Decarbonizing the cement and concrete sector: integration of the full value chain to reach net zero emissions in Europe

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Abstract. The construction sector represents a major share of greenhouse gas emissions related to industrial activities. The sector is mainly driven by one main material, cement. Most of the building stock in use in Europe today will last until 2050, meaning most building stock that will standing in 2050 has already been built. The same applies for the needed production capacity infrastructure in Europe. When opting for decarbonising the sector, this will have to consider looking at decarbonisation technologies and pathways. The objective of this study is to propose scenarios that can significantly reduce emissions by reducing the necessary investment. In order to achieve a significant reduction, the deployment of a major investment in carbon capture and storage is often the only way envisaged. We show that it is possible to achieve the objective of “2 degrees” of the Paris Agreement by involving all stakeholders and enhancing the digitalization and circular approach. We are also discussing the incentives that must be taken at European or national level in order to achieve the decarbonisation of the sector.

Keywords: policies, decarbonisation, scenarios, integrated value chain, circular economy

1. Introduction

Worldwide cementitious materials make up more than half of all the materials we use. While they are intrinsically materials with low embodied energy, these huge volumes mean they account for around 8% of global emissions. Cement demand in Europe represent 5% of the global market and has been stable for nearly a decade. It is not likely to increase significantly in the future, unlike emerging and developing countries, where demand for cement will continue to rise to meet the demand of the growing population and urbanization. Nevertheless the cement sector plays an important role in the European economy and also in reaching the goals of the Paris Agreement. The Paris Agreement commits governments to keep global warming ‘well below’ 2 degrees Celsius, and to ‘make efforts’ to keep it below 1.5 degrees by 2050. Meeting the Paris agreement likely means that net CO$_2$ emissions in developed countries should be zero by 2050.
Carbon neutrality is particularly challenging for the cement sector as less than 40% of emissions come from the energy used to produce the cement. More than 60% come from the chemical breakdown of limestone – calcium carbonate (CaCO₃) into CO₂ and a calcium source used to produce the active component of cement - the clinker - which will react with water at ambient temperature to produce a strong durable material. There is no practical alternative to the use of limestone, due to its abundance and widespread distribution in the earth’s crust. Therefore, total carbon neutrality can only be achieved by recapturing this “chemical” CO₂.

Technologies for carbon capture (CCS) are under development and there are many technical challenges to be surmounted. Even then they will be extremely expensive in terms both of capital investment and in operating cost.

In this paper we compare a scenario considering only breakthrough technologies (CCS) and a scenario focusing on circularity to reduce CO₂ emissions from cement production and minimize the cost of the remaining CO₂ which must be captured to achieve overall carbon neutrality. The report from Materials economics[2] discussed in detail the benefit of the circularity approach in the cement sector to reduce its impact. Contrary to a linear economy approach, the circular economy in concrete construction considers good recycling practices but also raw material savings as major levers towards a significant reduction in CO₂ emissions.

Finally, all results and calculation are presented in detail in a report: «A Sustainable future for the cement and construction industry in Europe: Technology assessment for full decarbonisation of the industry by 2050» from the same authors [1].

2. Technologies levers in cementitious construction value chain

2.1. Definition of value chain of cementitious construction
We considered the whole cement and concrete value chain, as represented below (Figure 1). Interviews with cement producers, European associations, constructors, showed us that for those different actors of the construction:

- maintaining the productivity on the construction site is considered very important,
- maintaining low cost of cement production and low cost of building construction are also very important,
- the availability of resources is a critical questions as often it is not easy to get access to the desired resource in the right amount,
- performance based standards would solve many problems but are currently not in place. National Standards on cement choice and kg of cement per m³ of concrete are too restrictive and do not allow CO₂ reductions which would otherwise be possible.

Moreover, the construction sector is a capital intensive industry with long returns on investment and little incentive to invest due to the current production overcapacity. It is also fragmented between a lot of players [3]. Few constructive partnerships have been observed, and it is mainly based on client-supplier relationships with no interactions. Furthermore, recent study from Mc Kinsey reported in 2015 that the construction sector is among the least digitized resulting in typical delays in completion of 20%, budget overruns of 80% and finally a very low financial return for the constructor [4]. Based on different discussions (workshops taking place in January and May at ECF Brussels) and reports published so far, future developments in the construction sector with a view to reducing their GHG emissions appear to be:

- an increase in the digitalization of the sector will happen leading to more prefabrication and the use of building information modelling,
- resource conservation and circular economy approach is gaining traction in economic and political circles.[2, 5]
Breakthrough technologies all require very high investment costs and industry is not willing to invest so much in the current situation.

