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Effect Assessment of Climate Requirements for Concrete - a Swedish Case Study

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Abstract

Reduction of climate impact can be governed and addressed in multiple ways and by various actors within the value chain. One approach is to impose technical measures for the climate impact of individual construction projects, and this is the approach used by the Swedish Transport Administration, Trafikverket, responsible for Sweden's transport infrastructure. A key part of this governance includes explicit requirements regarding the climate impact of concrete used for reinforced concrete structures. However, these requirements may have a strong influence on cost and technical properties, both during design, construction and service life. In addition, the possibility to fulfil the requirements depends on and affects the supply of raw materials, such as cement and supplementary cementitious materials, in the construction sector over time. This study investigates the consequences, based on a demand/asset perspective, that the requirements entail.

Keywords: Climate impact; CO_2 requirements; performance-based regulations; material optimisation; raw materials supply and demand; cement; concrete; supplementary cementitious materials.

1 Introduction

To achieve Sweden's climate goals and comply with international agreements, Trafikverket has set a strategic goal for climate-neutral infrastructure by 2040. This goal is made tangible through successive interim targets: a reduction of climate impact by 30% by 2025, 60% by 2030, and 80% by 2035, compared to 2015 levels. These targets are gradually implemented in procurement requirements aimed at consultants, contractors, and material suppliers.

In 2024, Trafikverket revised its climate requirements specifically for ready-mix concrete. To meet these requirements, the primary approach in industry today is to lower the climate impact mainly by replacing cement clinker with supplementary cementitious materials (SCMs) *e.g.* fly ash and blast furnace slag. However, these materials are finite resources, raising questions about future availability and cost development.

This study provides a technical and strategic overview of cost and supply/demand for cement clinker and SCMs for Trafikverket. It is based on their climate requirements and their planned volume of construction, with a particular focus on how market development and cement availability affect the ability to meet climate requirements.

2 Methods

The paper is based on a literature review of scientific publications, as well as reports from authorities, industry, and research and development projects. Trafikverket's climate requirements and the demand for cement are analysed by reviewing current and future requirements, volumes of construction and the availability of cement and SCMs. The analysis includes an assessment of market development and how these factors influence the ability to meet the climate requirements.

3 Results

3.1 Trafikverket

3.1.1 Cement demand

Trafikverket is one of Sweden's largest individual purchasers of concrete and thus a significant actor in the demand for cement clinker and SCMs, i.e., binders for concrete. Trafikverket's annual cement requirement amounts to about 400,000 tons, representing a significant share of the total cement use in Sweden [1]. Other analyses suggest that Trafikverket's cement need is approximately 500,000 tons per year [2]. Both reports indicate large uncertainties, but the order of magnitude is reasonable.

Cement is assumed to be used mainly for reinforced concrete structures, but there are several other applications, such as ground stabilisation, shotcrete, and unreinforced slabs. There are no available statistics on how cement use is distributed among different applications. Some estimates exist regarding the distribution between new construction, maintenance, and technically approved material for the year 2021, but uncertainties are large and year-to-year variations are expected to be significant [3].

At the same time, Trafikverket, in line with its climate goals, has begun to require climate-improved ready-mix concrete in procurements. The consequence of this is that cement clinker in concrete is increasingly being replaced by SCMs. Even when cement clinker is produced with carbon capture and storage (CCS), the use of SCMs is expected to be important to curb cost increases for concrete resulting from CCS technology. However, the SCMs currently used, with long-term experience, are finite resources and their future availability is uncertain [1].

It is also important to note that Trafikverket's current requirements for climate-improved concrete mean that access to SCMs is a critical factor. If these materials are not available in sufficient quantities, this affects the ability to meet climate requirements cost-effectively, which can lead to delays or cost increases in projects.

Trafikverket's cement needs for the next 15 years are closely linked to the long-term planning of transport infrastructure. According to the strategic planning input to the government from January 2024, investments in transport infrastructure are expected to remain at a high level [4].

Assuming a direct connection between investment volume and cement demand, and starting from Trafikverket's current annual cement need of about 400,000 tons, corresponding to an investment level of around SEK 70 billion per year, we can estimate the future demand. With an average investment of SEK 75 billion per year during the period 2025–2040 [5], cement demand could proportionally increase to roughly 430,000 tons per year. This assumption is simplified and does not account for potential changes in material selection, climate requirements, or technological innovations. However, Trafikverket's own forecasts indicate that the need for concrete will increase.

