Modelling circular economy action impacts in the building sector on the EU cement industry

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Abstract

The 2015 Paris Agreement aims to strengthen the global response to the threat of climate change by keeping global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. The industrial sector in particular will need a bundle of technologies and measures that go beyond energy efficiency and fuel switching. In this context, circular economy is an important pillar in reducing the demand for energy-intensive raw materials and gains momentum in the political debate. This contribution to the eceee Industrial Efficiency 2020 presents the potential impacts of selected circular economy actions in the building sector on cement production and CO_2-emissions in the cement industry. The analysis is based on a bottom-up material flow modelling approach. The assessed measures include actions along the whole value chain. Some examples are the reduction of over specification, material substitution (e.g. new binders, wood use), extending buildings' lifetime, design for disassembly, etc. Results show that circularity measures could substantially contribute to the objective of a CO_2-neutral economy (not taking into account rebound effects). The overall greenhouse gas reduction potential is calculated as 58 % compared to a 2015 base case. In addition, the individual actions' contribution is presented. We conclude that effort along the entire value chain is necessary to enable the construction sector to contribute to European climate policy.

Introduction

The 2015 Paris Agreement aims to strengthen the global response to the threat of climate change by keeping global temperature rise in this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. To achieve this target, the industrial sector in particular will need a bundle of technologies and measures that go beyond energy efficiency and fuel switching. In this context, circular economy is an important pillar in reducing the demand for energy-intensive raw materials and gains momentum in the political debate.

In December 2019, the European Comission published its communication on the "The European Green Deal" highlighting to mobilise industry for a clean circular economy to transform the European Union into a CO_2-neutral system in which growth is decoupled from resource use (COM(2019) 640). To support this, the European Commission published in March 2020 a "New Circular Economy Action Plan". The main pillars of this action plan include (COM(2019) 640):

- **Making products in the EU sustainable (Sustainable Product Policy)** via designing them to last longer, for reuse, for repair and recycle, and by increasing the share of recycled materials in production instead of using virgin materials. Furthermore, single use should be prevented and destruction of unsold durable goods forbidden.
- **Empowering consumers** via information that helps them to make sustainable choices and via a true 'right to repair'.
- **Ensuring less waste** via avoidance and high-quality secondary use (e.g. via an EU-wide harmonised collection and labelling model).

Main focus of the European Commission will be sectors with high resource demand combined with high circularity potential: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, and food. Taking up this important topic to decarbonise EU industry, this contribution to the eceee Industrial Efficiency 2020 presents the potential impacts of selected circular economy actions in the construction sector. This sector is important as it includes the production of vast amounts of an energy- and CO_2-intensive products. The single most important product is concrete (and its precursor products cement and clinker), which is normally regionally produced within the EU. Consequently, circularity measures in the construction industry could make a significant contribution to reduce CO_2-emissions in the European cement industry. For example, a recent study of Material Economics (2018) shows that a circular economy can lead to significant reductions in industrial CO_2 emissions at EU level. In the analysed 2050 Circular Scenario, a reduction potential of 56 % was calculated for selected industrial sectors (steel, cement, aluminium, plastics). Three main groups of measures are identified in the study: material recycling opportunities, product material efficiency and new circular business models.

For the reduction of demand in building materials this translates into circularity measures increasing 'buildings' longevity and adaptability; disassembly at the end of life; and reuse of intact structural components' as well as 'increased standardization, improved planning, appropriate storage and transportation' to reduce waste, new business models using space more efficiently and the use of recycled materials (e.g. cement or concrete). The analysis showed that material based CO_2 emissions in the buildings sector could be 53 % in 2050, incl. steel, aluminium, plastics and cement (Material Economics, 2018).

Further studies, e.g. Allwood et al. (2017) also identified similar pillars to reduce material demand in construction: Efficient structural design in line with existing Eurocodes (e.g. no overdimensioning, efficient offsite fabrication, reducing material in superstructure to decrease loads to the foundations); Building life extension (e.g. design for reconfiguration, easy access maintenance, and easier replacement of components); Material options either via material re-use (element- or component-level) or the use of natural elements. All of the above mentioned strategies can only be successful in the necessary extent if appropriate policy and regulatory measure support the transformation process.

The following analysis of circular economy action (CE-actions) impacts in the building sector on the EU cement industry is based on a bottom-up material flow modelling approach, which allows simulating the impact of circularity measures in a very detailed level. The assessed measures include actions along the whole value chain. Some examples are the reduction of over specification, material substitution (e.g. new binders, wood use), extending buildings' lifetime and design for disassembly. Results show that circularity measures could substantially contribute to the objective of a CO_2-neutral economy (not taking into account rebound effects). The impact of each action as well as their interaction will be discussed in the following sections and mitigation potentials identified.

