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Reaping the carbon rent: abatement and overallocation profits in the European cement industry, insights from an LMDI decomposition analysis

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Abstract

We analyse variations of carbon emissions in the European cement industry from 1990 to 2011, at the European level (EU 27), and at the national level for six major producers (Germany, France, Spain, United Kingdom, Italy and Poland). We apply a Log-Mean Divisia Index (LMDI) method, crossing data from three databases: the Getting the Numbers Right (GNR) database developed by the Cement Sustainability Initiative, the European Union Transaction Log (EUTL), and the Eurostat International Trade database.

Our decomposition method allows disentangling seven channels of emissions change: activity, clinker trade, clinker share, alternative fuels, thermal and electric energy efficiency, and electricity decarbonisation. We find that, apart from a slow trend of emissions reductions coming from technological improvements (first from a decrease in the clinker share, then from an increase in alternative fuels), most of the emissions changes can be attributed to the activity effect.

Using counterfactual scenarios, we estimate that the introduction of the EU ETS brought small but positive technological abatement (2.0% ± 1.1% between 2005 and 2011). Moreover, we find that the European cement industry have gained 3.5 billion euros of "overallocation profits", mostly due to the slowdown of production.

Based on these findings, we advocate for output-based allocations, based on a stringent hybrid clinker and cement benchmarking.

Key-words

Cement Industry, LMDI, EU ETS, Abatement, Overallocation, Windfall Profits, Overallocation Profits, Carbon Emissions, Energy Efficiency

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1. Introduction

Cement is the most used man-made material in the world (Moya et al., 2010), and also one of the most carbon-intensive products. The manufacture of cement accounts for approximately 5% of world's anthropic emissions (IEA, 2009). China has the lion's share of cement production with 58% of the 3,700 million tons produced in 2012. The European Union is now the third producer with 5% of world's production, behind India with 7% (U.S. Geological Survey, 2013).

European cement emissions have been covered since 2005 by the European Union Emission Trading Scheme (EU ETS), presented as Europe's flagship policy to tackle climate change (Branger et al., 2013a). In this cap-and-trade system, installations can buy or sell tradable allowances to fulfil emissions caps. A key feature of the EU ETS, whether allowances should be auctioned or received free of charge (and in the latter case, what should be the allocation plan, or the amount of allowances per installation), has been a very controversial topic (Boemare and Quirion, 2002; Ellerman and Buchner, 2007). While most of the economists favoured auctioning, the European Union opted for an almost fully free allocation for all sectors (industry and power sector) during phase I (2005-2007) and phase II (2008-2012); and maintained free allocations in phase III (2013-2020) fully for sectors "deemed to be exposed to carbon leakage" and partly for the rest of manufacturing industry (European Commission, 2009).

Indeed, the main argument used to justify free allocation has been the preservation of the competitiveness of heavy industries and the prevention of carbon leakage, which is a shift of emissions from carbon-constraint countries to less carbon-constrained countries induced by asymmetric carbon pricing (Dröge, 2009). However, economic theory suggests that free allocation, if independent from current production, is inefficient to prevent leakage in the short term and would only give a disincentive to plant relocation (Wooders et al., 2009). In other words, in the short run free allocations would compensate firms for profitability losses without addressing market share losses and carbon leakage (Cook, 2011).

In addition to generous allocation caps, the economic downturn after 2008 led to a decrease in industrial production, which generated an important surplus of allowances in the market. These financial assets have mainly been held by cement and steel companies, as electricity demand is much less impacted by the economic downturn.

Instead of suffering from financial losses, energy-intensive industries seem to have thrived from the scheme. Sandbag, a non-governmental organization, has estimated that the ten "carbon fat cats" have reaped billions of euros in windfall profits (Pearson, 2010). However, their analysis, based on the European Union Transaction Log (EUTL) data, rests upon equivalence between allowances surplus and overallocation, without considering that some allowances are obtained by reducing the carbon content of industrial products (Ellerman and Buchner, 2008). Indeed, apart from financial outcomes, an important question remains: whether the EU ETS fulfilled its original purpose which is triggering a transition toward a low-carbon industry.

Studies assessing abatement in the manufacturing industry come to mixed results (Neuhoff et al., 2014). Zachman et al. (2011) find a significant reduction in carbon intensity for basic metals (whose emissions occur mostly in the steel sector) and non-metallic minerals (whose emissions occur mostly in the cement sector) between 2007 and 2008 compared to 2005-2006. Yet Kettner et al. (2013) find very limited reduction in carbon intensity in the cement and lime sector, and attribute most of it to an increase in clinker imports[1] – which implies carbon leakage. Moreover Egenhofer et al. (2011) find almost no decrease in manufacturing industry's carbon intensity in 2008, which seems to contradict Zachman et al. (2011) results.

In this paper, we propose to disentangle the questions of abatement and overallocation in the European cement industry, exploiting EUTL data, Eurostat international trade data, and the detailed and comprehensive Getting the Numbers Right (GNR) database from the Cement Sustainability Initiative (CSI). We perform an LMDI (Log Mean Divisia Index) decomposition (Ang, 2004) of emissions due to cement production in Europe. We can measure the impact of seven effects on emissions variations, which correspond to different mitigation levers: activity, clinker trade, clinker share, alternative fuel use, thermal and electric energy efficiency, and decarbonisation of electricity. This analysis allows us to identify the key drivers behind changes in aggregated carbon emissions, in the EU 27 as a whole and in the six major European producers: Germany, France, Spain, UK, Italy and Poland.

A distinction can be made between the first two effects (activity and clinker trade) that generate non-technological abatement and the others that generate technological abatement. Making assumptions on counterfactual scenarios, we estimate the technological abatement induced by the EU ETS and decompose its main factors. Further, our emissions decomposition model allows us to disentangle in the allowances surplus (allocations minus emissions) what is due to technological performance and what is due to a change in activity or clinker outsourcing. We are then able to compute overallocation and "overallocation profits".

We find that the EU ETS has induced a small but positive abatement of 21 Mtons of CO_2 ($\pm$12 Mtons) from 2005 to 2011 (corresponding to a 2.0% $\pm$ 1.1% decrease), mostly thanks to the reduction in the clinker-to-cement ratio. However we cannot rule out another explanation, i.e. the massive increase in steam coal and petcoke prices in the 2000s (Cembureau, 2012). This aggregate figure hides important differences at national levels. Whereas technological abatement has been important in the UK (-12% $\pm$ 3%) and Germany (-5% $\pm$ 2%), it has been insignificant or negative in France, Spain, Italy and Poland. In addition, we assess that the European cement industry has reaped 3.5 billion euro of overallocation profits during phases I and II. Most of these profits come from the economic downturn that has reduced the demand for cement and then cement production, which in turn generated a massive surplus of allowances.

[1] Clinker is the CO2-intensive intermediate product required to produce cement.

The rest of the article is structured as follows. Section 2 details the cement manufacture process and the mitigation options. Section 3 explains the emissions decomposition methodology. Section 4 applies this decomposition to the evolution of emissions in the European cement industry from 1990 to 2011. Section 5 is an assessment of technological abatement induced by the EU ETS and overallocation profits. Section 6 concludes.

2. Mitigation options in the cement industry

2.1. Cement manufacture at a glance

Cement manufacture can be divided into two main steps: clinker manufacture, and blending and grinding clinker with other material to produce cement.

Clinker is produced by the calcination of limestone in a rotating kiln at 1450 degrees Celsius. Carbon dioxide is emitted in two ways. First, the chemical reaction releases carbon dioxide (ca. 538 $kgCO_2$/ton of clinker[2]) which accounts for roughly two thirds of carbon emissions in clinker manufacturing. The other part comes from the burning of fossil fuel to heat the kiln, mostly the cheapest ones, petcoke and coal (costs preclude the use of gas and oil, except in some locations where they are very cheap, hence not in the EU).

Raw material preparation, kiln functioning, blending and grinding consume electricity which causes indirect emissions. Yet nearly all carbon emissions (around 95%) in cement manufacture come from direct emissions in clinker manufacturing.

To reduce emissions from cement production[3], various options are then available:

- (i) *Reduction of cement production*, which may be due to a lower activity in construction, to leaner structures or to the substitution of cement by alternative material.

- (ii) *Clinker substitution.* Since clinker manufacture is the most carbon intensive part of cement manufacture, partially substituting clinker with some other material is an efficient way to reduce emissions per ton of cement produced. The most common type of cement, ordinary Portland cement, is produced mixing 95% of clinker and 5% of gypsum, but the clinker-to-cement ratio is lowered in blended cements.

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[2] The process CO_2 emission factor is generally considered as a fixed factor. However it is slightly variable mainly because of the ratio of calcium carbonate and magnesium carbonate in the limestone. When process emissions are actually measured, a narrow peak in the distribution can be observed at 538 $kgCO_2$/ton of clinker (Ecofys et al. (2009) Figure 2). However, the factor used in the EU ETS Monitoring and Reporting of Greenhouse gas emissions (MRG) is only 523 $kgCO_2$/ton of clinker, derived from IPCC methodology.

[3] If we consider cement *consumption* and not cement *production*, another option can be added: cement outsourcing. We did the same analysis for cement consumption with a more complicated decomposition adding cement trade. As the results barely changed (the cement trade effect represented less than 3 Mtons of CO_2 or 2% of emissions), we only kept the cement production analysis for simplicity.

- (iii) *Clinker outsourcing.* This is a way to reduce emissions in a given geographical perimeter, but emissions occur elsewhere, which causes carbon leakage.
- (iv) *Alternative fuel use*, which releases less CO_2 for the same calorific energy produced.
- (v) *Energy efficiency*, which can be divided in two parts, *thermal* energy efficiency and *electric* energy efficiency.
- (vi) *Decarbonisation of the electricity*
- (vii) *Carbon capture and storage*
- (viii) *Innovative cements*, or carbon neutral cements based on totally different processes.

The next section details these options, which do not have the same status. Lever (i) is driven by cement demand and is not a direct choice of cement companies. Levers (ii) to (v) are operational options used by cement companies (though lever (iii) does not reduce global emissions, it can be a rational choice for a company covered by an emissions trading scheme). Lever (vi) is beyond the reach of cement producers, and depends on electricity producers (which have an incentive to use it when there is a price on carbon). Abatement due to levers (i) to (vi) will be empirically assessed in this study. Levers (vii) and (viii) are in the research and development stage. Though promising, no abatement has been made using these options.

The challenge of a non-global climate policy is to induce all these options (except (iii)) without generating clinker or cement imports, which would generate carbon leakage.

2.2. Data sources

The work of this paper is based on the crossing of three databases:

- the *Getting the Numbers Right* (GNR) database (WBCSD, 2009) developed by the Cement Sustainability Initiative (CSI), operating under the World Business Council on Sustainable Development (WBCSD).
- the *European Union Transaction Log* (EUTL) which is the registry of the EU ETS, and provides allocations and verified emissions at the installation level.
- the *Eurostat* international trade database[4] for clinker trade.

[4] http://epp.eurostat.ec.europa.eu/newxtweb/setupdimselection.do, EU Trade since 1988 by HS2, 4, 6 and CN8 dataset (extracted in February 2014). The code for clinker is 252310 ("cement clinkers")

The GNR database covered 96% of the European cement production in 2011 (only minor producers with small production volumes are not included), which is remarkably high. Data are available[5] for 1990, 2000, and 2005 to 2011. Data can be obtained at the EU 28 level and at the national level for big producers (so we use data for Germany, France, Spain, the UK, Italy and Poland). Though the GNR database contains data on production and emissions, we use this database for its intensity (i.e. rate-based) indicators in the cement industry, for coverage and methodological issues (see part 3.1). A performance indicator not included in GNR, the electricity emission factor, comes from the Enerdata database[6].

The cement sector is a subsector of the cement/lime EUTL sector (47% of installations and 90% of allocations). We have collected one by one information on 271 cement plants with kilns. Some characteristics of our cement EUTL database, which are in line with Table 1.2 in European Commission (2010) and Table 4 in Moya et al. (2010)[7], are given in Table 1. The match between EUTL emissions and GNR gross direct emissions is good but not perfect[8]. In addition, we use Sandbag database[9] for offset credits utilization at the installation level.

Whereas total imports and exports are directly available in the Eurostat international trade database at the EU 27 level, they have to be computed from country-pairs raw data at the national level. Also, some corrections needed to be made to take into account the changing geographical perimeter of the EU ETS. Because of lack of data, we used the Comtrade database[10] for net imports in Norway, Iceland, and the EU 27 before 1999.

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[5] In March 2014

[6] http://www.enerdata.net/enerdatauk/knowledge/subscriptions/database/energy-market-data-and-co2-emissions-data.php

[7] Their list contains 268 installations in 2006 at the EU 27 level (Norway has two cement plants). There are some discrepancies in France (33 in instead of 30 for us), Germany (38 instead of 47), Italy (59 instead of 52), Romania (8 instead of 7) and Slovakia (6 instead of 4). We checked in the Cemnet database (http://www.cemnet.com/GCR/), but the plants not in our list were either grinding stations and/or not found in the EUTL (based on their location). Also, there could be some grinding plants in Germany in our EUTL database among the small emitters installations.

[8] GNR emissions are higher in the United Kingdom , Germany, Poland, and France (5%, 4%, 3% and 1% on average respectively) whereas they are lower in Spain, Italy and at the EU 27 level (4%, 6% and 1% respectively). Besides data-capture errors, differences in emissions can occur for different reasons. First, there is a mismatch in installations covered. GNR contains more plants because it includes grinding or blending plants, but some plants with kilns are not covered (the number of plants with kilns used to make distribution statistics on clinker are respectively 232, 33, 28, 33, 12, 50 and 10 for year 2011 in the EU 28, Germany, France, Spain, Italy, the UK and Poland), so emissions at the national level have to be extrapolated. Second, accounting methodologies are different. Process emissions are measured in GNR (there is a peak in the distribution at 538 $kgCO_2$/tClinker see figure 2 in (Ecofys et al., 2009)) whereas a default factor derived from IPCC methodology of 523 $kgCO_2$/tClinker is used in the EU ETS. Non-kiln fuels are not reported in some countries for the EU ETS but are (partially) in GNR. The carbon content of alternative fuels is also accounted differently: for waste fuels composed of both biomass and fossil carbon (e.g. tires), GNR reports all CO_2 emissions while EUTL reports only fossil emissions.

