is produced by hydro power (especially in Scandinavia) prolonged dry periods will limit this type of emission free energy production.

- Disasters
  Disasters of course can have impact on the CO_2 market in a number of ways. First a meltdown of a nuclear facility will force other emission intensive power production to take over. Hence increasing demand for allowances. But one can also think of an entire industrialized area being wiped out by a (man inflicted) catastrophe, which would result in a cancellation of emissions from that area.

Market prices

- Gas prices
  The gas price shows periods of significant correlation with the CO_2 price. Typically periods with increasing gas prices, while coal prices remain constant or decline (e.g. increasing dark spread) will push the CO_2 price, since coal fired production will become more economically feasible. The reverse also holds.

- Market liquidity
  The liquidity risk can be the result of a change in market psyche. When market players decide close their positions and stop the trading activities to see what the market is doing the liquidity of the market is reduced. Larger bid-ask spreads and higher volatility are often the result.

Value at Risk

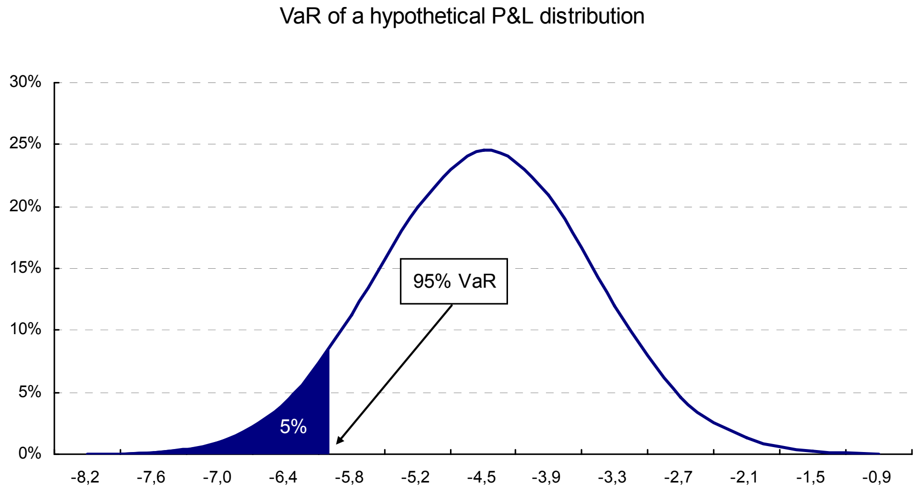
Background

Historical risk management was based on financial and accounting reports like the 'notional' amount. But due to the failure to account for short or long positions and to reflect price correlation, financial institutions had strong motivation to develop a robust risk management system.

Based on Markowitz (1952) findings, Sharpe (1964) developed his Capital Asset Pricing Model which defined the risk of an asset as the covariance with a fully diversified portfolio (e.g. a market index). Morgan/Reuters (1996) developed an internal system for reporting the one day risks and potential losses that, after publication, became the most successful and widely used system for reporting risks.

Based on the RiskMetrics™ framework of JP Morgan, the Value at Risk (VaR) principle aroused. The theory assumed that the risk and return of a security can be estimated by respectively the standard deviation and the mean of a normal distribution. Using correlation coefficients of different securities the VaR of an entire portfolio could be calculated. The model has been praised for its simplicity. It provides a single figure indicating potential loss over a given period of time at a given probability and can very well be used as a benchmarking tool.

For example, the 95% one day VaR is the number such that we are 95% sure losing not more than the number, when holding the current position for one day. Looking at the distribution function of daily returns the 95% VaR corresponds to the 95th quantile as is shown in the figure below.



This figure shows an example of 95% Value at Risk.
The VaR corresponds to the number on the x-axis at the arrow.

In estimating the VaR basically two approaches exist. The Value at Risk can be estimated in various different methods. Both parametric and non-parametric approaches exist. First the parametric approach which assumes some (constant) distribution of the returns. Using the parameters of this distribution calculating the appropriate quantile is very straight forward. Drawback however is the failure of the assumed (normal) distributions to encompass the often observed "fat tailed" distribution of financial returns. In compensating this effect Student-T and Generalized Error Distributions are suggested instead, to compensate this effect. Such models however continue to suffer from the draw backs of distributional assumptions.

Second is the non-parametric approach, which makes no assumptions about the distribution. Here the VaR is based entirely on the empirical distribution of the returns.

Covariance Value at Risk

The parametric approach assuming a normal distribution and constant volatility is called "Covariance VaR". The covariance VaR is the simplest and most widely used method. The quantile is calculated using the standard deviation and the mean of the normal distribution. As we already stated, the ease of calculating this type of VaR comes at a price. The distributional assumption is very controversial, and may lead to strong understating of the actual risk!

Historical Simulation Value at Risk

To overcome the weaknesses of making distributional assumptions, historical simulation can be used instead. The only assumption that has to be made here is that the events that occurred in the past have the same probability of happening in the future, and thus that the distribution of returns is constant and independent of the time. The VaR is estimated by taking the appropriate percentile from the sample data.

Aggregating Value at Risk

The VaR can be calculated on different levels of consolidation, differing from the total diversified portfolio level to a (less) diversified subset of a trading book or even an individual asset. When an asset or portfolio is added to a bigger portfolio in most cases some sort of diversification will take place. This diversification is the reason why the lower level VaR's will seldom aggregate to the VaR of the diversified portfolio. Thus the lower level VaR are often a very conservative estimate of the true value at risk. Garman (1997) introduces the Component VaR (CVaR) methodology. The CVaR has three important characteristics.

1) The component VaRs should sum to the diversified portfolio VaR.

2) Removing the component from the portfolio, the component VaR should approximately tell us how the portfolio VaR will change.

3) Component VaR will be negative for components which have a hedging effect on the remainder of the portfolio.

Carroll, Perry et al. (2001) suggests the following approach

$$CVaR_c = \rho_{c,p} \times \left(\frac{k_p}{k_c} \right) \times \left[VaR_c + E(c) \right] - E(c)$$

Where:

$CVaR_c$ = Component VaR of the "child"

$\rho_{c,p}$ = historical correlation between P&L of child and "parent" over last 60 days

σ = historical standard deviation over the last 250 trading days

VaR_c = VaR of the child over the last 250 trading days

VaR_p = VaR of the parent over the last 250 trading days

$E(c)$ = Mean P&L of the child over the last 250 trading days

$E(p)$ = Mean P&L of the parent over the last trading days

$$k_c = \frac{VaR_c + E(c)}{\sigma_c} \quad \text{And} \quad k_p = \frac{VaR_p + E(p)}{\sigma_p}$$

We want to analyze the effect of adding a portfolio of carbon related products to a typical well diversified portfolio like the ones banks have. For the analyses we have to come up with a realistic mixture of products that constitutes the portfolio. Important restraint here is that we analyze a static portfolio, where no change in the weights (e.g. trading) takes place. We assume short selling is not allowed.

For the optimization the Markowitz (1987) model is used. A risk free rate of 3,50% is assumed. Our approach in solving the Markowitz model is one based on simulation. We let Excel generate 4 random numbers. The i^{th} random number divided by the sum of the four is assigned as the weight for asset i. For the combination of weights and the covariance matrix the portfolio is then calculated. A simulation run of 10.000 iterations is performed, using the Sharpe ratio to determine the optimal weights. The resulting efficient portfolio is one with a mix of 6,5%, 7,2%, 84,4%, 1,9% for respectively CO_2 allowances, fuel, gas and gasoil.

Using actual profit and loss vectors of the different instruments the portfolio p&l is constructed with an initial value of 10.000.000 euro. Using the CVaR framework the effect of adding the portfolio to the books was calculated to be -39.592.

This means that adding the carbon related portfolio will have a diversifying effect on the banks global portfolio, which reduces the overall VaR with almost 40.000€.

Conditional Historic Simulation – VaR (CHISVaR)

The historic simulation method benefits from using the empirical distribution. The shortcoming of this methodology, is that it assumes that the distribution and volatility are independent over time (constant). In the chapter on volatility forecasting we however conclude that the observed volatility can be significantly heteroskedastic i.e. not constant.

This is where the CHISVaR comes in. The CHISVaR framework benefits both from the model free empirical distribution, as from the state of the art GARCH methodology we will use for modeling volatility. The CHISVaR is calculated by multiplying the appropriate quantile of the empirical distribution of the standardized residuals (for example the 0.99st quantile) by the day ahead forecast of the conditional standard deviation (the volatility forecast).

This combination of using a GARCH to model volatility and using the empirical distribution of the standardized residuals to calculate VaR is rather new and not very well documented. Spierdijk (2003) is one of the first to suggest the use of the empirical distribution in combination with ACD models (which are which are related to GARCH). The CHISVaR model, delivers robust results, far better than pure historic simulation or GARCH-VaR with a student-T distribution.

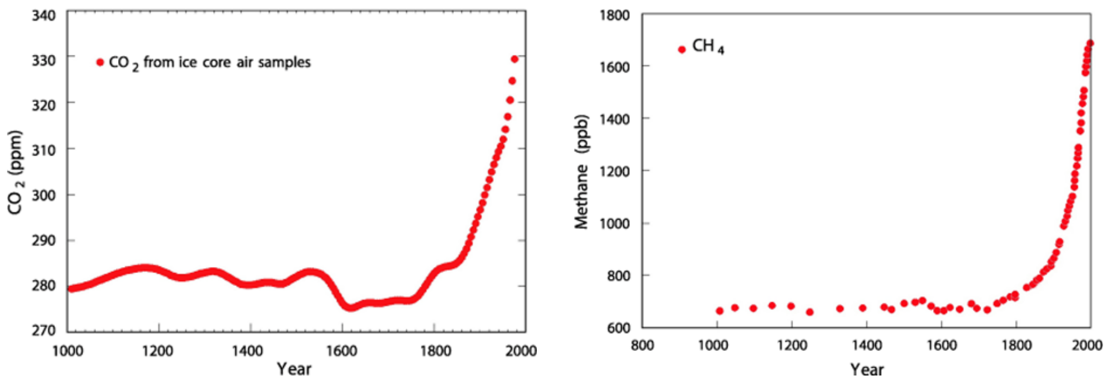
The relative small sample size we used to estimate the GARCH model could pose some problems. Hence we should be prudent applying this model for VaR calculations, however according to Nelson (1992) even when the GARCH model is misspecified, its performance can often still be robust.

IV. The Kyoto Protocol

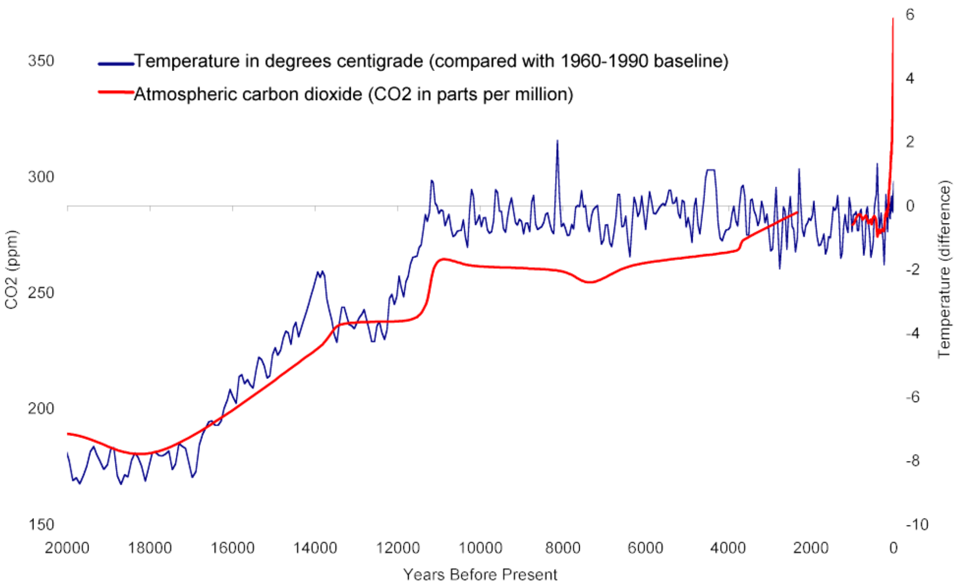
Global Warming

There are a number of gasses which absorb and emit infrared radiation. These so called Greenhouse Gasses (GHGs) are for instance: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3) play an essential role in the earth's global climate system according to the study by IPCC (2001)

The study by IPCC states the influence of human activities on the environment has extended to a larger scale since the beginning of the Industrial Revolution mid-18th century. Combustion of fossil fuels for industrial and domestic usage produces greenhouse gasses that affect the composition of the atmosphere. The increasing concentrations are illustrated by the figure below that plots the CO_2 and the CH_4 concentrations for the past 1000 years.



We know that the increase of CO_2 levels since the industrial revolution is *anthropogenic* because the changing isotopic composition of the atmospheric CO_2 betrays the fossil origin of the increase. To illustrate the relation between atmospheric CO_2 concentrations and average global surface temperatures they are plotted in the figure below.

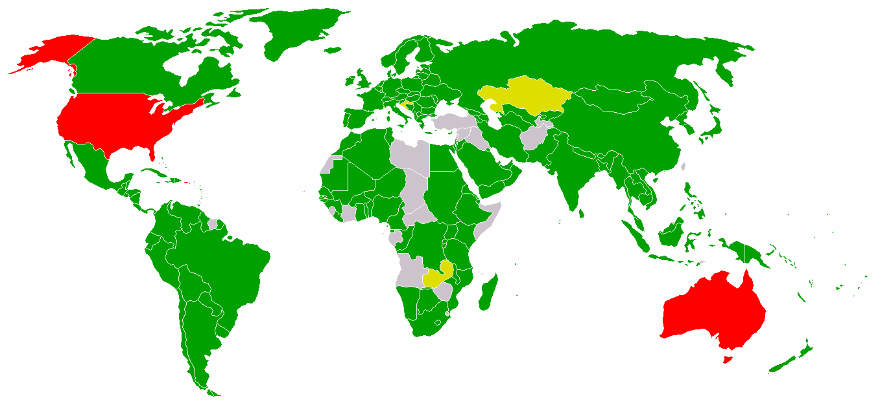


The figure plots the co-movement of CO_2 levels and surface temperatures for the past 20.000 years. The CO_2 levels (left axis) are displayed by the red line. The relative temperature levels (compared to a 1960-1990 baseline) are displayed by the blue line (right axis).

Source: Vostok Ice core CO_2 record

The Climate Treaty

CO_2 next to water vapour is the biggest cause of the greenhouse effect. Concern about the effects of ongoing increase in Greenhouse Gas (GHG) emission led to a United Nations Framework Convention on Climate Change UN (1992) in Rio de Janeiro in 1992. Article 2 of the framework states its objective is "to achieve stabilization of atmospheric concentrations of greenhouse gases (GHGs) at levels that would prevent dangerous anthropogenic interference with the climate system." In 1997 "The Kyoto Protocol" was adopted, but not ratified. The protocol requires industrialized countries to agree to limit their emissions of GHG to a certain level. At the time of writing, over 160 countries have ratified the protocol; the list of countries that did is shown in Appendix II. The figure below maps the countries that have not yet ratified the Kyoto Protocol, indicated by the red areas.



This figure visualizes the countries that ratified the Kyoto Protocol.
- Green areas are countries that ratified the Protocol
- Red areas are countries that declined
- Yellow countries are in the process of ratification.
- Grey countries keep a neutral stance

Source: Wikipedia

Time frame

The protocol lays down two distinct periods, the first from 2008 to 2012 and the second from 2013 to 2017. The European Union has added a habituation period which runs from 2005 to 2007 (we will come back to this in the chapter about the European Emission Trading Scheme). The figure below shows the time path of the different regulatory events.

Timing of climate change regulations

1992	*1997*	*2003*	*2005-2007*	*2008 - 2012*	*2013-2017*
UNFCCC adopted	Kyoto Protocol	EU ETS adopted	1st EU ETS trading period	1st Kyoto period	2nd Kyoto period

Different countries under the Kyoto Protocol

The protocol defines two types of countries. First are the so called "Annex I countries", these are the countries and economies listed in "Annex I" of the UNFCCC. These countries are attributed the leading role with regard to emission reductions, since they historically are the biggest emitters of GHGs.

The second types are the "Non-Annex I" countries. These are *the developing countries,* which in general attribute far less to global GHG emissions. Their emission constraints hence will be less stringent. The Annex I from the UNFCCC is listed in Appendix I.

The Annex I countries itself can be divided in two different sub categories called the "Annex II" countries and the "other Annex I" countries, where the Annex II countries are the members of the Organisation for Economic Cooperation and Development (OECD) and the latter are the Economies in Transition (EITs). The Annex II countries are for example Australia, Canada, Japan, Turkey, the US, the Western European countries and New Zealand. The "other Annex I" countries are for instance former members of the Soviet Union. Appendix I also lists the Annex II.

Appendix II lists the countries that have ratified the protocol; Appendix III lists the countries that didn't ratify the Kyoto Protocol.

Reduction targets

The global warming effect is caused in different extends by different gasses. Six gasses are identified, including: Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and three fluorinated gases, HFCs, PFCs, and SF_6. The impact of a certain gas on the global warming effect can be expressed as CO_2-equivallent (CO_2e). This way the emissions of the different gasses can be measured and compared. The table below presents the specific contribution per unit of gas to the global warming effect, also called Global Warming Potential.

Global Warming Potentials

Gas	Tonne CO_2 equivalent
Carbon Dioxide (CO_2)	1
Methane (CH_4)	23
Nitrous Oxide (N_2O)	296
Hydrofluorcarbons (HFCs)	
HFC-152a	120
HFC-134a	1.300
HFC-125	3.400
HFC-227ea	3.500
HFC-143a	4.300
HFC-236fa	9.400
HFC-23	12.000
Perfluorcarbons (PFCs)	
Perfluoromethane (CF_4)	5.700
Perfluoroethane (C_2F_6)	11.900
Sulfur Hexafluoride (SF_6)	22.200

The values are CO_2 equivalents, this means that one tonne SF_6 has an equivalent greenhouse effect of 22.200 tonne CO_2

Source: Third assessment IPCC, 2001

The six main gasses are included in the Kyoto protocol. One of the biggest hurdles that had to be taken during the negotiations in Kyoto was to determine the emission reduction targets. They agreed on different targets for different countries. The results of the negotiations, that ultimately form the basis of the protocol, are presented in the table below. The countries with a positive target are allowed to increase their emission levels, compared to their baseline year. Countries with a negative target have to reduce their emissions below their 1990 baseline.

Countries included in Annex B to the Kyoto Protocol and their emissions targets

Country	Target (1990** - 2008/2012)
EU-15*, Bulgaria, Czech Republic, Estonia, Latvia,Liechtenstein, Lithuania, Monaco, Romania,Slovakia,Slovenia, Switzerland	-8%
US***	-7%
Canada, Hungary, Japan, Poland	-6%
Croatia	-5%
New Zealand, Russian Federation, Ukraine	0
Norway	1%
Australia	8%
Iceland	10%

* *The 15 member States will redistribute their targets among themselves, taking advantage of a scheme under the Protocol known as a "bubble".*
** *Some EITs have a baseline other than 1990.*
*** *The US indicated not to ratify the Kyoto Protocol.*

Note: Although they are listed in the Convention's Annex I, Belarus and Turkey are not included in the Protocol's Annex B as they were not Parties to the Convention when the Protocol was adopted.

Clean Development Mechanism (CDM) and Joint Implementation (JI)

To provide flexibility in the location and timing of reduction measures some flexibility mechanisms are defined. These mechanisms facilitate international cooperation in complying with the targets by allowing international trade of emission allowances as well as international allocation of reduction projects.

The *Clean Development Mechanism* (CDM) states that Annex I countries can obtain *Certified Emission Reductions* (CERs) by investing in emission reduction project in developing countries (Non-Annex I). CERs can then be added to the registries and used for compliance with Kyoto targets or banked for later use. Important restriction is that the reduction project delivers additional reductions above a certain baseline scenario.