Methodology and Data

METHODOLOGY

With the goal to estimate the impact of CE-actions on the CO_2-emissions of cement and concrete use in the buildings sector, we divide the methodological approach in three phases. First, the **material flow from raw material to final product** is modelled (simplified approach based on Shanks et al. 2019). This requires the creation of a quantitative structure of the current material use as a base case. For cement, this involves the preparation of raw materials and the production of clinker, followed by grinding and mixing to cement. The second phase tracks the **material flows from the final product to its end use applications**. For cement, this involves the further processing and fabrication of cement to different types of concrete, namely precast concrete elements, concrete based on ready-mix cement and other (non-concrete) applications of cement. These concrete types are then allocated to their end use in residential and non-residential buildings as well as infrastructure. With this structure, the material flow from raw material to end use can be quantified (Figure 1). The base case reflects the material use in the EU28 in 2015. The corresponding energy demand and CO_2 emissions are determined along the material flow using specific energy consumption (per tonne of material/product) by energy carrier and process step and the associated CO_2 emission factors (for details on specific energy demand by process see Rehfeldt et al. 2017).

The **third phase introduces CE-actions** to the base case and thus estimates their CO_2-emission reduction potential, assuming otherwise constant conditions. These CE-actions influence the material demand (e.g. concrete demand in the residential sector) and thus reduce energy demand and process-related emissions along the value chain (see Figure 2).

The applied model also includes simplified calculations on the transport-related emissions. It includes the transported tonnage, modal split (truck, train, inland and sea ship), transport range assumptions and the respective specific emission factors. Based on Prodcom statistics (Eurostat 2019), about 26 Mt clinker and cement were traded outside the EU in 2015, most of them from Mediterranean EU-members. Most important trade partners are (North-) African and American countries as well as Turkey (European Commission 2018). The energy demand in the construction sector is represented in the model by the Eurostat energy balance category (76 TWh in 2015). It is not disaggregated further.

DATA

The generation of the material flow model in the phases one and two require physical data on material inputs and production amounts (e.g. clinker and cement), technological data (e.g. specific energy demand by clinker burning process, concrete composition) and data on the end use of concrete in the building sector (Table 1). Main data source of production figures and technological data is the GNR project, covering the EU28 and several individual countries with high cement production, for which the provided data has been validated and extended with national associations' statistics (e.g. VDZ for Germany, oficemen for Spain, mpa for the United Kingdom). These data points must be considered assumptions due to only partial coverage. For ex-

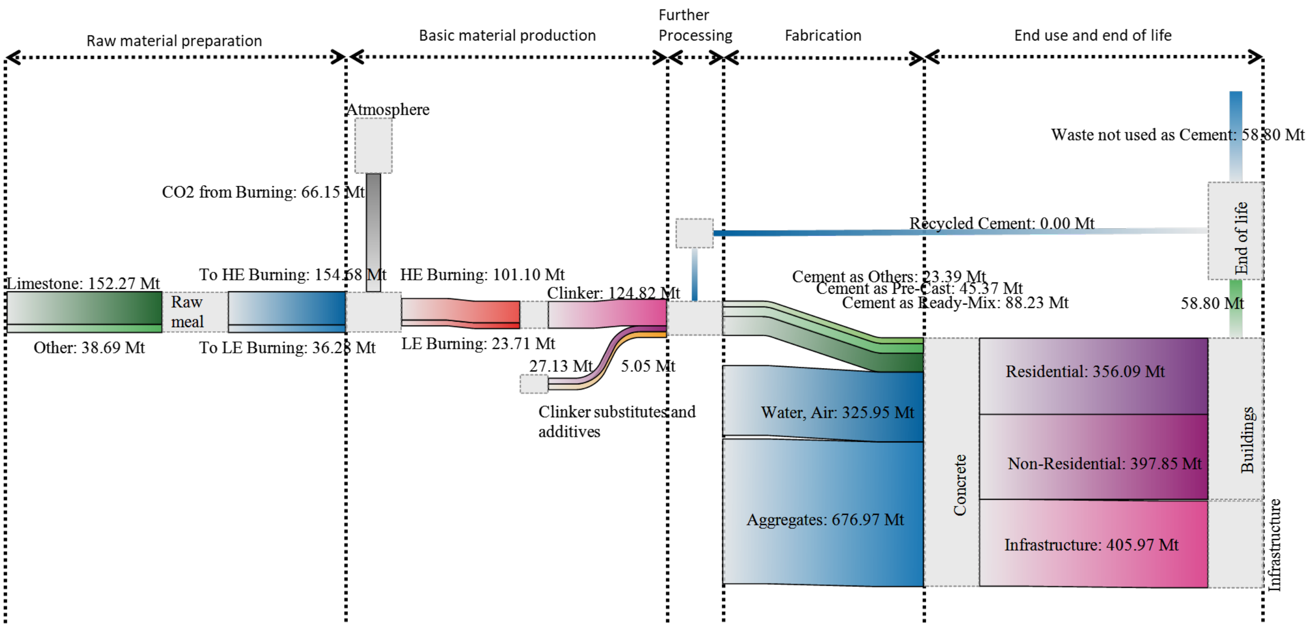

Figure 1. Material flow model of cement production/processing and end use in the EU28 building sector (base case 2015). Source: Fraunhofer ISI, own illustration of data given in Table 1.

