Abating CO_2 in Energy Intensive Industries

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Abstract

The European Union's most important policy instrument to achieve a reduction of Greenhouse Gases is the Emission Trading System (ETS). Companies covered by the ETS have to provide certificates for the pollution they cause. The system sets economic incentives for abating CO_2. Depending on the potentials for mitigation, the costs and the maximum amount of allowances, a value for carbon emissions can be estimated.

While most researchers focus on abatement potentials in the energy sector this paper evaluates the industrial sectors covered by the ETS, namely the production of iron and steel, cement, lime, pulp and paper, glass, ceramics and the refining sector. Based on reports and interviews a simple supply curve of abatement potentials is provided to estimate the influence of emission abatement in energy intensive industries on the carbon value in the EU-ETS.

The results are integrated in the Gams-based model DIME, a general equilibrium model. Its objective function minimises total discounted costs based on the assumption of a competitive generation market. It compares abatement potentials and costs in the energy sector with the costs of mitigation in the industrial sector. The consequences of political decisions are evaluated by applying different caps for the maximum amount of emissions in the ETS.

Keywords

EU ETS, energy intensive industries, abatement costs

JEL codes

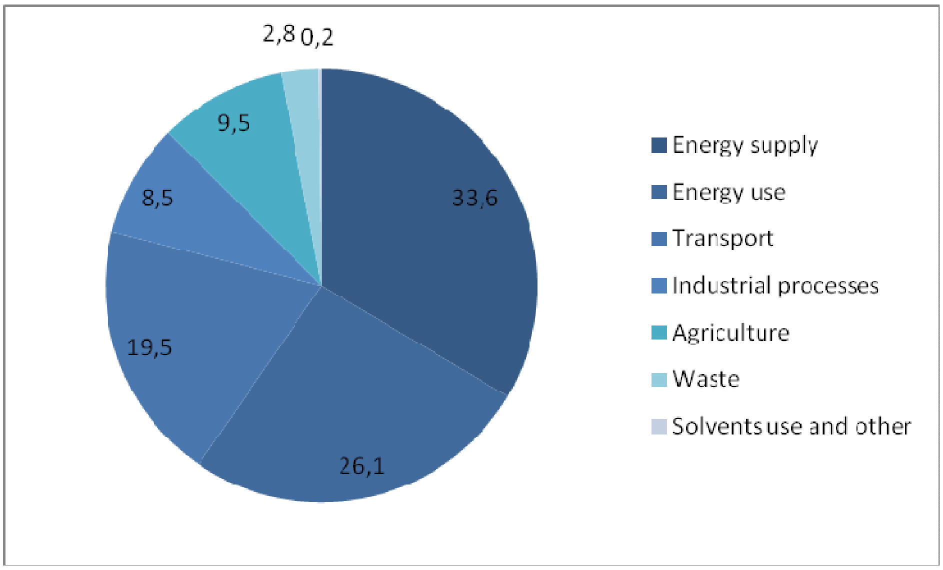
C61; L61; Q53

Introduction

In the EU-27, about 5177 million tonnes of CO_2-equivalent were released in 2005 [EEA, 2008a]; 7.9% less than in the Kyoto baseline year. About 46% of these emissions were covered by the ETS in 2005 [Watanabe/Robinson, 2005]. Beside electricity producers this includes the mineral oil refineries, coke ovens, ferrous metal processors, cement, glass, ceramics, pulp and paper producing companies as well as combustion installations larger than 20 MW_{th} found in other industries.

The EU member states' aim is to reduce their total CO_2 emissions by 2020 to a level equivalent to 80% of that of 1990. This 20%-target might be enhanced to 30%. Until 2050 emissions shall be reduced emissions to a level of 20-40% of the 1990 emissions.

Figure 1: **Total GHG Emissions in the EU-27 by Sector (2007)**



Source: EEA, 2009

In order to achieve these aims, carbon emissions have to be reduced significantly and in a short time frame. With high investments in renewable energy sources and nuclear power, carbon free production of electricity is possible. In contrast the potential of abating CO_2

emissions in the industrial sector is limited. Raw materials contain carbon that has to be released in order to manufacture the product; emissions are “process intrinsic”. They cannot be avoided unless the companies stop production.

This analysis describes carbon intensive processes in the ETS-covered industries and inherent emissions. The extent and costs of potentials to abate CO_2 are identified. A conclusion summarises the results and their relevance in the discussion about ETS.