A mechanism similar to CDM is *Joint Implementation* (JI). It aims at generating emission reductions through investments of one Annex I country in a reduction project in another Annex I country. The investing party receives an agreed amount of *Emission Reduction Units* (ERUs). Again the project has to be additional to the baseline scenario in order to qualify as a JI-project. Facilities that are already covered by an emission trading scheme in the EU are excluded, to prevent any double counting. JI-projects can for instance aim at reducing emissions of facilities that are not yet "capped" under the governments' policies. It should also be noted that nuclear energy projects do not qualify for JI/CDM credits, at least not in the first Kyoto period (2008-2012), how it will be treated in the period after that yet remains uncertain.

The most important issue for CDM and JI projects is to establish that the reductions exceed a baseline scenario. Finally the generation of 'carbon sinks' is also regarded as a reduction project, where forestation and injecting CO_2 into used gas fields are examples of such carbon sinks. One big advantage of these mechanisms is that they facilitate in directing foreign sustainable investments to developing countries. For a further discussion of CDM and JI projects we refer to Jong and Walet (2004).

V. The European Union Emission Trading Scheme (EU-ETS)

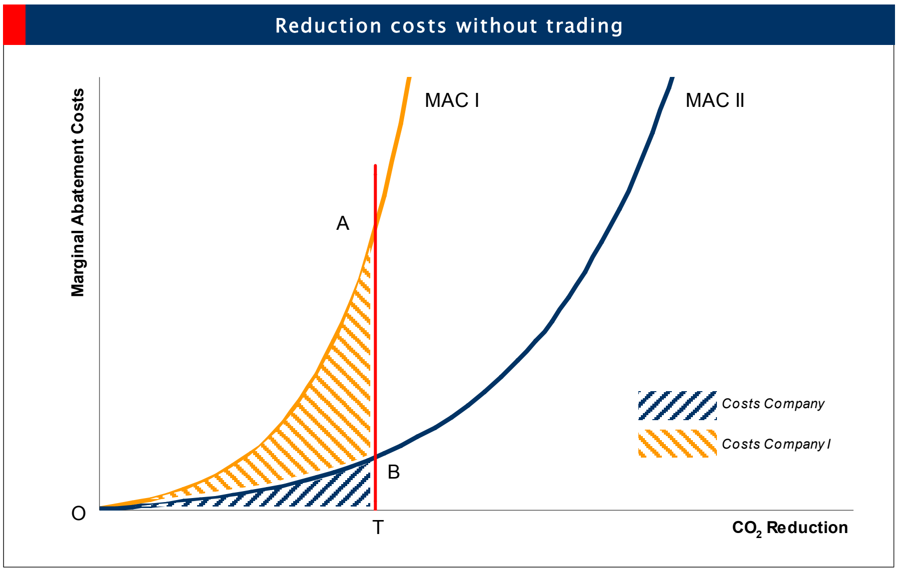
The European Union has ratified the Kyoto protocol in May 2002, committing itself to the emission reduction of 8% compared to 1990 levels. Champions of emission trading argue that emission trading is cost effective and generates good results. By introducing an economic interest to waist products, entrepreneurs can turn them into profit. The European Union Emission Trading Scheme (EU-ETS) is linked to the Kyoto Protocol through the "Linking Directive" of the EuropeanParliament (2004). The Linking Directive provides a mechanism that allows for Emission Credits generated by external projects to be used for covering emissions within Europe. This way the carbon market is truly spawning to be a global market.

In this chapter the EUs choice for emission trading will be given a scientific basis. The implications of the EU-ETS are identified by mapping the affected sectors, the stakeholders and the sellers & buyers.

Reduction method

The EU has adopted a so called cap-and-trade scheme. There have been and still are parties who argue that emission trading is the wrong methodology for cutting back emissions. In this paragraph we show there is solid economic reasoning behind the concept of emission trading. The reasoning is baked-up by the illustrations.

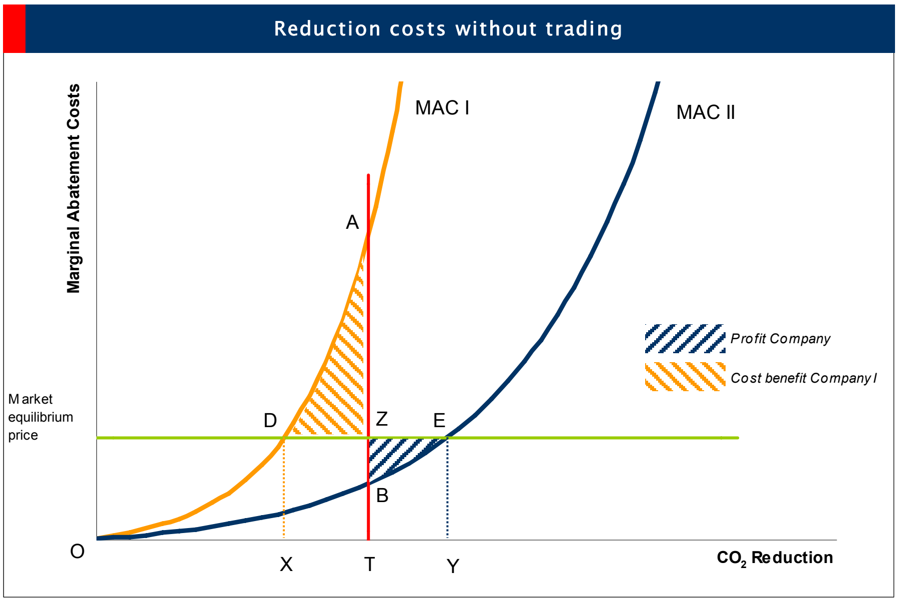
Suppose there are two companies (Company I and Company II) whose emissions have to be reduced to a target amount (T). The two different companies have different marginal abatement cost (MAC) curves for internal implementation of reduction measures. Marginal abatement costs represent the cost of increasing the reduction with one unit. Suppose the MAC curves look as plotted in the figure below. When both companies comply with the target by means of internal reduction, the shaded parts (OAT, OBT) represent the total costs of compliance for the two individual companies.



Hypothetical cost abatement curves for two companies. When assuming reduction target T, the cost levels A and B show a quite big spread. When no emission trading is allowed complying with the targets is far more expensive for company I.

In this case both companies comply with their targets, but the costs for *Company I* are relatively high. Now when the possibility of emission trading is introduced, it does not matter where the reductions are allocated, as long as both companies ultimately comply with their targets, either by internal reductions or by purchased allowances.

In our example the costs of reducing emissions are lower for the 2nd company, illustrated by the lower MAC curve. Consider line T in the graph. The marginal costs for Company II to create another abatement unit are far lower than for Company I. Now suppose Company I sources 1 abatement unit at Company II, thus Company II increases its reduction with 1 unit above the target. This sequence can be repeated stepwise until the equilibrium price is reached, and sourcing of abatements is no longer economically favourable for Company I. This results in the figure below, where the shaded areas are the benefits for the two companies due to the emission trading.



Emission trading allows Company I to source the emission reduction at Company II (T-X = Y-T). Company II can make a profit and Company I reduces its abatement costs. The shaded areas are the individual benefits for the companies under emission trading. The overall social-economic benefit of emission trading is equal to XDAT-TBEY

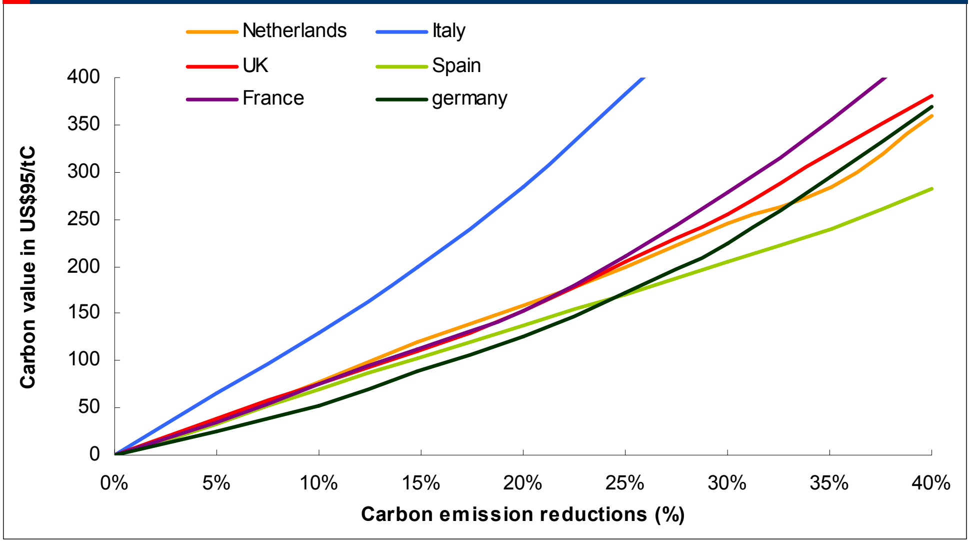
To see whether emission trading results in a cost optimal minimum, we can determine the total benefit as follows. The cost of reductions beyond X for company I are: XDAT, the cost for Company II to make the additional reductions up to Y are: TBEY. Accordingly the total benefit equals XDAT-/-TBEY. Since XDAT > TBEY, the benefit of emission trading is at least larger than zero.

Clearly the largest profit can be made by the company with the lowest cost curve. We have shown that emission trading is cost effective in reducing emissions and will seek to source emission reductions there where they can be realized at the lowest costs.

Another observation that can be made about the former example is that there apparently is a theoretical equilibrium price. Klaassen, Nentjes et al. (2005) conclude that in line with theory different forms of emissions trading (including auctions and bilateral sequential trading) are able to capture a significant amount of the potential cost savings of emission trading. Rhedanz and Tol (2005) show that emission trading is likely to be both cost efficient and environmental effective. Tietenberg (2003) argues that tradable permits are no panacea, but they do have their niche. Climate change may well turn out to be the most important niche.

Trading between different countries and economies follows the same analogy as the previous example, where the different countries have different MAC curves. The flexibility mechanisms CDM and JI are based on the principle of sourcing the reductions in the countries with low MACs. A study by Viguier, Babiker et al. (2001) estimated the MAC curves of several Member Countries. A selection of these is displayed in the figure below.

Marginal Abatement Cost Curves from EPPA-EU



The figure shows the dispersion of MAC curves across Member Countries (using the EPPA model). Spain is expected to have a big low-cost abatement potential, whereas Italy is expected to have a very high curve due to the relative small contribution electricity generation and heavy industries have to total emissions.

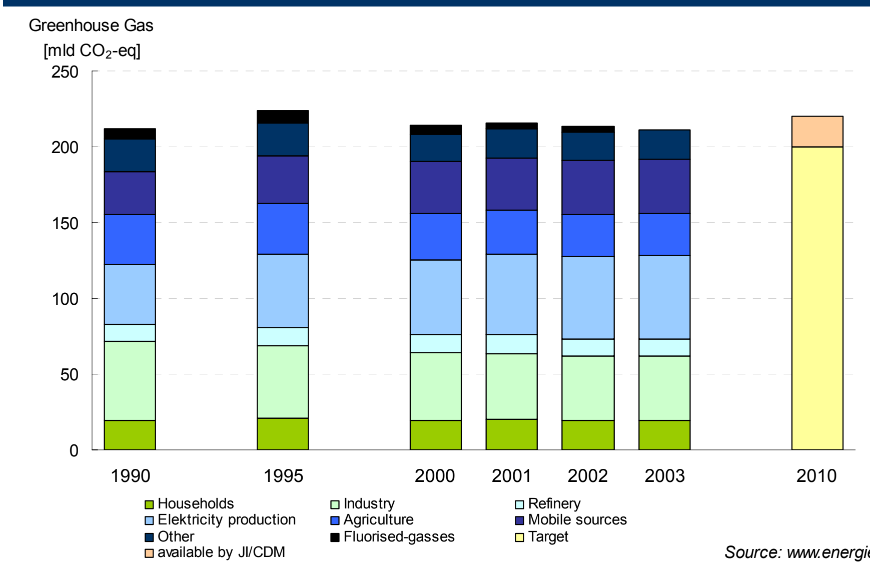
Source: MIT Joint Program on the Science and Policy of Global Change.

One important factor influencing the amount of CO_2 emissions is the type of fuel used for power generation. Since gas fired installations emit approximately half the amount of CO_2 per MWh compared to coal fired installations, 'switching' between the fuels can drastically influence the demand for allowances. This is further discussed in the section on fundamental price drivers.

Sectors

Constraints on GHG emissions and the cost of emission allowances are already affecting businesses significantly. Particularly the largest emitters are affected; these include energy intensive industries e.g. power generation, manufacturing and heavy industry. The figure below shows the emission of CO_2 in the Netherlands compounded per sector.

Dutch Greenhouse Gas emissions per sector



Source: www.energie.nl

There is an ongoing debate on whether the allowances should be allocated to the companies for free, or for instance be auctioned. Others like Beckman (2005) argue that the cap and trade principle favours the biggest emitters, and instead allowances should be allocated to the most efficient emitter.

The emission trading scheme will start with the largest emitters of CO_2. Emitters of other GHG's will, at least for the time being, not be included. Companies that have a capacity larger than the specified threshold will be given a certain number of emission certificates based on their historic emission levels (grandfathering). In general, the number of certificates given to the companies will be less than required (cap and trade). They can either reduce the output by installing abatement technologies, or they can source sufficient emission allowances on the market.

The table below exhibits the industrial activities that are included in the emissions trading scheme.

Affected sectors

Installations	*Capacity larger than*
Electricity generation	20 MWth
Steel industry	2,5 t/h
Cement ovens	500 t/d
Limestone and other ovens	50 t/d
Glass production	20 t/d
Ceramics factories	75 t/d or 4m^3 and 300kg/m^3
Paper and cardboard	20 t/d
Coke ovens	all
Refineries	all
Pulp plants	all

The table shows the threshold production capacities or outputs for installations in the EU. Installations that exceed the threshold are included in the emission trading scheme.

Source: Annex I of the directive 2003/87/EC of the European Parliament and of the Counsil.

On default a fine will be imposed for the lacking allowances. The penalty will be €100 for each tonne of carbon dioxide equivalent (€40 during the habituation period) and will not release the operator from the obligation to surrender an amount of allowances equal to the excess emissions.

Excess allowances can be sold, or saved for future years (banking), but only within the same trading period. It is not possible to roll-over allowances from the Habituation Period (2005-2007) to Period I (2008-2012) and likewise to Period II. The right to emit a certain amount of CO_2 becomes a tradable commodity. When several new exchanges (e.g. ECX, Nordpool, Powernext, EEX, EXAA) started to facilitate the trade in these certificates, the European allowances market was born.

The National Allocation Plans

The member states of the European Union have distributed the reduction targets among each other. The "Burden Sharing Agreement 1998" considers individual economic circumstances in formulating the reduction targets. The targets are presented in the table below.

Emission reduction targets 1990-2012	
Portugal	27%
Greece	25%
Spain	15%
Ireland	13%
Sweden	4%
Finland	0%
France	0%
Netherlands	-6%
Italy	-7%
Belgium	-8%
United Kingdom	-13%
Austria	-13%
Germany	-21%
Denmark	-21%
Luxembourg	-25%

Data represents national emission reduction targets that EU Member States have to comply with by 2012 based on 1990 levels
Source: 2000 emission data: Energy Information Administration.

As the EuropeanParliament (2003) prescribes that each Member State has to develop a National Allocation Plan (NAP) stating the total amount of allowances that intends to allocate for that period and how it proposes to allocate them based on the individual targets. The plan has to be published and submitted to the European Commission and other Member States at least 18 months before the start of the relevant period. The NAP has to be approved by the EC.

Dominant market players

The Dutch AllocationPlan (2005), that has been approved by the EC shows the amount of emission rights assigned at company level. The allocation of the Dutch emission rights is presented in Appendix IV. From this table the biggest market players in the Dutch market can be identified. These include Esso, Nerefco, Shell, Total, Dow Benelux, Chemelot Geleen, Corus Staal, Electrabel, E.ON, Nuon Power, Amercentrale, Rijnmond Energy Centre, Elsta and Delesto. These are the companies that have been allocated rights for emitting more than 1.500 kton per annum. The companies and the yearly amount of covered emissions are presented in the table below.

Large Dutch market players

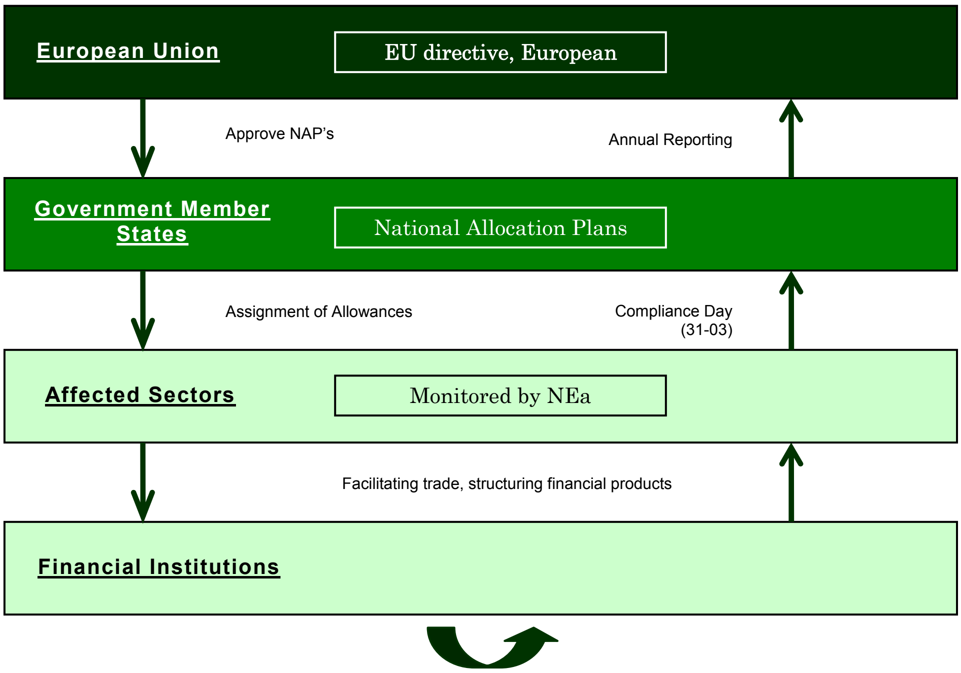
Company	kton/a
Corus Staal	10.376
Shell	9.275
Nuon Power	8.971
E.ON	7.719
Electrabel	7.702
Amercentrale	6.962
Chemelot Geleen	3.485
Dow Benelux	2.878
Esso	2.500
Nerefco	2.181
Delesto	2.095
Rijnmond Energy Centre	1.997
Elsta	1.954
Total	1.908

These are the biggest emitters affected by the trading scheme in The Netherlands. The numbers represent the allocation of emission rights for each year in the 2005-2007 period.

Source: nationaal toewijzingsbesluit broeikasgasemissierechten 2005-2007

The Stakeholders

A stakeholder analysis can show the impact of the EU-ETS. The primary stakeholders and the accompanying processes are presented in the figure below.



The primary task of the European Commission is to operate as a central junction of the registry system. Annual reports will be made on the basis of Member States reports, input from stakeholders, and reviews of the performance of the EU-ETS. These reports will be presented to Council and Parliament.

As of January 2005, companies in the affected industry sectors will have to monitor their emissions and produce annual emission reports. The excess emissions over the surrendered allowances will be settled by a fine of 40 euro per tonne CO_2, but the obligation to hand in the excess allowances remains. To avoid the fine, companies can either reduce their emissions or purchase additional allowances on the market.

