Climate Strategies
www.climatestrategies.org

Carbon Control and Competitiveness Post 2020: The Cement Report

FINAL REPORT

February 2014

Authors

Karsten Neuhoff
Bruno Vanderborght
Andrzej Ancygier
Ayse Tugba Atasoy
Manuel Haussner
Roland Ismer
Benedikt Mack
Jean-Pierre Ponssard
Philippe Quirion
Arjan van Rooij
Nagore Sabio
Oliver Sartor
Misato Sato
Anne Schopp

DIW BERLIN

UCL ENERGY INSTITUTE
Radboud University Nijmegen
Hertie School of Governance
IDDRI SciencesPo.
LSE The London School of Economics and Political Science
École Polytechnique
FAU Friedrich-Alexander Universität Erlangen-Nürnberg Fachbereich Rechtswissenschaft
Centre for Climate Change Economics and Policy
Grantham Research Institute on Climate Change and the Environment
CIRED

Climate Strategies

www.climatestrategies.org

About the Authors

Karsten Neuhoff,
German Institute for Economic Research, DIW Berlin
Bruno Vanderborght,
Independent Researcher
Andrzej Ancygier
Hertie School of Governance
Ayse Tugba Atasoy
German Institute for Economic Research, DIW Berlin
Manuel Haussner
University Erlangen-Nürnberg
Roland Ismer
University Erlangen-Nürnberg
Benedikt Mack
German Institute for Economic Research, DIW Berlin
Jean-Pierre Ponssard
CNRS-Ecole Polytechnique
Philippe Quirion
Centre International de Recherche sur l'Environnement et le Développement (CIRED), CNRS
Arjan van Rooij
Radboud University Nijmegen
Nagore Sabio
University College London
Oliver Sartor
The Institute for Sustainable Development and International Relations (IDDRI)
Misato Sato
The Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Sciences
Anne Schopp
German Institute for Economic Research, DIW Berlin

This report is an output from the Energy Intensive Industries project funded by Ministries in Germany, Netherlands, France, UK and by Tata Steel and Heidelberg Cement. The views expressed and information contained in it are not necessarily those of or endorsed by the funders which can accept no responsibility or liability for such views, completeness or accuracy of the information or for any reliance placed on them.

The authors are gratefull for detailed comments and other input to Samuela Bassi, Christopher Beauman, Simone Cooper, Michael Flach, Daniel Gauthier, David Grover, Guillaume Habert, Detlef Heinz, David Leal, Niall Mackenzie, Kerstin Ringelhan, Martin Schneider, Matthew Tisdale, Heleen de Coninck and Stefan Schleicher. Misato Sato is grateful for funding from ENTRACTE.

About Climate Strategies

Climate Strategies is an international organisation that convenes networks of leading academic experts around specific climate change policy challenges. From this it offers rigorous, independent research to governments and the full range of stakeholders, in Europe and beyond. We provide a bridge between research and international policy challenges. Our aim is to help government decision makers manage the complexities both of assessing the options, and of securing stakeholder and public consensus around them. Our reports and publications have a record of major impact with policy-makers and business.

Table of Content

EXECUTIVE SUMMARY

This report assesses how production and emission volumes, energy and CO_2 efficiency and competitiveness of companies in the Energy Intensive Industries have evolved prior and during the European Union Emissions Trading System (EU ETS). Furthermore the report assesses how the EU ETS and other policy instruments may have influenced investment and operational choices at the company level. In doing so, this work combines detailed analysis and comparison of available data with comprehensive interviews of industry executives.

Building on the experience gathered to date, the project then explored what is needed to unlock the mitigation potentials identified in the low-carbon roadmaps for the sector – with respect to potential reforms of the EU ETS as much as with respect to complementary policy instruments.

Top management's confidence in the EU ETS policy needs to be restored

Our research findings reveal that during its early years the EU ETS attracted top management attention to reducing CO_2 emissions. Cement companies firmly included CO_2 reduction targets and carbon costs into their planning and decision-making.

However, with a carbon price declining from 30 to 5 €/ton CO_2, with the limited effectiveness of the system to date, and with the system's complexities and uncertainties, and against the economic background of a global financial crisis, the EU ETS has slipped from the top of management's priorities. In addition to the carbon price being low, it is also as volatile as energy prices. The volatility increases the perception of complexity. This is not helped by the prolonged discussions on changes to the system, such as on backloading of allowances, structural reforms of the EU ETS and limitations on the eligibility of emission reduction credits. As a result, even the most knowledgeable top executives are no longer able to explain to their board the relevance of the policy framework for corporate decisions.

By early 2014, backloading has finally been approved and the European Commission has published its vision of a 2030 package on January 22, 2014. The discussion and ultimate implementation of the package including setting of new targets for 2030, structural reform of the EU ETS and formulation of other policy objectives, for example on innovation, provides the opportunity to recover the confidence and initiative of cement companies.

More effective economic incentives are needed to unlock mitigation

To date, most of the emission reductions in the cement sector are caused by drivers other than the EU ETS. The share of emissions from the cement sector in total EU ETS emissions decreased from 7% in 2008 to 5.6% in 2012 but this was largely due to a decrease of clinker and cement production as a consequence of the state of the economy. Carbon intensity of cement has improved by 3-5% since 2005, but largely linked to drivers outside of EU ETS. While this shows that the sector does respond to policy and regulation the limited scale of improvements is also evidence of EU ETS insufficiencies.

The combination of the free allocation and low carbon price for most of the period under Phase I and II provided an insufficient economic incentive to further leverage emission reduction options in this sector. However, to unlock significant additional emission reductions, a robust carbon price is necessary but not sufficient.

The EU ETS emission cap declines by 1.74% per year. Industry executives raised doubts whether given uncertainties about the scale and costs of different mitigation options this is technological and economical optimal for the cement sector. Such industry interpretation of an emission trajectory at sector level contrasts with the motivation of using an emission trading mechanism to provide flexibility through trading between sectors. But it points to the need for sector specific low-carbon roadmaps to provide guidance and allow for coordination. The road maps need to obtain broader visibility, including through the incorporation of customer side mitigation options.

Free allocation may explain absence of carbon leakage, but creates distortions

No operational leakage[1] has taken place so far and provisions concerning free allocation may be credited for that. There is also currently no evidence that investments in Europe have been cancelled and moved abroad because of the EU ETS. However, free allowance allocation provisions also create severe distortions. The shift from historic levels of emissions towards benchmark-based allocation has eliminated perverse subsidization of inefficient plants, but major distortions remain.

Activity level requirements imply that half of the historic production level must be maintained for installations to obtain maximum free allocation. This discourages asset rationalization and negatively affects energy efficiency improvement. It also causes excess clinker production, reducing clinker substitution with lower-carbon substitutes and distorting trade flows. The profits resulting from the excess allocation further distort competition. Apart from their direct consequences, these deficiencies fundamentally undermine the level of confidence in the policy by the top management, further lowering it in their priorities.

As most mitigation options are linked to efficiency, innovation and lead market investment, early clarity on the leakage protection measures post-2020 is essential to ensure early investment choices.

[1] Carbon leakage is a transfer of production to other countries triggered by climate policy instruments. This would lead to reduced emissions in the EU, but less of an overall reduction of global GHGs emissions. In our Report we differentiate between operational leakage, the replacement of domestic with foreign production, and investment leakage, the replacement of investment in domestic production capacity with investment in foreign production capacity.

Refining EU ETS carbon leakage protection to provide carbon price for consumers

The combination of free allowance allocation – in place to address carbon leakage concerns – and the competition with imports from countries where producers do not pay for carbon, results in a low and very uncertain carbon price pass through to cement prices. Without an increase of cement prices major mitigation options cannot be pursued as: (i) customers are unlikely to select other cement types with lower clinker content in the absence of economic incentives; (ii) firms will not develop new low-carbon cement types without prospects of future market demand; and (iii) the building industry has limited incentive to use cement more efficiently. Reflecting the full carbon price in cement prices in Europe could be realized through two mechanisms, in the absence of a global carbon price.

First, a shift to full auctioning could be combined with the inclusion of importers in the EU ETS as envisaged in Article 10b of the 2009 ETS directive. Imported clinker and cement would be liable to surrender allowances based for example on the current best available technology benchmark. This would ensure non-discrimination between domestic and foreign producers and contributes to World Trade Organization compatibility. International coordination would be required to avoid political repercussions.

Second, output based allowances allocation could be combined with an inclusion of consumption in the EU ETS. Allocating allowances proportional to clinker production volume (output based) instead of the current use of activity level requirements eliminates distortions for efficient production of clinker, but eliminates incentives for clinker substitution and efficient customer choices. Hence it is combined with a consumption charge on the clinker content in cement linked to the EU ETS. Firms producing or trading cement would have to levy the charge as the product is prepared for final domestic sale, irrespective of the country or production process of the clinker.

Both of these approaches would not impact the basic structure of EU ETS or the ETS directive, but merely implement one of the options already outlined in the directive for carbon leakage protection of individual sectors (inclusion of imports) and add one additional option (inclusion of consumption). However, the options are politically (inclusion of imports) and administratively (both options) challenging – and hence their application would likely be focused on products with very high shares of embedded carbon.

EU ETS not sufficient: enabling environment and innovation policy essential

Empirical evidence reveals that emissions trading on its own will be an insufficient policy to incentivise further CO2 mitigation. Coordination with and adaptation of other existing and new policies will be required to enable the realisation of low-carbon options.

Enabling mitigation options by addressing regulatory and institutional constraints: Much of the emission reductions in the cement sector to date have been initiated or facilitated by regulatory changes. For example, the co-firing of waste products required new permits, which together with the supply of suitable waste was required by the waste framework, incineration and landfill directive or the reduction of clinker content in cement and concrete achieved to date required adjustments to codes and standards. What precise requirements are needed for the exploration and diffusion of further mitigation options needs early analysis to avoid potential regulatory barriers.

Engaging decision makers to consider lower-carbon options in cement production and use: On the cement user side, adaptations of building practices, standards, and information systems will be needed to stimulate low carbon procurement in the construction industry. This can require provision of information, e.g. with labelling approaches and reporting requirements, as much as training and certification of different actors.

Support investment in innovation for longer-term mitigation options: Major mitigation options, such as material substitution and carbon dioxide capture and storage (CCS), will require significant investment in demonstration plants and large-scale adoption of new building practices and materials will require significant upfront demonstration of the viability of new practices and materials. Experience from the EU ETS and other sectors suggest that the necessary scale of funding is unlikely to materialize through private initiative alone. Further work is required to understand the precise requirements for funding and suitable mechanisms.

1. Introduction

The objective of this research is to provide objective, evidence-based analysis and explanation of the past and current effectiveness of the EU ETS for Energy Intensive Industries (EII). In doing so, we identify potential areas of improvement for the EU ETS and complementing policy instruments. The insights gained enable us to evaluate possible options to improve the effectiveness of policy to foster energy efficiency and greenhouse gas mitigation, whilst maintaining the international competitiveness of European EII.

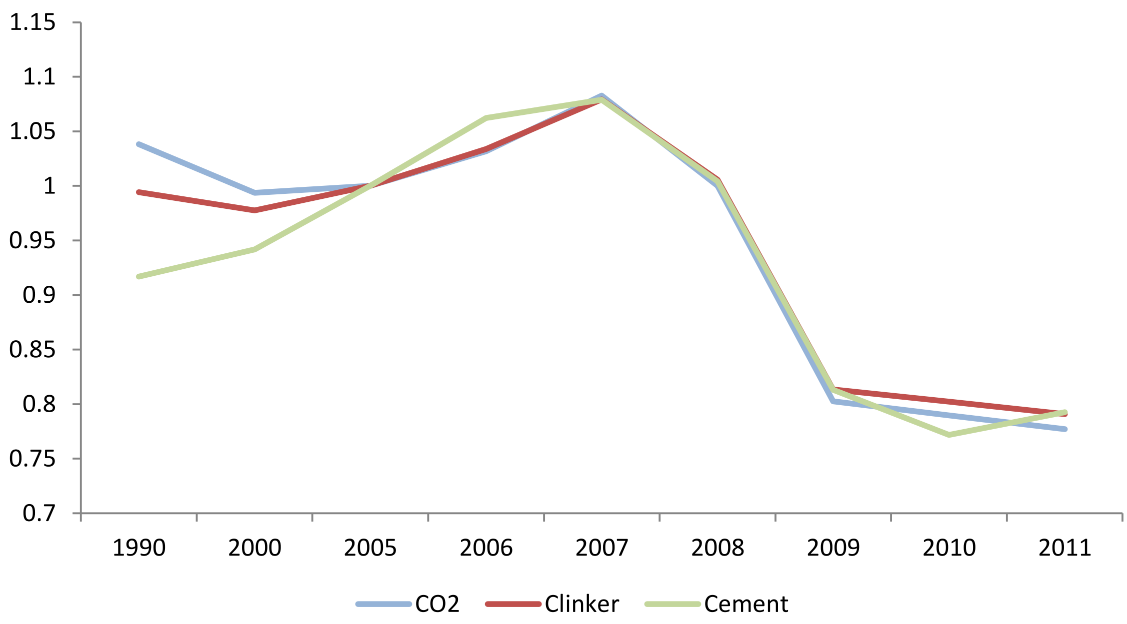
The research focuses on three of the most energy and carbon intensive industrial activities, namely cement, steel, and chemicals. This first study explores the situation in the cement sector based on data analysis of sources such as the WBCSD – CSI Getting the Numbers Right database, the EUTL, Eurostat, the UN Comtrade trade flow data and company annual financial reports. The researchers then conducted a series of interviews with executives from cement companies with the purpose of discussing and understanding the business decision processes and the role of the EU ETS and other policy instruments. Annex 1 includes the list of interviewed executives and a short description of the methodology. Wherever throughout this report there is a reference to the interviews, the conclusion is based on a representative majority of the interviews and thus likely scalable to the industry.

We found that the EU ETS attracted top management attention on the need to reduce CO_2 emissions. During the years with higher EUA prices and strong political support for consistent long-term targets, emission reductions formed part of the company strategy of most European cement firms.

However, the interviews with the cement executives revealed that over the last two years (2012-2013), the EU ETS drastically slipped to the bottom of company's management priorities. This was due not only to the overall economic situation with significant surplus capacity, but also to the ETS itself. Interest in measures that would lead to the reduction of CO_2 emissions at the management-level diminished as the EU ETS came to be considered ineffective and deficient in several ways. The lack of CO_2 market price predictability, the uncertainties about future structural reform of the ETS and about future measures for carbon leakage protection, as well as the uncertainty on the political support for consistent long-term CO_2 emissions reduction targets all added to a lack of confidence in the EU ETS.

Figure 1 depicts the absolute CO_2 emissions and the production volumes of clinker and cementitious products[2] from the European cement industry, relative to 2005 volumes. In the years 2009 – 2011 the absolute CO_2 emissions from the European cement industry were 20-22% lower than in the 2000-2005 period, and 25% below the 1990 level. This trend is predominantly a consequence of the economic cycle with emissions and output peaking in 2007 and decreasing by 30% over the following two years.

Figure 1. Absolute CO_2 emissions and the production volumes of clinker and cementitious products from the European cement industry, relative to the 2005 volumes



Source: CSI GNR Source

[2] Cementitious products are the sum of clinker not yet incorporated in cement, plus cement, plus clinker and cement substitutes used in concrete.

The cement sector received 8% of the total volume of allowances for the years 2008-2012 ranking second of the industrial sectors after steel and before refineries. At the same time the share of emissions from the cement sector in total EU ETS emissions decreased from 7% in 2008 to 5.6% in 2012, ranking as the third industrial sector after steel and refineries[3].

There is limited evidence that the EU ETS has accelerated the pace of improvement in the CO_2 intensity of clinker and cement production. The same pace of improvement has been observed during the 5-10 year period prior to the EU ETS and the 7 years of the ETS. During the EU ETS the average CO_2 emissions per ton of clinker decreased by 1.2% to 2% over the entire 7 years period from 2005 to 2011. Over the same period CO_2 emissions per ton of cement decreased by about 3% to 5%. There is a strong argument to consider the significant decrease of the cement production and the CO_2 emissions in the EU since the beginning of the EU-ETS in 2005 as a consequence of the economic crisis and not of the investment and operational leakage caused by the EU ETS.[4]

To understand this we present the main options for a reduction of the CO_2 emissions in the cement sector in the following section. Subsequently, in Section 3 the current progress to date of the different levers to reduce CO_2 emissions and the contribution of the ETS and other regulatory and economic drivers towards this progress are analyzed. The section does not provide a comprehensive coverage of all instruments in place, but merely discusses instruments where they were reported to be relevant for past decisions with mitigation impact. Section 4 discusses the effectiveness and other implications of the carbon leakage protection measures. Based on the empirical evidence gathered, we then discuss improvements to the policy framework that could unlock the portfolio of the mitigation options in Section 5.