[9] http://www.sandbag.org.uk/data/

[10] https://wits.worldbank.org/WITS/WITS/Restricted/Login.aspx

Table 1: Cement EUTL database. Country level (Sandbag database used for offset credits)

	Number of plants		Annual Allocation ($MtonsCO_2$/year)		Annual Emissions ($MtonsCO_2$/year)		Offset credits used	
Region	Phase I	Phase II	Phase I	Phase II	Phase I	Phase II	Total	% cap
EU ETS	255	263	158.9	179.0	154.4	131.6	88.7	9.9%
Germany	47	40	23.5	21.0	20.9	19.6	22.2	21.1%
France	30	30	14.1	15.3	14.3	12.5	10.1	13.3%
Spain	36	37	28.0	29.7	27.3	18.1	10.9	7.4%
United Kingdom	13	15	5.6	10.1	5.7	6.3	3.3	6.7%
Italy	52	54	26.2	28.0	27.8	21.1	10.0	7.2%
Poland	11	11	10.8	11.0	9.7	10.0	4.6	8.4%
Subtotal	189	187	108.2	115.0	105.8	87.5	61.2	10.6%
	74%	71%	68%	64%	69%	66%	69%	
Austria	9	9	2.8	2.7	3.0	2.6	1.2	9.2%
Greece	8	8	11.1	10.8	10.7	6.6	3.3	6.2%
Romania	7	7	2.3	9.3	2.2	5.1	4.3	9.3%
Czech Republic	6	5	3.0	2.8	2.9	2.5	1.4	10.0%
Portugal	6	6	6.8	6.7	6.6	5.1	3.3	10.0%
Belgium	5	5	5.5	5.0	5.0	4.3	1.0	4.0%
Bulgaria		5		3.6		1.9	2.1	11.5%
Hungary	4	5	2.4	2.2	2.1	1.4	0.9	8.4%
Ireland	4	4	3.6	4.0	3.8	2.1	2.2	11.0%
Slovakia	4	4	2.3	2.7	2.2	1.9	0.9	6.7%
Sweden	3	3	2.2	2.5	2.2	2.2	1.2	9.3%
Cyprus		2		1.7		0.9	0.8	9.3%
Finland	2	2	1.1	1.3	1.0	0.8	0.5	8.0%
Netherlands	1	1	0.8	0.7	0.6	0.5	0.3	8.8%
Slovenia	2	2	0.8	0.7	0.8	0.6	0.4	12.1%
Denmark	1	1	2.8	2.6	2.7	1.7	0.8	6.5%
Estonia	1	1	0.9	0.8	0.9	0.8	0.2	4.1%
Latvia	1	2	0.3	0.9	0.3	0.6	0.4	8.9%
Lithuania	1	1	1.1	1.0	1.0	0.7	1.0	20.0%
Luxembourg	1	1	0.8	0.7	0.7	0.6	0.4	10.0%
Norway		2		1.3		1.2	0.8	12.7%

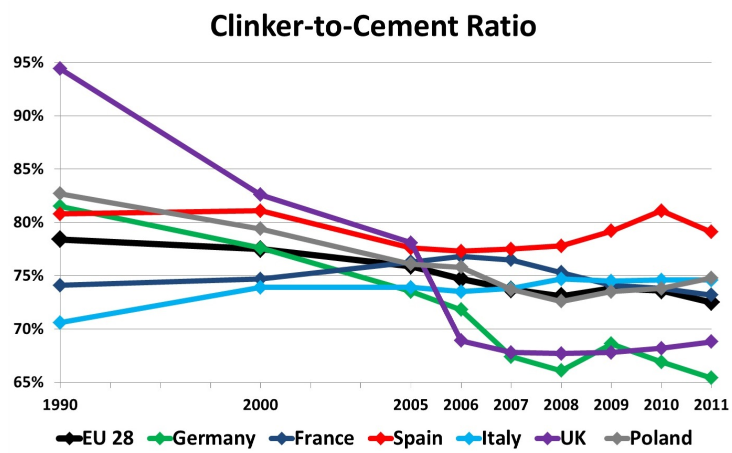


Figure 1: Clinker-to-cement ratio for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 3213

2.3. Clinker substitution

Reducing the clinker-to-cement ratio is a very efficient abating option since most of the carbon emissions are produced during clinker manufacturing. The most used clinker-substituting materials are fly ash (a residue from the coal-fired power stations), ground blast furnace slag (a by-product of the steel industry), pozzolanas (a volcanic ash) and limestone. Blast furnace cement offers the highest potential for clinker reduction with a clinker-to-cement ratio of 5-64%, compared to pozzolanic cement (45-89%) and fly ash cement (65-94%) (Moya et al., 2010).

Two barriers are impeding the deployment of blended cements. The first one is the regional availability of the clinker substitutes, or their price (since these products are bulky, transportation costs are important). The phasing out of coal-fired plants triggered by climate policy will make fly ash scarcer. Ground blast depends on iron and steel production, and pozzolanas are present only in certain volcanic regions (mainly Italy). Second, the physical properties of these alternative cements such as strength, colour and workability, and their acceptance by construction contractors, constitute another barrier to their implementation (IEA, 2009).

Figure 1 displays the clinker-to-cement ratio in 1990, 2000 and from 2005 to 2011 for the European Union (with 28 member states) and the six biggest cement producers in Europe: Germany, France, Spain, Italy, United Kingdom and Poland. The average EU 28 clinker-to-cement ratio has decreased from 78% in 1990 to 73% in 2011. The UK is the country for which the clinker-to-cement ratio has decreased the most dramatically, from 95% in 1990 to 68% in 2007 and stabilizing afterwards. Germany was in 2011 the country with the lowest clinker-to-cement ratio, 65%, and Spain the country with the highest, 79%.

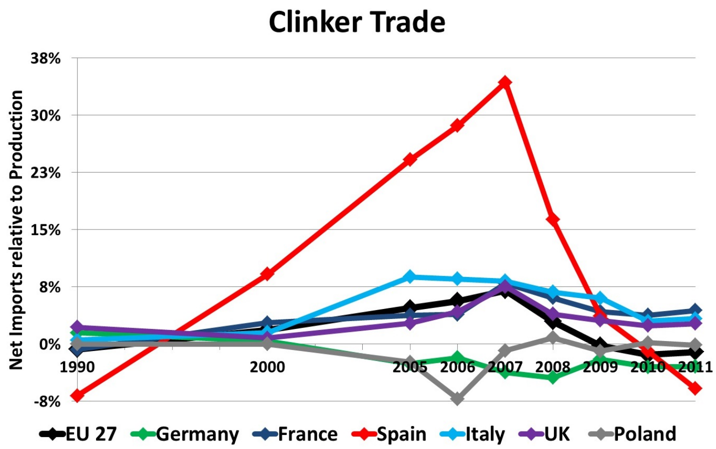


Figure 2: Net imports (imports minus exports) of clinker relative to local clinker production. Sources: Eurostat for net imports, EUTL and WBCSD GNR Database for production

2.4. Clinker outsourcing

Clinker outsourcing is a drastic method to reduce carbon emissions in a given geographical perimeter, but it does not in general reduce emissions on a global scale (carbon intensity is approximately the same in Europe and abroad and this adds emissions due to transportation). The increase in emissions abroad due to a regional climate policy is called carbon leakage (Reinaud, 2008). In the EU ETS, free allocation of allowances was presented as a way to mitigate the risk of leakage.

The purpose of this paper is to assess the actual emissions reductions in the cement industry, and not to provide a technology roadmap. Therefore it is not because clinker outsourcing is an undesirable option that it should not be considered in this framework. Under the EU ETS, it can be profitable since, provided a certain activity is maintained, the operator of an installation keeps receiving free allowances that can be sold on the market. However, logistics difficulties, high transportation costs and export barriers make clinker outsourcing less appealing than it appears. Clinker trade primarily occurs in case of over- or under-capacities (Cook, 2011) and represent only 6-7% of global production. The role of geography is an important consideration. High road transport costs exclude inland producers from international trade (Ponssard and Walker, 2008).

Figure 2 shows the clinker net imports (imports minus exports) divided by clinker production. The EU 27 switched from clinker importer to clinker exporter in 2009. We can see that clinker is a poorly traded commodity: since 1990 net extra-EU27 imports or exports have never been bigger than 5% of its production. Imports came from Asia (China and Thailand mostly) and the East Mediterranean region especially between 2001 and 2005 (mainly Turkey

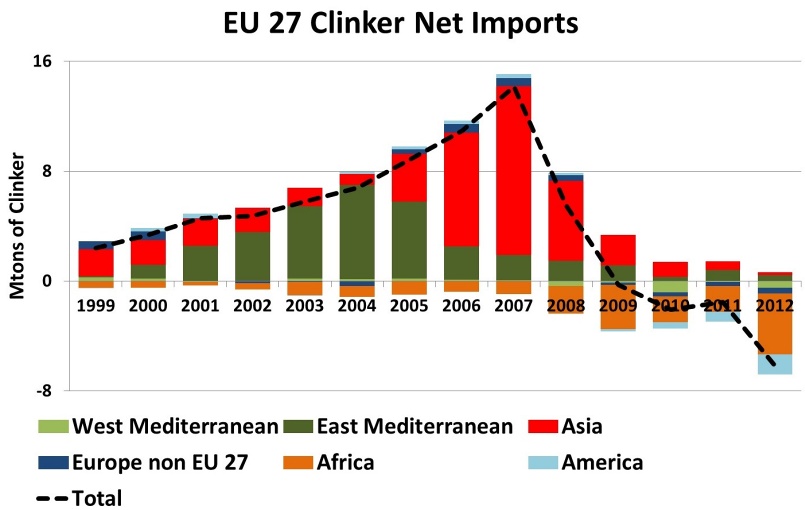


Figure 3: Origin of the EU 27 net imports. West Mediterranean comprises Morocco, Algeria, Tunisia and Libya. Source: Eurostat

and Egypt), and European clinker since 2010 have mainly been exported to the Gulf of Guinea and Brazil (see Figure 3). The European country with the most remarkable trajectory is Spain, which turned to be a clinker exporter after being a massive importer (up to 34% of its production in 2007, the second biggest net importer being Italy in 2005 with 9%). This swing can be explained by the boom and burst of the construction bubble.

2.5. Alternative fuel use

Conventional fossil fuel used in clinker manufacturing, coal and petcoke, have a high carbon intensity. Replacing these fuels by alternative, less carbon intensive fuels generates abatement. The share of alternative fuel in thermal energy has increased steadily in the European Union. Fossil and mixed wastes[11], which are generally less carbon-intensive than coal or petcoke, represented 2.29% of thermal energy in 1990, 11.2% in 2005 and 25.6% in 2011. Biomass represented[12] 0.14% of thermal energy in 1990, 3.57% in 2005 and 8.65% in 2011. Most cement companies receive a fee for the burning of waste as part of a waste management strategy to reduce incineration and landfilling; so using alternative fuel may be financially interesting regardless of the carbon price.

The carbon intensity of the fuel mix (visible in Figure 4) has decreased from

[11]Mostly mixed industrial waste, plastics and tyres in 2011 (respectively 29.1%, 29% and 19.1%)

[12]Mostly animal meal and dried sewage sludge (respectively 45.4% and 16.6%)

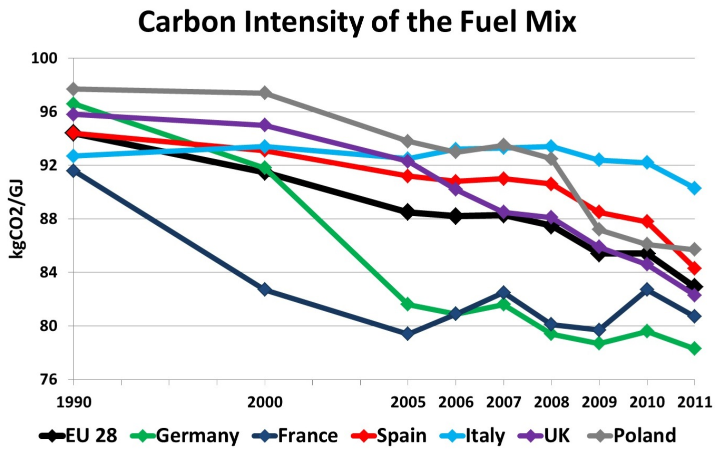


Figure 4: Carbon intensity of the fuel mix (in $kgCO_2/GJ$) for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 3221

94 $kgCO_2/GJ$ in 1990[13] to 82$kgCO_2/GJ$ in 2011. The country with the lowest carbon intensity of the fuel mix in 2011 is Germany, and Italy is the country with the highest (78 $kgCO_2/GJ$ for Germany in 2011 compared to 90 $kgCO_2/GJ$ for Italy).

Much higher substitution rates are possible than the actual mix but several factors limit the potential of alternative fuel use. First, the calorific value of most organic material is relatively low, and treatment of side products (such as chlorine) is sometimes needed (European Commission, 2010). Second, the availability of waste is dependent on the local waste legislation and collection network as well as the industrial activity nearby (IEA, 2009). Third, a higher CO_2 price may increase the global demand for biomass, for which cement companies compete with heat and electricity producers. This would increase its price and make it less appealing as a fuel substitute for the cement industry. Finally, social acceptance is of huge relevance as incineration is often viewed with great suspicion by surrounding inhabitants.

2.6. Thermal and electric energy efficiency

Cement manufacture requires both thermal energy for heating the clinker kiln and electric energy (about 10% of total energy needed) mostly for kiln functioning, grinding (preparing raw materials) and blending (mixing clinker with additives). The proportion of total electric energy used for these steps are respectively 25%, 33% and 30% according to Schneider et al. (2011).

[13]For this value only, we took the average of European country values weighted by their cement production. Indeed, the original GNR value (91.1 $kgCO_2/GJ$) was lower than all values corresponding to individual European countries .

New kilns using raw material as a powder (dry production route) are much more energy efficient than old kilns using raw material as a slurry (wet production route) since less heat is needed to dry the raw material[14] (3-4 GJ/tClinker instead of 5-6 GJ/tClinker in European Commission (2010)). In modern kilns, part of the heat of the exhausting gases of the kiln is recovered to pre-heat the raw material (pre-heaters) (Pardo et al., 2011). State-of-the art technology is the dry process kiln with pre-heating and pre-calcining, which requires approximately 3 GJ/tClinker and stands for 44% of the European clinker production (contrary to 23% in 1990[15]).

In addition to kiln technology, kiln capacity also influences energy efficiency. Bigger kilns have lower heat losses per unit of clinker produced and are therefore more energy-efficient. Finally, for a given installation, the way the machinery is operated (minimizing kiln stops and operating near the nominal capacity) can make a significant difference (about 0.15-0.3 GJ/tClinker according to Hoenig and Twigg (2009)).

Cement producers benefit directly from energy efficiency through lower energy costs, which represent roughly a third of production costs (Bolscher et al., 2013; Pardo et al., 2011). Generally new manufacture plants are equipped with best available technology, but the upgrading of old facilities is a slow process. Moya et al. (2011) find that the observed rate of retrofitting in the cement industry is much lower than the one derived from the number of feasible improvements with low payback periods, revealing an "energy efficiency gap" (Jaffe and Stavins, 1994) or "energy efficiency paradox" (deCanio, 1998).

Figures 5 and 6 show the thermal energy intensity and the electric energy intensity, respectively in GJ/ton of clinker and in kWh/ton of cement. The thermal energy intensity in the EU 28 decreased from 4.1 GJ/tClinker in 1990 to 3.7 GJ/tClinker in 2005 then stabilized. The electric energy intensity in the EU 28, after decreasing from 113 kWh/ton of cement in 1990 to 108 kWh/ton of cement increased up to 114 kWh/ton of cement. The most noticeable change comes from Spain which average electricity intensity soared from 99 kWh/ton of cement in 2005 to 134kWh/ton of cement, probably due to the decrease in production which led to the use of machineries well below nominal capacities.

No breakthrough technologies allowing decreasing significantly the kiln energy consumption are in sight (European Commission, 2010), so the potential for abatement is narrow. In addition, the other abatement drivers can be negatively correlated to energy efficiency. Clinker substitutes generally require more energy for grinding, and alternative fuels may have less calorific power or may need more energy to treat by-products. Moreover, higher environmental requirements (dust and gases treatment), increased cement performance (necessitating finer grinding) and kiln improvements such as pre-heaters and pre-calciners have induced higher power consumption (Hoenig and Twigg, 2009). These reasons

[14] It is common in the literature to distinguish four routes for cement manufacture: dry, semi-dry, semi-wet and wet (GNR)

[15] Source: GNR database

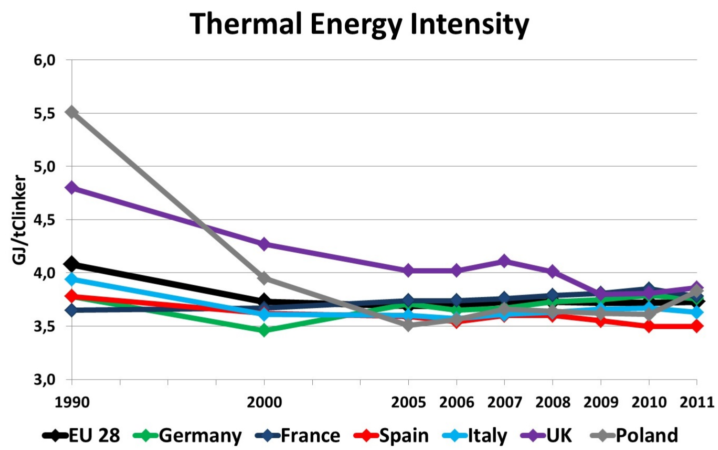


Figure 5: Thermal energy intensity in GJ/tClinker for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 329

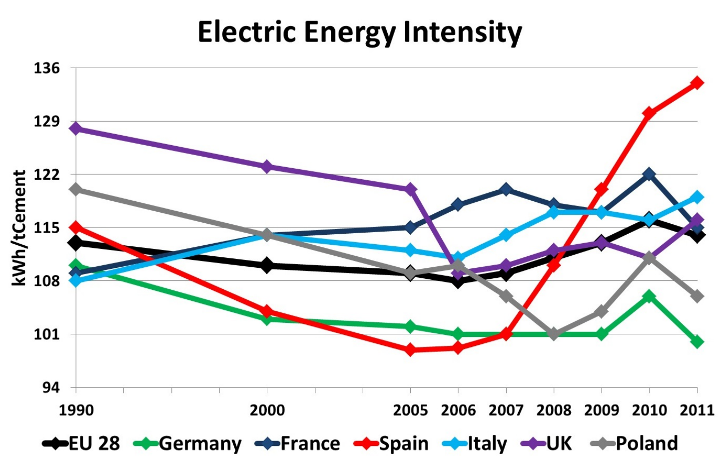


Figure 6: Electric energy intensity in kWh/tCement for the EU 28 and main European countries. Source: WBCSD GNR Database, variable 3212

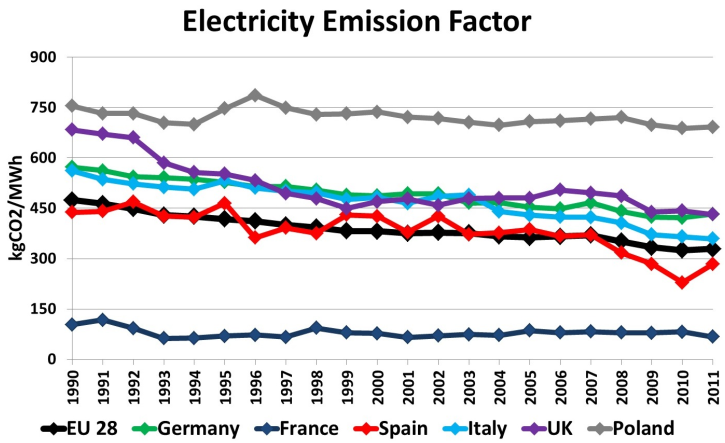


Figure 7: Electricity emission factor (in $kgCO_2/MWh$) for the EU 27 and main European countries. Source: Enerdata database

could explain why the energy efficiency has stabilized or deteriorated in the recent years.