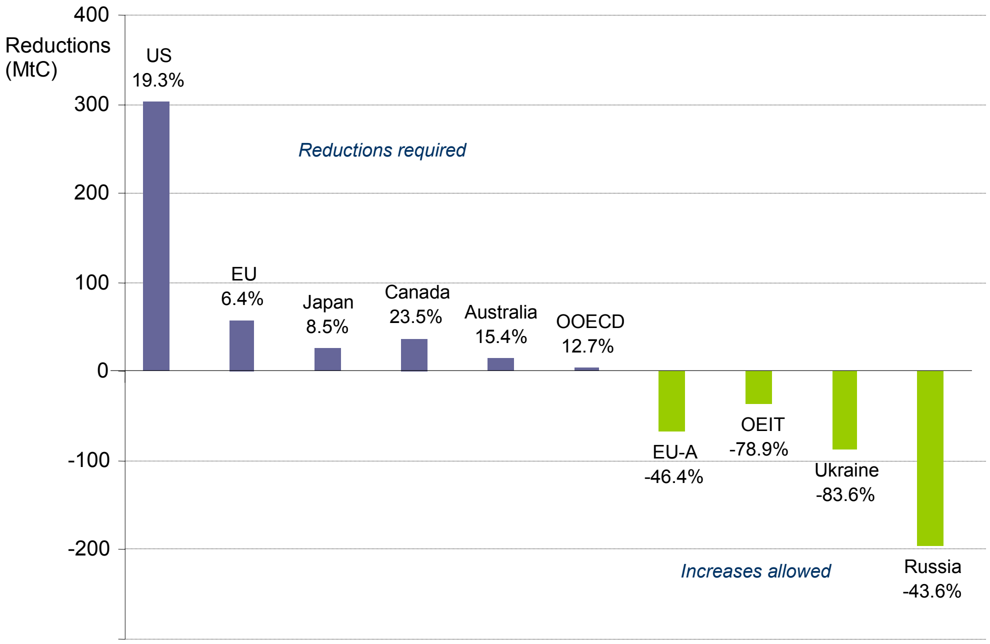
An important challenge for financial institutions is to create a transparent and liquid market for the allowances. To do this, multiple trading platforms are facilitating trade in emission related products e.g. the European Climate Exchange (ECX), Norpool, Powernext, European Energy Exchange (EEX) and the Energy Exchange Austria (EXAA). The liquidity of the market will be further boosted by facilitating in spot, future and forward trading as well as the creation of other derivative products.

These are the primary stakeholders of the EU-ETS. Recent events however suggest there is another stakeholder category in the market. Companies and organisations that voluntary seek to be environmentally neutral either by cutting back emissions, but more often by purchasing allowances on the market to cover the emissions. An example of an organisation taking social responsibility is the German Soccer Federation that together with the World Cup Organizing Committee agreed on a voluntary basis, to organize the World Cup in a way that will be as environmentally friendly as possible. Next to cutting back emissions, additional investments are made to cover the last 100.000 tons of CO_2.

Sellers and buyers

To identify which countries can be regarded as sellers or buyers the figure below plots the gap between a countries emission and its Kyoto target.

Figure: Gap between year 2000 emissions and Kyoto target (MtC/yr)



Data represents national CO_2 emissions from industrial activity of Annex I countries. The bars show the percentage gap between 2000 emissions and Kyoto commitments
EU-A: the 10 EU candidate countries under early accession.
OEIT: the 5 other countries applying for EU membership.
OOECD: the other OECD countries.
Source: 2000 emission data: Energy Information Administration.

Note that Russia is a very large source of allowances, since it is already 43% it final target. The US would have been the largest buyer, but obviously the US chose not to ratify the Kyoto Protocol.

VI. The Allowance Market

Introduction

In this section the carbon market is analyzed from an economic point of view. To clarify what is meant by the 'carbon market' the different instruments are first discussed. Next, the market fundamentals are identified. A decomposition of the various factors of influence will be interpreted to identify the key fundamentals of supply and demand. As the market is still characterised by its infancy, the impact of this on the carbon market will be discussed in the final part on market liquidity.

Instruments

The political framework dealing with GHG emission reductions created by the Kyoto protocol specifies three instruments for trade: the Assigned Amount Unit (AAU), the Certified Emission Reduction (CER) and the Emission Reduction Unit (ERU). The fundamental instrument used in the EU ETS is the European Union Allowance (EUA) which sort of is an AAU. An emitting company may use CERs and ERUs next to the EUAs to comply with the European reduction targets as was mentioned earlier this is facilitated by the Linking Directive.

The GHG instruments traded globally can be divided in two types of instruments. The first are the *allowances* that enter the market under "cap-and-trade" schemes. The allowance represents the right to emit e.g. one tonne of carbon dioxide equivalent. At the end of a compliance period for every unit emitted, an allowance has to be handed in, to regulator. The second type of instrument is the *emission credit,* which enters the market when a project reduces an emission source outside the regulators jurisdiction below an agreed "business as usual" scenario. These credits can be converted to allowances under the Linking Directive.

Emission Allowances

AAU is an allowance that is represented by a national cap of a developed country under the Kyoto protocol and is the fundamental instrument for achieving compliance of a ratifying country.

EUA is the instrument that is created by the European Commission for use in the EU ETS. Affected companies receive a number of EUAs to cover their emissions. EUAs cannot be transferred outside the EU, since there is no formal link between registries outside the EU.

Emission Credits

CER is an emission credit that was generated by a project in a non-developed country, certified by the Clean Development Mechanism (CDM) of the Kyoto Protocol.

ERU is an emission credit that was generated by a project in a developed country, certified by the Joint Implementation (JI) framework of the Kyoto Protocol.

VER is an emission credit that is not certified. It has been verified by an independent third party. It can be voluntarily purchased for example to offset emissions of a non affected company that wants to take responsibility.

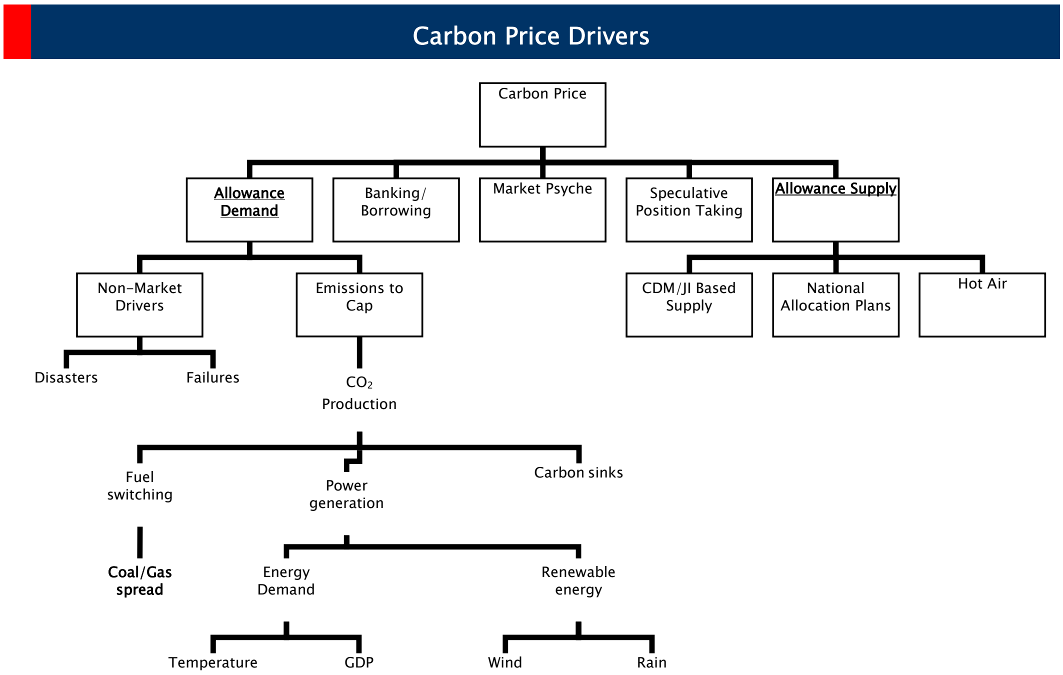
Regarding the Credits, risks are not only related to things happening in the project such as delays or financial setbacks, but also to the risks of the project not complying fully with the future rules the UN Supervisory Committee will develop. Credit purchase contracts therefore arrange for the division of risks between the buyer and the seller and this has its influence on the price.

Traded Contracts

As with commodities different contracts are possible for trade. The allowance itself can be traded (spot contract), the allowance can be transferred at a future date (forward or future contract), an option (right but not the obligation) to trade the allowance at a future date and price (option contract). In international markets the forward transactions i.e. contracts for forward delivery traded over the counter (OTC) are most commonly used.

Fundamental price drivers

The figure below shows the factors that influence the price of emission allowances. Banking and borrowing activities, market psyche as well as speculative position taking have a direct effect on the supply/demand balance & market liquidity. These in turn affect the price volatility.



According to the findings in chapter II, the market price will settle at a market equilibrium, which is mainly determined by classic supply and demand.

The Supply drivers

- *National Allocation Plans*
- *CDM/JI based supply*
- *Hot Air*

On the supply side, two factors can be identified that determine the total supply of allowances. First, the National Allocation Plans (NAPs) are established prior to each EU-ETS period. NAPs establish the emissions target for the covered sectors, as well as deciding how this target is divided among the various installations covered by the system, for a Member State. The NAP for each ETS period has to be published and notified to the European Commission and the other Member States.

For each trading period, the basic amount of supply is fixed at the sum of the NAPs. The NAPs are subject to policy changes of the Member State, but only for the NAP of the succeeding trading period. Member States can e.g. decide on a different allocation strategy, a different reduction target or changing the individual reduction targets for the affected sectors.

As the NAPs are fixed before the start of each trading period, they pose little uncertainty to the overall market. Especially since the ultimate reduction targets are fixed by the Kyoto Protocol. In the long run they *can* however be a source of ambiguity for individual companies, for it is uncertain what their future allocation will be.

The Linking Directive allows Member States to use CER's in covering their emissions, starting 2005. In the consecutive period, the use of Emission Reduction Units (ERU) derived from JI projects will also be included. To asses the amount of emission reductions generated by CDM projects, several studies have been performed. They range in there predictions from 100 through 750 MtC. The Figure below summarizes the different studies on CDM market size for the year 2010.

CDM market size estimates

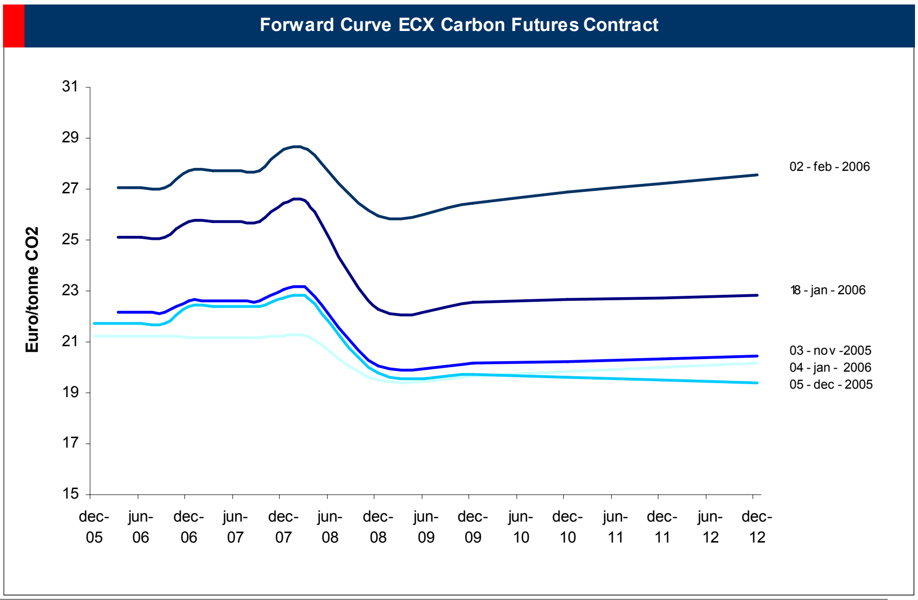
Sources	Size of the CDM market in MtC	Emission reductions required in Annex I (MtC)	CDM contribution %
EPPA	723	1312	55%
Haites	263-575	1000	27% - 58%
G-Cubed	495	1102	45%
Green	397	1298	31%
SGM	454	1053	43%
Vrolijk	67-141	669	10% - 21%
Zhang	132-358	621	21% - 58%

The figure represents the outcomes of different studies about the size of the CDM market and the contribution to the Kyoto Protocol.

Sources: Zhang (2000); Edmond et al (1998); Ellerman and Decaux (1998); Haites (1998); McKibbin et al (1999); Van der Mensbrugghe (1998) and Vrolijk (1999)

Recent attention about allowance supply has focused on Russia ratifying the Kyoto Protocol. As we previously saw Russia already has emission levels over 40% below their target. The lower emissions are mainly due to the disintegration of the Soviet system, which caused a strong economic decline. Consequently Russia now has a very large supply of so called 'hot air' allowances that it can sell to the market as of the first Kyoto Period. It is argued that instead of flooding the market with 'hot air' allowances, Russia is likely to adopt an OPEC-like strategy of retaining a certain level of shortage, so it can sell its allowances at higher prices. For a detailed discussion of the Russian hot air issue see Moe (2000).

Finally, in the long run the allowance price will be dominantly driven by political developments. In particular this relates to an international agreement to follow-up on the Kyoto Protocol, but political development in general plays a very important role in the emission market. The influence of politics on the CO_2 market can be illustrated by the figure below. It shows the forward curve of the CO_2 emission allowances at different points in time. The figure consistently shows a dip around the start of the first Kyoto Period.



The figure represents the Forward Curve of the ECX Carbon futures contract. Note that the first Kyoto Period will start in 2008. The figure illustrates the influence of political uncertainty associated with this start by the dip in de forward curve.

Sources: Chicago Climate Exchange

The drivers of demand

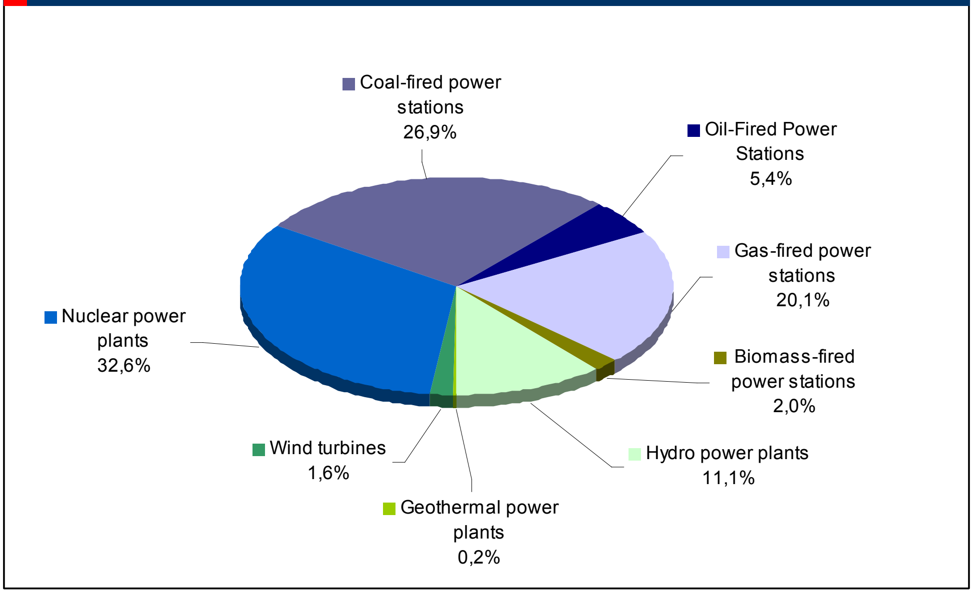
- *Emissions to Cap*
- *Weather conditions*
- *Carbon sinks*
- *Fuel switching*

For the demand side the drivers are more diverse and complex. We begin with the Emissions to Cap (EtC). EtC is basically the CO_2 production with relative to the NAP target, it is calculated by subtracting the seasonally adjusted (e.g. yearly) cap from the actual emissions. This metric gives an indication whether the market is producing more or less than the seasonally adjusted cap for that same period.

The EtC is determined by two factors. Since the NAPs are relatively constant (and strictly constant within trading periods) the EtC is mostly determined by the CO_2 production. Naturally, big influences on the production of CO_2 are the emission levels of the largest emitters: power generators. The level of their activity is explanatory for the level of their emissions. A study by Considine (2000) states consumption of electricity, heating oil and natural gas are quite sensitive to weather, in particular temperature. Hence we suspect that there will be correlations between the CO_2 allowance price and the electricity and fuel prices. These correlations are investigated further in the next section.

Not only does the temperature influence the demand for electricity and fuels, the wind speeds and rainfall affect the share of renewable energy and thus emission levels. These effects are especially important for the Scandinavian countries, since more than half of Scandinavia's energy comes from hydro power. Hydropower constitutes over 10 % of the total electricity generation within the EU-15 countries (see figure below). One can imagine that a big drought that cancelled the ability of hydro generation, results in other power stations increasing their output. A net increase of CO_2 output is then obvious. For a thourough discussion of the energy markets we refer to Kaminski (2005). Finally, a study by Boogert and Dupont (2005) shows that the supply of electricity can be greatly impaired if water temperatures rises above a certain level. The manner in which power manufacturers handle such a situation can theoretically influence CO_2 production.

Gross electricity generation, by fuel used in power stations 2003



This figure presents the electricity generation in the EU-15 countries. The slices represent the contribution of the according fuel to the total gross electricity generation.

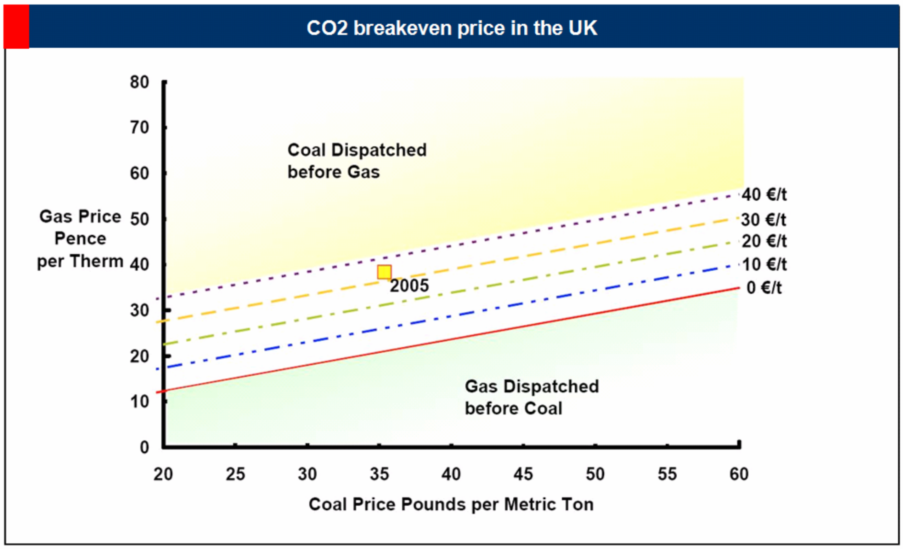
Source: Eurostat

Several technological solutions are feasible for reducing the demand of allowances. Investments in renewable energy and carbon sequestration (re-injecting CO_2 into the Earth or Sea) can be thought of. The size of the reductions obtained in this manner will, according to a study by McKinsey (2003), at most deliver 10 percent of the reductions needed.

Finally the amount of carbon exhausted from a gas fired facility is dramatically different than coal fired facilities. This is illustrated by the table below which states the amount of CO_2 exhausted per MWh produced. When the gas prices drop and the coal prices rise, switching between the fuels (*fuel switching*) becomes economically feasible. Thus the spread between the price of coal and the price of gas can determine the level of CO_2 emitted by power generators.

Emission Factors	tCO_2/MWh
Coal fired	0,9
Gas fired	0,4

Theoretically low gas prices will act as an incentive to build more gas fired generators. In advance an increasing share of power is generated by so called ‘hybrid installations’, these are installations that can switch between coal and gas. The figure below plots the break even prices for gas and coal for different CO_2 allowance prices.



The figure shows the break even prices of gas (Pence per Therm) and coal Pound per Ton) for different CO_2 prices at which it becomes economically feasible to switch from one fuel to the other.