At the same time, increased requirements for climate-improved concrete and the use of SCMs can affect Trafikverket's actual cement consumption. If the proportion of cement clinker in the cement decreases through increased use of SCMs, the total need for cement clinker may decrease—even if the volume of concrete increases. In total, an increased need for concrete results in increased need for cement. The climate goals require cement produced with CCS and SCMs. Given the anticipated high costs associated with CCS, reliance on SCMs becomes essential to meet financial targets.

3.1.2 Concrete in Relation to Climate Goals

In recent years, Trafikverket has tightened its requirements for concrete with the aim of reducing the climate impact. These requirements are closely linked to the Trafikverket's overarching goal for climate-neutral transport infrastructure by 2040.

For ready-mix concrete, Trafikverket imposes demands regarding climate performance. The requirements apply to a large proportion of the volume, although there are certain limitations for *e.g.* small projects. The maximum permitted climate impact is specified in terms of CO_2 emissions per cubic metre of concrete and differentiated by exposure class. These requirements are referred to as "basic requirements" and correspond to concrete with 20% reduced climate impact compared to industry benchmark [6], and approximately the same percentage SCM of the total binder. In addition to the “basic requirements” that apply generally, there are also more ambitious “optional climate requirements”. These specifies groups of concrete with 30% or 40% lower CO_2 emissions per cubic metre of concrete compared to industry benchmark.

Trafikverket has not specified that the requirements for concrete will be revised over time, but has established a number of interim targets at the project level to achieve the long-term 2040 goal. These interim targets mean that the climate impact from infrastructure projects should be reduced by 30% by 2025, 60% by 2030, and 80% by 2035, compared with the reference year 2015. As concrete accounts for a relatively large share of the total climate impact in most projects, these interim targets mean that merely achieving the basic concrete requirement will not suffice to meet the overall project target for total climate impact reduction. At present, it is possible to meet the optional climate requirements by using a higher proportion of SCMs, and in the future, the use of cement clinker produced with CCS may also be part of the solution for both the basic requirements, optional climate requirements, and project-level interim targets.

3.2 Supply and Demand for Cement in Sweden

In Sweden, the supply of cement and its raw materials is heavily dependent on domestic limestone quarrying, primarily from Heidelberg's plant on Gotland. This plant has historically accounted for approximately 75-80% of the total cement production in the country [1]. The remaining production takes place in Skövde, while about 15% of the cement is imported, mainly from Germany and other Baltic Sea countries.

The annual demand for cement in Sweden amounted to approximately 3.4 million tons in 2019, including blended cement and SCMs, of which 2.8 million tons were produced in Sweden. This represented an increase of about 30% between 2015 and 2019. Forecasts indicate that demand will remain at the same level or increase over the next decade, particularly due to needs in infrastructure, energy systems, mining, and the defence sector [1], [7]. However, there is a lack of detailed data on downstream use of cement in various applications in Sweden [8].

At the same time, there is an increasing ambition to reduce the climate impact of concrete by replacing parts of the cement clinker with SCMs [9]. This applies to all countries and for all types of structures. In building construction, there is often greater potential to increase the proportion of SCMs, especially in a Swedish context where Sweden lags behind many other countries, which means that competition for available SCMs increases further from today's levels. Overall, this means that the demand for SCMs is expected to increase significantly in the coming years.

The most common SCMs in Sweden are:

- Fly ash – imported. But its availability is decreasing as coal-fired power plants are closed in Europe.
- Ground granulated blast furnace slag (GGBS) – produced in Sweden in Oxelösund, but this production is expected to cease by 2030 in connection with the transition to electric arc furnaces. There are varying reports on the availability and suitability of importing GGBS

from countries further afield with greater availability, such as Japan and China.

- Silica fume – imported from Norway and mainly used in high-strength concretes. Limited use due to high costs and low availability.
- Limestone – good availability. A component in most cements, but limited by its low reactivity.
- Natural pozzolans – introduced to the Swedish market in 2024 as a component in cement.

