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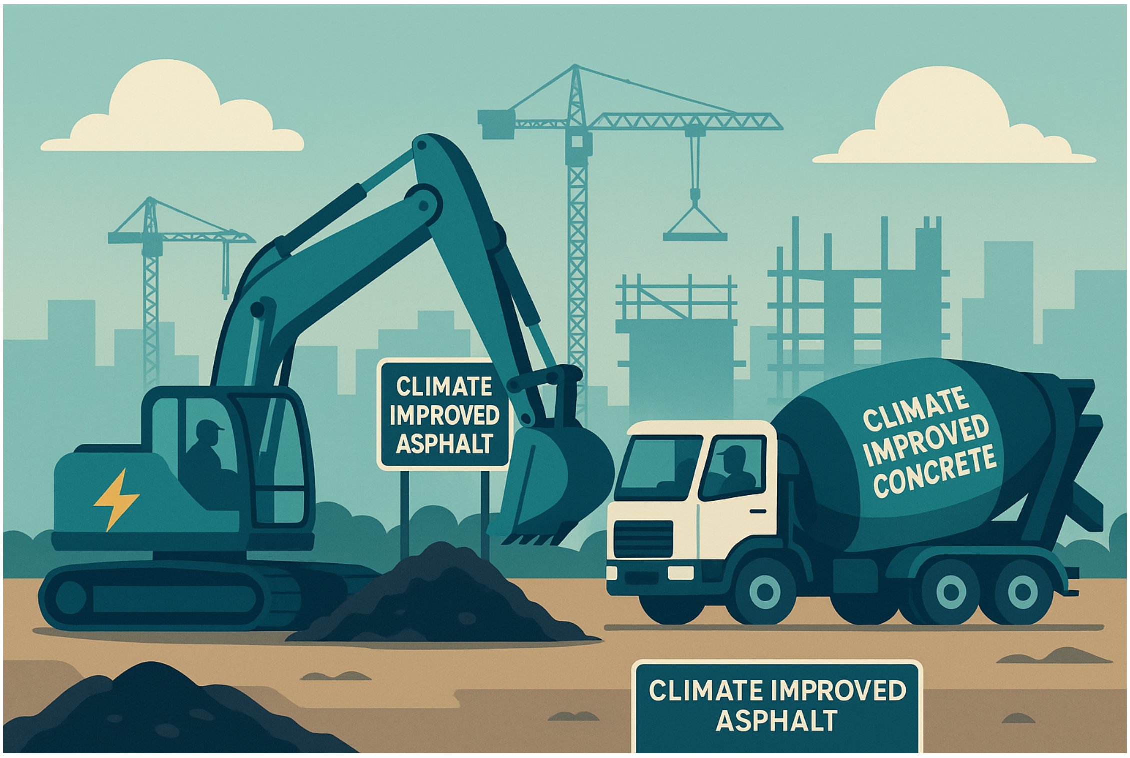

Marginal abatement cost comparison of climate improvement measures in civil construction

A study of climate improved concrete, asphalt and fuel alternatives

Master's thesis in Design and Construction Project Management

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Cover: Illustration of a climate-improved civil construction project with electric machines, climate-improved concrete, and climate-improved asphalt.

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Abstract

This study evaluates the cost-effectiveness and feasibility of climate improvement measures in civil construction by comparing alternative materials and fuels for asphalt, concrete, and heavy machinery. The research addresses a growing demand for sustainable infrastructure by analyzing the marginal abatement cost (MAC) of selected measures to reduce greenhouse gas emissions. Through a combination of literature review, interviews with industry professionals, and quantitative data from Skanska's operations, the study constructs a Marginal Abatement Cost Curve (MACC) tailored to a hypothetical mid-sized civil project. Key findings highlight that certain measures, such as using recycled asphalt with bio-based binders and transitioning to electric machinery, can offer both environmental benefits and economic advantages. However, barriers such as procurement practices and knowledge gaps among stakeholders often hinder adoption. The thesis concludes by emphasizing the importance of integrating environmental and financial assessments into project planning to support cost-efficient decarbonization strategies in the construction sector.

Keywords: Marginal abatement cost curve, electric machines, climate-improved concrete, climate-improved asphalt, cost effectiveness

Jämförelse av marginella reduktionskostnader för klimatförbättrande åtgärder inom anläggningsbranschen
En studie av klimatförbättrad betong, asfalt och alternativa bränslen
SAMIR BRKOVIC
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Sammanfattning

Denna studie utvärderar kostnadseffektivitet och genomförbarhet för klimatförbättrande åtgärder inom anläggningsbranschen genom att jämföra alternativa material och bränslen för asfalt, betong och tunga maskiner. Studien svarar på ett växande behov av hållbar infrastruktur genom att analysera den marginella reduktionskostnaden (MAC) för utvalda åtgärder som syftar till att minska utsläppen av växthusgaser. Genom en kombination av litteraturstudier, intervjuer med branschexperter och kvantitativa data från Skanskas verksamhet har en reduktionskostnadskurva (MACC) utvecklats för ett hypotetiskt medelstort anläggningsprojekt. Resultaten visar att vissa åtgärder, såsom användning av återvunnen asfalt med biobaserade bindemedel och övergång till eldrivna maskiner, kan ge både miljömässiga och ekonomiska fördelar. Samtidigt utgör faktorer som upphandlingspraxis och kunskapsbrist hinder för implementering. Studien avslutas med att betona vikten av att integrera klimat- och kostnadsperspektiv i projektplaneringen för att möjliggöra kostnadseffektiva klimatåtgärder i bygg- och anläggningssektorn.

Nyckelord: Reduktionskostnadskurvor, elmaskiner, klimatförbättrad betong, klimatförbättrad asfalt, kostnadseffektivitet

Acknowledgements

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Samir Brkovic, Philip Skogsberg, Gothenburg, June 2025

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis, listed in alphabetical order:

ABb	Asfaltbetong Bindlager
ABT	Tät Asfaltbetong
AG	Asfaltgrus
CCS	Carbon Capture and Storage
CO2-eq	Carbon Dioxide-Equivalents
EPD	Environmental Product Declaration
ETS	Emission Trading System
GHG	Green House Gas
GWP	Global Warming Potential
HVO	Hydrotreated Vegetable Oil
LCA	Life-cycle Assessment
LOU	Lagen om Offentlig Upphandling
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curve
MEAT	Most Economically Advantageous Tender
MK1	Class 1 Environmental Diesel, "Miljöklass 1"
RAP	Recycled Asphalt Pavement
SEK	Swedish Krona
SIS	Skanska Industrial Solutions

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1

Introduction

Civil construction focuses on designing, developing, and maintaining infrastructure projects essential for society. It encompasses a wide range of construction activities, from building roads, bridges, and tunnels to developing water supply systems, sewage networks, and energy infrastructure (Skanska, 2025b). These projects play a crucial role in supporting economic growth, improving living standards, and ensuring the efficient functioning of cities and communities. As environmental concerns rise due to climate change, the civil construction sector, both globally and in Sweden, must adapt to more ecologically sustainable practices.

This thesis is written in collaboration with Skanska Civil. Skanska is one of Sweden's largest construction and civil engineering companies, playing a key role in the development of sustainable infrastructure. In recent years, Skanska has intensified its sustainability efforts, working toward ambitious climate targets, including a 70 percent reduction in greenhouse gas emissions from its operations by 2030 compared to 2015, which aligns with its commitments under the GHG Protocol. Additionally, Skanska aims to reduce carbon dioxide emissions from its value chain during operations by 50 percent by 2030, relative to 2020 levels (Skanska, 2024).

1.1 Background

Like many other industrial sectors, the civil construction sector faces an urgent challenge: the need to decarbonize and achieve carbon neutrality . This transformation is crucial for aligning with the global climate goals, including the objectives of the Paris Agreement to limit global warming to below 1.5 °C (Karlsson et al., 2020). The challenge is complex, with multiple parts of the sector collaborating to drive the industry toward carbon neutrality (Karlsson et al., 2020). Both embodied and operational carbon must be addressed so that the industry can reduce its emissions (Pomponi & Moncaster, 2016). This thesis will focus on embodied carbon, meaning carbon emissions associated with materials and construction processes up until the building is complete and before the civil structure has transitioned into operational state (Pomponi & Moncaster, 2016). Overall, civil structures have significantly smaller operational carbon footprints compared to buildings (Cang et al., 2020) ; therefore, the focus of this thesis will be on embodied carbon.

1.1.1 Decarbonization challenge and climate impact of civil construction

Emissions of greenhouse gases (GHGs), including carbon dioxide (CO2), have been a major driver of climate change since the onset of the industrial era (IPCC, 2021). The construction industry significantly contributes to this issue due to its high energy consumption and reliance on carbon-intensive materials such as concrete, steel, and asphalt (Dsilva et al., 2023). These materials are used in vast quantities, resulting in substantial greenhouse gas (GHG) emissions. Despite growing concerns over environmental sustainability, the continued use of these conventional materials remains prevalent due to the lack of viable alternatives that offer comparable structural performance and durability at a similar price (Firoozi et al., 2024). To decrease the climate impact of the construction industry, the sector will have to transition to using materials that have a lower climate impact.

In addition to material-related emissions, the energy consumption associated with the production of civil structures is also high (Sezer & Fredriksson, 2021). Construction requires the transport of heavy materials to the site and the transport of heavy waste from the site. Additionally, heavy vehicles such as excavators and dump trucks are used for on-site production activities (Lou et al., 2025). Today, vehicles, for the most part, operate on fossil fuel combustion, resulting in greenhouse gas (GHG) emissions. The industry, therefore, faces a challenge in transitioning from fossil fuel dependency to operating vehicles with fuels that have a lower climate impact.

1.1.2 Market structure

In Sweden, the civil construction market is dominated by a few major companies that control a significant share of the industry (Byggvärlden, 2021). Beyond their core contracting operations, these firms also have divisions or subsidiary companies specializing in the production and supply of construction materials, as well as in the management and supply of construction equipment and machinery (Konkurrensverket, 2018). This vertical integration grants them extensive control over the construction supply chain, providing them with in-depth knowledge of material sources (Konkurrensverket, 2018). This high degree of vertical integration enables large firms to implement sustainability strategies more uniformly across the supply chain, potentially making it easier to adopt climate-improved materials or alternative fuels.

The client side of the market is dominated by the public sector, including the Swedish Transport Administration (Trafikverket) and Swedish municipalities. The construction projects from the public clients are tendered publicly. They are heavily regulated by the Public Procurement Act (LOU), in which the lowest price is the most critical factor in winning a bid. According to Chapter 16, Section 1 of the Swedish Public Procurement Act (2016:1145), public clients can base awards on either the lowest price or the most economically advantageous tender (MEAT). The emphasis on the lowest price in public procurement (as regulated by LOU) can act as a barrier to adopting sustainable practices, especially when climate-improved materials or fuels come at a higher upfront cost. This tension between costs and environmental goals can be a challenge in driving climate impact reduction in public projects, especially in cases where one must incur a cost increase to reduce emissions.

1.1.3 Industry efforts towards sustainability

The Swedish construction sector jointly stands behind reaching climate neutrality by 2045 (Fossilfritt Sverige, 2024). Fossil-Free Sweden (Fossilfritt Sverige) is a national initiative launched by the Swedish government in 2015, with the goal of making Sweden one of the world's first fossil-free welfare states. The initiative brings together businesses, industry organizations, municipalities, and other stakeholders to accelerate the transition to a climate-neutral society (Fossilfritt Sverige, 2024). Byggföretagen, the largest industry organization for construction and civil engineering companies in Sweden, has produced a roadmap for the construction sector to reach climate neutrality by 2045. Major contractors such as Skanska have each developed their own company-specific roadmaps aligned with these broader industry goals (Skanska, 2025c).

In response to increasing environmental regulations and sustainability demands, companies have introduced "greener" alternatives to traditional construction materials. Examples include low-carbon concrete and sustainable asphalt formulations (Reuters, 2025). Additionally, companies providing construction machinery today offer electric-powered construction machinery as well as equipment that can operate on biofuels, providing alternatives to fossil-fuel-driven machinery (Volvo CE, 2024).

In recent years, public infrastructure clients have increasingly used procurement as a tool to drive carbon reduction in construction projects (Lingegård et al., 2021). By integrating carbon management criteria into tenders and contracts, clients can influence contractors' material choices and construction methods, thereby promoting sustainable practices (Lingegård et al., 2021). Performance-based requirements, such as setting carbon baselines and offering incentives for reductions, have become more common in Sweden and internationally (Lingegård et al., 2021). The way civil projects are procured and the requirements set for contractors heavily affect how contractors work with climate reduction throughout all project phases.

1.1.4 Regulations and policies

The European Climate Law legally binds the EU to its target of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels, with the additional goal of achieving climate neutrality by 2050. According to the Council of European (2025), the EU introduced the Fit for 55 package, a set of legislative proposals designed to revise existing climate policies and implement new measures to align with the Union's 2030 and 2050 climate goals as established by the European Commission, Council, and Parliament.

A central element of this package is the EU Emissions Trading System (ETS), which introduces a price on carbon and requires entities covered by the system to buy allowances corresponding to their greenhouse gas emissions (Council of European, 2025). ETS 1 applies to energy-intensive industries, including cement, steel, and bitumen production. ETS 2 will apply to fossil fuel suppliers, requiring them to purchase allowances for the fuels they distribute. Although construction companies are not directly included in ETS 1 or ETS 2, they are indirectly affected by upstream suppliers of cement, bitumen, and fuel, which are subject to ETS, resulting in increased prices. As the carbon price under ETS continues to rise and the number of free allowances decreases, these costs are expected to grow unless emissions are significantly reduced.

Sweden has adopted one of the world's most ambitious climate policy frameworks, aiming to achieve net-zero greenhouse gas emissions by 2045. This overarching goal is legally binding under the Swedish Climate Act, which came into force in 2018 and requires that all national climate policy be aligned with Sweden's climate targets. The pathway to 2045 is structured through a series of progressively stricter interim targets: by 2030, emissions in sectors outside the EU ETS are to be reduced by at least 63% compared to 1990 levels, and by 2040, by at least 75%. Emissions from domestic transport, which play a significant role in infrastructure and construction projects, are to be cut by at least 70 percent by 2030 compared to 2010 levels (Naturvårdsverket, 2024).

According to Boverket (2024b), the Swedish National Board of Housing, all newly constructed buildings in Sweden are now required to include a climate declaration. In the climate declaration, there is a requirement to present the global warming impact from the production stage of the materials and the building. The use of Environmental Product Declarations (EPDs) is strongly recommended to aid in estimating global warming impact, as they provide reliable and standardized environmental data. If a product lacks a corresponding EPD, a 25 percent surcharge is applied to generic data, encouraging developers to choose construction material from producers who have developed verified EPDs to ensure more accurate climate impact assessments.

1.1.5 Public client requirements

In certain civil projects undertaken for Gothenburg Municipality, contractors may be required to produce a climate impact assessment for the projects (Göteborgs Stad, 2024). In projects where a climate impact assessment is required, the supplier must assess and report on the project's climate impact from the outset. The assessment may be required before various stages of the project, but is typically completed before the production stage (Göteborgs Stad, 2024).

The first part of the climate assessment is to produce a baseline scenario calculation, unless the client provides one. This baseline serves as both a point of comparison for future savings and a means to identify the project's most climate-intensive components (Göteborgs Stad, 2024). The calculation must adhere to the *Common Environmental Requirements for Contracts 2024* and also include an estimate of the project's climate impact without climate requirements, using standard values from the latest version of Trafikverket's climate calculation tool (Göteborgs Stad, 2024). Throughout the assignment, the supplier is expected to collaborate with the client to identify and implement climate-saving measures, actively working to minimize environmental impact (Göteborgs Stad, 2024). This may involve optimizing mass balance, selecting sustainable materials, refining structural designs, or pursuing other efficiency improvements (Göteborgs Stad, 2024). Any proposed measures must be approved by the client and include an evaluation of their impact on the project timeline, investment costs, and other relevant factors (Göteborgs Stad, 2024). To facilitate this process, Trafikverket's template *Measures for Reduced Climate Impact* is recommended (Göteborgs Stad, 2024).

Finally, the contractor must calculate and present the project's total climate impact, incorporating all approved climate-saving measures, in what is referred to as the *Project Climate Calculation*. This assessment must quantify emissions in kilograms of CO_2 equivalents (kg CO_2-eq). Unless otherwise specified, calculations should follow life cycle assessment (LCA) methodologies in compliance with EN 15978:2011 and EN 15804:2012 or later versions (Göteborgs Stad, 2024).

Trafikverket plays a central role in driving climate action in civil construction in sweden. Its long-term goal is climate-neutral infrastructure by 2040, with interim targets to reduce climate impact in investment and reinvestment projects by 15% (2020–2024), 30% (2025), 60% (2030), and 80% (2035), compared to 2015 levels (Trafikverket, 2024b). For interim years, they have produced a table, as shown below, which they expect their projects to follow (Trafikverket, 2024b).

Year	**Reduction Goal Compared to 2015 (% Minimum)**
2020–2024	15
2025	**30**
2026	36
2027	42
2028	48
2029	54
2030	**60**
2031	64
2032	68
2033	72
2034	76
2035	**80**
2036	84
2037	88
2038	92
2039	96
2040	**100**

Table 1.1: Reduction goals compared to 2015 levels

For projects exceeding SEK 50 million, Trafikverket requires detailed climate calculations using its *Klimatkalkyl* tool and the submission of a *PM Reducerad klimatpåverkan*, which outlines proposed measures to reduce emissions (Trafikverket, 2024a). Contractors must demonstrate that the selected measures meet or exceed the mandated reduction target. Trafikverket also mandates the use of verified Environmental Product Declarations (EPDs) for key materials, such as concrete and asphalt, to ensure transparency and accuracy in emission data (Trafikverket, 2024b). Sub-EPDs are accepted if developed using verified tools. These calculations focus on lifecycle stages A1–A3, i.e., material production.

Beyond large projects, climate requirements have been extended to smaller contracts and maintenance work. Materials such as concrete, asphalt, cement, and steel must meet specific carbon intensity limits, and renewable fuels or electricity are required for construction machinery by 2030 (Trafikverket, 2024a). By setting performance-based targets rather than prescribing methods, Trafikverket creates flexibility and incentives for contractors to propose innovative, cost-effective emission reductions (Fossilfritt Sverige, 2024).

1.1.6 Knowledge gap and financial feasibility of climate impact reduction measures

Reducing greenhouse gas emissions can no longer be treated as a niche responsibility or delegated to isolated specialists within an organization. Instead, it requires a systemic, integrated approach that permeates both private and public sectors, across individual projects and entire business operations. Climate considerations must become an embedded part of mainstream decision-making, alongside cost, time, and quality (Fossilfritt Sverige, 2024).

Today, a significant knowledge gap limits the ability of both clients and contractors to set and meet ambitious climate-related requirements. While existing requirements in procurement and regulation, such as material declarations and climate assessments, play an essential role in building awareness, they are often too conservative to drive substantial emission reductions. Rather than delivering immediate cuts, these measures tend to generate knowledge about where emissions occur and their relative scale (Fossilfritt Sverige, 2024). This is a necessary first step, but not sufficient for meeting long-term climate goals.

To move beyond awareness, emissions need to be quantified and assigned an economic value. One way to accomplish this is through pricing mechanisms or cost-effectiveness evaluations, where clients explicitly show how much they are willing to pay for solutions with lower carbon footprints. Trafikverket, for example, has introduced a system of percentage-based emission reduction targets in its projects, with financial incentives such as climate bonuses awarded when reductions exceed the required baseline (Fossilfritt Sverige, 2024). This model encourages the integration of carbon performance as a key project parameter, alongside cost and functionality.

Functional requirements, instead of prescriptive technical specifications, are also emerging as a way to enable innovation and climate improvements. For instance, Trafikverket has removed former limitations on the allowable percentage of recycled asphalt in asphalt mixes and replaced rigid binder specifications in concrete production with performance-based requirements. These changes create space for contractors to reduce emissions creatively and cost-effectively (Fossilfritt Sverige, 2024). Since contractors have numerous options for reducing emissions, and clients often prioritize the lowest-cost project execution, it becomes crucial to identify the most cost-effective mitigation measures. By understanding which emission reduction strategies offer the greatest impact per unit of cost, project stakeholders can prioritize actions that address both environmental goals and economic constraints. This ensures that climate efforts are integrated into projects without compromising financial feasibility.

1.2 Aim

This research aims to identify the cost-effectiveness of climate improvement measures related to concrete, asphalt, and fuel usage in civil construction projects. A MACC (Marginal Abatement Cost Curve) will also be developed, including the measures for a hypothetical example project. Additionally, the study aims to compare these climate-improved measures with conventional ones in terms of cost, environmental impact, and feasibility. It will also study the potential changes in these areas in the coming years. By addressing the current lack of knowledge and easily accessible data, the research aims to compile and provide reliable information to support environmentally responsible and cost-effective choices in medium —to small-sized civil construction projects.

1.2.1 Research questions

The research aims to address the following key questions:

1. What are the most cost-effective climate improvement actions for reducing CO_2 emissions in civil construction projects related to concrete, asphalt, and fuel usage?

2. How do climate improvement actions related to concrete, asphalt, and fuel usage compare to conventional practices regarding practical feasibility?

3. What are the projected changes in cost-effectiveness, environmental impact, and feasibility of climate improvement actions for concrete, asphalt, and fuel in civil construction over the next 5 years?

1.2.2 Delimitations

The research will focus specifically on concrete, asphalt, and fuel options within civil construction projects, excluding other construction materials such as steel or wood. The study is also limited to mid to small-sized civil projects and does not cover large-scale infrastructure developments. The study relies on data availability from Skanska and its subsidiaries, meaning that findings will primarily be based on information obtained from these sources and may not be universally applicable to all construction companies.