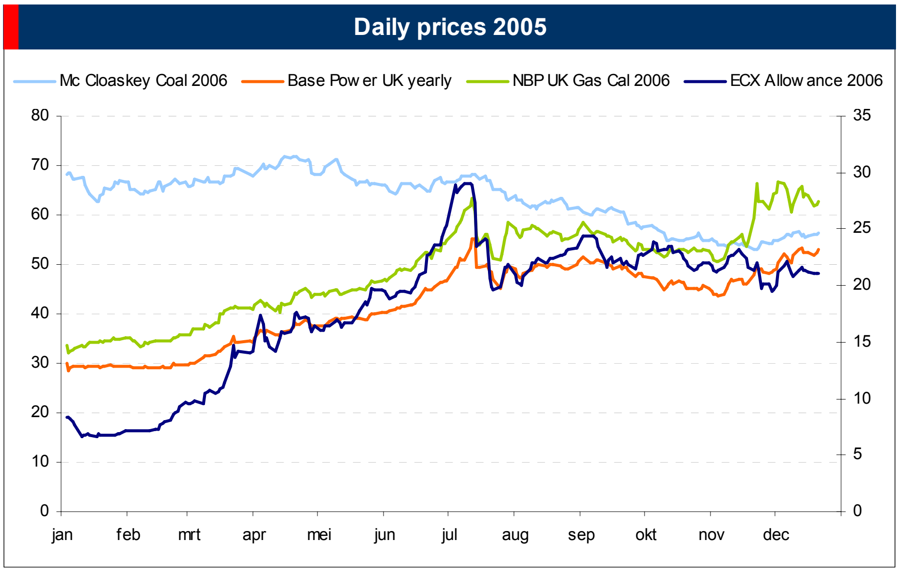
Assuming:
Coal 7 MWh/ton – 37% HHV Net Efficiency. Cost to plant £0.5/MWh. Emissions: 0.9 t CO2/MWh.
Gas 50% HHV Net Efficiency £0.5/MWh to plant 0.4 t CO2/MWh

Source: CERA

Finally, there is some non-market driven factors that can be of influence on the demand. Failures of for instance nuclear facilities can force the coal-fired facilities to increase production and hence increase the demand for allowances. Nevertheless, it is very hard to account for these influences.

Correlations

In this section we study to what extent the daily CO_2 allowance prices are affected by the price drives observed in the market. First, we plot the CO_2 allowance price against British gas and power prices. A survey by Point Carbon reports a large number of market participants see fuel prices and political factors to be respectively the most important and second most important factors for the price development.

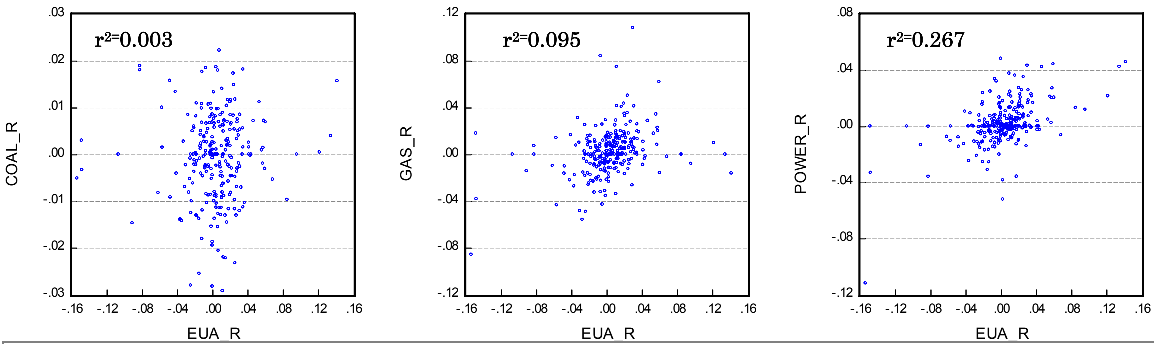


The figure shows the prices in euros of CO_2 allowances, gas and power for the year 2005.
The right axes is for the CO2 price (€) the left axis for the other instruments (€)
The green line represents the gas price, being a NBP calendar 2006 contract.
The orange line represents the power price, being a base load calendar 2006 contract.
The dark blue line represents CO_2 allowances, being the ECX 2006 Future contract.
The light blue line represents coal prices, being a Mc Closkey coal Calendar 2006 contract.

One can see that the carbon price moves in pace with the gas and power prices. In particular, the shape of the peak in July shows great resemblance among the series. The price of coal shows very little co-movement with either of the other prices. Note that the gas and power prices seem to follow a strong common trend.

Unconditional Correlation

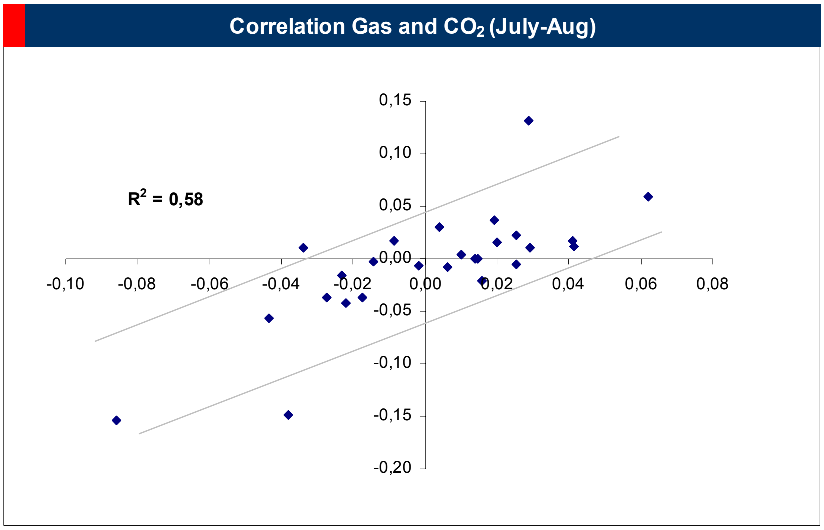
To visualize correlations between the CO_2 returns and the fuel returns, we make a scatter plot of the series, see the figure below.



This figure is a scatter plot to detect correlations of the CO_2 allowance returns versus Fuels for the year 2005
Coal: McCloskey Coal Calendar 2006 contract.
Gas: NBP calendar 2006 contract.
Power: Base load calendar 2006 contract,
CO_2: ECX 2006 Future contract.

Sample: Jan 2005 – Dec 2005
Source: Bloomberg, European Climate Exchange (ECX)

The scatter plots show no ckear correlation between CO_2 allowances and coal or gas returns. The correlation with power returns is much stronger. There are studies that argue that this is due to CO_2 prices being a dominant cost factor for power plants. However, when we decrease the sample size from the entire year to the months July and August, we suddenly can see quite a lot correlation between gas and CO_2 returns ($R^2 = 58\%$), see the figure below.

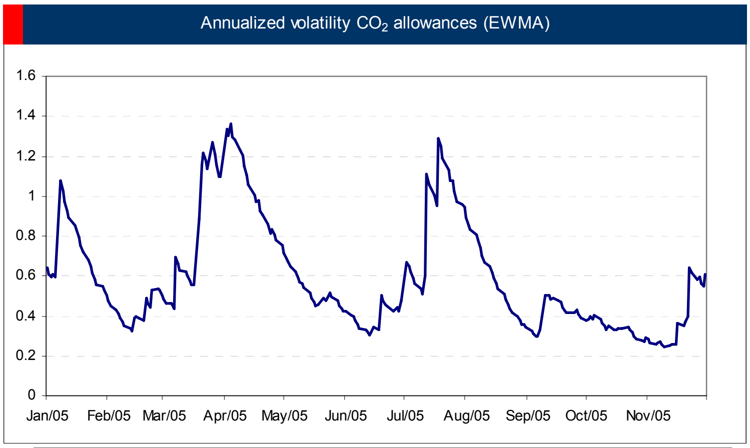


Scatter plot to detect correlations between CO_2 allowance return vs. gas return
Sample: 1 July 2005 – 15 August 2005
Gas: NBP calendar 2006 contract
CO_2: ECX 2006 Future contract

EWMA Correlation

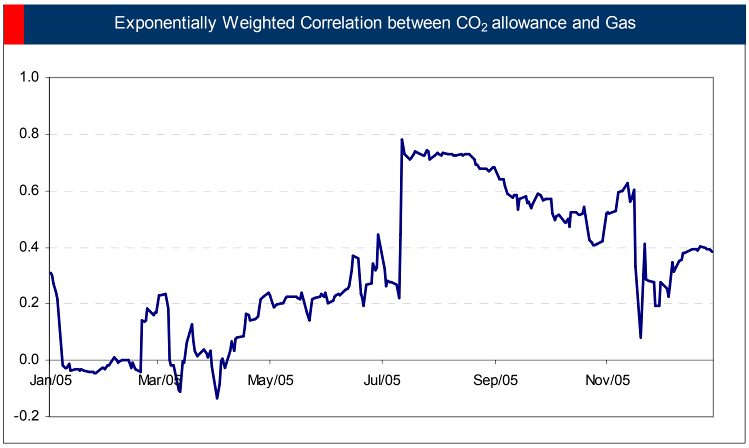
In the previous section we saw that there is no instrument that has a constant dominant correlation with the CO_2 emission allowance. However the figure above suggests that correlations might change over time. One of the easiest ways to model time varying correlation is by means of an exponentially weighted moving average model. The exponential weight gives more importance to recent events, than to events that occurred a longer time ago, in other words the correlation is calculated by averaging the historical data with weights decaying exponentially in time. The EWMA model is not mean reverting.

The decay factor λ can be determined by minimizing the in-sample forecasting error. Values often range between 0.75 being very restrictive (e.g. little persistence) and 0.98 being very persistent (e.g. not very reactive). For modeling the correlations we will use a value of 0.94 as suggested by RiskMetrics™. First we plot the EWMA volatility of the emission allowances, that way we can compare the effect of varying correlations and changing volatility.



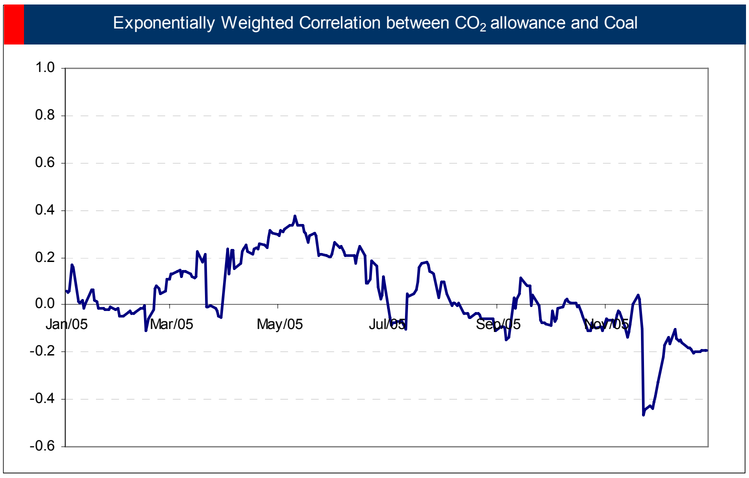
EWMA volatility (squared returns).
Lambda=0.94
Source: ECX

Now we can investigate the time varying correlations by plotting the following figures.



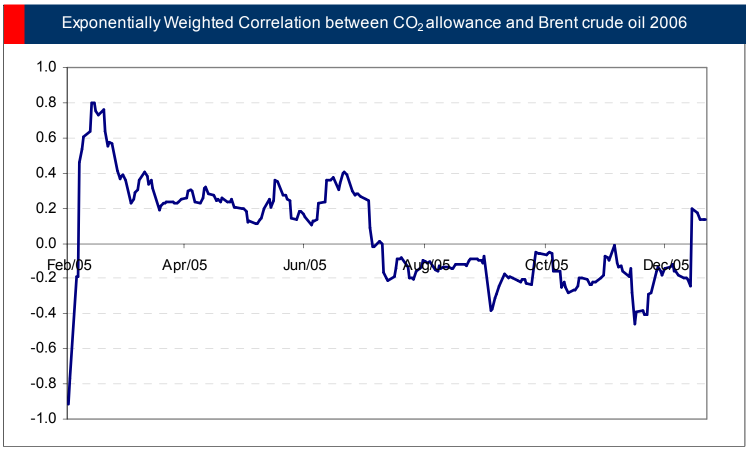
EWMA correlation between CO_2 and NBP Gas calendar 2006.
Lambda=0.94
Source: Bloomberg

The first figure plots the EWMA correlation between CO_2 and gas returns. In July the correlation shoots up from 0.2 to over 0.7 and in the following months slowly declines to values around 0.4. The period of very high correlation in July corresponds to a peak in the EWMA volatility. Next we will consider the coal returns.



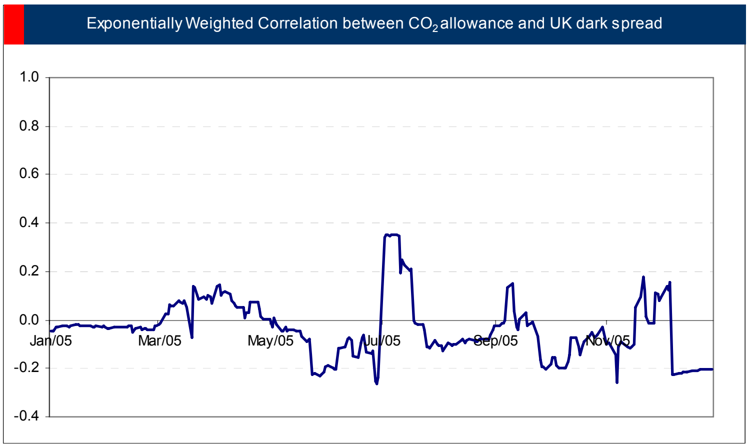
EWMA correlation between CO_2 and Mc Closkey coal Calendar 2006
Lambda=0.94
Source: Bloomberg

The correlation between CO_2 and coal returns is not so strong. The highest correlation was observed in May when it was above 0.3. Since then correlation declined and even became negative at the end of the year. Though some studies dictate a stronger role to coal as price driver, this can not be underpinned by the above analysis, which suggests only modest correlation between the two. Next we investigate the correlation with oil returns.



EWMA correlation between CO_2 and Brent Crude Oil calendar 2006.
Lambda=0.94
Source: Bloomberg

The oil returns show a steadily declining correlation with CO_2 allowances. In early 2005 high values of over 0.7 suggest oil was, at least then, a dominant factor. Since March of that year it has been varying between 0.4 and -0.4 and really can not longer be seen as strong correlated factor. Next the returns of the dark spread (difference between coal and gas prices) are considered.

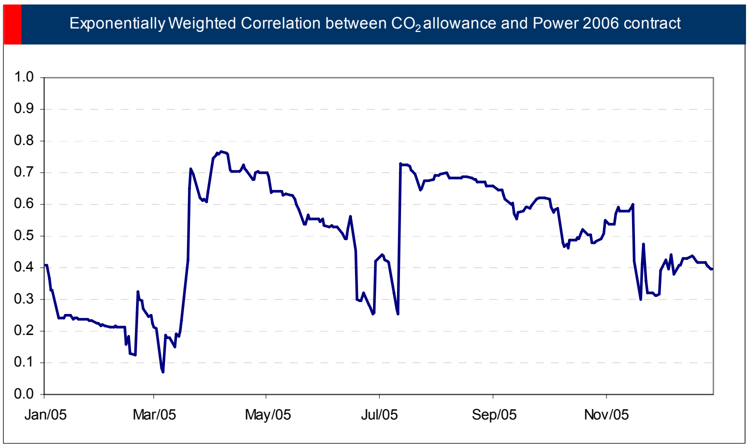


EWMA correlation between CO_2 and UK dark spread calendar 2006. Lambda=0.94

Source: Bloomberg

The result is striking. There have been many studies suggesting that the CO_2 allowances have a strong relation with the dark spread. The presumed effect of fuel switching is the main argument for this. The figure above however suggests the correlation has not been above 0.4 throughout the year. It should be noted that the above dark spread was created by subtracting two calendar 2006 contracts. There is a possibility that there is a dark spread, created by different instruments, that has shown higher correlations, however I have not been able to find such a combination.

Next we plot the EWMA correlation with calendar 2006 power returns. Power returns can not fundamentally be seen as a factor of influence on CO_2 contracts. The other way around however is more plausible. Since CO_2 can be a dominant cost factor for power producers, we suspect high correlations.

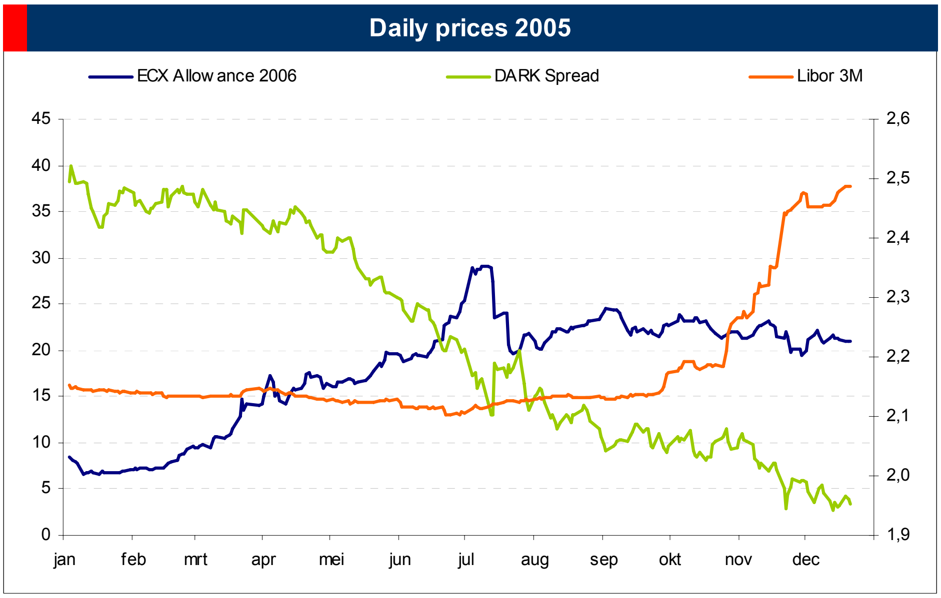


EWMA correlation between CO_2 and Power calendar 2006 contract. Lambda=0.94

Source: Bloomberg

As we suspected there is a continuing relative high level of correlation between power returns and CO_2 allowances. Only in the beginning of the year and some days around July does the correlation drop below 0.3.

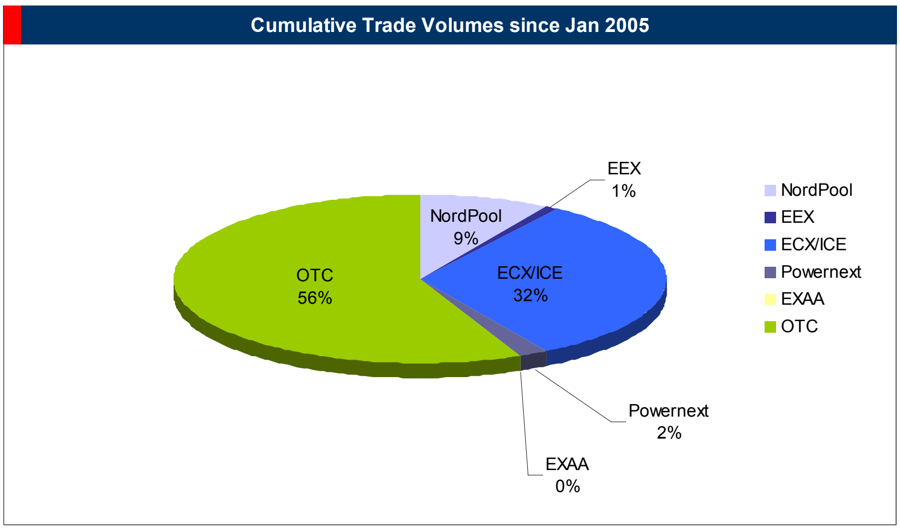
Finally, for illustrative purposes we plot the CO_2 price along with the 3 months LIBOR and the dark spread (difference between coal and gas price). We do this to investigate possible common trends. We conclude as we expected that LIBOR has no significant common trend with CO_2. The dark spread does not show a common trend either.



