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Identifying drivers of emission trends between 2005 and 2018

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Abstract: Decomposition analysis of CO2 emissions in the European cement sector

We analyse the drivers governing the development of CO_2 emissions from cement production from 2005 to 2018 for the EU28 as a whole and selected EU countries using the logarithmic mean Divisia index (LMDI) decomposition method. We build on a methodological approach developed by Branger und Quirion (2015). We replicate and substantially extend their study by refining the methodological approach and by updating and substantiating the employed dataset based on publicly available sources. In particular, we disentangle the dominant activity effect observed by Branger und Quirion (2015) into three drivers: (i) a construction activity effect, based on a country's production in construction index; (ii) a further activity effect determined by the cement-consumption-to-construction-activity ratio; and (iii) a domestic cement share effect, capturing the share of domestically produced cement in total cement consumption. At the EU28 level, CO_2 emissions declined from 150 $MtCO_2$ in 2005 to 120 $MtCO_2$ in 2018. We find that effects on cement clinker demand govern the development of CO_2 emissions in the EU cement sector. Spain and Italy, among the EU countries most severely affected by the financial crisis of 2008/09 and the European debt crisis in 2011/12, are the major contributors to reductions in CO_2 emissions. The decomposition analysis does not suggest that CO_2 pricing under the EU ETS has substantially contributed to emissions reduction in the cement sector since its introduction in 2005. The main drivers behind the observed decline are construction activity and further activity effects. While the first one is arguably not directly affected by CO_2 pricing, the latter needs to be understood in more detail to allow for clear conclusions. Additional CO_2 costs would suggest a competitive disadvantage for cement and clinker produced in the EU, however, the share of EU domestic production has increased for both products. Only for cement production, minor efficiency improvement and fuel switching effects can be observed but establishing a direct relation to CO_2 pricing under the EU ETS would require additional analysis. Results need to be interpreted in the context of two economic crises and CO_2 prices below 10EUR/tCO_2 for most of the analysed period. They do not allow to draw conclusions on the development of emissions of the cement industry in an environment of high and rising CO_2 prices and stringent climate protection measures.

Kurzbeschreibung: Dekomposition der CO_2-Emissionen im europäischen Zementsektor

Das vorliegende Papier analysiert für den Zeitraum 2005 bis 2018 die Treiber hinter der zeitlichen Entwicklung der CO_2-Emissionen der Zementproduktion für die EU28 als Ganzes und ausgewählte EU-Länder unter Verwendung der Dekompositionsmethode: logarithmic mean Divisia index (LMDI). Es baut auf einem methodischen Ansatz auf, der von Branger und Quirion (2015) entwickelt wurde. Die Studie wird repliziert und durch Anpassungen der Methodik und unter Verwendung aktueller und öffentlich verfügbarer Daten erheblich erweitert. Insbesondere entflechten wir den von Branger und Quirion (2015) beobachteten, dominanten Aktivitätseffekt in drei Treiber: (i) einen Bautätigkeitseffekt, der auf dem Index der Produktion eines Landes im Baugewerbe basiert; (ii) einen sonstigen Aktivitätseffekt, der durch das Verhältnis von Zementverbrauch zu Bautätigkeit bestimmt wird; und (iii) den Effekt des inländischen Zementanteils, der den Anteil des im Inland produzierten Zements am gesamten Zementverbrauch erfasst. Für die EU28 sind die CO_2-Emissionen der Branche zwischen 2005 und 2018 von 150 $MtCO_2$ auf 120 $MtCO_2$ gesunken. Die Analyse zeigt, dass nachfrageseitige Effekte die Entwicklung der CO_2-Emissionen im EU-Zementsektor bestimmen. Spanien und Italien, die zu den am stärksten von der Finanzkrise 2008/09 und der europäischen Schuldenkrise 2011/12 betroffenen EU-Ländern gehören, tragen am stärksten zum Rückgang der CO_2-Emissionen bei. Die Dekompositionsanalyse deutet eher nicht darauf hin, dass die CO_2-Bepreisung unter dem EU ETS im Betrachtungszeitraum von 2005 bis 2018 wesentlich zur Emissionsreduktion im Zementsektor beigetragen hat. Die Haupttreiber für den beobachteten

Rückgang sind die Bautätigkeit und sonstige Aktivitätseffekte. Während für ersteren die Entwicklung der CO_2-Preise direkt eher keine wichtige Rolle spielt, müssen die sonstigen Aktivitätseffekte noch genauer verstanden werden, um Rückschlüsse auf einen Zusammenhang mit der CO_2-Bepreisung zu erlauben. Während zusätzliche CO_2-Kosten einen Wettbewerbsnachteil für in der EU produzierten Zement und Klinker nahelegen würden, ist der Anteil der EU-Produktion für beide Produkte gestiegen. Auf der Angebotsseite sind geringfügige Effizienzverbesserungen und Brennstoffumstellungen zu beobachten, bei denen ein direkter Zusammenhang zur CO_2-Bepreisung noch genauer untersucht werden müsste. Die vorliegenden Ergebnisse müssen vor dem Hintergrund von zwei Wirtschaftskrisen und CO_2-Preisen im Bereich von weniger als 10 EUR/tCO_2 im Beobachtungszeitraum interpretiert werden. Sie lassen keine Rückschlüsse darauf zu, welche Effekte anhaltend hohe und weiter steigende CO_2-Preise und weitere stringente Klimaschutzmaßnahmen auf die Emissionen der Zementbranche in Zukunft haben werden.

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EEA	European Environment Agency
EU ETS	European Union Emissions Trading System
EUTL	European Union Transaction Log
GHG	Greenhouse gases
GNR	Getting the Numbers Right / GCCA in NumbeRs
LMDI	Logarithmic mean Divisia index

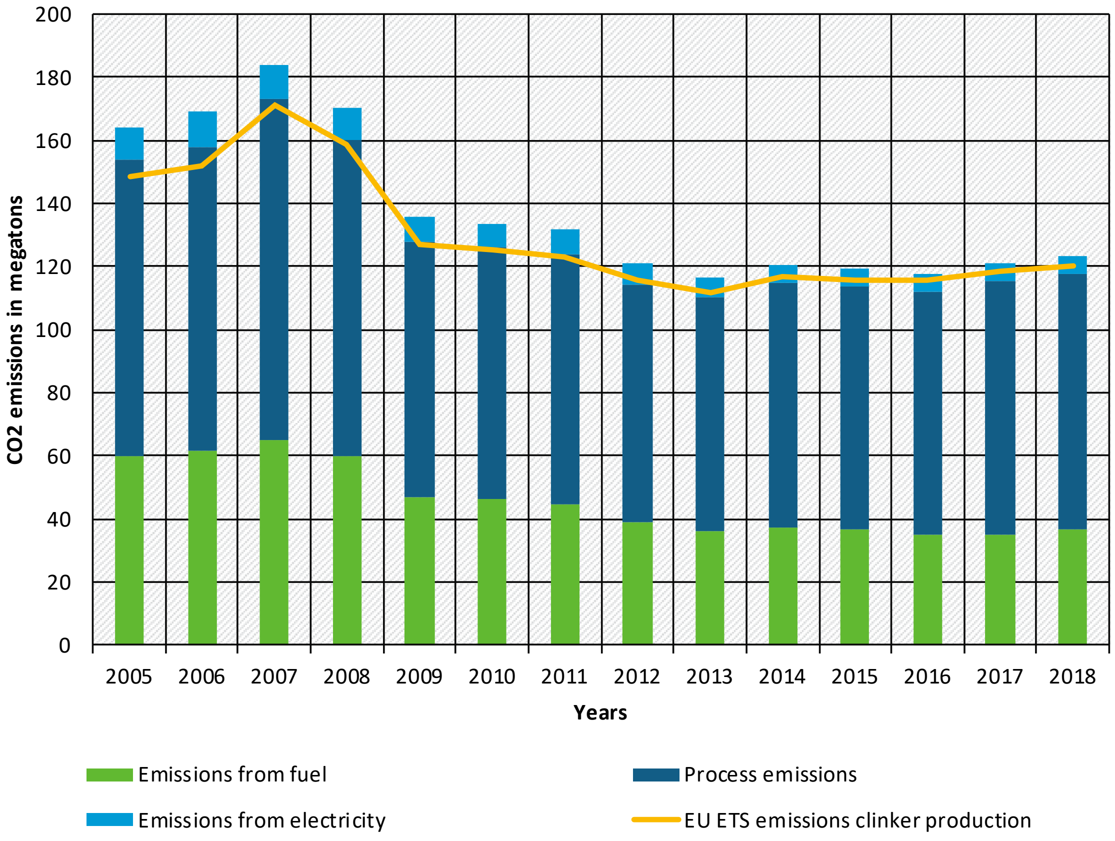
See also Table 1 for a list of variables.

1 Introduction

Cement is one of the most important building materials. It is produced from cement clinker and other materials. Cement production is an energy and emission intensive process and a significant contributor to both global and European greenhouse gas (GHG) emissions. In the European Union, cement clinker production is covered by the European Union Emissions Trading System (EU ETS). It is responsible for about 3% of the total greenhouse gas emissions of the European Union.

The CO_2 emissions of the cement clinker production in the European Union[1] covered by the EU ETS reached a maximum of 172 Mt in the year 2007 and have been on a plateau of around 120 Mt since 2009 (see Figure 1). The aim of this study is to analyse the drivers and quantify the effects that determine the development of the CO_2 emissions associated with cement production over time. A special focus is to analyse the impact of the EU ETS.

Figure 1: Evolution of the CO_2 emissions of cement production in the European Union



Source: EU ETS emissions from EEA (2020a). Emissions from fuel, process emissions and electricity calculated from GNR WBCSD Cement Sustainability Initiative (2020) and EEA (2020b).

The cement production process has two main subprocesses:

The first is the calcination of raw material in a rotary kiln producing cement clinker. Calcination is a reduction process that emits CO_2 and needs a heat input. The primary heat source of a rotary kiln is usually a solid fossil fuel like coal but also alternative fuels like waste and solid biomass

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[1] In January 2020, the United Kingdom left the European Union. As this study covers the period until 2018, data for the European Union includes the United Kingdom.

are used and the combustion of these fuels emits CO_2.[2] About two thirds of the emissions of the calcination originate in the reduction process while, depending on the fuel composition, only about one third of the emissions are attributed to the heat input (Ecofys; Fraunhofer ISI; Oeko-Institut 2009).

The second subprocess is grinding and mixing the cement clinker with admixtures (additives) to obtain cement as the final product. This is mainly a mechanical process driven by electrical energy. Thus, this process step is mainly associated with indirect emissions from electricity consumption in the manufacturing process.[3] Mitigation options in this second subprocess are e.g. the use of renewable electricity, changes in admixtures and efficiency improvements in the electrical drives (Ruppert et al. 2020; Cembureau 2020).