Covered Industries

The following paragraphs shortly describe the main industrial processes covered by the EU ETS. The quantitative importance of the sectors, energy requirements and CO_2 intensities are analysed.

Two different techniques are used to produce *iron and steel* in the EU. In integrated mills consisting of a blast furnace and a converter the raw materials are reduced and melted by burning coke. This process consumes about19.4 GJ of heat and 100 kWh of electricity per tonne of crude steel [Ghenda 2008]. Including conversion in the basic oxygen furnace, the production of one tonne of crude steel leads to emissions of 2.1 t CO_2 [Degner et al 2007] of which 2.05 tonnes are direct emissions.

The secondary route describes the Electric Arc Furnace (EAF), in which steel scrap is melted by using electric power, about 440 kWh/t of crude steel [IPPC 2008a]. The only sources for carbon emissions are by-products in the scrap steel, alloys and the erosion of the used electrodes, as well as the energy requirements to preheat the scrap. They are estimated to be 0.15 t CO_2/t of crude steel [Degner et al 2007].

In 2008, the European[1] steel companies produced 193 million tonnes of crude steel, 40% in EA-Furnaces, 60% in integrated steel mills [Worldsteel 2009]. In the last ten years, the European steel industry grew by 0.3% on average every year.

With emissions of nearly 190 million t CO_2 in 2008 the *cement and lime* industries are the second biggest industrial CO_2-emitters in the ETS. The main source for direct emissions is the "calcination" process. The outcome is lime. Cement producers burn this material with silica, alumina and ferrous oxide to clinker, the basic material for cement.

In 2006, the plants in the EU-27 member states produced 267 million tonnes of cement [IPPC 2009]. Growth is very low in the EU-27. The average emission for one tonne of cement is 0.86 t CO_2/t of clinker [IPPC 2009]. A little less than two thirds of these emissions are process intrinsic, about one third is released by combustion installations. The average electricity demand is calculated as 112 kWh/t of clinker.

On average 1.13 t CO_2 are emitted while producing one tonne of lime. About 0.75 t CO_2 are process related, the rest is needed in combustion installations [Bergmann 2007].

In the *Glass* industry the melting process accounts for about 75% of the overall energy requirements. On average about 0.62 t CO_2 are released per tonne of glass [Bergmann 2007]; 0.2 t CO_2 are process intrinsic [Gitzhofer, 2009]. About 238 kWh of electricity are needed. In 2005, the installations in the EU 25 produced 37.7 million tonnes of glass [IPPC, 2008b].

In 2008, the *ceramics* sector emitted 13.7 million tonnes of CO_2 equivalent, less than one percent of the total emissions [CITL, 2009]. Nearly half of the registered installations emit less than 20,000 t CO_2/year. The CO_2 intensity ranges from up to 3.4 t CO_2/t of household

[1] This includes the EU-27 member states, Liechtenstein, Iceland and Norway

ceramics to 0.17 t CO_2 per tonne of bricks. On average the industry branches directly emit 0.5 t CO_2 and use 380 kWh of electricity to produce one tonne of ceramics [Bergmann, 2007].

In the *paper and pulp* industry, nearly two thirds of the virgin fibres are generated by chemical pulping at high temperatures. In the (thermo) mechanical processes the wood is ground by stones or cut into chips before refining. For recovering fibre, the collected paper is pulped with mechanical and hydraulic agitation [IPPC, 2001].

The power consumption ranges from one to three MWh per tonne of newsprint [Reinaud, 2005]. Recovered fibre needs about 0.5 MWh/t of newsprint. Heat demand ranges from 5.5 to 21 GJ/t paper [Bergmann, 2007]. To produce one average tonne of paper about 810 kWh are required. 30% of this electricity is produced on site, mainly in Combined Heat and Power installations [DG Environment, 2006].

The fundamental process of *refining* is distillation. Heavier components are sorted from lighter ones according to their boiling point. In 2008 the refining industry registered 7.3% of the verified emissions in the EU ETS [CITL, 2009]. Emissions vary between 0.08 and 0.8 t CO_2/t of crude oil [Bergmann, 2007]. For this analysis an emission of roughly 0.11 t CO_2/t of crude oil and an exogenous electricity demand of 24 kWh/t of crude oil are assumed. About 57% of the electricity is auto-generated.