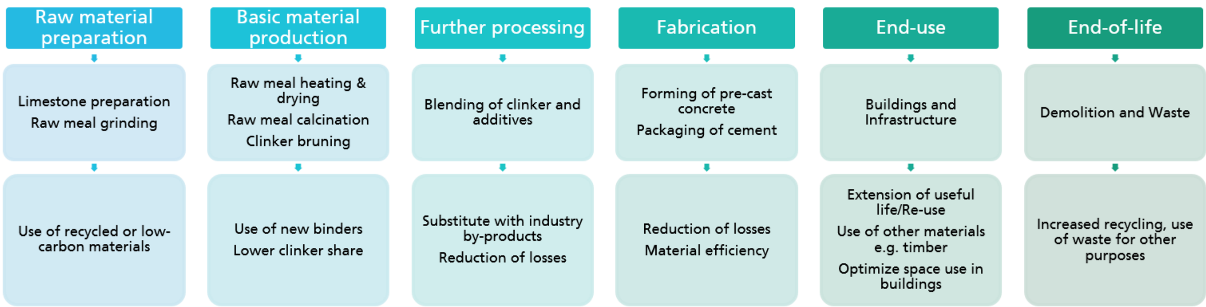

Figure 2. Generic illustration of linking CE-actions to the material flow of cement production. Source: Fraunhofer ISI own illustration.

ample, the end use of cement in residential, non-residential and infrastructure for the EU is derived from data of the Spanish and German cement associations, covering just 28 % of EU28 cement production. The delivery type (ready-mix, pre-cast, other) is based on data from Belgium, United Kingdom, Germany and Italy covering 44 % of the EU28 cement production.

Phase three uses data and estimates about the specific potential of CE-actions in the building sector (Table 2). Often only limited data is available for selected countries or best-practice cases. Nevertheless, in this step impacts of the CE actions compared to a baseline, as well as their feasibility and applicability has been assessed and interpreted in terms of the used modelling approach to affect distinct model values (e.g. the share of cement in concrete or the concrete demand for residential buildings).

Results

The implementation of the CE-actions shown in the previous section to the material flow of cement production and use in the construction industry yields the potential for significant CO_2-emission reductions. However, the actual future reduction potentials depend on a variety of factors, e.g. the future development of the European building stock, the future energy carrier mix of heat and electricity generation, local raw material availability, future policy and regulatory framework, and the ambition of the sector's transformation to sustainable production and consumption.

In this analysis, these important factors are kept constant at the level of the base case in 2050. Therefore, the results presented here do not picture a forecast or prediction of a future scenario but a counterfactual estimate of the CO_2-mitigation potential of CE-actions in the sector. They thus answer the question: "If the selected CE actions were applied in current conditions, what emission reduction would they cause?". Deviating from this basis, we consider a limited impact of actions that affect the building stock ('design buildings for disassembly', 'optimize the use of space', 'renovate instead of building anew', 'reuse structural concrete elements'), equivalent to a virtual diffusion through the stock until 2050. In this section, we present the potential CO_2-savings. First, in a summarized view as a combination of all considered CE-actions and second as an individual account of each CE-actions' contribution. For simplicity, the presentation is restricted to a 'high ambition' scenario, applying the maximum diffusion of all CE-actions. The results

Table 1. List of data points for the bas case material flow model.