Both subprocesses do not necessarily take place at the same plant and not even in the same country as cement clinker is a stable solid material that can be easily transported. Therefore, when analysing CO_2 emissions from cement production the consideration of clinker imports and exports is crucial.

The aim of this study is to identify the key drivers of emission trends from cement production. For assessing the potential impact of the EU ETS in this industry, it is necessary to distinguish between factors that can be influenced by a carbon price, and external factors that are independent or not closely linked to carbon pricing. There are several pathways how a carbon price could impact emissions from the European cement sector:

- Consumption of cement: carbon pricing increases the price of domestically produced cement clinker (if carbon costs are passed through to the product price); this could lead to the consumption of less carbon-intensive cement mixtures (e.g. lower clinker share), increased imports from third countries (Carbon Leakage) or a reduced total EU demand for cement (e.g. substitution by other materials).
- Production of cement clinker: carbon pricing provides an incentive to increase energy efficiency, use less CO_2-intensive energy sources or apply storage or recycling technologies.

External factors that drive cement production and hence CO_2 emissions are for instance the overall economic development and construction activity.

In our study, we try to disentangle and quantify these impacts using the logarithmic mean Divisia index (LMDI) decomposition method to analyse the development of CO_2 emissions of cement production over time. The study builds on a study carried out by Branger und Quirion (2015) with data for the years 1990, 2000 and 2005 to 2012. However, we enrich the governing function by including a more detailed representation of drivers on the demand side. Moreover, we extend the analysis until the year 2018, the most recent year where all relevant data was available or could be estimated under reasonable assumptions.

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[2] The combustion of fuels emits also non-CO_2 GHG like methane and nitrous oxide. The quantities of these other GHG are at least three orders of magnitude lower than the CO_2 emissions and are thus not considered in this study. CO_2 emissions from the combustion of biomass are treated as zero in both the EU ETS and the GHG inventories.

[3] Drying of cement admixtures requires small amounts of thermal energy. The associated emissions are not covered by the EU ETS. Both the thermal energy for drying and the associated CO_2 emissions are neglected in this decomposition analysis.

2 Methodology

2.1 Interaction between carbon prices and CO_2 emissions from cement production

The objective of an emissions trading scheme is to reduce greenhouse gas emissions in a cost-effective manner. By setting a cap on the amount of GHG emissions in the system, the right to emit becomes a commodity with a value. This value can then directly impact decisions for both the production and the consumption of a commodity, here cement clinker production and cement consumption.

For the **consumption of cement**, a CO_2 price can affect consumer choices. Higher cement prices can reduce demand for cement[4], increase demand for less emission-intensive cement mixtures or lead to evasion strategies, most notably the import of clinker and cement from third countries which do not have carbon pricing or only charge substantially lower rates than the CO_2 price in the EU ETS. This latter effect is a potential unintended consequence (carbon leakage)[5]. In order to avoid carbon leakage to the detriment of the European industry without providing benefits to the climate, cement clinker installations covered by the EU ETS receive free allocations for a major share of their emissions. The allocation rules have led to an oversupply with free allowances to the cement clinker industry at the EU level (Marcu et al. 2020). However, at the national level, the picture is more heterogeneous, with the allowance supply level[6] in 2018 ranging from 155% in the Netherlands to 70% in Sweden. Moreover, allocation rules have also provided incentives to hold production above certain thresholds to receive more free allocations, thereby decoupling it from demand to some extent.[7]

For the **production of cement clinker**, a CO_2 price by itself gives installations with lower CO_2-intensities a competitive advantage. Installations with higher CO_2 emissions per unit of product will face higher production costs, eventually driving them out of the market. As described above, operators have the possibility to reduce their carbon emissions from clinker production by e.g. increasing thermal efficiency in the calcination process by switching to less CO_2-intensive energy sources or by investing in mitigation technologies. For cement production direct mitigation options are limited to increasing mechanical efficiency. In the absence of financial incentives (either via R&D support or via pricing mechanisms like a CO_2 price), some of these options might be technically possible but were not economically feasible while others might require investments either for retrofitting existing installations or for the construction of new facilities.

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[4] The price could, for example, lead to an increased usage of wood, stone or alternative construction materials replacing cement.

[5] “Carbon leakage refers to the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints. This could lead to an increase in their total emissions. The risk of carbon leakage may be higher in certain energy-intensive industries.” https://ec.europa.eu/clima/policies/ets/allowances/leakage_en.

[6] Allowance supply levels are calculated as free allocations under activity code 29 for a given country divided by verified emissions under the same code and for the same country and year, based on EUTL data.

[7] A link of the free allocations to historical activity levels (HAL) in the years 2005-2010 has led to an oversupply in free allocations, in particular to those installations that have reduced their production levels since then. The third trading period of the EU ETS introduced a component based on the current activity level (activity level correction factor (ALCF)) to the allocation formula, to correct for the over-allocation. However, the ALCF is a stepwise function which has introduced the incentive to increase production to secure additional free allocations. In particular, installations had the incentive to produce at least 50% of their HAL in order to receive 100% of the HAL-based allocation. See Branger et al. (2015) for more details on the allocation rules and incentives implied by the ALCF in the cement industry in the EU.

In addition to **internal drivers** under the direct control of cement consumers or cement clinker producers influencing total CO_2 emissions from cement production we also use two **external drivers** to explain the development of the emissions:

- CO_2 intensity of the electricity mix: cement plants generally contract their electricity from external suppliers. While the EU ETS does affect the electricity mix this is outside of the control of operators in the cement sector.[8]
- Construction activity: The amount of buildings and infrastructure produced is assumed to be independent of the EU ETS carbon price. Among other things, construction activity reflects the overall economic situation, labour costs and prices for construction materials. Out of the production materials, cement is only one of many products, most of which are of much higher value. For this study, the total effect of a cost increase of cement due to the introduction of the carbon price in the EU ETS on the total cost of construction is deemed negligible and therefore we assume demand for construction activities to be an external driver to cement production which is unaffected by the EU ETS carbon price. This is different from the reduction in demand for cement and its substitution in construction, mentioned above. The price could, for example, lead to an increased usage of wood as a construction material replacing cement

Based on the work by Branger und Quirion (2015) we conduct a decomposition analysis of CO_2 emissions of the European cement production. We cover both, the direct CO_2 emissions of cement clinker production (covered by the EU ETS under activity code 29) and the indirect CO_2 emissions from electricity used in cement plants (covered by the EU ETS under activity code 20). We update the study with current data and complement it with two new drivers to reflect the construction activity and cement imports.

2.2 Decomposition analysis of the cement sector

2.2.1 General introduction to the decomposition analysis

2.2.1.1 Different decomposition methods proposed in literature

A decomposition analysis is a method to quantify the effects of important drivers on the development of a variable (e.g. the development of annual emissions) over time. The results are given in the same physical unit as the analysed variable (e.g. megatons of CO_2 emissions per year). The drivers have usually different units than the variable to be analysed and the decomposition analysis converts influences of the drivers to the unit of the analysed variable. It is important to note that the method critically hinges on the right choice of drivers as the method does not allow to access whether drivers are omitted or whether a driver shows a spurious influence on the trend of the analysed variable (thus it cannot access causal relations). Furthermore, the method cannot provide explanations for the development of the drivers themselves. To explain the development of the drivers, further assessment and expert knowledge are necessary.

Before a decomposition analysis can begin a so-called governing function must be determined. The governing function combines the analysed variable with all relevant drivers (Ang 2004;

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[8] We assume that the electricity mix used in cement installations is identical to the mix in the national electricity grid. In practice the electric energy used by cement installations could have a different CO_2 emission factor, either because the suppliers chosen by operators have different generation mixes or because operators intentionally contract green electricity as part of their corporate environment objectives.

Förster et al. 2018). Then a decomposition analysis method is applied to the governing function. There exist a couple of different decomposition analysis methods:

- The **Laspeyres method** calculates the contribution of every driver to the total change of the analysed variable between a base year and a year of analysis under the assumption that all other drivers stay at the level of the base year (Ang und Zhang 2000; Albrecht et al. 2002).
- The similar **Paasche method** calculates the contribution of every driver to the total change of the analysed variable between a base year and a year of analysis under the assumption that the driver to be quantified stays at the base year level while all other drivers are at the level of the analysis year (Ang und Zhang 2000; Albrecht et al. 2002).

These two methods are very similar; the difference is that the Laspeyres method is prospective and the Paasche method is retrospective (Albrecht et al. 2002). Both methods explain the isolated effects for each of the drivers of the governing function. But in general, the isolated effects of the drivers cannot fully explain the temporal development of the variable under consideration as drivers can interact. Both methods leave a residual. It corresponds to the combined effect of two or more drivers or is caused by further drivers not considered in the governing function. It is the difference between the sum of the isolated effects and the total change of the analysed variable.[9]

There are also decomposition methods which do not lead to a residual and hence have the advantage of resulting in a complete decomposition in a single step. Notable members of this group of decomposition methods are:

- The **cumulative method** calculates first the contribution of a single driver, then stepwise adds a second driver, a third driver and so on. The inclusion order of the drivers determines their contribution (Albrecht et al. 2002).
- The **Shaply method** uses the cumulative method but iterates all possible permutations of drivers and then takes the average of the calculated distribution per driver. The combination of permutating and averaging leads to order-independent results (Albrecht et al. 2002).
- The **logarithmic mean Divisia index (LMDI) methods** are a subset of a larger group of Divisia index decomposition methods. All use Divisia indexes[10] which are basically relative changes of both, the analysed variable and the drivers compared to the respective base year level and then using different weighting approaches with the LMDI using the logarithmic mean as weighting factor (Ang 2005).

Ang (2004) has analysed different methodological options for decomposition analyses with respect to the following criteria: their theoretical soundness, adaptability to different research questions, usability and complexity regarding the interpretation of results. Methods fulfilling these criteria can use strongly fluctuating input data with values that can also be negative or (near) zero and generate no or only very small residuals. The LMDI methods fulfil these criteria and especially do not leave a residual. Hence, Ang (2004) recommends the LMDI methods for decomposition analyses in the energy and greenhouse gas emission domain.

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[9] Thus, the decomposition is not complete, and it must be decided how to proceed with the residual. If the residual is small compared to the calculated effects, the residual might be neglected. Else, the residual can be reported explicitly and be interpreted as a measure for common effects. A third option is to use a suitable method to allocate the residual to the isolated effects.

[10] Named after the French economist François Divisia, cf. Roy (1965).

The LMDI methods were used in a large variety of studies.[11] They are well-established methods and the non-existence of a residual is an important advantage compared to other methods. Moreover, Branger und Quirion (2015) have also used the LMDI method for their decomposition analysis of CO_2 emissions of the European cement industry. Given its advantages and for reasons of methodological continuity we also rely on the LMDI method in our analysis.