2

Theory

To assess the cost-effectiveness of climate improvement measures in civil construction, it is crucial to establish a solid theoretical foundation first. This chapter outlines the key concepts, tools, and methodologies that underpin the analysis presented in this study. Concepts such as Life Cycle Assessment (LCA) and Environmental Product Declarations (EPDs) provide the framework for measuring climate impact, while Marginal Abatement Cost (MAC) and Marginal Abatement Cost Curves (MACC) offer a means to evaluate and compare the cost-efficiency of different mitigation strategies.

In this chapter, each of these theoretical tools is presented and explained in relation to their application in construction projects. Additionally, background information on the materials and technologies studied—concrete, asphalt, and fuel alternatives—is provided to offer context for the empirical evaluation of their performance and potential for reducing climate impact. By integrating environmental assessment methods with cost analysis, this chapter lays the groundwork for the comparative study that follows.

2.1 Lifecycle assessment (LCA)

To evaluate the climate impact of construction materials and processes, Life Cycle Assessment (LCA) serves as a foundational method. LCA provides a standardized and comprehensive framework for quantifying environmental impacts associated with all stages of a product's life cycle, from raw material extraction to end-of-life (Matlhare, 2024). Principles, requirements, and guidelines for conducting lifecycle assessments can be found in ISO 14040 and ISO 14044 (Matlhare, 2024).

For construction products in Europe, these standards are further specified through EN 15804, most recently updated as EN 15804+A2:2019. This amendment provides a harmonized structure for developing Environmental Product Declarations (EPDs) and introduces mandatory reporting categories and lifecycle stages.

According to EN 15804+A2:2019, a product's life cycle is divided into the following modules:

- A1–A3 (Product Stage): Raw material extraction, transportation to manufacturing, and production processes.

- A4–A5 (Construction Stage): Transport to the site and installation.
- B1–B7 (Use Stage): Use, maintenance, repair, and operational impacts (less relevant in non-operational infrastructure).
- C1–C4 (End-of-Life Stage): Demolition, waste transport, processing, and disposal.
- D (Beyond the System Boundary): Potential benefits or burdens from reuse, recycling, or energy recovery (EN 15804+A2:2019).

Embodied emissions from materials, which this study will focus on, stem from A1-A5. All the life cycle stages are illustrated in Figure 2.1.

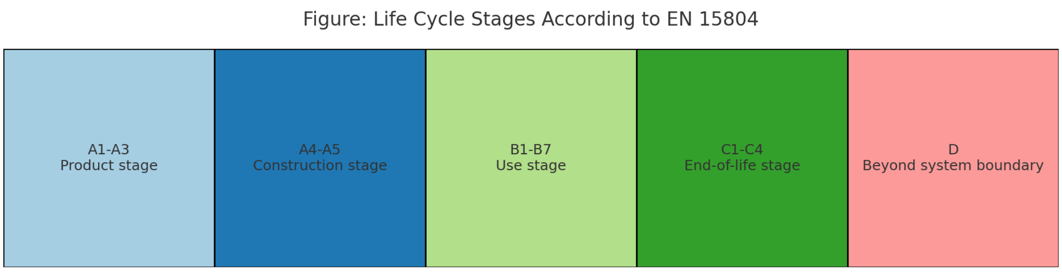

Figure 2.1: Lifecycle stages of a product according to EN15804+A2:2019)

2.2 Environmental Product Declaration (EPD)

An Environmental Product Declaration (EPD) is a standardized document that details the environmental impact of a product across various environmental impact categories, including climate impact (Matlhare, 2024). The climate impact category within an EPD is referred to as *Global Warming Potential (GWP)* (Matlhare, 2024). By estimating and summing the emissions and absorption of greenhouse gases over a product's entire lifecycle, the EPD presents its global warming potential in terms of CO_2-equivalents.

EPDs are developed in accordance with international standards, with EN 15804 being particularly relevant for construction-related products. Unlike an environmental rating system, an EPD does not evaluate or rank a product; instead, it serves as a transparent verification of its environmental impact. By using EPDs, specific environmental data for a product can be assessed, rather than relying on generic assumptions. Since climate impact can vary significantly based on the producer and location of production, EPDs provide crucial product-specific insights.

According to the updated EN 15804+A2:2019, the declaration of life cycle stages in Environmental Product Declarations (EPDs) is structured as follows:

- Modules A1–A3: Mandatory for all construction products. These represent the product stage (raw material supply, transport, and manufacturing).

- Modules C1–C4 and D: Also mandatory according to the +A2:2019 amendment when the product contains biogenic carbon, especially for materials like wood or bio-based components (e.g., pine oil in asphalt, some SCMs).

EN 15804+A2:2019 introduces a new approach to reporting Global Warming Potential (GWP) as well, by defining four distinct categories:

- GWP-total (GWP-GHG): The sum of all greenhouse gas emissions, including fossil, biogenic, and land-use change emissions.

- GWP-fossil (GWP-Fossil): Emissions from fossil fuel combustion and related processes.

- GWP-biogenic (GWP-Biogenic): Accounts for the sequestration (removal) and emissions of biogenic carbon.

- GWP-land use and land-use change (GWP-luluc): Emissions resulting from land transformation (e.g., deforestation).

A key change in this version is the separate reporting of biogenic carbon storage. The uptake and release of biogenic carbon are now accounted for under GWP-biogenic, rather than being included in GWP-fossil. GWP-biogenic will only show a negative value if the stored carbon originates from sustainably managed forestry. Furthermore, any stored biogenic carbon reported in earlier lifecycle stages must be released and recorded as an equal positive value by no later than C3 (Waste Processing) or C4 (Disposal). This means that if one calculates GWP-total by summing all three subcategories (GWP-fossil, GWP-biogenic, and GWP-luluc) while only considering A1-A3 (Raw Material Supply, Transport, and Manufacturing), the result may present a distorted view of the true environmental impact of the production phase. The handling of GWP-biogenic remains a topic of debate and varies among clients. Trafikverket, for example, does not account for GWP-biogenic and instead evaluates only GWP-fossil and GWP-luluc for A1-A3, in accordance with SS-EN 15804. This is because Trafikverket only accounts for A1-A3 for common construction materials such as concrete and asphalt (Trafikverket, 2025). This is partly because B and forward are scenario-based, meaning you cannot verify the environmental impact from those stages, but make estimates based on assumptions.

An EPD may be based on so-called generic data, while another EPD may rely on specific data (Lasvaux et al., 2015). Specific data is unique to a particular product produced at a specific plant (Lasvaux et al., 2015). The background and definitions of the declared data are always described in the EPD text. Therefore, it is essential to review this information before using the reported data in environmental calculations or for comparative purposes (Lasvaux et al., 2015). Otherwise, there is a significant risk that the data may not be comparable with those in other EPDs or may not accurately reflect the environmental impact being assessed.

All EPDs must be third-party verified by a program operator that adheres to ISO 14025, such as EPD Norge. The program operator ensures compliance with international standards by having the EPD reviewed by independent third parties before publishing it in their database.

A daughter EPD is not independently published or reviewed but is generated using a third-party verified EPD tool based on an already published EPD (OneClickLCA, 2025). Both Boverket and Trafikverket recognize daughter EPDs as valid verification (Trafikverket, 2025), (Boverket, 2024b). This approach is particularly cost-effective for companies with large product portfolios. For instance, SIS utilizes EPD tools for both asphalt and concrete.

2.3 Marginal abatement cost and marginal abatement cost curves

Marginal abatement cost (MAC) refers to the cost of reducing one unit of greenhouse gas emissions, typically measured in a specific currency per weight unit of CO_2-eq, e.g., SEK/kg CO_2-eq (Kesicki & Strachan, 2011). It represents the cost-effectiveness of climate impact actions by showing the cost of reducing one unit of CO_2-eq of GHG emissions. The result can be both negative and positive in value. A negative value indicates a net cost savings from mitigating GHG emissions, while a positive value indicates a cost associated with mitigating GHG emissions (Senatla et al., 2013). Negative MACs can be related to optimization actions, while positive ones can be related to transitioning to less carbon-intensive materials, which are more expensive than traditional ones (Rafique, 2024). MAC is useful in prioritizing mitigation strategies, as it provides an understanding of which actions one can begin with to minimize costs (Senatla et al., 2013).

For a visual representation of various mitigation strategies, a marginal abatement cost curve (MACC) can be produced (Kesicki & Strachan, 2011). In figure 2.2 an illustration of a MACC can me seen. The MACC is a graph with an x-axis representing the abatement potential of the mitigation measures and the y-axis showing their cost per unit of CO_2-eq reduced. Measures with negative costs appear below the zero line, and positive ones appear above it. Based on cost efficiency, the measures are illustrated as pillars ordered from left to right. If one decides to prioritize the choice of abatement measures based on cost efficiency alone, the accumulation of abatement can be illustrated as an arrow beneath the pillars along the x-axis. By setting an abatement target, one can use the MACC to identify the most cost-effective way to reach that goal (Ibrahim & Kennedy, 2016).

The MAC and MACC are excellent tools for ranking and illustrating mitigation actions based on cost-efficiency. However, they have shortcomings when it comes to strategizing a long-term plan to reach net-zero emissions (World Bank, 2023). In such cases, a more integrated approach is necessary for a sector to transition to carbon neutrality (World Bank, 2023).

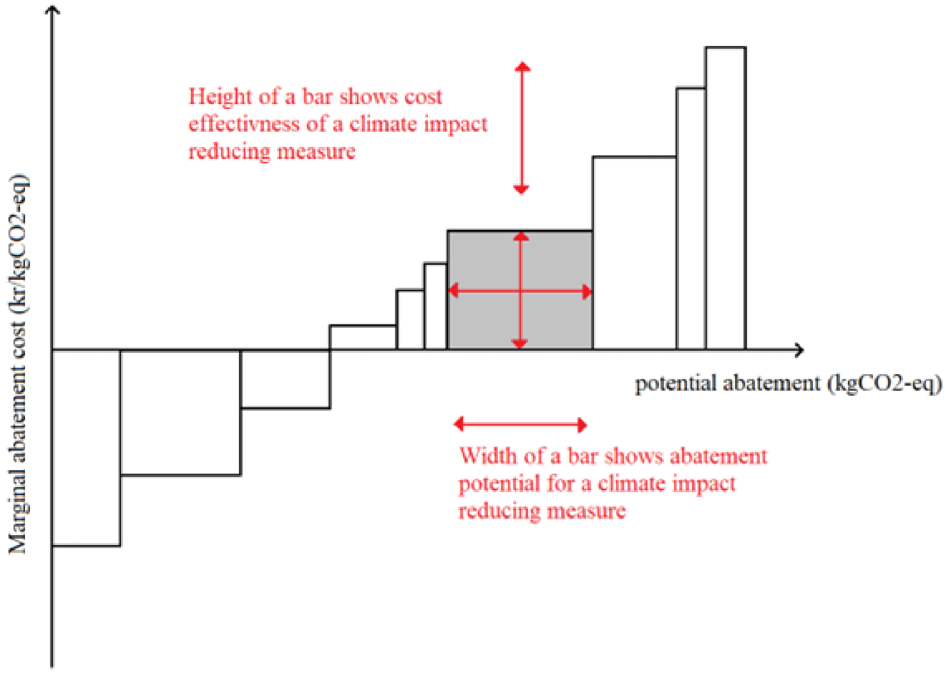

Figure 2.2: Illustration of a MACC

MACC is currently used as a tool to inform decision-makers by providing an easy-to-understand illustration that compares different mitigation measures and their cost efficiency (Rafique, 2024). Typically, the MACCs are produced for large-scale overviews, and for example, examine measures that can be implemented on a nationwide scale within a specific sector (Rafique, 2024).The MACCs also examine measures over a specified time horizon. Using the information, government and firm officials can make informed decisions regarding policy implementation (Rafique, 2024). Furthermore, the MACCs can be continuously updated and allow for adaptive decision making, taking real-world outcomes into account (Rafique, 2024).

In its simplest form, abatement costs can be calculated using the following equation (Senatla et al., 2013):

$$c_t = \frac{c_{mi} - c_{bi}}{CO_{2,ebi} - CO_{2,emi}} \tag{2.1}$$

c_{mi} = *costs incurred with abatement measure implemented*
c_{bi} = *costs incurred from baseline assumption and abatement measure not implemented*
$CO_{2,ebi}$ = *Emission equivalents with abatement measure implemented*
$CO_{2,emi}$ = *Emission equivalents without abatement measure implemented*

Calculating these values can be complex, as uncertainties can be significant when considering a long time horizon or when uncertainties related to technology development are present. How these uncertainties can be taken into account will not be presented in this report, as they are largely neglected due to our application of a simplified approach to smaller-scale construction projects, which do not span a long period of time. To fully understand the meaning of the curve, it is essential also to understand the underlying input assumptions used to produce it. Making these assumptions explicit enhances transparency and accountability for stakeholders. Unless explicitness and understanding of the input assumption are achieved, the MACCs should not be used in policy-making or planning processes (Senatla et al., 2013).

2.4 Asphalt

Traditional asphalt consists primarily of bitumen and aggregates. Bitumen is a viscous and sticky binder derived from crude oil. Asphalt is today a popular worldwide surface road material due to its favorable characteristics and cost efficiency. Asphalt is cheap, durable, elastic, and entirely recyclable. The negative aspect of asphalt is that it requires a significant amount of energy to produce, resulting in substantial greenhouse gas (GHG) emissions (Heidelberg Materials, 2024). To mix the aggregates and bitumen, they are heated at the production facility before mixing. This produces a softened mass that is flexible to process and can be laid on top of the ground. After it has been laid, the mass cools down and hardens, leaving a solid layer which can be used for vehicles and pedestrians. The heating process has traditionally been done using fossil fuels, but today bio-fuels have replaced the use of fossil fuels at many facilities in Sweden (Fosilfritt Sverige, 2022). The extraction of crude oil is the primary driver GWP-impact of Bitumen (Eurobitume, 2025). But early processing of crude oil to produce bitumen also requires a significant amount of energy, as does transportation, causing emissions (Eurobitume, 2025). Traditional asphalt consists of 95 % aggregates, which require heavy transport as well. Overall, the resource extraction and production, including transport, therefore cause a substantial climate impact.

Measures to reduce its climate impact can be done. As mentioned previously, asphalt is 100% recyclable, and by increasing the fraction of recycled asphalt used in the production of asphalt, the climate impact can be drastically reduced as the need for new bitumen and aggregates decreases (Fosilfritt Sverige, 2022). The use of fossil-free energy when it comes to production and transport within the whole life cycle and supply chain can also reduce the climate impact (Fosilfritt Sverige, 2022). SIS (Skanska Industrial Solutions) has, to date, focused on these two areas and claims to have drastically decreased the climate impact of their asphalt since 2015 by increasing the use of recycled asphalt and transitioning to the use of bio-fuels in their production (Skanska, 2025a). This has left bitumen as a big contributor to the GHG emissions which has been left to be addressed. Therefore, current research within the industry has been on finding alternative binders to replace the use of bitumen (Heidelberg Materials, 2024).

SIS has introduced its new version of asphalt, called BioZero, which replaces part of the bitumen with a byproduct of pine oil refinement. This oil partially reduces the need for new bitumen by using bio-based pine oil, and the pine oil also acts as a carbon sink. This means carbon storage, and by replacing about 15% of the bitumen with pine oil, the biogenic carbon storage can equal the GWP impact from the rest of the production. The Asphalt Zero fulfills the given requirements in Sweden and is CE-marked. SIS has also developed a version of Biozero called that requires no additional new bitumen by increasing the use of recycled asphalt and utilizing a modified pine oil that can replace even more bitumen. If accounting for biogenic carbon, a preliminary EPD showed a net negative EPD of 25 kg CO_2-eq per ton of asphalt.

In addition to its climate benefits, bio asphalt has been found to perform on par with or even better than traditional asphalt in certain respects, addressing concerns about durability (Zhang et al., 2022). Research indicates that bio-modified asphalt binders can enhance pavement performance at low temperatures and improve resistance to aging (Ingrassia et al., 2020). For instance, bio-asphalt mixtures generally exhibit higher resistance to thermal cracking (i.e. better low-temperature crack resistance) and good moisture durability compared to standard petroleum-based asphalt mixtures (Ingrassia et al., 2020). Some studies have observed that incorporating bio-oils (such as those derived from waste cooking oil or other biomass) in asphalt can make the pavement less prone to cracking and reduce age-related stiffness increase, thereby extending its service life (Zhang et al., 2022) (Ingrassia et al., 2020). These studies indicate performance advantages – such as improved flexibility in cold conditions and sustained binder properties over time and that using bio asphalt does not require compromising on quality or longevity of the road. In fact, ongoing developments in bio-binders (from sources like lignin, vegetable oils, and algae) are continually improving their rheological properties to meet high-temperature stability and fatigue resistance requirements. Overall, the introduction of BioZero and similar bio asphalt technologies demonstrates that it is feasible to significantly lower the climate impact of road construction while maintaining (or even enhancing) pavement performance, making asphalt a more sustainable choice for future infrastructure (Ingrassia et al., 2020).

2.5 Concrete

Concrete is a composite construction material primarily composed of aggregates bound together by a mixture of cement and water. Additionally, various additives are incorporated to enhance specific properties of the concrete.

Life Cycle Assessment (LCA) provides a holistic framework to evaluate concrete's environmental impact across all stages – from raw material extraction to end-of-life. In the case of concrete, LCA studies consistently show that the vast majority of greenhouse gas (GHG) emissions occur in the production phase (modules A1–A3) (Anderson & Moncaster, 2020). Globally, concrete accounts for approximately 8% of CO_2 emissions (Naturskyddsföreningen, 2022). A significant portion of these emissions arises from the cement production process itself, particularly during calcination—the chemical reaction in which limestone is transformed into cement clinker, releasing CO_2. The chemical formula for the calcination process can be seen below:

$$CaCO_3 + Heat \rightarrow CaO + CO_2 \tag{2.2}$$

The heat required to activate the reaction is the second-largest source of CO2 emissions in the production of cement and concrete. These emissions can be reduced by avoiding fossil fuels as an energy source and instead using alternatives such as biofuels or green hydrogen.

Since cement has a significant climate impact, alternative binders such as slag and fly ash have proven to be effective means of reducing the carbon footprint of concrete. In many structures, these supplementary cementitious materials (SCMs) can replace a substantial portion of the cement—often achieving emission reductions of up to 50%. However, SCMs only partially substitute the cement content, and due to the calcination process in clinker production, there is still no commercially viable way to produce concrete entirely without cement. Furthermore, the availability of traditional SCMs in Europe, such as fly ash (a by-product of coal combustion) and GGBS (a by-product of blast furnace steel production), is expected to decline as coal-fired power plants are phased out and steel production technologies evolve (Nilsson et al., 2020).

In response, emerging SCMs, such as calcined clays—especially metakaolin, produced by heating naturally occurring kaolinite clays—have attracted growing attention. These materials are not only abundant and geographically widespread, but also offer high potential for clinker substitution without the supply constraints associated with fly ash or slag. In parallel, another complementary strategy to reduce the climate impact of cement in concrete is optimizing the mix design. By carefully minimizing the cement content or adjusting the water-to-cement ratio in line with structural performance requirements, it is possible to avoid overdesign and thereby reduce unnecessary emissions embedded in excess binder (Nilsson et al., 2020).

To mitigate the remaining climate impact from unavoidable cement use, carbon capture and storage (CCS) has emerged as a critical technological pathway. CCS involves capturing CO2 at the production site—particularly during the calcination step in cement manufacturing—and permanently storing it underground (Svensk Betong, 2022). While the technology has historically been seen as energy-intensive and costly, recent developments in Scandinavia and elsewhere suggest rapid progress. In Norway, the world's first full-scale CCS project for the cement industry is under construction at Norcem's Brevik plant and is scheduled to begin operation in 2024. The facility will initially capture 400,000 tonnes of CO2 annually. In Sweden, Heidelberg Materials (formerly Cementa) plans to retrofit its Slite plant on Gotland with CCS technology by 2030, aiming to capture up to 1.8 million tonnes of CO2 per year, equivalent to the plant's entire direct emissions. Importantly, since parts of the fuel mix may be biogenic, capturing this CO2 could result in net-negative emissions, turning the plant into a carbon sink (Bioenergy International, 2024). According to Svensk Betong (2022), climate-neutral concrete is expected to be available on the Swedish market in 2035, in line with when CCS is expected to be implemented for cement production.

SIS has developed a clear and structured offering based on how much their climate-improved concretes lower emissions compared to conventional Swedish reference concrete. Clients can order concrete with a stepwise increasing 10% reduction in climate impact, starting at 10% and reaching up to 50%.

Despite its lower environmental impact, SIS's concrete retains all the essential properties of traditional concrete, meeting the same standards for durability, strength, lifespan, and workability (complying with the technical requirements of Eurocodes EN 1992). Additionally, by reusing residual materials such as slag, it contributes to circular processes.

2.6 Fuel

Fossil fuels have traditionally powered machinery and vehicles in the construction sector, but due to increasing environmental regulations and sustainability goals, alternative fuels such as renewable diesel (HVO100) and electric power have been introduced. These fuels differ significantly in origin, environmental impact, technical requirements, and economic aspects. An analysis of their characteristics and implementation possibilities can contribute to a more informed decision-making process for selecting fuels in construction projects.

2.6.1 Diesel (Mk1)

Mk1 diesel is a type of fossil diesel that has been adapted to meet Swedish environmental requirements by reducing its sulfur and aromatic compound content (Croon, 2024). This results in lower emissions of nitrogen oxides (NOx) and particulates compared to standard diesel (EN590). The Mk1 diesel can thus be seen as an improved version of conventional diesel fuel. However, it still contributes to high carbon dioxide emissions, as its fossil origin means that CO_2 emissions from combustion are comparable to those of other fossil fuels.