Stage	Indicators	Value	Unit	Type	Source	Confi-dence
Manufac-turing	Clinker production	125	Mt	Statistics	Cement Sustainability Initiative (2016)	High
	Cement production	157	Mt	Statistics	Cement Sustainability Initiative (2016)	High
	SEC_heat average	3.73	GJ/t	Statistics	Cement Sustainability Initiative (2016)	High
	Limestone use per tClinker	1.17	t/t	Assumption	Basten (2002)	Medium
	Other raw material use per tClinker	0.31	t/t	Assumption	Basten (2002)	Medium
	Clinker/Cement	0.80	t/t	Calculated		High
	Share biomass on total energy	15	%	Statistics	Cement Sustainability Initiative (2016)	High
	Share fossil fuels on total energy	57	%	Statistics	Cement Sustainability Initiative (2016)	High
	Share alternative fuel on total energy	28	%	Statistics	Cement Sustainability Initiative (2016)	High
	Process-related emissions (clinker)	0.53	tCO_2/ tClinker	Kiln mass bal-ance		High
Process-ing and use	Cement in residential	31	%	Assumption	VDZ (2018), oficemen (2016)	Medium
	Cement in non-residential	34	%	Assumption	VDZ (2018), oficemen (2016)	Medium
	Cement in infrastructure	35	%	Assumption	VDZ (2018), oficemen (2016)	Medium
	Cement as transport concrete	56	%	Assumption	Febelcem (2018), VDZ (2018), oficemen (2016), mpa (multi-ple), AITEC (2017)	Medium
	Cement as precast concrete	29	%	Assumption	Febelcem (2018), VDZ (2018), oficemen (2016), mpa (multi-ple), AITEC (2017)	Medium
	Cement as other deliverable	15	%	Assumption	Febelcem (2018), VDZ (2018), oficemen (2016), mpa (multi-ple), AITEC (2017)	Medium
	Share of cement in ready-mix concrete	13	%	Literature	Bender-Graß et al. (2015)	High
	Share of cement in precast concrete	17	%	Literature	Becke et al. (2014)	High
	Share of aggregates in concrete (ready mix)	68	%	Literature	mpa	High
	Share of aggregates in concrete (pre-cast)	63	%	Assumption		
	Energy use in construction sector	76	TWh	Statistics	Eurostat energy balance (2018)	High
Transport	Truck emission factor	0.06	tCO_2/kt-km	Literature	Andreesen (2011)	High
	Train emission factor	0.02	tCO_2/kt-km	Literature	Andreesen (2011)	High
	Ship (inland) emission factor	0.03	tCO_2/kt-km	Literature	Andreesen (2011)	High
	Ship (sea) emission factor	0.01	tCO_2/kt-km	Literature	Andreesen (2011)	High
	Transport range concrete and aggregates (truck)	100	km	Literature	Federal Cartel Office (2017)	Medium
	Transport range concrete and aggregates (train)	300	km	Assumption		Low
	Transport range concrete and aggregates (ship, inland/sea)	500–2000	km	Assumption		Low

Source: Fraunhofer ISI own compilation.

Table 2. Model implementation and specific potential of CE-actions.

Name	Source	Base for applicability	Applicability	Affected model value	Unit impact	Model impact
Reducing use of concrete at design stage (reducing over specification by volume)	Miller and Doh (2015)	Concrete use in buildings	100 %	Concrete use (buildings)	-12 %	-12 %
Reducing use of concrete at design stage (reducing over specification by strength class)	Miller and Doh (2015)	Cement in concrete (buildings)	100 %	Cement share in concrete	-29 %	-29 %
Use other types of cement as a substitute for ordinary cement	Stemmermann et al. (2011)	All cement	30 %	Limestone use in clinker	-50 %	-50 %
Use innovative pre-cast concrete as a substitute for ordinary cement	Aurélie et al. 2018	Precast concrete	100 %	Process-related emissions in pre-cast	-70 %	-70 %
Use industry by-products in cement production	Garcia-Segura et al. (2014)	Cement use	15 %	Clinker share in cement	-80 %	-80 %
Use timber as the structural material in buildings instead of mineral materials in residential buildings	Eliassen (2019), Hafner and Schäfer, (2017)	Residential buildings	100 %	Concrete use in residential	-45 %	-45 %
Optimize the use of space in office buildings	Economidou et al. (2011)	Non-residential buildings	100 %	Concrete use in non-residential	-36 %	-36 %
Optimize the use of space in residential buildings	Günther et al. (2019)	Residential buildings	100 %	Concrete use in residential	-11 %	-11 %
Renovate instead of building anew	Artola et al. (2016), Eskilsson (2015)	Residential buildings	100 %	Concrete use in residential	-7.5 %	-4 %
Reuse structural concrete elements	Economidou et al. (2011)	Concrete use in buildings	30 %	Pre-cast concrete use	-50 %	-14 %
Recycle cement in concrete waste using innovative technology	Bakker et al. (2015)	Construction waste	100 %	Alternative cement-source	-25 %	-25 %
Design buildings for disassembly	Paananen and Suur-Askola (2018), Tingley and Davison, (2012).	All concrete buildings	28 %	Reusable concrete (pre-cast)	-70 %	-0.42 %

Source: Ramboll own compilation.