2.2.1.2 The logarithmic mean Divisia index method in detail

As explained in the previous section, the logarithmic mean Divisia index (LMDI) method combines the calculation of index values for the drivers in the governing function and a weighting with a logarithmic mean. The general equation of the LMDI can be written as:

$$\mathit{\Delta} = C_t - C_0 = \frac{C_t - C_0}{ln\frac{C_t}{C_0}} \times \sum_i ln\frac{X_{i_t}}{X_{i_0}} \tag{1}$$

The term $\ln\frac{X_{i_t}}{X_{i_0}}$ transforms the ratio of a driver variable X_i at the time step t in respect to time step 0 into a positive value, if the ratio is larger than 1 and else into a negative value. As a ratio is calculated, the unit of measurement of the individual driver variables are irrelevant. Each of these transformed ratios are weighted with the term $\frac{C_t - C_0}{\ln\frac{C_t}{C_0}}$ which is the logarithmic mean of the time-dependent variable C at the time steps 0 and t. The sum of all the transformed and weighted contributions of the drivers is equal to the total effect Δ which is the difference of the value of the variable C at the time steps 0 and t.

The following equation is an example of the previous equation for three drivers and corresponds to the illustration in Figure 2:

$$\Delta = \frac{C_t - C_0}{\ln\frac{C_t}{C_0}} \times \ln\frac{X_{1_t}}{X_{1_0}} + \frac{C_t - C_0}{\ln\frac{C_t}{C_0}} \times \ln\frac{X_{2_t}}{X_{2_0}} + \frac{C_t - C_0}{\ln\frac{C_t}{C_0}} \times \ln\frac{X_{3_t}}{X_{3_0}} \tag{2}$$

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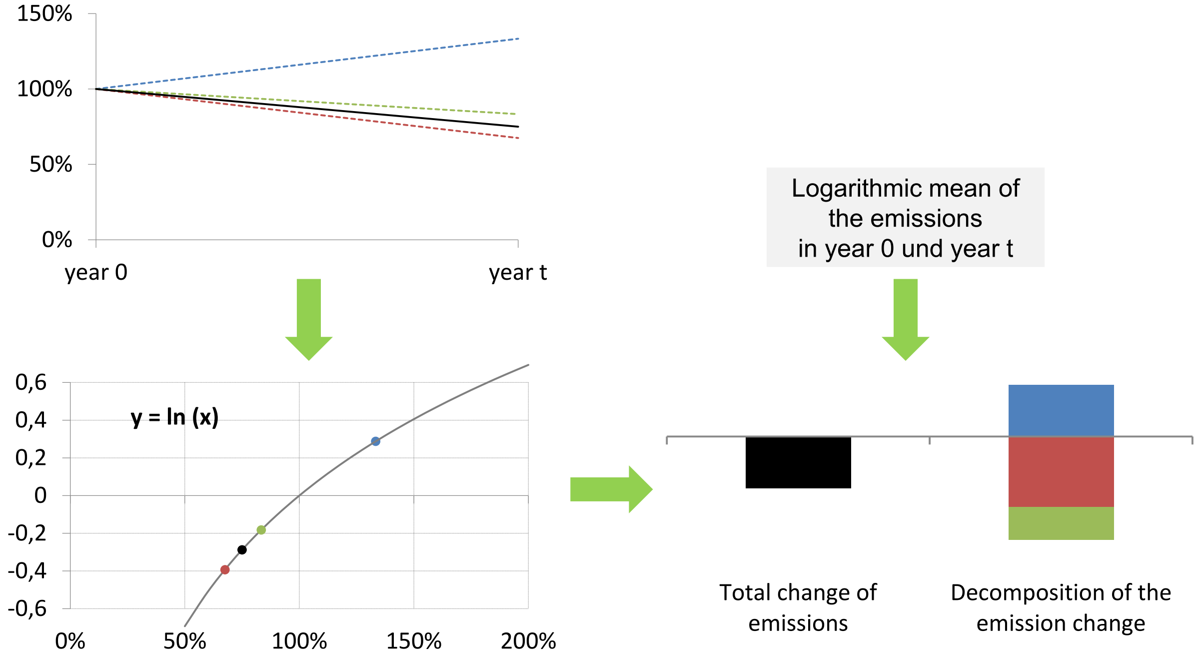
[11] Förster et al. (2018) contains an overview of recent LMDI studies analysing CO_2 emission trends.

Figure 2: **Illustration of the logarithmic mean Divisia index (LMDI) method**



Notes: The top-left graph depicts the development of the individual drivers (coloured lines), and the total change (black line) between year 0 to year t. The logarithm in the lower left graph converts the relative changes compared to the year 0 into (unitless) positive or negative changes. A multiplication with the logarithmic mean of the emissions in respective year t scales the unitless changes from the previous step and provides as a result the decomposition of the emission change in the lower right.

Source: Own illustration, Öko-Institut

2.2.2 Methodology by Branger und Quirion (2015)

The decomposition analysis of the European cement industry performed by Branger und Quirion (2015) include both fuel-related and process-related emissions of the cement clinker production. It further includes the indirect emissions associated with the electricity consumption of the cement production. Publicly available emission data from EU ETS facilities does not distinguish between fuel-related and process-related emissions thus a reconstruction of fuel-related and process-related emissions is needed. Branger und Quirion (2015) created a governing function for the emissions of cement production which includes both additive and multiplicative terms. Normally, a governing function that mixes additive and multiplicative terms cannot be analysed with the LMDI method. But Branger und Quirion (2015) set up their governing function in a way that the total emissions C_t can be split into three partial governing functions for fuel-related emissions $C_{F,t}$, process emissions $C_{P,t}$ and indirect emissions from electrical energy consumption $C_{E,t}$ which are arranged additively (see Table 2 for comprehensive variable descriptions and respective data sources) :

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

Using this approach, it is possible to include a larger variety of drivers in their analysis.

2.2.2.1 Fuel-related emissions

The fuel-related emissions $C_{F,t}$ are described with a multiplicative identity:

$$C_{F,t} = Q_{cement,t} \times R_t \times H_t \times I_{T,t} \times CEF_{F,t} \tag{4}$$

$$C_{F,t} = Q_{cement,t} \times \frac{Q^{NET}_{clinker,t}}{Q_{cement,t}} \times \frac{Q^{PROD}_{clinker,t}}{Q^{NET}_{clinker,t}} \times \frac{E_{T,clinker,t}}{Q^{PROD}_{clinker,t}} \times \frac{C_{F,t}}{E_{T,clinker,t}} \qquad (5)$$

The fuel-related emissions $C_{F,t}$ are a product of

- the quantity of cement manufactured $Q_{cement,t}$;
- the clinker-to-cement ratio R_t given as the ratio of the quantity of clinker used to manufacture cement $Q^{NET}_{clinker,t}$ and the quantity of cement manufactured $Q_{cement,t}$;
- the domestic clinker production ratio H_t given as the ratio of the quantity of clinker produced domestically $Q^{PROD}_{clinker,t}$ and the quantity of clinker used to manufacture cement $Q^{NET}_{clinker,t}$;
- the thermal energy intensity $I_{T,t}$ given as the ratio of the thermal energy used for clinker production $E_{T,clinker,t}$ (excluding energy for drying raw materials) and the quantity of clinker produced $Q^{PROD}_{clinker,t}$;
- the carbon intensity of the fuel mix $CEF_{F,t}$ given as the ratio of the fuel-related emissions $C_{F,t}$ and the thermal energy used for clinker production $E_{T,clinker,t}$.

2.2.2.2 Process emissions

The process emissions $C_{P,t}$are described with a second multiplicative identity:

$$C_{P,t} = Q_{cement,t} \times R_t \times H_t \times CEF_{pro} \qquad (6)$$

$$C_{P,t} = Q_{cement,t} \times \frac{Q^{NET}_{clinker,t}}{Q_{cement,t}} \times \frac{Q^{PROD}_{clinker,t}}{Q^{NET}_{clinker,t}} \times \frac{C_{P,t}}{Q^{PROD}_{clinker,t}} \qquad (7)$$

The process emissions $C_{P,t}$ are a product of

- the quantity of cement manufactured $Q_{cement,t}$;
- the clinker-to-cement ratio R_t as above;
- the domestic clinker production ratio H_t as above;
- the time- and country-independent carbon emission factor of limestone calcination CEF_{pro} given as the ratio of the process emissions $C_{P,t}$ and the quantity of clinker produced $Q^{PROD}_{clinker,t}$.

Note that process emissions are not published. Therefore, we follow the methodology used by Branger und Quirion (2015) and use equation 6 to estimate process emissions.

2.2.2.3 Indirect emissions from electrical energy consumption

The indirect emissions from electrical energy consumption $C_{E,t}$ are described with a third multiplicative identity:

$$C_{E,t} = Q_{cement,t} \times I_{El,t} \times CEF_{elec,t} \qquad (8)$$

$$C_{E,t} = Q_{cement,t} \times \frac{E_{E,t}}{Q_{cement,t}} \times \frac{C_{E,t}}{E_{E,t}} \qquad (9)$$

The emissions from electrical energy consumption $C_{E,t}$ are a product of

- the quantity of cement manufactured $Q_{cement,t}$;

- the electrical energy intensity $I_{El,t}$ given as the ratio of the electricity used for cement production $E_{E,t}$ and the quantity of cement manufactured $Q_{cement,t}$;
- the electricity emission factor $CEF_{elec,t}$ given as the ratio of the indirect emissions from electrical energy consumption[12] $C_{E,t}$ and the electrical energy used for cement production $E_{E,t}$.

2.2.2.4 Calculating overall emission effects

Each of the three partial governing functions are strictly multiplicative only and hence the LMDI method can be applied. The results of the partial decomposition analyses were then added to calculate the overall emission effects of the different drivers.

The total emission effect Δ^{tot} is the difference between the emission in the year of analysis and the base year:

$$\Delta^{tot} = C_T - C_0 \tag{10}$$

The decomposition analysis results give one emission effect per driver. The effects of all drivers add up to the total emission effect:

$$\begin{aligned}\Delta^{tot} = {} & \Delta^{\mathrm{act,F}} + \Delta^{sha,F} + \Delta^{tra,F} + \Delta^{eff,F} + \Delta^{fmix} \\ & + \Delta^{act,P} + \Delta^{sha,P} + \Delta^{tra,P} \\ & + \Delta^{act,E} + \Delta^{eff,E} + \Delta^{\mathrm{C,elec}}\end{aligned} \tag{11}$$

Some of the partial effects can be aggregated as they are of the same kind resulting in a shorter equation:

$$\Delta^{tot} = \Delta^{act} + \Delta^{sha} + \Delta^{tra} + \Delta^{fmix} + \Delta^{eff,F} + \Delta^{eff,E} + \Delta^{C,elec} \tag{12}$$

The following effects were included in the analysis by the development of corresponding drivers over time:

- activity effect Δ^{act} determined by the cement manufactured $Q_{cement,t}$;
- clinker share effect Δ^{sha} determined by the clinker-to-cement ratio R_t;
- clinker trade effect Δ^{tra} determined by the domestic clinker production ratio H_t;
- fuel emission effect Δ^{fmix} determined by the carbon intensity of the fuel mix $CEF_{F,t}$;
- thermal efficiency effect $\Delta^{eff,F}$ determined by the thermal energy intensity $I_{T,t}$;
- electric efficiency effect $\Delta^{eff,E}$ determined by the electrical energy intensity $I_{El,t}$;
- grid emission factor effect $\Delta^{C,elec}$ determined by the electricity emission factor $CEF_{elec,t}$.