Figure 1. Value chain from raw materials to demolition in cement and concrete sector

2.2. Technologies levers: breakthrough technology versus circular economy approach

Table 1 shows the different strategies and technologies used in our scenarios to reduce CO₂ emissions. A high number of strategies based on circular economy can be implement by mainly changing the practices today and involving all actors from the value chain. The breakthrough solutions as Carbon Capture and Storage and alternative clinkers involve only one main stakeholder: the cement producer.

Table 1. Technologies and practices used in the scenarios presented here.

| Scale  | Circular economy solutions                                                                 | Technologies update or breakthrough                                                                 |
|--------|-------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|
| Cement | Increasing use of alternative fuels as waste and Kiln optimisation[9]                      | Implementing Carbon Capture and Storage (CCS) technologies                                            |
|        | Recycling concrete fines as raw material in implementing Carbon Capture and Clinker process| Replacing clinker by supplementary by-products from alternative clinkers such as alkali activated binders, Calcium sulfoaluminates etc.[10] |
|        | Replacing Portland clinker by alternative clinkers such as alkali activated binders, Calcium sulfoaluminates etc.[11, 12]|                                                                                                       |
| Concrete| Efficient use of cement in concrete- reducing the overestimation and waste (without detrimental consequences of service and safety)[13–16] | Recycling concrete as aggregates for concrete[17, 18]                                                 |
| Structure| Reuse of elements- Flexible design                                                         | Optimal use of concrete in element ( without detrimental consequences of service and safety)[19, 20] |

3. Scenario: Breakthrough technologies versus Scenario: Optimisation and Circular economy approach

3.1. Scenario: Breakthrough technologies
In this scenario, very high investment is required. This investment must be made by a single actor: the cement producer. Cement companies would invest only if there is a high tax on CO$_2$, otherwise, they would prefer a public support. Two types of investments are then considered. First, cement producers adapt their clinker kilns with carbon capture post-combustion systems and develop CO$_2$ storage facilities. Second, alternative cements such as Calcium sulfoaluminates cement and carbonatable calcium silicate cements with a CO$_2$ saving potential of 40-50% becomes more common and available at larger scale in 2050. With 25% CCS and 10% alternative binders, a reduction of 25% is possible and in case of higher investment, 35% can be achieved compared to 2015. A major difficulty in this scenario is to access the real numbers for implementation of CCS and alternative binders.

CCS is still not a proven technology at large scale and its deployment is estimated to be expensive. Its potential is extremely interesting, in our calculations this technology allows to "reabsorb" all the CO$_2$ emitted during production. However, our calculation neglects the CO$_2$ coming from the electricity sector and the capacity of this sector to provide the necessary low carbon energy for the installation of CCS technology. In addition, transport to a use or storage site for the captured carbon is not considered.

**Figure 2.** CO$_2$ saving by 2050 for scenario: breakthrough technology.

### 3.2. Scenario: Optimisation and Circular economy approach

The use of waste as energy, as raw material in the manufacture of clinker or as SCM in cement and concrete production is emphasized. The good integration of actors in one territory favours good waste management practice and efficient collection of waste and biomass for alternative fuels as well as sorting construction demolition waste. If well sorted, the fine part of concrete demolition waste can be used as raw material in the manufacture of clinker and the rest as recycled aggregates in concrete. Waste from other industries: calcined overburden clays, wood ashes, agricultural ashes etc. are implemented as supplementary cementitious materials. The availability of local resources is no longer limited and the clinker factor can reach 0.5-0.6 if the required properties are reached.

Moreover, there is an important contribution at the concrete scale, the quantity of cement needed is optimized by a better packing of aggregates and by a respect of the various exposure classes of concrete in the building. This can be achieved through an active involvement of sand and gravel producers that can invest in crushers and sieve to produce diversity of aggregate size. It also involves the engineering offices which are currently specifying the use of a single type of concrete meeting the highest exposure class and therefore containing the most cement and which would change their practice and specify the appropriate exposure class for each part of the project. The only risk would be not to have the right
concrete at the right place due to confusion on construction site, but new technologies such as tracking concrete trucks with RFID technologies and Building information modelling [21, 22] can easily be implemented at low costs.