2. Mitigation options in the cement industry

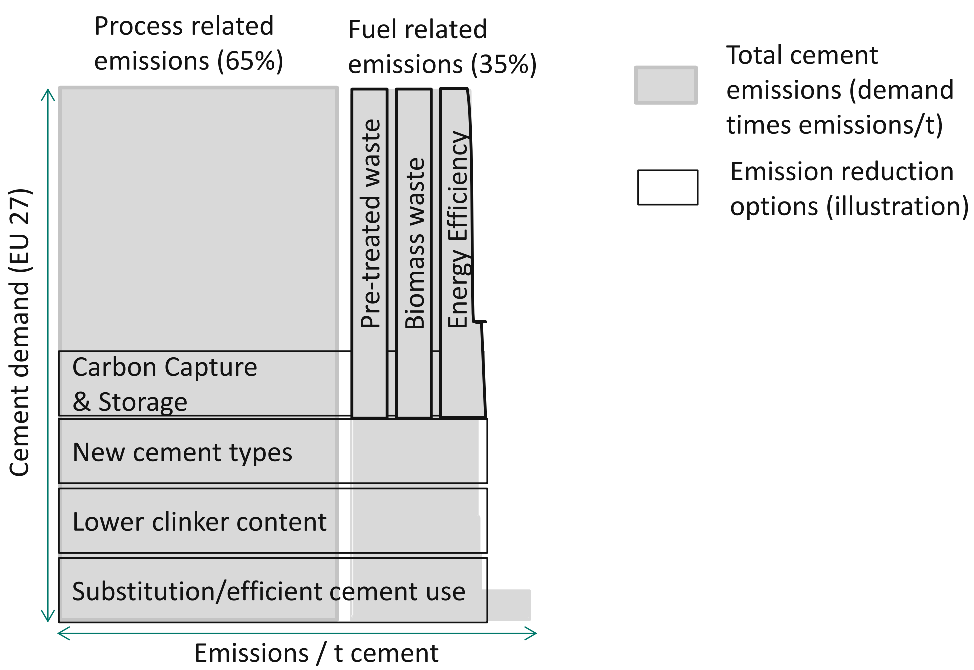
The purpose of this section is to briefly summarize the sources of CO_2 emission in the cement industry and the possibilities to reduce them.[5] Cement is the mineral glue that is responsible for the strength of the widely used construction materials concrete and mortar. The main ingredient of cement is clinker, which is activated by gypsum. The properties of cement can be changed by adding other mineral components, which

[3] European Environmental Agency and EU ETS registry (EUTL).
[4] Similar conclusions were made in the ecorys study prepared for the European Commission: Closure of plants and reduced cement production was caused by economic crisis and has not by the carbon price. Ecorys (2013) "Carbon Leakage Evidence Project", http://ec.europa.eu/clima/policies/ets/cap/leakage/docs/cl_evidence_factsheets_en.pdf (pp. 133-134).
[5] Ba-Shammakh, et al., Analysis and Optimization of Carbon Dioxide Emission Mitigation Options in the Cement Industry, American Journal of Environmental Sciences, 4 (5): 482-490, 2008; Moya et al., Energy Efficiency and CO2 Emissions: Prospective Scenarios for the Cement Industry, JRC Scientific and Technical Reports, 2010.

are partially substituting clinker, such as ground granulated slag from the steel industry, fly ash from coal combustion, ground limestone and burnt oil shale.

Clinker is produced by decarbonizing and mineralization of limestone in a high temperature process. Consequently it is the production of clinker that causes the majority of the CO_2 emissions of the cement industry. Overall the CO_2 originates from two main sources: The decomposition of limestone (so called process CO_2) and the combustion of fuels burnt to reach the high temperatures (fuel CO_2). The process CO_2 emissions amount to typically around 530 kg CO_2 per ton of clinker[6, 7]. Depending on the thermal energy efficiency of the clinker kiln and the fuel type, fuel emissions range between 220 kg and 500 kg fuel CO_2 per ton of clinker.

Figure 2. Fuel and process related emissions of cement sector and mitigation options to reduce the emissions.



In addition to the process and fuel related emissions, there are also indirect emissions that originate from the consumption of electric power (around 110

[6] Source: CSI Getting the Numbers Right database. <www.wbcsdcement.org>.
[7] IPCC and EU ETS Phase III benchmarks assume 525 kg CO2 per ton of clinker.

kWh/ton cement)[8] and emissions resulting from transport. Transport emissions obviously vary depending on transport distance and mode, but generally contribute a maximum of 5% to the production emissions. [9]

The main options to reduce emissions from the cement industry are discussed in the points that follow.

Reduction of fuel-related emissions:

- Substituting the traditional fossil fuels such as coal, lignite and petcoke, which emit around 100 kg CO_2/MJ, by alternative fossil fuels, mainly waste derived fuels emitting around 70 to 80 kg CO_2/MJ or biomass that is considered climate neutral if it is waste biomass or sustainably grown; and
- Improving the thermal energy efficiency of the clinker kilns by using Best Available Technology (i.e. pre-heater pre-calciner kiln technology) and Best Operating Practices (i.e. concentrating production in the most efficient installations and operating those close to their nominal capacity).

Reduction of process and fuel emissions:

- Substituting clinker by other mineral components in cement and concrete. This can involve enhanced clinker mineralization and reactivity which makes further clinker content reduction possible while maintaining concrete strength;
- Substituting cement with low-carbon cement alternatives; and
- Carbon Capture and Storage (CCS) or Carbon Capture and Utilization (CCU).

Indirect emission reductions:

- Improving the electric energy efficiency of clinker and cement production installations.

Several organizations have estimated the potential for cement CO_2 emissions reduction from 1990 to 2050. These include reports and roadmaps by the International Energy Agency in collaboration with the WBCSD Cement Sustainability Initiative (CSI), the CSI with the European Cement Research Academy (ECRA), Cembureau and the European and British cement trade associations (MPA) from the perspective of the cement industry and Ecofys with WWF and the UK Climate Change Committee from the NGO and governmental perspectives, respectively.[10]

---

[8] CSI „Getting the Numbers Right“, indicator 3212.

[9] The role of cement in the 2050 low carbon economy, The European Cement Association, 2013.

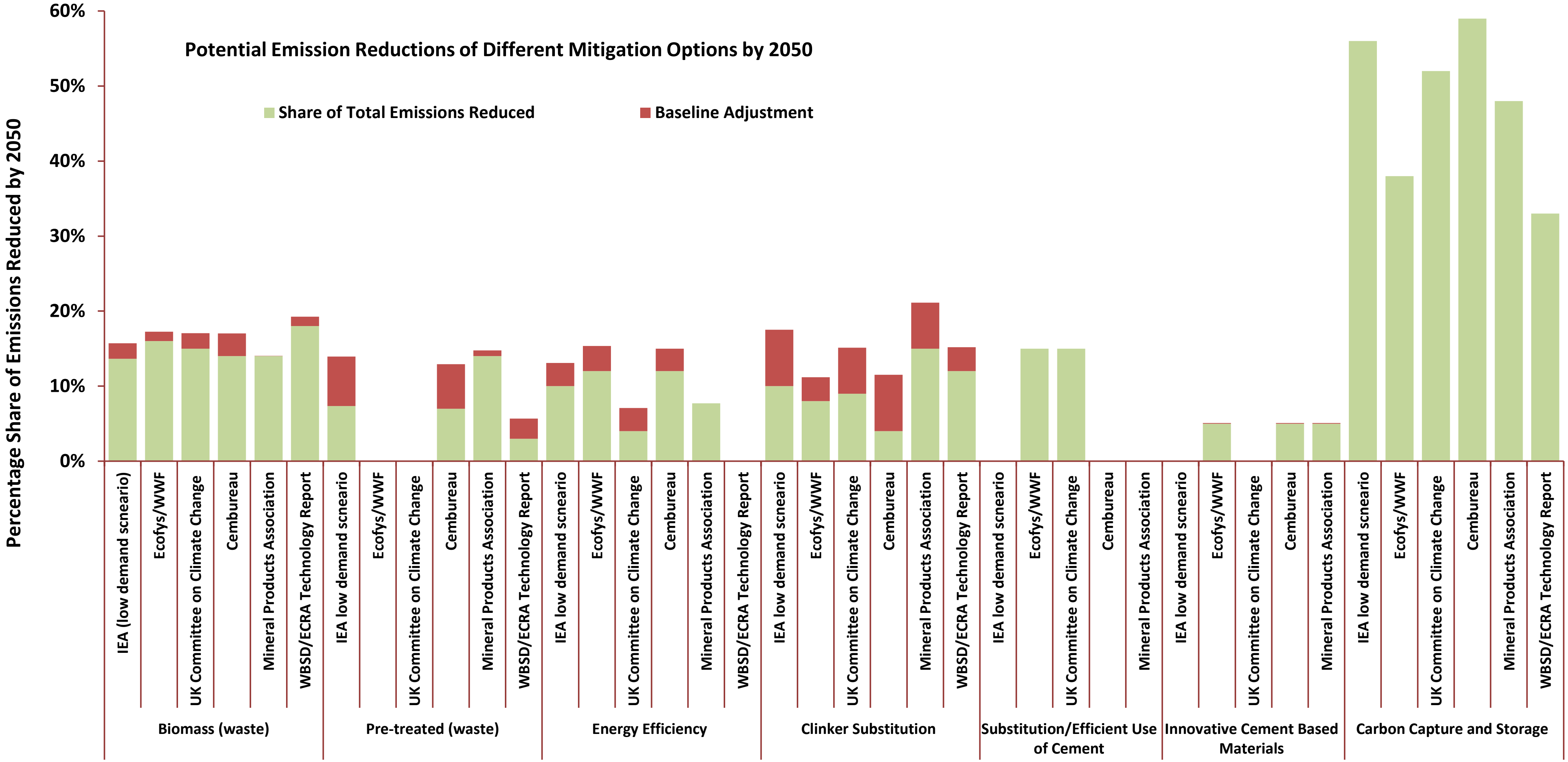
[10] Cement Technology Roadmap 2009 Carbon emissions reductions up to 2050, World Business Council for Sustainable Development and International Energy Agency; Development of State of the Art-Techniques in Cement Manufacturing: Trying to Look Ahead, (CSI/ECRA) Technology Papers, 2009; The role of cement in the 2050 low carbon economy, The European Cement Association, 2013; Mineral

Figure 3 shows the contribution of the mitigating options to achieve 80% emissions reduction by 2050. The roadmaps are fairly consistent in estimating about 15% of the reductions to be achieved by replacing fossil fuels by biomass, with only a small fraction of this potential already used. Clinker substitution is estimated as having a similar potential but with a larger variation across regions and a large share of the potential already implemented between 1990 and 2011. An important feature of the roadmaps proposed by the IEA and the industrial stakeholders is that they include "offsets" for the CO_2 emissions from fossil waste as a fuel (i.e. they refer to "net" instead of "gross" CO_2 emissions[11]) an indirect reduction that the EU ETS, WWF and the UK CCC do not account for. The estimations of the potential from cement substitution, more efficient usage of cement and new cement types are merely ballpark figures on which there is little consensus across the roadmaps. To bridge the gap to 80% reduction by 2050, about 40% to 60% of the total reduction should come from Carbon Capture and Storage.

Products Association Cement GHG Reduction Strategy, The mineral Product's Industires Contribution to the UK, 2012; How to Turn Around the Trend of Cement Related Emissions in the Developing World. WWF International.

[11] Net and gross CO_2 as defined by the WBCSD / CSI MRV protocol.

Figure 3. The relative share of the major emission reduction levers to reach 80% CO_2 emission reduction from 1990 to 2050



*Baseline Adjustments are based on the data collected from GNR database. Pre-treated waste have been calculated with the assumption that alternative fuel use mainly consists of biomass and pre-treated waste.

Source: Compilation of different cement sectoral roadmaps

Further options that reduce indirect CO_2 emissions where power generation remains fossil based include:

- Improving electric power efficiency of clinker and cement production. Grinding cement more finely and using more slag increases power consumption but enhances cement performance and thus makes it possible to use less clinker and cement in concrete;
- Recovering of waste heat from the clinker kiln and using this to produce electric power. It should be noted though that the more energy efficient the clinker kiln is, the less waste heat there is to recover.

The next section will describe how the ETS and other policy instruments have influenced progress and business decision-making on the different mitigation options.

3. Past drivers and future needs to unlock the various mitigation options

3.1. Alternative fuels, biomass and the CO2 intensity of the fuel mix

The EU cement sector reduced fuel related gross CO_2 emission intensity by 6% between 2005 and 2011, primarily by replacing coal with biomass, the latter of which is considered to be climate neutral by ETS accounting standards. There was also some CO_2 emissions reduction due to replacement of coal by waste.

The share of energy sourced from biomass has more than doubled from 3.6% in 2005, to over 5.1% in 2008 to 8.7% in 2011, replacing emissions from coal combustion of about 3.3 million ton CO_2. The share of fossil waste increased from 11% in 2005 to almost 26% in 2011[12]. Currently, 80% of installations in the EU use fossil waste. The decisive factors driving the usage of alternative fuel use are: (i) reducing energy cost (approx. 10 €/ton clinker); and (ii) long-term hedging of energy supply and cost risks. The economic incentive resulting from the EU ETS is still of secondary importance for the industry's biomass and of minor importance for fossil waste use. Using 1 ton of biomass saves about 1.5 tons of CO_2 and 1 ton of fossil waste saves about 0.3 tons of CO_2. At a CO_2 market price of 10 €/EUA, companies would save allowances worth 15 €/ton from biomass and 3 €/ton from fossil waste. If 50% of energy would be sourced from biomass, this would correspond to savings worth 3 €/ton clinker.

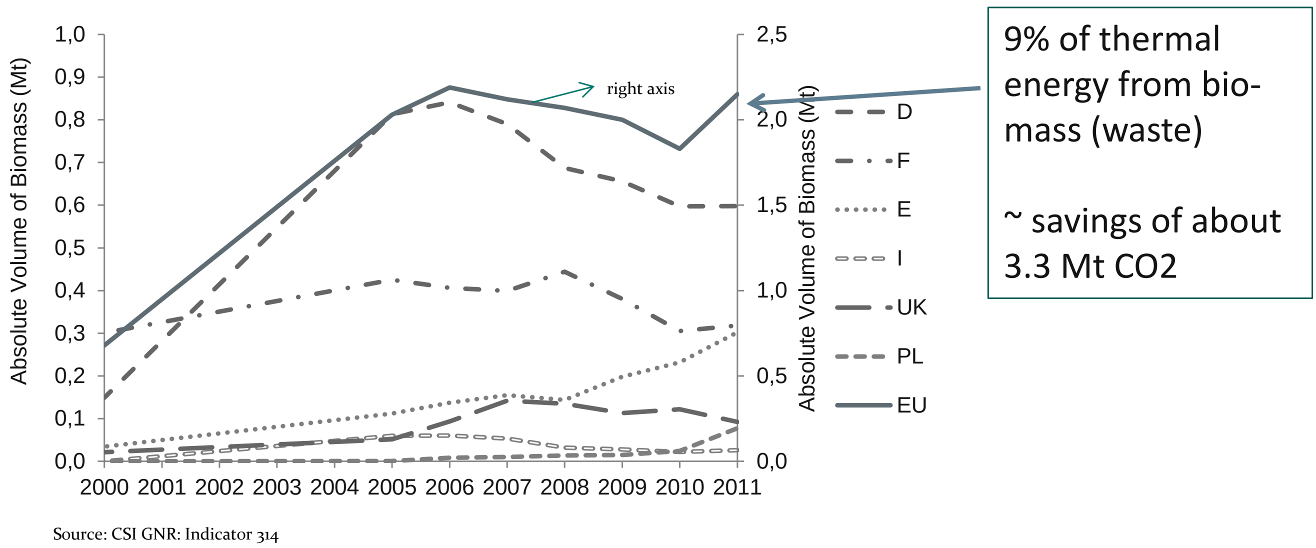
All over Europe the volume of biomass use in cement production (ton biomass / year) has changed little since 2005. Some exceptions include Spain (50 to 100% increase), the UK (+10%) and Poland (however with low volumes). In contrast, Germany and

[12] CSI „Getting the Numbers Right", indicator 3211a.

France witnessed a decrease of biomass volumes of about 25% during Phase II of the EU ETS. This can be linked to the support mechanisms for renewable energy that creates incentives for the use of biomass in heat and power production, but not in the cement sector. Hence the cement industry only uses less than 10% “traditional” biomass (primarily in Spain) and relies otherwise on wastes such as contaminated animal meal and fat, sludge from waste water treatment and the biomass fraction of treated municipal waste (Refuse Derived Fuel). The high temperatures achieved during clinker production make it ideal for bio-waste disposal, by ensuring that any biological contamination in animal waste products is destroyed. It thus allows cement installations to use biomass products that would otherwise have to be treated in dedicated waste incineration.

The share of energy sourced from biomass varies widely across Member States and installations. Some installations use up to 40% of biomass, but usually the share is lower. In France and Germany up to 80% – 90% of installations use biomass. In Italy, only 10% of installations use small quantities of biomass, and there has been no increase of the number of installations using biomass since 2000. The Italian average thermal substitution rate remains 3 to 7 times below the European average. This is due to a combination of aspects linked to permitting such as: low understanding and limited trust in the information provided; local resistance; fragmented and decentralized permitting competences; and numerous and lengthy appeal procedures making the rational implementation of policies and changes extremely difficult.

Figure 4: Volume of biomass used for cement production in selected EU countries (years 2001-2004 interpolated)

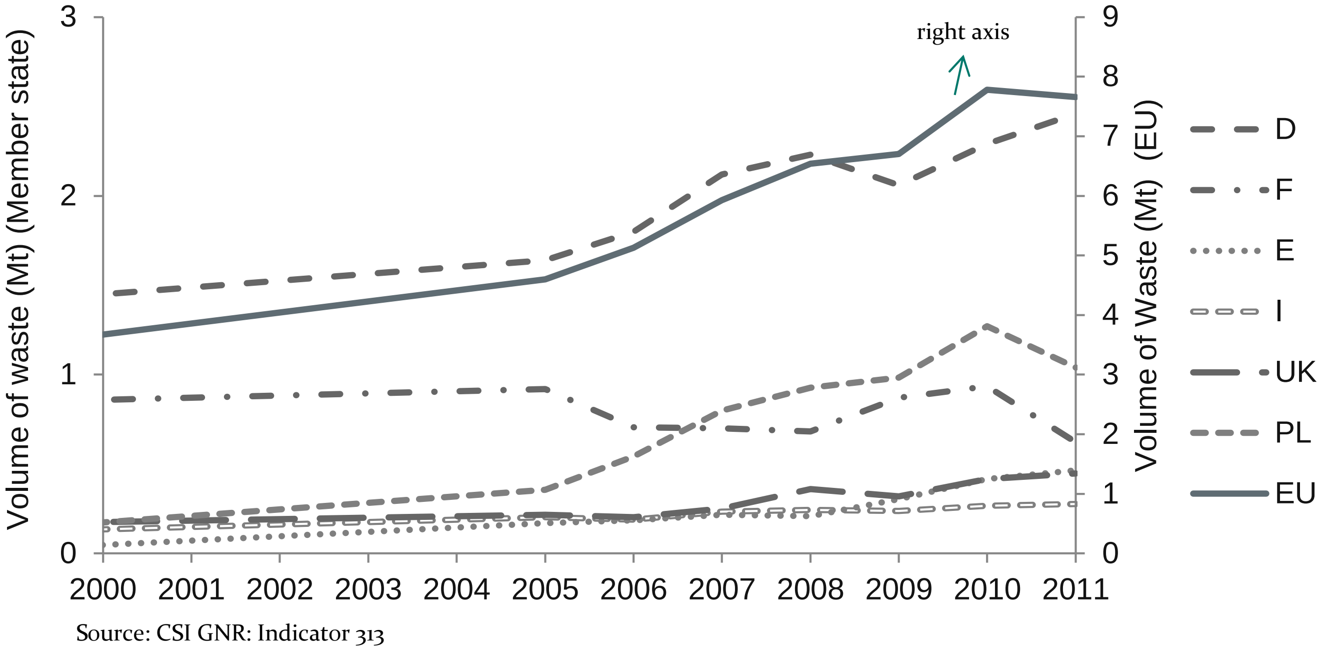


Source: CSI GNR: Indicator 314

Across Europe, fossil wastes are often accepted for co-incineration with payment of a service fee in the order of 10 €/ton waste, which could increase to 100 €/ton waste for difficult hazardous waste materials. However, for some easy high calorific wastes such as waste oil, the cement company has to pay instead. Thus, in principle there is a strong economic incentive for the use of fossil waste without the EU ETS. This incentive to use waste is also linked to other regulatory measures. In particular, the EU Directive (99/31/EC)[13] restricts landfill of waste, and the gradual increase of the use of waste in cement plants after the implementation of this Directive could be linked to its slow transposition into national laws. The 2009 deadline for the transposition was in fact met by only 9 Member States. Italy is again an outlier, as the number of installations using waste as a fuel has not increased since 2000. This is again due to the challenging local permitting processes.