2.2.3 Methodology used

2.2.3.1 Governing function

We expand the governing function (Equation 12) to include i) construction activity based on the construction production volume as an external driver and ii) cement trade. The aim is to better separate the production of cement – a driver influenced by the EU ETS – from the overall demand for construction services – a driver external to the EU ETS. The relationship between

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[12] We deviate from the approach used by Branger und Quirion (2015) by applying a direct emission factor instead. See section 2.2.3.3 for more details.

domestic cement production and imports/exports can be influenced by a price on carbon. The construction volume is an index "intended to reflect the monthly volume value added of the construction sector" (Eurostat 2020). We also assessed the options to include GDP or the number of building permits. Both have the disadvantage of being less closely related to actual building activity. GDP captures the overall national economy and impacts of GDP development on the demand for construction activity can be delayed or indirect. This is also true for building permits: the timespan between obtaining a permit and actual construction can be considerable. In addition, the permits only cover buildings but exclude civil engineering projects such as dams, roads and bridges.

The final formula used for this study is

$$\Delta^{tot} = \Delta^{con} + \Delta^{act} + \Delta^{tra_{cem}} + \Delta^{sha} + \Delta^{tra} + \Delta^{fmix} + \Delta^{eff,F} + \Delta^{eff,E} + \Delta^{C,elec} \qquad (13)$$

The term Δ^{act} is replaced by three new terms:

- Construction activity effect Δ^{con} determined by the construction activity $Q_{construction,t}$;
- domestic cement share effect $\Delta^{tra_{cem}}$ determined by the cement-consumption-to-cement-production ratio;
- a further activity effect Δ^{act} determined by the cement-consumption-to-construction-activity ratio. However, the indicator must be interpreted with care: it is calculated as the development of the cement consumption (physical units) in a country compared to the construction volume which includes both materials and labour (monetary units). A decreasing trend means that cement becomes a less relevant part of the construction costs, either due to a change in building methods/types or because the cost of other materials and labour have increased compared to the costs of cement. This effect captures all other reasons for a change in domestic cement production not explained by the construction activity and net imports. Reasons for this could be a change in the type and quality of construction work or a switch of building materials. For example, if fewer buildings are being constructed but these buildings meet higher standards, this would decrease the cement consumption whereas the construction activity (measured in monetary terms) might not be affected.

All other terms are equal to Branger und Quirion (2015).

2.2.3.2 Emissions source-drivers-matrix

Table 1 groups the drivers according to whether they are under the control of actors in the cement industry, and more specifically, whether these are cement consumers and / or cement clinker producers. A third category of drivers is arguably not under direct control of the industry. In the columns the matrix clarifies which of the three major direct and indirect categories of emissions sources of cement clinker and cement production are affected by the respective drivers.

For cement consumption, the further activity effect and the domestic cement share effect both affect emissions in all three categories. As electricity input is not a major factor in cement clinker production, it is assumed that indirect emissions are not affected by the clinker share and domestic clinker share effect.

On the supply side, the thermal efficiency effect, and the fuel mix effect both affect fuel-related emissions. Electric efficiency is only a driver to indirect emissions from electrical energy.

Construction activity is understood to be out of the direct control of actors in the cement industry, affecting all three sources of direct and indirect emissions. The grid emission factor is also external to the cement clinker and cement industry and only affects indirect emissions.

Table 1: Emissions Source-Drivers-Matrix

	Fuel-related emissions: $C_{F,t}$	Process emissions: $C_{P,t}$	Indirect emissions from electrical energy: $C_{E,t}$
Under the control of cement consumers	Further activity effect: $\Delta^{act,F}$	Further activity effect: $\Delta^{act,P}$	Further activity effect: $\Delta^{act,E}$
	Domestic cement share effect: $\Delta^{tra_{cem},F}$	Domestic production share effect: $\Delta^{tra_{cem},P}$	Domestic cement share effect: $\Delta^{tra_{cem},E}$
	Clinker share effect: $\Delta^{sha,F}$	Clinker share effect: $\Delta^{sha,P}$	
	Domestic clinker share effect: $\Delta^{tra,F}$	Domestic clinker share effect: $\Delta^{tra,P}$	
Under the control of cement clinker producers	Thermal efficiency effect: $\Delta^{eff,F}$		Electric efficiency effect: $\Delta^{eff,E}$
	Fuel mix effect: Δ^{fmix}		
External drivers, not under the control of the cement industry	Construction activity effect: $\Delta^{con,F}$	Construction activity effect: $\Delta^{con,P}$	Construction activity effect: $\Delta^{con,E}$
			Grid emission factor effect: $\Delta^{C,elec}$

Source: Own table based on Branger und Quirion (2015).

2.2.3.3 Data sources

While Branger und Quirion (2015) used 1990 as the base year for their analysis we chose 2005 as the base year of the decomposition analysis. The year 2005 was the start of the EU ETS and relevant data was not available for the years before 2005. Branger und Quirion (2015) analysed the European Union and its six largest member states (France, Germany, Italy, Poland, Spain and the United Kingdom). These are not only the largest member states by population but were also the six largest contributors of emissions from cement clinker production in 2018. The choice of further countries was limited by data availability from the GNR[13] database, our main data set, which only provides detailed information for these six countries plus Austria and Czechia, as well as EU-level data. In January 2020, the United Kingdom left the European Union. As our study covers the period until 2018, data for the European Union includes the United Kingdom.

The most important data source is the GNR database of the Global Cement and Concrete Association (WBCSD Cement Sustainability Initiative 2020). It is a collection of various time-series for cement production-related data and was also the main data source in the analysis by Branger und Quirion (2015). The GNR database contains data in absolute quantities but also a variety of intensities useful for the decomposition analysis. Where GNR data was not available or useful, alternative data sources were used and are described in the following paragraphs.

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[13] GNR is the abbreviation for "**G**etting the **N**umbers **R**ight" or "**G**CCA in **N**umbe**R**s", cf. https://gccassociation.org/sustainability-innovation/gnr-gcca-in-numbers/.

Branger und Quirion (2015) calculated $Q_{cement,t}$ from the quantity of clinker used to manufacture cement $Q_{clinker,t}^{NET}$ and clinker-to-cement ratio R_t. As the current GNR does contain R_t only for the years 2012 onwards, we decided to use $Q_{cement,t}$ from GNR directly. This choice had some implication on emissions (see below).

The decomposition analysis is based on the split of total emissions C_t from cement production in the three parts fuel-related emissions, process emissions and indirect emissions from electrical energy consumption (equation 3). However, neither of the two EU ETS databases – European Union Transaction Log (EUTL)[14] of the European Commission (EU 2020) and the EU Emissions Trading System data viewer of the European Environment Agency (EEA 2020a) – contain fuel-related and process emissions separately. The reporting only covers total emissions per plant which is the necessary reporting item for the EU ETS. Therefore, emissions in this study are calculated using equation 3, and equations 14, 16 and 18 in the appendix. However, as the quantity of clinker manufactured $Q_{clinker,t}^{PROD}$ is calculated from EU ETS emissions $C_{ETS,t}$, the analysis is still implicitly based on EU ETS emissions.

As $C_{ETS,t}$ we use data from the EU ETS data viewer instead of EUTL data used by Branger und Quirion (2015) as it was the aim of our study to decompose the emissions of the EU ETS emissions under activity code 29 (EEA 2020a). However, as not all relevant data was available for the years 2005 to 2011 we had to deviate from the approach by Branger und Quirion (2015) and reconstructed the fuel-related and process-related emissions using solely GNR data. This choice implied that the emissions we decomposed did not match exactly EU ETS emissions from activity code 29. Figure 1 in the introduction shows how well EU ETS emissions and reconstructed emissions match.[15]

Consistent with the analysis by Branger und Quirion (2015), in our analysis we calculated the net import of clinker $NI_{clinker,t}$ as the difference of clinker imports and exports. Likewise, we calculated the net import of cement $NI_{cement,t}$ as the difference of cement imports and exports. Mass quantities were taken from Eurostat's PRODCOM database (Eurostat 2021).

As carbon emission factor for limestone calcination CEF_{pro}, Branger und Quirion (2015) used a value of 0.538 t CO_2/t clinker for all countries and all years, taken from Ecofys; Fraunhofer ISI; Oeko-Institut (2009). As the choice of the emission factor has only minor effects on the results we preferred to be consistent with Branger und Quirion (2015) and used the same value.

Like in Branger und Quirion (2015), electricity consumption $I_{El,t}$ is also taken from the GNR database.[16] As data source for the electricity emission factor $CEF_{elec,t}$., Branger und Quirion (2015) used chargeable Enerdata[17]. As this data source is not free of charge, we chose to use publicly available and openly licensed data from the EEA (EEA 2020b) instead. While Enerdata seems to contain consumption-based emission factors, the EEA data are production-based emission factors for the specific countries. Branger und Quirion (2015) have shown that electricity consumption only contributes a small share towards total emissions and emission changes. Thus, using a different data source and a slightly different method for the electricity

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[14] https://ec.europa.eu/clima/ets/.

[15] In our analysis the difference between EU ETS emissions of activity code 29 (cement clinker production) and the sum of calculated fuel-related and process-related emissions on EU28 level is less than 2% with the largest deviation of 3.9% in 2006.

[16] The data set used in the GNR database is called "33AGW - Cement plant power consumption - Weighted average (kWh / t cement)". There are no further details given on whether this term only includes electricity consumption for grinding or also electricity consumed in clinker production.

[17] https://www.enerdata.net/research/energy-market-data-co2-emissions-database.html.

emission factor (production- vs. consumption-based) is a choice with only a minor influence on the results of the analysis.

All other values were calculated. Table 2 provides a list of all variables used in the decomposition analysis and their data sources used by Branger und Quirion (2015) and in our analysis.