The availability of the two most commonly used SCMs, fly ash and GGBS, is expected to decrease significantly in Europe over the coming decades, which will have direct consequences for Sweden. The reduction is driven by the ongoing transition away from coal-fired power and blast furnace-based steel production in Europe [10].

Even in scenarios where cement demand in Europe is assumed to decrease, the analysis shows that the availability of conventional SCMs will not be sufficient to meet demand [10]. For Sweden, this means that dependence on imports from EU countries could become a risk factor, and that domestic development and production of SCMs will become increasingly important to enable a continued reduction in clinker content in cement.

To meet future needs, the development of new SCMs, such as calcined clays, natural pozzolans, mining waste, metallurgical slag, and recycled concrete, is required [9], [11]. The lack of detailed data on cement use in various applications in Sweden complicates analyses of possible, cost-effective, and suitable alternatives. A robust and sustainable supply therefore requires both knowledge building about new materials, technical development, and long-term strategic planning.

3.3 Technical Requirements in Other Countries

To understand how Trafikverket's requirements for concrete relate to international practices, it is relevant to consider the technical requirements for cement composition and testing methods in other EU countries. Several publications provide broad overviews of requirements, both in terms of cement composition and testing requirements, including acceptance criteria. These also cover other aspects of concrete requirements, such as total cement content and maximum water-cement ratio (*w*/*c*). The summaries show significant variations in requirements for most parameters, including cement composition and testing requirements. Testing methods greatly influence which cement compositions are practically feasible among those accepted in the standard [12], [13].

Overall, the comparison shows that countries with climates like Sweden often have broadly similar requirement structures, but the details of requirements, testing, and execution vary significantly.

It is evident that countries with climates similar to Sweden already extensively use cement types with high proportions of SCMs. This enables both reduced climate impact and improved durability. Through the concrete standard SS 137003 T1:2024, Sweden has taken important steps in the same direction but continued knowledge acquisition from other countries can further strengthen the opportunities for innovation and the use of concrete with lower climate impact.

3.3.1 Effects of Performance Requirements for Durability in the EU

The introduction of Exposure Resistance Classes (ERC) in Eurocode 2 (EN 1992-1-1:2023) marks a shift in how the durability of concrete structures is specified and verified within the EU. ERC aims to improve the link between environmental exposure, concrete properties, and the technical service life of structures by introducing a performance-based and verifiable methodology for durability design. Unlike the current system, where exposure classes are linked to general technical requirements, the ERC concept introduces a new structure where each exposure class is complemented by a specific resistance class.

The goal of transitioning to ERC is to create a more robust and scientifically grounded system for durability design, where verification can be done either by meeting threshold values or by performance-based testing according to standardised methods. This allows greater flexibility in material selection, particularly concrete with high proportions of SCMs or new SCMs, while ensuring that durability requirements are met.

The implementation of ERC in Sweden is not yet established. Therefore, it is currently not possible to precisely predict the effects ERC may have on the Swedish market or on transport infrastructure projects. However, it is clear that ERC will impact both design, material selection, and verification methodology in future projects.

The introduction of ERC is expected to have several important effects on both the demand for cement and the ability to use it as efficiently as possible. Firstly, the ERC system means that durability requirements are no longer strictly tied to prescriptive parameters, but instead to verifiable function in specific environmental exposures and expected service life. This creates greater scope for optimising cement use, as it becomes possible to tailor the composition to actual function rather than general minimum requirements.

At the same time, ERC means that the demand for cement must be dimensioned more precisely in relation to the desired service life and exposure environment. To achieve higher ERC levels, higher quality or reactivity of the cement may be required, which can increase the demand for specific types of SCMs or require optimisation of particle size distribution and hydration kinetics. It also requires manufacturers to develop robust verification methods and clients to have access to reliable performance data.

In summary, ERC offers an opportunity to use cement more strategically and efficiently, but also requires increased material knowledge, testing capacity, and documentation to ensure that the concrete meets the new performance-based requirements.