A key feature of the Mk1 diesel is its compatibility with existing diesel-powered vehicles and machinery (Croon, 2024). The well-established infrastructure for distribution and storage ensures that it remains the dominant fuel in the construction and civil engineering sector. Moreover, it is relatively low-cost compared to renewable alternatives, making it attractive from an economic perspective. However, long-term environmental policies pose a risk of increased costs in the form of carbon taxes and regulations, which may reduce their competitiveness in the future.

2.6.2 HVO100

HVO100 (Hydrotreated Vegetable Oil) is a synthetic diesel fuel produced by hydrotreated vegetable oils and/or animal fats (Croon, 2024). Its chemical composition closely resembles that of fossil diesel, allowing it to be used in existing diesel engines without requiring technical modifications. HVO100 is notable for significantly reducing CO_2 emissions, with up to a 90% reduction compared to fossil diesel.

One of the main advantages of HVO100 is its potential to facilitate a faster transition to more sustainable fuels without requiring new investments in vehicles or infrastructure. By enabling a fast transition for diesel equipment already in use, HVO100 complements longer-term solutions, such as electrification, filling an important role in the sector's climate mitigation toolkit (Gustavsson Binder, n.d.).

However, there are limitations, particularly concerning the availability of sustainable raw materials and production costs (Gustavsson Binder, 2022). The raw materials may compete with food production and other sectors, potentially affecting both price and supply. Additionally, the infrastructure for distributing HVO100 is not as developed as that for fossil diesel, which may present logistical challenges for companies seeking to implement it on a larger scale.

Recent analyses show that the HVO100 market has shifted into a buyer's market in the mid-2020s, following a period of tight supply and high prices. Global production capacity for HVO has expanded significantly, leading to a supply surplus that has driven down prices in Sweden and internationally. This state is expected to persist at least until 2027, when growing demand may finally catch up with production capacity (Gustavsson Binder, n.d.). This marks a dramatic shift from the late 2010s and early 2020s, when demand for HVO grew faster than supply, exerting upward pressure on prices. Looking toward 2027–2030, the market balance is projected to tighten again as climate policies and demand ramp up across Europe (Gustavsson Binder, n.d.).

The price trajectory of HVO100 in Sweden has been volatile over the past few years. Initially, after the introduction of Sweden's blending mandate (reduktionsplikt) in 2018, pure HVO100 fuel retailed at a modest premium (around 1–2 SEK per liter higher) than regular diesel. However, in 2022, the market saw an unprecedented price spike. This sharp increase coincided with a scheduled tightening of the blending requirement, though analysts note that external factors (such as surging international demand for HVO) were likely the primary drivers. The trend of high prices continued through 2022, exacerbated by Russia's invasion of Ukraine, which drove up the prices of crude oil and other fuels. HVO100 usually tracks the price movements of conventional diesel (maintaining a roughly constant differential), so as diesel prices rose in 2022, HVO100 rose in tandem. By late 2023, the situation reversed as new HVO production capacity came online globally (including additional refining capacity within Sweden), increasing supply and competition.

Sweden's Blending Mandate (Reduktionsplikt): Sweden's reduktionsplikt is a law requiring fuel suppliers to reduce the life-cycle greenhouse gas intensity of sold fuel by blending in biofuels. In the past, this policy was a major driver of HVO consumption, as suppliers blended HVO into standard diesel to meet steadily increasing reduction targets. However, in 2023, the Swedish government decided to roll back the blending mandate to the EU's minimum requirement, aiming to alleviate high fuel prices for consumers. This effectively means the required biofuel share in ordinary diesel dropped drastically. This policy shift implies a significant reduction in guaranteed demand for HVO. The current low mandate is in effect until at least 2026, after which it may be revisited. Market participants expect that Sweden may eventually need to increase its mandate after 2027 to get back on track for its climate goals. In summary, the near-term easing of the blending policy has tempered compliance-driven demand for HVO, shifting more importance onto voluntary use (while also contributing to a smaller diesel–HVO price gap as noted above).

Tax Exemption for HVO100: To support renewable fuels, Sweden has traditionally exempted pure or high-blend biofuels from energy and carbon taxes. HVO100 is currently fully tax-exempt in Sweden. This tax relief has been crucial for HVO100's competitiveness: without it, HVO100 would incur roughly the same taxes as fossil diesel, adding almost 5 SEK per liter to its cost. The European Commission must approve such state aid measures, and Sweden's exemption for HVO100 has been extended in recent years – as of 2023, the EU has approved it to continue through end of 2026. The certainty of this tax policy through 2026 provides a stable incentive for users to choose HVO100, as it keeps the price at the pump significantly lower than it would be otherwise. However, there is some uncertainty about what will happen after 2026. If the tax exemption were discontinued (or not extended further), HVO100's price could abruptly spike. According to industry analyses, such a scenario would likely be highly detrimental to HVO100 demand, causing most price-sensitive customers to abandon HVO entirely.

One reason HVO100 has been feasible as a large-scale solution is the development of distribution infrastructure in Sweden. Public fueling stations for HVO have proliferated over the past several years. As of 2022, an estimated 450 public filling stations across the country offer HVO fuel. This coverage includes stations from major fuel chains as well as independent biofuel suppliers. For instance, the company OKQ8 alone provides HVO100 at roughly 299 of its service stations, amounting to 38% of its network. Stations delivering HVO100 are not evenly distributed across Sweden. This is partly mitigated by the fact that large consumers can receive bulk deliveries of HVO. Bulk distribution (fuel delivered by tanker truck to a company's storage tank) is a critical supply mode for construction contractors, bus fleets, and others who consume high volumes.

Sweden's infrastructure policy has supported the availability of renewable fuels: the so-called *Pump Act* (*pumplagen*) mandates that filling stations above a certain size must offer at least one renewable fuel option. Traditionally, this led many stations to install ethanol (E85) or biogas pumps; increasingly, HVO100 has become a compliant choice for stations to satisfy the *pumplagen* requirement, further expanding its presence. In summary, by the mid-2020s Sweden has established a robust refueling network for HVO, both through public stations and direct bulk supply, making it logistically feasible for construction companies and vehicle fleets nationwide to adopt HVO100 as a diesel alternative.

2.6.3 Electric powered vehicles

The electrification of heavy machinery and vehicles in the construction sector is viewed as a long-term solution to reduce emissions and enhance energy efficiency. Electric motors have a significantly higher efficiency than internal combustion engines, meaning that a larger proportion of the supplied energy is converted into work (Bodemer, 2023). If electricity is generated from renewable energy sources such as wind, hydro, or solar power, emissions from electrically powered machinery can be close to zero.

Despite its environmental benefits, electrification presents several challenges within the construction sector (Käck & Jansson, 2024). One of the most significant limitations is the need for charging infrastructure, which can be challenging to implement at temporary construction sites. The battery capacity of today's heavy machinery is limited, which can lead to operational downtime and production disruptions. Additionally, the initial investment costs for electric vehicles pose an economic challenge; however, their long-term operating costs may be lower than those of diesel and biofuel alternatives.

3

Method

To assess the cost-effectiveness (carbon abatement cost) of climate-improvement actions and their feasibility, this study employs a mixed-methods approach. This method combines quantitative data (e.g., numerical climate and cost data) with qualitative insights (e.g., interviews and contextual understanding) to provide a more comprehensive analysis as described in Creswell (2009). Skanska provides comprehensive climate impact and pricing data, enabling a detailed and meaningful comparison of sustainable and traditional materials within its supply chain.

The qualitative component of the study will involve interviews with industry professionals to gain insights into climate impact, cost considerations, and decision-making processes. These interviews will also be a key source of pricing and climate impact data that cannot be obtained through other means.

This study employs deductive reasoning, starting from the general premise that climate-improvement actions can be evaluated based on their carbon abatement costs (Bryman, 2016). From this theoretical framework, we examine specific material choices within Skanska's supply chain to test and analyze this principle in practice. By integrating both qualitative and quantitative data, the research aims to explore how budget allocation can be optimized to reduce climate impact (Creswell, 2009).

3.1 Literature

A literature review will be conducted to examine specific climate reduction measures related to concrete, asphalt, and fuel, assessing their environmental impact. The methodologies used in producing Environmental Product Declarations (EPDs) and Life Cycle Assessments (LCAs) will be studied to gain an understanding of climate impact calculations. The theory behind MACC will be examined for use as part of our analysis. The findings from the literature review will also serve as a foundation for developing relevant interview questions, ensuring that the study captures key aspects of climate impact considerations within the civil construction sector.

To establish a theoretical foundation for evaluating climate-improvement measures in civil construction, a semi-systematic literature review was conducted. This approach, as outlined by Jesson et al. (2011), is suitable when a review needs to address a broad, practice-oriented field by integrating both peer-reviewed literature and relevant grey sources such as technical reports and government guidelines.

The review focuses on key concepts central to this study, including carbon abatement cost, marginal abatement cost curves (MACCs), Environmental Product Declarations (EPDs), and Life Cycle Assessments (LCAs), as well as specific measures related to asphalt, concrete, and fuel transition. The goal was to identify applicable climate-improvement actions and understand how their cost-effectiveness and feasibility could be assessed using current literature.

Databases and sources: The review included searches in academic databases such as Scopus, Chalmers Library, and Google Scholar. Additionally, relevant grey literature was gathered from industry stakeholders (e.g., Skanska), Swedish authorities (e.g., Trafikverket, Boverket), and policy publications (e.g., Fossilfritt Sverige). Google searches were used to find grey literature. This mix ensured both scientific rigor and industry relevance.

Search strategy and terms: Search strings combined key terms such as:

- "Environmental Product Declarations" AND "construction materials"
- "Marginal abatement cost" OR "MACC" AND "construction"
- "Low-carbon concrete" OR "clinker substitution"
- "Recycled asphalt" OR "bio-based binders"
- "HVO100" OR "renewable diesel" OR "electric construction machinery"
- "Lifecycle assessment" AND "infrastructure projects"

Inclusion and exclusion criteria: Included sources (1) addressed emissions or cost aspects in civil construction, (2) were published from 2010 onward, and (3) aligned with European regulatory frameworks such as EN 15804+A2:2019. Sources were excluded if they were without empirical relevance.

The findings from this literature review informed the theoretical framework (Chapter 2), supported the selection of representative materials and fuels for analysis, and helped shape the interview questions (Chapter 3.2).

3.2 Interview

To complement the quantitative data and explore practical aspects of climate improvement in construction, this study employed semi-structured interviews as its primary qualitative method. This approach is particularly well-suited for exploratory research, allowing for a flexible yet focused investigation of expert insights (Kvale & Brinkmann, 2009). Semi-structured interviews enable researchers to follow a guide of predefined themes while still allowing interviewees to elaborate freely on issues they consider relevant.

The interviews aimed to gather perspectives on the feasibility, decision-making processes, cost drivers, and future developments related to low-carbon materials and fuel alternatives. Three groups of participants were targeted:

- **Material experts** — to provide technical and environmental data on asphalt and concrete alternatives, including data used in EPDs and LCA assessments.
- **Machinery experts** — to discuss practical and financial aspects of transitioning from fossil fuels to HVO100 and electric machines. Also, to provide fuel consumption and cost data regarding machinery.
- **Clients** — to understand how public procurement criteria, climate requirements, and budget considerations influence the implementation of climate-improved measures.

Participants were selected based on their roles at Skanska and a partnering public client, using purposive sampling to ensure domain-specific knowledge (Kvale & Brinkmann, 2009). Interviews were conducted individually, either in person or via video call, and followed a thematic guide structured around the research questions.

Some interviews were recorded (with consent) and transcribed for analysis, while during others we wrote notes. Key insights were identified and organized thematically to support triangulation with quantitative data and literature findings. This triangulation strengthens the validity of the findings by cross-verifying data sources (Creswell, 2009)

3.2.1 Material experts

To analyze the climate impact of construction materials, material experts were interviewed. These experts provided insights into the most commonly used materials in civil projects, the methodologies used to calculate their environmental impact, and the development of Environmental Product Declarations (EPDs) and Life Cycle Assessments (LCAs). Furthermore, pricing data and insights for the materials were gathered to support cost-effectiveness analyses.

In total, four material experts were interviewed:

- Material expert at SIS specializing in concrete. Who gave key insights into the feasibility and prospects of climate-improved concrete variants and how they differ from traditional concrete. This interview was conducted in person and lasted for one hour.
- Material expert SIS specializing in concrete. This expert gave insight into how the EPD:s for concrete at SIS are developed and how they and the climate imporved concrete offering at SIS relates to industry-indexes produced by Svensk

Betong. This interview was conducted over video call and lasted for half an hour.

- Material expert specializing in BioZero Asphalt at SIS. The expert gave insights into the feasibility and future of BioZero asphalts and their components. Furthermore, he elaborated on the production process of Asphalt and how it has changed over the years, as well as what expected changes are to be seen. This was conducted over video call and lasted for one and a half hours.

- One material expert at SIS working with sales and operations of an asphalt production plant in Lidköping. This expert proposed the most common types of asphalt layers and provided the cost for layering for each variant. Furthermore, he elaborated on the feasibility of BioZero variants and the costs associated with the production of traditional and BioZero asphalt. This was provided during a one-and-a-half-hour interview over an online video call.

3.2.2 Machinery experts

The environmental impact of fuel choices and the transition to electric machinery was investigated through interviews with machinery experts at Skanska. These interviews focused on the carbon footprint of different fuel types and electric machines. Additionally, the financial implications of transitioning from conventional vehicles to electric alternatives were assessed in collaboration with these experts. Two machinery experts were interviewed:

- One machinery expert at Skanska who has been responsible for researching and developing strategies for transitioning the machine fleet to a sustainable and fossil-free one. He provided insights into feasibility and how the future outlook for electric machinery was to be affected by policy shifts. This was provided during a one-and-a-half-hour in-person interview.

- One machinery expert at Schakt och Transport who provided emission and fuel use data for all the machinery. Additionally, he provided all the pricing data for the machinery. This was obtained during a one-and-a-half-hour in-person interview.

3.2.3 Client

To understand clients' decision-making regarding climate improvement choices, an interview was conducted with a project manager at Göteborgs Stad. Clients set the budget and ultimately decide which climate improvements to proceed with, which is why the client's insight was important in tying the other insights into project decision-making. Furthermore, their environmental strategies and goals were interesting to study to see how they relate to and interplay with the decisions made regarding climate improvement choices in construction projects. Client knowledge regarding the studied subject was investigated.

3.3 Data collection & analysis

This study is based on quantitative data related to both the pricing and climate impact of selected construction materials and fuels. Since the data for these two dimensions were obtained from different sources and through different procedures, the methodologies used to collect them are described separately in the following sections. This distinction is necessary to ensure transparency in data handling and to reflect the methodological rigor applied to each dataset. The collected data serve as the foundation for calculating marginal abatement cost curves (MACCs) and for comparing the environmental and economic performance of various material and fuel choices. In Figure 3.1, a flowchart illustrating the data collection and calculation process is presented. Cost and GWP data formed the basis for the MAC calculations, which were presented in the results chapter. These results were later used to construct a MACC by applying the MAC calculation to example project data, which included quantities of machine hours and material amounts.

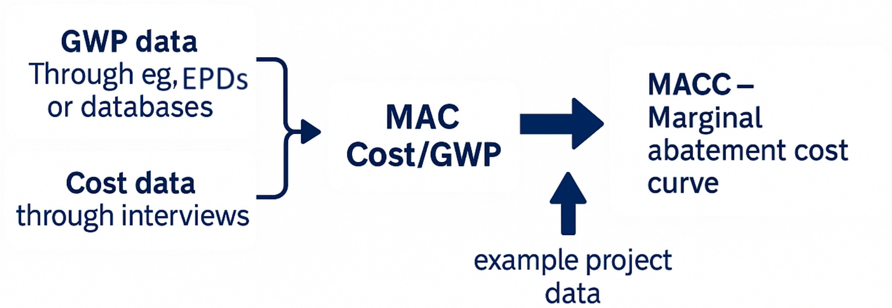

Figure 3.1: Flowchart illustrating the data collection process and calculation of MAC and production of a MACC

3.3.1 Asphalt

This section describes the methodology used to analyze the cost-effectiveness of climate-improved asphalt types compared to conventional alternatives, with a focus on their GHG emissions and associated costs. The objective is to quantify the marginal abatement cost (MAC) of replacing traditional asphalt with environmentally optimized alternatives, specifically those incorporating recycled content and biogenic binders. The study focused on three common asphalt types used in Swedish civil construction: ABT (Tät Asfaltbetong), ABb (Asfaltbetong bindlager), and AG (Asfaltgrus).

3.3.1.1 Data Collection and Data Analysis

Climate impact data were gathered from Environmental Product Declarations (EPDs) produced by SIS (Skanska Industrial Solutions) and available on EPD Norge, representing GWP-values where given in kg CO_2-eq per tonne of asphalt. Cost data were provided by the material expert at the Lidköping Asphalt production plant, with prices reported in Swedish kronor (SEK) per square meter of paved surface. The agreed-upon prices were provided under the assumption of a project requiring a paving surface of 5,000 m^2 for each asphalt type. In paving cost, both the work for the paving and the material costs are included. According to material experts, only material costs differ when comparing the paving costs of conventional and BioZero asphalt, which simplifies the comparison of prices when used in Equation 2.1, since the cost for paving work cancels each other out.

As GWP values were given in kg CO_2-eq per tonne of asphalt, a conversion to kg CO_2/m^2 was needed. This was achieved by utilizing the density of the asphalt types as provided by the material expert at the Lidköping asphalt production plant, as shown in Table 3.1 in the next subsection.

Marginal abatement costs were calculated using the cost and emission differences between conventional and climate-improved alternatives, as outlined in Equation 2.1. This allowed for a standardized comparison of different pavement options in terms of cost-effectiveness per reduced unit of CO_2-equivalent emissions.

3.3.1.2 Asphalt Scope

Three representative asphalt types were selected for this study based on their frequent use in medium and small civil construction projects across Sweden, according to a material expert. In Table 3.1, the properties of the agreed-upon asphalt types are specified.

Asphalt Type	**Layer Thickness (mm)**	**Max. Aggregate Size (mm)**	**Bitumen Penetr. Grade**	**Density (ton/m^3)**
ABT	40	16	100/150	2.42
ABb	45	16	70/100	2.45
AG	55	22	100/150	2.50

Table 3.1: Properties of chosen asphalt types

For each type, both conventional and BioZero alternatives were studied. BioZero is SIS's climate-improved asphalt that replaces a portion of bitumen with bio-based pine oil and increases the share of recycled asphalt. GWP values were limited to the A1–A3 stages of the life cycle, representing the material production phase (including raw material extraction, transport, and manufacturing). Only materials complying with current Swedish regulatory and performance standards were considered. Experimental or prototype mixes were excluded.

3.3.1.3 Reliability and Limitations

The asphalt data was sourced directly from SIS, providing detailed insights into cost and environmental impact estimates. The climate data was retrieved from third-party verified Environmental Product Declarations (EPDs), while the cost estimates were obtained through an interview with a SIS expert who conducted calculations based on a defined example project. Although the data collection was case-specific and not repeated across multiple scenarios, reliability in this context is supported by the traceability of EPD sources and the transparent calculation method, as suggested by Andersson et al. (2024), who emphasize the importance of procedural clarity and source documentation in establishing reliability in applied research. All BioZero variants included in the study are CE-marked and meet Swedish performance requirements. However, some limitations must be noted:

Climate impact data variability: Verified EPDs were used for the climate impact data; however, differences between production facilities and their associated binder suppliers, as well as regional transportation distances, may cause variability in emissions.

Cost data variation and fluctuations: Cost data reflects current market conditions in western Sweden but may differ regionally or over time due to price volatility in bitumen, bio-oils, and recycled materials.

Biogenic carbon accounting: Emission reduction from biogenic carbon storage is included in BioZero calculations. Since the accounting of biogenic carbon varies between stakeholders, interpretation of the results may differ. For instance, Trafikverket does not consider biogenic carbon storage when calculating GWP for asphalt.

3.3.2 Concrete

The following subsection outlines the methodology used to quantify both the environmental and economic implications of transitioning from standardized Swedish concrete to alternative concrete mixes with a lower climate impact. This includes defining baseline materials, specifying alternative formulas, identifying relevant environmental indicators, and applying cost analysis based on material prices and climate impact. The methodology also incorporates assumptions regarding construction practices, performance requirements, and available industry data to ensure the analysis reflects realistic market conditions.

3.3.2.1 Data Collection and Data Analysis

The study relies on empirical data collected from industry sources. In accordance with a concrete expert at SIS, the climate impact for standardized concrete was collected from the industry organization *Swedish Concrete*. Meanwhile, the climate impact of the concrete with less climate impact was calculated using the standardized framework developed by SIS, which can be found in Section 2.5. Climate impact data were collected in units of CO_2-eq/m^3 (GWP-GHG). SIS provided the prices in SEK/m^3, reflecting current market prices. Due to both climate impact and price being expressed per cubic meter, the marginal abatement cost was calculated using Equation (2.1), eliminating the need for conversions. Cost differences are solely due to material price changes, assuming no additional labor or processing costs are incurred by using the new mix.

3.3.2.2 Concrete Scope

In consultation with a material expert, the most commonly used concrete type was selected for the study. Given the study's focus on civil construction projects, frost-resistant infrastructure concrete was chosen, as it is considered the standard in western Sweden due to the region's weather conditions. The specific properties of the selected concrete types are presented in Table 3.2.

Concrete type	Infrastructure concrete (Frystestad)
Strength class	C32/40
Vct	0.45
Exposure class	XC4, XS2, XD4, XF2, XA2
$\mathbf{D_{max}}$	16 mm
Consistency class	S4

Table 3.2: Properties of selected infrastructure concrete (Frystestad)

The alternative (climate-improved) concretes have the same strength class and durability performance (C32/40, exposure classes XC4/XS2/XD4/XF2/XA2) as the standard concrete, ensuring functional equivalence for comparison. The concrete selected (C32/40, exposure classes XC4, XS2, XD4, XF2, XA2) conforms to EN 206 exposure category definitions, representing a typical infrastructure concrete used in Sweden.