Table 2: Variables and data sources

Variable	Definition	Data source used by Branger und Quirion (2015)	Data source used in this analysis
t	Year. All variables (except CEF_{pro}) are time-dependent and have an annual resolution.	Independent variable	Independent variable
C_t	Total carbon emissions in the cement manufacturing process	Calculated (see equation 3)	
$C_{ETS,t}$	Direct carbon emissions in the cement manufacturing process	EUTL (NACE 23.51)	EEA EU ETS data viewer (activity code 29)
$C_{F,t}$	Fuel-related emissions	Calculated (see equation 4)	
$C_{P,t}$	Process emissions	Calculated (see equation 6)	
$C_{E,t}$	Indirect carbon emissions due to electricity consumption	Calculated (see equation 8)	
$Q_{clinker,t}^{NET}$	Quantity of clinker used to manufacture cement	Calculated: $Q_{clinker,t}^{NET} = Q_{clinker,t}^{PROD} + NI_{clinker,t}$	
$Q_{clinker,t}^{PROD}$	Quantity of clinker manufactured	Calculated: $Q_{clinker,t}^{PROD} = \frac{C_{ETS,t}}{CEF_{pro}+I_{T,t}\times CEF_{F,t}}$	
$NI_{clinker,t}$	Net imports (imports minus exports) of clinker	Eurostat PRODCOM database (product code 23511100)	
$Q_{cement,t}^{NET}$	Quantity of cement consumed domestically	Calculated: $Q_{cement,t}^{NET} = Q_{cement,t} + NI_{cement,t}$	
$Q_{cement,t}$	Quantity of cement produced	Calculated: $Q_{cement,t} = \frac{Q_{clinker,t}^{NET}}{R_t}$	GNR
$NI_{cement,t}$	Net imports (imports minus exports) of cement	Eurostat PRODCOM database (product codes 23511210 and 23511290)	
H_t	Domestic clinker production ratio	Calculated: $H_t = \frac{Q_{clinker,t}^{NET}}{Q_{clinker,t}^{PROD}}$	
R_t	Clinker-to-cement ratio	GNR	
$I_{T,t}$	Thermal energy intensity	GNR	
$I_{El,t}$	Electric energy intensity	GNR	
$CEF_{F,t}$	Carbon intensity of the fuel mix	GNR	
CEF_{pro}	Carbon emission factor of limestone calcination (time-independent)	Ecofys; Fraunhofer ISI; Oeko-Institut (2009)	
$CEF_{elec,t}$	Electricity emission factor	Enerdata	EEA
$E_{T,clinker,t}$	Thermal energy used	GNR	
$E_{E,t}$	Electric energy used	Calculated: $E_{E,t} = I_{El,t} \times Q_{cement,t}$	
$Q_{construction,t}$	Construction production volume index	Not used	Eurostat data set sts_copr_a

Source: Adapted from Branger und Quirion (2015).

3 Decomposition of CO_2 emissions from cement production

3.1 Results for the EU including UK

Between 2005, the start of the EU ETS, and 2018 CO_2 emissions from cement production in the EU and the UK have decreased by 40.9 Mt CO_2. As shown in Figure 3, all three effect categories – external effects, supply-side effects and demand-side effects – show a net contribution to this emission decrease, though to a quite different extent. According to the decomposition analysis, the demand-side effects contribute 55% in explaining the drivers of emissions decrease, while supply-side effects contribute 37% and external effects 8%.

- Effects on the consumption of cement
  - The decrease in the further activity effect is the largest driver of emission reductions. Across all countries except Austria this effect has contributed to lower emissions. It captures all changes to the cement production not explained by the construction activity or the trade balance. This effect can be driven by a change in type and quality of construction work (e.g. construction becoming less cement-intensive and more labour-intensive or technology-intensive) or a switch of building materials (e.g. an increase in wood, steel and glass in building materials). Similar to the construction activity (see further below) this decrease is mainly driven by Spain and Italy, but Germany also has a relevant contribution to the EU-wide effect.
  - Overall, the relationship between cement produced and cement consumed has not changed much. In Spain a higher ratio of domestic production has led to emission growth, but this was mainly compensated by lower production in several other countries.
  - Due to low CO_2 prices and over-allocation of free allowances in the 2nd and 3rd trading period of the EU ETS, it is arguable whether CO_2 pricing in the EU ETS had an effect on emission reductions of cement clinker and cement production. Contrary to the expected effect of carbon pricing, the clinker share has increased since the introduction of the EU ETS and with it also CO_2 emissions. One reason for this could be an increasing demand for higher quality products with a higher clinker share. Further specialisation into higher quality products seems also to be a strategy followed by the industry as a reaction to the economic crisis (EC 2018). An additional incentive for increasing the clinker share in cement might be set by the production-based free allocation rule introduced in the 3rd trading period. Even with low demand, producers had an incentive to hold production levels above 50% of historical levels to receive free allocations for 100% of historical production levels (see Branger et al. (2015) for a detailed description of incentives and associated observed effects).
  - A similar trend can be observed for clinker trade: in 2005 the EU was a net importer but since 2008 exports have been greater than imports. EC (2018) refers to industry sources explaining this shift: producers that are able to recover their fixed costs from domestic supply can offer clinker to the international market based on marginal operation costs only. Spain, Italy, Ireland and Portugal are said to have followed this strategy. This is in line with our findings which document Spain switching from clinker importing to exporting from 2008 onwards and highlighting it as a major contributor to the increase in clinker trade in Figure 3 . Bearing in mind that Spain is also among the countries

where the free allocation rules might have prevented a reduction of overcapacities in clinker production, Branger et al. (2015) suggest that the increase in clinker exports has indirectly been favoured by the EU ETS. At the least one can say that – in the period considered here (2008-2018) which was characterised by low CO_2 prices - the CO_2 prices in the EU ETS did not impair the competitiveness of the European cement sector.

- The overall impact of the demand-side effects is a reduction of 22.4 Mt CO_2.

► Effect on the production of cement

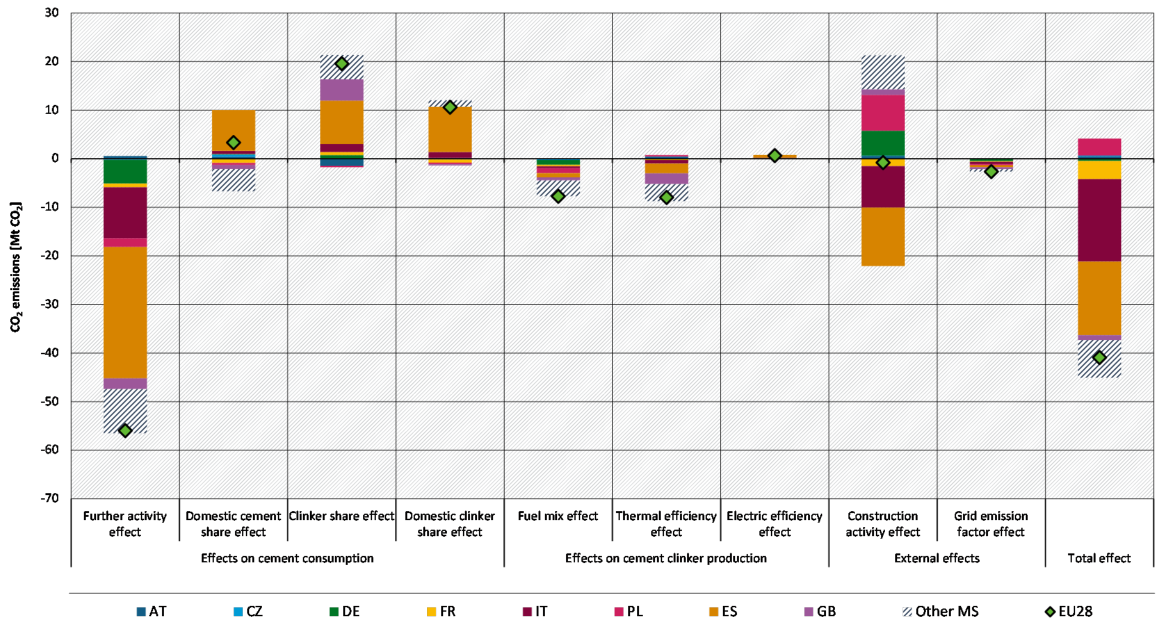
- The fuel mix became less carbon-intensive across all Member States and the UK and thus has reduced emissions since 2005. A switch in the fuel mix can be predominantly observed in those countries that had or still have a domestic coal production (such as the UK, Germany, Poland, Czechia and Spain) and thus traditionally had access to this once cheaply available heat source. At the same time a well-organised and functioning waste management system is a prerequisite for the availability of alternative fuels.
- An increase in thermal efficiency of the clinker kiln fleet in the EU countries and UK has contributed to a reduction in emissions from the EU cement sector. The underlying drivers of a change in thermal efficiency can have two origins: On the one hand the thermal efficiency of a kiln can degrade over its lifetime due to wear and tear. On the other hand, new installations or substantial modernisation will come with an increase in thermal efficiency. Depending on which of the two effects is dominant in the respective country thermal efficiency drives an increase or decrease in emissions. Spain and the United Kingdom were the two countries where the increased thermal efficiency contributed the most to the EU total. Only Austria, Czechia and Poland show a small decrease in thermal efficiency.
- The electric efficiency effect, defined as electrical energy consumption per produced quantity of cement of the installations, shows a very minor contribution towards explaining changes in total CO_2 emissions in the EU cement sector. Interestingly, its overall contribution is to increase emissions, suggesting a net decreasing electrical efficiency. More stringent environmental regulations or more intensive grinding for higher quality cements could also have led to an increase in specific electricity demand.
- The overall impact of the supply-side effects is a reduction of 15.0 Mt CO_2.

► External effects

- From a top-down perspective, total construction activity at the EU level has not changed much between 2005 and 2018. However, at the national level, Spain and Italy were hit hard by the financial crisis in 2009 and construction activity still has not returned to 2005 levels (also see Figure 6 and Figure 8). On the other hand, the demand for construction activity in other EU countries (mainly in Germany and Poland) and the UK increased leading to a net zero effect.
- The average grid emission factor has substantially improved from 402 g CO_2/kWh to 285 g CO_2/kWh (EEA 2020b) but its overall impact as a driver of CO_2 emissions at the EU level is minor. The reason for this is that according to our calculations the CO_2 emissions from electricity generation only contribute by 3-6% to the total emissions from cement production in Europe.
- The overall impact of the external effects is a reduction of 3.4 Mt CO_2.

- The overall reduction of CO_2 emissions from cement production of 40.9 Mt CO_2 is mainly due to Spain and Italy. Austria, Czechia and Poland are the only countries where emissions from cement production increased between 2005 and 2018.