3.4 Measures Along the Value Chain to Achieve Climate Goals in the Cement and Concrete Sector

To enable the cement and concrete industry to contribute to the Paris Agreement's goal of limiting global warming to 1.5°C, a comprehensive transformation is required. Several scientific studies [13][14][15][17] indicate that focusing solely on individual technical solutions is insufficient. Instead, a system perspective is needed, where measures are taken along the entire value chain, from raw material extraction to the finished building, to achieve a cost-effective, safe, and robust climate transition.

Several international analyses suggest that up to 80% of emissions from cement and concrete can be reduced by 2050 through a combination of measures that are already technically available [13][15][17]. These measures can be grouped into four main categories:

1. **More Efficient Design of Buildings and Structures**: By optimizing load-bearing structures and reducing over-dimensioning, the amount of concrete can be reduced by 10-30%. Research indicates that data-informed design can reduce concrete volumes by 15-45% in common bridge structures [17][18].
2. **Reduced Cement Content in Concrete**: Through improved aggregate packing, optimised water-cement ratio, and increased use of SCMs, the cement content in concrete can be reduced by up to 20%. In Sweden, there is potential for a 5-10% reduction, although the transition from natural gravel to crushed aggregates counteracts reduced cement contents.
3. **Reduced Clinker Content in Cement**: By increasing the use of SCMs, the clinker factor can be reduced from current levels (approximately 0.73 in Europe) to 0.60 or lower.
4. **Carbon Capture and Storage (CCS) at Clinker Production**: To address process-related emissions from the calcination of limestone, CCS is required. CCS is considered crucial for achieving net-zero emissions but requires significant investments and fossil-free electricity.

It is the combination of these measures, rather than individual technological leaps, that offers the greatest potential to reduce emissions from the construction sector [13][15][18].

In summary, the literature shows that a combination of technical solutions and systematic collaboration is crucial to reducing the climate impact of concrete structures in line with national and global climate goals, as well as achieving these goals in an economically sustainable manner.

3.5 Costs and Consequences

3.5.1 EU ETS and CBAM

The implementation of the European Union's Emissions Trading System (EU ETS) and the Carbon Border Adjustment Mechanism (CBAM) has significant implications for the concrete industry. The EU ETS, has led to increased costs for cement clinker production due to rising carbon allowance prices, expected to reach approximately €102 per ton of CO_2 by 2030. This increase directly impacts the cost of cement clinker, making production more expensive [19][20][21].

CBAM, aimed at preventing carbon leakage by imposing a carbon cost on imports, further exacerbates these cost pressures. This measure is expected to reduce competition from cheaper, more carbon-intensive cement imports, increasing the overall cost of cement in the European market.

CCS technology is seen as a critical solution for achieving net-zero emissions in the cement industry. While CCS can significantly reduce emissions, it comes with high energy and investment costs, estimated to add €71 to €75 per ton of cement [23]. Despite these costs, CCS is considered one of the most cost-effective pathways to achieving net-zero emissions, especially when combined with increased use of SCMs to reduce clinker content in cement.

The combination of ETS, CBAM, and CCS creates a complex economic landscape for the cement and concrete industry. These measures drive significant reductions in carbon emissions but also lead to increased production costs. A strategic approach is necessary to manage these costs, including developing and adopting new SCMs and optimising cement and concrete formulations to maintain competitiveness while meeting stringent climate targets [22][23][24].

3.5.2 Consequences on the Market and Cement Supply

The demand for SCMs has increased significantly in Sweden, driven by economic incentives and requirements to reduce the climate impact of concrete. The market has responded by increasing imports of conventional SCMs, as well as investing in the development and production of new, locally available alternatives [26]. The cost development for SCMs is influenced by availability, logistics, and processing costs. The increased demand has also led to a growing interest in imports from other parts of the world, affecting market dynamics and price levels.

Overall, the increased costs for cement clinker and the rising demand for SCMs have led to new investments in the development and production of new SCMs in Sweden and Europe, as well as changes in trade patterns [26][27][28]. This development is a direct consequence of the increased climate requirements and the economic incentives to reduce the climate impact of concrete. Market development is, of course, impossible to predict, but the trend towards increased volumes of SCMs as a result of rising costs for cement clinker is clear.