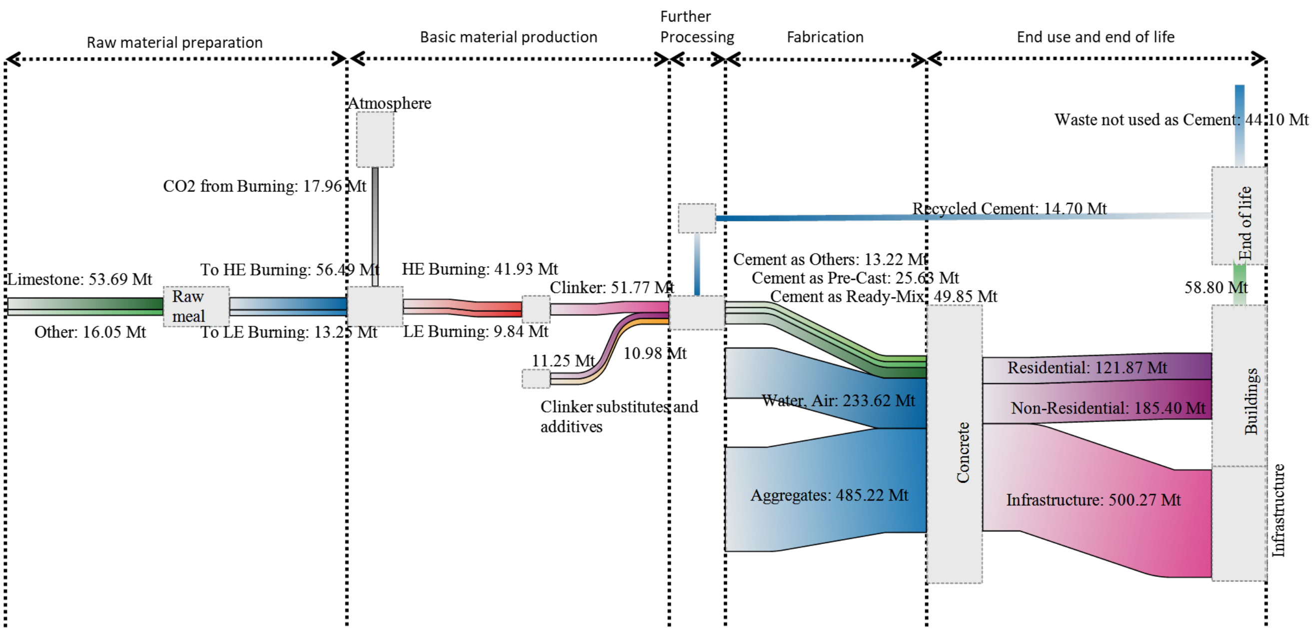

Figure 3. Material flow model of cement production/processing and end use in building sector (scenario including CE-actions). Source: own illustration of data given in Table 1, Table 2.

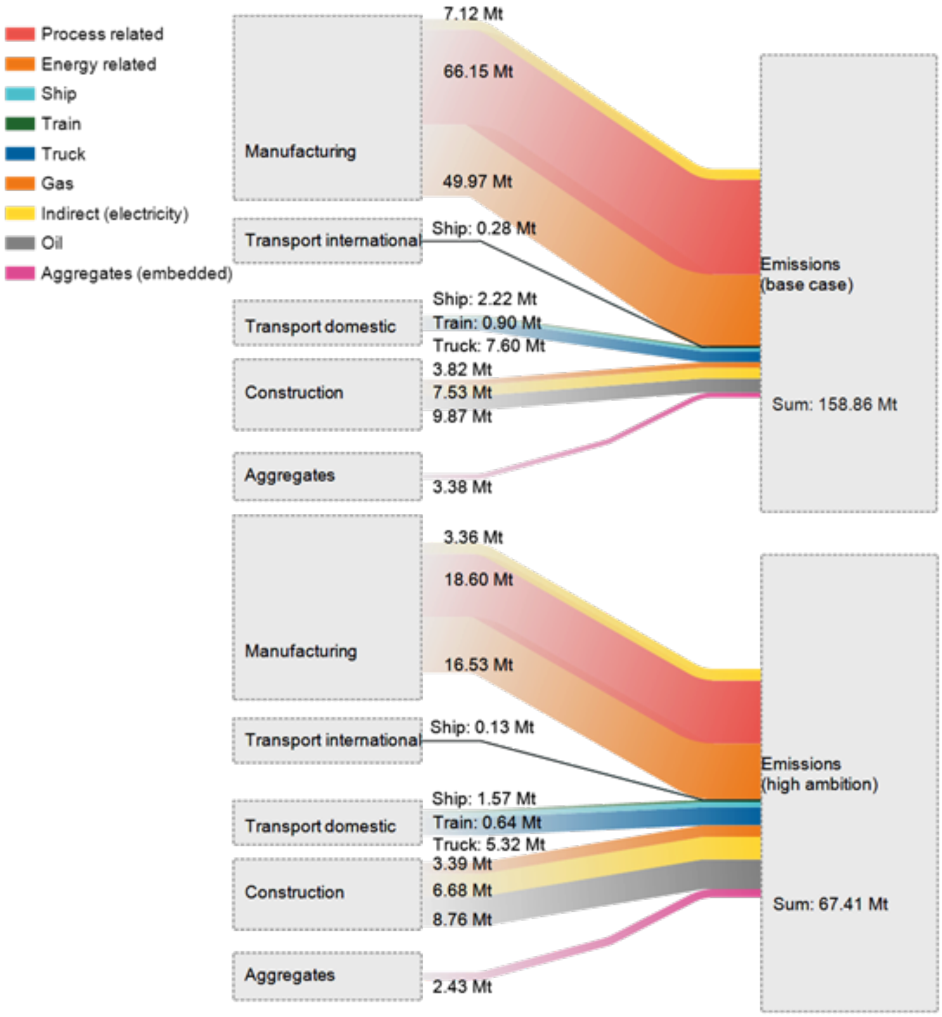

Figure 4. CO_2-emissions by source category (top: base case, bottom: high ambition scenario). Source: own illustration using e!Sankey.

are based on the material flow presented in Figure 3, including the effects of CE-actions.