The use of biomass and waste requires investments in waste pre-treatment, storage and handling facilities. The use of biomass also decreases the clinker production capacity of the installation. This is, however, of limited concern during times of (significant) over-capacity.

Figure 5. The volume of waste used as fuel in cement plants



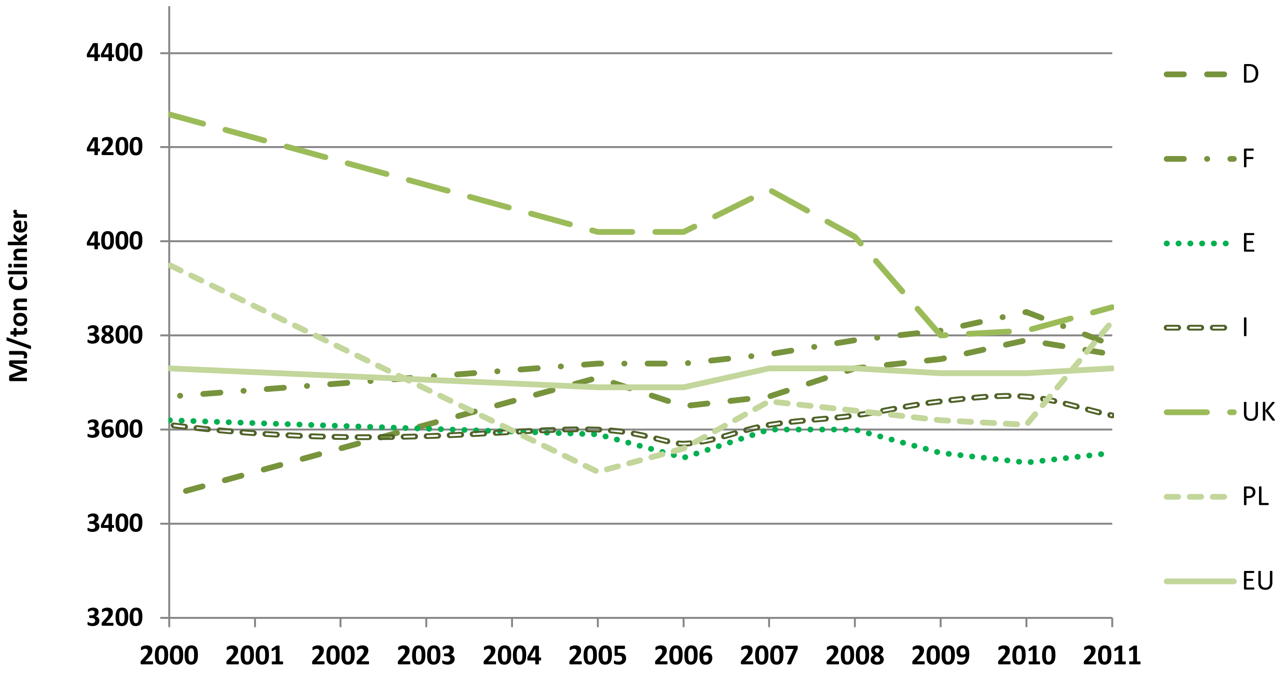
Source: CSI GNR: Indicator 313

[13] Directive 99/31/EC on Landfill of Waste.

3.2. Emissions savings through investments in energy efficiency

During the 12 years between 2000 and 2011, including 8 years of the EU ETS, the EU average thermal energy efficiency of kilns remained unchanged at 3'730 MJ/ton, which is 20% above Best Available Technology level.

Figure 6. Change in the average thermal energy efficiency of the cement plants.



Source: CSI GNR: Indicator 329

About 45% of European clinker production is based on dry kilns with multistage preheater and precalciner (PHPC). They are considered as Best Available Technology (BAT) with the potential thermal energy consumption of 2'900 – 3'300 MJ/ton clinker.[14] However, the average operational energy consumption observed in European PHPC kilns was higher than the potential. Between 2005 and 2011 the annual EU average thermal energy consumption of PHPC kilns was stable at about 3'550 MJ/ton clinker[15]. This is due to the kilns utilization below design capacity and less stable process control and fuel mix. Increasing the share of alternative fuels in the fuel mix may increase energy consumption by 2% because of the water content and coarse particles.

Another 45% of EU production capacity is in dry kilns that are not BAT. These are either preheater kilns without precalciner or long dry kilns without PH and PC.

---

[14] Moya, J. A., et al., "The potential for improvements in energy efficiency and CO_2 emissions in the EU27 cement industry and the relationship with the capital budgeting decision Criteria", Journal of Cleaner Production 19 (2011) 1207-1215.
[15] CSI „Getting the Numbers Right", indicator 3210a.

The remaining 10% of European production is based on 10 wet and 30 semi-wet clinker installations. These technologies are more energy intensive[16] than the best available technology: By 9% in the case of an average semi wet kiln and by 50% for a wet kiln. Yet the use of wet and semi-wet kilns in Europe declined only very slowly since 2000 and at an even slower pace after the introduction of the EU ETS (Table 1)[17]. Replacement of the remaining kilns could contribute to emission reductions of 0.5 Mt CO_2/year for the EU cement sector.

Modern PHPC kilns capacity was built or expanded in Germany, the UK and Poland prior to 2005, and in Ireland and some East European countries (Bulgaria, Romania, Latvia, Slovakia and Cyprus) during Phase II of the EU ETS.

Table 1. Share of cement produced in Best Available Technology (BAT), semi-wet and wet kilns

Year	Percentage of total EU clinker produced in different kiln types		
	BAT (preheater + precalciner)	Semi-wet (9% more energy)	Wet (50% more energy)
2000	34%	12%	6% in 19 installations
2005	42%	9%	5% in 13 installations
2011	44%	7% (30 kilns)	5% in 11 installations

Source: CSI GNR

Investment decisions are made considering a consolidation of many market, economic, financial and regulatory aspects, of which the EU ETS and its carbon cost is just one out of many.

Investment decisions in the European cement industry were made particularly difficult by the economic downturn since 2008. Investments in modernization of installations and cost reduction traditionally require better financial performance (ROIC, IRR, payback) than investments that allow accessing new markets or increasing the value and price of products. However, with the current limited profitability of the cement industry, short-term - up to 3 years - financial aspects and performance (gearing and ROIC, IRR, payback period) play a much bigger role than previously also for long-term investments. This is particularly the case for the multinational groups where gearing, debt reduction and the financial rating are absolute top priorities.

Within such a short-term focused financial appraisal applied even to investments in long-lasting assets, the longer-term objectives and risks for carbon inefficient assets induced by the EU ETS play only a secondary role in the investment decisions. Assuming a carbon price of 20 €/EUA, replacing a wet or semi-wet kiln with a PHPC

[16] CSI „Getting the Numbers Right".

[17] CSI "Getting the Numbers Right", indicator „synthesis".

kilns leads to cost savings of 4.6 €/ton and 1.4 €/ton clinker respectively. While this is not a negligible cost, it is insufficient for justifying a wet to dry kiln conversion. The refurbishment of existing installations to bring them to BAT level is expensive, especially because many of the less efficient installations in Europe are of relatively small size (less than 1 Mton/year).

Based on the interviews with company executives, wet kilns can still reach a financial contribution (i.e. sales price minus production cost) of about 20 to 30 €/ton product, despite the higher thermal energy consumption and CO_2 emissions. Apart from the investment costs having been amortized, (semi) wet installations in Europe reduce their energy cost through sourcing high to very high (up to 70%) energy contributions from waste, often industrial wastes that are obtained including a service fee.

The CO_2 cost is thus insufficient to trigger a wet to dry kiln conversion at carbon prices in the range of 10 to 20 €/EUA. The effect of carbon prices is weakened through the allowance allocation provisions within the EU ETS. As installations receive the full allowance allocation as long as annual production volume is not bellow 50% of historic production volume, old installations can operate at a lower capacity factor (as they are already depreciated) and still benefit from full allowance allocation, thus obtaining surplus allowance allocation that contributes to net revenue. [18]

A set of the EU ETS provisions and implementing measures contribute to a perception of reduced regulatory predictability and investment uncertainty that may have contributed to a delay of investment decisions. These include the revision of the list of carbon leakage-exposed sectors which takes place every 5 years, uncertainties about carbon leakage protection measures after 2020 and the complexity of historically based allocation rules. It also relates to ongoing discussions on backloading, structural reforms of the EU ETS, 2030 targets and international agreements concerning the reduction of CO_2 emissions. However, according to several executives interviewed, the risks induced by the EU ETS are also used as a welcome excuse for the deferral of difficult decisions.

3.3. Emission reductions through substitution of clinker with other materials

Since it is the production of clinker that causes CO_2 emissions, the substitution of it by other hydraulic minerals is the most effective way to reduce CO_2 emissions in cement. The European cement norm[19] allows six clinker substituting minerals, from which the most important are ground granulated blast furnace slag from the steel industry, fly ash from coal fired power stations, limestone and burnt oil shale. Reducing the clinker content in cement is currently the most effective mitigation

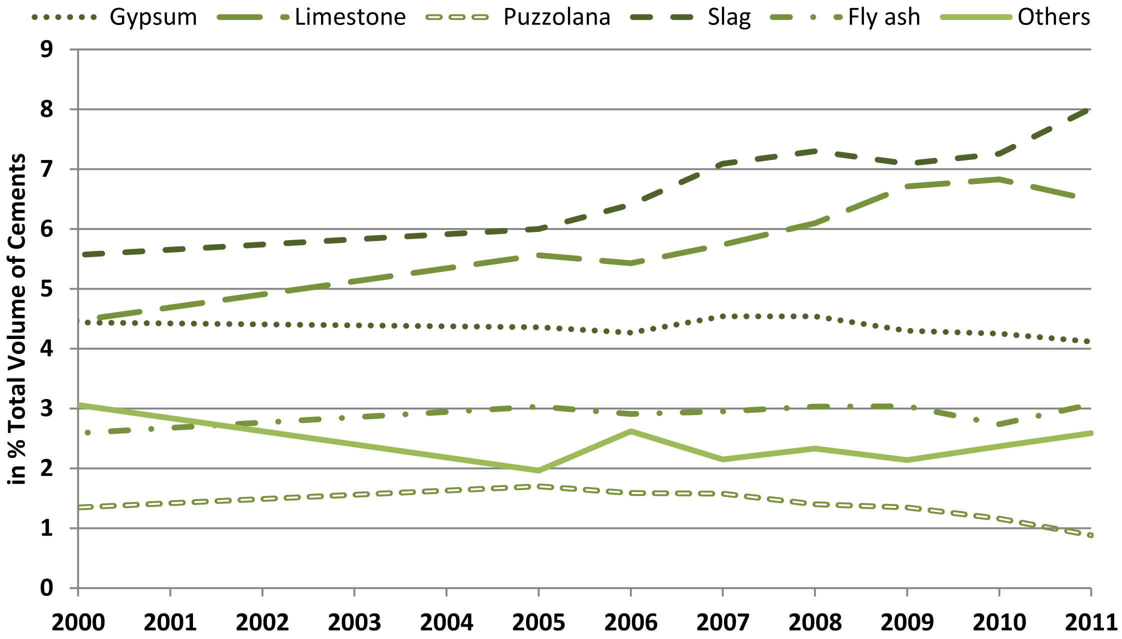
[18] Demailly, D., et al., "How to design a border adjustment for the European Union Emissions Trading System?", Energy Policy 38 (2010) 5199–5207.

[19] European Standard EN197-1 Cement - Part 1: Composition, specifications and conformity criteria for common cements.

option because it not only prevents fuel CO_2 but also the process CO_2 emissions from the chemical transformation of limestone in clinker.

The EU average clinker content in cement has decreased by about 2% during Phase I of the EU ETS, but during Phase II the average clinker substitution [20] from all hydraulic minerals has been stable at 20 to 20.5% (Figure 7).

Figure 7. Share of materials substituting clinker in cement.



Source: CSI GNR: Indicator 3219

Clinker substitution is an important business aspect with multiple dimensions elaborated below, affecting the core product and assets of the cement industry, i.e. clinker, clinker installations and limestone reserves. The degree of substitution depends on the factors outlined below.

Regional availability of substituting materials

The regional availability of slag, fly ash and pozzolanic materials is a pre-requisite for their use as clinker substitute, given transport costs for acquiring inputs from longer distances.

Fly ash is essentially a waste product from dust filters installed at coal fired power stations. Thus the different share of coal in the local power generation mix impacts the availability of fly ash. For example, Poland uses 9% of fly ash in cement

[20] Clinker substitution consists of all mineral components other than clinker and gypsum.

production, significantly above the European average of 3%. The potential for further increases of the use of fly ash is limited and will decline if climate policy triggers a shift away from coal power generation.

Most slag from steel plants is utilized across Europe for cement production. Significant up-front investment costs are required for processing facilities prior to inclusion of slag into cement. In the UK and Ireland, clinker is also substituted with slag at the concrete mixer instead of during cement production. Total clinker substitution for these countries, in cement and in concrete combined, is similar to the rest of Europe.

Geology limits the availability of pozzolanic minerals to a few southern European countries with volcanic activity such as Italy to Greece.[21] Also, burnt oil shale is an excellent cementitious product. It is produced in a fluidized bed combustion installation and co-generates electric power. CO_2 emission per ton of cement is low because there is no limestone decomposition, it requires a low combustion temperature (half that of a clinker kiln) and it co-generates power. However, geology limits the availability of open-air mining of useful shale to a few regions in Europe.

Cost of substituting materials

Fly ash and slag are by-products of power and steel production. Their use requires some up-front investments in treatment plants. Cement producers compete for the limited available fly ash and slag, resulting in significant prices that however usually remain below the total cost of providing clinker. In addition, there is a trend that with contract renewals the value of the CO_2 savings from clinker substitution by slag is shared between the cement and steel companies. Typically supply contracts secure cement companies a stable access to fly ash and slag at a fixed price.

Dependence on other companies

The economic cycles of cement and steel do not always coincide. This may lead to temporary imbalances in the supply and demand of slag as a clinker substitute. Since 2009 slag has been (temporarily) stockpiled in limestone quarries of cement companies rather than being used in cement. There are no accurate data available on the volume and time of slag stockpiled. A reasonable estimate could be around 3 million ton or about 15% of the slag volume used annually across Europe.

Meeting consumer needs

Clinker substitution may impact the technical qualities and requirements of the concrete, such as early and late strength, sulphate resistance, colour and workability. This requires overcoming demand-side resistance to new products.

[21] "A blue print for a climate friendly cement industry. How to Turn Around the Trend of Cement Related Emissions in the Developing World", Ecofys, 2008.

Some companies have started with Product Carbon Footprinting, labelling and advertising reduction of embedded CO_2 in marketing and sales of different cement types. Market acceptance has been mixed but generally rather muted. Product quality and price remain the two most important aspects for the customer. This shows the importance of economic incentives for emission reductions from the EU ETS into consumer choices. The cost of embedded CO_2 should be reflected in the cement price to more effectively stimulate consumer choices to low carbon cement types.

The EU ETS

Substituting for example 25% to 30% of clinker, i.e. selling CEM II instead of CEM I cement, saves about 0.2 ton CO_2/ton of cement. At a carbon price of €10 this would offer savings of 2 €/ton of cement. This raises the question as to why the EU ETS has not induced further clinker substitution.

Most cement executives interviewed stated that, while recognizing that clinker substitution is an effective option to reduce CO_2 emissions, the influence of the EU ETS is not (yet) weighted as much as other factors that drive decisions about clinker substitution. This can be broken down to two factors:

First, cement companies only add a limited and uncertain share of opportunity costs for CO_2 allowances to cement prices (see section 4.2). Thus there is currently a very limited economic incentive for cement consumers to shift towards cement with lower clinker content. A (full) CO_2 cost pass-through in the cement pricing may be necessary to effectively influence consumer choices towards lower CO_2 cement types and producers.