2.7. Decarbonisation of electricity

For simplicity in this study we consider that all the electricity consumed comes from the grid[16]. In this context, this mitigation option does not depend on the cement industry but on electricity producers. Indirect electricity emissions represent around 6% of total emissions in the cement industry. Under the EU ETS framework, these emissions are attributed to electricity producers and not to cement manufacturers. Cement companies do not receive allowances for these emissions and neither do they have to surrender allowances for them. However, they may face indirect costs through the rise in electricity price due to the passing-through of allowance price. Though small, this abatement option has still the potential to decrease total emissions of the cement industry.

Figure 7 shows the evolution of the electricity emissions factor (in $kgCO_2/MWh$). It has globally decreased in all European countries, and the EU 27 average dropped from 474 $kgCO_2/MWh$ in 1990 to 359 kg CO_2/MWh. In 2011, the country with the highest electricity emissions factor was Poland with 700 $kgCO_2/MWh$ (because of the predominance of coal power) and the country with the lowest was France with 67 $kgCO_2/MWh$ (because of the high share of nuclear and hydro power).

[16]The number of plants recovering heat for power generation is unknown (Matthes et al., 2008). Self-generation of power is more frequent in countries where electricity supply is not reliable.

2.8. Carbon capture and storage

Most of carbon emissions of cement manufacturing are process emissions due to the chemical reaction during limestone calcination. The only way to avoid these emissions (apart from alternative cements based on different chemical processes) would be carbon capture and storage (CCS) using post-combustion technologies. Emissions due to fossil fuel burning could also be managed with CCS technologies. A promising option in this direction is oxyfuel technology where air is replaced by oxygen in cement kilns to produce a pure CO_2 stream easier to handle (Barker et al., 2009; Li et al., 2013).

R&D in CCS is active but these potentially promising technologies are far from being operational at the industrial scale (Moya et al., 2010). A high carbon price (estimations vary but an order of magnitude is 50€/tonCO_2) would be necessary to trigger investments towards this medium-term option. Further, CCS technologies are energy-intensive and would increase power consumption significantly (by 50% to 120% on plant level according to Hoenig and Twigg (2009)). Finally, their large-scale development would necessitate a full chain of CCS framework, including transport infrastructure, access to storage sites, legal framework on CO_2 transportation, monitoring and verification, and therefore political and societal acceptance (IEA, 2009).

2.9. Innovative cements

Several low-carbon or even carbon-negative cements are at the R&D development stage, such as Novacem (based on magnesium silicates rather than limestone), Calera or Geopolymer (Schneider et al., 2011). Providing they prove their economic viability and gain customer acceptance (which is extremely challenging in itself), replacing existing facilities would require extensive time and investments.

2.10. Cement substitution in construction

This option, aimed at reducing the overall quantity of cement produced, depends on architects and construction companies. Like decarbonisation of electricity, it depends on other stakeholders. Whereas cement companies are indifferent to the carbon content of electricity (for a given electricity price), a reduction of cement used in construction is at first sight against the interest of the cement industry.

Reducing cement in construction would be possible through alternative material and/or leaner structures. Wood would be the most natural alternative construction material alternative for cement, provided its availability on a large scale would be assured.

3. Methodology

3.1. Decomposition of carbon emissions due to cement production

In the rest of this section, C stands for emissions, Q for quantities and E for energy consumption. The definition of all the variables used can be found in Table 2.

Table 2: Definition of variables

Variable	Definition	Unit
t	Year. All variables (except CEF_{pro}) are yearly	
C_t	Total carbon emissions in the cement manufacture process	$MtonCO_2$
$C_{EUTL,t}$	Direct carbon emissions in the cement manufacture process	$MtonCO_2$
$C_{F,t}$	Fuel-related emissions	$MtonCO_2$
$C_{P,t}$	Process emissions	$MtonCO_2$
$C_{E,t}$	Indirect carbon emissions due to electricity consumption	$MtonCO_2$
$Q^{NET}_{clinker,t}$	Quantity of cement manufactured	Mtons
$Q^{PROD}_{clinker,t}$	Quantity of clinker manufactured	Mtons
$NI_{clinker,t}$	Net imports (imports minus exports) of clinker	Mtons
$Q_{cement,t}$	Quantity of clinker used to manufacture cement	Mtons
H_t	Clinker home production ratio $(= \frac{Q^{NET}_{clinker,t}}{Q^{PROD}_{clinker,t}})$	None
R_t	Clinker-to-cement ratio	None
$I_{T,t}$	Thermal energy intensity	GJ/tClinker
$I_{El,t}$	Electric energy intensity	MWh/tCement
$CEF_{F,t}$	Carbon intensity of the fuel mix	tCO_2/GJ
CEF_{pro}	Carbon emission factor of limestone calcination	tCO_2/tClinker
$CEF_{elec,t}$	Electricity emission factor	tCO_2/MWh
A_t	Allocation cap	$MtCO_2$
C_eCI_t	Cement carbon intensity	tCO_2/tCement
C_kCI_t	Clinker carbon intensity	tCO_2/tClinker

Note: Some variable units for LMDI analysis differ from units used in section 2.1

We distinguish $Q^{PROD}_{clinker,t}$ which is the quantity of clinker *produced* at year t and $Q^{NET}_{clinker,t}$ which is the quantity of clinker actually *used* for cement manufacturing. The difference between the two comes from international trade (we neglect stock variations):

$$Q^{NET}_{clinker,t} = Q^{PROD}_{clinker,t} + NI_{clinker,t} \tag{1}$$

$NI_{clinker,t}$ being net imports of clinker. We split emissions in three: emissions due to fuel burning (subscript F), process emissions (subscript P) and indirect emissions due to electricity consumption (subscript E):

$$C_t = C_{F,t} + C_{P,t} + C_{E,t} \tag{2}$$

Only direct emissions are accounted in the EU ETS.

$$C_{EUTL,t} = C_{F,t} + C_{P,t} \tag{3}$$

First emissions due to fuel burning $C_{F,t}$ can be decomposed as follows:

$$\begin{aligned} C_{F,t} =& Q_{cement,t}\frac{Q^{NET}_{clinker,t}}{Q_{cement,t}}\frac{Q^{PROD}_{clinker,t}}{Q^{NET}_{clinker,t}}\frac{E_{T,clinker,t}}{Q^{PROD}_{clinker,t}}\frac{C_{F,t}}{E_{T,clinker,t}} \\ &= Q_{cement,t} \times R_t \times H_t \times I_{T,t} \times CEF_{F,t} \end{aligned} \tag{4}$$

where $E_{T,clinker,t}$ is the thermal energy used, R_t the clinker-to-cement ratio, H_t is the clinker home production ratio ($H_t > 1$ if more clinker is produced than used, or equivalently if net imports are negative), $I_{T,t}$ is the thermal energy intensity (in GJ/tClinker) and $CEF_{F,t}$ is the carbon intensity of the fuel mix (in tCO_2/GJ).

The formulation for process emissions $C_{P,t}$ is:

$$\begin{aligned} C_{P,t} =& Q_{cement_t}\frac{Q^{NET}_{clinker,t}}{Q_{cement,t}}\frac{Q^{PROD}_{clinker,t}}{Q^{NET}_{clinker,t}}\frac{C_{P,t}}{Q^{PROD}_{clinker,t}} \\ &= Q_{cement,t} \times R_t \times H_t \times CEF_{pro} \end{aligned} \tag{5}$$

where CEF_{pro} is the CO_2 emission factor for the calcination of limestone which is considered here time invariant, absent any information on its evolution.

The formulation for $C_{E,t}$ is:

$$\begin{aligned} C_{E,t} =& Q_{cement,t}\frac{E_{E,t}}{Q_{cement,t}}\frac{C_{E,t}}{E_{E,t}} \\ &= Q_{cement,t} \times I_{El,t} \times CEF_{elec,t} \end{aligned} \tag{6}$$

where $E_{T,clinker,t}$ is the electric energy used, $I_{El,t}$ is the electric energy intensity of production (in MWh/tCement) and $CEF_{elec,t}$ is the electricity emission factor (in tCO_2/MWh).

Total emissions of cement manufacturing are then

$$C_t = Q_{cement,t} \times (R_t \times H_t \times (CEF_{pro} + I_{T,t} \times CEF_{F,t}) + I_{El,t} \times CEF_{elec,t}) \quad (7)$$

Abatement levers are more visible on this formula only composed of positive terms: besides reducing activity (reducing $Q_{cement,t}$) or outsourcing clinker (reducing H_t), technological abatement options are reducing R_t (clinker substitution), $CEF_{F,t}$ (alternative fuel use), $I_{T,t}$ and $I_{El,t}$ (thermal and electric energy efficiency), and reducing $CEF_{elec,t}$ (decarbonisation of electricity).

For the data, we take directly from GNR the variables R_t (variable 3213), $CEF_{F,t}$ (variable 3221), $I_{T,t}$ (variable 329) and $I_{El,t}$ (variable 3212). These data are given at the EU 28 level (whereas we focus on the EU 27 level) but the error is low since they are intensity variables, and Croatia's cement production stands for less than 2% of the EU 28 cement production (Mikulčić et al., 2013). $CEF_{elec,t}$ comes from Enerdata database and CEF_{pro} from Ecofys et al. (2009) (we take, unless explicitly mentioned, the measured value from the GNR database, 538 $kgCO_2$/tClinker, rather than the default factor of 523 $kgCO_2$/tClinker derived from IPCC methodology used in the EU ETS).

H_t and $Q_{cement,t}$ are indirectly found by computation. The quantity of clinker produced is obtained by dividing EUTL emissions[17] by the clinker carbon intensity (using the EU ETS value of CEF_{pro}):

$$Q^{PROD}_{clinker,t} = \frac{C_{EUTL,t}}{CEF_{pro} + I_{T,t} \times CEF_{F,t}} = \frac{C_{EUTL,t}}{C_k CI_t} \quad (8)$$

where $C_k CI_t$ is the clinker carbon intensity. Then H_t is given by:

$$H_t = \frac{Q^{PROD}_{clinker,t}}{Q^{PROD}_{clinker,t} + NI_{clinker,t}} \quad (9)$$

where $NI_{clinker,t}$ come from Eurostat international trade database. $Q_{cement,t}$ is obtained by:

$$Q_{cement,t} = \frac{Q^{PROD}_{clinker,t} + NI_{clinker,t}}{R_t} \quad (10)$$

We compute the production of clinker and cement (Figure 8) instead of taking them directly from the GNR database for two reasons. First, it allows to find EUTL emissions after recalculation for direct emissions. This aspect is crucial for methodological reasons in the allowances surplus decomposition to

[17] Sometimes EUTL emissions do not exist (before 2005) or are not reliable: for the EU 27 in phase I, because some countries were not covered, and for the UK in phase I, because of the opt-out condition, some plants were not part of the scheme. In these cases we use GNR direct emissions, corrected by a factor to take into account the discrepancy between GNR and EUTL emissions. The factor is 2005-2010 EUTL emissions divided by 2005-2010 GNR emissions (we take the period 2008-2010 for EU 27 and the UK).

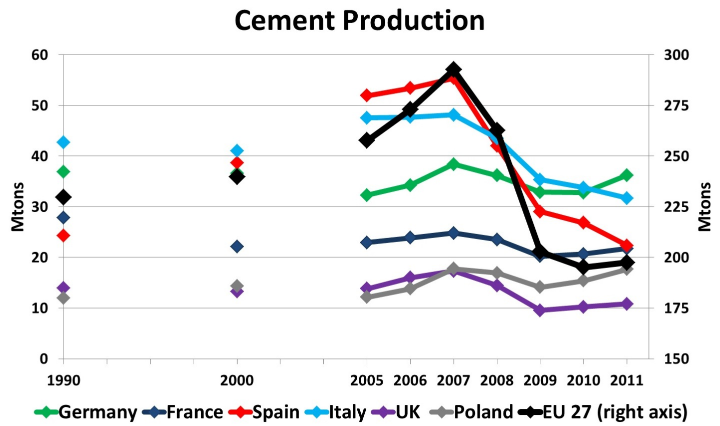


Figure 8: Cement production in million tons for the EU 27 (right vertical axis) and the main European countries (left vertical axis). Source: Computation from WBCSD GNR Database, EUTL database and Eurostat International Database

extract overallocation (see part 5.3). Second, because of coverage issues, the GNR database can be inaccurate to give quantitative values such as clinker and cement production (especially for cement because many grinding plants using imported clinker may not be covered). As an example, in Spain in 2007 (the country-year with the highest clinker importation), the GNR database gives respectively a production of 29.6 Mt and 45.9 Mt of clinker and cement, whereas our own computation (with 11.0 Mt of clinker net imports) gives 32.0 Mt and 55.4 Mt, which are closer to official figures of the Spanish cement association: 32.1 Mt and 54.7 Mt (Oficemen, 2013).

3.2. LMDI method

Index decomposition analysis (IDA) has been widely used in studies dealing with energy consumption since the 1980s and carbon emissions since the 1990s. Ang (2004) compares different IDA methods and concludes that the Logarithm Mean Divisia Index (LMDI) is the preferred one. A comprehensive literature survey reviewing 80 papers of IDA studies dealing with emissions decomposition is given in Xu and Ang (2013), and shows that the LMDI method becomes the standard method after 2007.

The general formulation of LMDI (see Ang (2005)) is the following. When emissions can be decomposed as $C_t = X^1 \times X^2 \times \cdots \times X^n$, the variation of emissions $\Delta^{tot} = C_T - C_0$ can be decomposed as $\Delta^{tot} = \Delta^1 + \Delta^2 + \cdots + \Delta^n$, with

$$\Delta^k = \frac{C_T - C_0}{\ln(C_T) - \ln(C_0)} \times \ln(\frac{X_T^k}{X_0^k}) \tag{11}$$

LMDI decomposition is mostly used to study the difference in emissions between two dates for a given country, but the mathematical formulation also works for difference in emissions for two countries at a given date, or (as we will do later), for difference in emissions for a given country between a real and a counterfactual or reference scenario.