In the base case, the emissions from manufacturing, transport, construction activities, emissions embedded in the concrete aggregate and indirect emissions from electricity use amount to 158.86 Mt (Figure 4, top). Direct emissions from manufacturing account for 116.12 Mt (73 %). The next highest emission source is energy use in the construction sector with 13.70 Mt, followed by domestic transport (10.73 Mt) and embedded emissions in concrete aggregates (3.38 Mt). International transport, which mainly takes place via ship and includes low amounts of transported goods (21 Mt of clinker and cement, combined import and export) accounts for 0.28 Mt of emissions. The values given here account for the full emissions generated by international transport (port to port). The mode of domestic transportation with the highest emissions is by road (truck), with 7.60 Mt, followed by ship (2.22 Mt) and train (0.90 Mt). Indirect emissions from electricity use (in the construction sector itself and in cement manufacturing) account for 14.65 Mt.

In the high ambition scenario (100 % diffusion of all CE actions), the emissions from manufacturing, transport, construction activities, embedded emissions in the concrete aggregate and indirect emissions from electricity use amount to 67.41 Mt (Figure 4, bottom). Direct emissions from manufacturing account for 35.14 Mt (52 %). The next highest source is energy use in the construction sector with 12.15 Mt, followed by domestic transport (7.52 Mt) and embedded emissions in concrete aggregates (2.43 Mt). International transport accounts for 0.13 Mt. The mode of domestic transportation with the highest emissions is by road (truck), with 5.32 Mt, followed by ship (1.57 Mt) and train (0.64 Mt). The emission reduction amounts to 80.03 Mt (50 %). Indirect emissions from electricity use (in the construction sector itself and in cement manufacturing) account for 10.04 Mt.

In the high ambition scenario, the applied CE-actions thus reduces the overall emissions of the construction sector related to cement/concrete manufacturing, transport and use by about 58 % (91.45 Mt). The selected CE-actions affect all investigated source categories, from process- to energy related manufacturing emissions to transport and energy use during construction. However, the manufacturing stage is most affected, with relative savings of about 70 %. In contrast, emissions caused by energy use during construction is merely reduced by 12 %[1].

1. Due to the relatively low absolute emissions, the construction sector itself is not focused by this analysis and no CE-action directly targets it. It is, however, affected by CE-actions targeting end-use.

Table 3. Individual CE-actions' emission reductions.

Emission reduction in Mt	**Cement**				**Transport**				**Construction**		**SUM**
Emission source	Manu-facturing process-related	Manu-facturing energy-related	Manu-facturing indirect (electric-city)	Manu-facturing Aggrey-gates	Ship interna-tional	Ship inland	Train	Truck	Energy use	Indirect (electric-city)	Cement, Trans-port & Construc-tion
Base case 2015 (total emissions)	**66.15**	**49.97**	**7.12**	**3.38**	**0.28**	**2.22**	**0.90**	**7.60**	**13.70**	**7.53**	**158.86**
Reducing use of concrete at design stage (reducing over specification by volume)	5.16	3.90	0.56	0.26	0.02	0.17	0.07	0.59	0.00	0.00	10.74
Reducing use of concrete at design stage (reducing over specification by strength class)	8.11	6.12	0.87	-0.38	0.03	-0.18	-0.06	-0.53	0.00	0.00	13.98
Use other types of cement as a substitute for ordi-nary cement	9.92	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	9.94
Use innovative pre-cast concrete as a substitute for ordinary cement	13.38	10.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.49
Use industry by-products in cement production	7.94	6.00	0.00	0.00	0.01	0.00	-0.02	-0.12	0.00	0.00	13.79
Use timber as the structural material in buildings instead of mineral materials in residential buildings	9.14	6.90	0.98	0.47	0.04	0.31	0.12	1.05	0.00	0.00	19.01
Optimize the use of space in office buildings	8.17	6.17	0.88	0.42	0.04	0.27	0.11	0.94	1.23	0.68	18.91
Optimize the use of space in residential buildings	2.23	1.69	0.24	0.11	0.01	0.07	0.03	0.26	0.43	0.23	5.31
Renovate instead of building anew	0.72	0.54	0.08	0.04	0.00	0.02	0.01	0.08	0.31	0.17	1.98
Reuse structural concrete elements	6.21	4.69	0.67	0.32	0.03	0.21	0.08	0.71	0.00	0.00	12.93
Recycle cement in concrete waste using innovative technology	6.19	4.68	0.67	0.00	0.03	-0.02	0.00	-0.03	0.00	0.00	11.51
Design buildings for disassembly	0.05	0.04	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.11
Combination (remaining emissions)	**18.60**	**16.53**	**3.36**	**2.43**	**0.13**	**1.57**	**0.64**	**5.32**	**12.15**	**6.68**	**67.41**

Source: Fraunhofer ISI own calculations.