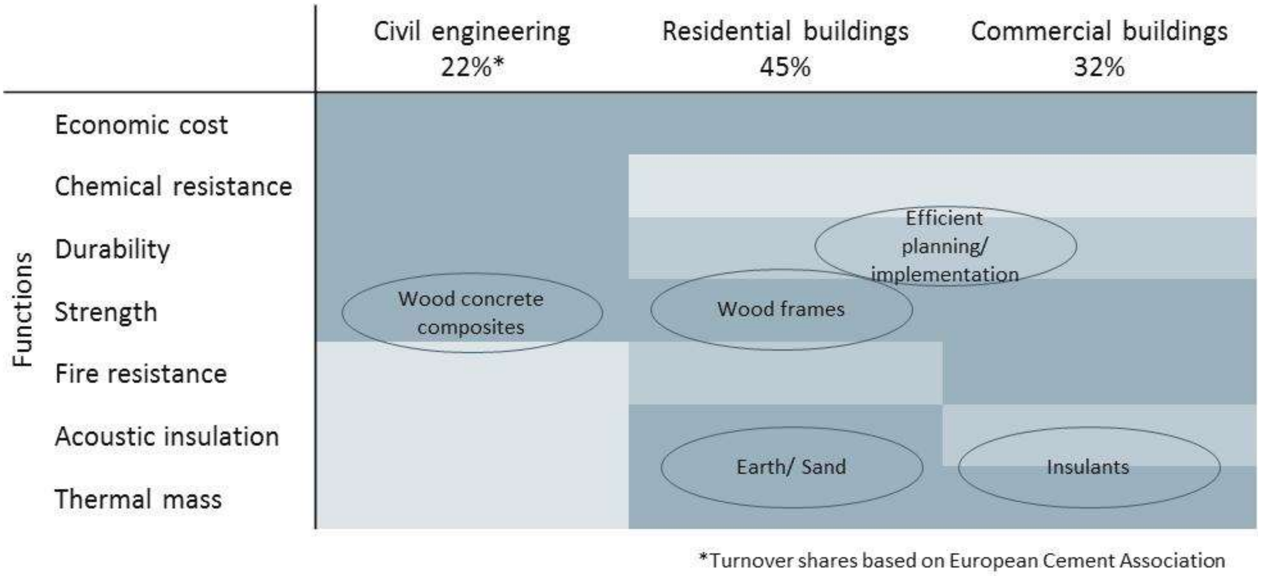
Secondly, cement companies discount the value of potential emission savings from clinker substitution if allowances are allocated for free. This repeated observation in industry reality contradicts simplified economic models of companies maximizing profits. In theory, companies should pursue equal levels of abatement if they can save costs from buying fewer allowances or if they can increase revenue from selling additional surplus allowances. Why the reality diverges from this theory can be linked to: (i) the uncertainty whether lower clinker production will be reflected in the base-line for allowance allocation in future periods; and (ii) the norms in corporate accounting procedures that report costs, but ignore forgone opportunity costs savings (see also section 4.3 on use of profits from over-allocation by cement companies).

As a result, some companies have invested in production with reduced clinker content, mainly in view of a long-term corporate CO_2 reduction strategy. Yet the effective incentive from the EU ETS was limited across Europe and the average share of clinker substitution remained stable. Regional differences did however occur. Germany and the UK have further increased clinker substitution during both EU ETS phases, in the UK mainly with fly ash. Poland increased clinker substitution during Phase I but not Phase II. In Italy and the Czech Republic clinker substitution remained remarkably unchanged since the beginning of the EU ETS. Slag use at the concrete mixer in the UK has also not changed since 2005. Spain on the other hand has *decreased* clinker substitution during EU ETS Phase II, going back to the year 2000 level (see further in section 4.3). Also Austria increased the clinker content of cement, reaching substitution levels only slightly above the EU average.

3.4. Efficient cement use and substitute building materials

Cement and concrete are the most common construction materials today. This is due to the fact that they provide functional performance capabilities at relatively low cost, unequalled by any other building material. To our knowledge the potential share of cement and the associated emissions that can be saved by using cement more efficiently (e.g. better design) or substituting cement products with alternative materials has not been systematically assessed. It is unlikely that there will be one single substitute for cement. Instead, approaches for more efficient cement use and suitable alternative materials will depend on the specific functions that need to be provided. These functions can differ between residential and commercial buildings and civil engineering (Figure 8).

Figure 8: Efficient cement use and cement substitution with alternative materials (dark ~ relevance of function)



In civil engineering, bridges are one example where - from a technical point of view - the use of concrete can be reduced by using wood-concrete-composite bridges. In this way, concrete can support compression loads and wood can be used to take over tension forces[22]. In interviews with engineers, it was reported that wood-concrete-composites can save 50% of concrete and 20% of steel required for the construction of bigger heavy traffic bridges or long deck constructions.

[22] Flach, M. and Frenette, C.D., (2003), Wood-Concrete-Composite-Technology in Bridge Construction.

In the construction of residential and commercial buildings, concrete is typically used to address various functions: strength; fire resistance; thermal mass; or acoustic insulation. Several studies show that building components such as frames, inner and outer walls and floors can be built with wood while allowing for the same functions. It embodies - according to life cycle assessments - less carbon emissions than concrete.[23] The potential for wood might be, however, higher for residential buildings than for commercial warehouses, since the fire protection requirements for commercial warehouses are more stringent. Furthermore, the function of thermal mass can be provided by sand or earth[24]. It was reported that if concrete is used only for the structural purpose, potentially more than 20% of concrete can be saved at the building level from a technical perspective.

However, the actual potential to substitute cement products by other building materials depends not only on these technical considerations, but also on factors such as the availability of alternative materials, their economic cost, entrepreneurial activity in the field, cultural aspects and the role of building regulations. To better understand the potential to reduce cement demand and the associated emissions a more systematic analysis is needed in these fields.

In addition to concrete substitution, the use of concrete can be reduced through better planning and implementation. It has been argued that early collaboration between structural engineers and architects can reduce the required material use.[25] One example for better planning is the coordination between foundation, walls and floors – thus, walls and floors made of lighter materials than concrete require less concrete for the foundation.[26] Moreover, better implementation can reduce the use of concrete for building floors. For example, concrete is needed on top and at the bottom to fulfil strength requirements. The filling could be left empty or be filled with Styrofoam. However, in practice concrete is also put as filling, since this allows for easy implementation.

Previous studies estimate that the price elasticity of substitution is in the range of -0.5 to -1[27] If the cement price is without carbon cost at current European levels of 60 €/ton, a CO_2 price of 40 €/ton in 2050 could reduce cement demand by 20-35%.

---

[23] Albrecht, S. Rüter, S. Welling, J. Knauf, M. Mantau, U. Braune, A. Baitz, M. Weimar, H. Sörgel, S. Kreissig, J. Deimling, J. Hellwig, S., (2008), Ökologische Potenziale durch Holznutzung gezielt fördern, Bericht gefördert von BMBF; Gustavsson L., Madlener R., Hoen H.-F., Jungmeier G., Karjalainen T., Klöhn S., Mahapatra K., Pohjola J., Solberg B., Spelter H. (2006). The Role of Wood Material for Greenhouse Gas Mitigation, Mitigation and Adaptation Strategies for Global Change, 11(5-6): 1097-1127; O'Connor, J. and Sathre, R., (2010), A Synthesis of Research on Wood Products and Greenhouse Gas Impacts, 2nd Edition, Vancouver, FP Innovations.

[24] Pacheco-Torgal, F. and Jalali, S., (2011), Earth construction: Lessons from the past for future eco-efficient construction, Construction and Building Materials, Vol. 29, pp. 512–519; Goodhew, S. and Griffiths, R. (2005), Sustainable earth walls to meet the building regulations, Energy and Buildings, Vol. 37, pp. 451–459.

[25] Mehta, K. and Meryam, H., (2009), Tools for Reducing Carbon Emission due to Cement consumption, Structure magazine, January 2009.

[26] John, V., Habert, G. (2013), Graue CO_2-Emissionen im Gebäude – wo sind sie hauptsächlich verortet? Ökobilanzanalyse mittels zweier verschiedener virtueller Blickwinkel auf die Konstruktionsweisen und Bauteile von vier unterschiedlichen Mehrfamilienhäusern, Bauingenieur 08, pp. 342-348.

[27] Cour and Møllgaard (2002) -0.3; Roller and Steen (2006) -0.5 – 1.5; Jans and Rosenbaum (1997) -0.8; Ryan (2005) -3.

However, as there was to date no significant carbon cost pass through to the cement price, the EU ETS with free allowance allocation provisions has not contributed to the substitution of cement by other building materials.

At the same time one needs to be careful not to increase the CO_2 emissions by replacing concrete with other materials that lead to higher emissions. Therefore passing the costs of carbon to final customers must not be limited only to cement-based products but also to its possible substitutes, i.e. steel. In sum, this brief review points to various opportunities to reduce demand for cement and to the need for more systematic analysis on the reduction potential of concrete.

3.5. Developments of alternatives to cement

Low-carbon cement options include “new” cements based on “old” ideas, such as calcium sulfo-aluminate cement, clinker mineralization and alkali-activated cement, as well as new processes and products such as Celitement (Schwenk) and Novacem. Cement sector executives argue that developing and demonstrating such new products will take 10 to 15 years.

Probably the most important barrier for product innovation is absence of market demand for products with lower embedded carbon, especially as long as carbon prices are low and not reflected in cement prices. Even with carbon prices included in cement costs it will be difficult to encourage users to shift to new cement types: The application of cement and concrete for infrastructure with a very long life-time, foundations, buildings and housing makes proven durability of the product an absolutely essential requirement of the customer.

As discussed for the case of cement substitutes, also low-carbon cement alternatives are unlikely to provide the very same functions of cement. Instead a specific low carbon cement type might be used – and possibly preferred – according to the specific application. A further rational for a more differentiated set of low-carbon cement types might emerge from potentially limited availability of individual resources.

3.6. Development of CCS

CO_2 capture and storage (CCS) is a mitigation option that captures CO_2 from the flue gases of stationary installations, compresses the purified CO_2 and transports it to a geological storage location, injecting it deep underground for permanent isolation from the atmosphere.[28]

Since 2007 the European Cement Research Academy (ECRA) has been conducting research projects on carbon capture technologies for the cement industry and makes

[28] IPCC, 2005: Special Report on Carbon Dioxide Capture and Storage. Cambridge University Press: Cambridge, United Kingdom.

the extensive technical reports publicly available.[29] Cement companies as well as cement equipment and gas technology companies participate in this joint research effort.

After initial assessment ECRA focused on two capture technologies. With the "post combustion" technology a flue gas treatment installation at the end of a traditional clinker production installation absorbs the CO2 out of the flue gases into a chemical liquid, to be followed by a regeneration of the liquid and separation of pure CO2. With the "oxyfuel technology" ambient air is separated in oxygen and nitrogen and the fuels in the clinker kiln are burnt with an oxygen/CO2 mixture instead of with air. The main components of the resulting flue gases are CO2 and water which are separated prior to compression of the CO2.

ECRA's research has revealed that both technologies could be used for retrofitting existing clinker installations. The energy required to separate 1 ton of CO2 with the post combustion technology is almost the same as the clinker BAT thermal energy demand. The energy penalty of the oxyfuel technology is lower: the thermal energy demand per ton clinker would be roughly the same as with traditional BAT but electric energy consumption will double.

Norcem, the Norwegian subsidiary of Heidelberg cement, hosts a test rig enabling the testing of different CO2 capture technologies since mid-2013.

Still a lot of research and development, including pilot plants, remains to be done. While the economic analysis is only preliminary in this research, it indicates investment costs around 100M Euro and abatement cost around 30 to 40€ per ton CO2 captured, excluding compression, transport and storage.

CCS in general has several barriers, which also apply to CCS in cement. Capture leads to higher energy consumption. Specifically the cost of CCS technologies in the cement sector will likely exceed 40 euro/tCO_2[30] and societal acceptance of CO_2 storage is uncertain[31]. R&D on CO_2-storage is generally done by companies specialised in the underground, such as oil and gas companies, requiring a new type of cooperation between cement and underground companies, which some see as another barrier. European environmental organisations are generally opposed to CCS in the power sector as it displaces renewables, but more supportive of CCS in industry where few other options for deep emission reductions exist.[32]

---

[29] European Cement Research Academy – ECRA CCS technical reports parts 1 to 3 <www.ecra-online.de>.

[30] IEA/UNIDO, 2011. Technology Roadmap: Carbon Capture and Storage in Industrial Applications. IEA: Paris, France.

[31] Global Energy Assessment, 2012: Chapter 13: Carbon capture and storage. Available on www.iiasa.at/gea.

[32] "Climate Action Network Europe Position Paper CO2 Capture and Storage" Climate Action Network Europe 2006, <http://www.climnet.org/resources/doc_download/1119-caneurope-ccs-position-paper-11-2006>.

No EU Member State has a specific policy on CCS in the cement industry, although several documents have been recommending specific activities.[33] The EU Economic Recovery Package of 2008 has made available funds for CCS demonstrations, but all six proposed projects involved coal-fired power. The NER300 call was open to CCS on cement-plants, but no applications were submitted from the cement sector.

An interesting new ECRA R&D initiative, though still at a very early stage, aims at finding other solutions than permanent storage of the captured CO_2. It focuses on conversion of the captured CO_2 into hydrocarbons such as methanol, using solar and renewable energy. In this form the captured CO_2 could be reconverted into a fossil fuel or resource for industry.

ECRA's decision to engage in this long-term R&D is inspired by the European Union's long term CO_2 reduction ambition. It is however not financially supported through nor are there economic incentives from the EU ETS yet. According to McKinsey & Co, CCS retrofitting of existing cement plants is at the highest cost end of the Carbon Abatement Cost Curves.[34] Since the purpose of an ETS is precisely to incentivize the least costly abatement options, economic theory suggests that CCS will not be stimulated by the ETS unless the other reduction levers are insufficient to meet reduction targets and the ETS price rises accordingly. Prior to this, other support mechanisms are needed for large scale demonstration of CCS in the cement industry.

[33] IEA/UNIDO, 2011. Technology Roadmap: Carbon Capture and Storage in Industrial Applications. IEA: Paris, France.

[34] McKinsey & Company, 2009, Pathways to a Low-Carbon Economy; Version 2 of the Global Greenhouse Gas Abatement Cost Curve.

4. Effects of the EU ETS on pricing, operational and investment decisions

4.1. Pricing: Are carbon costs passed on to cement purchasers?

One of the ways that the carbon market is intended to drive emission reductions is by incentivizing substitution and a more efficient utilization of products with high CO_2 emissions. If producers of carbon-intensive products pass the cost of CO_2 incurred in the production of their goods through to final product prices, consumers will have an incentive to either switch to less carbon-intensive alternatives or use these products more efficiently. The CO_2 cost pass-through may also be important for producers of less carbon-intensive alternatives, such as low-carbon cements, to be confident that their products can be commercially competitive.

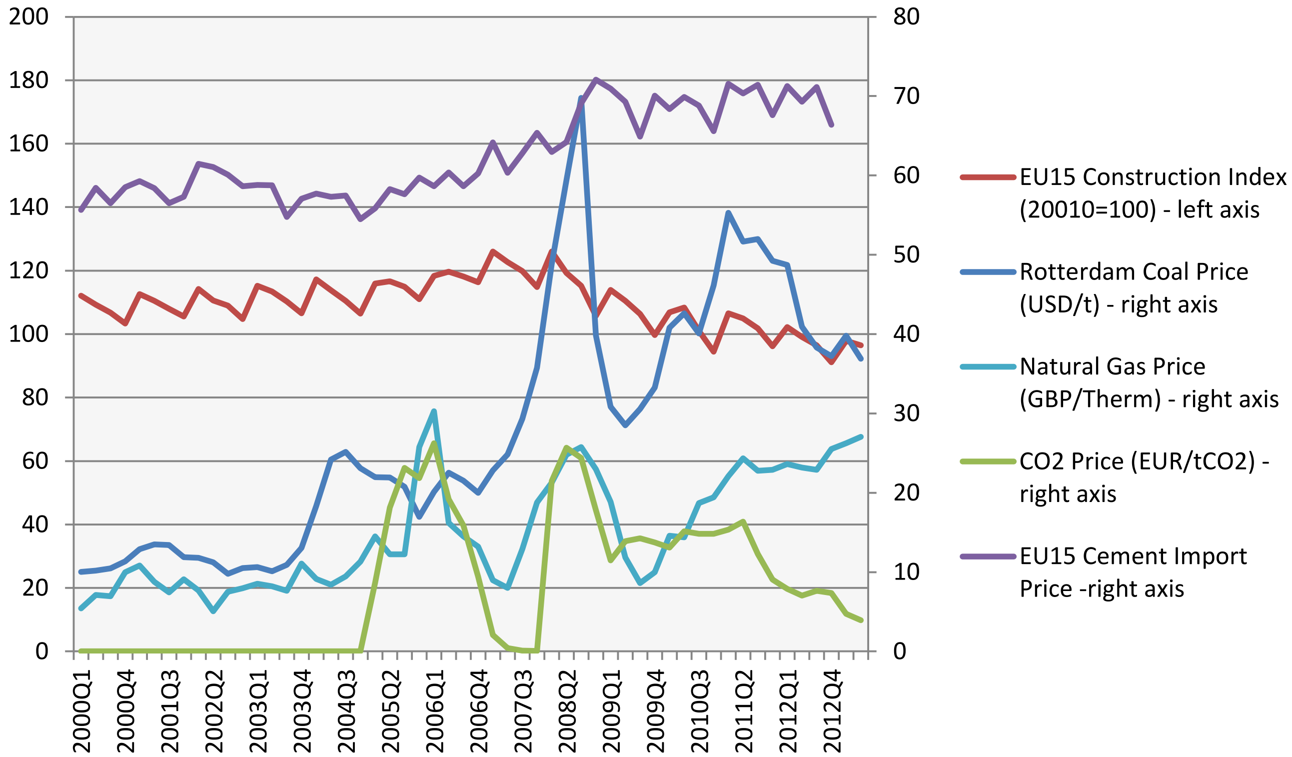
Historically, European cement companies adopted a “cost-plus” approach to product pricing, whereby prices were based on costs plus a desired margin. More recently, some companies began debating a shift towards an approach to pricing based on the “value-added”, which the consumers gain from using the product in a given application.

During the expert interviews cement executives, who were asked about price pass-through, stated that they did not pass on carbon prices to consumers in the cement sale price. This statement was subsequently checked against the available data on cement prices, which also suggest that cement prices do not include CO_2 opportunity costs.

Data on cement prices were obtained by dividing Eurostat’s quarterly intra EU trade value data for grey Portland cement by the corresponding trade flow quantities within the EU-15 since 2000. This was done because EU-wide data on cement prices are not publicly available. While trade volumes within the EU-15 only represent a small portion of total sales in the sector, a check of the implied trade values against Eurostat’s annual production value and volume data, reported by Prodcom, reveal that the implied prices from trade closely follow prices for all production.