Marginal abatement costs were calculated only for scenarios of 10% and 20% emission reduction in concrete. Higher reduction levels were excluded because they would likely violate current Swedish standards or guidelines for concrete composition, necessitating extensive testing and approvals. In practice, many clients (e.g., public infrastructure agencies) are hesitant to use non-standard concrete mixes, so 20% is a practical upper limit within the scope of this study. Just as with asphalt, only the climate impact from life cycle stages A1-A3 was examined. This includes embodied carbon from the production of the material.

3.3.2.3 Realiability and limitations

The climate impact data for concrete alternatives was sourced from the standardized framework developed by Svensk Betong, with 10% and 20% reductions applied to their index values. This constitutes a limitation of the study, as first-hand EPDs or daughter EPD calculations from SIS would have been preferred, but could not be provided. The method was still considered representative and consistent with industry practice as—based on agreement with a material expert at SIS—it was understood that EPDs or daughter EPDs are always provided for projects that order the climate-improved concrete. These declarations consistently reflect the same GWP figures published in the Svensk Betong framework, and the case-to-case variance is minimal.

The cost data was provided through an interview with a SIS representative who conducted pricing calculations based on a hypothetical project scenario. As this estimation was tailored to a single example case, the data are not generalizable in a statistical sense.

In line with Andersson et al. (2024), who stress that reliability in applied research is linked to procedural transparency and the traceability of sources, this study ensures reliability by clearly documenting the origin of data, the assumptions behind cost calculations, and the methods used to interpret them. While repeatability is limited due to case-specific pricing, transparency in data derivation enhances the credibility and replicability of the analytical process.

3.3.3 Fuel

This subsection outlines the methodology employed in studying the economic and environmental implications of transitioning from fossil diesel (Mk1) to HVO100 or electric power in construction machinery. The methodology is designed to ensure the collection of reliable data, enabling an accurate comparison of cost and emissions outcomes associated with fuel selection. The following subsections describe the data collection process, sources, and analytical methods utilized in this research.

When discussing machinery with experts, three categories of machines were selected for study. These three machine types were chosen because they are commonly used in small—to medium-sized construction projects and are available in both conventional diesel-driven and electric versions. These machine types included a 25-ton crawler excavator, a 20-ton wheel loader, and a truck with four axles, also known as "tridem" trucks. The specific models and the included costs are specified in Tables 3.2 and 3.3 below.

Machine type	Model	Included in Pricing
Excavator crawler ca. 25 ton	EC230-E	Machine rent + Driver + Fuel
Wheel loader ca. 20 ton	L120	Machine rent + Driver + Fuel
Truck 4-axles "Tridem"	VOLVO FH 8*4	Machine rent + Driver + Fuel

Table 3.3: Machine type and pricing components for Diesel/HVO100

Machine Type	Model	Included in Pricing
Excavator crawler ca. 25 ton	EC230-Electric	Machine rent + Driver + Battery pack
Excavator crawler ca. 25 ton	Sany215E	Machine rent + Driver
Wheel loader ca. 20 ton	LiuGong 856	Machine rent + Driver
Wheel loader ca. 20 ton	L120-Electric	Machine rent + Driver
Truck 4-axles "Tridem"	Scania Urban BEV	Machine rent + Driver

Table 3.4: Machine types and pricing components for Electric machines

3.3.3.1 Data Collection and Data Analysis

The study relies on empirical data obtained from industry sources and environmental databases. The primary data categories and their respective sources are outlined below:

Hourly Machine Cost: Market prices for construction machinery operation were obtained from machinery experts at Skanska's machinery subdivision *Schakt & Transport*. Included costs are presented in Tables 3.2 and 3.3 above. These prices reflect current market rates and take into account factors such as depreciation, maintenance, and operational expenses.

Average Fuel and Electricity Consumption: Machine-specific fuel consumption rates were provided by Skanska's machine experts. These figures represent the average fuel consumption per hour for various machine types under typical operating conditions for small to medium-sized construction projects. The base data used to calculate these averages is based on long-term statistics from currently active machines in Skanska's operation. This statistic includes both active working hours and passive hours (when machines are standing idle).

Fuel Price: Average fuel prices were calculated using the 2024 price data provided by OKQ8 (OKQ8, 2015), Skanska's supplier of fuel. This approach ensures that the analysis accounts for fluctuations in market prices and provides a representative cost comparison between Mk1 and HVO100.

Electricity Cost: The cost of electricity was determined using the average electricity price in 2024 in Swedish electric zone 3, based on data from Elbruk.se (2025) and Göteborgs Energi (2025). These prices include electricity spot prices, markups, energy tax, and grid charges. This ensures a fair comparison between fuel-powered and electric-powered machinery.

Fuel GWP: Emission factors for the studied fuels were obtained from Skanska's environmental experts, who have estimated values for 2025 based on current biofuel quota obligations in Sweden. This dataset provides standardized emission values, ensuring consistency and comparability in assessing the environmental impact of different fuel alternatives. The emission factors were reported in units of CO_2-eq/L (GWP-GHG).

Electricity GWP: Emission factors for electricity use were sourced from the Boverket Environmental Database (Boverket, 2024a). These factors reflect the Swedish electricity mix, which incorporates both renewable and fossil-based energy sources, providing an accurate representation of the carbon footprint associated with electricity consumption. The electricity emission factor was given in the unit CO_2-eq/kWh (GWP-GHG).

The collected data were analyzed using a comparative cost-emission framework. The following calculations and methodologies were applied:

Total Hourly Cost Calculation: The total hourly cost for each machine was determined by combining the hourly machine cost and fuel expenses, when fuel is not already included in the machine cost, as shown in Equation 3.1. Fuel costs were calculated based on the fuel consumption rate and average fuel price.

$$\text{Machine cost per hour} + (\text{Fuel consumption} \times \text{Fuel price}) = \text{Total hourly cost} \quad (3.1)$$

Total GWP calculation: Emission values for each machine type were derived by multiplying the fuel consumption rate by the emission factor provided by Boverket, as shown in equation 3.2.

$$\text{Fuel consumption} \times \text{Fuel GWP} = \text{Total GWP} \quad (3.2)$$

Maringal abatement cost: The additional cost per kg of CO2 reduction was calculated by comparing the cost and GWP differences between Mk1, HVO100, and electric as per equation 2.1.

3.3.3.2 Electric Machinery Scope

The study only considers factory-produced electric machines and therefore excludes converted diesel machines. Additionally, only machines that are currently available on the market and in regular production are included, excluding prototypes and experimental models. Pricing for electric machinery is based on a 12-month leasing period to ensure comparability with traditional fuel-powered alternatives.

3.3.3.3 Reliability and Limitations

The study ensures reliability by sourcing data from industry experts and validated environmental databases. However, certain limitations in reliability must be acknowledged:

Fuel and Electricity Consumption Variability: Actual fuel consumption may vary depending on machine workload and operational conditions, which are not fully captured in the average values used in this study.

Fuel Market Price Fluctuations: The fuel price data represent an annual average, which may not fully reflect short-term fluctuations.

Fuel Emissions: The fuel emission data is based on estimations provided by Skanska experts. Due to the changes in the biofuel quota obligation implemented in early 2024, no publicly available emission data for the relevant fuels has been published to date.

Machine-Specific Variations: The study generalizes machine costs and fuel efficiency based on provided data, which may not fully capture variations across different models, operational settings, and regional price differences.

3.4 Development of MACC

Having calculated the climate impact and marginal abatement cost for the abatement measures, a MACC will be developed to illustrate how it would look when applied with resource use data from a project. Using the reported resource use in the completed Skanska project, *Färjenäsparken – etapp 2*, we will utilize a MACC to demonstrate the reduction in climate impact and the cost of individual abatement measures. The specific project is a park and quay development, but will not be further detailed. More information can be read on the client website Göteborg Stad (n.d.). The data collected will be presented in the results.

3.5 Generative AI

Generative AI tools were used selectively during the writing process to support academic formulation and efficiency. The primary functions of these tools included editing text for clarity, paraphrasing longer segments into more concise expressions, and suggesting logical structures for sections such as the literature review, methodology, and discussion. These tools facilitated a more structured writing workflow and enabled iterative refinement of academic language. ChatGPT was the primary AI tool used for this purpose, and Grammarly was employed to identify grammatical errors.

All AI-generated outputs were carefully reviewed, evaluated, and edited by the authors to ensure that the final text reflected the research intentions and adhered to the thesis objectives. No text or analysis was accepted without human verification, and critical sections such as empirical data interpretation, interview coding, and calculation of marginal abatement costs were performed exclusively by the researchers.

3.6 Sustainability and Ethical Considerations

All interviewees were informed about the purpose of the thesis, and their participation was voluntary. Sensitive company data will not be published unless agreements have been made with the company. The report was handed to company supervisors for approval before publication. Efforts were made to minimize biases and present the data and conclusions neutrally. The study will examine construction data and practices to develop a framework that supports the long-term sustainability goals of both contractors and clients. There is a heavy focus on climate reduction, which is not the only environmental sustainability issue related to the choice of materials. Furthermore, the social sustainability of the choice of material, fuel, and machinery is not studied. The study could contribute to reducing climate impact, which is often neglected due to budget or knowledge constraints.

4

Empirical Study

4.1 Interviews

To complement the quantitative data collection and gain practical insights into the use and feasibility of climate improvement measures, a series of semi-structured interviews was conducted with industry stakeholders. The purpose of these interviews was to contextualize the empirical data and explore how decisions regarding materials and machinery are made in real-world projects, particularly in terms of cost, climate impact, and procurement conditions.

The qualitative findings from these interviews were used to verify the accuracy of the data and guide assumptions made in the quantitative analysis. It will also deepen the discussion around feasibility and implementation challenges related to low-carbon construction alternatives, as well as how these developments will unfold in the near future.

4.1.1 Asphalt

The interviews with Skanska's asphalt specialists provided detailed insights into the use of climate-improved asphalt mixes (often referred to by Skanska as "Zero" or "BioZero" asphalt) in comparison to conventional asphalt. The experts discussed key differences in material composition, recycling practices, production energy sources, as well as cost and carbon footprint implications.

4.1.1.1 Material Composition and Recycling

A major focus area in "green" asphalt is the substitution of traditional fossil-based bitumen with bio-based binders and the maximization of recycled content. Skanska's current climate-improved asphalt uses a blend of conventional bitumen and a bio-based binder derived from pine oil (a forestry by-product). In practice, the binder in their "Zero" asphalt is roughly a 90/10 mix of bitumen and refined tall oil. One expert noted that using much more than ∼10% pine-oil binder can compromise technical performance—for very stiff (hard-grade) asphalt, too high a bio-binder fraction would make the mix too soft. Thus, for demanding applications (e.g., heavy-load or high-temperature roads), there is a limit to how much of the fossil binder can be replaced.

That said, the bio-binder is chemically similar in origin to bitumen—both come from organic sources, just on different time scales (petroleum bitumen from ancient biomass vs. pine oil from contemporary forestry)—meaning it can perform the same binding role in the mix. The experts explained that pine oil is obtained from the pulp industry by refining black liquor, separating lignin (a solid) and pine oil (a liquid). The pine oil can be used as a binder, while lignin, if added to asphalt, acts more like a filler (adding biogenic carbon content but not binding the aggregates). Incorporating lignin in the mix essentially stores additional biogenic carbon in the pavement, which remains through the asphalt's life and recycling process. However, current regulations and mix design constraints mean bitumen still provides the primary binding functionality and constitutes the majority of binder by weight.

In addition to binder changes, Skanska's climate-improved asphalt leverages high recycled asphalt pavement (RAP) content. The interviews highlighted that a significant portion of new asphalt is produced with reclaimed old asphalt. For example, at Skanska's Upplands Väsby plant (one of its largest), roughly one-third of the raw material comes from recycled asphalt: "we manufacture almost 300,000 tons of asphalt (per year). That means we essentially reuse 100,000 tons of asphalt each year in one plant," one expert noted.

There are practical limits and quality considerations in recycling: reclaimed asphalt must be processed (crushed and sorted) and matched to the target mix. Some asphalt types allow less recycled content—for instance, a fine-grained mix like ABT 8 is "pretty difficult because you can't blend in too much recycling," whereas a coarser mix (e.g., ABT 11, a common dense asphalt) or base course mixes can accommodate higher RAP percentages. The quality of the reclaimed material is crucial; ideally, the recycled asphalt comes from relatively recent pavement layers that are not overly aged or contaminated. Old asphalt that has been in service for decades tends to have tough binder and sometimes large aggregate chunks or attached base material, requiring additional crushing and yielding excess fines. The experts prefer recycled millings from pavement that was about 10 years old: "the newer it is, the better it is" for use in a new mix.

All reclaimed asphalt can technically be reused by adjusting mix proportions and processing, with one notable exception: pavement containing coal tar (an older sealing material) is excluded from hot recycling due to health and environmental concerns. If old "tar asphalt" is encountered, it cannot be reheated (as that would release carcinogenic compounds); instead, it may only be reused cold (for example, as unbound fill material). Apart from that case, reclaimed asphalt is viewed as a valuable resource rather than waste.

There are stockpiling regulations to ensure recycled material is used in a timely manner: Skanska cannot stockpile more than 30,000 tons of reclaimed asphalt at a plant or store it longer than three years. Excess material or low-quality excavated asphalt (e.g., pieces mixed with a large amount of soil or debris from road excavations) may incur disposal costs. In practice, if there is an oversupply of reclaimed asphalt that cannot be used immediately, facilities might charge around 200 SEK per truckload to take it in (or conversely, accept it for free when they actually need recycled feedstock). This indicates the balance that must be struck between maximizing recycling and maintaining material quality for new asphalt production.

Looking ahead, Skanska is also testing more aggressive formulations to increase bio-based content and recycled fractions further, an experimental product referred to as *"Zero Plus"*. According to the interviewees, Zero Plus is still under development and "not something that is in production at this stage." The idea is to push the boundaries of the pine-oil binder usage in "more extreme forms" and pair it with even higher recycled asphalt usage. By doing so, Skanska expects "Zero Plus" could store significantly more biogenic CO_2 within the asphalt (through bio-derived components like lignin or other additives) and utilize more reclaimed material, thereby substantially lowering the net carbon emissions per ton of asphalt.

However, the product is not yet ready for commercial rollout. Experts estimate that it may take another 2- 3 years of testing before it can be offered more broadly. Currently, the special bio-binder for it must be imported from elsewhere in Europe. This indicates that while the technological pathway for even "greener" asphalt exists, scaling it up will require further R&D and supply chain development.

4.1.1.2 Production and Energy Sources

Beyond the asphalt mixture itself, another critical aspect of climate-improved asphalt is how it is produced—in particular, the energy sources used for heating and mixing, as well as the fuels used in transport and paving operations. Traditional asphalt production is energy-intensive, requiring the heating of aggregate and bitumen to approximately 150–170 °C. Skanska has transitioned to using renewable alternatives in place of fossil fuels in this process.

The interviews revealed that Skanska's asphalt plants in Sweden primarily use biofuels for the production process. For example, in western Sweden, many of Skanska's plants use wood pellets (produced from waste wood, such as used pallets, ground into sawdust) as fuel for the dryers, thereby eliminating the need for heating oil or natural gas. Some competitors use bio-oils (such as biofuel oil made from pine oil or other renewable feedstocks) to fire their asphalt plant burners. Both approaches achieve a significant reduction in production CO_2 emissions, though they have cost implications. One expert estimated that using bio-oil to heat the aggregates can be about 30- 35 SEK more expensive per ton of asphalt produced, compared to Skanska's own setup with wood pellets.

Skanska's strategy of operating more, smaller plants in each region also means shorter average haul distances for asphalt delivery, whereas a competitor with fewer large plants has longer transport distances, which can also affect fuel use and emissions in delivery. The choice of biofuel (solid vs. liquid) and plant efficiency will influence the overall energy cost and carbon footprint; however, in all cases, these renewable energy sources help reduce the embodied emissions of the asphalt product.

Another part of the asphalt's lifecycle emissions comes from the construction phase—the transport of asphalt to the site and the paving operations (machinery laying and compacting the asphalt). These aspects are often considered separately from the asphalt mix's own footprint, but they were discussed in the interviews as parallel climate improvement measures. Skanska and other contractors are transitioning their fleets and equipment to fossil-free fuels. A concrete example was given in which 100% HVO fuel, a renewable diesel substitute, was used for all paving machines and trucks on a project. In fact, Sweden's Transport Administration (*Trafikverket*) has set requirements that by 2025, at least 50% of diesel fuel usage in road projects must be HVO or equivalent biofuel. This is driving the adoption of HVO in asphalt transport and laying.

The Skanska expert described how they internally estimate the cost impact: they know the typical fuel consumption of a paving crew (per hour of paving, per truck haul, etc.), so they can calculate the additional fuel cost if switching from regular diesel to HVO and include that in project bids. The paving process itself remains unchanged when using biofuels—it primarily involves fueling the same equipment with a drop-in renewable fuel. Skanska projects aim to be "fossil-free, 100%" in terms of machinery within the next couple of years, according to one interviewee. However, it was noted that haulage contractors (trucking firms) can be slower to change since they operate on thin margins and the client must accept the higher fuel cost. Nonetheless, client demand for low-carbon construction is growing. When customers explicitly ask for fossil-free transport and laying, it enables these measures to be implemented (even if they come at a slight price premium).

In summary, the production of climate-improved asphalt involves decarbonizing the manufacturing energy (using bio-based plant fuels) and can be complemented by decarbonizing the construction phase (using HVO or electrified equipment for transport and laying). These measures address various aspects of the asphalt's lifecycle emissions. Skanska's experts stressed that the end product—the asphalt pavement—is functionally the same regardless of these energy source changes. From a site execution perspective, "laying and transport (of green asphalt) is no different from regular asphalt; the only difference is the cost," as one interviewee emphasized. In other words, using a climate-improved asphalt mix does not alter the paving process; it primarily affects upstream factors, such as the choice of binder and fuel.

4.1.1.3 Cost and Procurement Practices

Cost emerges as a key differentiator for climate-improved asphalt versus conventional asphalt in the current market. Because many environmental improvements are voluntary or exceed the minimum requirements, they often rely on clients' willingness to pay or the contractor's ability to absorb short-term costs. The pine oil binder is more expensive than bitumen, and implementing the new binder and other changes required capital investments (e.g., modifying plants with additional binder storage tanks and handling systems). Taking these factors into account, Skanska has been communicating to clients that its "Zero asphalt" comes at roughly 200 SEK higher cost per ton compared to standard asphalt. This 200 SEK/ton surcharge was described as including not just the raw material difference but also development and investment costs. At current pricing levels, 200 SEK/ton is on the order of a 20% increase in the asphalt material cost (for example, if conventional asphalt is around 1000 SEK/ton).

However, the experts were quick to point out that this is a temporary premium while volumes are low. In 2022, Skanska's production of CO_2-reduced asphalt was only about 1% of its total volume. Such a low volume means higher unit costs. If this were to become standard practice, they expect costs to "decrease drastically"; larger volumes would allow bulk purchase of bio-binder, more efficient logistics, and amortization of the initial investments. In short, the ∼200 SEK premium is partly a result of being in an early market phase. As one interviewee explained, "like most new things, it's expensive in the beginning and then costs will come down over time." The goal is for climate-friendly asphalt to eventually approach price parity with conventional asphalt as the market and supply chains mature.

From a procurement perspective, contractors currently handle this premium in different ways. In some cases, clients (municipalities, highway authorities) are beginning to explicitly request low-carbon asphalt, in which case the added cost can be built into the contract price. In other cases, Skanska may choose to offer a climate-improved alternative as an option. One important observation from the interviews is that clients typically pay for asphalt by area (e.g., per square meter of paved road) rather than by ton of material. This means the effective cost difference on a project is smaller than it might seem on a per-ton basis, because the paving and transport costs are unchanged. The ∼20% higher unit material cost, when "spread out" over the total paved area including laying costs, results in a smaller percentage increase in the overall bid. In practice, the interviewee noted that a customer sees the asphalt item as "laid and finished", so the extra 200 SEK/ton might translate to, say, only a single-digit percentage increase in the total installed cost (depending on the project specifics). This framing can help justify the choice when communicating with clients.

The discussions also touched on how the added cost relates to the environmental benefit. One way to view it is as the marginal cost of CO_2 reduction. The expert estimated that 200 SEK/ton roughly corresponds to about 10 SEK per kilogram of CO_2 saved by using the green asphalt. They mentioned that in many construction projects, a carbon price of around 7 SEK/kg is used as a benchmark for evaluating sustainability measures (for instance, the City of Stockholm has applied such values, and in Norway, about 7.5 SEK/kg is used). By that metric, the current cost of CO_2 reduction via climate-friendly asphalt (∼10 SEK/kg) is slightly higher than the societal carbon value. This is largely because, as noted, the volumes are still small; effectively, we are "paying a premium" for early implementation. The implication is that as the cost premium decreases (closer to 100 SEK/ton or less), the cost per kg CO_2 saved will drop into the range or below the 7 SEK/kg level, making it a more cost-effective abatement measure.

In bidding situations, Skanska initially applied a uniform approach to pricing the green asphalt. The interviewees stated that at this startup stage, the same approximate premium (200 SEK/ton) is applied regardless of which plant or region the asphalt comes from. This was an intentional decision to simplify the offering and communicate a clear message to the market. Interestingly, the most modern plant (Upplands Väsby) is actually the most efficient and could likely produce the climate asphalt slightly cheaper; however, for now, Skanska maintains a consistent national price. Over time, if certain locations have advantages (such as cheaper biofuel, closer bio-binder supply, or higher throughput), pricing may adjust. However, at present, the focus is on establishing a viable baseline price for the low-carbon product.