The figure shows the prices in euros of CO_2 allowances, gas and power for the year 2005. LIBOR 3 Months is plotted on the right axis. On the left axis: ECX 2006 Future contract, dark spread (Difference between coal and gas).

Source: European Climate Exchange, Bloomberg

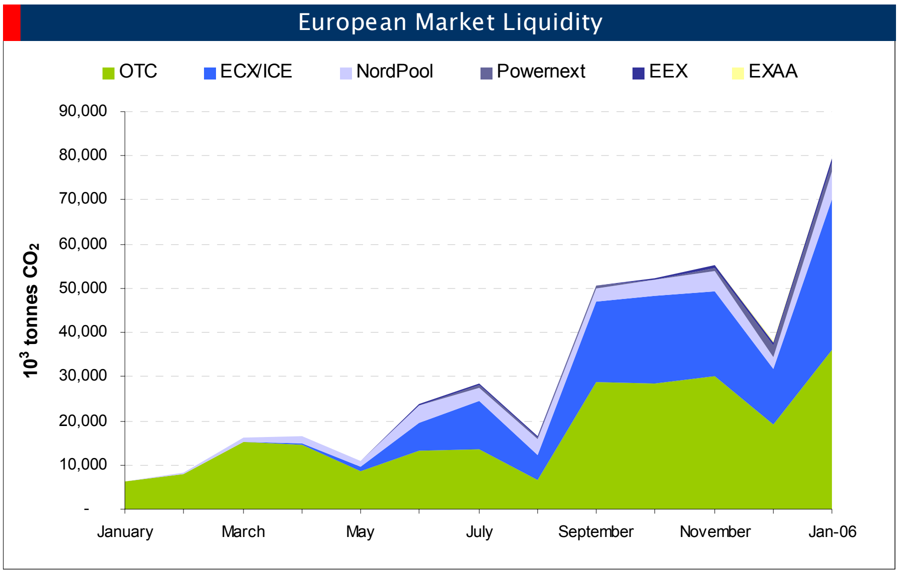
To understand the aspects of the market liquidity of Carbon Allowances, a review will be done of the historical market liquidity. First let us look at the traded volumes. The figure below shows the relative size of the different trading platforms.



The figure shows the contribution of each trading platform to the total traded volume in 2005. OTC represents an estimation by Point Carbon of "over the counter" transactions.

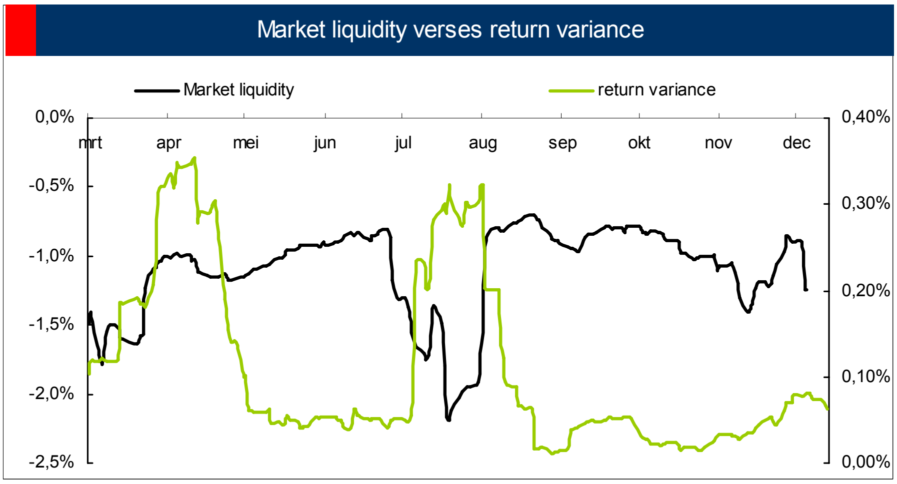
Source: Nordpool, European Energy Exchange (EEX), European Climate Exchange (ECX), Powernext, Energy Exchange Austria(EXAA), Point Carbon

We can state that market volumes in principle have been increasing as more and more registries came online. The figure below plots the monthly traded volumes for each exchange.



Many authors among who Amihud, Yakov et al. (1986) suggest that market liquidity of assets can be estimated by the bid-ask spread, this is the difference between the buy and sell price. This methodology for estimating the market liquidity will be applied here to the CO_2 allowance market. We will use data from NordPool for the period of 1 January 2005 to 1 December 2005.

As an indication of the liquidity of the European allowance market, the spread between the bid and ask prices is calculated as the difference relative to ask prices. Markets with high liquidity will have smaller spreads and vice versa. The returns of liquid markets have a relatively small bandwidth (e.g. variance), less than liquid markets are more volatile because of the associated liquidity risk. We would therefore expect a negative correlation between market liquidity and volatility.



This figure plots the variance of the returns (green line/right axis) against the market liquidity (black line/left axis). The market liquidity is estimated by the difference between the bid and ask price. The variance is the variance over the last 15 days. There is a negative correlation between the two. Since low liquidity corresponds to high return variance.

Source: Bloomberg, NordPool

The figure above plots the variance of the returns against the market liquidity. The market liquidity is the moving average of the bid-ask spread of the allowance price. Note that lower market liquidity corresponds to higher variance of returns. Correlation between the two is evident. Apparently the assumption that market liquidity can be estimated by the bid ask spread also holds for the CO_2 allowance market. According to Point Carbon the lower liquidity is associated with a lack of sellers on the market.

The average spread is 1.21%. In other commodity markets, the spreads are considerably smaller. The gold market for instance has an average spread of 0.17%. The reason why the spread overall remains high, even though trade volumes have been increasing, is probably that OTC trading still accounts for more than half of the volumes traded.

VII. Forecasting the Volatility

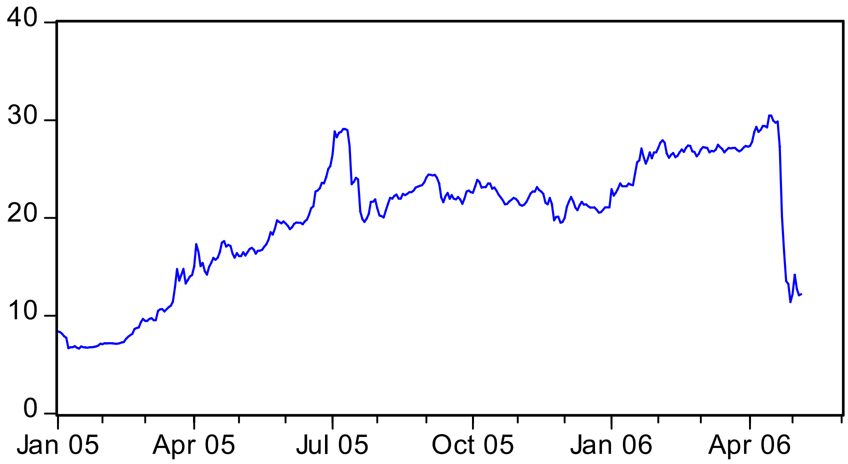
In this section the volatility of the carbon market is analyzed. There is an extensive amount of literature available on volatility modelling and forecasting. Our aim however is to make a simple and robust model that can give an acceptable forecast of the short term volatility. We will start with a general data exploration. Based on our findings different modelling approaches are identified. After estimating these models, their performance is analyzed and compared.

Exploratory data analysis

Sample period

We consider the price data of the European Union Allowance (EUA) future contract traded on the European Climate Exchange (ECX). As we previously showed, this is the most frequently traded contract on the most liquid exchange. Carbon trade data is available from as early as October 2004, however this relates to very obscure over the counter (OTC) transactions mainly between NUON and Shell. Since the actual trading period started in January 2005, this was when market liquidity quickly increased. One can see the change in price behavior at the start of this period in the figure below.

European emission allowance price



This figure plots the CO_2 prices. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.

Sample: October 2004 – May 2006
Source: European Climate Exchange (ECX)

For this reason the sample period for our quantitative research will start on the 3rd of January 2005. This corresponds to the first trading day of 2005. The end of the sample will be the 1st of February 2006, that way we have a sample of about 280 trading days. Note that this is a relative small sample size for performing statistical analyses; estimated models could be impaired by this. The default sample is set to this range since it corresponds to the amount of data that was available throughout this study. Figures and analyses have, where possible, been updated to match most recent data.

Stationary data

A stochastic process which has a probability distribution that is independent of time (e.g. constant) is said to be stationary. As a result, moments like mean and variance do not change over time. The figure of the carbon prices suggests the time series to be non stationary. This is important because in case of non-stationary series, results of analyses of the price will be misleading and for instance often have seemingly high R^2 scores. The presence of a unit root can help determine if the time series is indeed non-stationary. We can formally test for weak stationarity using the following equation, the Augmented Dickey Fuller test developed by Dickey and Fuller (1979):

[1] $$\Delta X_t = \mu + \gamma X_{t-1} + \sum_{i=1}^{k} \delta_i \Delta X_{t-i} + \varepsilon_t$$

The test is performed on the log of the prices with, based on the Akaike Info Criterion (AIC), zero lags specified. The table below shows the output of the test.

Unit root test EUA price			
sample: Jan 2005- Feb 2006			
ADF Test Statistic	-1.3	1% level	-3.5
Prob.	0.6440	5% level	-2.9
		10% level	-2.6
		**MacKinnon CV for rejection of hypothesis of a unit root*	

Table I: *ADF test for presence of unit root in CO_2 prices*

Note that the presence of a unit root really can only be safely rejected using large samples of data. The ADF test statistic is bigger than the critical levels; therefore we do *not reject* the null hypothesis of a unit root. Hence we assume that the price process is non-stationary.

This actually is a quite common characteristic of financial price processes. Often the returns actually are stationary, and since we are interested in volatility this would enable some nice analyses. To do a formal test for stationary returns, first the returns series have to be created. This is done using the following equation.

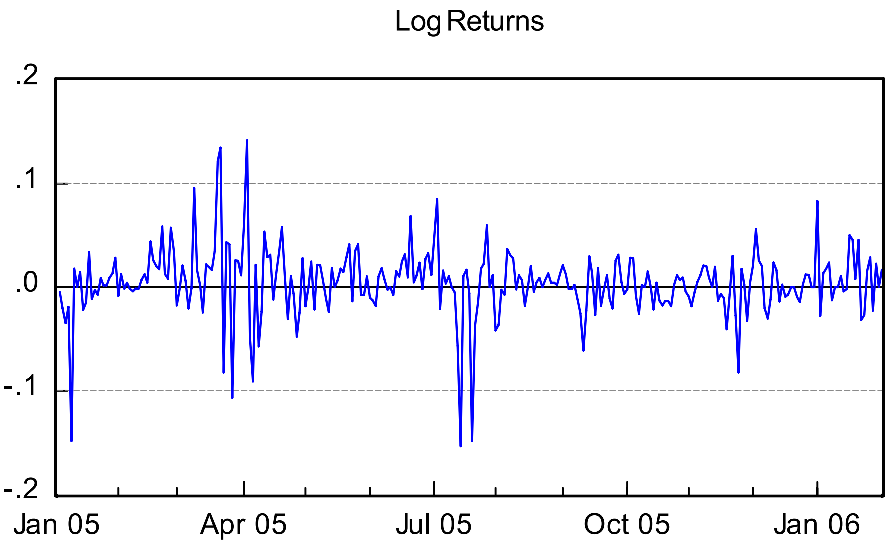
[2] $$X_t = Ln\left(\frac{Y_t}{Y_{t-1}}\right)$$

Where:

X_t = log return

Y_t = price at time t

Visual exploration of the return graph, affirms the expectation of stationary returns. Notice how the returns tend to revert to a constant mean.



This figure plots the Log returns of CO_2 emission allowances. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.

Sample: Jan 2005 – Feb 2006
Source: European Climate Exchange (ECX)

Now we can formally test our expectation of stationary returns the with the ADF test. The Akaike Info Criterion is used to determine the number of lags to include in the test, resulting in 2 lags. The test output is presented in Table II.

Unit root test EUA price				
Sample: Jan 2005- Feb 2006				
ADF Test Statistic	-8.3	1%	Critical Value*	-3.5
Prob.	0.0000	5%	Critical Value	-2.9
		5%	Critical Value	-2.6
**MacKinnon CV for rejection of hypothesis of a unit root*				

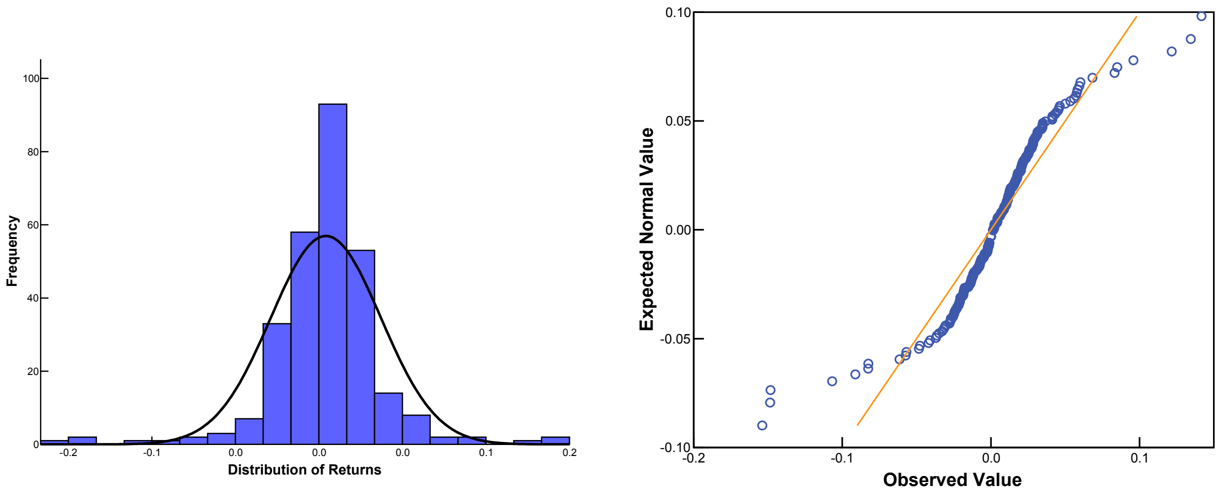
Table II: *ADF test for unit root in CO_2 returns*

Clearly the null hypothesis of a unit root can be rejected. The ADF test value of -8.2705 is large enough to confidently assume the return process to be stationary (as is illustrated by the probability value of zero to four decimal places).

Unconditional distribution

Next object of investigation is the probability density function of the returns. Fama (1963) and Mandelbrot (1963) first observed the leptokurtic unconditional distributions in asset returns. The heavy tails could be explained by the relation between conditional and unconditional densities. When the conditional distribution is normal, the unconditional distribution will simply be a normal mixture distribution with different volatilities, resulting in the heavy tails. In line with the conclusion that financial time series frequently show non-normality by Leland (1999) and the research of Mugele, Rachev et al. (2005) on the fat tails of European power markets, we suspect the returns of CO_2 allowances to have a non-normal unconditional distribution.

To investigate the distribution first a histogram of the returns is plotted next to a Q-Q plot in the figure below.



This figure plots distribution of the Log returns of CO_2 emission allowances next to a Q-Q plot. The figures visually suggest the distribution to be fat-tailed. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.

Sample: Jan 2005 – Feb 2006
Source: European Climate Exchange (ECX)

The histogram is plotted against a normal curve. The histogram suggests the returns to be leptokurtic, since it clearly exhibits "fat tails" combined with a high peak around the mean.

The returns can be visually compared to the normal distribution by means of a Q-Q plot. The fat tails are illustrated by the deviations from the straight line at both ends of the line. Based on the leptokurtic characteristics a high value for Kurtosis is expected. To formally test the hypothesis of normal returns, a Jarque-Bera test is performed. The result is presented in Table III along with the first moments of the distribution.

Data exploration	
Sample: Jan 2005- Feb 2006	
Mean	0.00
Median	0.00
Maximum	0.14
Minimum	-0.15
Std. Dev.	0.03
Skewness	-0.60
Kurtosis	9.70
Jarque-Bera	544
Probability	0.00

Table III: *Descriptive statistics CO_2 returns*

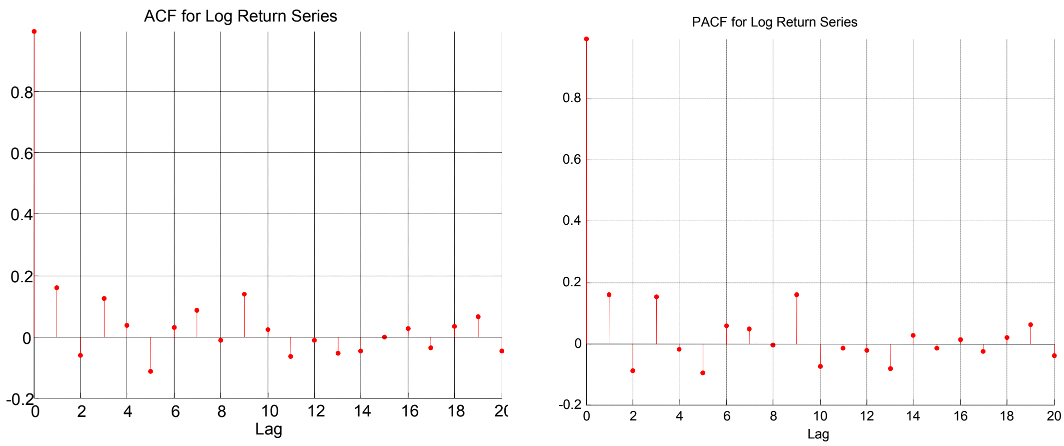
The mean seems to be very close to zero. The distribution is slightly skewed according to the skewness of -0.6. The high value for kurtosis affirms the fat tailed (leptokurtic) distribution we expected. Note that a normal distribution has a kurtosis of 3. The formal test (Jarque-Bera) has a value of 544; the probability of a normal distribution with a test score that high is equal to zero (see the consecutive zeros for the probability value). So the hypothesis of normality in de distribution of returns is rejected.

Volatility Clustering

According to Engle (1993) volatility clustering is a profound characteristic of financial data. Mandelbrot (1963) and Fama (1965) observed that large price changes are often followed by more large price changes, and small changes by more small changes. This volatility clustering also called heteroskedasticity has been observed in many other studies including Baillie, Bollerslev et al. (1993). We interested in volatility clustering since volatility clustering suggests the changing variance can be predicted, because information of today can help predict what happens tomorrow.

Autocorrelation in the returns

Let us first examine the autocorrelation structure of the returns. In efficient arbitrage free markets, returns are regarded to be uncorrelated. Since correlation in returns would enable arbitrage opportunities which, in efficient markets, would cancel the initial opportunity. Using Matlab the (Partial) Autocorrelation functions are plotted.



This figure plots (partial) autocorrelation function of CO_2 allowance returns. The red dots represent the amount of (partial) autocorrelation at the specific lag. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.
Sample: Jan 2005 – Feb 2006

The ACF and PACF provide some indication of the correlation structure of the returns. The figure shows there indeed might be autocorrelation in the returns. We can do a formal test for autocorrelation using Ljung and Box (1978) on the returns. Results are presented in the table below.