Figure 9 shows the quarterly average grey Portland cement price as implied by EU-15 import prices. The figure also shows the evolution of construction activity in the EU-15, steam coal prices, natural gas prices, and carbon prices in the EU ETS since 2000. Assuming an average CO_2 intensity of 0.6 ton/CO_2 per ton of cement, a carbon price of €10 would add up to €6 to the price of cement if fully passed on to consumers. However, no such relationship between cement and carbon prices can be observed since the introduction of the EU ETS in January 2005. It can be seen that the cement prices rose gradually from around 60 to 70 €/ton between the third quarter of 2004 and the final quarter of 2008. However, the periods in which the sharpest rise in prices occurred do not correspond closely to the introduction of the EU ETS in January 2005. On the contrary, cement prices only began to rise significantly in mid-to-late 2006, after the sharp decline of the carbon price, and in late 2007- early 2008, when the main cause appears to have been the sharp spike in energy prices and growth in construction activity.

Figure 9. Implicit EU-15 cement prices vs. carbon and energy prices and construction demand



Source: Reuters, Eurostat, IMF Commodity database, ICE

There has also been no consistent decline in the cement price accompanying the decline in the carbon price since 2011. These data therefore appear to confirm the statements made by cement executives that the opportunity cost of carbon prices are not passed on to cement purchasers.

Various reasons are discussed and were reported why carbon prices were not passed on in cement prices. Concerns about competition with imported cement may limit the possibility of passing through carbon costs on to final consumers. If carbon cost were passed through in cement prices, then imports would become more attractive, certainly at carbon prices above €15 to 20/EUA. Free allocation was precisely intended to prevent such substitution of domestic production with imports and resulting carbon leakage by preventing the need to pass on the cost.

If cement companies were able to pass on the carbon cost without leading to carbon leakage, that would be the empirical proof that the industry were not exposed to the risk of carbon leakage. Thus it could also be argued that ongoing negotiations of carbon leakage protection measures motivated a restraint on pass-through of carbon prices.

Longer-term strategic considerations – such as maintaining market share and good client relationships – could partially balance the incentive to pass on opportunity carbon prices to the product prices.

Another concern is that raising prices to reflect opportunity costs of carbon would, in the presence of free allowances, lead to a large rise in profit margins. Some interviewees expressed concerns that this might raise suspicions of competition authorities, which pay close attention to pricing practices in the cement sector.

The substantial unbalance between production capacity and market demand during recent years has also eroded the industry's capability to include other cost increases, such as increased energy costs, into product prices.

Finally, several interviewed executives confirmed that their companies do not yet use the carbon content embedded in cement for marketing and pricing of different cement types. Cement companies do not use carbon cost pass through to promote the sales of low carbon cement, quite the opposite, some try charging a premium for "green" low carbon products. This notion of "value added" unfortunately goes against the concept of internalization of the environmental cost.

The limited or absent carbon prices pass-through to the cement price is closely linked to the fact that cement firms have so far received their required emission allowances for free under the EU ETS. This may be subject to change during the EU ETS Phase III if installations face a real carbon cost if capacity utilization is similar to or above the production volume during the reference period and emissions of the installations are above the benchmark rate.

4.2. Trade and re-investment: Is there evidence of carbon leakage?

There are a number of definitions of the term 'carbon leakage'.[35] This report focuses on the question as to whether the EU ETS had direct effects on trade and investment patterns, which resulted in EU production and emissions 'escaping' to regions not covered by the EU ETS. The main concern is that by increasing production costs for EU cement companies, the EU ETS directly leads to an increase in the share of EU demand met by imports.

In discussing this question, we differentiate between *operational leakage,* in which imports gain market share from domestic production because of different carbon costs between producing regions, i.e. operational leakage that occurs in the short term; and *investment leakage,* i.e. leakage which occurs via the impacts of the EU ETS on the cement sector investment policy and which could occur over a longer time horizon. It is also possible that, under certain circumstances, the EU ETS causes

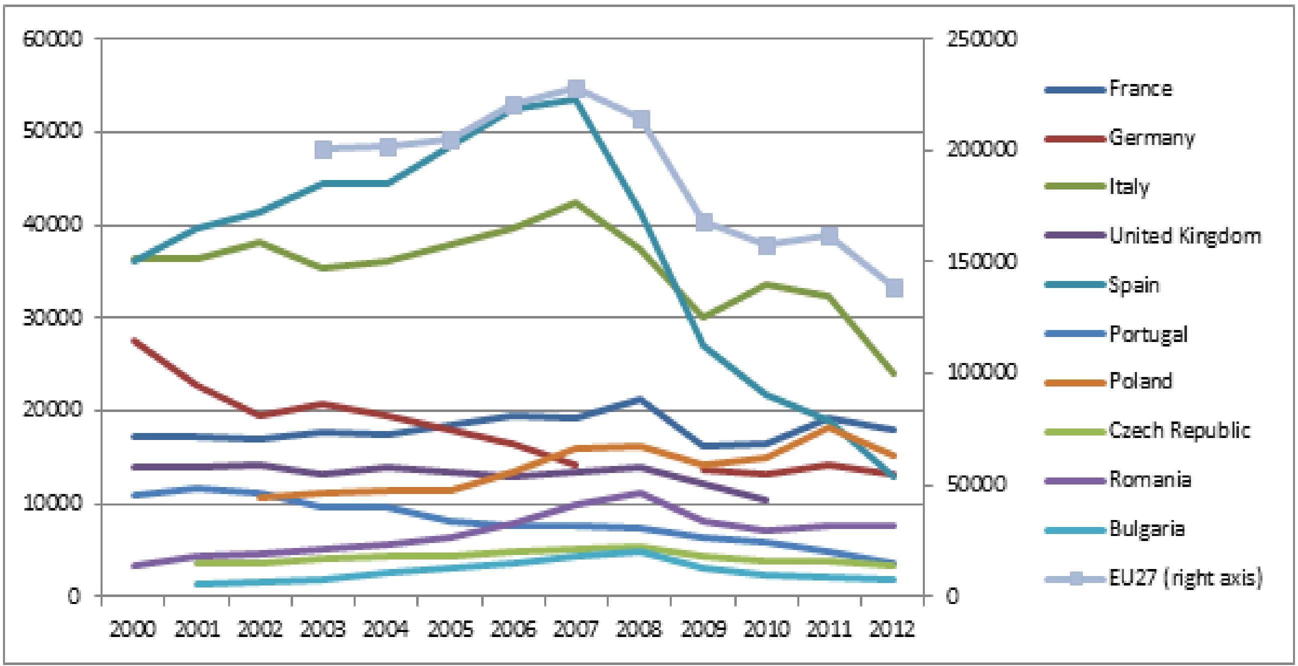
[35] It is most commonly perceived as the marginal emission changes in country B that is induced by climate policy in country A. Many channels of potential leakage (both positive and negative) have been identified including impacts on international trade, investments, international energy prices and technology spill-overs (see Dröge, S. 2011). Using border measures to address carbon flows. Climate Policy, 11(5), 1191– 1201.

reverse operational leakage, if it has a direct effect on increasing EU exports and this possibility is also discussed.

4.2.1. EU cement and clinker consumption and trade

Any analysis of European trade in cement and clinker must first take account of consumption patterns in the EU. Figure 10 shows apparent EU cement consumption (production plus net imports) for the past 13 years at the example of selected EU countries. It shows that cement consumption is strongly affected by the economic cycle. Consumption increased in most Member States and for the EU-27 as a whole prior to the recession of 2009, after which it has fallen significantly. This phenomenon is most clearly visible in those Member States that have been the most strongly affected by bursting of the construction booms prior to 2008 and the subsequent European debt-crisis, namely Spain and Italy. Two notable exceptions to the overall trend are Germany and Poland. Germany's consumption has been declining steadily throughout the 2000s, as the surge in demand that accompanied the decade following re-unification has petered out. Poland has seen continued strong growth in consumption even after the crisis broke out due to its strong economic performance and high levels of construction and infrastructure building.

Figure 10. Development of cement consumption by Member State in kt.

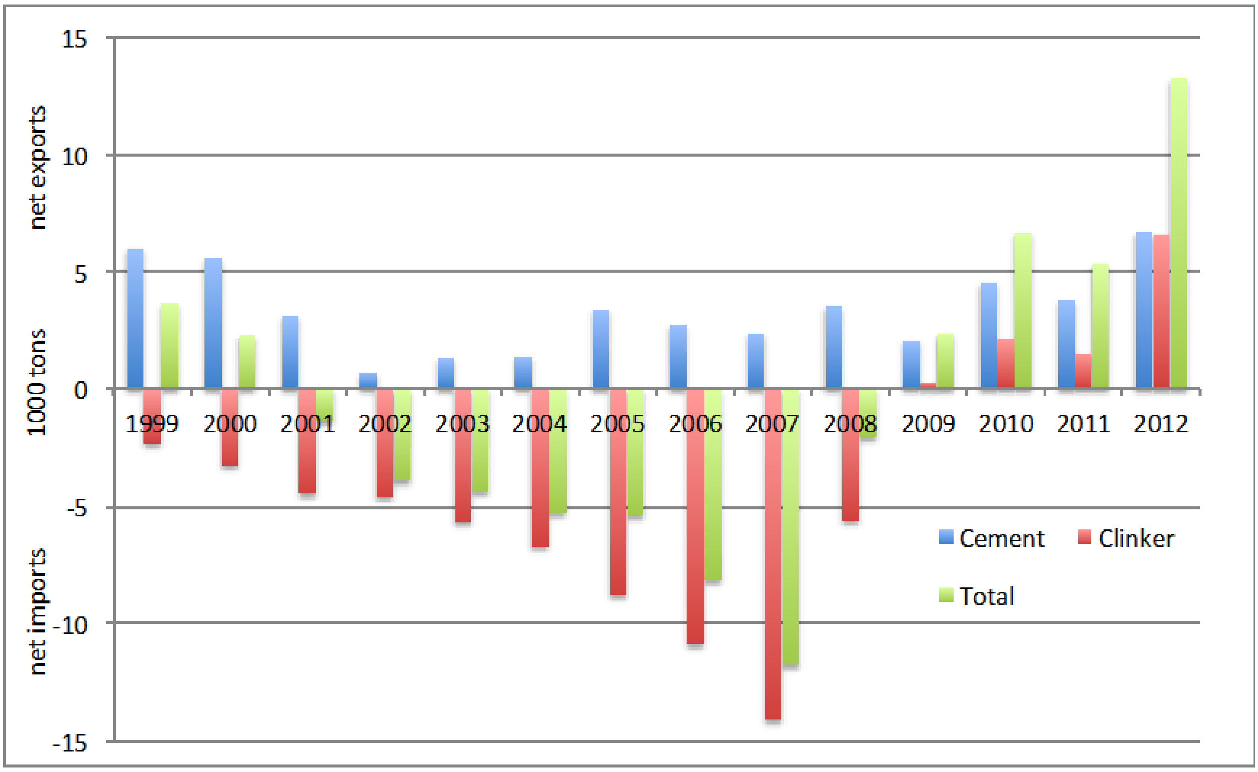


Source: Based on Eurostat (Prodcom)

Compared to the cement consumption, trade volumes are small. Only 2% to 4% of the cement production is exported to countries outside of the EU, while import volumes are only half of this. As a result, Europe has been a small net exporter of cement during the period 1999-2012. Intra-EU trade volumes are also small, on average amounting to 2% to 4% of the domestic production, and have remained relatively stable over time. One exception is Germany, which exports 12% of the cement production, and France, which has seen a significant increase of imports from other EU countries to 12% of production in recent years.

Since the bulk handling of clinker is much easier than cement (which requires dedicated handling and storage equipment because cement is dusty and must be kept dry) a bigger volume of clinker is traded with countries outside of the EU (Figure 11). Before 2009, Europe was a net importer of clinker (peaking at net imports of 14Mt clinker from non-EU countries in 2007), largely due to demand in Spain and Italy. Meanwhile EU clinker export volumes were small prior to the crisis (<3 Mt; i.e. ~2% of domestic production). This trend reversed in 2009, and EU net clinker flows reversed to a small trade surplus of over 300 kt, driven mainly by exports from Spain, Portugal and Greece. Brazil and African countries are the main destinations for the exported clinker. The EU therefore shifted from a net exporter of cement and a net importer of clinker before 2009 to a net exporter of both products.

Figure 11. Evolution of net exports of cement and clinker to non-EU countries (1999-2012).



Source: Based on UN Comtrade and Eurostat

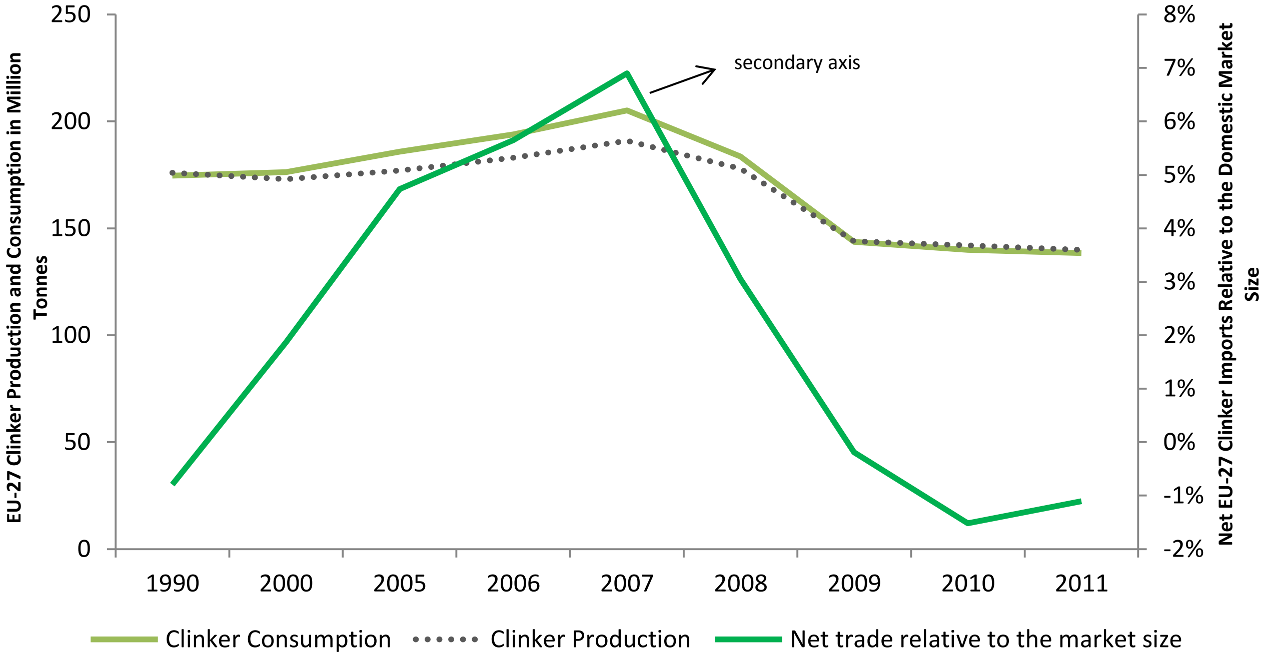
These findings highlight two important points. Firstly, trade flows in the cement sector have been strongly driven by differences between domestic clinker and cement production capacity and demand. For example, during the 2002–2007 construction boom, Spain became a large net importer of cement and clinker, where clinker imports amounted to 20% to 30% of domestic production volumes. Spanish imports of clinker came mostly from Egypt and China, whereas cement imports originated in Turkey. However, following the end of the construction boom in 2008, the Spanish cement sector turned into a net exporter, exporting 2% to 5% of the domestic clinker production to outside the EU, and increasing it to over 20% in 2012. Similarly, clinker and/or cement exports increased markedly after 2008 for Portugal, Greece, Ireland and Sweden, where excess capacity tended to be the highest. Figure 10 shows why this has occurred: Domestic consumption of cement has fallen dramatically in the majority of the EU countries since 2008.

Secondly, trade volumes are typically low as a share of the total EU production. This underlines the localized nature of cement markets, with significant barriers to trade in the sector, including high transport costs[36] as a share of value added and the need for specialized import and storage capacity for cement. Once again, the example of Spain is illustrative: During the economic boom years, imports rose gradually as import terminals and clinker grinding stations were built near ports operating with imported clinker. Since the crisis and the resulting over-capacity, the same ports and grinding capacity have been used to export Spanish domestic clinker and cement.

4.2.2. Is there evidence of operational leakage?

Based on the analysis of trade data, the literature, and the interviews with the cement executives, no evidence was found of operational leakage having occurred due to the EU ETS. As noted, the main driver for the rapid growth in clinker net imports prior to 2008 was the imbalance between domestic capacity and demand (see Figure 12). As demand collapsed, so did net imports of clinker in 2008 despite a large rise in the EU ETS carbon price in that year.

Figure 12. EU27 clinker: relationship between consumption, production and net imports/exports.



Source: Eurostat Comext, GNR

[36] McKinsey (2008) estimated that transport costs for a ton of clinker from Alexandria to Rotterdam are in the order of 20€/ton, and that inland shipping costs are approximately 3.5€/ton per 100km and inland road transport was about 8.6€/ton per 100km.

Discussions with cement company executives confirmed the hypothesis made from the observed data, that import flows have so far not been driven by carbon prices. For example, one executive noted that unless future EUA prices are "significantly higher" than those observed in Phase II, justifying the logistics and cost of offshoring production for import into the EU based purely on carbon price differences would be "too difficult". However, the possibility that significantly higher carbon price differences in the future may result in operational leakage (in the absence of a level playing field with producers) in third countries was consistently maintained.

This evidence is consistent with existing econometric studies on this question which include the EU ETS Phase II.[37] They found that the carbon price was not statistically significant in explaining *short-run* changes in the level of net imports of cement and clinker by the EU27. This is also consistent with the evidence given in Section 4.1 on the fact that European cement producers do not appear to pass-through carbon costs into their prices.[38]

4.2.3. Is there evidence of investment leakage?

Empirical evidence of investment leakage is more difficult to establish, since a longer time-frame is required to observe impacts on investments and this is not necessarily correlated with short-term carbon prices. Nevertheless, anecdotal evidence from the expert interviews suggests that the likelihood of investment leakage having occurred due to the EU ETS is thus far very small.