Figure 3: **Decomposition of the change of EU28 CO_2 emissions from cement production between 2005 and 2018 by country and effect**



Source: Own calculations, Öko-Institut

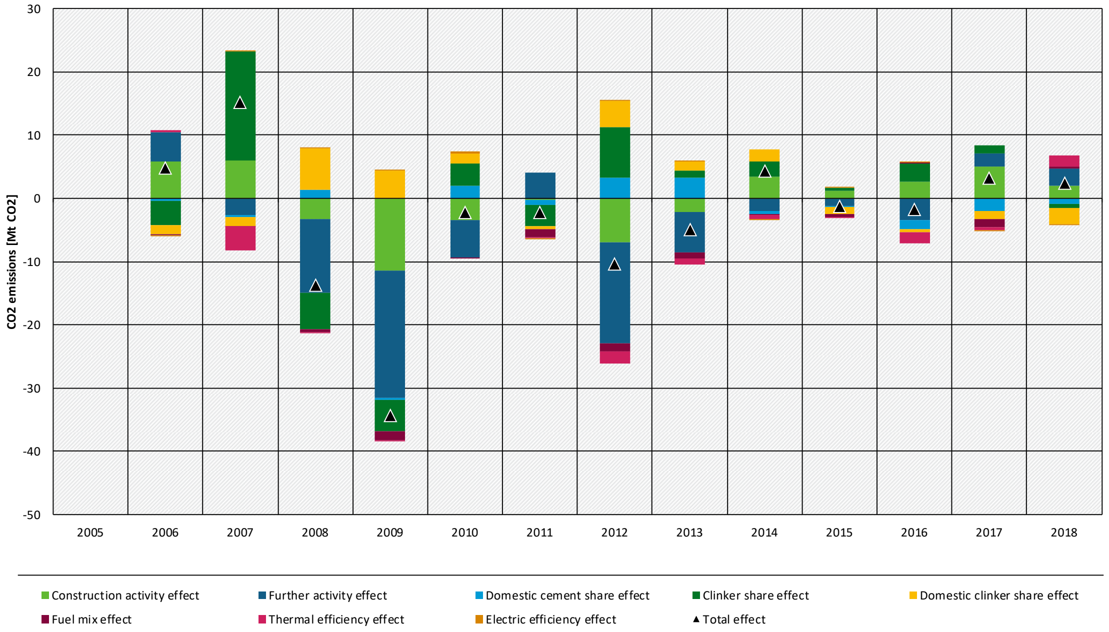
The development of the individual drivers is shown in Figure 4. The main emission reductions took place in the period 2007 to 2012. The global financial crisis in 2008/09 and its repercussions in the following years had a clear impact on the demand for construction. The construction activity effect peaked in 2007 and then declined steadily until 2013. Only afterwards did the activity pick up again across the EU and recovered to 2005 levels only in 2018. The further activity effect has declined in a similar manner but never recovered. Increased thermal efficiency and a substitution towards less-emitting energy sources have also contributed to declining emissions. The main reasons for increasing emissions were an increasing share of clinker in the cement used and a higher domestic production share. The share of cement produced domestically also increased slightly. This shows that in the past, European cement production has remained competitive despite carbon pricing through the EU ETS and has not been pushed out of the market by cheaper imported clinker or cement. Construction activity declined sharply, especially in Spain and Italy, as a consequence of the economic recession starting in 2008 and again worsened by the crisis of the years 2011-2013. This was partially offset by increasing usage of domestic cement and clinker.

Figure 4: **Decomposition of the development of CO_2 emissions from cement production since 2005 in the EU28**

Source: Own calculations, Öko-Institut

The annual changes in Figure 5 show a similar story: demand for construction activities and cement decreased sharply in 2008/2009 and again in 2012. During the same years the domestic clinker share increased. The graph also shows that the construction sector started recovering in 2014; since then the effect has been positive for all years.

Figure 5: **Decomposition of the annual change of CO_2 emissions from cement production in the EU28**



Source: Own calculations, Öko-Institut

3.2 Results for selected countries

Due to the scope and breakdown of the data sources used a national assessment is only possible for some countries. In the following we show the results of those countries which have the strongest impact on overall CO_2 emissions from cement production in the EU and those that drive the changes in the individual effects.

3.2.1 Spain

Spain was hit particularly hard by the global financial crisis from 2008 onwards culminating in the European debt crisis in 2011/2012. While the first crisis mainly impacted the construction activity effect (i.e. cement consumption declined more or less in line with the overall construction activity), the crisis of 2011/12 manifests itself through the further activity effect which encompasses a broader range of possible reasons. This indicates that this second crisis led to a structural change in the construction activity with cement playing a reduced role compared to the situation before. Construction activity has not recovered and is still significantly below 2005 levels.

The cement industry was able to compensate the negative economic consequences at least partially by increasing the ratio of production to consumption both for cement as well as clinker. In effect, Spain became a net exporter of both products in 2009 and remained so until 2018. According to Branger et al. (2015) Spain is also among the countries where the design of the free allocation rules of the 3rd trading period of the EU ETS could have contributed to an oversupply of clinker and cement. As a consequence, the surplus production was increasingly directed towards exports outside the EU28, generating additional emissions in Spain.

Figure 6: Decomposition of the development of CO_2 emissions from cement production since 2005 in Spain

Source: Own calculations, Öko-Institut

Figure 7: Decomposition of the annual change of CO_2 emissions from cement production in Spain

Source: Own calculations, Öko-Institut

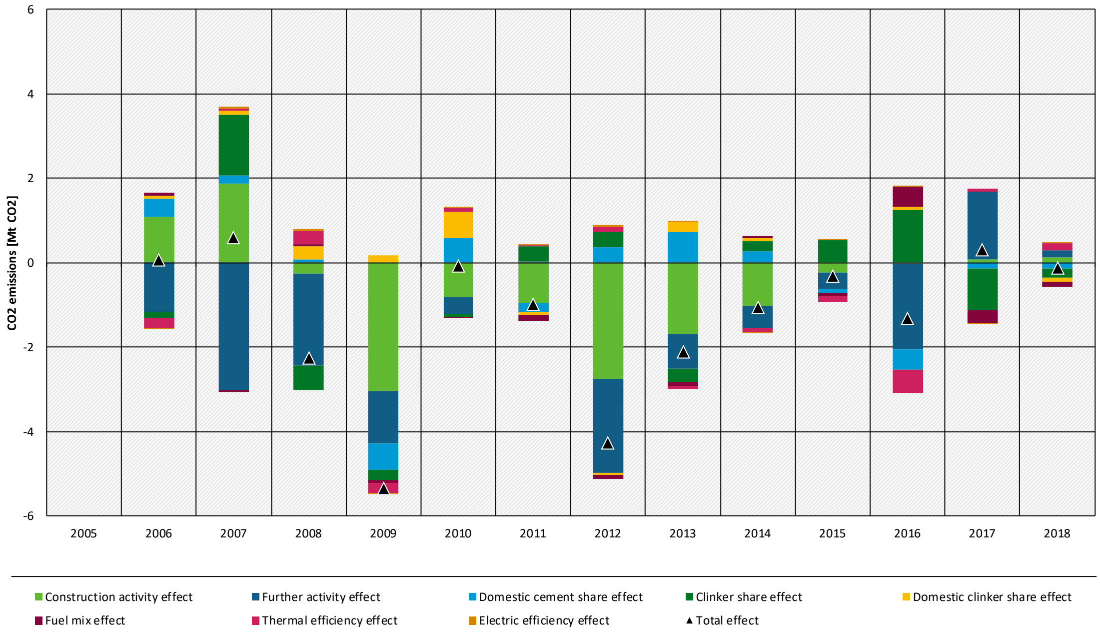
3.2.2 Italy

Like in Spain, the construction sector in Italy was hit hard by the global financial crisis and the euro crisis. But, in contrast to Spain, the change in the construction activity affects CO_2 emissions more strongly than the change in the further activity effect. The share of domestic cement and clinker increased compared to pre-crisis levels but despite this Italy remained a net importer of both goods. Construction activity has not recovered and remains substantially lower than 2005.

Figure 8: Decomposition of the development of CO_2 emissions from cement production since 2005 in Italy

Source: Own calculations, Öko-Institut

Figure 9: **Decomposition of the annual change of CO_2 emissions from cement production in Italy**



Source: Own calculations. Öko-Institut

3.2.3 France

In France, over the course of the last five years of the period analysed, all drivers except the clinker share effect have contributed to an emission reduction compared to 2005. The French construction sector was hit by both the global financial crisis as well as the European debt crisis although the effect of the euro crisis was less pronounced. Domestic cement and clinker production reduced their share in the consumption of both goods. Already in 2005, France was a net importer of both goods and increased its reliance on imports over the years. Moreover, domestic production even declined in physical terms as well. The share of alternative fuels in France increased substantially since 2005 with a stronger increase since 2013, which is reflected in the fuel mix effect.

Figure 10: **Decomposition of the development of CO_2 emissions from cement production since 2005 in France**

Source: Own calculations, Öko-Institut

Figure 11: **Decomposition of the annual change of CO_2 emissions from cement production in France**

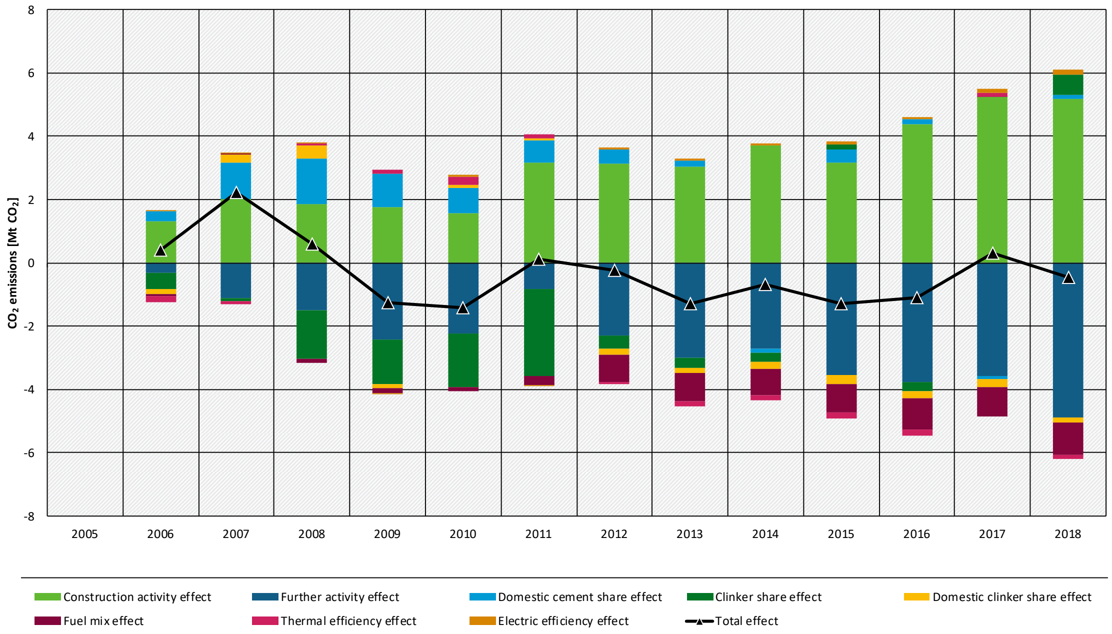
Source: Own calculations., Öko-Institut

3.2.4 Germany

In Germany construction activity did not decline due to the crises between 2008 and 2012. Construction activity has been the main driver increasing emissions from the cement sector since 2015. The further activity effect responded somewhat to the crises but also declined in most years after 2012. The resulting effect compensates the increased construction activity.