Among the 34 studies since 2002 using LMDI decomposition analysis in Xu and Ang (2013) literature review, the majority (14) are economy-wide and only seven are focusing on industry. But except for Sheinbaum et al. (2010) (iron and steel in Mexico), they are not sector-specific but deal with industry or the manufacturing sector as a whole; in China (Liu and Ang, 2007; Chen, 2011), Shanghai (Zhao et al., 2010), Chongqin (Yang and Chen, 2010), the UK (Hammond and Norman, 2012) or Thailand (Bhattacharyya and Ussanarassamee, 2004). For sector specific studies (not using the LMDI method), one can cite two international comparisons for cement (Kim and Worrell, 2002a) and steel (Kim and Worrell, 2002b) and a study in the iron and steel industry in Mexico (Ozawa, 2002).

The closest study to ours is Xu et al. (2012), which was not in Xu and Ang (2013), focusing on the cement industry in China. They have a decomposition per kiln type, allowing to disentangle in the energy efficiency effect a structure effect (change of kiln type) from a kiln efficiency effect[18]. However they do not consider clinker trade in their decomposition, which is arguably of little importance for China, but matters for Europe .

Expanding equation (7) leads to the following decomposition:

$$
\begin{aligned}
\Delta^{tot} &= C_T - C_0 \\
&= \triangle^{act-F} + \triangle^{sha-F} + \triangle^{tra-F} + \triangle^{fmix} + \triangle^{eff-F} \\
&+ \triangle^{act-P} + \triangle^{sha-P} + \triangle^{tra-P} \\
&+ \triangle^{act-E} + \triangle^{eff-E} + \triangle^{Celec} \\
&= \triangle^{act} + \triangle^{sha} + \triangle^{tra} + \triangle^{fmix} + \triangle^{eff-F} + \triangle^{eff-E} + \triangle^{Celec}
\end{aligned}
\tag{12}
$$

doing the appropriate groupings: $\triangle^{act} = \triangle^{act-F} + \triangle^{act-P} + \triangle^{act-E}$, $\triangle^{tra} = \triangle^{tra-F} + \triangle^{tra-P}$ and $\triangle^{sha} = \triangle^{sha-F} + \triangle^{sha-P}$.

All the precise formulas are given in the appendix.

There are then seven factors in the decomposition:

- The *activity effect* ($\triangle^{act}$): impact of the total cement production on emissions variations. It corresponds to lever (i) in part 2.1
- The *clinker trade effect* ($\triangle^{tra}$): impact of the clinker trade on emissions variations. It corresponds to lever (iii) in part 2.1.
- The *clinker share effect* ($\triangle^{sha}$): impact of the clinker substitution on emissions variations. It corresponds to lever (ii) in part 2.1.

[18] Kiln energy intensity over time per kiln type was not available in the GNR database, so we opted for a simpler decomposition.

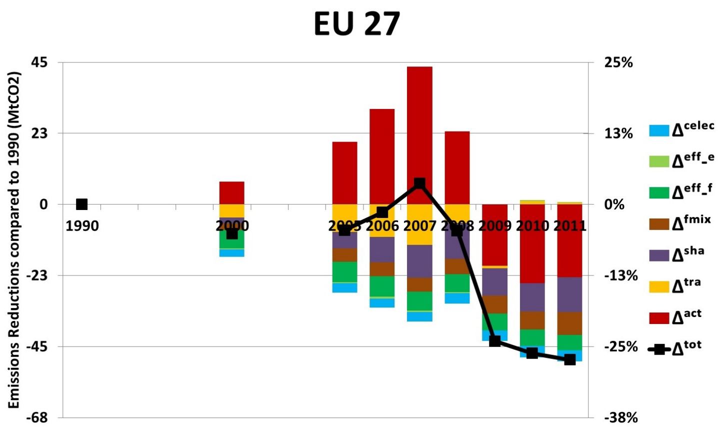


Figure 9: LMDI decomposition analysis of cement emissions compared to 1990. EU 27

- The *fuel mix effect* ($\triangle^{fmix}$): impact of the use of alternative fuel use on emissions variations. It corresponds to lever (iv) in part 2.1.
- The *thermal* and *electric energy efficiency effect* ($\triangle^{eff-F}$ and $\triangle^{eff-E}$): impact of the thermal and electric energy efficiency. They correspond to lever (v) in part 2.1.
- The *electricity carbon emissions factor effect* ($\triangle^{Celec}$): impact of the carbon emissions factor on emissions variations. It corresponds to lever (vi) in part 2.1.

One can distinguish the first two effects (activity and clinker trade) which are "non-technological" abatement options from the others that are technological abatement options.

4. Evolution of carbon emissions in the European cement industry

4.1. EU 27

Figure 9 displays the evolution of carbon emissions over time compared to their 1990 level alongside the LMDI decomposition analysis explained above [19].

Emissions in the cement industry first decreased in the 1990s and the beginning of the 2000s (-5% from 1990 to 2005) then increased sharply to exceed the 1990 level (+4% in 2007 compared to 1990). The economic recession led to a severe decrease in emissions: they were in 2009 24% lower than 1990 (which

[19] In the graphic we display variations from 1990 (fixed date) to year i. To compute variations between years i and j, we only have to take the differences, as the decomposition is linear and $\triangle_{i,j} = C_i - C_j = C_i - C_{1990} - (C_j - C_{1990}) = \triangle_{i,1990} - \triangle_{j,1990}$

corresponds to a 26% reduction in emissions in two years) and kept decreasing slowly afterwards.

The LMDI analysis allows us to highlight that most of the emissions variations in the EU 27 can be attributable to the activity effect: cement emissions have increased or decreased mostly because more or less cement has been produced. The activity effect was responsible for an increase of 43.6 Mtons of CO_2 in 2007 compared to 1990 (+22.6%) and for a decrease of 63.1 Mtons of CO_2 two years later (corresponding to a 34.4% decrease).

At the European level, the clinker trade effect partially compensates most of the time the activity effect: it is negative when the activity effect is positive and conversely. Said differently, a production increase generally leads to an increase in clinker net imports and a production to a decrease in clinker net imports, which can be explained by production capacities constraints (Cook, 2011). Holding 1990 the reference level, the clinker trade effect was at its highest in 2007 when clinker net imports reached 14.1 Mtons. At this time, 12.8 Mtons of CO_2 (7.2% of 1990 emissions) were avoided in Europe because of clinker outsourcing. With the economic downturn and the decrease in overall production, clinker net imports dropped and Europe turned to be a clinker exporter in 2009. Between 2007 and 2010, while the activity effect led to a decrease of 68.6 Mtons of CO_2, the change of clinker trade balance was responsible for an increase of 13.9 Mtons of CO_2 in Europe.

The two most important levers of technological emissions reductions are clinker substitution and alternative fuel use. The clinker share effect led to a reduction of 5.2 Mtons of CO_2 in 2005 compared to 1990 (-2.9%) and an extra 5.8 Mtons in 2011 compared to 2005 (-3.4%). Alternative fuel use led to a reduction of 4.1 Mtons of CO_2 in 2005 compared to 1990 (-2.3%) and an extra reduction of 3.3 Mtons between 2005 and 2011 (-1.8%).

Thermal energy efficiency was the most important driver of emissions reduction in the 1990s: between 1990 and 2000, it induced a decrease of 6.5 Mtons of CO_2 (-3.7%). Afterwards, the thermal energy efficiency in Europe has stagnated, generating no extra emissions reduction. The electric energy efficiency effect is by far the less influential. It led to 0.4 Mtons of CO_2 of emissions reduction between 1990 and 2005. Then a deterioration of the electric energy efficiency led to an increase of 0.5 Mtons of CO_2 between 2005 and 2011. Two possible reasons could explain the stagnation of thermal energy efficiency and the deterioration of electric energy efficiency in the 2000s. First, kilns were operated in undercapacity, so below their optimal efficiency level. Second, the two other main abatement options (clinker reduction and alternative fuel use) may reduce energy efficiency (see part 2.6).

Finally, the electricity carbon emissions factor effect has had a progressing impact in reducing cement emissions, overall small but not negligible. This channel of emissions reduction, which has the particularity to depend on other stakeholders than the cement industry itself, was responsible for a decrease of 2.4 Mtons of CO_2 between 1990 and 2000 and 1.1 Mtons of CO_2 between 2000 and 2011 (-1.4% then -0.6%).

All these observations can be summed up as follows. Clinker substitution,

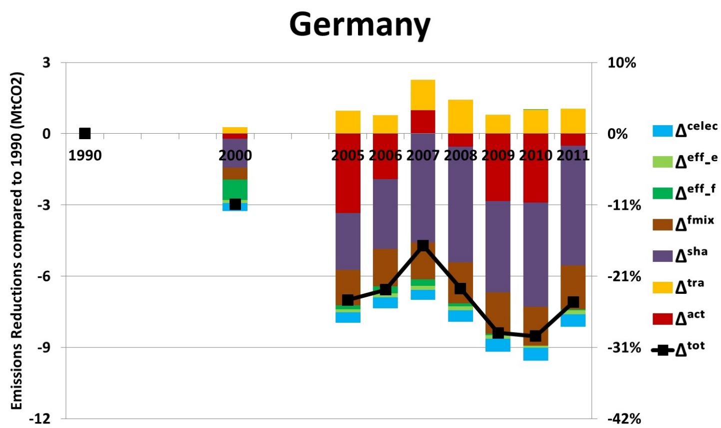


Figure 10: LMDI decomposition analysis of cement emissions compared to 1990. Germany

alternative fuel use, and to a lesser extent decarbonisation of electricity, have brought a continuous decrease in carbon emissions over the past twenty years (respectively 11.1, 7.2 and 3.5 Mtons of CO_2 between 1990 and 2011, e.g. 6.3%, 4.1% and 2.8% reduction). They overall are responsible for 13.1% decrease in carbon emissions. Energy efficiency induced a decrease in emissions in the 1990s (6.9 Mtons of CO_2 or -3.9% between 1990 and 2000) then slightly deteriorated, probably because of clinker share reduction and alternative fuel use. Overall it was responsible for 4.9 Mtons of emissions reductions between 1990 and 2011 (-2.8%). Apart from this long-time slow trend of emissions reduction, most of the emissions fluctuations are explained by the activity effect, which are partially compensated by the clinker trade effect.

4.2. Main European producers

Figures 10 to 15 show the same graphic for the biggest European cement producers: Germany, France, Spain, the UK, Italy and Poland. For each country, we do not detail the analysis as much as for the EU 27 but only pinpoint the most remarkable facts.

- *Germany.* Germany is showing that decreasing emissions while maintaining production is feasible. Clinker substitution and alternative fuel use has allowed significant emissions reductions (-24% between 1990 and 2011). Moreover, Germany was a clinker exporter at the peak of economic activity in 2007 while EU 27 as a whole was importing clinker. It is the only big Western Europe country which did not face a plummeting of its cement production. On the contrary, the cement production was higher in 2011 than in 1990, while carbon emissions were 25% smaller.

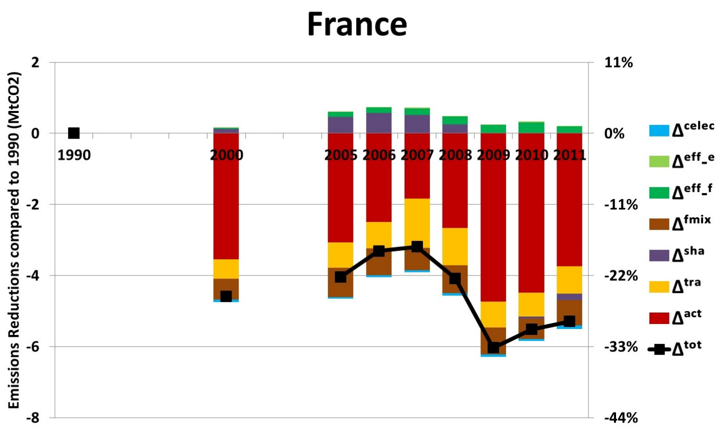


Figure 11: LMDI decomposition analysis of cement emissions compared to 1990. France

- *France.* France reduced emissions while making virtually no technological improvement between 2000 and 2011. While cement production has decreased massively, inducing a decrease in emissions oscillating between 12 and 30% of 1990 emissions, clinker net imports have also increased (inducing a decrease in emissions of approximately 18 % of the 1990 emissions level between 2005 and 2011). France is the only European country for which the activity effect and the clinker trade effect do not go in opposite directions. The clinker share effect, after being responsible for an increase in emissions until 2006, brought emissions reductions afterwards, coming back approximately to its 1990 level, whereas in most European countries (except Italy) it has been a continuous source of important emissions reductions. The energy efficiency, which was the best of big Western European countries in 1990, has continuously deteriorated and led to emissions increase. The biggest source of emissions reductions, alternative fuel use, was only applied in the 1990s; then no improvement was achieved.

- *Spain.* Spain cement emissions are overwhelmingly affected by the activity effect and the clinker trade effect. At the highest point of the housing bubble in 2007, the activity effect would have doubled emissions (+101%) compared to 1990, but was partially compensated by the clinker trade effect (-42.4%). The burst of the housing bubble induced a massive reduction of cement production and therefore of emissions by the activity effect, which were partially offset by clinker net imports massive reductions, and an increase in the clinker-to-cement ratio. Still, some emissions reduction has been made using alternative fuel use (especially since 2010), energy efficiency, and electricity decarbonisation, bringing altogether 7.6% of emissions reductions in 2011 compared to 1990.

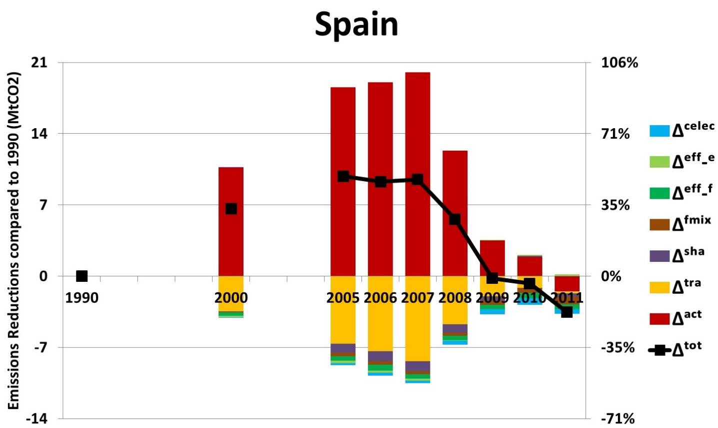


Figure 12: LMDI decomposition analysis of cement emissions compared to 1990. Spain

- *UK*. In 1990 the UK cement industry was the most CO_2 intensive in Western Europe. However it managed to be part of the good students twenty years later. The reduction of the exceptionally high clinker-to-cement ratio (94% in 1990) down to 68% in 2007 led to massive emissions reduction (a 28% decrease in 2007 compared to 1990), which was partially offset by clinker exports. Other levers of emissions reduction such as energy efficiency and alternative fuel use were applied significantly. On top of all these factors, the economic downturn activity led to an important decrease in emissions in 2008 and 2009 with a small rebound afterwards (whereas the economic activity was responsible for a small increase in emissions in 2005-2007). Overall, the UK is the major European country with the biggest fall in emissions in 2011 compared to 1990 (-52%, compared to -25% in Germany, -29% in France and in Italy, -18% in Spain and +8% in Poland).

- *Italy*. Like France, Italy had good environmental indicators in 1990 such as the lowest clinker-to-cement ratio and a relatively low carbon intensity of the fuel mix. While being a major source of emissions reductions in other countries, the clinker share effect led to an increase in emissions in Italy, because of the increase in the clinker-to-cement ratio in the 1990s and its stabilization in the 2000s. Moreover, since 2000, roughly no progress has been made in energy efficiency and alternative fuel use. The activity effect has had qualitatively a similar impact as in the UK (as Italy produces approximately twice more cement, the effect is twice less in percentage). Overall, the 29% emissions reduction compared to 1990 are almost only explained by the activity effect.