The experts also raised the broader question of supply chain readiness—if demand for green asphalt surges, will the inputs be available at scale? There is some uncertainty about the future availability and price of the bio-based components. "Will there be pine-oil binder for everyone who wants it?" one expert asked rhetorically, noting that this could become a bottleneck if the whole industry attempts to switch to biogenic binders. Similarly, HVO fuel, which is currently a by-product of, e.g., the slaughter (animal fat) and forestry industries, might face supply constraints or price increases as demand grows. These factors will influence the long-term procurement strategy and pricing for climate-improved asphalt. In the short term, Skanska is managing with dedicated suppliers and even importing some bio-binders from abroad for trials; however, scaling up will require broader market development.

4.1.1.4 Carbon Emissions and EPDs

Finally, the interview data provided information on the carbon emissions performance of the climate-improved asphalt, as documented through Environmental Product Declarations (EPDs) and internal calculations. Skanska's "Zero" asphalt is not completely zero-carbon in an absolute sense, but it achieves a significant reduction in CO_2 emissions relative to conventional hot-mix asphalt. The experts mentioned that industry requirements are quickly tightening; for instance, Trafikverket's environmental specifications will require asphalt to stay below roughly 26 kg of CO_2 per ton of asphalt produced by 2025 (and around 23–24 kg by 2027). For comparison, traditional asphalt might emit on the order of 40–50 kg CO_2/ton (depending on fuel and binder), so these targets are pushing producers to adopt measures like those described above.

Skanska's latest plant in Upplands Väsby—which uses biofuel energy and high recycling—is able to produce asphalt with very low associated emissions. In fact, Skanska has developed EPDs for its products; at the time of the interview, only the Upplands Väsby factory had an updated EPD for the climate-improved mix, but by the end of the year, they expected to have similar data from other plants (e.g., Linköping and Alvesta). The Upplands Väsby plant is described as "our most modern and best asphalt plant" and serves as a benchmark for what can be achieved. The expert suggested using Upplands Väsby's EPD as an example to compare the carbon footprint of conventional vs. "green" asphalt.

While the exact EPD figures were not given verbatim in the interview, one expert illustrated the impact in qualitative terms: with the current BioZero asphalt, the direct emissions are on the order of 20 kg CO_2 per ton, and by incorporating biogenic content, they “store” roughly an equivalent amount (20 kg) of biogenic CO_2 in the asphalt itself. In other words, the production emissions might be about half that of conventional asphalt, and the addition of bio-derived carbon (from pine oil and possibly lignin) means a portion of carbon is locked into the pavement (originating from CO_2 that was absorbed by trees). This could result in a net lifecycle impact that is far lower than that of regular asphalt. In the ideal case, if the biogenic carbon stored equals the remaining emissions, the product could be considered net carbon-neutral at the point of production. This concept of “storing carbon in the road” was highlighted as an innovative advantage of using biomass-derived binders or additives. It is important to note that the stored biogenic carbon remains in the material through reuse; as long as the asphalt is recycled and not combusted, the carbon remains sequestered.

The above scenario is largely in line with Skanska’s forthcoming “Zero Plus” asphalt, which is expected to maximize this effect (higher bio-content and recycled content to drive net emissions toward zero). As mentioned, Zero Plus is still in the trial phase, but experts anticipate that it will have an even lower cost per kilogram of CO_2 abatement because it can achieve greater carbon savings, potentially without a proportional increase in cost. For now, the available BioZero product already enables a substantial reduction in emissions—on the order of a 50% cut in CO_2 per ton compared to a conventional mix, based on the discussion. Every project that opts for this material contributes to emissions savings, which can be quantified and reported via the EPD.

In the interviews, the experts also noted that industry stakeholders (clients, authorities) are increasingly interested in these EPD results. By requiring documentation of carbon footprint, clients create a pull for low-CO_2 options. Skanska’s team expects that by having verified EPD data for both conventional and low-carbon asphalt from multiple plants, they can clearly demonstrate the difference in emissions, bolstering the case for choosing the climate-improved alternative when evaluating project options.

In summary, the empirical evidence from the asphalt expert interviews suggests that climate-improved asphalts, such as Skanska’s BioZero, are technologically feasible and already in limited use, offering notable CO_2 reductions through a combination of bio-based binder substitution, the use of recycled materials, and renewable energy in production. The main trade-off at present is cost, with about a 20% per-ton price premium, although this is expected to diminish as the market scales up. The product’s performance is comparable to conventional asphalt for most applications (no changes in laying or quality for standard use), with some limits for very high stiffness requirements. Key practical considerations include ensuring a steady supply of bio-binder and managing the quality of recycled asphalt, but Skanska’s experience suggests that these can be handled with careful planning.

4.1.2 Concrete

One prominent theme from the interview was the adjustment of cementitious material composition as a primary strategy for reducing the carbon footprint of concrete. The SIS expert explained that clinker content in cement is being actively reduced by partially substituting it with supplementary binders such as fly ash, ground granulated blast furnace slag, and other natural pozzolans. These alternative binders are industrial by-products that serve as cement replacements, and their use can significantly lower CO_2 emissions from concrete production.

Achieving a 50% emissions reduction is typically the upper limit with today's binder technology, since a portion of Portland cement remains necessary for most structural applications. Nevertheless, the interviewee emphasized that using these alternative binders not only cuts carbon emissions but also supports circular economy principles by incorporating industrial waste streams (for example, using steel slag or coal fly ash that would otherwise require disposal). Overall, the expert conveyed optimism that clinker-reduced cements and blended binders are a feasible and already available route for industry to produce lower-carbon concrete.

Another key theme was ensuring that the workability and mechanical performance of concrete are not compromised when using climate-improved mixes. The material specialist noted that, in practice, modern low-carbon concrete formulations have been engineered to retain the same hardened properties as traditional hardened concrete. Despite the changes in binder composition, the concrete's consistency, setting behavior, and strength development can be kept within normal ranges through careful mix design. The interviewee reported that climate-improved concrete delivered by SIS has comparable slump and workability to standard mixes, meaning it can be placed, consolidated, and finished using conventional methods without issue. In some cases, the mixes are slightly more sensitive to variations (for instance, water content or ambient conditions) due to the different binders, so strict quality control is maintained during batching to prevent any separation or segregation of materials.

The interview findings suggest that workability and structural performance do not pose a significant barrier to implementing low-carbon concrete, provided that the proper adjustments are made. These greener mixes maintain their durability, strength, and workability on par with conventional concrete. This insight is crucial for feasibility, as it ensures that adopting climate-improved concrete does not compromise on-site performance criteria.

The SIS expert further highlighted that any new low-carbon concrete must meet the same durability standards as traditional mixes, especially given Sweden's harsh climate and strict regulations for different exposure classes. The expert noted that the mixes have been tested and designed to meet the requirements for relevant exposure classes (e.g., those involving freeze-thaw cycles with de-icing salts, carbonation risk, or chloride ingress in marine environments), in line with European and Swedish concrete standards. In practice, this means measures like air-entrainment can be used to ensure frost durability, and the binder replacements (such as slag and fly ash) are kept within ranges that still achieve the necessary resistance to carbonation and chloride penetration over the structure's service life.

According to the interviewee, the climate-improved concretes supplied by SIS retain the same standards for durability and lifespan as conventional concrete, and are compliant with the technical requirements of Eurocode 2 (EN 1992) for structural concrete. However, the expert did acknowledge a practical nuance: the feasible extent of cement substitution tends to depend on the exposure class of the application. In less aggressive environments (lower exposure classes), a higher portion of Portland cement can be replaced by alternative binders without issue, whereas in more aggressive exposure classes (e.g., sustained freeze-thaw or marine exposure), the replacement level might be more limited to ensure sufficient durability. This implies that while climate-improved concrete is broadly applicable, engineers still match the mix design to the durability demands of the project. The interviewee's input here underscores that maintaining durability is not a fundamental obstacle—it is manageable with proper design—but it does guide where and how the most aggressive carbon reductions in concrete can be realized.

Curing time and strength development: The expert explained that mixes with high slag or fly ash content often gain strength more slowly in early days. On a construction site, this translates to potentially more extended curing periods or delayed formwork removal compared to ordinary concrete. While this is a manageable issue, it requires planning and slight adjustments in the construction schedule as an implementation consideration.

Additionally, the expert pointed out that all new concrete formulations must undergo thorough testing and comply with existing standards (such as EN 206 and relevant Swedish standards for concrete). Standardization acts as both a safety net and a hurdle: on one hand, climate-improved concretes must be CE-marked and certified to the same performance criteria as traditional mixes, ensuring reliability. On the other hand, the current standards framework can be somewhat conservative, since it was developed around ordinary Portland cement-based concrete. The interviewee noted that gaining approval for a new mix design (for example, one with an unfamiliar natural pozzolan or an innovative admixture) may require additional certification steps or documentation of long-term performance, which can extend the test duration before such a mix is entirely accepted for use. There are also exposure class limits in standards that implicitly cap the extent to which one can replace cement for specific environments. In wintertime, heated concrete can be delivered to avoid issues with early freezing, which could be a problem in winter, especially with climate-improved concrete due to its longer hardening time.

In line with circular economy efforts, the interviewee described how SIS seeks to utilize returned concrete (unused fresh concrete that comes back from construction sites) rather than treating it as waste. One approach mentioned is reusing this returned concrete as input for new batches—for example, by treating and incorporating it as part of the aggregate or cementitious content in subsequent mixes. Overall, this does not have a significant impact on climate reduction.

4.1.3 Fuel

4.1.3.1 Transition MK1 to HVO100

Cost remains the primary consideration with the transition to HVO100. The renewable fuel is more expensive than standard diesel, so widespread use hinges on who pays that premium. Because all other operating costs (machine rental, operator, and maintenance) remain the same, the difference comes down to the fuel price. The experience among machine operators is that the machine runs equally when fueled with Mk1 diesel or HVO100. In sum, transitioning to HVO100 is viewed as a readily implementable and cost-effective step, provided there is alignment on sustainability goals and the slight cost uplift is accounted for in the contract. The supply of biofuels such as HVO100 has some future uncertainty, according to the expert. In the event of high demand, there may not be enough supply for all contractors if the transition occurs quickly. Furthermore, regular diesel cars and trucks can also run on HVO100, which could increase demand, especially in cases where there is an increased requirement for biofuel blending in regular Diesel.

4.1.3.2 Transition Mk1 to Electric machinery

The next step beyond biofuels is the adoption of battery-electric construction equipment. Electrification offers the maximum emissions reduction—essentially eliminating tailpipe CO_2 emissions on site—but the interviews underscored significant practical challenges. Battery-electric excavators, loaders, and trucks are now emerging in the market, and Skanska has trialed several models in its pursuit of achieving fossil-free operations.

The machinery expert described how these electric machines can drastically improve local air quality and noise levels on-site. For example, a battery excavator operates almost silently, which was appreciated by crews working alongside it. However, the limitations of current battery technology became evident in pilot projects. A 25-ton electric excavator trial revealed that simply tracking (crawling) the machine across a large work area quickly drained the battery. On-site operations must be carefully optimized in terms of both machine usage and charging infrastructure—particularly for battery-electric crawler machines—in order to ensure they can operate as efficiently and seamlessly as their diesel-powered counterparts.

The benefit of the newly released electric models is that their battery can last a full working day. This means that low-voltage charging in between working days is sufficient, and there is no need for charging during working hours or breaks. This could also eliminate the need for expensive additional charging infrastructure, such as battery packs or high-voltage charging stations. At a typical construction site, there is usually sufficient charging capacity to charge two machines simultaneously. If additional machines are required, the project must be planned accordingly so that the charging infrastructure is established before production commences.

Cost and availability are currently the most significant barriers to electrifying construction fleets. Interviewees explained that the upfront price or rental rates for electric versions of heavy machines are substantially higher than for diesel models. The machinery division at Skanska often leases these novel machines for limited periods to mitigate financial risk and gather experience, rather than purchasing them outright. Even so, the hourly cost can be many times that of a conventional machine.

Due to the expense and limited supply, the deployment of electric machinery tends to be on a trial or strategic basis. Skanska has been coordinating the use of the limited number of available electric units across multiple projects. This type of logistical sharing maximizes the utilization of the high-value asset (and gives more teams experience with it), but it also entails moving the machine over long distances between sites. Hauling a 20–30 ton machine by truck is itself costly and has a carbon footprint, somewhat offsetting the on-site benefits. It also highlights that contractors cannot yet procure an electric dumper truck or excavator for every site—they must schedule and allocate the few machines where they will have the most impact.

The interviews also touched on equipment availability and vendor choices. Major Western manufacturers (Volvo, Caterpillar, etc.) are only gradually rolling out electric heavy machinery, so supply is constrained in the near term. Meanwhile, new entrants from China have begun offering alternatives. The Skanska expert mentioned Chinese brands (e.g., Sany and LiuGong) that are aggressively pushing into the European market with lower-cost equipment. Sany in particular has announced bold electrification goals—aiming for its entire lineup to be electric by 2026—and plans to launch a range of electric excavators soon.

Skanska's team has limited direct experience with these brands and has expressed cautious interest. They are already testing their dump trucks and excavators to evaluate their performance and compatibility (hydraulics, control systems, etc.) before considering purchasing or leasing larger quantities. The general sentiment was that while these new suppliers could improve availability and price, there was uncertainty about their long-term reliability and support.

More broadly, the technological trajectory remains uncertain—for larger heavy machines (above 30 tons), battery-electric may not be practical with current technology, and hydrogen or other solutions could play a role. Manufacturers have showcased several prototype hydrogen-fueled excavators and trucks, but they are not yet commercially available. As one interviewee noted, the industry is in flux with "many new concepts" expected in the coming years, and it is "very uncertain where we will end up" in terms of the dominant solution. This uncertainty in the market adds a layer of risk for contractors when deciding on long-term investments in electric machinery.

4.1.3.3 Client and policy considerations

A recurring theme in the interviews was that feasibility is closely tied to economic and policy factors. Implementing low-carbon fuels in construction machinery is not just a technical choice but a strategic and financial one. The Skanska experts emphasized that client alignment is often the key factor in determining whether these measures are adopted on a project. Suppose a client (e.g., a public infrastructure owner or private developer) places a high value on sustainability and carbon reduction. In that case, they are more likely to accept the additional costs or logistical complexities associated with it. In such cases, contractors can include HVO fuel or electric machine rental in the project plan, knowing that the client is willing to pay for the climate benefit.

Conversely, if the contract is awarded solely based on the lowest cost and the client has no carbon targets, it becomes difficult for a contractor to justify using a more expensive fuel or machine unilaterally. One interviewee noted that haulage firms operating on thin margins “can be slower to change” to biofuels or electrified trucks, since the client must accept the higher fuel cost for them to break even. Thus, the clients’ willingness to invest in sustainability is crucial to transitioning from small pilots to business as usual.

Beyond individual clients, public policy and market incentives play a significant role in accelerating or impeding the transition. The experts gave examples of both supportive and shifting policy measures in Sweden. On one hand, sector-specific requirements (like Trafikverket’s 50% HVO mandate by 2025) directly drive demand for renewable fuels on construction sites. There have also been government grant programs and *Klimatklivet* initiatives that co-funded electric heavy vehicles in the past, which improved the economics for early adopters.

On the other hand, recent policy changes have introduced uncertainty. The national biofuel blending policy was relaxed in 2024, reducing the required share of biofuels in standard diesel. While this was intended to control fuel prices, it could also slow the momentum of HVO adoption by making fossil diesel relatively more attractive again. Likewise, the Swedish “climate bonus” subsidy for electric vehicles, which previously helped offset the steep purchase price of electric trucks and machines, was significantly cut back. According to the interviewees, the removal of such incentives means that contractors must now carry the full cost difference for electric equipment, thereby prolonging the period before these investments pay off.

This policy landscape, a mix of carrots and sticks, was cited as a critical factor in planning fleet transitions. If future regulations tighten (for example, setting carbon limits on construction machinery) or if incentives return, the calculus could quickly change in favor of cleaner fuels.

In summary, the Fuel category of abatement measures (covering both HVO biofuel and electrified machinery) was described in the interviews as a promising but complex area. Technically, there are viable solutions available today to dramatically cut equipment emissions on construction sites. HVO can replace diesel one-to-one, and electric machines can eliminate emissions for certain operations. The feasibility in practice comes down to managing the trade-offs: HVO is easy to implement but relies on continued supply and slight cost premiums, whereas electrification offers significant emissions gains but faces operational limits (battery range, charging needs, cold-weather performance) and high costs.

The machinery expert from Skanska emphasized that a successful transition will likely require a combination of these approaches, tailored to the project's size and context. Crucially, it will also require stakeholder commitment—both from clients who set the expectations and from policymakers who shape the market conditions. With strong client sustainability goals and a supportive policy framework, the interviewees believe that the shift to fossil-free construction machinery can rapidly transition from isolated pilot projects to widespread deployment in the coming years. Cooperating and focusing on clients that share ambitious climate goals might be strategically necessary to transition to a fully electric machinery fleet.

4.1.4 Client Interview

In a detailed interview with a representative of Göteborg municipality (the public client), several themes emerged regarding the cost-effectiveness and feasibility of climate improvement measures in civil construction. The discussion primarily focused on the core topics of concrete, asphalt, and fuels. It was also discussed regarding their experience with a quay project where Skanska was the contractor and the project had a high environmental focus, as well as in a more general sense.

4.1.4.1 Cost-Effective Climate Improvement Actions for CO2 Reduction in Concrete, Asphalt, and Fuel

When discussing the client's initiatives with them, they identified a range of climate initiatives related to concrete, asphalt, and fuel use, and highlighted which actions they believe delivered the most significant CO_2 reductions at the lowest cost. Many early measures were characterized as "low-hanging fruit", straightforward changes that reduced emissions while lowering or maintaining costs. For example, in the mentioned quay reconstruction project, the client and contractor eliminated an unnecessary concrete injection procedure and other over-engineered elements. This design optimization significantly reduced material use (and associated cement consumption) and yielded an approximately 50% reduction in CO_2 emissions during the project's first phase, all while saving money.

The client explained that these measures, which also included substituting high-impact materials with lower-carbon alternatives (such as using locally sourced oak instead of imported tropical hardwood or a textured concrete finish instead of granite slabs), both reduced the project's carbon footprint and lowered costs, making them exceedingly cost-effective. Such measures required no advanced technology—only a willingness to question conventional design choices—and thus were implemented immediately when identified.

When discussing materials specifically, the client emphasized the impact of improvements to the concrete mix. A "climate-improved" concrete was introduced in later stages of the quay project, utilizing cement replacements (such as blast-furnace slag) to reduce the mix's carbon intensity. This alternative mix yields substantial

CO_2 savings relative to standard concrete. According to the client, the cost premium for this low-carbon concrete was modest, “not such a huge gap” compared to conventional concrete, and it even offered performance benefits in durability—the resulting concrete “becomes more durable and lasts longer,” as noted by the interviewee. Thus, climate-improved concrete was viewed as a worthwhile measure: it delivers significant emission reduction (by cutting cement-related CO_2) for a relatively small cost increase, making it one of the more cost-effective actions when considering long-term value. In practice, the client has started specifying such mixes in new projects as part of their environmental goals.

For asphalt, the client highlighted asphalt recycling as a highly cost-effective climate action. They noted that it is now technically possible to produce pavement with a high grade of recycled asphalt (reclaimed asphalt pavement, RAP) content, essentially reusing old asphalt instead of new raw materials. This approach was described as not only viable but actually cheaper than producing asphalt with all-new materials. The client stressed that using high levels of recycled asphalt can dramatically lower CO_2 emissions (by reducing the need for new bitumen and aggregate production) while reducing material costs. In other words, maximizing asphalt recycling is a win–win measure, yielding carbon reductions at a negative or minimal net cost. This contrasts with many assumptions that green alternatives are always costlier—in the case of asphalt, the interviewee explained, recycling more can sometimes cut costs instead.

In terms of construction fuels, the client’s experience has shown that switching from fossil diesel to renewable alternatives yields significant emission cuts, although some cost increase usually accompanies this. In the referenced project, the contractor initially used standard diesel for machinery in the first phase. By the second phase, however, they began using HVO (Hydrotreated Vegetable Oil), a renewable diesel substitute, to fuel construction equipment. The client reported that moving to 100% bio-based fuel for machines eventually became an attainable goal: “now we have 100% renewable fuel on site,” the interviewee noted, as the effort “grew organically.” This fuel switch can reduce CO_2 emissions from machinery on the order of 85–90% compared to conventional diesel.

The client acknowledged that HVO was more expensive than regular diesel, labeling it a “cost-increasing” measure that had to be factored into the budget. Interestingly, the cost savings achieved from the earlier efficiency measures (the “low-hanging” optimizations) were largely reinvested to cover the extra expense of HVO fuel (as well as climate-friendly concrete and electric vehicles). In effect, the initial cost savings were used to fund these greener but more expensive practices, keeping the overall project budget manageable. Despite the added fuel costs, the client regarded the switch to renewable fuel as essential for driving down carbon emissions in construction operations, and thus a core climate action, albeit one that must be justified by either savings elsewhere or a strong environmental mandate.

Beyond HVO, the client also experimented with the electrification of construction equipment as an emissions reduction measure. They mentioned the introduction of some electric trucks and machinery on-site. Electric construction vehicles produce zero tailpipe emissions, which can essentially eliminate on-site CO_2 from fuel; however, their deployment is currently limited by high purchase costs and developing infrastructure. The client indicated that, like HVO, electric equipment is a cost-increasing measure at present. Nonetheless, they piloted electric machines in partnership with contractors, demonstrating a willingness to invest in innovative solutions when feasible. The immediate emissions benefit is clear (especially if the electricity is from renewable sources), so the main challenge is financial rather than technical.