Mechanisms to Abate CO_2

Between 1990 and 2006, emissions from industrial processes decreased by 12% - 0.7% every year. They are expected to decline by 0.5% every year until 2010 because of small improvements and market penetration for state of the art technologies. Energy related emissions, which partly belong to the industrial sector, are also assumed to decrease by 1% every year [European Environment Agency, 2008b].

Additional changes in processes to reduce industrial emission of CO_2 might be economically feasible, if the carbon constraint tightens and the value of carbon emissions rises. This analysis connects possible abatement potentials with costs per tonne of avoided CO_2. If abatement leads to additional or reduced electricity demand, the average required amount of power was multiplied with country-specific prices for electricity and added to the costs.

The first option to mitigate CO_2 emissions and therefore save production costs is producing steel in EAF plants instead of integrated steel mills. This *process change* is limited to additional steel production because scrap is already scarce [DG Environment, 2006]. McKinsey assumes costs of €10 to abate one tonne of CO_2 through this mechanism in 2020. This number is expected to decrease to €7 until 2030 [Vahlenkamp, 2007]. Subtracting the cost of additional electricity demand, this abatement option would cost €- 6 for one tonne of directly emitted CO_2 in 2010 and €-12 in 2030.

Direct casting is often quoted as a means to mitigate CO_2 emissions. The steel is not cooled down after production, but directly casted in order to save reheating energy. Another mentioned abatement potential is “smelt reduction”. The preparation of coke would be integrated with iron-ore reduction. Experts doubt the applicability [Lüngen 2009]. Therefore this analysis ignores these two options.

In the cement industry, 90% of the direct emissions occur in clinker production. This product can be partly substituted, e.g. by blast furnace slag from the steel producing industry [IEA, 2007]. Substitution requires a retrofit for grinding facilities. Additionally, the electricity demand rises by about 45 kWh/t of grinded material or 52.3 kWh/t of abated CO_2 [Woyward, 2009]. The potential is limited by market parameters to about 10% of the existing production. A change from wet to dry processes could save about 200 kg CO_2/tonne of clinker, but requires about 130$/t of annual capacity [Hendriks, 2004]. The only three countries using wet processes are not expected to modify their production process because they only have access to wet materials [IPPC, 2009].

The favourable cost and emission structure in the recycled fibre process would result in a process change in the pulp and paper industry. But because Western Europe appears to be close to its practical limit for paper recycling [IEA, 2007], this option is ignored - as is the option to add additional recycled glass to the glass making process.

CO_2 can be captured at different stages of combustion processes and then stored, for example in empty natural gas fields [Ecofys, 2004]. The *Carbon Capture and Storage*

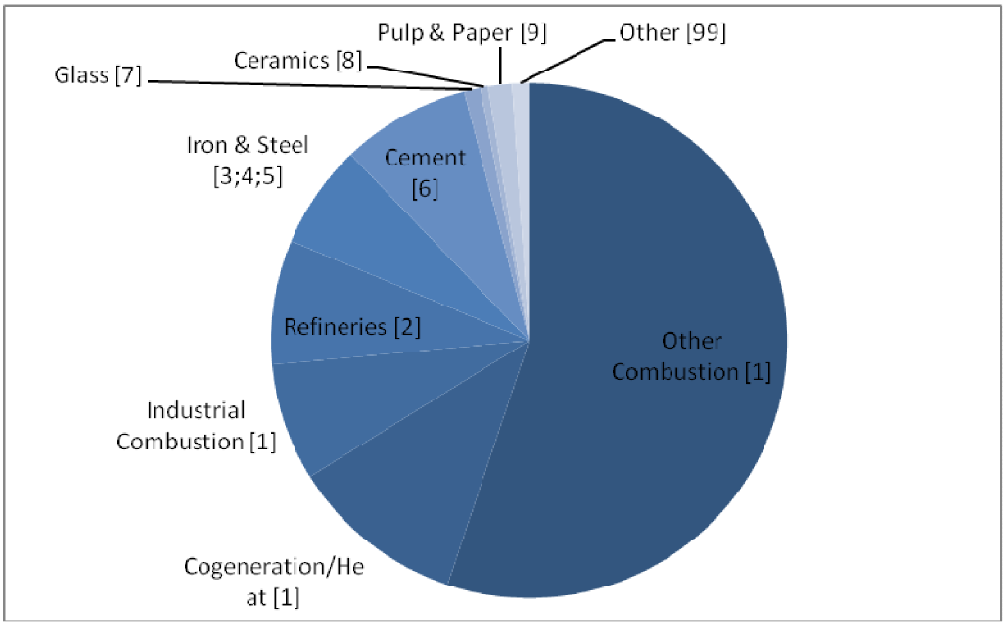
technology is best applied to sources which have large, concentrated streams of CO_2 emissions. These are found in the steel and cement industries. Based on the Ecofys calculations McKinsey assumes costs of 54 – 57 €/t CO_2 [Vahlenkamp, 2007]. Other experts estimate costs of up to €100 per avoided tonne of CO_2 [Flement/Schlegel, 2006]. Transferring McKinsey's assumptions for Germany to other ETS-states, up to 2.5 million tonnes of CO_2 may be abated in 2030 by using CCS in the steel and cement sectors.