- *Poland*. Unlike the other European countries, Poland faced a sustained

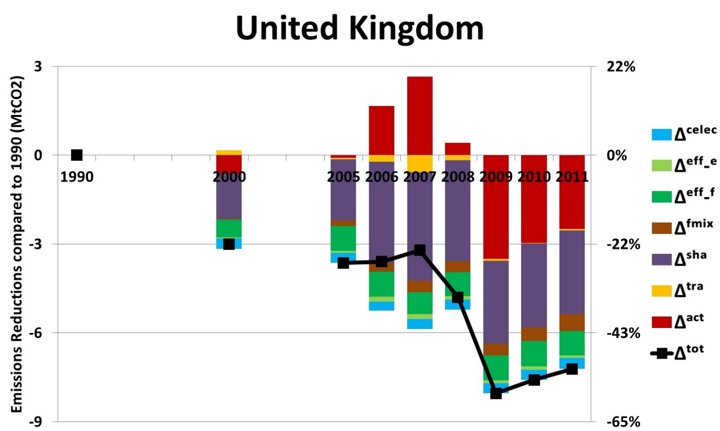


Figure 13: LMDI decomposition analysis of cement emissions compared to 1990. the UK

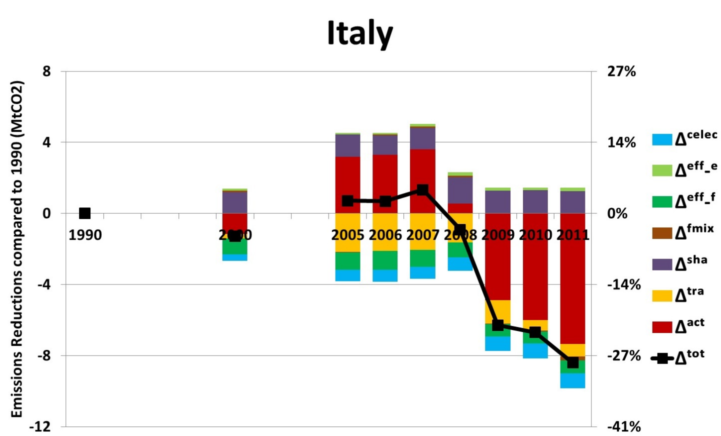


Figure 14: LMDI decomposition analysis of cement emissions compared to 1990. Italy

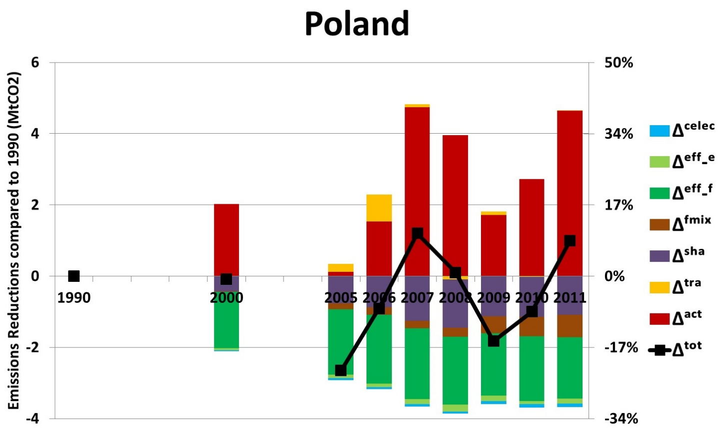


Figure 15: LMDI decomposition analysis of cement emissions compared to 1990. Poland

increase in its production (only slightly hit by the recession). In 2011 the activity effect was responsible for a 43.2% increase in its emissions compared to 1990. Most of this increase was compensated by other sources of emissions reductions, explaining why emissions only increased by 8% in 2011 compared to 1990. The most used emissions reduction option was energy efficiency, mostly in the 1990s.

5. Impact of the EU ETS on the cement industry

5.1. First sight

Figure 16 displays the results of the LMDI decomposition between 2000 and 2005 (before the launching of the EU ETS) and after the beginning of the EU ETS (2005-2011).

Between 2000 and 2005, the emissions of the cement sector increased by 0.7%, whereas between 2005 and 2011, they dropped by 24.3%. One could think then that the EU ETS was extremely efficient at reducing emissions. However, the LMDI analysis shows that the activity effect itself stands for 23.3% of emissions decrease between 2005 and 2011, compensated by a 4.8% increase in the clinker trade effect. This decrease in clinker net imports is essentially due to the weak domestic demand leading to overcapacities of production.

Among the technological abatement options, between 2005 and 2011, the clinker share effect, the fuel mix effect and the decarbonisation of electricity induced respectively emission reductions of 3.8%, 2.0%, and 0.5%, compensated by a 0.5% increase due to the energy efficiency effect. Before the beginning of the EU ETS, between 2000 and 2005, the clinker share effect, the fuel mix effect, the carbon emissions factor effect and the energy efficiency effect induced respectively an emissions reduction of 2.0%, 1.2%, 0.5%, and 0.3%.

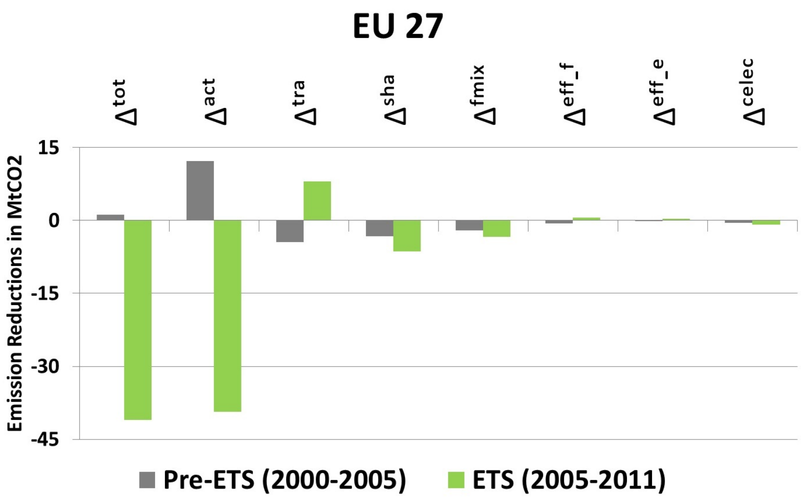


Figure 16: LMDI decomposition analysis of cement emission variations in the EU 27, before and after the beginning of the EU ETS (2000-2005 and 2005-2011)

It seems then that the introduction of the EU ETS may have to a small extent accelerated the use of clinker substitution, alternative fuel use and decarbonisation of electricity[20], while these mitigation options may have deteriorated energy efficiency.

Figure 16 does not display *abatement* but simply *evolution* of emissions over time. Abatement is the difference between *actual* emissions and *counterfactual* emissions, which would have occurred if the EU ETS had not existed. Therefore, quantitatively estimating the abatement due to the EU ETS necessitates the construction of a counterfactual scenario. The methodology and results are given in the next section.

5.2. Abatement

The method follows three steps. First, we produce two counterfactual scenarios making assumptions on the different parameters of the emissions decomposition detailed in section 3.1. Second, we compute the difference $C_t^{real} - C_t^{counterfact}$ for each year, then decompose it through an LMDI decomposition analysis. Third, we add the different yearly effects and analyse the different levers of abatement. In this section and the next one, we consider the geographically changing EU ETS perimeter[21] instead of the EU 27, as we study

[20]Though most of the decarbonisation of electricity may be due to renewable subsidies rather than the EU ETS itself (Weigt et al., 2013)

[21]The EU 27 minus Romania and Bulgaria until 2007, plus Norway, Lichtenstein and Iceland after 2008. However Cyprus and Bulgaria data is not available until 2008, and UK data is inaccurate for phase I because of the opt-out condition. The considered geographical perimeter

the impact of the EU ETS on the cement industry.

For the counterfactual scenario, we assume that the quantity of cement produced is unchanged ($Q_{cement,t}^{counterfact} = Q_{cement,t}$), and so is the home production ratio ($H_t^{counterfact} = H_t$). The EU ETS may have induced a more important production after the economic recession because of allowance allocation method (which discourages plant closure); or conversely a less important production because of cement substitution (lever (i)), competitiveness losses and leakage incentives (which have not been empirically proven so far, see Branger et al. (2013b)); but these effects are likely to be small.

For the other variables, R_t, the clinker-to-cement ratio, $CEF_{F,t}$ the carbon intensity of the fuel mix, $I_{En,t}$, the thermal energy intensity of production, $I_{El,t}$, the electric energy intensity of production and $CEF_{elec,t}$, the electricity emission factor; we consider two scenarios for the counterfactual. In the "Freeze" scenario, the variables keep their value of year 2005 from 2005 to 2011. In the "Trend" scenario, the variables decrease (or increase) at same rate as the average yearly variation between 2000 and 2005[22].

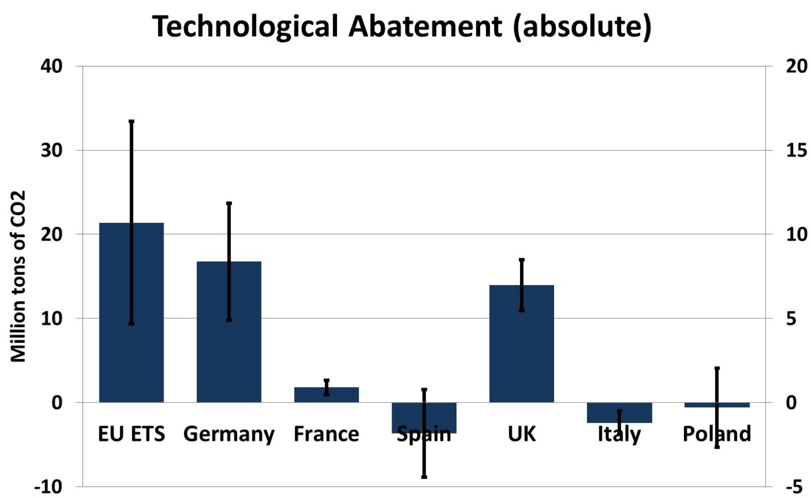
As an example, let us consider a given country for which the clinker-to-cement ratio is at 80% in 2000 and 77% in 2005 (which corresponds to an average decrease of 0.8% per year). In the "Freeze" scenario, the clinker-to-cement ratio will stay at 77% from 2005 to 2011. In the "Trend" scenario, the clinker-to-cement ratio will start at 77% in 2005 and decrease by 0.8% per year, to finish at 74.1 % in 2011. In this case, the estimated abatement will be higher in the "Freeze" scenario, since the counterfactual scenario is more pessimistic (higher emissions).

Estimating what would have happened in the absence of an event (here the introduction of the EU ETS) is in itself very challenging. Suggesting that parameter values would have ranged between the "Freeze" and "Trend" scenarios is a rule of thumb that is admittedly simplistic, but has the virtue of avoiding deciding arbitrary values for the parameters. Table 3 displays results when this method is used for predicting 2005 values in the EU 28 based on 1990 and 2000 values. Except for the clinker-to-cement ratio parameter which is slightly out of the interval, the order of magnitudes are correct.

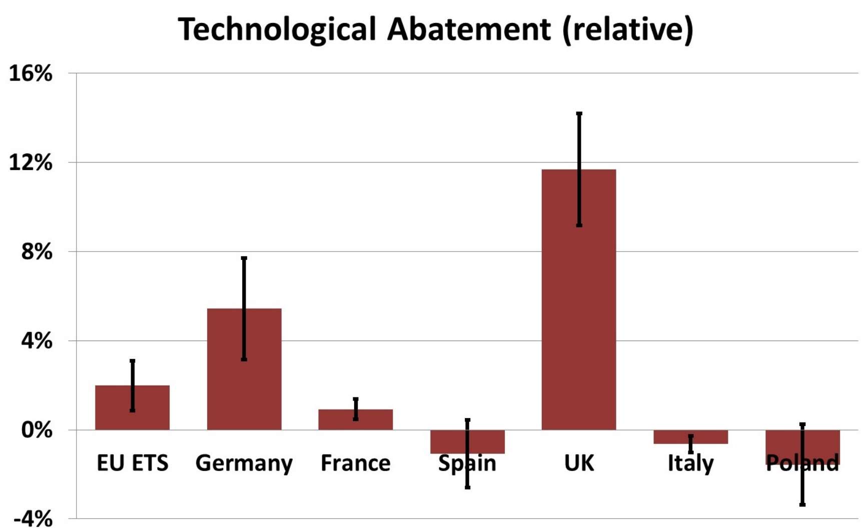
Figure 17 shows the results of the abatement estimates. Values displayed correspond to the average of the two scenarios, and with original values of scenarios as error interval. We find that between 2005 and 2011, the European cement industry has abated between 21 Mtons (± 12 Mtons) of CO_2 emissions, which corresponds to a decrease by 2.0% (± 1.1%) of emissions. However, this abatement could be due to an external cause rather than the EU ETS:

at the European level is guided by the available EUTL data coverage (so only a part of the UK production is considered in phase I). The production of clinker and cement as well as net imports have been modified to take into account the changing geographical perimeter.

[22] Ideally we would have used the 2004 values if they were available in the GNR database as in this method the technological abatement is necessarily zero in 2005. However some time was probably needed for cement companies to adapt and take the EU ETS into account in their operational decisions.



(a) Absolute abatement (left axis for the EU ETS perimeter, right axis for others) in million tons.



(b) Relative abatement in percentage of total emissions

Figure 17: "Technological" abatement between 2005 and 2011. The bars correspond either to the "Freeze" scenario estimates (the top bar except for France) and the "Trend" scenario estimates (the bottom bar except for France).

Table 3: Verification. Are the "Freeze" and "Trend" scenarios a good interval for variables change over time? Test on 2005 EU 28 values based on 1990 and 2000 values.

Variable	Unit	1990	2005 "Freeze"	2005 Real	2005 "Trend"	Observation
R_t	%	78%	78%	76%	77%	< "Trend"
$I_{En,t}$	GJ/tClinker	4,08	3,73	3,69	3,57	Interval OK. "Freeze" closer
$CEF_{F,t}$	$kgCO_2/GJ$	113	110	109	109	Interval OK. "Trend" closer
$I_{El,t}$	kWh/tCement	93	84	79	79	Interval OK. "Trend" closer
$CEF_{elec,t}$	$kgCO_2/MWh$	474	381	363	342	Interval OK. "Freeze" closer

energy prices. Indeed the prices of steam coal and petcoke price (the two main energy carriers used to produce clinker) have roughly doubled from 2003-4 to 2010-11 as graphs p.31 of Cembureau (2012) show[23]. Increasing "conventional energy" prices reinforce the profitability of using substitutes rather than clinker, alternative fuels, and increase energy efficiency.

Germany is the European country that has abated the most in absolute quantities (8 Mtons ± 3 Mtons) and the UK[24] is the country that has abated the most in percentage (-12% ± 3%). The abatement in France is small but positive (-0.9% ± 0.4%) while the abatement in Italy is small but negative (+0.6% ± 0.4%). The uncertainty in the evaluation of abatement in Spain and Poland is high (but both average values are negative).

The above-mentioned results come from a simple difference between actual and counterfactual emissions. An LMDI decomposition analysis allows to investigate what levers have been used to provide actual abatement. The results are visible in Figure 18. Almost all of the technological abatement in the EU ETS perimeter comes from clinker share reduction (between 15 and 27 Mtons of CO_2) then comes alternative fuels (between 0 and 7 Mtons of CO_2), while the decrease in energy efficiency led to negative abatement (between 4 and 6 Mtons of CO_2).

The detailed results country by country are given in the appendix and a summary of the results is given in Table 4. Clinker reduction is the main lever of technological abatement and led to actual abatement in Germany, France, the UK, and Poland but negative abatement in Spain and Italy. In the UK clinker reduction led to massive abatement (5 to 7 Mtons of CO_2, which corresponds to 7 to 10 % of the UK emissions). In all countries except France, abatement due to clinker substitution has decreased (being negative in some countries) after

[23] Steam coal and petcoke prices have fallen since 2011, among other reasons because of the shale gas boom in the US. If the downward trend persists, a degradation of the cement performance indicators would support this explanation.