4 Discussion

Trafikverket's annual cement usage is projected to increase driven by long-term investment plans. The majority of this cement is used for reinforced concrete structures, which must comply with climate requirements. While basic requirements for ready-mix concrete are not expected to tighten, project-level targets towards climate neutrality by 2040 will become more stringent. This necessitates the use of concrete with lower climate impact, *i.e.* within the optional climate requirements for concrete.

To meet climate goals, a combination of methods is most effective. A system perspective is needed, where measures are taken along the value chain, from material production to constructiun, to achieve a cost-effective, safe, and robust climate transition. One part is adopting the basic and optional climate requirements for ready mix concrete, where increasing the proportion of SCMs, implementing performance-based requirements, and using cement clinker produced with CCS technology are key strategies. Increasing SCM usage is currently the most applicable method, but its potential is limited by standards to ensure durability. Performance-based durability requirements could allow for more efficient cement and SCM use. Despite the potential to reduce clinker content, cement clinker will remain essential for durability in most applications.

CCS technology is essential for achieving net-zero emissions, despite its high energy and investment costs. The combination of ETS, CBAM, and CCS creates a complex economic landscape, driving significant reductions in carbon emissions but also increasing costs. A strategic approach is necessary to manage these costs and ensure sufficient durability when concrete formulations evolve.

The total need for SCMs is expected to increase, as the potential to increase SCM proportions is significant. However, the supply of traditional SCMs is declining due to the climate transitions in the energy and steel industries. This makes the development and implementation of new SCMs critical for a cost-effective climate transition. Fundamental knowledge and understanding are needed to ensure the long-term durability of concrete with new SCMs, as well as large-scale industrial production.

In conclusion, Trafikverket's overall cement demand is projected to rise, primarily driven by long-term infrastructure investments and increasingly stringent climate requirements. However, the lack of comprehensive downstream data for cement usage across diverse applications impedes the ability to conduct precise assessments of the impacts of performance-based durability criteria, such as those implemented through ERC. Current conditions indicate that approximately 40% of the cement in factory-produced concrete should consist of SCMs, necessitating a doubling of SCM utilisation compared to present levels.

To achieve a cost-effective climate transition, it is imperative to increase SCM incorporation, develop robust performance-based requirements, and utilise clinker produced with CCS technology. Yet, the dwindling supply of conventional SCMs—due to ongoing climate transitions in related industries—highlights the urgent need for development and adoption of new SCMs to satisfy future demand. Trafikverket's concrete specifications reinforce the criticality of SCM availability, in meeting climate objectives and in alleviating cost pressures associated with cement.

Ultimately, a long-term strategic approach is required to mitigate cost escalations, with climate targets and requirements serving as key guiding factors as they prepare construction projects to decrease cement clinker usage. Beyond these, the implementation of advanced performance-based standards will enable more efficient utilisation of both cement clinker and SCMs, while sustained research and knowledge development are vital for the successful industrial integration of new SCMs and for ensuring the durability and resilience of future concrete structures.

5 Conclusions

Achieving Trafikverket's climate goals, project-level climate targets and fulfilling the climate requirements for ready-mix concrete necessitate a comprehensive, system-wide perspective that addresses every stage of the value chain—from material production, design and construction. Key strategies include the adoption of performance-based standards, increased use of SCMs, and the integration of cement clinker produced with CCS as well as structural and material optimization.

It is essential to ensure a reliable and growing supply of SCMs, as these materials are fundamental to reducing the climate impact of concrete and meeting Trafikverket's increasingly ambitious project-level climate targets while still meeting a cost-effective climate transition. The requirements for ready-mix concrete not only promote a more efficient and sustainable use of cement during the planning and design phases but also serve as instruments for controlling and mitigating cost increases associated with application of CCS technology on cement clinker production and regulatory mechanisms such as the EU ETS and the CBAM.

Ultimately, Trafikverket's approach demonstrates how strategic, climate-focused specifications for concrete can drive both emissions reductions and cost efficiency. Sustained investment in research, knowledge development, and industrial-scale implementation of new SCMs will be crucial for ensuring the long-term durability and resilience of future concrete structures, thereby supporting Sweden's broader climate ambitions and long - term infrastructure needs. At the same time, a successful climate transition for concrete hinges not only on technical innovation and supply chain strategy, but also on regulatory adaptation and Trafikverket's active participation in developing and adopting new solutions.

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