In this scenario, the involvement of construction companies and concrete producers is dominant. The structural element will be optimized, an example of partially hollow structures that reduce concrete usage by 50 to 70% maintaining the same performance. An additional reduction is however possible because the reduction of concrete in a structure and the reuse of elements present a large potential. Although difficult to quantify, the work of De Wolf et al.[23] and Shank et al.[16] show that a reduction of 10%-20% can be made today without design changes. By combining low carbon cement and reducing the amount of cement and concrete in a structure, more than 50% reduction is possible.

Regardless of the chosen routes: use less cement or use less concrete, the mix design of the concrete must be perfectly controlled as well as its placement and curing. This can be achieved more easily in a controlled environment such as ready mix plants for the concrete mix design and the precast industry for the structural design. In order to properly control the quantity of concrete for the structure, the precast industry will have to develop skills in cement substitution, today the use of CEM I is preferred to ensure rapid demoulding. This scenario will therefore favour the development of precast elements, more complex shapes can be used and only the performance of the finished element counts for its future use. The market share between ready mix concrete, precast industries could be changed to get higher impact. This scenario is the most promising to reduce CO₂ emissions while integrating all construction actors and reducing investment compared to scenario: breakthrough technologies. A reduction between 70 and 75% is possible compared to 1990 (Figure 3).

3.3. Go well below 2 degrees
The circular economy approach can be considered more interesting as it integrates the full value chain in the CO₂ reduction strategies and considerably lowers the investment needed compared to the use of breakthrough technologies. However none of the scenario achieve the reduction required to reach the 2 degree target or the Paris Agreement. In this section, we tested combined scenarios using costly and integrative technologies in order to reach EU recommendations.

It is actually possible either to make more constraining efforts in the sector with better quality control allowing for instance to change the standards and push forward the circular economy approach or to
combine the circular economy approach and the breakthrough technologies (to include carbon storage to a good value chain integration). The following figure shows that the 2-degree target can be achieved by pushing the circular economy approach beyond the actual standards or by combining the circular economy approach with 25% CCS and that 95% reduction can be achieved by using 80% CCS.

![Figure 4. Potential CO2 saving by 2050 by combining circular economy approach with breakthrough technologies.](image)

4. **How to implement the Scenario: Optimisation and Circular economy approach?**

The use of alternative fuel to improve the energy efficiency is highly linked to the waste supply chain. Without a policy to favour the co-processing and a legislation against landfill of waste, no CO2 can be saved. Incentives or taxes should prioritise waste managers. Adopting this policy will also support a shift in waste heat recovery and renewable energy. The other technology to reduce CO2 at the clinker scale is to replace the main component of clinker and the main emitter of CO2 during calcination: the limestone. One of the most interesting ways to do this is to replace part of limestone with concrete fines from demolition. This implies a good demolition process which is able to separate the coarse aggregates, the sand and the cement matrix properly. Fostering local business models between cement and demolition/recycling companies in a circular economy approach should be done. Furthermore, focusing on recycling fines allows to maintain the use of coarse recycling concrete to be valorise as aggregates or as road base (main reuse of demolished concrete today).

Another lever consists to replace a part of clinker in cement by substitutes such as fly ash, ground blast furnace slag and limestone. To date, clinker substitution has contributed on 20-30% decrease in CO2 emissions compared to 1980’s[24]. Unfortunately, further increases in substitution are limited by the reactivity and the availability of classic SCMs; it will involve the need to introduce new types such as ternary blends with calcined clays and limestone. Incentives should financially support the investment in grinders and calciners.

On the concrete scale, it is essential to convince concrete producers and engineers to design and request concretes that strictly meet normative needs. In this way, the quantity of cement can be reduced and waste can be reduced also.
Reducing CO2 emissions at the scale of the structure would mean reducing the quantity of concrete. It is admitted that the quantity of concrete is often overestimated (about 20%), even part of the concrete is not used and ends up in waste. This is also dependant on a strong landfill regulation to promote deconstruction instead of demolition and incentive should promote the optimisation as a criterion in awarding contracts.

5. Conclusions
A circular economy approach that involves all the actors in a value chain significantly reduces CO2 emissions and reduces investment.

Pushing technologies at the concrete scale as concrete mix design optimisation, structural optimisation and recycling/reuse will have potentially an effect in lowering cement demand which to be taken in consideration by public authorities.

In order to further reduce CO2 emissions, the use of breakthrough technology as carbon capture and storage will be unavoidable. However, the investment may be more moderate if the proposed efforts in our scenario: circular economy approach are implemented. In addition, a further reduction of CO2 emissions in this scenario is possible. The main difficulty is to propose relevant initiatives that will allow better communication throughout the stakeholder chain.

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