Some of the cement executives who we interviewed were of the opinion that it is not a good long-term strategy to build installations outside the EU dedicated to serve the European cement market. Several of them expressed the view that "BAT production close to the market" is the best business and environmental option for a heavy commodity, with low added value and high energy and transport costs.

While the majority of emission allowances required for EU cement production were distributed for free in Phases I and II, under the benchmarking system introduced under Phase III, installations will receive free allocation equivalent to 88.4% of their historical production[39], multiplied by the clinker benchmarks. There was considerable uncertainty about these free allocation levels before they were finally determined in September 2013. While the long-term path of 1,74% per year decreasing ETS cap is embedded in the Emission Trading Directive, there is a number of aspects of the directive that are considered to provide uncertainty for investments. These include: (i) the 5-yearly revision of the list of carbon leakage-exposed sectors; (ii) the uncertainty on carbon leakage prevention measures after 2020; (iii) the complexity and

[37] Ellerman et al (2010), who looked at data from 2005 to 2008 and by Frédéric Branger, Philippe Quirion, Julien Chevallier (2013). Carbon leakage and competitiveness of cement and steel industries under the EU ETS: much ado about nothing, CIRED Working Paper No 2013-53 who analyse data up to 2012.

[38] Price pass through is however not a necessary condition for operational leakage to occur. Theoretically, leakage could also occur via international arbitrage of production costs by European companies if capacity constraints are not binding and carbon costs are sufficiently high to render such activities attractive.

[39] This reflects the average allocation rate after accounting for the cross-sectoral correction factor.

deficiencies of the historically based allocation rules; and (iv) the perception of the lack of legislative predictability caused by on-going discussions on back-loading, structural reforms and 2030 targets and international agreements.

While this renders planning and investment decision-making in Europe more difficult, there is no evidence that investments in Europe have been cancelled and moved abroad because of the EU ETS. It was not possible to establish to what extent such uncertainty leads to investment leakage as opposed to simply slowing investment decision-making on European operations.

4.3. Distortions arising from fixed ex-ante allocation and activity thresholds

Up to now, free allocation is based on the principle of fixed ex-ante historic allocation (HA). When allocation is not adapted to the changes of actual production volumes, this can lead to significant excess initial free allocation in times of low cement demand.

During Phase II, the criteria to continue receiving full free allocation despite a partial cessation of production varied across Member States. In most countries there was no minimum activity level specified, thus enabling up to 95% excess allocation.

The fixed ex-ante allocation followed by the substantial decrease of production caused by the economic downturn therefore led to a significant excess of freely allocated allowances. Across the EU this excess of the cement industry increased from 27% of the total cement sectoral allocation in 2009 to 37% excess in 2012. Since emissions intensity per ton clinker improved by just about 1%, this excess is essentially due to production decrease. Most cement companies sold this excess. The financial revenue as reported by the five largest cement companies in Europe aggregate to well over one billion Euro from 2009 to 2012[40]. The companies did not earmark these profits from over-allocation for energy efficiency or emission reduction projects but included them in the overall corporate budget.

Phase III includes EU harmonized allocation rules dealing with partial cessation of production, requiring 50% utilization of the Historic Activity Level (HAL) to receive full free allocation the next year, and requiring 25% operation to receive 50% of the allocation.[41] This rule was intended to avoid over-allocation accruing to installations which produce at only a small fraction of their capacity.

However, analysis of the EUTL emissions data and discussions with cement executives revealed that it continues to create perverse incentives which, especially in a context of low demand for clinker, lead to various distortions.

---

[40] Reference: Finacial reports from Lafarge, Cemex, HeidelbergCement, Italcementi and Holcim.
[41] Cf. Art. 23 Commisson Decision 2011/278/EU.

4.3.1. Effects on operational decisions

A problem with these activity thresholds is that companies can intentionally spread production over several installations with the purpose of maintaining the full issuance of free allowances at all those installations. Where the regional cement market demand is insufficient to reach the minimum activity level, companies will have an incentive to export excess production if they cannot sell it domestically and to increase the clinker content in cement – since the activity rules apply to clinker production.

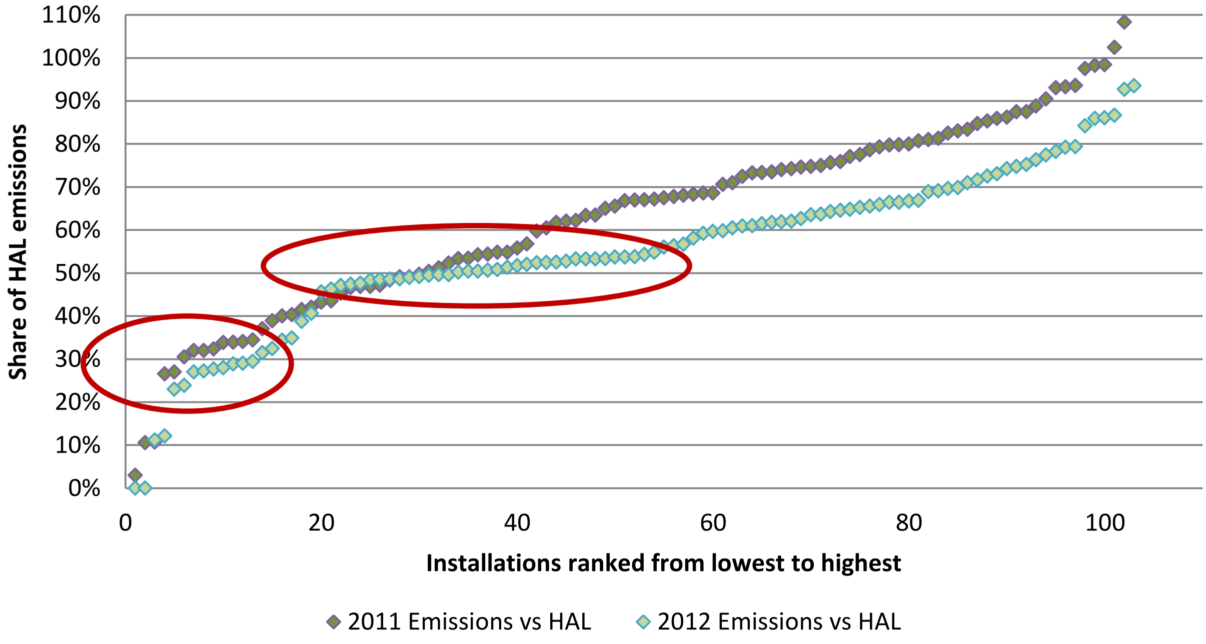
The company executives who were interviewed consistently confirmed these practices, which are not only limited to the countries most hit by the crisis but are widespread across the EU. They reported that this is an unintended and unwanted effect and would prefer it would not exist, but the way the rules of the system are designed they are incentivized to exploit them.

Evidence of this threshold effect can be found in the EUTL. Figure 13 looks at installations in 5 countries where demand has been the most depressed: Greece, Italy, Ireland, Portugal and Spain. Each data point represents an installation showing the ratio of its verified emissions in 2011 and in 2012 to its verified emissions in its historical activity level year, as reported in the EUTL. There is a cluster of about 30% of the installations operating around 50% historic allocation level in 2012 but not in 2011. Moreover, in 2012 (but not 2011) the line suddenly drops at around 47-48%[42] and another smaller cluster appears at just over 25% at which point there is another threshold in the allocation rules. The free allocation activity thresholds are evaluated and applied retrospectively, i.e. production declines in 2012 are used to determined allocations in 2013. Therefore, this is the result that would be expected if companies were indeed exploiting the existence of the thresholds to maximize their allocations in these countries.

---

[42] There are several installations from which the share of HAL emissions is just below 50%. This calculation is however just a proxy for the estimation of the production capacity utilisation which is not publicly available.

Figure 13. Comparison of 2011 and 2011 emissions levels with historic activity level (HAL) in Spain, Italy, Greece, Portugal and Ireland EU ETS cement installations



Source: Authors' calculations based on EUTL data.

An unintended consequence of this allocation rule is the potential to inhibit incentives to reduce emissions through operational efficiency. In fact, companies can be indirectly encouraged to increase rather than decrease their emissions in a number of ways, for example by:

- Keeping obsolete and often less energy efficient installations in operation instead of closing them;
- Using an installation at 51% of the full capacity and thus operating it energy inefficiently rather than concentrating the production of a plant on full capacity; and
- Producing additional clinker to meet the threshold and then using this clinker in cement instead of other low-carbon substitutes, such as slag or other products. In Spain for example, the content of clinker in cement increased from 77.5% in 2006-08 to 80% in 2009-11[43].

These activities will tend to increase emissions in the cement sector, particularly in an economic environment of excess capacity, where there is a scope for operational efficiencies to be achieved among existing installations.

[43] Some of this increase may be attributed to the increased export of CEM I cement.

4.3.2. Effects on asset rationalisation and investment in efficiency

It was also suggested by some interviewees that the partial cessation rules may create distortions at the level of longer-term decision-making, such as asset rationalization. This relates to incentives for new investments in energy and carbon efficiency improvements. Asset rationalization, including closure of structural excess capacity, is a difficult business decision that is not taken lightly. Such decisions must take into account a range of factors, including:

- Prospect of the future evolution of the economy;
- The value of the operating permits, the limestone reserves and quarrying permits;
- Access to cement markets and market share;
- Social costs of closures;
- Costs of site clean-up; and
- Impact on company's balance sheet.

Asset rationalization is related to investments in energy and emissions efficiency because for these investments to be profitable, as with all capital expenditures, it is desirable that the new investment will be fully exploited. This is because the greater the rate of capacity utilization of the newly built capital or retrofit is, the shorter is the investment payback period. If the partial closure rules incentivize running plants at below full capacity in order to spread production across existing installations, or if they also contribute to excess capacity, production and lower cement prices, then they will tend to reduce the payback of new investments that improve energy and emissions efficiency.

Box. 1 How transport costs influence asset rationalization decisions?

An objection to asset rationalization (and thus concentration of production) can be linked to potential increases of transport volumes involved in serving cement demand with fewer plants. Also increased use of clinker substitutes may require the sourcing of slag or fly ash from longer distances. To quantify the relevance of this argument we put the CO2 emissions from transport in perspective to the CO2 emissions from cement production. These emissions may be compared to the difference in production emissions of the average plants and the 10% plants with the lowest emissions in Europe. This difference is 52 kg CO2 per ton clinker and 86 kg CO2 per ton cement.

The next table gives typical CO2 emissions per ton kilometer for different transport modes[44] and the distance that clinker and cement may be hauled so that the transport emissions equate the difference between the average and 10% best production emissions. This illustrates that heavy products like clinker, cement and slag can be transported over relatively long distances, even by truck, before CO2 transport emissions offset the CO2 savings from production emission improvements.

---

[44] Guidelines for Measuring and Managing CO_2 emissions from freight transport operations, CEFIC, March 2011.

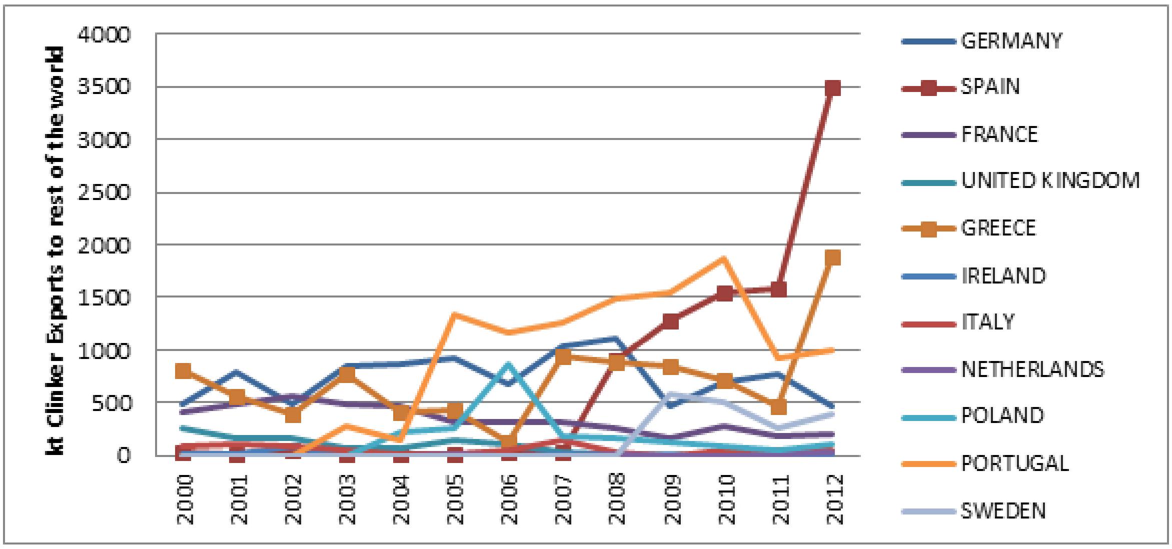
	g CO_2/ton km	Transport distance clinker	Transport distance cement
Truck	100	520	860
Rail	22	2'300	3'900
Inland water	31	1'700	2'800
Short sea freight	16	3'200	5'400
Deep sea freight	8.4	6'200	10'000

4.3.3. Effects on trade and cement markets

In addition to influencing production optimization decisions, there is also evidence that the resulting excess production of clinker can have effects on trade and cement markets.

Figure 14 shows data on clinker exports to all countries for a handful of EU member states. The data reveal that some of those member states most heavily hit by the decline in demand for cement since the economic crisis, most noticeably Greece and Spain, have witnessed very large and sudden increases in the volume of exports of clinker in 2012 to both EU and non-EU countries. Part of these increases are driven by the worsening of the economic situation in these countries in 2012, and thus a need to export or sell production to remain in operation. However, the very large sudden spike in exports in 2012, combined with the evidence of companies in these countries producing just above 50% of historical activity levels, suggests that these exports are likely to be related to the activity thresholds. This interpretation was also confirmed by discussions with cement executives during the interviews.

Figure 14. Exports of cement clinker by country



Source: Eurostat, Comtrade, CN8 "Cement clinker"

The evidence thus suggests that the fixed historic allocation and specific closure thresholds contained in the current EU ETS free allocation rules have distortionary effects on production and export levels, especially under conditions of extremely depressed local demand, as in Spain and Greece. While it was not possible for us to differentiate between the incentives created by the EU ETS and other drivers for continued operation of plant, the activity level requirements are likely to have contributed to the increase in export volumes to EU and non EU countries.

The effect is likely to decline during 2013 due to lower allowance prices reducing the incentive to retain production volumes above threshold levels. However, when the EUA market price would increase again, the unintended negative effects of the phase III allocation rules will be amplified again.

5. Implications for policy design

The facts in sections 3 and 4 put into evidence the reality and the causes of the limited environmental and economic effectiveness of the EU ETS, which can be summarized in the points that follow.

- A **CO_2 price** of 20€/EUA or lower is too low to incentivize any of the CO_2 and energy mitigation levers in the cement industry. During the period with higher CO_2 market price, management attention for CO2 mitigation was substantial.
- Besides the CO_2 price, also the **CO_2 cost** signal is too weak. When the method and level of allowance allocation ensure a sufficient volume of initial allowances the real carbon cost to producers is small, zero or even negative, leaving only an opportunity cost and as such eroding the effectiveness of the cost signal for cement companies.
- In the **absence of the carbon price reflected in cement prices** there is little effective economic incentive for consumers to select low CO_2 cement types, low CO2 cement producers, more efficient use of cement or alternative building materials and practices.
- Free allowance allocation is used to prevent carbon leakage in a world of uneven carbon constraints. However **fixed ex-ante historic allocation, including the phase 3 activity level rules that are in place to make the ex-ante allocation relevant for carbon leakage protection,** may be blamed for a number of unintended negative effects on trade flows, internal market distortion, windfall financial gains, and inhibition of asset rationalisation, energy efficiency improvement and clinker content reduction. These facts suggest that fixed ex-ante allocation may fall short of preventing operational leakage of marginal production volumes.
- Several aspects of the ETS **Directive** and **implementation measures** cause a persistent and growing perception of **complexity**, of uncertainty and lack of medium to long term **regulatory predictability**, thus negatively influencing the investment climate. This contributes to little confidence of executives of cement companies in the functioning of the EU ETS and carbon market.
- The empirical evidence also reveals that an **ETS on its own will be an insufficient** policy to incentivize further CO_2 mitigation options. Some coordination with and adaptation of other existing policies will be needed, such as creation of a level playing field with renewable energy systems and adaptation of the incineration and waste directives. At the cement customer side adaptations of building practices, standards, tendering, labelling and information systems will be needed to stimulate low carbon procurement in the construction industry. Other supporting measures will be needed for innovative low-carbon cement and CCS.

Improvement of the policies and implementation measures will thus have to deal with:

1) Strengthening the CO2 price signal;
2) Strengthening the CO2 cost signal to the cement producer and the cement consumer;
3) Improving medium and long-term clarity on targets, policies and implementation measures;
4) Support for innovation and CCS; and
5) Adaptations of other policies and standards, policies and practices.

The following five subsections will discuss these requirements. Figure 15 illustrates how these requirements need to be met by unlocking the portfolio of mitigation options. As discussed in the preceding sections, to date progress has been limited to the first three mitigation options with limited progress in efficiency investment.

At this stage of the research, we limit ourselves to an introduction of the policy options, deferring further analysis to the final report, including an analysis of other sectors and broader considerations.

Figure 15: Issues where improvements of policy and implementation measures are needed

		CO_2 Price	Free allocation		Clarity on future develop-ment	Innovation support	Adjustments to regulations and building codes
			CO_2 Cost to producer	CO_2 Cost pass through			
		Section 5.1	Section 5.2		Section 5.3	Section 5.4	Section 5.5
Traditional mitigation levers	Biomass	■	■				■
	Fossil Waste	■	■				■
	Clinker substitution	■	■	■			■
	(Efficiency) Investment	■	■		■		
	Asset rationalisation	■	■		■		
Customer side	Low CO2 cement	■		■	■	■	■
	Efficient use, building practices	■		■		■	■
	CCS	■	■	■	■	■	■

5.1. Strengthening the carbon price signal

To date, most of the mitigation actions in the cement sector were motivated by economic aspects, regulation and business decisions other than the EU ETS and CO2 cost. The CO2 price has generally been too low to further influence such mitigation actions.