	AC	PAC	Q-Stat	Prob
	Sample: Jan 2005- Feb 2006			
1	0.16	0.16	6.16	0.01
2	-0.10	-0.13	8.71	0.01
3	0.11	0.16	11.92	0.01
4	0.00	-0.07	11.92	0.02
5	-0.14	-0.10	16.99	0.01
6	0.05	0.08	17.69	0.01
7	0.07	0.01	18.81	0.01
8	-0.04	-0.00	19.16	0.01
9	0.15	0.17	25.12	0.00
10	0.03	-0.07	25.37	0.01
11	-0.09	-0.02	27.53	0.00
12	-0.03	-0.04	27.75	0.01
13	-0.07	-0.09	28.88	0.01
14	-0.06	0.02	29.91	0.01
15	-0.02	-0.05	30.01	0.01

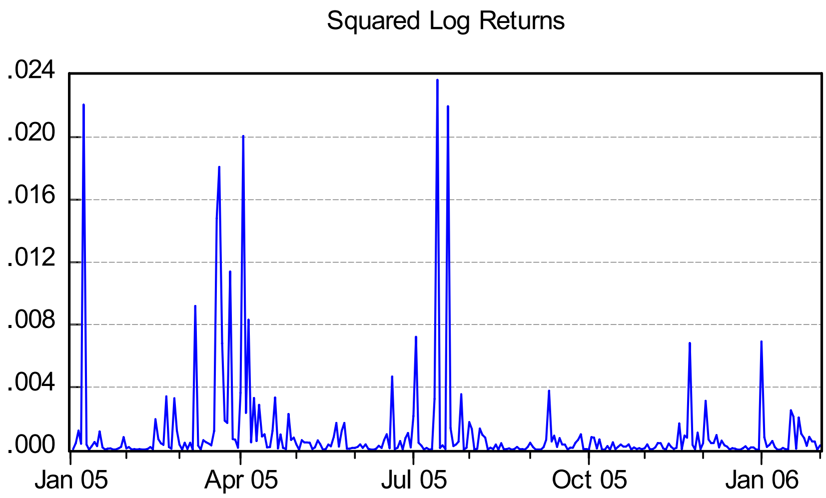
Table IV: *Ljung-Box test CO_2 returns*

The significant autocorrelation suggest that the market is not efficient.

The probability values indicate that autocorrelation is significant for al 15 lags since for all lags the null hypothesis of no autocorrelation can be rejected at a significance level of 5%. An important observation is that this is not what one would expect in regular financial markets. The carbon market apparently is not (yet) very efficient, since past returns apparently can help predict future returns. In an efficient market one would not expect such arbitrage opportunities.

Autocorrelation in the squared returns

Next the squared returns are object of investigation. The phenomenon of volatility clustering discussed by Engle (1993) can be visualized by looking at the squared returns (note that the mean of the log returns is close to zero. By squaring the returns, both the volatility clusters and the mean reverting behavior in between the clusters should appear. Note that the mean to which the volatility reverts will correspond to long term volatility forecasts and due to the long term principle be indifferent of current news.



This figure plots squared CO_2 returns showing volatility clustering. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.

Sample: Jan 2005 – Feb 2006
Source: European Climate Exchange (ECX)

The clusters of volatility appear very clearly in the above figure, with the two biggest clusters in April and July of 2005. In a previous chapter we concluded that the volatility in April was induced by news about decisions of the European Council concerning the NAP's of the United Kingdom and the Czech Republic as well as a strong price hike on the back of commodity prices. The high volatility in July was caused by a combination of the terrorist attacks in London and plummeting gas prices. The period's in-between clearly show the mean reverting behavior discussed before.

To quantify the correlation of squared residuals a Ljung-Box test is done on the squared returns, 15 lags specified. The results are presented in the figure below.

	AC	PAC	Q-Stat	Prob
Sample: Jan 2005- Feb 2006				
1	0.21	0.21	9.83	0.00
2	0.09	0.04	11.48	0.00
3	0.01	-0.02	11.49	0.01
4	0.31	0.32	32.87	0.00
5	0.18	0.07	40.40	0.00
6	-0.01	-0.11	40.41	0.00
7	0.01	0.06	40.45	0.00
8	0.17	0.11	47.39	0.00
9	0.27	0.15	63.83	0.00
10	0.13	0.07	67.82	0.00
11	0.05	0.01	68.34	0.00
12	0.12	0.06	71.80	0.00
13	0.04	-0.14	72.20	0.00
14	-0.04	-0.14	72.58	0.00
15	-0.04	0.01	72.94	0.00

Table V: *Ljung-Box test for squared CO_2 returns*

Based on the probability values we conclude that autocorrelation is significant for al 15 lags since for all lags the null hypothesis of no autocorrelation can be rejected at a significance level of 5%. This is a very strong evidence of volatility clustering and hence heteroskedasticity.

Model estimation and forecasting

GARCH Volatility

Traders have been practicing volatility forecasting, by calculating standard deviations for some periods of time and creating a moving average from it. Engle (1982) seeks to find a statistical way to determine the best method for volatility forecasting. He created the ARCH model, later generalized by Bollerslev (1986). According to Engle (1993) research has established that the GARCH(1,1) model is a parsimonious model that performs rather well for a wide variety of financial applications. In line with Engle (2001) EWMA is a non-stationary version of GARCH(1,1) where the persistence parameters sum to one. The GARCH model is mean reverting, whereas the former EWMA model is not mean reverting. We are interested in the GARCH model, since we have shown the returns to have GARCH effects.

Note that we are working with a rather small sample size of 280 trading days. Hwang and Pereira (2003) suggest that typical GARCH models, considering the size of biases and convergence errors, require at least 500 observations for robust estimation. Our small sample size will accordingly result in a negatively biased estimate.

The GARCH(p,q) model has the following structure:

[5] $$r_t = \mu_t + \sigma_t \varepsilon_t$$

With

[6] $$\sigma_t^2 = \omega + \sum_{i=1}^{p} \alpha_i (r_{t-i} - \mu_t)^2 + \sum_{i=1}^{q} \beta_i \sigma_{t-i}^2$$

So the conditional variance depends on a constant (ω), the lagged squared error(s) and its own lagged value(s). The alphas describe the effect of last period's error. The beta's the effect of last period's variance. The sum of the two is the persistence of the volatility.

Recall that we showed the returns are not normal, distributed, hence we will estimate the GARCH model using Quasi Maximum Likelihood (QML) method. We estimate GARCH(p,q) models for different values of p and q, and calculate the according Akaike Info Criterion (AIC) and the Schwarz Criterion (SC). The model with the smallest value has the best performance. Results of the estimation sequence are presented in the table below.

model	AIC	SC
Sample: Jan 2005- Feb 2006		
GARCH (1,0)	-4.35	-4.29
GARCH (1,1)	-4.39	-4.32*
GARCH (2,1)	-4.39	-4.30
GARCH (2,2)	-4.39	-4.29
GARCH (3,2)	-4.42*	-4.31
GARCH (3,3)	-4.39	-4.26
GARCH (4,3)	-4.40	-4.26
GARCH (4,4)	-4.40	-4.24
GARCH (5,4)	-4.39	-4.22
GARCH (5,5)	-4.38	-4.19
GARCH (6,5)	-4.37	-4.17
GARCH (6,6)	-4.35	-4.13

Table VII: *Model selection scores*

The AIC suggests the best model to be a GARCH(3,2) model. The SC however penalizes more for including too many terms in a model. Based on the small sample size, the robust performance suggested by Engle, and the SC, the GARCH(1,1) model is chosen.

The estimation output is presented in the table below.

	Variance Equation			
	Coef	*Std. Err.*	*z-Stat.*	*Prob.*
C	0.00	0.00	1.65	0.09
ARCH(1)	0.42	0.14	2.16	0.03
GARCH(1)	0.56	0.11	5.80	0.00

Sample: Jan 2005- Feb 2006
Bollerslev-Wooldrige robust standard errors & covariance

Table VIII: *GARCH(1,1) parameter estimation output*

This results in the following parameter specification:

$$\omega = 0.00$$
$$\alpha_1 = 0.42$$
$$\beta_1 = 0.56$$

First, all parameters are positive, but notice that the value of ω is very close to zero. The probability value also is reasonably big; suggesting the probability that the parameter is zero is high. To check if the estimation of the model resulted in a correct and usable model some post estimation tests have to be done. Next, we want to check if the long term volatility is stationary (mean reverting). The process is stationary in variance if:

[7] $$\sum_{j=1}^{p} \alpha_j + \sum_{j=1}^{q} \beta_j < 1$$

In this case the process has a stationary variance, since the sum of the parameters is smaller than one.

[8] $$\alpha + \beta = 0.98$$

In the long term the volatility will revert to its mean. Since the process is stationary we can calculate the long term mean volatility by:

[9] $$\sqrt{\frac{0.000}{(1-0.42-0.56)}} = 0$$

To check the performance of the GARCH model the squared standardized residuals will be studied next. The standardized residuals are calculated by dividing the residuals by the conditional standard deviation. It is important to note whether the GARCH model succeeded in capturing the autocorrelation the squared residuals. To asses the amount of remaining autocorrelation the Ljung-Box test is performed.

Auto correlation squared residuals				
	AC	*PAC*	*Q-Stat*	*Prob*
1	0.0	0.0	0.1	0.7
2	-0.1	-0.1	1.1	0.6
3	-0.1	-0.1	2.3	0.5
4	0.0	0.0	2.3	0.7
5	0.0	0.0	2.3	0.8
6	0.0	-0.1	3.0	0.8
7	0.0	0.0	3.3	0.9
8	0.1	0.1	9.5	0.3
9	0.0	0.0	9.6	0.4
10	0.0	0.0	9.7	0.5
11	0.0	0.1	10.1	0.5
12	0.0	0.0	10.1	0.6
13	0.0	0.0	10.3	0.7
14	-0.1	0.0	11.1	0.7
15	0.0	0.0	11.2	0.7

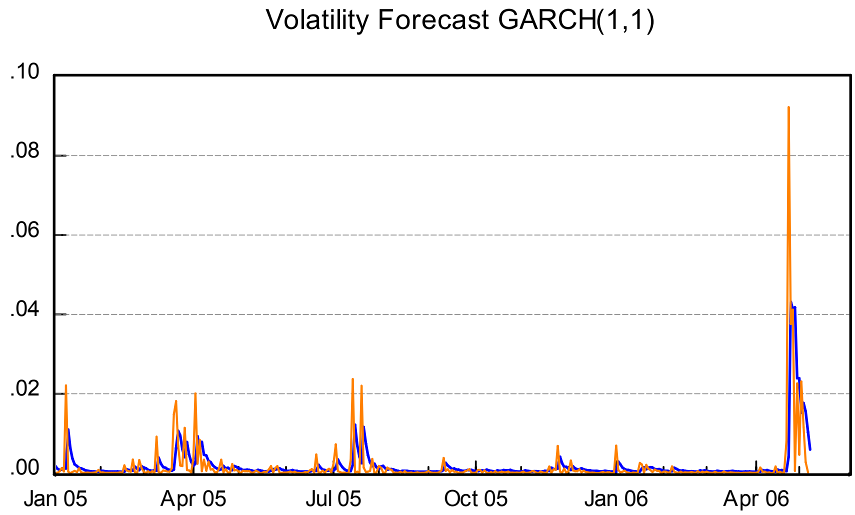
Table IV: Remaining autocorrelation from *GARCH(1,1)*

It is nice to see that the GARCH model captures a lot of the auto correlation in the squared returns. Remaining GARCH effects could perhaps be dealt with by specifying more model parameters. This however was restrained when we chose to be reserved in adding model parameters.

Note the GARCH(1,1) model specification is:

[10] $$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2$$

So when we want to predict the volatility 1 step ahead, we need ε_t^2 and σ_t^2 e.g. the current values. Then we can simply calculate the step 1 ahead. We create a series of the day-ahead forecasts and plot them against the squared returns.



This figure plots the day ahead volatility forecast by the GARCH(1,1) model. The orange line represent the actual squared returns, the blue line represents the one day volatility forecast by the garch model. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.

Sample: Jan 2005 – May 2006
Source: European Climate Exchange (ECX)

The orange line corresponds to the actual squared returns and the blue line to the forecast. The forecast shows very little ghosting effects incurred by high peaks than for instance a MA model would. The GARCH(1,1) volatility model will be formally tested in the last paragraph of the chapter, where it is applied to a risk management framework.

ARMA-GARCH Volatility

The GARCH model which models the conditional variance can be complemented by adding parameters that model the conditional mean of the returns. A so called ARMA-GARCH model is the result. Recall that there was significant autocorrelation in the returns (5). This autocorrelation can be exploited by adding the ARMA term. The basic structure of an ARMA(m,n) process is as follows:

$$X_t = \sum_{i=1}^{m} \alpha_i X_{t-i} + \sum_{j=1}^{n} \theta_j \varepsilon_{t-j} + \varepsilon_t$$

Where ε_t iid $\sim N(0,1)$

Eviews is used to estimate a range of ARMA(m,n) terms for m and n orders up to 10. The Schwarz Criterion is used to select the best model. In this case the ARMA(5,0) has the best SC. Now we introduce the AR(5) term for the mean return in the GARCH(1,1) estimation. Using QML the output is as followed:

Sample: Jan 2005- Feb 2006

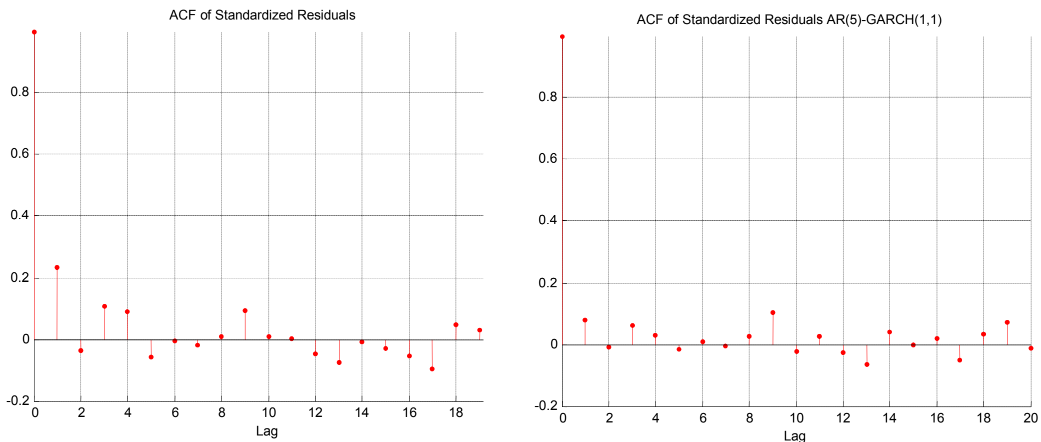
Bollerslev-Wooldrige robust standard errors & covariance

	Coefficient	Std. Error	z-Statistic	Prob.
C	0.01	0.00	3.39	0.00
AR(1)	0.22	0.06	3.72	0.00
AR(2)	-0.09	0.05	-1.73	0.08
AR(3)	0.10	0.06	1.86	0.06
AR(4)	0.05	0.07	0.78	0.44
AR(5)	-0.07	0.06	-1.18	0.24
C	0,00	0.00	1.51	0.13
ARCH(1)	0.23	0.12	1.84	0.07
GARCH(1)	0.69	0.13	5.28	0.00
R-squared	0.06	Mean dependent var		0.01
Adjusted R-squared	0.03	S.D. dependent var		0.03
S.E. of regression	0.03	Akaike info criterion		-4.32
Sum squared resid	0.27	Schwarz criterion		-4.21
Log likelihood	607.91	F-statistic		2.00
Durbin-Watson stat	2.02	Prob(F-statistic)		0.05

Table X: *Estimation output of the AR(5)-GARCH(1,1) model*

As with the GARCH model we previously estimated we have to establish if all assumptions are met. The GARCH parameters are all positive and the sum is less than one, so the long term volatility is stationary (mean reverting).

To check the performance of the ARMA-GARCH model the standardized residuals will be studied. We would like to know if the ARMA-GARCH model succeeded in capturing the autocorrelation the residuals. For easy comparison the ACF of the residuals and the ACF of the standardized residuals are plotted next to each other.



This figure plots the autocorrelation function of the residuals and AR(5)-GARCH(1,1) standardized residuals The left figure show bigger autocorrelation than the right figure. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.
Source: European Climate Exchange (ECX)

Clearly the autocorrelation has been reduced. A formal test to prove this is shown in the table below where a Ljung-Box test is performed on the first 15 lags.

	AC	PAC	Q-Stat	Prob
	Sample: Jan 2005- Feb 2006			
1	0.08	0.08	1.77	0.18
2	-0.01	-0.01	1.78	0.41
3	0.06	0.06	2.78	0.42
4	0.03	0.02	3.08	0.55
5	-0.02	-0.02	3.14	0.68
6	0.01	0.01	3.16	0.79
7	-0.01	-0.01	3.17	0.87
8	0.03	0.03	3.36	0.91
9	0.10	0.10	6.42	0.70
10	-0.02	-0.04	6.57	0.77
11	0.03	0.03	6.76	0.82
12	-0.03	-0.05	6.96	0.86
13	-0.06	-0.06	8.17	0.83
14	0.04	0.05	8.61	0.86
15	-0.00	-0.01	8.61	0.90

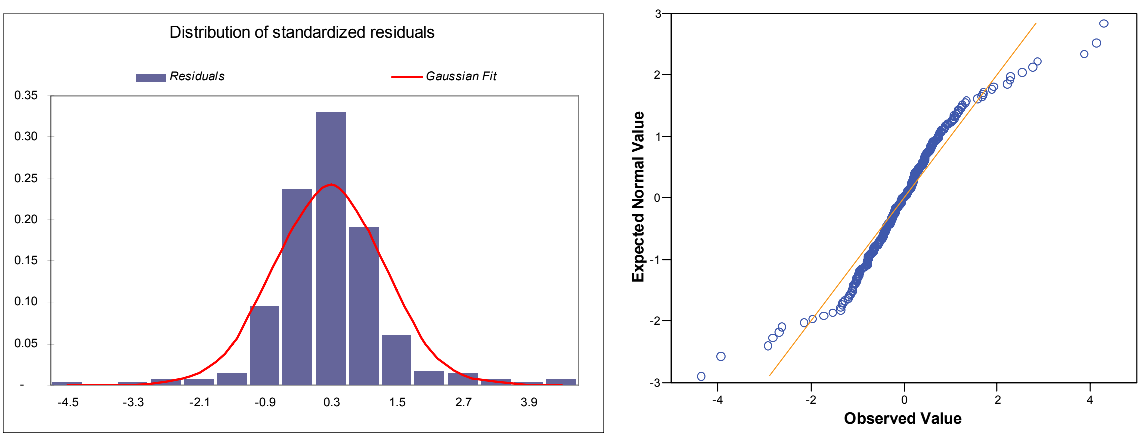
Table XI: *Ljung-Box test for autocorrelation*

The high probability values indicate we can not reject the null hypotheses of no autocorrelation at the significance level of 5%. So the AR(5) model effectively deals with the autocorrelation.

We have now explored two different models; one with a structure in the variance (GARCH) and one wit a structure in both the variance and the mean (AR-GARCH). For our further studies we will build on the GARCH(1,1) model.

Distribution of the residuals

Finally the distribution of the standardized residuals of the parsimonious GARCH(1,1) model is analyzed. First we look at the histogram with a fitted normal curve and a Q-Q plot.



This figure plots the histogram and Q-Q plot of standardized residuals GARCH (1,1) CO_2 returns. The instrument is an ECX future 2006 contract traded at the biggest emission trading platform: the European Climate Exchange.
Sample: Jan 2005 – Feb 2006
Source: European Climate Exchange (ECX)

The figure indicates that the standardized residuals are not normal distributed. The Q-Q plot affirms the notion of a leptokurtic distribution. The formal test for normal distributed standardized residuals is presented in the table below.

Data exploration	
Sample: Jan 2005- Feb 2006	
Mean	-0.03
Std. Dev.	1.00
Skewness	1.05
Kurtosis	8.18
Jarque-Bera	403.8
Probability	0.00

Table IX: Jarque-Bera test for normality of standardized residuals GARCH(1,1)

The test formally affirms the expectation of non-normality, indicated by the low probability level of the test. The methodology of using QML for the estimation procedure was the right thing to do since ordinary maximum likelihood requires normality.