To a limited extend, companies are able to pass on additional costs of production. Demand is not completely elastic. Ending production is the last resort for industrial operators to avoid payments for EUAs. In this case, the demand for industrial products would have to be satisfied by imports. The risk of this *Carbon Leakage* depends on different factors. Freight rates are the most obvious ones. Transport by ship is much cheaper than by road, facilities at the seaside, near big inland ports or close to railroads are more likely to be exposed to competition [IPPC, 2009]. Based on a study by the Boston Consulting Group a set of transport costs per tonne of a good in the different EU member states was developed [BCG, 2008].

Data and Assumptions

To analyse the extent of the described abatement options a detailed picture of the ETS structure is required. According to Trotignon and Delbosc about 10% of the combustion sector's allocated emissions could be assigned to the industry sector; 15% are released by Cogeneration installations [Trotignon/Delbosc 2008].

Figure 2: **Verified Emissions (2009)**



Source: Trotignon/Delbosc, 2008; CITL; own calculations

In 2010 nearly 990 million EUAs are expected to be emitted in the industrial sector. This number is estimated to decrease by 0.5% every year because of small improvements and market penetration for state of the art technologies as well as fuel changes in the combustion processes.

Abatement potentials were calculated by applying the average emission data to production in the different member states. Only for glass and ceramic installations, the abatement potential was derived from the verified emission data of 2009 [CITL, 2010]. These industries are characterised by small specialised installations – many of them do not reach the required capacity to be covered by the ETS.

The potential of carbon leakage is limited exogenously. Every year, additional 5% of the industry can stop its production, if it is economically efficient. This is a simplification of the fact that social costs as well as transportation costs would rise immediately if whole sectors decided to import their products.

Implementation

DIME is a linear optimisation model developed at the Institute of Energy Economics at the University of Cologne. Based on a detailed database of European power plants, it simulates the power plant dispatch as well as investment decisions regarding the supply side of the electricity sector. DIME's objective function minimises the total discounted costs based on the assumption of a competitive electricity generation market. A maximal bound of CO 2 -emissions for the energy sector can be added exogenously. The strength of the cap limits the options to produce energy in the modelled energy sector of the 27 EU member states, Norway and Switzerland. This analysis partly extends DIME by adding parameters from the industrial sector.

Under the assumption of perfect competition the marginal cost of extending the CO 2 bound of the energy sector is interpreted as the price for CO 2 -emissions. If these marginal costs in the international energy sector in the analysed year exceed the cost of abating CO 2 in the industrial sector, the model can enlarge the CO 2 bound by the defined abatement potentials.

$$\sum(r, CO2TOT(r,y)) - AbatTot(y) \leq CO2Bound(y)$$

The total volume of certificates called by the energy sector is defined as the sum of the certificates called from the different abatement options in the different regions.

$$AbatTot(y) = ((r,i), AbatVol(r,i,y))$$

The number of called amounts of certificates has to be lower than the maximum abatement potential.

$$AbatVolPot(r,i) \geq AbatVol(r,i,y)$$

The potentials are growing with every year.

$$AbatVolPot(r,i) \times (1 + g(r,i))^j \geq AbatVol(r,i,y)$$

For every certificate the energy industry requires from the industrial sector, the cost of the used mechanisms has to be taken into account.

$$CO2Cost_{Ind}(r,y) = \sum(i, AbatVol(r,i,y)) \times AbatCost(r,i,y)$$

They are integrated into the objective function, added to the fixed costs, variable costs, grid costs, costs of imports/exports, and costs and revenues of cogeneration and heat production.