4.1.4.2 Practical Feasibility Compared to Conventional Practices

When comparing these climate-focused actions to conventional construction practices, the client discussed the feasibility of implementing each and the practical challenges that arose. A recurring theme was that the simplest measures were highly feasible, often easier than conventional practice, whereas more advanced measures demanded changes in the typical workflow or market conditions. For instance, the early-phase optimizations (reducing unnecessary work and material use) were described as relatively easy to execute because they aligned with the contractor's interest in efficiency and cost savings. In a conventional scenario without climate considerations, those changes might not have been pursued; yet, in this case, they proved both practically and economically advantageous.

The client's experience suggests that many emission-cutting opportunities (like eliminating redundant design elements or substituting materials) can be realized without technical difficulty, provided stakeholders are open to re-evaluating the standard approach. In the interview, the client noted that simply asking bidders, "How can you make this project more environmentally friendly?" during the procurement process yielded valuable ideas. This suggests that integrating climate goals into the project brief (even informally, as done in the second phase) can be a feasible strategy for uncovering win–win solutions that conventional practice might overlook. In summary, embedding environmental considerations into project planning was seen as straightforward and even beneficial, rather than a hindrance.

On the other hand, some of the more innovative measures required adjustments and encountered practical challenges when contrasted with business-as-usual. The switch to climate-improved concrete was one such example, though the client found it quite manageable in practice. Working with a lower-carbon concrete mix required coordination with suppliers and trust in relatively new material compositions, but it did not significantly disrupt the construction process. The contractor did not report any major technical difficulties with the concrete itself; standard construction methods could be used, and the end quality met requirements (with improved durability as a bonus). Thus, from a feasibility standpoint, adopting low- CO_2 concrete was comparable to using conventional concrete, needing only minor adaptations (like possibly slightly longer curing times or early contractor involvement to adjust the mix design).

For asphalt recycling, the client indicated that high-recycled-content asphalt is technically feasible with today's technology. In conventional practice, asphalt production often includes a portion of reclaimed material (e.g., 10–20% recycled content is common), but pushing that to higher levels requires more advanced processes. According to the client, contractors have started saying it may be possible to "switch fully" to recycled asphalt and still meet specifications. In fact, at least one contractor asserted that using 100% recycled asphalt could perform just as well as conventional asphalt. The primary practical difference lies in the production method, which requires asphalt plants equipped to process reclaimed asphalt pavement on a large scale and with rigorous quality control.

The client did not cite any insurmountable technical barriers—indeed, they seemed optimistic about the approach—but it was implied that uptake is still in progress. While conventional practice hasn't yet widely produced 100% recycled mixes, the client's remarks suggest that, from a practical and operational standpoint, such asphalt may be produced and laid similarly to ordinary asphalt in the future. Thus, the feasibility is high where the infrastructure (recycling facilities) exists, and it even simplifies material sourcing (less need for new aggregate/bitumen).

The use of renewable fuel (HVO) and electric machinery presented more noticeable practical differences compared to the conventional norm of diesel equipment. The client acknowledged that adopting HVO across the project required aligning the contractor and suppliers to ensure a steady supply of the biofuel. However, operationally, it was very straightforward—machines designed for diesel can typically run on HVO with no modifications. The ease of this switch was a positive aspect: in daily construction operations, nothing changed for equipment operators, except that they had to refuel from an HVO source.

In contrast, the real challenge was financial, since conventional practice (fossil diesel) was cheaper and more readily assumed in budgets. The client, as the budget-holder, had to be convinced to pay the premium for HVO, and they managed this by leveraging cost savings from elsewhere. Technically, using biofuel was as feasible as conventional fuel; the decision hinged on the client's willingness to deviate from the cheapest option in favor of sustainability. In this case, strong internal advocacy and a broader perspective on emissions reduction made it possible. The client's perspective is that such fuel switching is practically feasible in execution, but it requires a shift in procurement mindset to accept higher upfront costs—a shift they were able to make after witnessing the substantial CO_2 benefits.

Implementing electric construction vehicles was identified as the most challenging action in practical terms. Conventionally, all heavy equipment is diesel-powered, and moving to electric alternatives is a significant change. The client identified several hurdles, including limited availability of suitable electric machinery, significantly higher purchase costs, and uncertainties regarding maintenance and lifespan. They noted that currently, only a few models (e.g., those from large manufacturers like Volvo) are available on the market in Sweden, and production volumes are very low.

One striking example the client gave was that a Swedish-made electric excavator could cost roughly 70% more than a comparable Chinese electric excavator—and both are considerably more expensive than a diesel unit. This raises a practical dilemma: whether to invest in costly local technology or opt for cheaper imports, and how either choice might impact long-term project reliability and support. The client described this decision as “a very hard question” in terms of feasibility and strategy, indicating that market factors heavily influence the practicality of adopting electric machinery.

Despite these obstacles, the client did trial electric equipment in collaboration with their contractors. They treated it as an innovation investment, essentially subsidizing the trial by absorbing the extra costs to learn about the technology’s performance. The takeaway is that, relative to conventional diesel machines, electric machinery is currently less convenient and more expensive to deploy; however, it is technically feasible on a small scale. Charging infrastructure must be arranged and crews trained, but these were surmountable with planning. The client implied that broader feasibility will improve as the equipment market matures. For now, such measures remain on the innovative end of the spectrum—feasible in niche uses or pilot projects, but not yet routine in the way that using standard diesel equipment is.

Overall, the client’s experience demonstrates that climate improvement measures can be effectively integrated into projects alongside conventional practices, but each approach comes with its own set of practical considerations. Many actions (especially those involving smarter use of materials) were seamlessly incorporated and even improved project efficiency. Others demanded a willingness to adapt procurement practices (e.g., sourcing new material types or fuels) or invest in emerging technology. Notably, the client emphasized that achieving significant emission reductions necessitated close collaboration with contractors and suppliers, shifting somewhat beyond the traditional client-contractor dynamic. In the second phase of the quay project, a partnering approach was used, where the client explicitly solicited green solutions from bidders. This contrasts with a conventional procurement approach that focuses purely on the lowest cost and schedule. The partnering setup improved feasibility by giving contractors a platform to propose and implement novel measures (like the climate concrete and HVO fuel) with the client’s support.

In summary, compared to conventional practice, these climate actions were practically feasible when the project framework encouraged innovation and when stakeholders were committed to shared environmental goals. The interviewee acknowledged that not all projects or contractors might replicate this success easily—their case with Skanska was somewhat pioneering. However, it demonstrated that with the right mindset, feasibility challenges can be overcome and climate measures can be woven into project delivery almost as seamlessly as traditional methods.

4.1.4.3 Projected Changes and Future Outlook (Next Five Years)

Looking ahead, the client offered insights into how the cost-effectiveness, environmental impact, and feasibility of these measures are expected to evolve in the next five years. There is a clear expectation that many climate-oriented practices, which are currently novel, will become more standard and economically favorable in the near future. One major driver of change identified was the development of policy and regulations. The client referred to national and local climate targets—for instance, Sweden's regulatory roadmap for renewable fuels, which is dramatically increasing the required share of biofuels in diesel (stepping up from about 20% renewable content toward 100% within a few years). Such policies mean that by 2025–2030, using fossil diesel will be heavily restricted or significantly more expensive due to carbon taxes and blending mandates.

In practical terms, this will likely make renewable fuels like HVO much more commonplace and cost-competitive. The interviewee expects that as regulations tighten (e.g., higher "reduction obligation" levels and new EU green taxation), the cost difference between HVO and conventional diesel will shrink. In five years' time, the cost premium for low-carbon fuels is projected to decrease, improving their cost-effectiveness. Likewise, if fossil-based operations become costlier (through carbon pricing or fuel taxes), measures such as HVO or electrification naturally become relatively more financially attractive. The client views this regulatory push as crucial to advancing the entire industry, noting that what was initially a voluntary choice in their project could soon become a compliance requirement everywhere, thereby normalizing the practice.

The environmental impact of the studied measures is expected to remain positive, and in some cases, improve further with technology advances. For example, the client is optimistic that the carbon footprint of concrete will continue to decline as cement producers innovate (potentially through increased use of industrial byproducts or carbon capture in cement plants). Over the next five years, incremental improvements in climate-improved concrete mixes could yield even lower embodied CO_2 without sacrificing quality. Similarly, in asphalt, the client believes that higher recycling rates will become routine, which means the average asphalt laid in projects will have a smaller carbon footprint than today's standard mix.

The interview also touched on emerging ideas like using biogenic binders (such as tall oil, a pine forestry residue) in asphalt to create a sort of carbon sink within the material—although the client's team had not yet explored that in detail, it represents the kind of innovation that could turn asphalt surfaces into a net-negative emissions product in the future. While such innovations may not become mainstream within five years, the client is convinced that the industry is headed in that direction, and that today's experimental green asphalt will become the "standard asphalt" of the future. Overall, the expectation is that the environmental benefits of these actions will become even more pronounced as processes are refined, potentially achieving greater CO_2 reductions (per unit cost) than they do currently.

From a feasibility and implementation standpoint, the next five years are seen as a period of rapid progress. The client anticipates significant influence from international leaders and early adopters. "We will be influenced by Norway a great deal in the coming years—that's where it's happening," the client remarked, pointing out that Norway's construction industry and public sector are pioneering many low-carbon approaches (such as emission-free construction sites with all-electric machinery and strict emissions requirements for materials). This cross-border influence means Swedish clients and contractors are likely to adopt similar measures sooner rather than later.

In practice, the client expects that feasibility will improve as supply chains adapt, with more suppliers offering low-carbon concrete as a standard option, asphalt plants investing in recycling technology, and equipment manufacturers releasing more models of electric or hybrid construction machinery. With increased availability and competition, costs are expected to decrease—for instance, the client noted that as electric equipment production scales up (from a handful of units to thousands), economies of scale will significantly reduce prices. They also mentioned that the price gap between conventional and electric machinery might narrow as conventional equipment faces higher running costs (fuel, emissions fees) and as cheaper international models enter the market. By around 2025–2030, the client expects closer parity between the costs of diesel and electric machines, making the choice easier to justify on projects. In essence, as technology matures and demand grows, previously challenging measures will become far more feasible and commonplace.

Moreover, the client foresees that organizational learning and policy commitments will change the baseline for projects. In the interview, they reflected on how their own organization underwent a "journey" from having no environmental requirements to now making them an integral part of project planning. Extrapolating this trend, the next five years will likely see climate criteria firmly embedded in procurement processes for Gothenburg's civil works. As environmental goals become more ambitious (e.g. the city aiming for climate neutrality), the client's team is preparing to require even greater CO_2 reductions in each new project. This could mean that what are optional improvements today (such as using 100% HVO or a minimum percentage of recycled materials) might become standard specifications by default.

With repeated implementation, these measures will also become easier to execute; contractors will gain experience and refine their methods for low-carbon construction, improving reliability and reducing uncertainties. The client cautioned that achieving the next tier of emissions cuts will be harder. The interview noted that going beyond an initial 50% reduction toward, say, a 75% reduction is "really difficult" and may approach the limits of current technology. Nonetheless, they have set ambitious targets and view even partial attainment as worthwhile. In practice, this means continuous improvement: each project will attempt to push a bit further (for instance, piloting a higher percentage of electric equipment or trying a new material), building on the last. Over the course of five years, these incremental advances can cumulate into a substantial shift in typical practice.

In summary, the client expects that in the near future the cost-effectiveness of climate measures will improve (as cleaner options become cheaper and dirtier options are penalized), the environmental impact will further decrease (with more CO_2 saved per project as new innovations roll out), and the feasibility will greatly increase (thanks to technology maturation, policy support, and industry experience). What was once novel or challenging is anticipated to become routine. The interviewee's forward-looking perspective is ultimately hopeful: they believe that the innovations pioneered in their current projects are harbingers of a broader change in the civil construction industry. In five years' time, actions such as using climate-improved concrete, fully recycled asphalt, and renewable fuels are likely to be far more widespread and standardized, driven by both external pressures and demonstrated success. The client is preparing to "look more to leaders like Norway" and continue pushing the envelope, confident that early financial trade-offs will diminish and the alignment between cost-effectiveness and low carbon will strengthen as the market catches up. Thus, the qualitative insights from the client interview paint a picture of steady progress: climate-smart practices moving from experimental to feasible to mainstream within the coming half-decade, fundamentally reshaping how civil construction projects are evaluated in terms of cost and carbon.

4.2 Empirical data

This section presents the collected empirical data on the climate impact, as measured by GWP, and the economic cost associated with selected asphalt types, concrete mixes, and construction machine fuel alternatives. These data provide the quantitative foundation for calculating marginal abatement costs and enable comparison between conventional and climate-improved alternatives. The values presented are based on data gathered through interviews with material and machinery experts at Skanska and SIS, complemented by relevant EPDs and industry-standard databases.

4.2.1 Asphalt

The asphalt data was obtained from a material expert at Skanska Industrial Solutions (SIS) and is presented in Table 4.1. Since the paving costs were provided in SEK/m^2, both cost and environmental impact were assessed per unit of paved area to ensure consistency in comparison. The global warming potential (GWP) values were sourced from Environmental Product Declarations (EPDs), where they are expressed per tonne of asphalt. To align these values with the cost metric, the GWP per area (kg CO_2-eq/m^2) was calculated using the material densities specified by the expert, as detailed in Table 3.1. The GWP per both weight and area is presented in Table 4.1.

4.2.2 Concrete

The concrete data was obtained from a material expert at Skanska Industrial Solutions (SIS) and is summarized in Table 4.2. As pricing was provided in SEK per cubic meter (SEK/m^3), both cost and climate impact were analyzed in relation to

Asphalt Type	**Alternatives**	**Paving Cost (SEK/m^2)**	**GWP/Weight (kg CO_2-eq/tonne)**	**GWP/Area (kg CO_2-eq/m^2)**
ABT	Conventional	115	15.4	1.493
ABT	BioZero	142	-1.81	-0.175
ABb	Conventional	121	13.0	1.437
ABb	BioZero	148	-2.77	-0.305
AG	Conventional	132	11.2	1.541
AG	BioZero	168	-2.77	-0.381

Table 4.1: Comparison of paving cost and global warming potential per asphalt type and alternative

volume to maintain internal consistency. The global warming potential (GWP) was collected in accordance with the methodology and following the framework established by *Svensk Betong*, based on industry-standard GWP values and expressed in kg CO_2-eq per cubic meter. These GWP values are limited to life cycle stages A1–A3 and reflect the embodied emissions associated with material production.

Concrete Type	**Cost (SEK/m^3)**	**GWP (kg CO_2-eq/m^3)**
Infrastructure concrete (frystestad)	1600	355
Infrastructure concrete (frystestad) 10	1640	320
Infrastructure concrete (frystestad) 20	1670	284

Table 4.2: Cost and global warming potential of infrastructure concrete types

4.2.3 Fuel

The data for fuel and machine alternatives were collected in cooperation with environmental experts at Skanska and machinery experts from Skanska's internal division, *Schakt & Transport*, and are presented in Tables 4.3 to 4.7. The purpose of this data collection was to evaluate the economic and environmental implications of transitioning from conventional diesel-powered construction machinery to electric or renewable fuel alternatives.

The total hourly cost should be calculated according to Equation 3.1, but since the given prices for the traditional combustion engine machines were provided including fuel, the machine cost and total hourly cost are equal in Table 4.3. In contrast, the electric machines have an added fuel cost, as fuel is not included in the machine cost. The calculated total hourly cost for the electric machines is presented in Table 4.6.

The total GWP is calculated using Equation 3.2 and is presented in Tables 4.4 and 4.7.

Machine & Model	Machine Cost (SEK/h)	Fuel Consumption (L/h)	Mk1 Price (SEK/L)	Total Hourly Cost (SEK/h)
Excavator crawler ca. 25 t. (EC230-E)	1 210 kr	10	14,57 kr	1 210 kr
Wheelloader ca. 20 t. (L120)	1 230 kr	10	14,57 kr	1 230 kr
Truck 4-axles (Volvo FH 8*4)	890 kr	18	14,57 kr	890 kr

Table 4.3: Machine cost breakdown including fuel consumption and total hourly cost for diesel machines

Machine & Model	Fuel Consumption (L/h)	Mk1 GWP (kg CO_2-eq/L)	Total GWP (kg CO_2-eq/h)
Excavator crawler ca. 25 t. (EC230-E)	10	3,14	31,4
Wheelloader ca. 20 t. (L120)	10	3,14	31,4
Truck 4-axles (Volvo FH 8*4)	18	3,14	56,52

Table 4.4: Fuel consumption, Mk1 GWP and corresponding CO_2-equivalent hourly GWP per machine

Fuel type	Fuel Price (SEK/L)	GWP (kg CO_2-eq/L)
Mk1	14,57	3,14
HVO100	16,85	0,58

Table 4.5: Fuel price and global warming potential (GWP) per litre for Mk1 and HVO100.

Machine & Model	Machine Cost (SEK/h)	Electricity Consumption (kWh/h)	Electricity Cost (SEK/kWh)	Total Hourly Cost (SEK/h)
Excavator crawler ca. 25 t. (EC230)	2679	24,9	1,24	2 709 kr
Excavator crawler ca. 25 t. (Sany215E)	1750	20	1,24	1 775 kr
Wheelloader ca. 20 t. (LiuGong 856)	1269	19	1,24	1 292 kr
Wheelloader ca. 20 t. (L120 Electric)	1958	19	1,24	1 981 kr
Truck 4-axles (Scania Urban BEV)	1250	58,5	1,24	1 322 kr

Table 4.6: Hourly costs of electric machines including electricity consumption

Machine & Model	Electricity Consumption (kWh/h)	Electricity GWP (kg CO_2-eq/kWh)	Total GWP (kg CO_2-eq/h)
Excavator crawler ca. 25 t. (EC230)	24,9	0,021	0,523
Excavator crawler ca. 25 t. (Sany215E)	20	0,021	0,42
Wheelloader ca. 20 t. (LiuGong 856)	19	0,021	0,399
Wheelloader ca. 20 t. (L120 Electric)	19	0,021	0,399
Truck 4-axles (Scania Urban BEV)	58,5	0,021	1,229

Table 4.7: Electricity consumption and corresponding CO_2-equivalent emissions per machine

5

Results and Analysis

This chapter presents the findings in relation to the three guiding research questions. It begins with the calculation and comparison of marginal abatement costs for the studied construction materials and fuels, providing insight into the cost-effectiveness of climate-improved alternatives relative to conventional practices. The analysis also evaluates the feasibility of implementing these measures in practice, taking into account both technical and economic considerations. Finally, the chapter discusses projected developments over the next five years, examining how cost-efficiency, environmental impact, and implementation feasibility of climate mitigation strategies for concrete, asphalt, and fuel are expected to evolve within the context of civil construction.

5.1 Asphalt

When analyzing the asphalt abatement costs calculated using Equation 2.1 and presented in Table 5.1, the analysis of asphalt alternatives demonstrates an apparent reduction in climate impact when transitioning from conventional asphalt mixes to SIS's climate-improved "BioZero" alternatives. Across all three studied asphalt types —ABT, ABb, and AG —the BioZero variants exhibit lower global warming potential (GWP) values. The emissions reductions range between approximately 27% and 37%, with the most significant relative reduction observed for AG-type asphalt.

Despite these environmental benefits, the transition to BioZero asphalt entails an observable cost premium. This increase is primarily attributed to the substitution of conventional bitumen with bio-based binders, as well as the higher use of recycled asphalt, which, while environmentally advantageous, requires more complex processing and quality control. The resulting marginal abatement costs (MACs), as shown in Table 5.1 and Figure 5.1, range between 16 and 19 SEK per kg CO_2-equivalent, varying by asphalt type.

Although these MAC values are significantly higher than those observed for some other materials in this study, they remain within a range that may be considered reasonable under certain procurement conditions, particularly in projects where environmental criteria are prioritized or incentivized. The cost-effectiveness of BioZero asphalt thus depends not only on the direct financial evaluation of abatement per unit of CO_2-equivalent but also on the broader procurement context and the valuation of long-term climate benefits.

Asphalt Type	**Increased Cost (SEK/m^2)**	**GWP Reduction (kg CO_2-eq/m^2)**	**Abatement Cost (SEK/kg CO_2-eq)**
ABT	27	1.668	16.18
ABb	27	1.742	15.50
AG	36	1.922	18.73

Table 5.1: Marginal abatement cost of asphalt types using BioZero compared to conventional alternatives

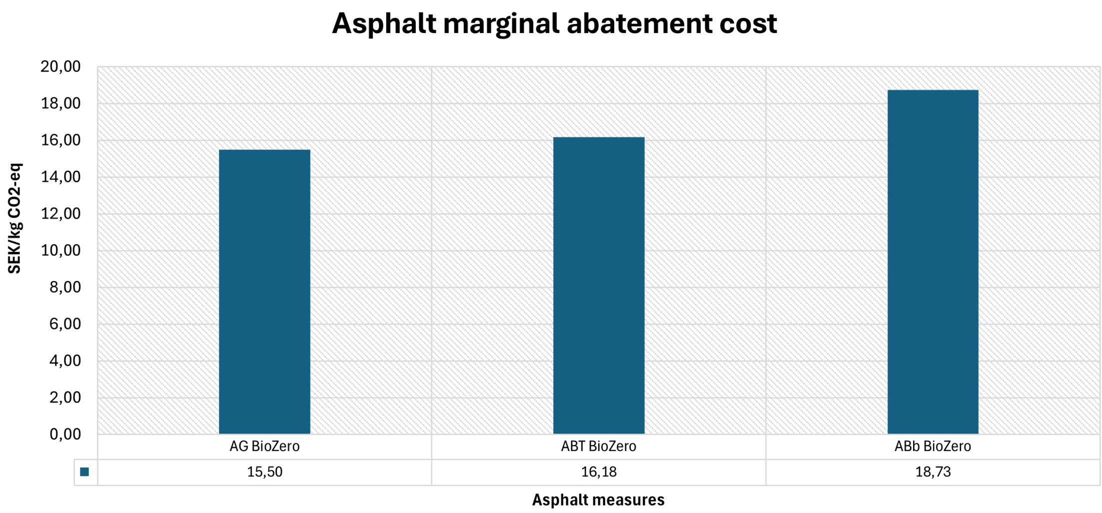

Figure 5.1: Abatement cost for asphalt measures

Beyond these quantitative results, it is crucial to compare the climate-improved asphalt with conventional practice in terms of practical feasibility. Technically, the BioZero mixes are designed to be drop-in replacements for standard asphalt, and all studied variants are CE-marked and satisfy Swedish specifications for their intended use. Field performance (strength, durability, and workability) is expected to be comparable to that of conventional asphalt, as the core properties (aggregate grading, binder content, etc.) remain within normal ranges. The key difference lies in materials sourcing and production, as part of the bitumen is replaced by a bio-based binder, and production energy is derived from renewable fuels. One expert noted that very high fractions of pine-oil binder can make asphalt slightly softer, indicating that for heavy-load or high-temperature applications, there is a limit to how much of the fossil binder can be replaced without performance issues. In practice, this means that climate asphalt can be used in most regular applications today, but highly demanding paving jobs may still require a portion of conventional bitumen for added stiffness. Otherwise, from a paving and laying perspective, contractors can handle BioZero asphalt using the same equipment and methods as those used for ordinary hot-mix asphalt.