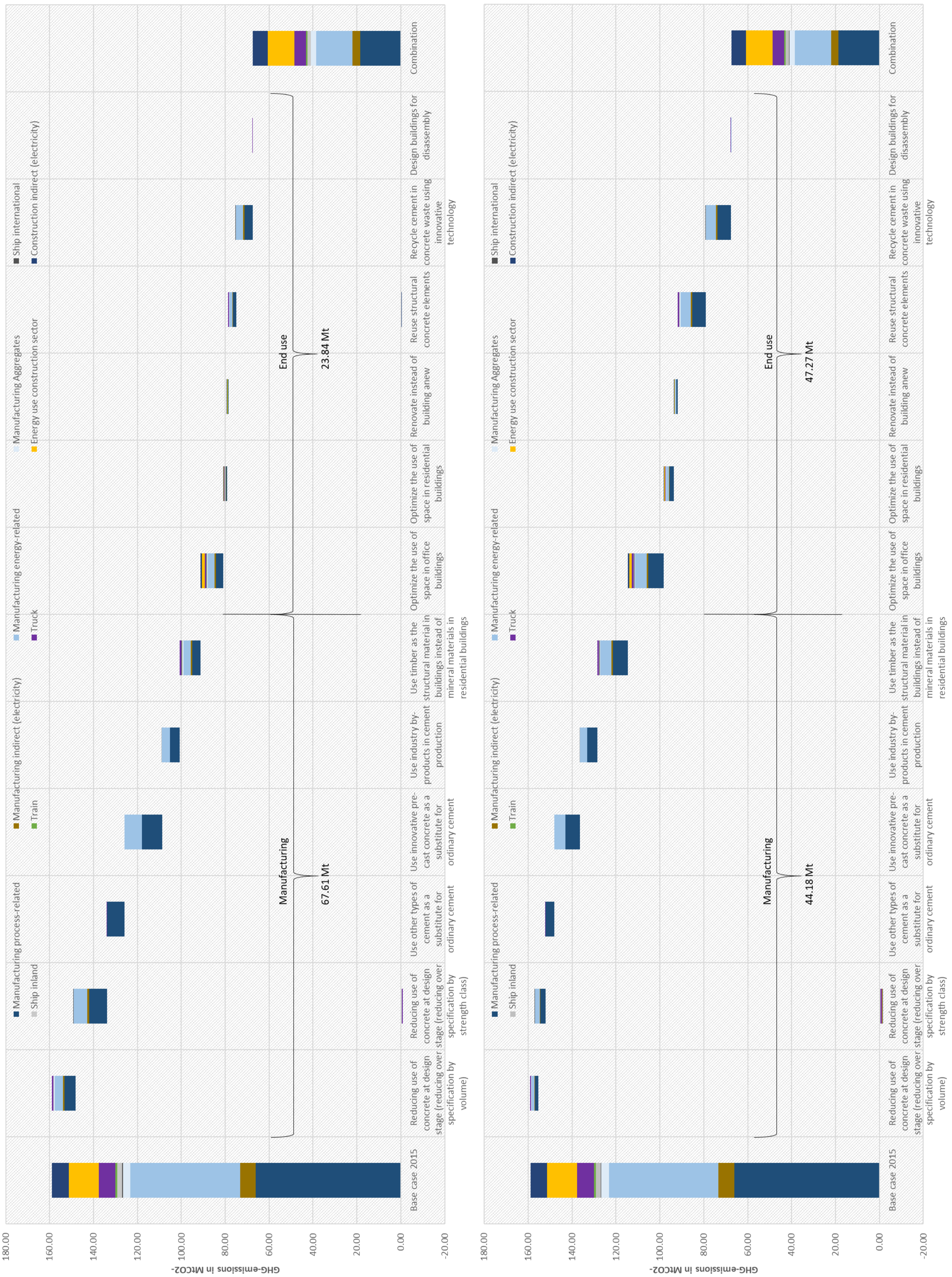

Figure 5. Representation of individual CE-actions' impact on emission reduction and allocation of interaction effects (top: interaction effects mainly allocated to manufacturing stage; bottom: interaction effects mainly allocated to end-use stage). Source: Fraunhofer ISI own illustration.

The considered CE-actions contribute differently to this combined result. Table 3 shows the emission reductions by CE-action, if they are applied individually. Among the CE-actions with the strongest individual contribution are the use of new cement types for pre-cast concrete elements (23.49 Mt), increased use of timber as building material (19.01 Mt) and reduced space use in buildings (18.91 Mt offices and 5.31 Mt residential buildings).

Note that these individual emission reductions cannot be summed directly, as interaction effects between the CE-actions yield diminishing returns. The combined effect of all actions (91 Mt) is thus substantially lower than the sum of the individual actions' effects (142 Mt). For example, the replacement of clinker in cement with industry by-products (individual effect: 13.79 Mt) and optimized space use in residential buildings (individual effect: 5.31 Mt) reduce emissions by 18.6 Mt when combined (0.5 Mt less than individually).