This shows the importance of the economic signal and the need for carbon prices to make further mitigation opportunities economically viable. However, currently the low and uncertain future of the carbon price reduces the value attributed to carbon when considering benefits of efficiency investments or low-carbon innovations.

Various options to adjust the emissions cap, to make it more responsive to economic developments and to stabilize the allowances price are currently being discussed in view of the structural reform of the EU ETS. Ultimately, these options will have to be designed so as to best meet the needs of the different sectors covered by the EU ETS, and thus need to balance the needs of various sectors.

Strengthening the CO2 price should go hand in hand with a structural reform of the carbon leakage protection and the allowance allocation while enabling – and stimulating – a carbon cost pass through to customers.

5.2. Reduce distortions from carbon leakage protection measures

Therefore, in addition to an appropriate carbon price level, the design details of the EU ETS need to be compatible with delivering appropriate economic incentives for carbon reduction. This would result from a shift from free allocation to full auctioning of allowances. However, this would entail the necessity of cost pass through in product prices and in order to address carbon leakage concerns, allowances are allocated for free.

Figure 16: Fundamental trade-off exists between once and for all free allocation and output based allocation. EU ETS allowance allocation provisions balance some of the basic features.

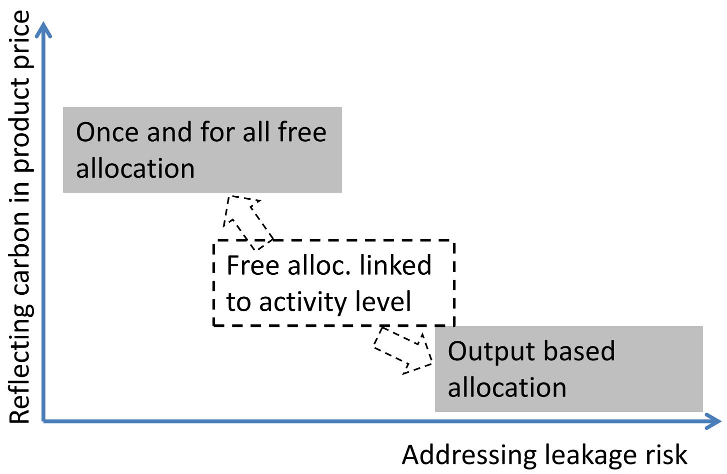


Figure 16 illustrates two fundamental approaches to free allowance allocation, which are now first described as a way to characterize the properties of the free allowance allocation provisions that have been used to date:

Once and for all free allocation: Free allocation is fixed not only for one trading period like in the EU ETS, but for all future trading periods and continued even after closure of an installation, as for example with SO_x and NO_x cap and trade systems in the United States. Such an allocation would not distort investment and operational choices – but merely comprise a lump- sum transfer to company owners. The free allowance allocation would therefore also not impact pricing decisions, implying that the full carbon price will be passed on to consumers where possible, and no carbon leakage protection is granted through the mechanism.

Output based allocation: If allocation is directly linked to the production output volume of e.g. clinker, [45] then only costs for allowances to cover emissions exceeding the benchmark rate are incurred. Therefore, only these (limited) costs are included in product prices and both incentives for substitution and the threat of carbon leakage are avoided. If allocation benchmarks are set e.g. at the level of the best 10% of the installations, then surplus allocation is avoided at the installation level for the inefficient installations. This enhances predictability of the mechanism and the impact of the carbon price for management choices. [46]

Neither of these two basic options for all free allowance allocation was considered to be satisfactory at the time of designing allocation rules. In phase I and II allocation was proportional to historic emission volumes, and in the national allocation plans formulated by EU member states typically linked to the requirement of continued operation of the plant. In phase III the disincentives for emission reductions that result from repeated free allocation based on historic emissions was tackled with a benchmark approach. Allocation was also more closely linked to output with activity level requirements of 25% and 50% of capacity utilization.

This activity level requirement contributes to carbon leakage protection. Our analysis suggests that neither operational nor investment leakage has occurred in the cement sector. However, the incentive to maintain production above the activity threshold may have contributed to an increase of export volumes in countries with large surplus capacity. The carbon price pass through has to date been very low, further reducing the risk of operational leakage but also undermining the market potentials for low-

[45] Also output based allocation linked to the cement production volume was discussed. Compared to output based allocation linked to the clinker production volume, incentives to reduce the clinker content in cement are preserved this way. However, incentives for the substitution of cement with other low-carbon building materials or for its more efficient use remain muted. Also, the definition of such a benchmark was seen to be more difficult regarding the larger regional variations of clinker content. Philippe Quirion, "Historic versus output-based allocation of GHG tradable allowances: a comparison", Climate Policy 9 (2009) 575-592.

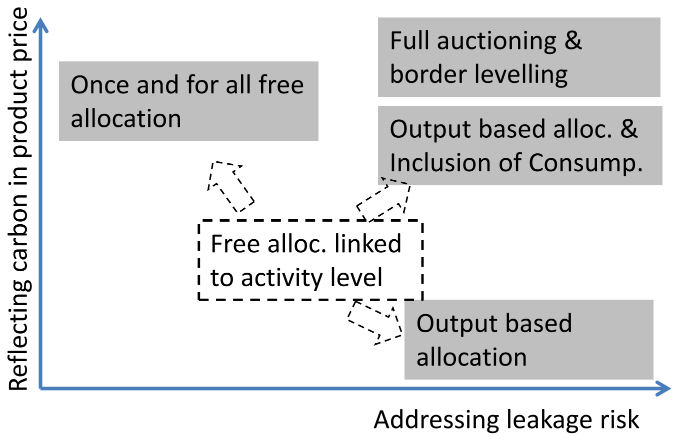
[46] Output based allocation does not need to alter the overall EU ETS cap as the balance of allowances not allocated can be added or subtracted from the auction volume.

carbon cement, efficient use, and cement substitutes which hinge on carbon prices being reflected in the cement price.

It is difficult to envisage how a further refinement of the activity level requirement can avoid this inherent trade-off in the design of free allowance allocation provisions between addressing carbon leakage protection and reflecting the carbon price in the product price to encourage down-stream mitigation options: if the activity level requirements are further refined, then this will ultimately turn the approach towards an output based allocation, with the drawback of eliminating incentives for substitution and efficient use of clinker and cement. If activity level requirements are removed, then carbon leakage protection features are eliminated.

Hence, Figure 17 includes two additional options for a further development of the carbon leakage protection measures.

Figure 17: In a very carbon intensive sector like cement additional provisions are required to ensure carbon leakage protection and carbon price in product price: Border Levelling or Inclusion of consumption



Output based free allowance allocation combined with inclusion of consumption under the EU ETS[47]

Output Based Allocation (OBA) avoids the over- or under-allocation as a consequence of the state of the economy. Output based allocation ensures direct costs for allowances to meet the gap between emission performance and benchmark, which creates an incentive for business to improve performance. Output based allocation also avoids the risk of windfall profit or incentives that inhibit asset rationalization. [48]

[47] Approach economically comparable with BTA: Thus recourse should be taken to BTA literature: Cf. Frédéric Branger and Philippe Quirion, Would Border Carbon Adjustments prevent carbon leakage and heavy industry competitiveness losses?, CIRED Working Paper Series; Stéphanie Monjon and Philippe Quirion, Addressing leakage in the EU ETS: Border adjustment or output-based allocation.
[48] Philippe Quirion, "Historic versus output-based allocation of GHG tradable allowances: a comparison", Climate Policy 9 (2009) 575-592.

However, only the marginal carbon cost, i.e. the cost of the CO_2 emission above the benchmark, will be included in product cost and price calculations. Thus, incentives for clinker substitution, consumer choices for composite cement and product substitutes are not incentivized.[49]

To re-establish the full incentives, OBA would need to be complemented with the inclusion of clinker consumption in the EU ETS. This may, for example, involve making firms liable for a charge on the clinker content of their product, as a proxy for the carbon content, because the product is prepared for final sale. Thus, products could be freely traded nationally and internationally and would, like tobacco and liquor, only bear the EU ETS price related charge and therefore include the carbon costs only once they are moved towards consumption.

As a result, the consumption of the European cement would bear the carbon cost. At the same time, lower-carbon clinker substitutes, alternative cements or low-carbon building materials would thus compete on a level playing field with cement. This would be implemented at the domestic level and, as it does not differentiate between domestically produced and imported cement, it would not distort trade. The approach would thus have the economically desired properties.

OBA in combination with inclusion of consumption could be anchored in the EU ETS directive as alternative approach to provide protection for the sectors on the carbon leakage list, thus also ensuring that output based allocation is implemented jointly with the inclusion of consumption.

Since this option relates to a charge on domestic consumption of a product, irrespective of its origin, it is likely to avoid free trade concerns of border related options. However, at this early stage of the proposal many domestic as well as international political and implementation issues remain to be investigated. Of particular concern to the cement sector is whether carbon prices are also reflected in competing products so as to avoid distortions in cross-sector competition.

Moving to full auctioning in combination with border levelling

Another option would be to include the operators and installations for import and possibly export of clinker and cement in the scope of the EU ETS and moving to zero free allocation i.e. full auctioning of allowances.[50]

While this would be the most effective in internalizing the full carbon cost in the production and consumption of clinker, cement and concrete, and would thus maximize the incentive for all emission reduction levers, there remain many aspects and consequences to be thoroughly investigated before coming to conclusions. These

[49] Cement benchmarking could avoid some of these disincentives, but faces in practice various administrative barriers.
[50] Ismer, R. and Neuhoff, K., 2007, Border Tax Adjustments: A feasible way to support stringent emission trading, European Journal of Law and Economics 24, p. 137–164; Monjon, S. and P. Quirion, 2010. How to design a border adjustment for the European Union Emissions Trading System?, Energy Policy, 38(9): 5199-5207.

include the legal, practical and political aspects of the inclusion of importers and exporters in the scope of the Directive, especially the aspects of the implicit or explicit inclusion of the emissions of the clinker and cement producers outside the European territory in the system. It would also be necessary to investigate the ramifications for the competitiveness of those building materials versus other building materials that would not be subject to full auctioning.

5.3. Clarity on future developments

As most mitigation options are linked to efficiency, innovation and investment, early clarity on the procedures post-2020 will be essential to ensure early investment choices. The sunset clauses for carbon leakage protection measures post-2020 and the revision of the list of the carbon leakage exposed sector create a high level of uncertainty for industry. Ironically, no one other than the industry believes that carbon leakage protection measures will not be in place when needed – hence it is important to develop and communicate a clear strategy on carbon leakage protection post-2020.

Improving the medium- and long-term predictability of the EU ETS for the cement industry is an essential requirement to improve the effective inclusion of the carbon price in business decisions. For strategic choices not only the carbon price, but also clarity on the carbon constraint is important. This requires primarily a sector specific outlook as it starts to emerge from sector specific low-carbon roadmaps. However, it is still unclear how mitigation costs variations across energy and carbon intensive sectors will evolve and therefore what contributions different sectors will make to mitigation. The EU ETS has the potential to provide credibility to the overall mitigation target and thus also the low-carbon roadmaps while allowing for flexibility and a clear mechanism for the adjustment of the sector specific low-carbon roadmaps.

Some interview partners suggested that the complexity of the mechanism and associated trading requirements could be reduced if the cement industry were to leave the EU ETS and would instead be covered by a carbon tax. Such a change – apart from the extensive period of uncertainty during the transition and the previously challenges of implementing a tax at European scale – would also eliminate one of the key benefits the EU ETS can offer to coordinate a low-carbon development: credibility of emission reduction targets through a price mechanism that adjusted with target achievement.

Furthermore, most of the complexity of the EU ETS is linked to implementation measures that aim at protecting competitiveness. Also with a carbon tax, protecting competitiveness and preventing carbon leakage would be a legitimate concern. Similar to free allowance allocation, there would be a high political and lobbying pressure from the side of the industry to get exemptions and rebates from the carbon tax with the purpose of preventing carbon leakage. But this would at the same time create complexity in the tax structure and erode the economic incentive and thus emission reductions.

Hence we consider such shift in the European context not to be a viable option.

5.4. Support for innovation

New low-carbon cement types and carbon capture and storage require significant investment in research, development and demonstration. A subsequent large scale adoption of new building practices and materials furthermore requires significant up-front investment to demonstrate viability of new practices and materials. In addition, issues around societal acceptance of such practices will have to be resolved. It is unlikely that this will be unlocked by the ETS alone. Supplementary policies, mechanisms and initiatives will be needed.

Currently, there is only limited engagement of cement companies in such activities which can be explained by three factors. First of all, the low carbon price and uncertainty about its development in the future leads to the lack of confidence that carbon prices will contribute to an increase in cement price. This implies that there is very limited market demand for alternative materials that may lead to lower CO_2 emissions, but are – at least initially – more expensive than traditional cement. Secondly, for substitutions for cement, the cement sector (as well as any other commodity sector) will be reluctant to invest in innovative alternatives that compete with their existing products and thus create competition for their existing production facilities. Finally, successful low-carbon cements will require several years to gradually capture market share. It is unclear to what extent the initial investor will be able to capture the future benefits of the product.

However, beyond the market demand, some interview partners also voiced concern about the existence of suitable low-carbon cement options. It is unclear to what extent this reflects concerns that there will be not one single substitute for all the functions provided by cement or that, in the absence of effective carbon prices, low-carbon cement alternatives are not competitive. A number of low-carbon alternatives to cement are listed in Annex 2.

In addition to marketable innovation, mechanisms like labelling could also contribute to closer consumer engagement and thus create niche-markets for low-carbon cement options. But this would depend on the credibility of labelling approaches and transparent and robust information on the alternative products.

5.5. Adjustments to regulations and building codes

Much of the emissions reduction in the cement sector to date was linked with adjustments to regulation. Co-firing of waste products required new permits, which, together with the supply of suitable waste, resulted from the EU Waste Framework Directive. Also, the reduction of clinker content in cement required adjustments of codes and standards for concrete and buildings in several jurisdictions. Additional use of these options could require for example symmetric rules for the treatment under renewable energy support mechanisms for co-firing of biomass in power and clinker installations and symmetric rules for the inclusion of installations for the incineration of waste (currently excluded from Annex 1 of the Directive).

In addition, further reduction of clinker content in concrete, the use of low-carbon concrete and substitute building materials may require adjustments of codes and standards for concrete and buildings in member states. Investment in innovative techniques and products depends on confidence that such adjustment will be pursued in a timely manner. Hence, an early analysis is necessary to assess whether and what precise adjustments are needed for the exploration and diffusion of further mitigation options.

Beyond the adjustment of regulation to prevent barriers for the use of economically attractive mitigation options, regulation can also help to support the diffusion of economically viable options that are currently not selected due to inertia and other priorities in decision-making processes. Therefore, regulatory approaches would complement effective carbon pricing mechanisms. This has been the prominent motivation for fuel efficiency standards in the automotive sector or codes on thermal efficiency in buildings. Standards and regulation thus helped to facilitate the innovation and deployment of lower-carbon technologies. Equally, regulation on the thermal performance of buildings limits the operational energy use in buildings – and could be complemented with standards to limit the volume of carbon to be embedded in the materials of the building.

Potentially, norms and standards could be even more ambitious and prescribe activities that might not be economically viable – e.g. due to continued challenges for the implementation of an effective carbon price. This could involve requiring a certain thermal performance of a clinker installation or limiting the clinker share that can be used for certain cement applications. This could address the concerns about a limited investment of the industry in efficiency improvement measures due to more attractive investment opportunities in other activities. With regulatory requirements, the investment option would be judged against the future net-revenue streams of an installation that can only be accessed through the "license to operate" obtained with efficiency investments.

Annex I. Interviews

The research team first collected and analysed data from a number of sources such as the WBCSD – CSI Getting the Numbers Right database, the EUTL, Eurostat, UN Comtrade trade flow data and company annual financial reports. The researchers then conducted a series of interviews with executives from cement companies with the purpose to discuss the business decisions processes and the influence of the EU ETS and other policy instruments on the different aspects that influence energy and CO2 intensity, trade flows, competitiveness, investments and innovation on the short, medium and long term.
The interviewers had knowledge of the facts and figures of each subject of the sections 3 and 4 and focused the discussions on the related business considerations of each of those.

The following executives were interviewed in the period July to September 2013:

Heidelberg Cement:	Daniel Gauthier, Chief Executive Officer Heidelberg Cement (Europe and Africa);
Cemex:	Ignacio Madridejos, Madrid, President of Cemex (Northern Europe);
Schwenk:	Gerhard Hirth, Managing Director of Schwenk (Germany);
Holcim:	Lukas Epple, CEO of Holcim (Belgium);
Lafarge:	Christophe Bouf, Director of Strategy;
CRH:	Mossy O'Connor, CEO of CRH (Poland); and
ECRA:	Martin Schneider, CEO of the European Cement Research Academy.

In addition, CO_2 policy and public affairs experts were interviewed:

CO2 policy experts:	Rob Vander Meer, Heidelberg Cement and Vincent Mages, Lafarge.
Public affairs:	Alain Guillen, Lafarge

Wherever this report draws conclusions from the interviews, they are based on a representative majority of the interviews and cannot be attributed to a single interviewee.

Annex II. Inclusion of consumption

Purpose

Emission trading mechanisms have the objective of imposing a liability and thus cost for CO2 emission reductions at the site of emissions, which is then passed through the value chain so as to create economic incentives for emission reduction along the value chain. To address leakage concerns, allowances are allocated for free to emitting installations. The design of free allowance allocation faces a trade-off between providing effective leakage protection and muting the carbon price signal by linkages to output or activity levels. As a result free allowance allocation both distorts the incentive effect of EU ETS for clinker production and reduces or mutes the carbon price signal necessary to encourage mitigation through substitution and effective use of cement. It is therefore argued that free allowance allocation should be more closely linked to production volumes of installations (output based allocation) so as to increase the incentive properties (and clarity) for upstream produces. This would however – on its own - also mute the carbon price signal for down-stream producers. This situation triggered the discussion on whether it would be possible to re-instate the carbon price signal downstream through inclusion of consumption in EU ETS.

The approach 'inclusion of consumption' is based on the idea that consumers should be charged for the carbon embedded in the consumed goods based on a benchmark applied to the clinker content. Thus it complements output based allocation of allowances (based on the same benchmark) and reinstates the full carbon price signal for consumption choices and all the up-stream decisions that are lead by consumer preferences.