The feasibility of large-scale adoption also hinges on supply chain and economic considerations. Bio-based binders and HVO biofuel are currently more expensive and limited in supply. Industry experts have raised concerns about whether there will be "pine-oil binder for everyone who wants it," cautioning that a rapid, industry-wide switch to biogenic binders could face bottlenecks in availability. In the short term, Skanska has managed supply by partnering with specific bio-binder producers and importing some volumes for trials; however, scaling up usage will require broader market development. On the economic side, the price premium for BioZero asphalt (roughly +20–30% on material cost) is a potential barrier. Contractors and clients must be willing to invest extra money for the climate benefit. However, there are encouraging signs in the industry. Trafikverket and other public clients have begun to incentivize low-carbon methods. Trafikverket, for example, now requires that at least 50% of diesel fuel used in road projects be HVO or equivalent by 2025, a mandate that directly supports the adoption of biofuels in asphalt production and construction machinery.

Moreover, Trafikverket has introduced emission reduction targets in its projects, creating flexibility and incentives for contractors to propose innovative low-carbon solutions. Such policies improve the practical feasibility of climate-improved asphalt by driving demand and partially offsetting the cost differential. In summary, compared to conventional asphalt, the BioZero approach is technologically feasible and already in limited use, but its expansion will depend on continued material supply development and the willingness of clients to bear a modest cost increase for sustainability.

Looking forward over the next five years, the cost-effectiveness, environmental impact, and implementation of climate-friendly asphalt are expected to progress significantly. On the cost side, as renewable binder and fuel technologies mature, the price premium of BioZero is likely to diminish. If bio-binder production scales up and more suppliers enter the market, economies of scale and increased competition could drive down costs. Simultaneously, rising carbon costs or stricter emission regulations would make conventional asphalt more expensive, effectively improving the relative cost-effectiveness of the low-carbon option. Environmental impact is also poised to improve. Skanska is already developing a more advanced version, "BioZero+", which aims to use no new fossil bitumen by combining an even higher recycled asphalt content with a more advanced pine-based binder. This could potentially push CO_2 reductions to on the order of 70–100% relative to today's mix, essentially approaching net-zero asphalt production. Indeed, the current BioZero product already achieves about a 50% cut in CO_2 per ton, and BioZero+ is expected to improve upon that. If BioZero+ or similar innovations become commercially viable in the next few years, the environmental benefits of climate-improved asphalt will be markedly higher than those quantified in this study.

In terms of feasibility, ongoing and upcoming policy measures strongly indicate greater adoption. Trafikverket's environmental specifications are tightening rapidly; for instance, by 2025, new asphalt must emit less than ∼26 kg CO_2/ton, dropping to ∼23–24 kg by 2027. Conventional asphalt today emits approximately 40–50 kg/ton. These ambitious targets virtually mandate the use of biofuels, higher recycling rates, and bio-binders to comply. Thus, within five years, many practices that are considered "climate improvement actions" now (like using HVO fuel or BioZero binder) may well become standard requirements rather than optional measures. The likely scenario for 2030 is that climate-improved asphalt will be far more common, supported by a more robust supply chain for bio-binders and a better business case as carbon accounting is enforced. Contractors will also have accumulated more experience with these materials, further smoothing implementation. In conclusion, the asphalt sector is expected to see steadily improving cost-effectiveness of CO_2 abatement and greater feasibility of low-carbon techniques, driven by technological innovation and policy push, with significant reductions in environmental impact on the horizon.

5.2 Concrete

By subtracting the cost of conventional action from the climate-improving measure in Table 4.2, a cost increase was calculated. A GWP reduction was calculated by subtracting the GWP values in table 4.2. Using Equation 2.1, abatement costs were calculated using the input from Table 4.2. The results are compiled in Table 5.2, and a bar chart illustrating the two climate-improved concrete variants is shown in Figure 5.2.

$$\text{Infrastructure concrete 10:} \quad \frac{1640 - 1600\ \text{SEK/m}^3}{355 - 320\ \text{kg CO}_2\text{-eq/m}^3} = 1.14\ \frac{\text{SEK}}{\text{kg CO}_2\text{-eq}}$$

$$\text{Infrastructure concrete 20:} \quad \frac{1670 - 1600\ \text{SEK/m}^3}{355 - 284\ \text{kg CO}_2\text{-eq/m}^3} = 0.99\ \frac{\text{SEK}}{\text{kg CO}_2\text{-eq}}$$

Concrete Type	**Increased Cost (SEK/m^3)**	**GWP Reduction (kg CO_2-eq/m^3)**	**Abatement Cost (SEK/kg CO_2-eq)**
Infrastructure concrete (frystestad) 10	40	35	1.14
Infrastructure concrete (frystestad) 20	70	71	0.99

Table 5.2: Marginal abatement cost of freeze-resistant infrastructure concrete types

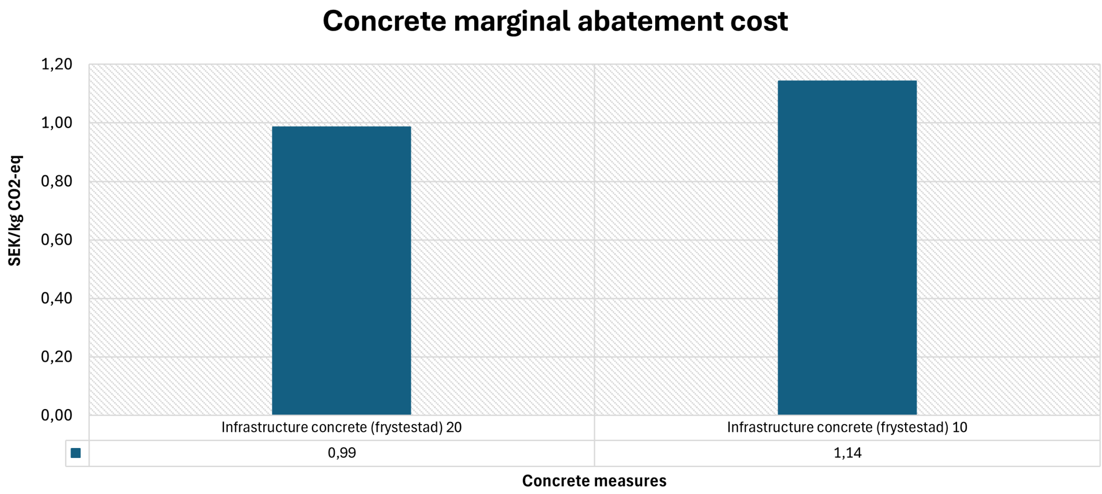

Figure 5.2: Abatement cost for concrete measures

The results show an abatement cost for concrete between 0.99 and 1.14 SEK/kg CO_2-eq. A modest 2.5–4% increase in concrete cost yields a 10–20% reduction in embodied emissions, making low-carbon concrete one of the most cost-effective measures identified.

From a technical standpoint, these low-carbon mixes are designed as direct substitutes for conventional concrete. They maintain equivalent strength, durability, and workability, and comply with relevant standards such as EN 206. Contractors can use them without changing construction methods. Some operational considerations exist—such as slightly longer curing times or more sensitive early strength development—but these are manageable through planning and standard site procedures, especially with heated concrete in winter.

Exposure class constraints and approval processes further shape the feasibility of implementation. While mixes with 10–20% clinker reduction are viable in most infrastructure applications, more aggressive reductions may be limited in harsh environments due to durability requirements. Still, performance-based approaches and improved mix designs are gradually expanding the practical range of these alternatives.

Economically, the cost barrier is relatively low; however, widespread adoption depends on effective procurement practices. If climate criteria are not factored into tenders, contractors may default to cheaper conventional options. However, the industry is seeing a shift, with public clients increasingly integrating CO2 performance in procurement, creating more substantial incentives for using climate-improved concrete.

Looking ahead, both the environmental and economic outlook for low-carbon concrete is promising. The price premium is expected to decline as supply chains scale, and new technologies, such as carbon capture and calcined clay binders, will further reduce emissions. By 2030, it is likely that mixes with 30–50% CO2 reduction will be commonly used. Policy developments, standard revisions, and accumulated contractor experience will make climate-improved concrete increasingly feasible, affordable, and mainstream.

In summary, the findings suggest that concrete presents a clear opportunity for scalable, cost-efficient climate mitigation. With supportive procurement models and ongoing technical advances, low-carbon concrete could become a standard material in civil construction over the next five years.

5.3 Fuel

When studying fuel, the analysis demonstrates that substituting fossil diesel (Mk1) with HVO100 in construction machines and transport vehicles leads to a substantial reduction in carbon dioxide (CO_2) emissions. Calculations based on Equations 3.1 and 3.2 (as described in the method section) and the resulting data in Table 5.3 indicate that this transition consistently reduces emissions across all studied machine types. When summarizing the differences in hourly costs and emissions between Mk1 and HVO100. The findings show that the cost of reducing CO_2 emissions by switching to HVO100 is approximately 0,89 SEK per kilogram of CO_2-equivalent. This value remains constant across different machine types due to their similar operational cost structures. Since the primary variation stems from the fuel price difference, the abatement cost per reduced CO_2 unit is largely uniform when using HVO100 instead of Mk1 diesel.

In contrast, switching from Mk1 diesel to electric machinery offers a more significant reduction in emissions, virtually eliminating direct CO_2 emissions from on-site operations. However, this environmental benefit comes with higher associated equipment and operational costs. Hourly cost increases for electric machines vary substantially, ranging from a few tens of SEK up to over 1,000 SEK, depending on the type of machine and the maturity of the electric alternative. The cost efficiency of CO_2 reduction through electrification is thus more variable than with HVO100, ranging from approximately 0 to 50 SEK per kg of CO_2 reduced, as shown in Table 5.3 and Figure 5.3.

Machine & Model	**Increased Cost (SEK/h)**	**GWP Reduction (kg CO_2-eq/h)**	**Abatement Cost (SEK/kg CO_2-eq)**
Excavator crawler ca. 25 t. (EC230)	1 499	30,88	48,56
Excavator crawler ca. 25 t. (Sany215E)	565	30,98	18,23
Wheelloader ca. 20 t. (LiuGong 856)	-62	31,00	-2,02
Wheelloader ca. 20 t. (L120 Electric)	751	31,00	24,24
Truck 4-axles (Scania Urban BEV)	432 kr	55,29	7,82

Table 5.3: Abatement cost for each electric machine relative to diesel equivalents.

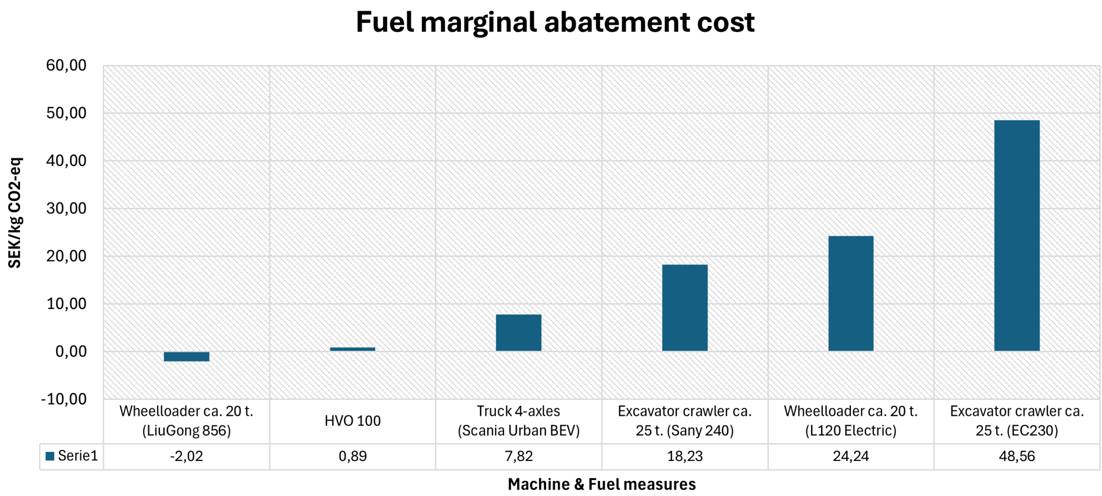

Figure 5.3: Abatement cost for electric machine measures

These examples illustrate that while electrification offers the greatest potential for emissions reduction, its cost-effectiveness varies significantly. The specific machine type and the relative costs of current electric technology primarily drive the variation. Therefore, the optimal choice between HVO100 and electrification depends not only on environmental ambition but also on economic feasibility in each specific application.

From an operational standpoint, HVO100 is nearly identical to conventional diesel—it is a drop-in fuel that can be used in the same engines without modification, so construction machines run equally well on HVO as they do on Mk1 diesel. Contractors report that using HVO "does not change" the equipment's performance or the work process; the only difference is a slight increase in fuel cost. This means switching a fleet to biodiesel can be done immediately, provided the fuel is available and the project budget (or client) can accommodate the price premium.

In practice, early adoption has been driven by client requirements and sustainability goals: for example, Trafikverket now mandates that at least 50% of diesel use in road projects be HVO by 2025, directly spurring contractors to use HVO100 on site. Skanska itself has set a goal for 100% fossil-free machinery (predominantly via HVO) within the next few years. Such initiatives illustrate that client influence is crucial—when clients specify or incentivise low-carbon fuels, contractors readily implement HVO, whereas without such support, they may revert to cheaper diesel.

The main practical limitation for HVO is on the supply side: interviews noted some uncertainty about future HVO availability if demand accelerates across the industry. Regular diesel vehicles (not just construction equipment) can also run on HVO, so a broader shift to biofuels could strain supply if production does not keep up. Nonetheless, HVO100 is currently being successfully deployed on projects, and contractors have managed procurement by partnering with fuel suppliers to secure the needed volumes. In summary, using HVO100 in place of diesel is highly feasible from a technical and operational perspective, with the caveats that fuel supply must be assured and someone must bear the additional fuel cost.

By contrast, the feasibility of battery-electric machinery in construction is presently more limited. Electric excavators, loaders, and trucks are available in limited models and quantities, and they present both technical and logistical challenges. One Skanska pilot, operating a 25-ton battery excavator, highlighted that heavy, continuous operations (even simply tracking across a large site) can rapidly drain the battery, requiring careful planning of work tasks and charging opportunities.

5.4 Price efficiency comparison and MACC

When comparing all the studied climate-saving measures, we gain a clearer understanding of how they relate to one another in terms of marginal abatement costs. Below in Figure 5.4, all the measures are illustrated next to each other in ascending order from left to right.

HVO100 and climate-improved infrastructure concrete both stand at around 1 SEK/kg CO_2-eq. The BioZero asphalt types exhibit approximately 15–18 times higher marginal abatement costs than the climate-improved concrete. The electric machinery (wheel loaders and excavators) shows a wide spread, with the Chinese variants (Sany and LiuGong) being significantly lower in cost than their Volvo counterparts. The LiuGong wheel loader even resulted in a negative marginal abatement cost, making it the only measure that provides both cost-saving and emission-saving. The electric truck falls in the middle of the chart, proving to have a marginal abatement cost lower than BioZero asphalt and most machinery, yet still considerably higher than climate-improved concrete and HVO100.

The resource use data presented in Table 5.4 is based on quantities collected from the “Färjenäsparken Etapp 2” project. While the project itself did not implement the specific abatement measures analyzed in this study, it did utilize the same types

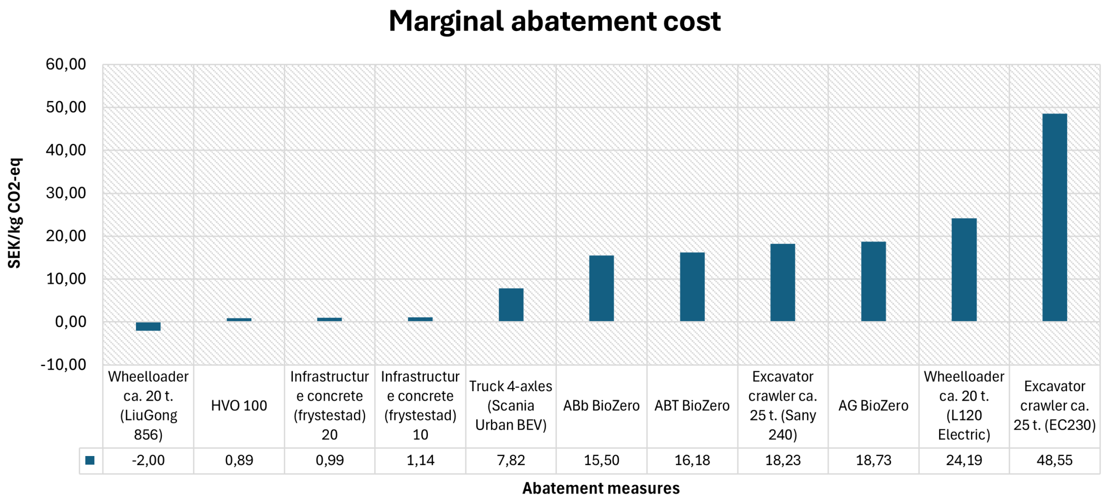

Figure 5.4: Abatement cost for all studied measures

and quantities of machinery hours and material volumes. For the purpose of this analysis, the original resources have been substituted with corresponding climate-improved alternatives. Thus, Table 5.4 reflects how the studied abatement measures would perform if applied to an equivalent scope of work as in the reference project. Despite the fact that HVO100 has a lower MAC than the electric machines (Except for the LiuGong), some machinery hours were added to illustrate how they would stand in comparison.

Abatement Measure	Resource Use
Wheelloader ca. 20 t. (LiuGong 856)	160 h
HVO 100 Excavator crawler 25t	240 h
HVO 100 Tridem	800 h
Infrastructure concrete (Frystestad) 20	100 m^3
Electric Truck 4-axles (Scania Urban BEV)	400 h
ABT BioZero (40 mm - Thickness)	2000 m^2
Excavator crawler ca. 25 t. (Sany 215E)	240 h
AG BioZero (55 mm - Thickness)	1100 m^2

Table 5.4: Resource use for each abatement measure.

In Table 5.4, the resulting Abatement and Total abatement costs are presented. MAC and abatement are based on the previous results for the abatement measures.

In Figure 5.5, we can see the final MACC based on the information in Table 5.4. The area illustrates the cost of a measure. The red line is supposed to demonstrate an abatement target. This target is adjustable depending on project goals. If one wants to prioritize which measures to include in the project based on cost efficiency, then everything to the right of the line can be discarded. In Figure 5.5, the abatement target was set to 80000 kg CO2-eq, which, according to the MACC, would mean that all measures except for the Sany 240 and the AG BioZero should be included.

Abatement Measure	MAC	Abatement	Tot. Abt. Cost
–	SEK/CO_2-eq	kg CO_2-eq	SEK
Wheel loader ca. 20 t. (LiuGong 856)	-2.00	4960.16	-9920.32
HVO 100 Excavator crawler 25t	0.89	6144.00	5468.16
HVO 100 Tridem	0.89	36864.00	32808.96
Infrastructure concrete (Frystestad) 20	0.99	7100.00	7029.00
Electric Tridem (Scania Urban BEV)	7.82	21815.04	170593.61
ABT BioZero (40 mm Thickness)	16.18	3336.00	53976.48
Excavator crawler ca. 25 t. (Sany 215E)	18.23	7435.20	135543.70
AG BioZero (55 mm Thickness)	18.73	1916.20	35890.43

Table 5.5: Marginal abatement costs and total emissions reductions for selected climate measures.

The resulting MACC can be seen in figure 5.5.