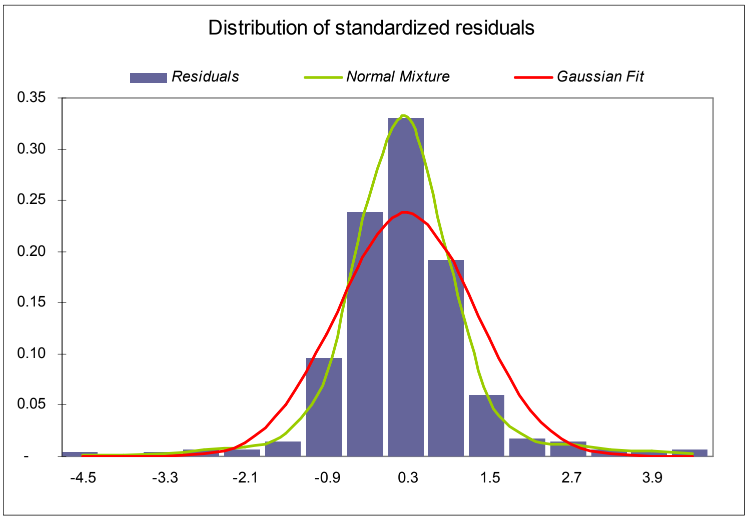
We are however interested in the distribution of the residuals. A method gaining popularity is the density mixture model. The underlying principle is to make a distribution by combining a finite number of normal distributions, each given a certain weight. For a detailed discussion about mixture modelling we refer to Alexander (2001). The models equation looks as follows:

$$\sum_{i=1}^{k} p_i f(x \mid \theta_i) \text{ with } k > 1,\ \sum p_i = 1$$

Where $f(x \mid \theta_i)$ are normal distributions with $\theta_i =$ mean and variance. The proportions p_i sum to one. Using the open source software package "R" we will estimate the optimal number of components as well as the mean, standard deviation and assigned weight. The number of components is determined by the Bayesian Info Criterion. The moments and weights of the components are estimated by an Estimation Maximization algorithm discussed by Fraley and Raftery (2002). The results are presented in the table below.

Normal mixture components			
	weight	*mean*	*st dev*
one	0.18	0.19	1.93
two	0.82	-0.08	0.61

The procedure resulted in a mixture model build from two components. The figure below plots the mixture distribution against the empirical distribution of the residuals.



This figure plots the histogram of the standardized residuals, the mixture model by the green curve and a fitted normal curve by the red line. The mixture was estimated using an Estimation Maximization algorithm.

The mixture model seems to very accurately match the empirical distribution of the standardized residuals. For easy comparison we look at the first four moments of both the empirical distribution and the mixture model.

Data exploration mixture model	Mean	Variance	Skewness	Kurtosis
Mixture model	-0,03	0,98	1,72	8,24
Standardized Residuals	-0,03	1,00	1,05	8,18

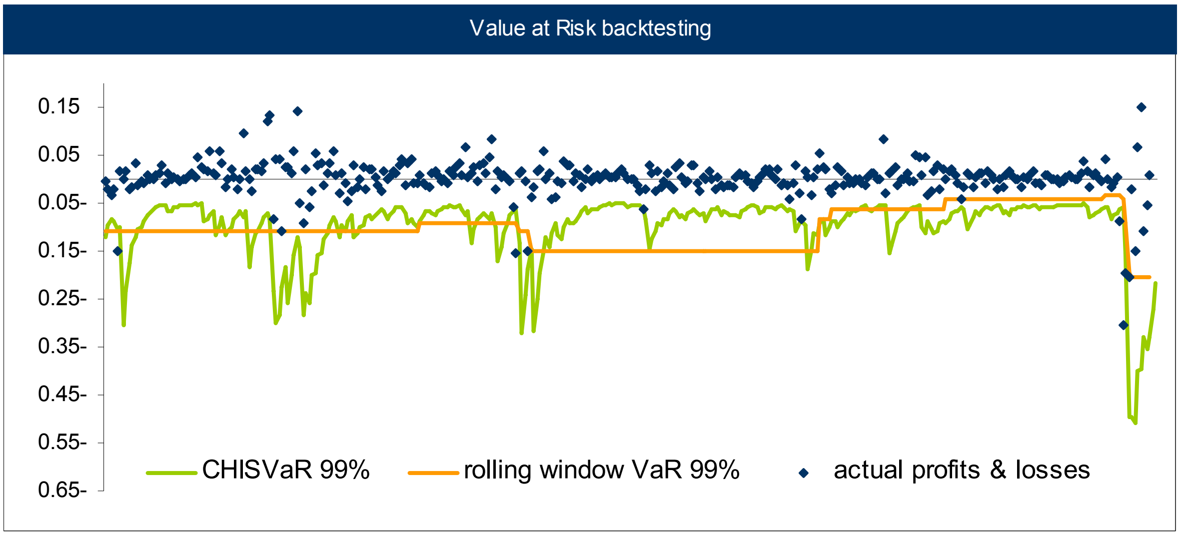
The estimated mixture model fits the empirical distribution well. High kurtosis is fully captured by the mixture model.

The standardized residuals can be used for different purposes. The calculation of conditional Value at Risk is an example. Although for this application often the best results are obtained using the empirical distribution rather than some parametric assumption, the mixture model is a straight forward method that often succeeds well in capturing the so called fat tails. We refer to Hamilton (1994) for a discussion of the applications of mixture models.

Application to Value at Risk modelling

We will consider one CO_2 contract that is traded at the ECX. Using a 250 day rolling sample period the historic simulation VaR is calculated. Note that these are constant value at risk figures that will only change when the sample is altered, for instance when a new day is added to the sample.

Now using the standardized residuals from the GARCH(1,1) model we calculate the CHISVaR. The CHISVaR method has both the benefits of the GARCH model and the empirical distribution. In the figure below we have plotted the different VaR estimations against the actual profits and losses.



This figure plots the Value at Risk predictions against the actual profit and losses of the next day.
The blue dots represent the profits and the losses.
The orange line is the 99% 1-day VaR based on historic simulation using a rolling 250 day period.
The green line represents the 99% 1-day conditional historic simulation VaR (CHISVaR) based on the GARCH(1,1) model.
Dots that fall below the VaR curves are acknowledged as outliers.

To test the out of sample performance the sample is increased to include the turbulent events in May 2006.

We can compare the performance of the Value at Risk models by doing a formal test formulated by Kupiec (1995). He developed a simple framework for back testing VaR models by comparing the expected amount of outliers (in this case 1%) to the actual number of outliers. The likelihood ratio is given by:

$$LR = -2\ln\left[(1-p)^{n-x} p^{x}\right] + 2\ln\left[\left(1-\frac{x}{n}\right)^{n-x}\left(\frac{x}{n}\right)^{x}\right]$$

With:
x= number of failures
n= number of observations
p= specified accuracy of VaR model

This follows a Chi-square distribution with one degree of freedom. We perform the test out of sample using data from January 2005 to May 2006. The results are presented in the table below.

Back testing 1-day 99% Value at Risk

349 observations	*expected outliers*	*actual outliers*	*Liklihood Ratio**	*critical value*	*p value*
CHISVaR	3	5	0.582	3.84	0.45
Rolling VaR	3	7	2.760	3.84	0.10

** test statistic by Kupiec (2005)*

As we can see the CHISVaR had 5 outliers where 3 (3.49) where expected. This corresponds to a likelihood ratio of 0.582. The critical value for rejecting the VaR model is 3.84, thus our model is accepted. The performance of the rolling VaR also leads to accepting the model since the likelihood is smaller than the critical value. Note however that the CHISVaR performance is better than the Rolling VaR.

The out of sample performance of the CHISVaR model is rather well. The combination of the GARCH model and the empirical distribution proofs to be a very promising tool for Value at Risk calculations.

VIII. Conclusions

In this chapter we will reflect on the results from the different analysis that we made. We have seen that the burning of fossil fuels is adding to the global warming effect. The various international regulations that are in force aim at reducing the human induced CO_2 production by enforcing an emission cap.

Under the European Trading Scheme emission trading is the reduction method of choice. By making the market fundamentally short on allowances trading is stimulated. The ratification of the Kyoto Protocol by Russia is posing a vast amount of 'hot air' allowances, since Russia already is far below its emission reduction target.

Recent events have stressed once more that one of the most important factors influencing the allowance market is the amount of actual emissions with regard to the current reduction target. For emission markets to function well the market has to be fundamentally short.

The market liquidity estimated by the bid-ask spread has seen a remarkable dip in the summer of 2005. This corresponded to an increase in volatility. The reason behind the temporary low liquidity was a lack of sellers on the market.

For the CO_2 analyses we have used the emission allowance forward contract with delivery in December 2006. This is the most frequently traded instrument on the most liquid market; the European Climate Exchange. Although our case study focuses on this specific instrument, we suspect it to function as a benchmark for the European allowance market.

We have shown that the returns on the CO_2 allowances have had periods of high correlation with NBP UK gas calendar 2006. Correlations were up to 70% in July 2005. Other fuel related instruments have been investigated, but showed no consistent levels of correlation.

Based on the risk factors and the broad market analysis of this research, Event Risk Scenario's have been formulated. They are a practical tool towards stress testing models. The stress scenarios are listed in Appendix V.

The Conditional Historic Simulation Value at Risk (CHISVaR) using a GARCH model and the empirical distribution, to calculate the Value at Risk proved to deliver a better performance than conventional VaR calculations. This was established by doing formal out of sample back testing.

The CHISVaR model is very promising and deserves more attention in the literature, for it combines the benefits of the parsimonious GARCH model and the model free empirical distribution.

IX. Recommendations

During this study several subjects came up that can be interesting to do further research on. This section will summarize the different recommendations along with a short description.

Influence of risk factors on forward prices

Given the limitation on available time, the author has been unable to do a thorough and complete analysis of the effects that the individual and combined risk factors have on the forward curve. One can suspect that political uncertainty for instance can induce big shifts in the forward curve.

Correlation to a news index

During the study an idée emerged that the market psyche could be modeled by creating a 'news index'. The market psyche corresponds to such events where it is the news, be it the truth or not, that moves the market. The index can be made by categorizing the news related to the emission markets and performing some kind of regression analysis on it. The index then could work as an early warning system for large market movements. Recent events have showed that information distribution on the market is far from perfect, resulting in very big impact of news that actually could have been foreseen in an earlier stage if reporting instruments had been sufficiently in place. In this case the news that Spain and Belgium had lower EtCs than expected collapsed the market. Had proper reporting instruments been in place, than the information probably would have reached the market in an earlier stage and priced in accordingly.

Comparing emission market data from different countries

In this study we looked at one instrument from one market platform. The choice for this instrument was based on traded volumes. It was the most frequent traded instrument on the most liquid market platform. The reasoning behind this is that the smaller markets probably use this instrument as a benchmark for their own trading activities. Further research could be done on the relation between the different instruments on the different trading platforms. Especially since more and more derivatives are coming to the market.

Application and testing of the CHISVaR methodology

The method of using the empirical distribution of the standardized residuals from a GARCH process to calculate Value at Risk in general deserves a lot more attention. Most GARCH related Value at Risk models suffer from complicated or unrealistic parametric assumptions. In contrast CHISVaR delivers robust results, because it benefits from both the state of the art GARCH methodology and the simplicity of the empirical distribution, which allows the data to speak for itself.

Application of CHISVaR methodology for multi day Value at Risk

The conditionality that forms the basis of the underlying GARCH model brings up a new restriction for calculating the multi day Value at Risk. Since the square root of time rule would be in great contradiction with the volatility clustering that forms the basis of the GARCH principle. A different approach is thus needed. Christoffersen, Diebold et al. (1998), Diebold, Hickman et al. (1997) and Hirtle (1998) already recognized the scaling issues.

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Appendix I: Countries under the Kyoto Protocol

ANNEX I Countries

Australia
Austria
Belarus[a]
Belgium
Bulgaria[a]
Canada
Croatia[a] *
Czech Republic[a] *
Denmark
European Economic Community
Estonia[a]
Finland
France
Germany
Greece
Hungary[a]
Iceland
Ireland
Italy
Japan
Latvia[a]
Liechtenstein*
Lithuania[a]
Luxembourg
Monaco*
Netherlands
New Zealand
Norway
Poland[a]
Portugal
Romania[a]
Russian Federation[a]
Slovakia[a] *
Slovenia[a] *
Spain
Sweden
Switzerland
Turkey
Ukraine[a]
United Kingdom of Great Britain and Northern Ireland
United States of America

[a] *Countries that are undergoing the process of transition to a market economy.*

* *Countries added to Annex I by an amendment that entered into force on 13 August 1998, pursuant to decision 4/CP.3 adopted at COP.3.*

ANNEX II Countries

Australia
Austria
Belgium
Canada
Denmark
European Union
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Japan
Luxembourg
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
Turkey
United Kingdom of Great Britain and Northern Ireland
United States of America

Publisher's note: Turkey was deleted from Annex II by an amendment that entered into force 28 June 2002, pursuant to decision 26/CP.7 adopted at COP.7.

Appendix II: Countries that ratified the Kyoto Protocol

The list contains the latest information concerning dates of signature and ratification received from the Secretary-General of the United Nations, as Depository of the Kyoto Protocol.

1	Albania
2	Algeria
3	Antigua and Barbuda
4	Argentina
5	Armenia
6	Austria
7	Azerbaijan
8	Bahamas
9	Bahrain
10	Bangladesh
11	Barbados
12	Belarus
13	Belgium
14	Belize
15	Benin
16	Bhutan
17	Bolivia
18	Botswana
19	Brazil
20	Bulgaria
21	Burkina Faso
22	Burundi
23	Cambodia
24	Cameroon
25	Canada
26	Cape Verde
27	Chile
28	China
29	Colombia
30	Costa Rica
31	Cuba
32	Cyprus
33	Czech Republic
34	Democratic Republic of the Congo
35	Denmark
36	Djibouti
37	Dominica
38	Dominican Republic
39	Ecuador
40	Egypt
41	El Salvador
42	Equatorial Guinea
43	Eritrea
44	Estonia
45	Ethiopia
46	Fiji
47	Finland
48	France
49	Gambia
50	Georgia
51	Germany
52	Ghana
53	Greece
54	Grenada
55	Guatemala
56	Guinea
57	Guinea-Bissau
58	Guyana
59	Haiti
60	Honduras
61	Hungary
62	Iceland
63	India
64	Indonesia
65	Iran
66	Ireland
67	Israel
68	Italy
69	Jamaica
70	Japan
71	Jordan
72	Kenya
73	Kiribati
74	Kuwait
75	Kyrgyzstan
76	Laos
77	Latvia
78	Lesotho
79	Liberia
80	Liechtenstein
81	Lithuania
82	Luxembourg
83	Macedonia
84	Madagascar
85	Malawi
86	Malaysia
87	Maldives
88	Mali
89	Malta
90	Marshall Islands
91	Mauritania
92	Mauritius
93	Mexico
94	Micronesia
95	Moldova
96	Monaco
97	Mongolia
98	Morocco
99	Mozambique
100	Myanmar
101	Namibia
102	Nauru
103	Nepal
104	Netherlands
105	New Zealand
106	Nicaragua
107	Niger
108	Nigeria
109	North Korea
110	Norway
111	Oman
112	Pakistan
113	Palau
114	Panama
115	Papua New Guinea
116	Paraguay
117	Peru
118	Philippines
119	Poland
120	Portugal
121	Qatar
122	Romania
123	Russia
124	Rwanda
125	Saint Lucia
126	Saint Vincent and the Grenadines
127	Samoa
128	Saudi Arabia
129	Senegal
130	Seychelles
131	Singapore
132	Slovakia
133	Slovenia
134	Solomon Islands
135	South Africa
136	South Korea
137	Spain
138	Sri Lanka
139	Sudan
140	Swaziland
141	Sweden
142	Switzerland
143	Syria
144	Tanzania
145	Thailand
146	Togo
147	Trinidad and Tobago
148	Tunisia
149	Turkmenistan
150	Tuvalu
151	Uganda
152	Ukraine
153	United Arab Emirates
154	United Kingdom
155	Uruguay
156	Uzbekistan
157	Vanuatu
158	Venezuela
159	Vietnam
160	Yemen

Appendix III Countries that have not ratified the Protocol

The list contains the latest information as received from the Secretary-General of the United Nations, as Depository of the Kyoto Protocol.

1	Afghanistan
2	Andorra
3	Angola
4	Australia
5	BosniaandHerzegovina
6	Brunei
7	CentralAfricanRepublic
8	Chad
9	Comoros
10	Côted'Ivoire
11	Croatia
12	Gabon
13	Iraq
14	Lebanon
15	Libya
16	Palestine
17	RepublicofChina(Taiwan)
18	RepublicoftheCongo
19	SaintKittsandNevis
20	SanMarino
21	SaoTomeandPrincipe
22	SerbiaandMontenegro
23	SierraLeone
24	Somalia
25	Suriname
26	Tajikistan
27	Timor-Leste
28	Tonga
29	Turkey
30	UnitedStates
31	VaticanCity
32	WesternSahara
33	Zambia
34	Zimbabwe

Appendix IV: National Allocation Plan The Netherlands

(Bijlage bij de artikelen 3 en 4 van het ontwerp nationaal toewijzingsbesluit broeikasgasemissierechten 2005-2007)

Naam inrichting	plaats inrichting	Toegewezen broeikas-gas emissie-rechten voor de planperiode 2005-2007 (in kton)	Per kalenderjaar van de planperiode te verlenen broeikasgas emissie-rechten (in kton/a)
Raffinaderijen			
Esso Nederland BV, afdeling raffinaderij	Botlek Rotterdam	7.501,090	2.500,363
Kuwait Petroleum Europoort BV	Europoort (Rt)	1.807,272	602,424
NEREFCO	EUROPOORT-ROTTERDAM	6.543,483	2.181,161
Shell Ned. Raffinaderij BV	Hoogvliet (Rt)	19.940,914	6.646,971
Total Raffinaderij NL	Vlissingen	4.944,478	1.648,159
Koch HC Partnership B.V.	Europoort-Rt	317,414	105,805
Mijnbouw (Nogepa)			
Bergen Drying Facility	Alkmaar	142,521	47,507
P15-D	p/a Den Haag	291,904	97,301
Kotter	Den Haag	111,032	37,011
P6-A	Den Haag	152,849	50,950
Gasbeh. Stat. Harlingen TC	Den Helder	140,099	46,700
Gasunie CS Oldeboorn	Groningen	1,782	,594
Gasunie CS Ommen	Groningen	136,955	45,652
Gasunie CS Alphen	Groningen	,044	,015
Gasunie CS Beverwijk	Groningen	33,735	11,245
Gasunie CS Wieringermeer	Groningen	17,474	5,825
Gasunie LNG Maasvlakte	Groningen	1,103	,368
Gasunie CS Ravenstein	Groningen	186,013	62,004
Gasunie CS Spijk	Groningen	97,553	32,518
Gasunie CS Zweekhorst	Groningen	12,726	4,242
Gaszuiveringsinstallatie - GZI	Emmen	221,151	73,717
Eni Nederland BV	Hoofddorp	325,850	108,617
F03-FB-1	-	232,676	77,559
K14-FA-1	-	371,072	123,691
Ameland Westgat - 1	-	132,794	44,265
Den Helder - GBI	Den Helder	102,546	34,182
Grijpskerk - GDF	Grijpskerk	44,174	14,725
F2A-platform	Voorburg	133,945	44,648
Total Platform F15A	Den Helder	62,902	20,967
Total Platform K5CC	Den Helder	400,097	133,366
Total Platform K6CC	Den Helder	151,823	50,608
Total Platform L7CC	Den Helder	173,836	57,945
Gaz de France, K12-B	Zoetermeer	116,936	38,979
Gaz de France, K12-C	Zoetermeer	105,018	35,006
Gaz de France, L10-A	Zoetermeer	267,899	89,300
Unocal Nethb.v. Helder (Haven)	Voorburg	117,473	39,158
Unocal Nethb.v. Hoorn-Halfweg	Voorburg	88,498	29,499
L8-P4	Den Haag	93,561	31,187
Chemie + rubber/kunststof			
Frisia Zout B.V.	Harlingen	462,282	154,094
AIR LIQUIDE INDUSTRIE B.V.	BOTLEK rt	102,061	34,020