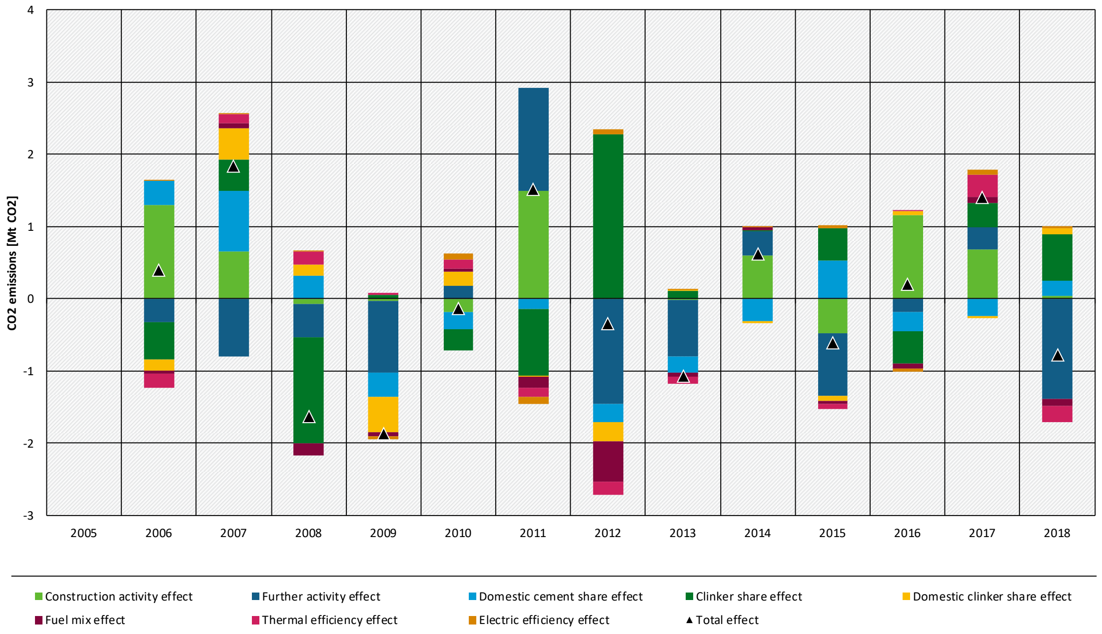
Compared to other countries, the fuel mix effect is quite pronounced in Germany whereas thermal efficiency has not changed much. Overall, CO_2 emissions from the cement sector in Germany have remained relatively stable since 2005.

Figure 12: Decomposition of the development of CO_2 emissions from cement production since 2005 in Germany



Source: Own calculations, Öko-Institut

Figure 13: Decomposition of the annual change of CO_2 emissions from cement production in Germany

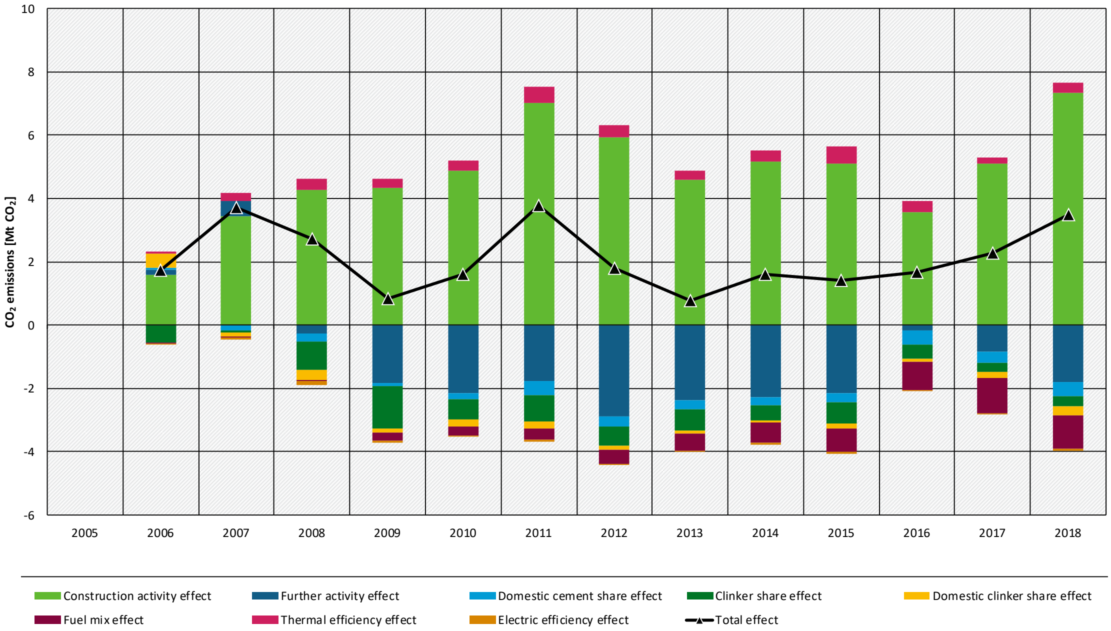


Source: Own calculations, Öko-Institut

3.2.5 Poland

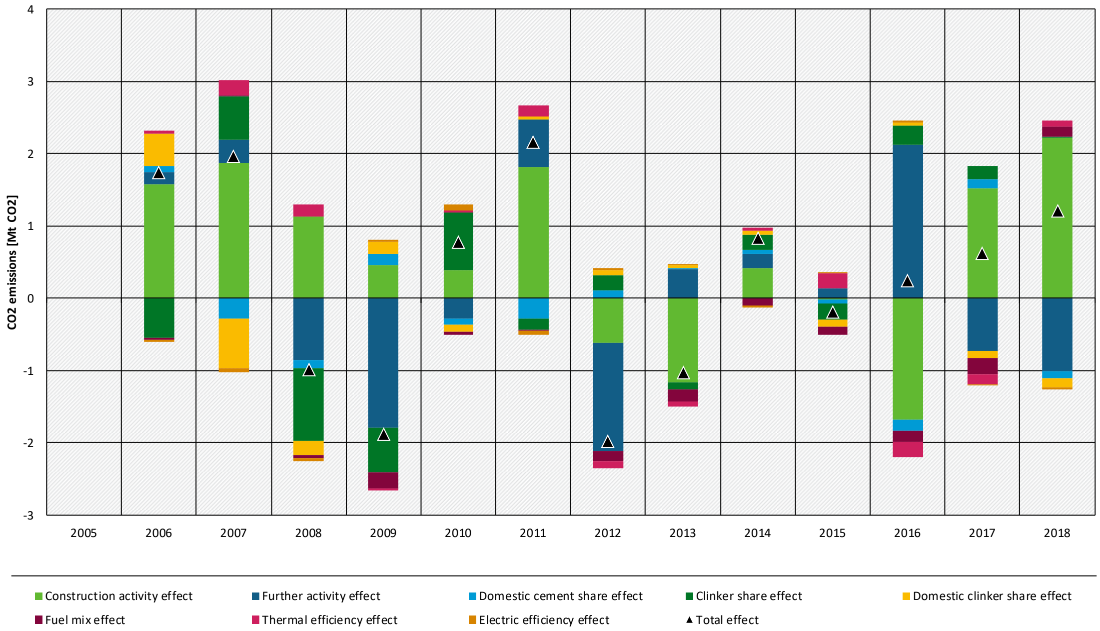
Among the countries assessed, construction activity was impacted the least by the global financial crisis in Poland. The European debt crisis led to a decline, but the 2011 level returned in 2018 due to a recovery of construction activity. Poland has been among the few countries with a net increase in CO_2 emissions from the cement sector since 2005. This is mainly due to the increased construction activity but also to a decreased thermal efficiency. Together with the further activity effect fuel switching was the main effect which helped curb the growth of emissions.

Figure 14: Decomposition of the development of CO_2 emissions from cement production since 2005 in Poland



Source: Own calculations, Öko-Institut

Figure 15: **Decomposition of the annual change of CO_2 emissions from cement production in Poland**



Source: Own calculations, Öko-Institut

4 Conclusions

Branger und Quirion (2015) developed a sound methodological approach for an LMDI decomposition analysis of the CO_2 emissions originating from the European cement industry. By using three partial governing functions and adding up the results of the corresponding effects in the three partial decompositions they were able to include more detail in the analysis than a single governing function could have provided. We replicate, and substantially extend their study by refining the methodological approach and by updating, and substantiating the employed dataset based on publicly available sources. In particular, we disentangle the dominant activity effect observed by Branger und Quirion (2015) into three drivers: (i) a construction activity effect, based on a country's production in construction index; (ii) a further activity effect determined by the cement-consumption-to-construction-activity ratio; and (iii) a domestic cement share effect, capturing the share of domestically produced cement in total cement consumption. The results of our analysis match the results of the preceding study quite well and we were able to extend the analysis until the year 2018 and to add more details on the activity effect.

Our decomposition analysis provides several insights, both at the country level and the level of individual drivers. At the EU level, the decomposition analysis identifies emission reductions in Spain and Italy as the main drivers for the decline in CO_2 emissions from the EU cement sector between 2005 and 2018. Out of the eight EU countries analysed in this paper, Poland is the only one where emissions from the cement sector have increased. Across the examined countries, emission trajectories are mainly driven by effects on the consumption of cement, rather than factors governing its production. Hence, negative economic shocks like the financial crisis of the years 2008/09 and the European debt crisis in 2011/12 have strongly contributed to reducing emissions from the EU cement sector. EU countries struggling most from these shocks like Italy and Spain show a significant reduction in emissions which can be attributed to a reduction in the construction activity effect and the further activity effect. Mostly unaffected by the financial crisis, Germany's emissions from the cement sector remained relatively stable between 2005 and 2018.

Interestingly, while both economic and financial shocks affected the Spanish cement industry and led to a reduction in CO_2 emissions, they worked through different channels: While the financial crisis of 2008/09 mainly affected both the construction activity and the further activity driver, the European debt crisis only channelled through the further activity effect. This suggests a structural change in the Spanish cement industry between 2008 and 2012.