[24] For the UK at the national level, we use corrected GNR data for emissions for phase I as in the previous section because of inaccuracy of EUTL data

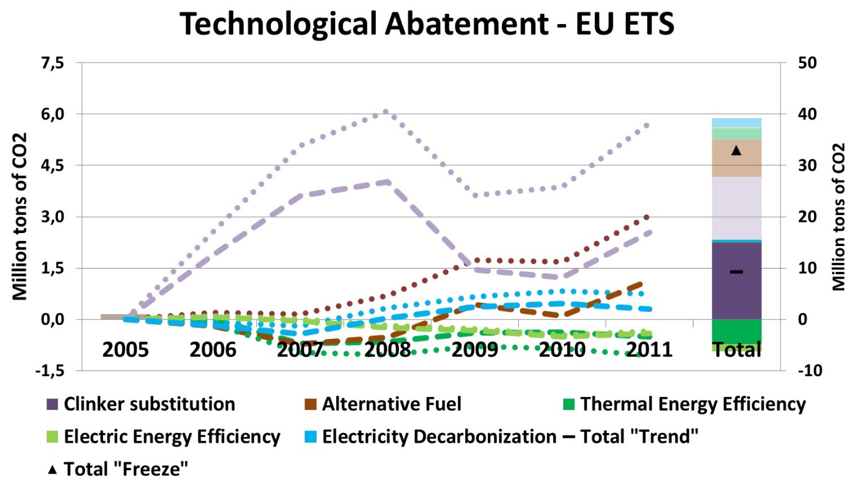


Figure 18: Technological abatement in the EU ETS perimeter. The curves on the left side show the abatement due to the different effects under the "Freeze" scenario (dotted line) and the "Trend" scenario (dashed line). The histogram on the right gives the sum of abatements over the years, in full color for the "Trend" scenario, and in full color *plus* faded color for the "Freeze" scenario.

the economic downturn. This could be explained by overcapacities and excess in clinker production. Alternative fuel led to positive abatement in Spain, the UK and Poland and negative abatement in other countries (in France and Germany it could be because decarbonisation of the fuel mix had already started before the beginning of the EU ETS, so the "Trend" scenario gives lower emissions and actual abatement is harder to achieve). Energy efficiency effect brought negative abatement in Spain (especially due to the drastic decrease in electric energy efficiency), Italy, France and Poland, was neutral in the UK and brought positive abatement in Germany (to a very small extent). Electricity decarbonisation led to positive abatement in France, Spain and Italy and was insignificant in Germany, the UK and Poland.

Table 4: Impact of different technological options on technological abatement

	EU ETS	Germany	France	Spain	the UK	Italy	Poland
Clinker reduction	+	+	+	−	+	−	+
Alternative fuel	+	−	−	+	+	−	+
Energy Efficiency	−	+	−	−	=	−	−
Elec Decarbonisation	+	=	+	+	=	+	=

Note: a + in clinker reduction means that clinker reduction indeed provided positive technological abatement. = stands for indeterminate (when the error interval overlaps zero in the decomposition)

5.3. Overallocation profits

Numerous studies have demonstrated that electricity companies have reaped windfall profits by passing-through the allowance price to their consumers while they had received them for free (Sijm et al., 2006). Indeed, even allocated free of charge, allowances can be sold and therefore bear an opportunity cost.

The ability to pass-through the allowance price to consumers is not established for cement companies. The economic theory suggests that for linear demand curves, pass-through rates are higher in competitive markets rather than in monopolies (because prices are more directly linked with marginal production costs), and for markets with elastic supplies and inelastic demands (Sijm et al., 2008; Wooders et al., 2009). The cement industry is an oligopoly with moderately elastic supply and inelastic demand (Selim and Salem, 2010), which would suggest moderate-high pass-through rates (75-80%) (Oxera Consulting, 2004). However, the only empirical study of pass-through rates in the European sector to our knowledge is an old study from Walker (2006), which unveils positive put moderate pass-through rates (25-35%, differentiated among countries).

In this article, we focus on another source of "windfall" profits obtained from the EU ETS: overallocation profits. The principle of overallocation profits is straightforward. When the number of EUAs[25], given free of charge to cement companies, is higher than emissions necessary to manufacture the amount of cement really produced; a surplus of EUAs is automatically generated. These allowances can then be sold and generate profits.

If we take away emissions due to electricity consumption in equation (7), which are not accounted for cement companies in the EU ETS, we have the equation:

$$C_{EUTL,t} = Q_{cement,t} \times R_t \times H_t \times (CEF_{pro} + I_{En,t} \times CEF_{F,t}) \tag{13}$$

where $C_{EUTL,t}$ are direct emissions, $Q_{cement,t}$ the cement production, H_t the clinker home production ratio, CEF_{pro} the process emissions, $I_{En,t}$ the energy intensity and $CEF_{F,t}$ the carbon intensity of the fuel mix.

With the given state of technology in the EU 28 in 2005, and no clinker trade ($H = 1$), an allocation cap A_t allows to produce a certain quantity of cement $Q^{A_t}_{cement}$ without buying or selling allowances:

$$\begin{aligned} Q^{A_t}_{cement} &= \frac{A_t}{R_{EU28_{2005}}(CEF_{pro} + I_{En,EU28_{2005}} CEF_{F,EU28_{2005}})} \\ &= \frac{A_t}{C_e CI_{EU28_{2005}}} \end{aligned} \tag{14}$$

[25]for European Union Allowance, the "standard" allowance. Allowances from offsets credits are CER (Certified Emission Reductions) for Clean Development Mechanisms and ERU (Emissions Reduction Units) from Joint Implementation

with the cement carbon intensity of the EU 28 in 2005 ($C_eCI_{EU28_{2005}}$) being 656 kg of CO_2 per ton of cement[26]. In the rest of the article we will call $Q^{A_t}_{cement}$ the "production equivalent associated to the cap A_t".

We compute the difference between *actual* emissions C_t (associated with values $Q_{cement,t}$, R_t, H_t, $I_{En,t}$ and $CEF_{F,t}$) and the *reference* situation corresponding to the cap A_t (associated with values $Q^{A_t}_{cement}$, $R_{EU28_{2005}}$, $H = 1$, $I_{En,EU28_{2005}}$ and $CEF_{F,EU28_{2005}}$); and decompose it[27] using the same LMDI decomposition method as in section 4. We then keep the activity effect, the clinker trade effect, and regroup the other effects under the name "technology" effect.

The technology effect gives the proportion of the EUAs surplus due to technological performance, while the activity and clinker trade effects give the proportions of the EUAs surplus due to underactivity and clinker outsourcing. Overallocation is then defined as the sum of the activity and clinker trade effects. The computed overallocation can be seen as the difference between actual allocation and output-based allocation, based on current clinker production with a certain technology state (European-average in 2005).

We choose to base the reference situation for technological performance on the European-average values of 2005 so as the reference situation brings *zero extra costs on average at the European level.* The estimation of overallocation is then rather conservative, another option could have been to take the technological performance of best-performing installations, as in the phase III benchmarking (Ecofys et al., 2009). We also compute overallocation for year 2012, with 2012 GNR intensity values (such as the clinker-to-cement ratio) at their 2011 level, because given the order of magnitude of the effects, a small change in the technology effect does not change significantly the results, while the heart of the reasoning is based on the activity and trade effects for which data is available in 2012.

Figure 19 shows the decomposition of the EU ETS allowances surplus over time. The EUAs surplus is the sum of the activity effect, the trade effect and the technology effect; which are positive respectively when production is lower than the production equivalent associated to the cap ($Q^{A_t}_{cement}$), when net imports are positive, and when cement carbon intensity is lower than the 2005 EU 28 level. Overallocation, the sum of the activity and trade effects, can be negative (in this case there is underallocation) when cement production is high and/or the region is exporting clinker. It can also be higher than the EUAs surplus if the technology effect is negative (high cement carbon intensity). The activity and trade effect can cancel out, leading to no overallocation, for example when a region is producing a high quantity of cement but importing clinker.

We also add on the EUAs surplus the offset credits used by the cement

[26] Calculated with the EU 28 values in 2005 of R, CEF_{pro}, I_{En} and CEF_F which are respectively 75.9%, 0.538 tCO_2/ton of clinker, 3.69 GJ/ton of clinker and 0.0885tCO_2/MJ.

[27] We use in this section the EU ETS value of CEF_{PRO} in this section as the pivot of reasoning is the EUAs surplus and not "real" emissions

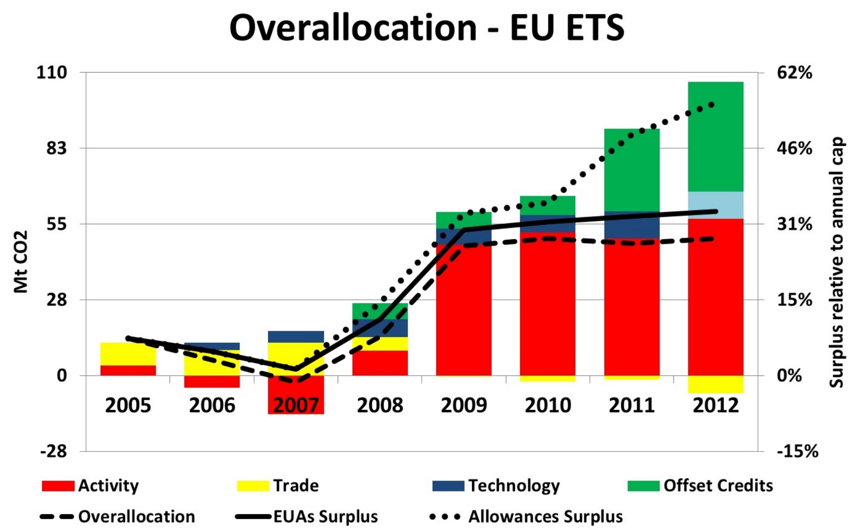


Figure 19: Overallocation over time in the EU ETS perimeter. 2012 Technology effect is based on 2011 GNR values

industry to display the "real" allowances surplus. Indeed, European authorities allowed companies to use offset credits (CERs or ERUs) to fulfil emissions caps during phase II. The offset limit as share of allocation was not harmonized at the European level but differed among member states: 22% for Germany for example but only 8% in the UK (Vasa, 2012). Companies could directly finance projects and receive offset credits or purchase offset credits in the secondary market (including pure swapping with EUAs to exploit the spread and maximize trading profit).

The first year the EU ETS entered into force, the overall cap was moderately too generous with 12 million EUAs of overallocation (roughly 8% of the cap). The increase in production the following two years because of economic growth and housing bubble in certain countries, while the cap was unchanged, made the overallocation shrink. Given the European production at that time, there would have been underallocation had net imports not be so massive. Between 2005 and 2007, roughly 30 million EUAs are saved thanks the outsourcing of 9, 11 and 14 Mt of clinker.

The economic downturn after 2008 led to a severe decrease in production and therefore a massive surplus of EUAs. We estimate that the low activity brought respectively 48, 52, 50 and 57 million of overallocated EUAs from 2009 to 2012 (between 25% and 32% of the annual cap). After 2009, Europe became a net exporter of clinker (up to 6 Mt of clinker in 2012), so the clinker trade effect brought negative overallocation (e.g. underallocation) of 10 million EUAs (1.5% of the cap). In the EUAs surplus for phases I and II, 45 million EUAs

(3% of the cap) can be attributed to the technology effect[28]. For phase II, the surplus of 248 million EUAs was due for 85% to overallocation.

While having an excess of allowances, companies used intensively project-based credits. Sandbag data at the installation level reveals that virtually all cement installations used offset credits, and that the overwhelming majority of them surrendered credits up to a fixed share of allocation, which can be inferred at the maximum amount authorized for cement installations in each country[29]: 22% in Germany, 13.5% in France, 7.9% in Spain, 8.0% in the UK, 7.5% in Italy and 10% in Poland. In total, 89 million offset credits were used, representing 10% of the cap. The total surplus for phase II was then 337 million allowances, representing almost the equivalent of two years of allocation.

Figure 20 displays the decomposition[30] of the phases I and II allowances surplus at the EU ETS level and for the main European producers[31]. Complete decomposition year by year like in Figure 19 for each country is available in the appendix.

The cumulated overallocation at the EU ETS level for phases I and II is estimated at 225 million EUAs (89% due to the activity effect and 11% due to the trade effect). The country with the highest overallocation is by far Spain (65 million EUAs) followed by Italy (27 million EUAs), because of massive clinker imports in phase I and important falls in production in phase II.

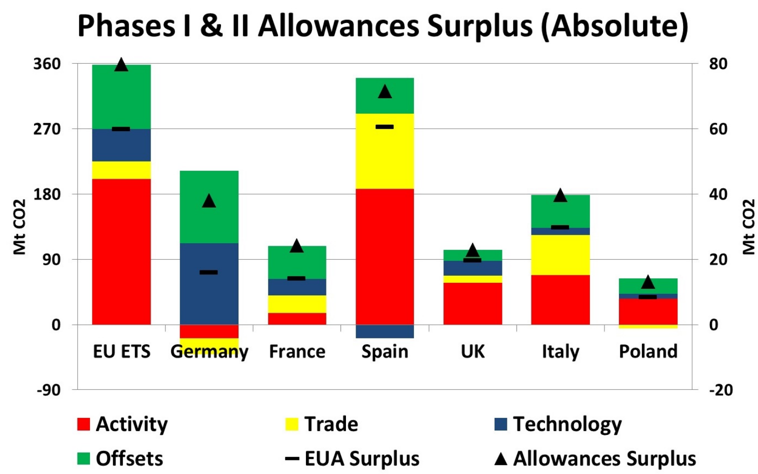
In these two countries, while the overallocation in phase II is overwhelmingly dominated by the activity effect, the impact of the trade effect on cumulated overallocation for phases I and II is significant (36% for Spain and 45% for Italy). Indeed there was a negative activity effect in phase I (higher production than the production equivalent associated to the cap) which cancels some of the positive activity effect (underproduction) in phase II. Conversely, there was no significant negative trade effect in phase II to cancel out the positive trade effect in phase I. Italy kept being a net clinker importer in phase II while Spain net

[28]It corresponds to a "Freeze" scenario for which cement production would have been equal to the production equivalent associated to the cap, which was higher than actual production, that is why this figure is higher than the "Freeze" scenario of the previous section (33 million)

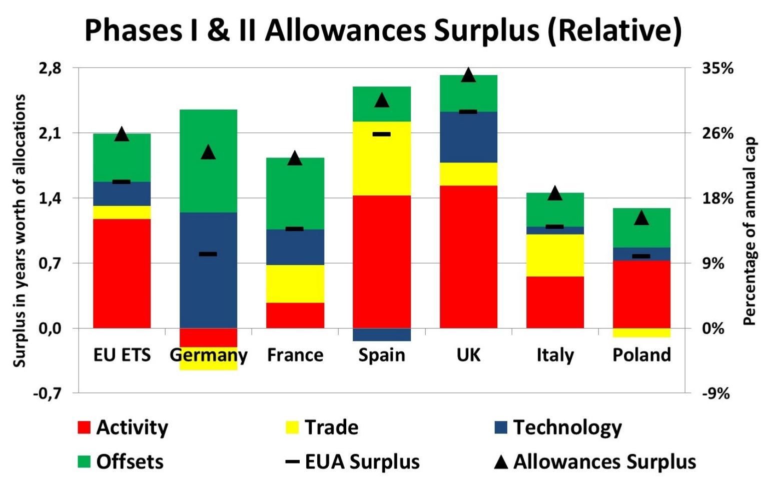
[29]For Spain (20.6%) and Italy (15%), there is a discrepancy between the share of allocation authorized at the *national* level in Vasa (2012) and the one we found at the cement installation level. An explanation could be that in these two countries the proportion of offset was probably differentiated among sectors at the installation level

[30]For computing overallocation per country it was chosen to consider a European-average benchmark rather than national benchmark to put each country on an equal footing. However as the guiding principle of allocations in phase I and II was grandfathering, we also made computation with national carbon intensities of cement (respectively 618, 637, 672, 710, 644 and 660 kgCO_2/tCement in Germany, France, Spain, the UK, Italy and Poland). For a given cap, a lower carbon intensity of cement will correspond to a higher equivalent quantity of cement, and then a higher surplus and higher overallocation profits due to activity. The only noticeable difference is for Germany: because of its high technological performance, the alternative computation led to a smaller technology effect and a greater (and positive) activity effect, and then no underallocation. For the rest differences are not significant.

[31]For UK at the national level we use in this section EU ETS data rather than GNR corrected data though the coverage is incomplete, because the pivot of reasoning is the EUAs surplus.



(a) Decomposition of the allowances surplus (left axis for the EU ETS perimeter, right axis for main European countries)



(b) Decomposition of the allowances surplus, in years worth of allocations or relative to average annual cap

Figure 20: Decomposition of the allowances surplus

exports after 2009 were much smaller in magnitude than its net imports before the crisis.