In the applied model, the allocation of these effects to CE-actions depends on the order of calculation. The first of two interacting CE-actions will include the interaction effect, the second will not. To highlight these interaction effects, Figure 5 presents two alternative approaches on the accounting of chained CE-actions' impacts. In the top half, the CE-actions are calculated from left to right, allocating interaction effects mostly to the manufacturing stage (and within it, to the first CE-actions). The first six CE-actions thus account for almost three quarter of the total potential (67.61 Mt of 91.45 Mt) In the bottom half, the CE-actions are calculated from right to left, leaving a considerable higher share of the combined emission reduction (47.27 Mt) in the end use stage. Both perspectives are arbitrary and equally justified. A closer investigation of the individual CE-actions may reveal how a fair allocation of the impacts should be conducted. This might be especially relevant for the realization of cross-sectoral CE-actions[2].

Summary and Conclusions

In this contribution, we develop a material flow model of cement manufacturing, processing and its use in the construction sector and linked it with energy demand and CO_2-emissions along the material flow. We include emissions from manufacturing, extra-EU and domestic transport, fuel use, electricity and process emissions and energy use for actual construction activity for the base year of 2015. The application of selected actions of material efficiency, circular economy and sufficiency to this quantitative base case in a high ambition scenario shows that the considered actions can contribute substantially to the decarbonisation of the sector, yielding CO_2-emission reductions of 91 Mt (58 %). The manufacturing stage (i.e. clinker burning) accounts for the highest share both in absolute emissions and saving potentials. However, actions affecting the end use (e.g. optimized space use, reuse of concrete elements) indirectly affect the manufacturing stage by reducing material demand and thus also show relevant potentials. Therefore, while the manufacturing stage is the by far most emission intensive element in the life cycle of cement and concrete, CE actions in all life cycle stages can be effective measures for CO_2-emission reduction. Although not focused in this contribution, energy efficiency, fuel switch and innovative production processes for basic materials in general and cement in particular are of equally high importance.

The applied methodology and data inherently show a number of uncertainties that shall be mentioned swiftly.

First, the data used to set up the quantitative model include assumptions and extrapolations from limited data sets. For example, while data on clinker and cement production can be considered to be highly reliable, the respective cement's end use (residential and non-residential buildings, infrastructure) is not regularly reported but extrapolated from national reports, covering ~60 % of European cement production. Shifts in the end use shares may have substantial effect on the actions' effects, as these target specific end uses. Sensitivity calculations (not presented in this paper) show low sensitivity with regard to a shift between residential and non-residential buildings (-0.08 Mt/% residential share). The share of infrastructure has a higher impact (+0.75 Mt/% infrastructure share) on the remaining CO_2-emissions. This can be explained with the focus on building-related actions.

Second, data on the actions specific saving potential are uncertain. While for model implementation, in Table 2, strict values were used, sources present ranges of saving potentials. For example, the optimization of space use in residential buildings is estimated to reduce the required space somewhere between 4 % (EU) and 11 % (Germany).

Third, the material flow model includes only a limited representation of the end use, in particular the building stock. While for many investigated actions that affect the yearly production of cement (e.g. cement substitutes, clinker share variations), this perspective is sufficiently detailed, other actions would benefit from much more detailed representation of the building stock. An example for the difficulties arising from the missing building stock model is the action 'optimize the use of space in residential buildings', when it is not only applied to new but also existing buildings. On the level analyzed in this paper, it is unclear which building types could be affected by the action, what effort would be required and how this effort would impact the emission saving potential.

Generalized, is has to be stated that this contribution does not provide real life estimates of saving potentials that can be achieved directly in each of the EU Member States. Rather, it is a matter of calculating and determining generic potentials to give a model-based indication of CE-action impacts under the specific assumptions made. For real life implementation, these have to be checked on a case-by-case and country basis in reality (e.g. technical restrictions, policy and regulatory framework, societal barriers, etc.). Nonetheless, this contribution shows that circularity measures can make a major contribution to climate protection and especially to the decarbonisation of energy- and CO_2-intensive basic industries in the EU28.

It has also been shown that measures along the entire value chain are relevant. Although innovative cement products using new binders have the highest potential for CO_2 avoidance in absolute terms in the individual analysis (under the assumptions of the base case), the differences to other measures such

2. For example actions, that must be realized in the construction sector but create savings in the manufacturing stage. If not properly addressed, these split incentives may delay implication.

as the optimisation of space utilisation in buildings or the use of timber are not very strong. If the current market maturity of the innovative technologies is taken into account, the measures in the other life cycle phases receive even more weight. Overall, however, there is still a need for further research and modelling in order to robustly assess the potential of CE actions for CO_2 avoidance and to develop (policy) framework conditions for their widespread implementation.

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