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GE Plastics (Air Liquide)	Bergen op Zoom	267,307	89,102
Air Products Nederland BV	Botlek-Rotterdam	1.146,186	382,062
Air Products Nederland Pernis	Vondelingenplaat	233,345	77,782
Akzo Nobel Base Chemicals BV	Rotterdam	619,246	206,415
Akzo Nobel Chemicals	Hengelo	1.376,557	458,852
Chemelot Geleen	Geleen	10.457,646	3.485,882
Crompton b.v.	Amsterdam	66,308	22,103
Dow Benelux B.V.	HOEK	8.635,959	2.878,653
DSM Anti-Infectives B.V.	Delft	457,739	152,580
DSM Special Products BV	Rotterdam - Botlek	716,361	238,787
Du Pont de Nemours (Ned.) B.V.	Dordrecht	684,674	228,225
Eastman Chemical Middelburg BV	Middelburg	167,996	55,999
ExxonMobil Chemical B.V. RAP	Rotterdam - Botlek	1.117,738	372,579
ExxonMobil Chemical BV ROP	Rozenburg	377,316	125,772
General Electric Plastics B.V.	Bergen op Zoom	1.456,867	485,622
INEOS Silicas Netherlands BV	Eijsden	103,993	34,664
Kerr-McGee Pigments (Holland)	Rotterdam	245,005	81,668
Lyondell Chemie Nederland BV	Botlek/Rotterdam	334,725	111,575
Methanor VOF	Farmsum	1.898,723	632,908
Nedmag Industries B.V.	Veendam	331,573	110,524
NOVA Chemicals Netherlands BV	Breda	24,941	8,314
PURAC biochem bv	Gorinchem	129,681	43,227
Resolution Europe BV	Vondelingenplaat Rt	72,848	24,283
Shell Ned. Chemie, Moerdijk	Moerdijk	7.887,980	2.629,327
Shin-Etsu PVC b.v.	Rotterdam	334,060	111,353
Uniqema Nederland BV	Gouda	172,897	57,632
Alcoa Chemie Nederland B.V	Botlek Rt.	72,296	24,099
W/KC AkzoNobel Center V.O.F.	Arnhem	102,038	34,013
Akzo Nobel Pharma BV Moleneind	Oss	84,056	28,019
AkzoNobelCatalysts Amsterdam	Amsterdam	270,008	90,003
Fuji Photo Film BV	Tilburg	161,659	53,886
Yara Sluiskil B.V.	Sluiskil	4.439,947	1.479,982
PPG Industries Chemicals bv	Delfzijl	206,248	68,749
Diolen Industrial Fibers b.v.	Emmen	62,266	20,755
Basismetaal			
Corus Staal B.V.	Velsen-Noord	31.130,242	10.376,747
Ruigenhil Vastgoed BV (Nedst)	Alblasserdam	155,185	51,728
Alcoa Kerkrade Cast House	Kerkrade	47,368	15,789
Aluminium & Chemie R`dam B.V.	Rotterdam	533,860	177,953
Aluminium Delfzijl	Delfzijl	75,709	25,236
Pechiney Nederland NV	Vlissingen	288,266	96,089
Bouwmaterialen			
Rockwool Lapinus B.V.	Roermond	465,148	155,049
TREGA International B.V.	Maastricht	74,308	24,769
Steenfabriek De Rijswaard BV	Aalst	79,257	26,419
B.V. Stf Huissenswaard	Angeren	40,786	13,595
B.V. Steenfabriek Spijk	Spijk	67,468	22,489
Waalsteenfabriek De Bylandt BV	Tolkamer	82,099	27,366
Wienerberger Heteren	Heteren	27,202	9,067
Wienerberger Erlecom	Erlecom	44,292	14,764
Wienerberger Bemmel	Haalderen	24,593	8,198

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Wienerberger Esbeek	Esbeek	14,328	4,776
Wienerberger Haaften	Haaften	45,939	15,313
Wienerberger Kijfwaard Oost	Pannerden	36,032	12,011
Wienerberger Kijfwaard West	Pannerden	44,567	14,856
Wienerberger Nuance	Afferden	18,942	6,314
Wienerberger Oosterhout	Oosterhout	18,478	6,159
Wienerberger Poriso	Brunssum	39,751	13,250
Wienerberger Reuver	Reuver	5,612	1,871
Wienerberger Daams	Spijk	24,149	8,050
Wienerberger Milsbeek	Milsbeek	11,326	3,775
Wienerberger Rijssen	Rijssen	10,013	3,338
Wienerberger Timmermans	Elst	36,177	12,059
Wienerberger Thorn	Thorn	29,603	9,868
Wienerberger Doorwerth	Doorwerth	34,060	11,353
Wienerberger Roodvoet	Rijswijk	21,049	7,016
Wienerberger Wolfswaard	Opheusden	42,012	14,004
ENCI B.V. vestiging Ijmuiden	1970 AL IJmuiden	95,621	31,874
ENCI B.V. Maastricht	Maastricht	2.351,193	783,731
LAFARGE GIPS BV	DELFZIJL	99,476	33,159
Papier en karton			
Berghuizer Papierfabriek NV	Wapenveld	825,692	275,231
Crown Van Gelder N.V.	Velsen-Noord	615,342	205,114
De Eendracht Karton B.V.	Appingedam	348,098	116,033
Georgia-Pacific Nederland b.v.	Cuijk	69,184	23,061
Kappa Attica B.V. locatie KM4	Oude Pekela	83,771	27,924
Kappa Attiva B.V., locatie KM1	Oude Pekela	46,097	15,366
Kappa Graphic Board Hoogezand	Hoogezand	243,893	81,298
Kappa Graphic Board Sappemeer	Sappameer	116,325	38,775
Kappa Roermond Papier BV	Roermond	503,113	167,704
Kappa Triton	Coevorden	83,299	27,766
Kappa Triton	Nieuweschans	134,830	44,943
Mayr-Melnhof Eerbeek b.v.	Eerbeek	234,868	78,289
Favini Meerssen B.V.	Meerssen	60,538	20,179
Papierfabriek Doetinchem BV	Doetinchem	102,023	34,008
Favini Apeldoorn B.V.	Apeldoorn	92,968	30,989
Norske Skog Parenco BV	RENKUM	673,473	224,491
Sappi Maastricht B.V.	Maastricht	877,109	292,370
SAPPI Nijmegen BV	Nijmegen	285,925	95,308
SCA Hygiene Products	Tilburg	36,917	12,306
SCA Packaging De Hoop	Eerbeek	779,760	259,920
Van Houtum Papier bv	Swalmen	80,594	26,865
Voeding & genot + overige industrie			
ADM Europoort B.V.	Europoort	1.032,539	344,180
ADM cocoa	Koog aan de Zaan	184,273	61,424
Cargill Multiseed	Amsterdam	107,082	35,694
Loders Croklaan B.V.	Wormerveer	108,671	36,224
Unimills B.V.	Zwijndrecht	181,594	60,531
Borculo Domo Ingredients	Borculo	298,685	99,562
Poederunit Beilen	Beilen	163,212	54,404
DMV international	Veghel	482,150	160,717

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DOC Kaas	Hoogeveen	107,148	35,716
DOC Kaas	Hoogeveen	66,228	22,076
Friesland Coberco Lochem	Lochem	104,382	34,794
Friesland Coberco Bedum	Bedum	58,251	19,417
Friesland Consumer Products	Leeuwarden	236,543	78,848
Hollandse Melksuikerfabriek BV	Uitgeest	11,586	3,862
Nestlé Nederland bv.	Gorinchem	78,050	26,017
Nestlé Nederland b.v.	Venray	87,915	29,305
Amylum Nederland B. V.	KOOG AAN DE ZAAN	272,957	90,986
AVEBE B.A. - locatie Veendam	Veendam	58,524	19,508
AVEBE B.A. - locatie Foxhol	Foxhol	200,457	66,819
AVEBE B.A. - Gasselternijveen	Gasselternijveen	319,077	106,359
AVEBE B.A. - Ter Apelkanaal	Ter Apelkanaal	549,665	183,222
Aviko B.V.	Steenderen	238,140	79,380
Cargill Sojafabrieken	Amsterdam	225,921	75,307
Cerestar Benelux B.V.	Sas van Gent	692,503	230,834
CERESTAR - A Cargill Company	Bergen op Zoom	219,917	73,306
Farm Frites B.V.	Oudenhoorn	138,029	46,010
WKC Lamb-Weston Meijer	Middelburg	285,577	95,192
Sensus	Roosendaal	68,323	22,774
Smiths Food Group BV	Broek op Langedijk	34,180	11,393
B.V. Oldambt	Oostwold	141,576	47,192
Coöp. Grasdrogerij Ruinerwold	Ruinerwold	130,113	43,371
JG Timmerman Groenv. BV	Kortgene	116,738	38,913
Rendac Bergum B.V.	Sumar	135,280	45,093
Rendac Son B.V.	Son	109,670	36,557
Fribecoh B.V. Drogerij	Loenga	39,205	13,068
CSM Suikerfabriek Vierverlaten	Groningen	284,957	94,986
CSM Suikerfabriek "Wittouck"	Breda	173,263	57,754
Suiker Unie fabriek Dinteloord	Dinteloord	282,260	94,087
Suiker Unie Groningen	Groningen	238,132	79,377
Suiker Unie fabr. Puttershoek	Puttershoek	189,717	63,239
Bavaria NV	Lieshout	181,655	60,552
Heineken Nederland B.V.	`s-Hertogenbosch	46,860	15,620
Heineken Nederland B.V.	Zoeterwoude	240,903	80,301
Interbrew Nederland N.V.	Breda	37,469	12,490
Koninklijke Nedalco B.V.	Bergen op Zoom	108,130	36,043
Koninklijke Douwe Egberts N.V.	Joure	27,179	9,060
Vlisco Helmond BV	Helmond	85,984	28,661
Ten Cate Advanced Textiles bv	Nijverdal	85,532	28,511
Ten Cate Technical Fabrics bv	Nijverdal	34,931	11,644
BSN Glasspack N.V.; Leerdam	Leerdam	367,425	122,475
BSN Glasspack N.V.; Maastricht	Maastricht	338,515	112,838
BSN Glasspack N.V.; Schiedam	Schiedam	190,487	63,496
Glaverbel Nederland BV	Tiel	306,071	102,024
Heye Glas Nederland C.V.	Moerdijk	89,191	29,730
PPG Industries Fiber Glass bv	Hoogezand	176,478	58,826
Rexam Glass Dongen BV	Dongen	286,992	95,664
SG Isover Benelux b.v.	Etten-Leur	150,521	50,174
Philips Lighting B.V.	Roosendaal	74,013	24,671
Service terminal Rotterdam vof	Rotterdam (Botlek)	7,587	2,529
Odfjell Terminals (Rotterdam)	Botlek-Rotterdam	89,430	29,810

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Elektriciteitsproductie-inrichtingen			
DELTIUS B.V.	Ritthem	91,448	30,483
Electrabel Centrale Bergum	Bergum	1.936,900	645,633
Electrabel Centrale Gelderland	Nijmegen	6.760,280	2.253,427
Electrabel Centrale Harculo	Zwolle	414,424	138,141
Electrabel Eemscentrale	Eemshaven	12.983,150	4.327,717
Electrabel Flevocentrale	Lelystad	,000	,000
Electrabel WKC Almere	Almere	1.019,256	339,752
WKC Ypenburg	Den Haag	,010	,003
E.ON Centrale Leiden	Leiden	395,361	131,787
E.ON Centrale Den Haag	Den Haag	407,717	135,906
E.ON Centrale RoCa	Rotterdam	2.241,372	747,124
E.ON Centrale Galileistraat	Rotterdam	1.565,159	521,720
E.ON Centrale Maasvlakte	Maasvlakte Rotterdam	18.555,950	6.185,317
EPZ Borssele 12	Borssele	6.094,852	2.031,617
BEC-Cuijk	Cuijk	64,859	21,620
WKC Enschede	Enschede	425,295	141,765
WKC Erica	Erica	302,498	100,833
WKC Helmond 1/2	Helmond	326,011	108,670
WKC Helmond 3	Helmond	28,776	9,592
WKC Klazienaveen	Klazienaveen	298,758	99,586
WKC Moerdijk	Moerdijk	1.799,574	599,858
Amercentrale	Geertruidenberg	20.886,004	6.962,001
Clauscentrale	Maasbracht	2.950,537	983,512
Dongecentrale	Geertruidenberg	228,925	76,308
WKC Swentibold	Geleen	2.489,350	829,783
Essent Pompstation Breda	Breda	3,470	1,157
Essent Pompstation Tilburg	Tilburg	4,300	1,433
Nuon Power Borculo B.V.	Borculo	266,393	88,798
Nuon Power Buggenum	Haelen	2.106,645	702,215
Nuon Power Ede B.V.	Ede	392,849	130,950
Nuon Power Lokatie Diemen	Diemen	1.872,485	624,162
Nuon Power Locatie Hemweg	Amsterdam	11.822,194	3.940,731
Nuon Power Locatie IJmond	Velsen-Noord	1.183,540	394,513
Nuon Power Lokatie Purmerend	Purmerend	523,437	174,479
Nuon Power Locatie Utrecht	Utrecht	4.061,409	1.353,803
Nuon Power Locatie Velsen	Velsen-Noord	4.680,135	1.560,045
Nuon Power Purmerend HWC	Purmerend	16,833	5,611
Rijnmond Energy Centre	Vondelingenplaat-Rotterdam	5.993,519	1.997,840
IndustriePark Kleefse Waard	Arnhem	442,332	147,444
Emmtec Services bv	Emmen	1.208,239	402,746
WKC Oosterheem	Zoetermeer	28,596	9,532
WKC Vaanpark	Barendrecht	24,511	8,170
WKC Wateringseveld	Den Haag	30,639	10,213
Gebouwde omgeving			
Universiteit Utrecht	Utrecht	143,004	47,668
Acad. Ziekenhuis Groningen	Groningen	75,178	25,059
Academisch Medisch Centrum	AMSTERDAM	123,299	41,100

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KUN/UMC	Nijmegen	116,756	38,919
Vrije Universiteit	Amsterdam	95,649	31,883
E-prod Joint Ventures			
Zuurbier en Co Rozen BV	Heerhugowaard	88,542	29,514
WKC Kapelle (Epsilon)	Kapelle	65,829	21,943
Seasun BV (WKC Kapelle)	Kapelle	145,892	48,631
Elsta B.V. & Co.C.V.	Hoek	5.862,010	1.954,003
WKC Bergen op Zoom	Bergen op Zoom	264,173	88,058
WKC Den Bosch (Heineken)	Den bosch	271,462	90,487
WKC Eindhoven	Eindhoven	289,860	96,620
Delesto b.v.	Delfzijl	6.287,079	2.095,693
ENECAL V.O.F.	BOTLEK rt	756,030	252,010
EUROGEN C.V.	BOTLEK rt	1.647,086	549,029
Europoort Utility Partners VOF	Rotterdam-Europoort	409,642	136,547

Appendix V: Stress scenario's

We have identified several risk factors. In this section we will formulate event risk scenario's based on these factors. Market risk managers can use these scenarios for stress testing. First we will identify historic event scenarios, followed by hypothetical event scenarios. The hypothetical scenarios are created by making a cluster of risk factors that have an additive effect on the allowance market

Historic Event scenarios

- Emission to Cap lower (May 2006)
- *CO_2 price crash 50%*

- Market Turbulence (April 2005)
  Volatility up 500%

- Gas prices up 45% (June-July 2005)
  CO_2 price up 60%

- Reduced market liquidity, lower gas prices (July 2005)
  CO_2 price down 40%

Hypothetical Event Scenarios

- Very dry winter + gas prices up + coal prices down
  (Power produced by CO_2 intensive facilities. Demand for certificates up by 10%)

- Cold, wet summer + gas prices down + coal prices up
  (Power produced by CO_2 efficient facilities. Demand for certificates down 10%)

- Stagnating economies EU-15
  (Lower economic activity results in lower emissions. Demand for certificates down 10%)

- Prospering growth economies EU-15
  (High economic activity results in higher emissions. Demand for certificates up 10%)

- Political debate creates uncertainty
  (Market dries up, lack of liquidity. Volatility up)

Glossary

Annex I countries	**Annex I countries** are the 36 countries and economies in transition listed in Annex I of the UNFCCC. Belarus and Turkey are listed in Annex I but not Annex B; and Croatia, Liechtenstein, Monaco and Slovenia are listed in Annex B but not Annex I. In practice, however, Annex I of the UNFCCC and Annex B of the Kyoto Protocol are often used interchangeably.
Annex II Countries	**Annex II countries** of the UNFCCC includes all original OECD member countries plus the European Union.
Baseline	The **baseline** represents forecasted emissions under a business-as-usual (BAU) scenario, often referred to as the 'baseline scenario' i.e. expected emissions if the emission reduction activities were not implemented.
BAU	A **Business As Usual** scenario is a policy neutral reference case of future emissions, i.e. projections of future emission levels in the absence of changes in current policies, economics and technology.
Cap and Trade	A **Cap and Trade** system is an emissions trading system, where total emissions are limited or 'capped'. The Kyoto Protocol is a cap and trade system in the sense that emissions from Annex B countries are capped and that excess permits might be traded. However, normally cap and trade systems will not include mechanisms such as the CDM, which will allow for more permits to enter the system, i.e. beyond the cap.
CDM	**Clean Development Mechanisms** one of the three flexibility mechanisms in the Kyoto Protocol. It is similar to JI except that the host country doesn't have a commitment and hence does not have allowances to transfer.
CER	**Certified Emission Reduction**. Tradable emission reductions generated by CDM projects undertaken in developing countries, to be certified in order to be transferable.
CO2	**Carbon dioxide** is an atmospheric gas that derives from multiple sources including volcanic out gassing, the combustion of organic matter and respiration processes of living aerobic organisms. Plants utilize carbon dioxide during photosynthesis and release oxygen to the atmosphere which is subsequently used for respiration by organisms, forming a cycle. The oceans can absorb certain levels of CO_2.
ERU	**Emission Reduction Unit**. Tradable emission reductions generated by joint implementation projects (JI).
ETC	**Emission To Cap** is calculated by subtracting the seasonally adjusted cap from emissions (actual or forecasted). This metric gives an indication of whether the market (for a specific period) is producing more or less than the seasonally adjusted cap for that same period. More specifically, if not taking CERs into account, a positive (negative) E-C means that the market is fundamentally short (long), suggesting a buy (sell) signal.
EU ETS	European Union Emission Trading Scheme

Financial Additionality	CDM projects have to be **financially additional**, which means that the projects that Annex I countries support within the framework of the CDM should not be financed by official development aid, but that additional funding is to be made available for such projects.
GHG	**Greenhouse gases** are trace gases that control energy flows in the Earth's atmosphere by absorbing infra-red radiation. There are six GHGs covered under the Kyoto Protocol - carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). CO_2 is the most important GHG released by human activities.
Grandfathering	**Grandfathering** is a method for allocation of emissions, where permits are allocated, usually free of charge, to emitters and firms on the basis of historical emissions.
JI	Under **Joint Implementation**, an Annex I Party may implement a project that reduces emissions (e.g. an energy efficiency scheme) or increases removals by sinks (e.g. a reforestation project) in the territory of another Annex I Party, and count the resulting emission reduction units (ERUs) against its own target. While the term "joint implementation" does not appear in Article 6 of the Protocol where this mechanism is defined, it is often used as convenient shorthand. In practice, joint implementation projects are most likely to take place in EITs, where there tends to be more scope for cutting emissions at low cost.
OTC	Over The Counter
Spot Market	A market for the immediate delivery of a commodity.
Carbon Sink	A **carbon sink** is a reservoir that can absorb or "sequester" carbon dioxide from the atmosphere. Forests are the most common form of sink, as well as soils, peat, permafrost, ocean water and carbonate deposits in the deep ocean.
Compliance	**Compliance** is the periodic demonstration by an operator of an emitting installation that it has conformed with the rules of the EU Emissions Trading Scheme. Compliance is achieved by surrender to the Member State (for cancellation), by April 30 each year, a number of allowances that is equal to the total verified emissions from that installation during the preceding calendar year.