Overallocation was also positive in France (9 million EUAs, more than half of it due to trade) and Poland (7 million EUAs, with a negative trade effect), while there was actually underallocation in Germany (minus 9 million EUAs, due to high production after 2008 and clinker exports). In relative terms, overallocation was also the highest in Spain (2.2 years worth of allocations) followed by the UK (1.7) and Italy (1.0).

The technological performance varies significantly across countries and so does the share of the technology effect in the EUAs surplus (which is 45 million EUAs at the EU ETS level). Germany ranks first with 25 million EUAs earned thanks to low cement carbon intensity, followed by France and the UK (5 million EUAs each). The technology effect is very small in Italy and Poland (2 million EUAs each) and even negative in Spain (minus 4 million EUAs). In relative terms, Germany is also first (1.2 years worth of allocations) followed by the UK (0.5).

As mentioned before, because of uneven authorized thresholds, the number of surrendered offset credits varied significantly among member states. During phase II, they represented respectively 21.1%, 13.3%, 7.4%, 6.7%, 7.2% and 8.4% of annual EUAs cap in Germany, France, Spain, the UK, Italy and Poland. These differences raise equity concerns across member states, that add to equity concerns linked with national allocation plans. Fortunately, member states with the most stringent allocation plans were generally the most generous regarding the use of offset credits (see Table 5). The use of offset credits have made the allowances surplus of Germany more than double compared to the EUAs surplus (38 million allowances compared to 16 million EUAs, representing an increase of 140%). The impact of offset credits on the surplus was also relatively important in France (+72%) and Poland (+55%) but less in Italy (+34%), Spain (+18%), and the UK (+17%).

Table 5: Decomposition of phase II allowances surplus

	EU ETS	Germany	France	Spain	UK	Italy	Poland
EUAs Surplus (M)	248	7	14	58	19	35	5
EUAs Surplus (% cap)	28%	7%	18%	39%	39%	25%	9%
Technology Effect (M)	38	17	3	-2	4	1	2
Activity Effect (M)	216	-7	7	59	14	28	4
Trade Effect (M)	-6	-3	3	2	1	6	0
Overallocation (% Surplus)	85%	-142%	75%	104%	79%	97%	70%
Offsets	89	22	10	11	3	10	5
Offsets (% cap)	10.4%	21.1%	13.7%	7.4%	8.0%	7.3%	8.5%

After having decomposed the allowances surplus and computed overallocation, let us turn to overallocation profits and offset savings. To estimate overallocation profits, we multiply yearly overallocation by the yearly average

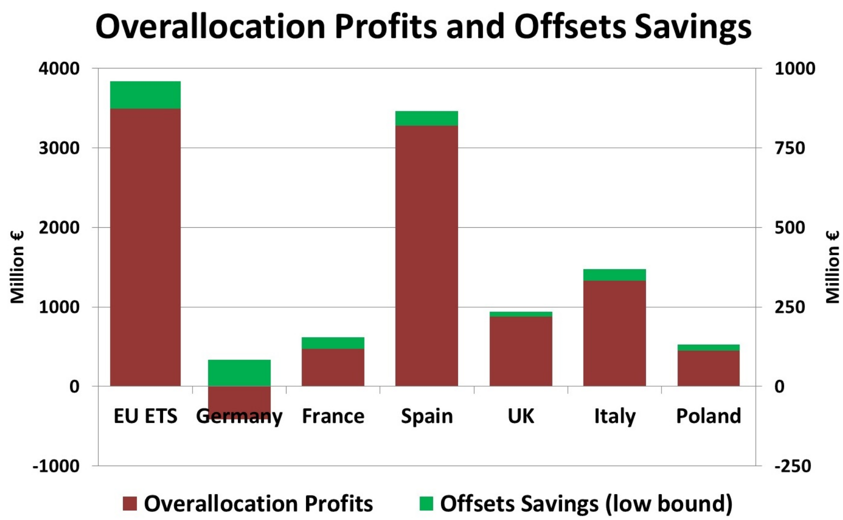


Figure 21: Overallocation profits and offset savings in the EU ETS perimeter (left axis) and main European countries (right axis)

allowance spot price[32]. If negative, overallocation profits correspond to underallocation profit losses. If overallocation is estimated with high accuracy, overallocation profits are less obvious because carbon prices vary within a year and more importantly allowances can be banked except from phase I to phase II (and it is well-known that companies have kept a significant share of them as a hedge against a future scarcity of allowances).

To estimate a low bound of savings brought by offset credits, we multiply yearly surrendered offset credits by yearly EUA-CER spread values of Stephan et al. (2014) (respectively 4.05€, 1.54€, 2.06€, 3.34€ and 4.87€ from 2008 to 2012). Actual savings are higher for two reasons. First, if companies are at the origin of the projects, actual costs of project-based credits are much lower and then savings higher (for example a HFC gas project can bring offset credits less than a few euros per ton of CO_2, bringing more than ten euros per allowance of savings before 2012). Second, the use of offset credits increased the global cap and therefore decreased the EUA price (Stephan et al., 2014).

Results are reported in Figure 21. We estimate overallocation profits at the EU ETS level at 3.5 billion euros. Overallocation profits would have been higher with higher EUA prices, but the latter dropped precisely because of a surplus of allowances, which was the main cause the overallocation profits. However the EUA price would have been higher had the offset credits not authorized.

[32]Obtained by Tendances Carbone of CDC Climat (http://www.cdcclimat.com/-publications-.html), from 2005 to 2012 respectively: 18.04€, 17.3€, 0.7€, 22.2€, 13.1€, 14.3€, 13.0€ and 7.4€)

The country with the highest overallocation profits is by far Spain (820 M€) followed by Italy (333 M€). Then come the UK (221 M€), France (118 M€) and Poland (113 M€). Germany has 103 M€ of underallocation profit losses. A low bound of offset savings is assessed at 342 M€ at the EU ETS level, and Germany is the country that benefits the most with 83 M€.

Cumulated overallocation profits for the six countries reported is around 1.6 billion euros, that is a bit less than half of overallocation profits at the EU ETS level, whereas they stand for two thirds of allocations. We can guess (based on EUTL data of EUAs surplus) that overallocation profits were particularly high because of the activity effect in Romania, Bulgaria, Greece, Cyprus, Hungary and Ireland where the accumulated EUAs surplus in phase II roughly corresponded to two years of allocations (see Figure 22).

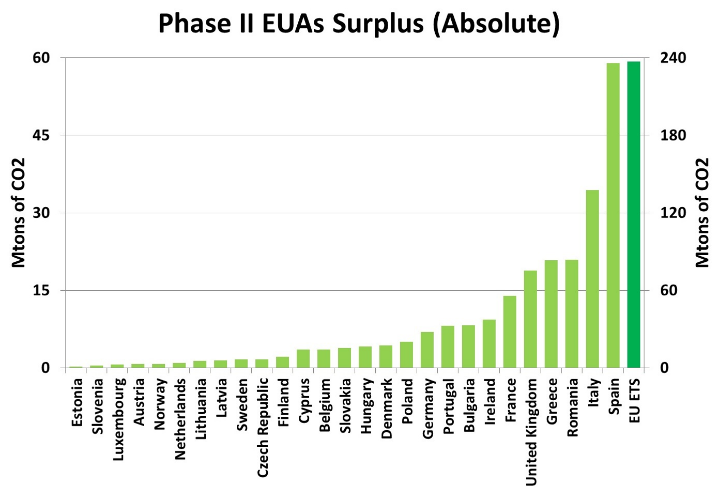
Discussing about overallocation profits by company and not by country is also relevant as the European cement market is dominated by a few multinational companies (see Tables 6 and 7). In the case of the EU ETS, we find that the five and fifteen biggest firms stand respectively for 56% and 86% of emissions in phase II. Unfortunately, the GNR database only distinguishes countries and not companies, so the only information we can have is the EUAs surplus through the EUTL database and the offset credits used by through the Sandbag database. A back of the envelope estimation (considering that among the total 3.5 G€ of overallocation profits, companies overallocation profits are proportional to their EUAs surplus) leads to overallocation profits of 679M€, 436M€, 370M€, 364M€ and 328M€ for respectively Lafarge, HeidelbergCement, Holcim, Cemex and Italcementi.

Table 6: The major European cement producers are present in many different countries in 2012

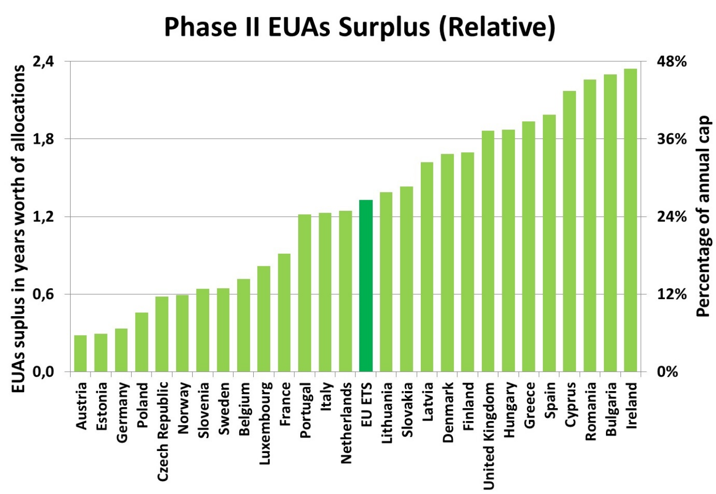
	% Emissions Phase II	Countries EU ETS	Germany	France	Spain	UK	Italy	Poland
Lafarge	15%	11	X	X	X	X		X
Heidelberg	14%	11	X			X		X
Holcim	10%	10	X	X	X		X	
Italcementi	11%	6		X	X		X	
Cemex	7%	5	X		X	X		X
Buzzi	7%	5	X				X	X

Lafarge declared in its annual reports[33], from 2008 to 2012, 605 M€ of gains

[33] Lafarge annual reports of year 2008 to 2012 (Lafarge, 2009, 2010, 2011, 2012) in pages F29 for 2009 to 2011 and F31 for 2012. The gains are respectively 85 M€, 142M€, 158M€, 136M€ and 84 M€ from 2008 to 2012. The same sentence is also copied and pasted in each annual report in year X: "For year X+1, based on our estimate of allowances to be received and based on our current production forecasts, which may evolve in case of market trends different from those expected as at today, the allowances granted should exceed our needs on a consolidated basis."



(a) Absolute EUAs surplus (right axis for the EU ETS perimeter)



(b) Relative EUAs surplus

Figure 22: EUAs surplus (allocations minus emissions) in the European cement industry (Source EUTL)

Table 7: EUTL Cement database. Company level (Sandbag database used for offset credits)

Company	Number of Plants	Annual Allocation ($MtonsCO_2$/year) Phase I	Phase II	Annual Emissions ($MtonsCO_2$/year) Phase I	Phase II	Offset credits used Total	% cap
Lafarge	36	21.8	28.3	21.3	18.9	13.3	9.4%
HeidelbergCement	34	20.8	23.0	18.0	18.5	12.7	11.0%
Italcementi	34	15.5	19.3	15.9	14.4	8.4	8.7%
Holcim	28	14.8	17.6	14.3	12.6	8.9	10.1%
Cemex	17	13.9	14.1	13.4	9.1	6.6	9.5%
Subtotal Top 5	149	86.7	102.4	83.0	73.4	49.9	9.7%
	55%	55%	57%	54%	56%	56%	
Buzzi	22	11.7	11.0	10.8	9.1	6.6	12.1%
CRH	9	8.1	8.6	7.8	6.2	3.6	8.4%
Cementos Portland	8	7.8	7.8	7.6	4.7	3.1	7.9%
Titan	5	4.4	5.1	4.4	3.6	2.4	9.5%
Cimpor	5	4.6	5.0	4.7	3.6	2.4	9.6%
Colacem	7	4.2	4.6	4.7	3.6	1.6	7.1%
Cementir	5	4.3	4.4	4.3	3.2	1.5	6.9%
Vicat	5	2.3	2.6	2.5	2.2	1.9	14.6%
Tudela Veguin	4	2.5	2.5	2.5	1.9	1.0	7.9%
Schwenk	4	2.4	2.1	2.4	2.0	2.3	22.0%
Subtotal Top 15	223	139.1	156.0	134.6	113.3	76.4	9.8%
	83%	88%	87%	87%	86%	86%	
Total EU ETS	271	158.9	179.0	154.4	131.6	88.7	9.9%

due to excess rights over actual emissions. This figure is not directly comparable to our estimation of overallocation profits, because an unknown (but small) fraction is due to technological performance (not considered as overallocation profits in our estimation), and more importantly because allowances can be banked.

Further, our definition of overallocation profits let offset credits aside. However, surrending offset credits allows to bank more EUAs (almost 40% more at the European level for phase II), and therefore increases gains due to excess rights over actual emissions which are reported by companies.

Based on all these points, we can estimate that the biggest European producer has sold at least half of the EUAs surplus, and can infer a similar case for the whole cement industry. Indeed, companies faced cash constraints because of the economic recession and EUAs selling provided an easy access to liquidity. These EUAs transfers have added to the downward trend of the carbon price(IETA, 2012), decreasing in turn the value of overallocation profits.

6. Conclusion

We have analysed and quantified the key drivers of carbon emissions in the European cement industry using an LMDI decomposition analysis. Most of the emissions changes in the EU 27 can be attributed to the activity effect. After an increase in production in the 2000s which induced an increase of 43.6 Mtons of CO_2 in 2007 compared to 1990 (+22.6%), the collapse of production was responsible for a decrease of 63.1 Mtons of CO_2 from 2007 to 2009 (-34.4%). The clinker trade effect has counterbalanced approximately one third of the high activity effect in phase I, because clinker imports tend to increase when production capacities are fully employed. In addition, there has been since the 1990s a slow trend of emissions reductions mostly due to the clinker share effect, but also to the fuel mix effect and the electricity emissions factor effect. They overall account for a decrease by 13.1% in emissions between 1990 and 2011. Finally, the energy efficiency effect was responsible for a decrease in emissions in the 1990s but an increase afterwards (overall it was responsible for a decrease of 2.8% of emissions between 1990 and 2011). The deterioration of energy efficiency was probably due to the mitigation options and to the fact that any plants now operate well below their optimal efficiency level.

Then, we have estimated technological abatement induced by the EU ETS. Because of a small acceleration of clinker reduction and alternative fuel use after 2005, 21 Mtons of CO_2 ($\pm$12 Mtons) of emissions have been abated from 2005 to 2011, corresponding to a 2.0% ($\pm$ 1.1%) decrease. However these effects could have been due to the rise of energy prices rather than the EU ETS. The UK and Germany (12% $\pm$ 3% and 5% $\pm$ 2% of emissions abatement) are the good students in Europe, while in France, Spain, Italy and Poland technological abatement was insignificant or even negative.

Finally, decomposing the allowance surplus allowed assessing overallocation and then overallocation profits. The cement industry has reaped 3.5 billion euros of overallocation profits during phases I and II, mainly because of the slowdown of production, while allowance caps were unchanged. The overallocation profits have been particularly high in countries with important production slowdown, such as Spain (820 M€). Furthermore, we estimate a low bound of offset credits savings at 342 M€.

European cement companies have been suffering from the economic downturn through reduced sells, low returns on investments (BCG, 2013) and a decline in profits (Bolscher et al., 2013). However, their financial situation would have been far worse had the EU ETS not be implemented. During phase II, the scheme has been tantamount to a subsidy of 3.5 euros per ton of cement produced in Europe[34], which had increased significantly the profitability of the sector[35]. Presented as a threat to competitiveness, the EU ETS has paradoxically boosted European cement industry competitiveness defined as ability to earn (Quirion, 2010).

Since 2013 and the beginning of phase III, the EU ETS conditions have been less favourable for the cement industry, because of an increased stringency of the allocation methodology. The allocation is now based on the average of 10% best performing installations, corresponding to 766 kgCO_2/tClinker (European Commission, 2011). European authorities have opted for a clinker-based benchmark, instead of a cement-based benchmark, to avoid incentivizing clinker outsourcing. However this allocation method does not give an incentive to reduce the clinker-to-cement ratio (Demailly and Quirion, 2006), which as we have seen is the main lever of carbon emission reductions. A hybrid methodology, based on combined clinker and clinker-to-cement ratio benchmarking (Holcim, 2010), could have offered the best of both worlds. In such a system, allowances are distributed in proportion to cement production when clinker is grinded on site, by far the most frequent case, and in proportion to clinker production otherwise. So far, the majority of cement companies have refused this system mostly because it would generate transfers towards plants located near a source of substitutes (integrated steel plant for slag, coal power station for fly ash) to the detriment of the other plants. Yet the current system generates much higher transfers across plants which contrasted utilisation rates.