Approach

The inclusion of consumption into the EU ETS would extend the application of the EU ETS to carbon embedded in the consumed goods. As the participation of each consumer in the trading scheme would not be feasible, an indirect consumption charge should be levied, which reflects the carbon embedded in the consumed goods. The charge would be payable to national trust funds[51] at the time of the release of the product for consumption within the territory of the European community, irrespective of the origin of the product. A product not released for consumption within the territory of the community but destined for export thus would not bear the levy. The consumption based design as well as the levying of the charge, irrespective of the origin of the product, would assure accordance with world trade rules, as there would be no discrimination[52].

A direct link to the EU ETS would be established by basing the levy on the EU ETS allowance price, applying the same emission benchmark used in EU ETS for free allowance allocation for clinker producers and by using part of the money raised through the levy for the acquisition of allowances. The number of allowances acquired and retired would reflect the carbon embedded in the European Union consumption which is not already covered by allowances

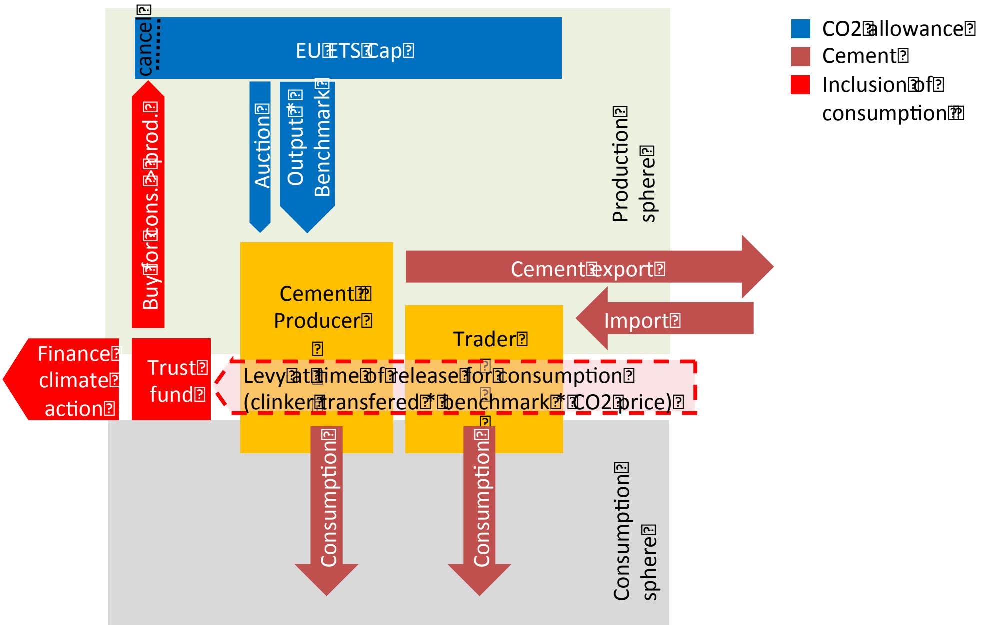
---

[51] A tax can be defined as compulsory, unrequited payment to general government. Taxes are subject to the principle of universality and flow to the national budget. No earmarking is involved. In contrast, the envisaged charge levied is not given to a national budget but to a body governed by public law ("national trust funds"). Additionally, the charge is earmarked and introduced to make the inclusion of consumption into EU ETS feasible.

[52] *Cf.* in particular Art. III (1), (2) GATT.

surrendered by producers. The remainder of the money would have to be used to finance adaptation and mitigation efforts. Thus, the spirit of the EU ETS Directive that envisages that the auction revenue from the EU ETS allowances are to be earmarked (at least 50 %[53]) for such a climate action is re-established even in cases where the primary auction volume is reduced due to the continued output based allowance allocation at the production level.

Figure 18: Inclusion of consumption.



Calculation of the charge

To link the charge with the current carbon price, the levy could be calculated as follows:

$$charge = clinker\ embedded * \ benchmark * \ carbon\ price$$

$$Units:$$
$$Euro = ton\ clinker * ton\ CO2\ per\ ton\ clinker * Euro\ per\ EUA$$

The carbon price should be calculated based on the allowance price on the primary market. Instead of determining the carbon content according to the life cycle carbon footprint of each product, the calculation would be based on the product of clinker embedded and benchmark (product instead of process based approach). This method simplifies the assessment of carbon and lowers the costs of implementations by building on established benchmarks according to Art. 10a (1) DIR 2003/87/EC[54]. A daily adjustment of the carbon price should be avoided on grounds of costs and feasibility. Rather, it seems appropriate to apply an average

[53] *Cf.* Art. 10 (3) DIR 2003/87/EC as amended by DIR 2009/29/EC.
[54] As amended by DIR 2009/29/EC.

carbon price. To reflect the market price at the time of consumption and thus the real value of carbon emissions, it might be a reasonable compromise to use a monthly or quarterly carbon price average.

Consumption sphere

One major challenge is to determine when a product leaves the production sphere and enters the consumption sphere. The more production processes are involved in producing a consumable good, the more difficult the implementation and the more extensive the administration become. However, this problem does not arise in the cement sector, since cement can already be regarded as consumable product and the end consumer can be determined easily. Accordingly, the charge should be levied when cement is sold. If further trade levels were to follow, the last level being exempted from the charge should be the wholesale. This minimizes administrative costs and experiences from the administration of excise duties can be applied, which is based on a similar system. Thus, the charge will be due when cement is i.e. used for construction.

Administration and monitoring

To ensure effective monitoring, a European based record for cement trade flows could be implemented which records trade flows of producers, traders, imports and exports via electronic procedure. A database should be included, providing information to producers and traders about the eligibility of trading partners to dispatch and receive goods without triggering the charge. On the basis of recorded imports and exports, the amount of carbon embedded in international trade can easily be calculated, which is necessary for the readjustment of emission allowances. Necessary electronic administration systems can be based on already established software and experiences in regards to the implementation and administration of excise duties.

On the national level, the mechanism can be built on established administration processes. Thus, the trust funds should be under the control of the national authority, which is responsible for the implementation of the EU ETS according to Art. 18 DIR 2003/87/EC. At this level, it is possible to control the payment of the levy charge and to monitor the respective transactions.

Legal background

A European based implementation requires a legal base established in the Treaties of the European Union[55]. Art. 192 TFEU[56] opens the door for environmental policy measures. Depending on the nature of the measure in question, different legislative procedures are applicable. Whereas Art. 192 (1) TFEU refers to the ordinary legislative procedure, Art. 192 (2) lit. a TFEU demands a unanimous decision by the Council for provisions primarily of fiscal nature, which might not be obtainable. The scope of Art. 192 (2) lit. a TFEU comprises taxes in the narrow sense and charges which are fiscally usable, meaning that the amount payable can easily be adjusted by governments and can be used to cover general expenditures. In contrast, parafiscal charges are covered by Art. 192 (1) TFEU.

---

[55] Art. 4 (1), 5 (1) TEU.
[56] Treaty on the Functioning of the European Union.

This raises the question whether the proposed scheme would be primarily fiscal in nature. In its ATA decision[57], the European Court of Justice ruled that the inclusion of aviation into the EU ETS "is not intended to generate revenue for the public authorities, does not in any way enable the establishment, applying a basis of assessment and a rate defined in advance, of an amount that must be payable [...]" and thus does not give rise to a tax, fee, charge or duty. These findings of the Courts can be generalized and applied to the EU ETS as a whole. Hence, the inclusion of consumption into the EU ETS by itself would be qualified as not being fiscal in nature. Accordingly, it could be based on Art. 192 (1) TFEU.

In our view, this result does not change if consumers, retailers or wholesalers are on grounds of feasibility, not directly included in the EU ETS . This is because the charge payable to the trust funds should not be considered as fiscal in nature. According to settled case-law, the European Court of Justice qualifies a charge as a parafiscal charge which comprises the following features: Earmarking, assigned to a body governed by public law, no inflow to the national budget. This means that the proposed scheme could be based on Art. 192 (1) TFEU instead of Art. 192 (2) lit. a TFEU, the charge would not go to the member states budgets and the charge would only constitute a mechanism to make the scheme 'inclusion of consumption' feasible.

[57] Case C-366/10 *ATA v Secretary of State for Energy and Climate Change* (ECJ, 21 December 2011), para 142ff.

Annex III. Innovative Cement-Based Materials

Although there are some examples of using cement alternatives for certain applications, the existing innovative cement-based products are currently nearly all at either a demonstration or early commercialization stage or at a research and development phase. Each product has its specific benefits, mostly for the pre-targeted application areas, as well as its challenges, mainly caused by the limited availability of the different materials necessary for its production. Accordingly, the replacement and CO_2 emissions saving potentials vary across different innovative cement materials.

In most cases, the purpose is to reduce the CaO content in the product, because it is essentially the calcination of $CaCO_3$ that causes process and fuel CO_2 emissions. Another innovative stream works with $MgCO_3$ based products, in which the reaction producing magnesium oxide (MgO) also releases CO_2 emissions with the additional benefit of the product capturing CO_2 emissions during the stabilization phase after being constructed. In the categorization mentioned below, the different types of cements and concretes were clustered in 5 categories, including products that are worked on by different cement companies. It must be noted that although some of these products have already been developed over a decade ago, they still have not grown out of the demonstration phase and are not used commercially on a wider scale. Some of the products are not worked on anymore.

The standards classify cements by their uses because their chemical composition is usually very complex and in some cases not perfectly known. In a more generic classification, conventional cements can lie into the category of hydraulic (e.g. Portland cement), which are based on a mixture of alumina, silicate and calcium oxides, such as belite, alite and celite, and which react with water to settle and harden. Non-hydraulic cements harden due to the reaction of carbonation in presence of the carbon dioxide present in the air. The objective of innovative cement materials lies in reducing the clinker content.

Limestone based cements

Calcium sulfoaluminate cement

This class of cement can be made at a lower temperature and contains less lime than Portland cement. It could offer CO_2 emissions reductions of 25 to 50% compared to the Ordinary Portland Cement (OPC). However, it is more expensive than OPC and belite-based cements are slower to set.

Aether

Aether™ cement is an alternative production method being developed by Lafarge also based on a raw material recalculation, where calcium oxide content is reduced and substituted by more aluminium and silicon oxides. The composition of the resulting product is a mixture based on belite as a major phase and calcium sulphoaluminate and calcium alumino-ferrite as the two other principal phases. The produced cements are adapted for specific applications rather than general concrete use. Lafarge has tried the Aether™ production in a semi-industrial facility in Poland, in its UK-based BRE semi-dry installation with Lepol kiln and in a dry kiln facility in France. Emissions savings of 25-30% can be achieved, through lower fuel consumption due to the lower temperature, lower process emissions given the lower calcium oxide content and, finally, high savings in the grinding and mixing operations can be potentially obtained due to the excellent Aether™ clinker grinding properties.

Calcium aluminate and calcium alumina silicate cements

These cements are made in a rotary kiln using bauxite instead of the typical calcium silicates. Although these cements reduce CO_2 emissions, they are more expensive and less available as OPC. They are often blended with high concentrations of ground granulated blast furnace slag (GGBFS).

Artifical Pozzolans

The use of artificial pozzolans, produced i.e. by thermal activation of kaolin-clays to obtain metakaolin, allows reducing CO_2 emissions by up to 20% compared to OPC clinker. Its challenge lies in its availability. It could be very expensive due to the extreme shortage of kaolin rich clays.

Celitement

Celitement is calciumhydrosilicate, a material that is produced using the same raw materials as OPC, based on calcium and silicon oxides, but requiring a much lower calcium to silicon ratio. The difference is that instead of a mixture, Celitement contains only one product that adds mechanical strength to concrete, while reducing the amount of energy, emissions and limestone requirements. It includes a third of the lime when compared with OPC and could save up to 50% of the CO_2 emissions in production. Additionally, the unit operations are well known, it has a homogenous composition and is compatible with conventional cement use, and therefore can be mixed with it. The product is developed in the Karlsruhe Institute for Technology (KIT), Germany, and the Celitement GmBH was founded to develop the product and process for commercial use.

Natural Pozzolans

Natural pozzolans have a similar composition to artificial pozzolans but occur naturally. Historically, the volcanoes that Romans and Greeks used to construct the strong buildings that are still erect today were the Vesuvius and volcanoes in the famous island Santorini. Natural pozzolans can replace clinker up to 35%. Nevertheless, its cost depends widely on the region and the availability.

Supersulfated cements

Supersulfated cements contain 80-85% of GGBFS, 10-15% of calcium sulfate and 5% of clinker, and are produced for high sulphate and chemical resistance, but they are expensive given the availability of materials.

Non-limestone based cement

Magnesium-Based Cement

Magnesium cement follows a similar reaction as OPC, with the exception that here calcium carbonate and oxides are substituted by the corresponding magnesium carbonate and oxides. It requires around 30% less energy given the fact that the reaction occurs at a much lower temperature. During the carbonation process it captures atmospheric CO_2 emissions even faster than concrete made from OPC. These sorts of cement develop considerably greater compressive and tension strengths compared to OPC.

CeramiCrete

These materials are 2 to 3 times stronger than the regular concretes. Conversely their costs are 2 to 3 times of cement based concretes. These are created from acid-based reactions and more resistant to the environment

Novacem

Novacem has the properties of CO_2 capture during the stabilization phase in addition to maintaining comparable to cement structural properties. The capture process is a well-known natural procedure called mineral carbonation or mineral sequestration. The process in itself involves the inverse reaction to calcination as the mineral oxide is turned into stable carbonates by the addition of CO_2. The most innovative fact comes in the use of magnesium silicate, which decarbonizes at a much lower temperature, namely 650 °C, than conventional clinker. In the process itself, more than 50% emission reductions can be obtained, while during the construction phase, the process is claimed to capture up to 1 tonne of CO_2 per tonne of cement constructed. The development took place in Imperial College Laboratories, for which an Australian firm has acquired the intellectual property rights.

TecEco

These cements contain magnesia and have the ability to sequester carbon-dioxide from the atmosphere. Additionally, it can also immobilize toxic substances within its structure. However, as they are magnesia based cements, their potential worldwide use is limited due to the insufficient availability of raw material.

Alkali activated cements or geopolymers

Geopolymers are a different class of cements based on pozzolans. Conventional pozzolanic cements require lime to activate the pozzolan, whereas geopolymers make use of sodium hydroxide or sodium silicates. They offer up to 80% lower CO_2 emissions than OPC. An additional beneficial function of the material is that it allows to reach very high strengths for corrosive and very high temperature environments. Nevertheless, geopolymers require high alkalinity to complete its chemical reaction for formation. To maintain high alkalinity, water is not added to its mixture. As a result, the viscosity could be very high which makes it less workable. Availability of pozzolans may be challenging in some regions. World supply of sodium hydroxides or silicates required for this is lacking to meet the demand of this technology. They suffer from the nanoporosity durability flaw.

E-crete

E-crete is an alternative cement based on geopolymeric, well known waste materials, such as pulverized fly ash (PFA) and GGBFS. The properties of the product and availability of the raw materials are under discussion, but the product has already been commercialised in road construction in Australia. Therefore, it might be that only further regulations would need to be developed according to different uses.

Sialite cement

This silica alumina based cement can be produced using the industrial waste, similar to E-crete, but also from waste bricks or tailing. Sialites could reduce CO_2 emission by 30% to 90%. Its raw materials are based in more than 60% on industrial solid wastes.

Calera

The Calera Corporation had a process that emulates marine cement by initially taking calcium and magnesium ion from sea water which, combined with captured CO_2 and SO_2 via a precipitation reaction, produced the desired calcium and magnesium carbonates. The process had clean flue gas as emission, recovers waste materials and the waste water stream from the precipitation is recovered by reverse osmosis and through a specific technology to give back the sodium hydroxide solution to the raw stream. However, the idea of using sea water was abandoned because of resulting acidification of the ocean and the need of enormous volumes of water and thus energy. Subsequently, Calera moved to natural brine solutions, but these are rather (to very) rare. Calera now looks at artificial brine solutions, but they are very costly and energy intensive to produce.

Innovations on concrete-based materials

The most important application of cement is to produce concrete, which is the combination of cement with an aggregate to produce a strong building material. Besides the innovation with regards to cement, there is the innovation with regards to concrete, with the purpose of either using less clinker in concrete (and thus reduce CO_2) or reducing the mass of concrete while achieving similar strength.

Fiber reinforced concretes

The basis of fiber reinforced concretes is that for a similar application they require less material than conventional concretes due to adding specific fibers that help strengthening the final material for the specific use.

Ductal

Ductal is an example of materials that offer enhanced tensile strength based on the addition of different types of fibers, such as steel, glass, synthetic and natural type of fibers to the concrete mix. This solution reduces the consumption of clinker in the concrete mix for targeted applications. Bridges are the potential application area of the material, especially for substituting the use of steel for bridge applications. Consequently, the CO_2 emissions are reduced by nearly 60%.

Carbon Concrete

This sort of concrete is based on adding carbon fiber to the concrete structure already in place or to the mix to improve the mechanical strength. It offers strength close to that of traditional concrete and additionally requires less material compared to similar applications where concrete is used. It may be suitable for heavy industrial roads and saltwater applications.

Carbon Cure

This technology aims at accelerating and strengthening concrete curing (i.e. hardening) by re-carbonating parts of the CaO in the cement or concrete under a CO_2 enriched atmosphere in autoclaves, thus "sequestering" CO_2 in concrete. This technology is thought to be only applicable for concrete products (that can be made in autoclaves, thus not for structures) that contain no steel reinforcement as the CO_2 absorption decreases the alkalinity (pH).

Many of these products have been on the market for more than 15 years (such as Geopolymers and Ductal) but have had difficulties in penetrating the market. Currently, research on cement and concrete materials is carried out both by independent and public organizations and within the companies themselves.

Climate Strategies is a leading independent, international research organisation based in the UK. Through our network of global experts, we assist governments and industrial stakeholders around the world in developing climate change and energy policies. We are a not-for-profit organisation with all our activities funded through a broad spectrum of governments, businesses and foundations.

Companies House Number 05796323.

Climate Strategies

www.climatestrategies.org