$$TC = \sum \begin{matrix} ((y), d\_fac(y) \times (FC(y) + VC(y) + GrC(y) - DC(y) - \\ \sum((ha,cg), hr(ha,y,cg)) + \sum(r, CO2Cost_{Ind}(r,y)))) \end{matrix}$$

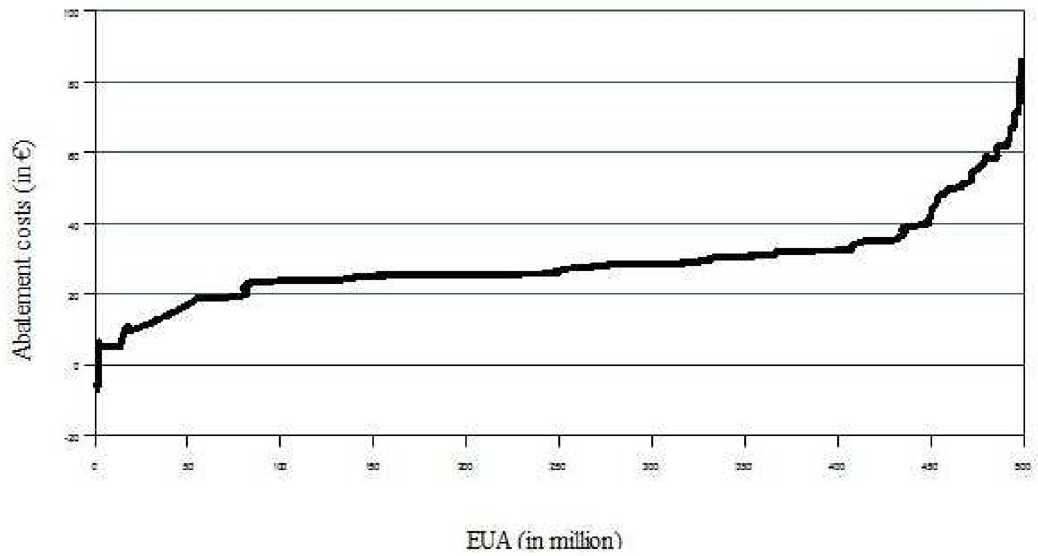
Some of these abatement mechanisms require additional electricity consumption in the industrial sector. This demand is implemented by the “addload-factor”.

$$\begin{aligned} &Addload(r,y,s,d,h) = \\ &\sum(i, af(i) \times AbatVol(r,i,y) \times StrSea(s) / n\_d(dayt,s) / 12 \times Str\_ind(r,s,h)) \end{aligned}$$

<u>Results</u>

Taking into account all possible abatement options in the EU member states and their specific costs a merit order of abatement can be formed. Figure 3 shows the merit order in 2010. Up to 500 million EUA could be set free by the industrial sector, if the potential of carbon leakage is fully exploited. The extent of additional EUAs from the industrial sector grows over time with the potential of carbon leakage.

Figure 3: **Abatement Costs and Potentials in 2010**



Especially the cement and the steel sectors can contribute to the reduction of carbon emissions at low costs. Already with today's EU ETS cap, it is economically attractive to change the process of steel-making. The reduction of clinker is also required in countries, where substitutes are available.

The steel and the cement industries also belong to the first ones that would leave the ETS covered states, if carbon limits are tightened. A third sector in danger of carbon leakage is the ceramics industry. Although transport costs "per tonne of CO_2" are relatively high, its electricity demand makes the industry vulnerable.

Carbon leakage might be a problem in the glass or the lime sectors, if the carbon constraint is tightened in a very short time frame, especially before 2020. Until that year, old, heavy emitting power plants are still in operation and require EUAs, while renewable energy, e.g. from large wind parks, is not yet fully available.

Geographical characteristics might help to protect against competition. The Czech Republic is assumed to be one of the countries with the highest transport costs for imports. Long distance transport by ship or barges is not possible. Goods have to be transported by rail or truck – much more expensively. In this analysis the risk of carbon leakage was the lowest in this member state.

Conclusion

The comparison of abatement costs in the energy sector and the industrial sector leads to the conclusion that large parts of European industries are in risk of carbon leakage. Because of the lack of large scale abatement options, operators in the steel, the cement and the ceramics industries, as well as in the paper and pulp, the lime and the glass industries might decide to stop production in ETS covered countries. A compensation for process intrinsic direct and indirect emissions might be advisable in order to prevent negative effects on the European economy such as unemployment. One mean of compensation could be grandfathering for non-abatable emissions.

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