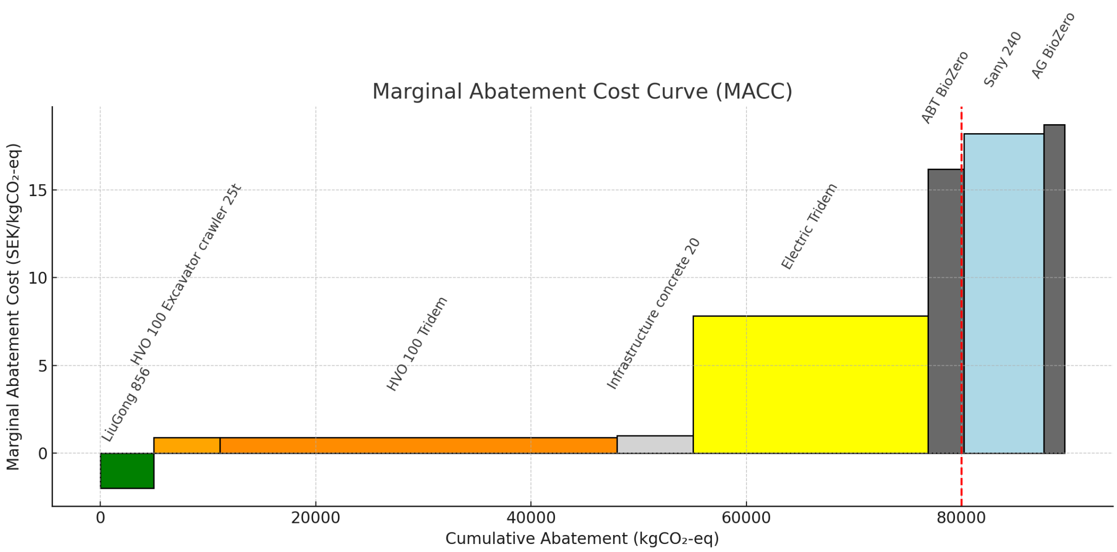

Figure 5.5: MACC for example project

6

Discussion

This chapter interprets and critically examines the findings of the study in relation to its aims and the broader context of climate improvement in civil construction. The discussion explores how the identified measures—climate-improved concrete, alternative asphalt techniques, and renewable fuels—compare in terms of feasibility, implementation barriers, and cost-effectiveness. It also considers the practical implications of the results, the role of policy and market dynamics, and the trade-offs involved in applying different mitigation strategies. Finally, this chapter addresses key limitations and reflects on the robustness and generalizability of the conclusions drawn.

6.1 Cost effectivness

A central finding of this study is that not all climate impact-reducing measures are prohibitively expensive — in fact, several options deliver emissions cuts at marginal cost. For example, substituting fossil diesel with HVO100 biofuel was found to reduce CO_2 emissions by roughly 80% with an abatement cost of only about 0.9 SEK/kg CO_2. Likewise, using low-carbon “green” concrete mixes (with partial clinker substitution) can cut embodied emissions by 10- 20% at a low marginal abatement cost of about 1.0 SEK/kg CO_2. These values make HVO fuel switching and optimized concrete two of the most cost-effective measures identified in this analysis.

By contrast, the BioZero asphalt alternative—while achieving a significant emission reduction relative to conventional asphalt—carried a higher cost premium (approximately 20–30% per ton) that translated to 15–18 SEK/kg CO_2 abatement cost. Fully electric construction machinery offers the deepest emissions cuts (eliminating virtually 100% of on-site CO_2), but current electric equipment entails significantly higher ownership costs; in our results, electrification showed a wide cost range from slightly negative (0) up to approximately 48 SEK/kg CO_2 abated, depending on machine type and scenario.

The fact that some measures (such as HVO and green concrete) fall near the low end of the cost per kilogram, while others (BioZero asphalt, certain electrification cases) are higher, underscores the importance of price efficiency in choosing abatement strategies. Contractors and clients can prioritize the “low-hanging fruit” (measures with low MAC) to achieve substantial carbon savings without straining budgets. Indeed, many emission reductions can be achieved without “breaking the bank,” provided they are recognized and prioritized in project planning.

6.1.1 Policy support

Translating these findings into practice will require adjustments in industry procurement norms and supportive policies. Traditionally, construction procurement (especially in the public sector) prioritizes the lowest bid, which can discourage bidders from proposing climate-improved solutions that add cost, even modestly. However, if tender evaluations include carbon performance alongside price, contractors have an incentive to adopt low-carbon methods. Encouragingly, there are signs of this shift. Trafikverket has introduced climate requirements and incentives in its contracts: for instance, by 2025, all road projects must use at least 50% HVO fuel, and bonus payments are offered for exceeding specific CO_2 reduction targets. Such measures effectively integrate carbon considerations into project criteria, moving away from a purely lowest-price model.

The results of this thesis support these policy moves, given that options like HVO and green concrete add only marginal costs, a procurement framework that rewards low-carbon bids can achieve significant cuts without unreasonable expense. The implication for practice is that public clients should continue refining procurement criteria to reward low-carbon methods, whether by setting minimum environmental standards (e.g., a biofuel usage mandate) or by explicitly evaluating bids on both cost and carbon performance. This creates a more level playing field where contractors who invest in green solutions are not penalized financially, and it signals to the market that funding will be available for climate improvements. In the absence of such adjustments, there is a risk that the higher-cost measures identified (e.g., electric machinery or BioZero asphalt) might not be adopted at scale because contractors fear losing competitive bids. Aligning procurement models with sustainability goals is, therefore, essential for translating the cost-effectiveness insights from this study into tangible reductions in emissions in the real world.

Policy support has already proven to be a powerful driver for implementing these measures. Sweden’s biofuel blending mandate (Reduction Obligation) and Trafikverket’s HVO requirement are concrete examples of top-down measures that drive change. By mandating HVO use, the policy forces the additional biofuel cost to be internalized in project budgets – every bidder knows that a significant portion of diesel must be replaced with HVO, so this cost becomes a baseline rather than an optional add-on. This mitigates the risk of one contractor undercutting others by ’skimping’ on climate measures, thereby improving feasibility through targeted policy interventions. Moreover, guaranteeing demand for HVO encourages fuel suppliers to invest in production and distribution capacity, which over time can improve availability and potentially reduce the price premium. It must be noted, however, that such mandates can strain supply and even increase prices if not coordinated with the scaling up of production – a concern that arose in our analysis of BioZero asphalt's bio-binder supply. Policymakers and industry stakeholders will need to collaborate to ensure that supply chains expand in tandem with any new requirements, whether by stimulating domestic production of biofuels and binders or securing reliable imports.

Overall, the current policy trend in Sweden aligns with our findings, pushing the industry toward a greater use of biofuels and low-carbon materials. Firm commitments (like mandates or climate-performance criteria in contracts) are proving to be key enablers that turn theoretically cost-effective options into standard practice on the ground.

6.2 Feasibility

The practical implementation of climate-improvement measures in construction projects is largely determined by their technical feasibility and on-site performance. This study finds that several low-emission alternatives—HVO100 fuel, low-carbon concrete, BioZero asphalt, and electric machinery—are not only technically functional but also increasingly viable on real construction sites, provided that certain operational factors are addressed.

HVO100 stands out for its immediate applicability. As a drop-in replacement for fossil diesel, it requires no engine modifications, no changes in fueling routines, and has shown equivalent performance in the field. This compatibility enables rapid adoption across fleets without operational disruption. While it does not reduce tailpipe pollutants or noise, it significantly lowers lifecycle CO2 emissions and is already in widespread use.

Electric construction equipment presents more complex, yet manageable, feasibility considerations. Some battery-powered excavators have successfully operated full workdays on a single charge, allowing for overnight recharging without downtime. However, effective planning is essential, particularly regarding equipment scheduling and charging logistics. Infrastructure needs remain modest for small-scale electrification; however, scaling up may require early investment in site power capacity. In return, electric machines offer substantial co-benefits—zero exhaust emissions and drastically reduced noise levels, which improve worker safety and urban site acceptability.

Low-carbon concrete mixes using supplementary cementitious materials (e.g., slag, fly ash) are technically robust and already in commercial use. These alternatives match conventional mixes in structural performance, but may exhibit slightly slower early strength development, especially in colder conditions. Mitigating measures, such as pre-heated delivery or insulated curing, are well-established and allow reliable scheduling. Thus, low-carbon concrete is entirely feasible, though attention to curing conditions and quality control remains essential.

BioZero asphalt, using biogenic binders and recycled materials, has demonstrated field-level feasibility with no deviation from standard laying or curing procedures. Its mechanical performance is comparable to conventional asphalt in most applications. While the supply of bio-binders and the quality of recycled content must be managed by the asphalt plant, no new machinery or methods are needed on site. This makes it a highly practical alternative in road projects, aligning with standard worksite practices.

In summary, all four measures are technically feasible today. HVO and low-carbon concrete can be widely implemented with minimal adjustments, while BioZero asphalt and electric machinery demonstrate strong site-level viability, provided appropriate planning is in place. The results demonstrate that climate performance can be improved without sacrificing technical or operational reliability.

6.3 Climate data

Transparent data and standardized carbon accounting are crucial for effective climate action. This study relied on verified Environmental Product Declarations (EPDs) and life-cycle assessment (LCA) data to quantify emission reductions, highlighting EPDs as foundational tools in climate-smart construction. They support informed decision-making, enable credible comparisons, and reduce the risk of greenwashing. EPDs also facilitate climate-focused procurement, with clients increasingly requiring low-carbon materials. In Sweden, Boverket's climate declarations for new buildings are an example of this trend, likely to extend to infrastructure. Skanska's leadership in developing EPDs for asphalt and concrete exemplifies the value of investing in product transparency. In the future, expanding EPD coverage, including for construction processes, and training stakeholders to interpret this data are key. Ultimately, robust carbon data enables sustainability goals to be translated into measurable project outcomes, ensuring that implemented measures deliver real impact.

A key carbon-accounting issue in this study is how to handle biogenic carbon storage in materials like BioZero asphalt. BioZero shows a slightly negative emission factor due to the biogenic binder derived from pine oil, which acts as a temporary carbon sink. If the binder's carbon remains stored—e.g., through long pavement lifespans and recycling—the asphalt could contribute to net-zero or even negative emissions. This presents a major opportunity for clients with climate goals, but also raises concerns about transparency. Standards like EN 15804 require biogenic uptake and release to be accounted for over a 100-year horizon. If the asphalt is incinerated, the benefit may be lost. To avoid misleading claims, results should be presented with and without biogenic sinks, and assumptions must be clearly communicated. Long-term viability also depends on the sustainable sourcing of bio-binders. Done responsibly, BioZero could help reframe roads from emissions sources to carbon sinks.

6.4 Projected changes and Future outlook

Rapid developments in technology and market competition are likewise expected to improve the cost efficiency of abatement measures in the near future. In the asphalt domain, experts anticipate that the price premium of BioZero will decrease as renewable binder technology matures and production scales up. Increased supplier competition and economies of scale could drive down the cost of bio-binders and bio-fuels, while parallel policy pressures (e.g., higher carbon taxes or stricter emission limits for construction projects) may make fossil-based options more expensive. This dual trend would improve the relative cost-effectiveness of products like BioZero asphalt. On the environmental side, ongoing innovation is likely to yield even greater CO_2 reductions: Skanska is already developing a next-generation "BioZero+" asphalt aimed at eliminating the use of new fossil bitumen entirely, potentially achieving significant negative emissions compared to today's mix. If such innovations become commercially viable, the climate impact of asphalt construction could be dramatically lower than what was attainable at the time of this study—reinforcing the long-term feasibility of near-zero-carbon road projects.

A similar trajectory is expected for construction machinery and fuels. Battery-electric equipment costs are projected to decline as battery technology improves and manufacturing volumes increase, helping to bring down the currently high MAC of electrification. Meanwhile, biofuel economics will be influenced by policy incentives and feedstock availability. For example, as of this writing Sweden exempts HVO fuel from energy tax (through 2026), saving roughly 5 SEK per liter compared to fossil diesel. This tax break keeps HVO's price lower and its abatement cost modest. However, if the exemption is not extended, HVO could suddenly incur the full tax after 2026, causing its price to spike and making its CO_2 abatement cost less attractive. In such a scenario, battery and hydrogen fuel-cell technologies (whose costs are on a downward trend) could overtake HVO in cost-effectiveness. In other words, the relative economics of using HVO versus electric machinery are not static.

Today, a rational strategy for a contractor like Skanska might be to maximize the use of HVO in all diesel machinery (achieving immediate, cheap emissions cuts) while selectively deploying electric machines in scenarios where they make sense—for instance, where an electric option has near-parity life-cycle cost or where a client is willing to pay a premium for zero-emission equipment. Over the next few years, however, this balance may shift: if battery prices drop and more electric models are mass-produced, the purchase price premium for electric excavators and loaders will shrink. Additionally, operational energy costs for electric equipment (per hour of work) are generally lower and more stable than for fossil diesel. If a project can source renewable electricity affordably (e.g., on-site solar or favorable grid contracts), the total operating cost of electric machinery can be very competitive. In fact, our case data included one example where using a low-cost electric machine with inexpensive electricity resulted in net cost savings compared to diesel.

The practical implication is that contractors should remain agile and forward-looking in equipment investment. Committing solely to one pathway, whether all biofuel or all electric, would be risky in a dynamic market. A more resilient approach is to pursue a dual-path strategy: in the near term, use biofuels to quickly reduce emissions from the existing diesel fleet (a “quick win” that aligns with immediate climate goals), while also investing in pilot projects and incrementally increasing the share of electric machinery as the economics continue to improve. Clients can facilitate this transition by offering longer-term contracts or co-investing in green equipment, under the expectation that the benefits will likely pay off in both cost and carbon terms within a few years.

Staying attuned to market signals, such as the launch of new electric models, changes in biofuel tax policy, or future carbon pricing on diesel, will be necessary for decision-makers. In summary, the study suggests that HVO and electrification should be viewed as complementary rather than competing solutions in the medium term: HVO provides a bridge to achieve significant near-term emissions reductions, while electrification (along with emerging options like hydrogen in the future) represents the ultimate goal for fully decarbonizing construction machinery. Industry practitioners are advised to plan for both options, using the cost findings here as a guide to identify where each is advantageous, and be prepared to adjust the strategy as relative costs evolve.

It is also worth noting the role of competition and innovation among equipment manufacturers in enabling cost-effective decarbonization. The analysis of electric machinery included a comparison between a Swedish-made electric excavator and a comparable Chinese model, revealing that alternative suppliers can significantly lower the cost of green technology. In our data, for instance, a Chinese electric wheel loader was found to perform the same job as a European model but at a significantly lower hourly cost—so much lower that, despite its higher initial price than a diesel unit, its total cost of ownership per tonne of CO_2 saved was far more attractive (on the order of 18 SEK/kg for the import vs. 48 SEK/kg for the local brand, from Table 5.3).

This finding has two implications. First, contractors aiming to reduce emissions should actively survey the market for new solutions; sticking only to familiar, established brands may mean missing out on more affordable, environmentally friendly equipment. If a non-traditional supplier can provide a reliable electric machine that cuts emissions and even saves money in operation, adopting it would be an obvious win-win. Of course, practical considerations must be weighed: firms need to evaluate the reliability of these new brands, availability of service and spare parts, and compliance with local regulations before switching to less-established equipment.

Second, the emergence of lower-cost competitors sends a signal to dominant manufacturers (e.g., Volvo CE, Caterpillar) that there is growing demand for cost-competitive electric options. To maintain market share, these incumbent firms may need to accelerate innovation and reduce prices for their electric fleets, lest they be undercut as performance gaps close. For the industry as a whole, this competition is beneficial; it spurs technological progress and offers buyers a wider range of choices. In practice, we may soon see a broader spectrum of electric machinery at various price points, enabling construction companies of all sizes to find options that fit their budget and carbon reduction targets.

Contractors and clients should stay informed about these developments (through industry networks, demonstration projects, etc.) and be willing to consider unconventional partnerships, such as importing equipment or collaborating with new technology providers, as a way to achieve decarbonization more economically. One caveat is that in a world of shifting geopolitics and trade relations, heavy reliance on foreign-made equipment could introduce supply risks; thus, a balanced approach and diversification of suppliers is prudent. Nonetheless, embracing innovation and competition appears to be an effective avenue to drive down the cost of emissions abatement in construction.

6.5 Holistic viewpoint

While this thesis has focused on studying the adoption of low-carbon materials and fuels, it is important to acknowledge that, in practice, the first priority in sustainable construction is often to reduce overall material and energy usage. Measures such as optimizing structural design to use less concrete or improving logistics to minimize machine idling are typically "win-win" strategies that lower emissions and save money. These demand-reduction approaches were outside the scope of our study (which examined switching to greener alternatives for given quantities of materials and work), but they represent a critical complement to the measures evaluated.

In a holistic carbon management plan, a project would ideally avoid unnecessary consumption through efficient design and planning, then abate remaining emissions using the kind of climate-improved materials and technologies analyzed in this thesis. This layered approach ensures that the most cost-effective carbon savings (often the avoided use of carbon-intensive resources) are captured first, before spending extra on greener substitutes for the essential uses.

Future studies could integrate this dimension, but even within our scope, the results support the notion that substantial mitigation is achievable without exorbitant cost. Some of the measures studied here can even approach net-zero emissions for their segment—for example, 100% electric machines virtually eliminate tailpipe CO_2, and BioZero asphalt in some cases can claim net-negative cradle-to-gate emissions—whereas others (notably concrete, absent carbon capture) will likely require further innovations to reach near-zero. This implies that, looking forward, additional solutions such as high clinker-replacement cements or carbon capture in cement production will be needed if the construction sector is to fully neutralize its carbon footprint. Thus, while climate-improved materials like those studied are a major step in the right direction, they should be integrated into a broader strategy that also emphasizes demand reduction and continued innovation toward truly zero-carbon materials.

7

Conclusion

This thesis aimed to explore how climate-improvement measures in the categories of fuels, concrete, asphalt, and machinery can contribute to lower greenhouse gas emissions in civil construction, while also assessing their cost-effectiveness, feasibility, and future potential. Using the concept of Marginal Abatement Cost (MAC), the study evaluated several promising technical alternatives and analyzed how these could align with both the contractor's and client's climate goals. The investigation was grounded in life-cycle data, industry interviews, and a reference project case to ensure practical relevance.

Climate Impact and Cost-Effectiveness

The analysis reveals that considerable emission reductions can be achieved through mature, technically feasible solutions, although the cost-effectiveness varies widely. Among the studied measures, switching from fossil diesel to HVO100 for machines and transport vehicles proved to be both low-cost and immediately deployable, with MAC values around 0.89 SEK/kg CO_2-eq. In contrast, electric machinery and BioZero asphalt showed high emission reduction potential but at higher marginal costs, especially in early adoption phases. The most cost-efficient abatement came from replacing a fossil-powered wheel loader with a Chinese electric equivalent, which even resulted in negative MAC, meaning net savings per ton of CO_2 abated. These results suggest that strategic selection and phasing of measures can optimize both environmental and financial outcomes.

Feasibility in Practice

The study confirms that most climate-improvement solutions are technically feasible on real construction sites. Low-carbon concretes can match the performance of traditional mixes with minor adjustments to curing practices. HVO100 is fully compatible with existing diesel engines, requiring no modifications to the equipment. Similarly, low-carbon concrete mixes—such as those substituting Portland cement with slag—offered substantial emission reductions at low additional cost. With a MAC of 0.99 SEK/kg CO_2-eq, these mixes are both cost-efficient. Electric machinery has proven viable in pilot projects, although attention must be paid to charging logistics and task planning. BioZero asphalt can be laid with standard methods and has shown reliable quality in field applications. However, some limitations remain regarding the scalability of bio-based inputs and the availability of robust charging infrastructure for larger fleets. Nonetheless, the overall technical maturity of the studied measures indicates that implementation is achievable without compromising construction schedules or safety.

Outlook and Future Potential

Looking ahead, the outlook for further decarbonization in civil construction is promising, especially as technologies mature and economies of scale reduce costs. Electrification of heavy machinery is expected to grow rapidly, driven by both regulatory pressure and operational benefits such as reduced noise and local emissions. HVO100 remains a strategic transitional fuel, although its long-term availability and pricing may depend on international biofuel markets. Climate-improved asphalts like BioZero will likely expand in use as supply chains for biogenic binders mature and standards for carbon accounting evolve. CCS will likely be important to reduce the climate impact of concrete in the future, but it is predicted that it will lead to increased abatement costs. Policy instruments—such as carbon pricing, public procurement criteria, and stricter emissions declarations—are also expected to increasingly shape market dynamics. In this context, early adoption of EPD-backed materials and fossil-free operations can offer competitive advantages in tenders and long-term alignment with science-based climate goals. Future gains may also arise from combining multiple measures in integrated strategies, supported by transparent carbon data and digital tools.

Final Reflection

In conclusion, the construction sector already possesses viable tools to reduce its climate footprint significantly. While some innovations come with higher costs or logistical challenges, many offer immediate and scalable benefits. Through a careful balance of cost, feasibility, and strategic alignment, contractors and clients can begin transitioning toward low-carbon infrastructure today. The findings of this thesis demonstrate that decarbonization in civil construction is not only necessary, it is also increasingly practical. Moreover, those who act early and strategically may help shape the future standard of sustainable construction.

7.1 Future studies

While this thesis has provided valuable insights into the cost-effectiveness and feasibility of selected climate-improvement measures in civil construction, several areas warrant further investigation to support continued progress:

- **Wider material coverage:** Future studies should broaden the scope to include additional material categories such as steel, plastics, and composites—key components in many infrastructure projects. Furthermore, exploring a wider range of variants within the studied materials, such as higher levels of clinker substitution in cement or alternative fossil-free fuel types (e.g., biogas or hydrogen-based solutions), would provide a more complete picture of available abatement strategies.

- **On-site implementation and performance:** Further research should examine the practical aspects of applying climate-improved materials on-site. For example, studying how low-carbon concretes behave during curing under various weather and scheduling conditions, or how BioZero asphalt performs over time in terms of durability, maintenance, and lifecycle emissions, would enhance the industry's ability to plan and trust these innovations in long-term use.

- **Dynamic cost and emission modeling:** This study has shown that marginal abatement costs and carbon impacts are not static. As technologies mature, supply chains evolve, and energy systems decarbonize, the relative climate and economic performance of these measures will change. Continuous monitoring and updated evaluations are therefore recommended to ensure decision-makers have access to current, data-driven guidance.

These directions would not only strengthen the empirical base for future abatement strategies but also support evidence-based policy, procurement, and design choices in the ongoing transition toward climate-neutral infrastructure.

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