In the study, we specify which and how the different drivers might have been influenced by CO_2 pricing through the EU ETS. The decomposition analysis method does not allow for any inference on causal effects; however, we provide clear arguments how drivers of cement consumption or cement production could react to CO_2 pricing signals. The construction activity itself (construction activity effect) and the change in type and quality of construction work (further activity effect) are the two main drivers governing the emissions trajectory from cement production between 2005 and 2018. While for the first one we argue that CO_2 pricing is not a major factor behind changes in this driver, the latter needs to be further disentangled to allow for clear conclusions. Presumably, cement from installations under the EU ETS could have had a competitive disadvantage due to additional CO_2 costs. However, both the share of domestically produced clinker and domestically produced cement have increased since the introduction of the EU ETS. In particular the increase in domestic clinker production, which is the most emission-intensive process step in cement production, suggests that the emissions pricing under the EU ETS did not have much influence on cement sourcing choices. This can be explained with low CO_2 price levels on the one hand, and the free allocation of certificates which have shed the industry from larger impacts on the other hand.

When it comes to cement production, CO_2 pricing could have induced a rapid increase in fuel efficiency or fuel switching. According to our analysis, both effects would have led to a reduction of emissions of 5% each, if examined in isolation. The contribution of the EU ETS to this development is not clear.

To put the results into perspective, it is important to note that the analysis looks at a past period with low CO_2 prices and two economic crises. Until 2015, CO_2 prices in the EU ETS were below 10€ per tCO_2. Since then prices have multiplied fivefold and are projected to increase further. Furthermore, one must bear in mind that the EU ETS is a cross-sectoral cap-and-trade system that aims at inducing emission reductions where they can be realised with the lowest costs. Hence, observing a lack of emissions decline from cement production does not allow for drawing conclusions on the overall effectiveness of the system. The analysis presents a rich explanation and decomposition of the drivers in the past, but the results cannot be used to infer effects of the EU ETS with high and increasing prices and a rapidly declining cap on the industry in the future.

While this analysis has substantially contributed to understanding drivers of emissions reduction in the EU cement sector, there are several avenues for further research. The further activity effect, identified as the strongest driver of CO_2 emissions, has yet to be understood in more detail. Given a consistent dataset, the effect could be further disentangled into the effect of substitution between different construction materials, the effect of predominant types of construction, the role of business cycles and further effects driving the input of cement for construction. While providing an excellent dataset for analysing the development to the EU cement sector, GNR data show some discontinuities which could be further analysed, potentially refining the presented results.

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A Annex

A.1 Reproducibility of the results by Branger und Quirion (2015)

Before expanding the governing function we tried to reproduce the results of Branger und Quirion (2015). As our analysis started with the year 2005 and their analysis ended with 2012, we compared the emission changes between 2005 and 2012 at EU28 level. The total effect (i.e. the emission change) differed by only 0.7% despite different approaches on calculating fuel-related and process-related emissions. Like in the Branger und Quirion (2015) results, we identified the activity effect as the dominant driver with our effect calculated to be larger by 23%. Branger und Quirion (2015) identified the clinker trade effect as the second largest emission effect and the largest driver for increasing emissions. In our analysis the effect differed only slightly (less than 1%). Both analyses show that the fuel mix effect, electric efficiency effect and grid emission factor had only a minor impact on the emission change between 2005 and 2012. Two drivers showed different directions of emission effects: While Branger und Quirion (2015) calculated an emission decreasing clinker share effect, our analysis showed an emission increasing effect. For the thermal efficiency effect, Branger und Quirion (2015) calculated a very small, almost zero emission increase while in our calculation the thermal efficiency showed a small emission decrease.

Although the different data sources led to some differences in results, we were able to reproduce the general picture and therefore decided to extend the analysis until the year 2018 and include further drivers (see chapter 2.2.3.1). The differences can partly be attributed to data revisions. The differences in both the activity effect and the clinker share effect are at least partly caused by our change of the data source for the cement production data (see chapter 2.2.3.3).

A.2 Final equations

A.2.1 Fuel-related emissions C(F,t)

$$C_{F,t} = Q_{cement,t} \times X_t \times H_{cement,t} \times R_t \times H_t \times I_{T,t} \times CEF_{F,t} \tag{14}$$

$$C_{F,t} = Q_{construction,t} \times \frac{Q^{NET}_{cement,t}}{Q_{construction,t}} \times \frac{Q^{PROD}_{cement,t}}{Q^{NET}_{cement,t}} \times \frac{Q^{NET}_{clinker,t}}{Q^{PROD}_{cement,t}} \times \frac{Q^{PROD}_{clinker,t}}{Q^{NET}_{clinker,t}} \times \frac{E_{T,clinker,t}}{Q^{PROD}_{clinker,t}} \times \frac{C_{F,t}}{E_{T,clinker,t}} \tag{15}$$

The fuel-related emissions $C_{F,t}$ are a product of

- the construction production volume index $Q_{construction,t}$;
- the cement intensity X_t given as the amount of cement used $Q^{NET}_{cement,t}$per unit of the construction production volume index $Q_{construction,t}$;
- the cement home production ratio $H_{cement,t}$ given as the ratio of the quantity of cement produced $Q^{PROD}_{cement,t}$ and the quantity of cement used domestically $Q^{NET}_{cement,t}$;
- the clinker-to-cement ratio R_t given as the ratio of the quantity of cement used domestically $Q^{NET}_{clinker,t}$ and the quantity of cement produced $Q^{PROD}_{cement,t}$;
- the clinker home production ratio H_t given as the ratio of the quantity of clinker produced $Q^{PROD}_{clinker,t}$ and the quantity of clinker used to manufacture cement $Q^{NET}_{clinker,t}$;

- the thermal energy intensity $I_{T,t}$ given as the ratio of the thermal energy used for clinker production $E_{T,clinker,t}$ (excluding energy for drying) and the quantity of clinker produced $Q_{clinker,t}^{PROD}$;
- the carbon intensity of the fuel mix $CEF_{F,t}$ given as the ratio of the fuel-related emissions $C_{F,t}$ and the thermal energy used for clinker production $E_{T,clinker,t}$.

A.2.2 Process emissions C(P,t)

$$C_{P,t} = Q_{cement,t} \times X_t \times H_{cement,t} \times R_t \times H_t \times CEF_{pro} \tag{16}$$

$$C_{P,t} = Q_{construction,t} \times \frac{Q_{cement,t}^{NET}}{Q_{construction,t}} \times \frac{Q_{cement,t}^{PROD}}{Q_{cement,t}^{NET}} \times \frac{Q_{clinker,t}^{NET}}{Q_{cement,t}^{PROD}} \times \frac{Q_{clinker,t}^{PROD}}{Q_{clinker,t}^{NET}} \times \frac{C_{P,t}}{Q_{clinker,t}^{PROD}} \tag{17}$$

The process emissions $C_{P,t}$ are a product of

- the construction production volume index $Q_{construction,t}$ as above;
- the cement intensity X_t as above;
- the cement home production ratio $H_{cement,t}$ as above;
- the clinker-to-cement ratio R_t as above;
- the clinker home production ratio H_t as above;
- the time- and country-independent carbon emission factor of limestone calcination CEF_{pro} given as the ratio of the process emissions $C_{P,t}$ and the quantity of clinker produced $Q_{clinker,t}^{PROD}$.

A.2.3 Indirect emissions from electrical energy consumption C(E,t)

$$C_{E,t} = Q_{cement,t} \times X_t \times H_{cement,t} \times I_{El,t} \times CEF_{elec,t} \tag{18}$$

$$C_{E,t} = Q_{construction,t} \times \frac{Q_{cement,t}^{NET}}{Q_{construction,t}} \times \frac{Q_{cement,t}^{PROD}}{Q_{cement,t}^{NET}} \times \frac{E_{E,t}}{Q_{cement,t}^{PROD}} \times \frac{C_{E,t}}{E_{E,t}} \tag{19}$$

The emissions from electrical energy consumption $C_{E,t}$ are a product of

- the construction production volume index $Q_{construction,t}$ as above;
- the cement intensity X_t as above;
- the cement home production ratio $H_{cement,t}$ as above;
- the electrical energy intensity $I_{El,t}$ given as the ratio of the electricity used for cement production $E_{E,t}$ and the quantity of cement manufactured $Q_{cement,t}$;
- the electricity emission factor $CEF_{elec,t}$ given as the ratio of the indirect emissions from electrical energy consumption[18] $C_{E,t}$ and the electrical energy used for cement production $E_{E,t}$.

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[18] We deviate from the approach used by Branger und Quirion (2015) by applying a direct emission factor instead. See section 2.2.3.3 for more details.

A.2.4 Calculating overall emission effects

The effects of all drivers add up to the total emission effect:

$$\begin{aligned}\Delta^{tot} = {} & \Delta^{con,F} + \Delta^{act,F} + \Delta^{tra_{cem},F} + \Delta^{sha,F} + \Delta^{tra,F} + \Delta^{eff,F} + \Delta^{fmix} \\ & +\Delta^{con,P} + \Delta^{act,P} + \Delta^{tra_{cem},P} + \Delta^{sha,P} + \Delta^{tra,P} \\ & +\Delta^{con,E} + \Delta^{act,E} + \Delta^{tra_{cem},E} + \Delta^{eff,E} + \Delta^{\mathrm{C,elec}}\end{aligned} \tag{20}$$

Some of the partial effects can be aggregated as they are of the same kind resulting in a shorter equation:

$$\Delta^{tot} = \Delta^{con} + \Delta^{act} + \Delta^{tra_{cem}} + \Delta^{sha} + \Delta^{tra} + \Delta^{fmix} + \Delta^{eff,F} + \Delta^{eff,E} + \Delta^{C,elec} \tag{21}$$

The following effects were included in the analysis by the development of corresponding drivers over time:

- Construction activity effect Δ^{con} determined by the construction activity $Q_{construction,t}$;
- a further activity effect Δ^{act}determined by the cement-consumption-to-construction-activity ratio;
- domestic cement share effect $\Delta^{tra_{cem}}$ determined by the cement-consumption-to-cement-production ratio;
- activity effect Δ^{act} determined by the cement manufactured $Q_{cement,t}$;
- clinker share effect Δ^{sha} determined by the clinker-to-cement ratio R_t;
- clinker trade effect Δ^{tra} determined by the clinker home production ratio H_t;
- fuel emission effect Δ^{fmix} determined by the carbon intensity of the fuel mix $CEF_{F,t}$;
- thermal efficiency $\Delta^{eff,F}$ determined by the thermal energy intensity $I_{T,t}$;
- electric efficiency $\Delta^{eff,E}$ determined by the electrical energy intensity $I_{El,t}$;
- grid emission factor effect $\Delta^{C,elec}$ determined by the electricity emission factor $CEF_{elec,t}$.