Indeed, overallocation is still likely to happen as this benchmark is then multiplied for each installation by the historical activity level (HAL), which is generally based on pre-crisis level[36]. Because of high uncertainty in future production levels, the difference between HAL and actual production can be very large. The choice of HAL has then deep financial repercussions on companies:

[34] 3.5 billion euros of overallocation profits divided by 1 billion ton of cement produced

[35] Based on financial data (including reported sales of allowances), Boyer and Ponssard (2013) find that the EBIDTA/sales ratio (Earnings Before Investment, Depreciation, Taxes and Amortization) of the Western European cement industry for phase II would have been 26.3% without sales of allowances, instead of 32.9%. Furthermore, the impact would have been more important had cement companies sold all these financial assets instead of banking a significant share.

[36] The HAL is, except for capacity changes, the median value of the annual activity of 2005-2008 or 2009-2010 (whichever is the highest) (European Commission, 2011)

a too high HAL automatically brings overallocation profits while a too low one induces profit losses. Output-based allocations have the desirable benefit to by-pass the HAL determination, and potential overallocation profits or underallocation profit losses that go with it. The fluctuating cap of the cement sector, or manufacturing sector, if the whole manufacturing sector receives output-based allocations, could be damped by adjusting the number of auctioned allowances dedicated to the power and combustion sectors. Indeed, the latter are by far the largest sectors covered by the EU ETS with roughly two thirds of allowances, and their emissions are much less pro-cyclical than industrial emissions. In addition, whether they buy allowances from auctioning or from manufacturing companies makes little practical difference, and they could pass-through to their customers the costs shocks coming from allowances scarcity (Sijm et al., 2006). An advantage of emissions trading regularly put forward, environmental integrity e.g. a fixed cap on emissions, could then be maintained.

Admittedly, output-based allocations have drawbacks such as providing little incentive to reduce the consumption of polluting goods (Quirion, 2009; Neuhoff et al., 2014). Moreover, the output-based allocation of allowances constitutes a production subsidy which may be useful to tackle leakage when imports are significant, which occurs when the business cycle is high, as we have seen, but not when it is low. Hence an anti-leakage policy whose level is linked to the business cycle might be more efficient, as analysed by Meunier et al. (2012). Full auctioning for the cement sector would be the first best solution, but it is politically hard to achieve and presents some risks of carbon leakage in case of high carbon price (Dröge, 2009). Border carbon adjustments (BCAs), the second-best option, could partially avoid carbon leakage[37] and restore competitiveness so as to allow full auctioning; but their compatibility with the World Trade Organization and their political acceptability at the international level is very challenging (Branger and Quirion, 2014a). Output-based allocations, especially based on a combined clinker and clinker-to-cement ratio benchmarking, would then represent a third-best solution, inducing less economic distortions and more incentive to reduce carbon emissions than the current allocation methodology.

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7. Appendix

7.1. Formulas

$$\triangle^{act-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln(\frac{Q_{cement,T}}{Q_{cement,0}}) \tag{15}$$

$$\triangle^{sha-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln(\frac{R_T}{R_0}) \tag{16}$$

$$\triangle^{tra-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln(\frac{H_T}{H_0}) \tag{17}$$

$$\triangle^{fmix} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln(\frac{CEF_{F,T}}{CEF_{F,0}}) \tag{18}$$

$$\triangle^{eff-F} = \frac{C_{F,T} - C_{F,0}}{\ln(C_{F,T}) - \ln(C_{F,0})} \ln(\frac{I_{T,T}}{I_{T,0}}) \tag{19}$$

$$\triangle^{act-P} = \frac{C_{P,T} - C_{P,0}}{\ln(C_{P,T}) - \ln(C_{P,0})} \ln(\frac{Q_{cement,T}}{Q_{cement,0}}) \tag{20}$$

$$\triangle^{sha-P} = \frac{C_{P,T} - C_{P,0}}{\ln(C_{P,T}) - \ln(C_{P,0})} \ln(\frac{R_T}{R_0}) \tag{21}$$

$$\triangle^{tra-P} = \frac{C_{P,T} - C_{P,0}}{\ln(C_{P,T}) - \ln(C_{P,0})} \ln(\frac{H_T}{H_0}) \tag{22}$$

$$\triangle^{act-E} = \frac{C_{E,T} - C_{E,0}}{\ln(C_{E,T}) - \ln(C_{E,0})} \ln(\frac{Q_{cement,T}}{Q_{cement,0}}) \tag{23}$$

$$\triangle^{eff-E} = \frac{C_{E,T} - C_{E,0}}{\ln(C_{E,T}) - \ln(C_{E,0})} \ln(\frac{I_{El,T}}{I_{El,0}}) \tag{24}$$

$$\triangle^{Celec} = \frac{C_{E,T} - C_{E,0}}{\ln(C_{E,T}) - \ln(C_{E,0})} \ln(\frac{CEF_{elec,T}}{CEF_{elec,0}}) \tag{25}$$

7.2. Technological abatement country by country

7.3. Overallocation country by country

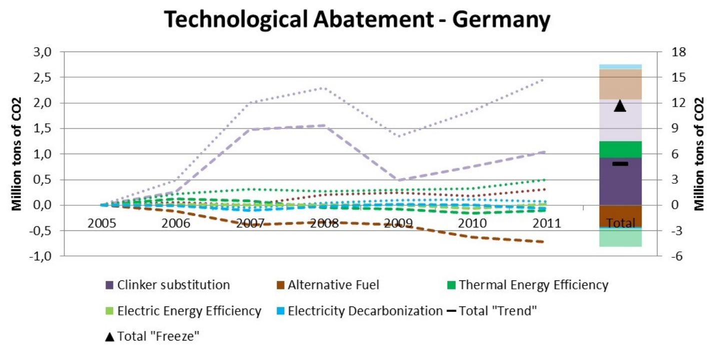

Figure 23: Technological abatement in Germany. The curves on the left side show the abatement due to the different effects under the "Freeze" scenario (dotted line) and the "Trend" scenario (dashed line). The histogram on the right gives the sum of abatements over the years, in full color for the "Trend" scenario, and in full color *plus* faded color for the "Freeze" scenario.

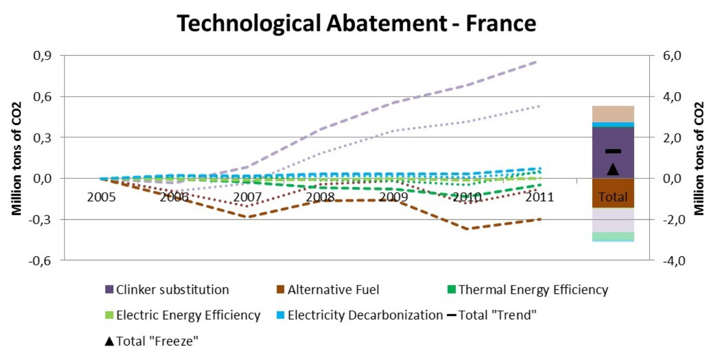

Figure 24: Technological abatement in France.

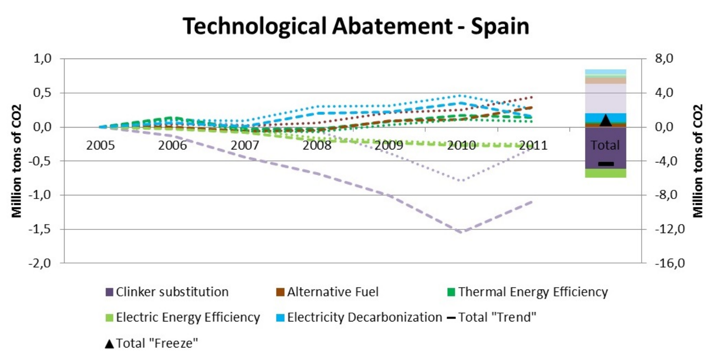

Figure 25: Technological abatement in Spain.

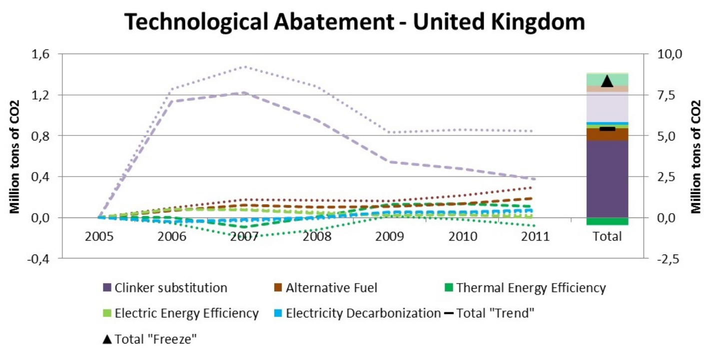

Figure 26: Technological abatement in the UK.

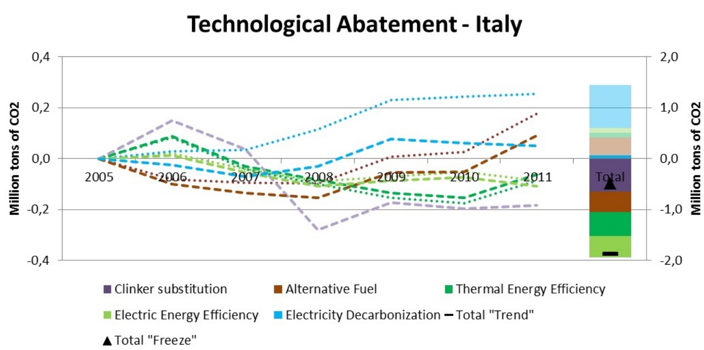

Figure 27: Technological abatement in Italy.

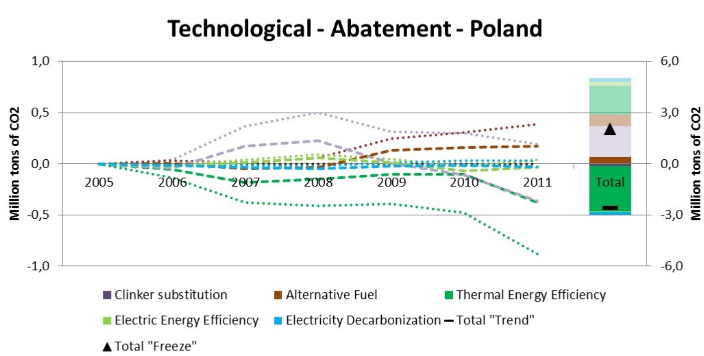

Figure 28: Technological abatement in Poland.

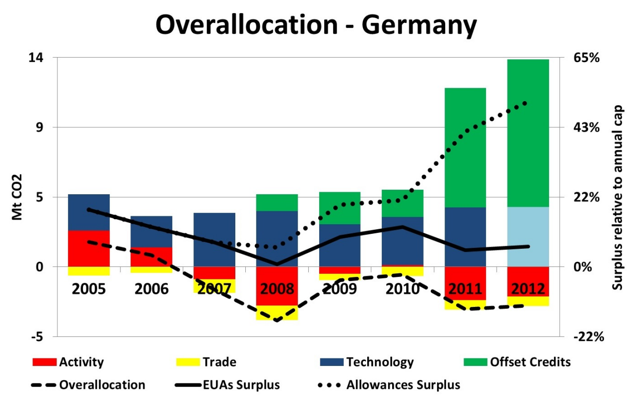

Figure 29: Overallocation in Germany. 2012 Technology effect is based on 2011 GNR values

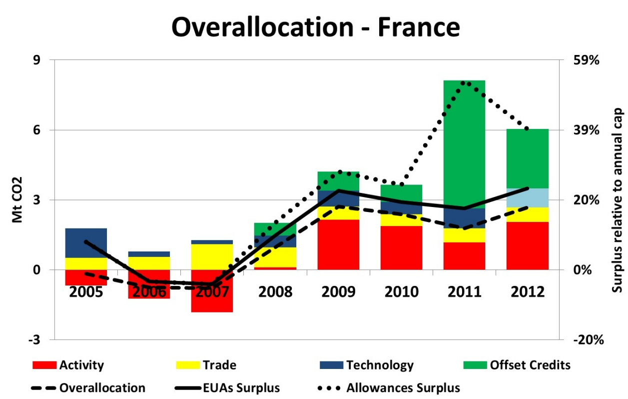

Figure 30: Overallocation in France

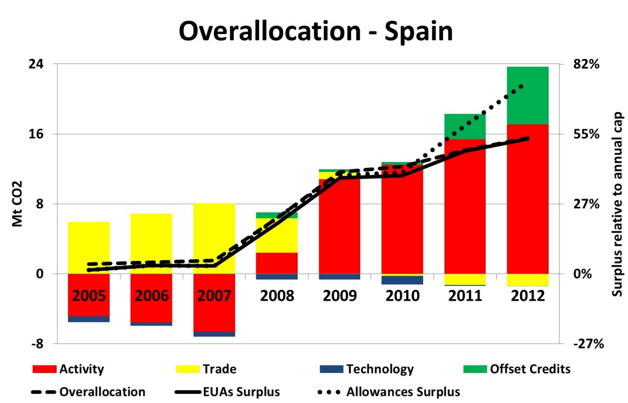

Figure 31: Overallocation in Spain

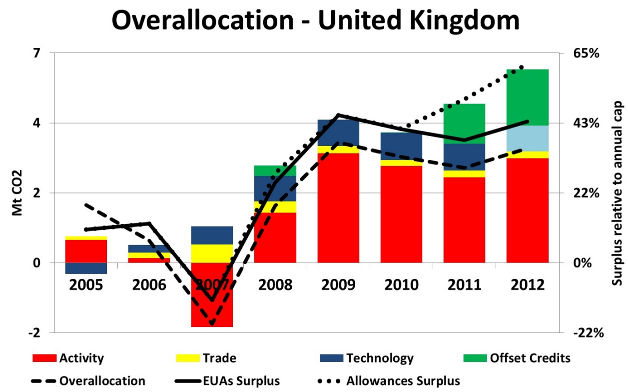

Figure 32: Overallocation in the UK

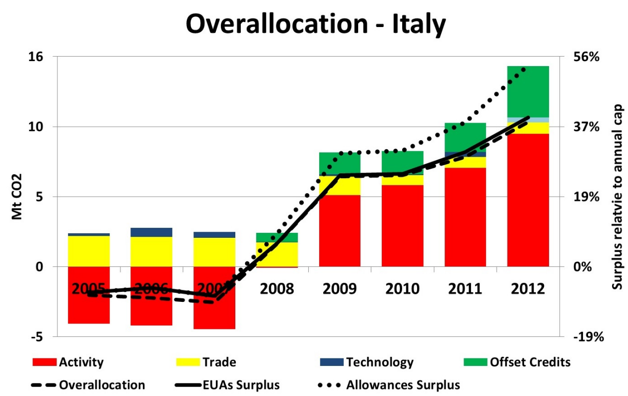

Figure 33: Overallocation in Italy

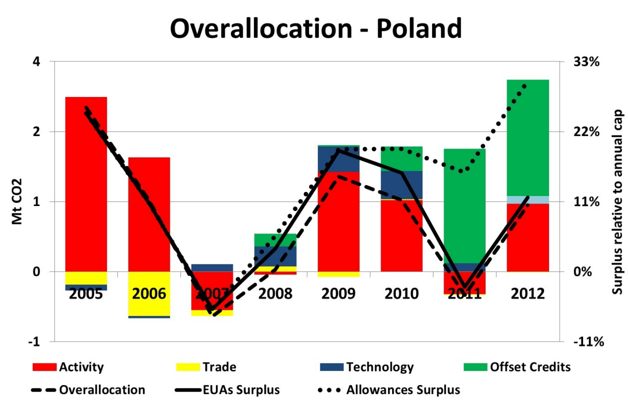

Figure 34: Overallocation in Poland