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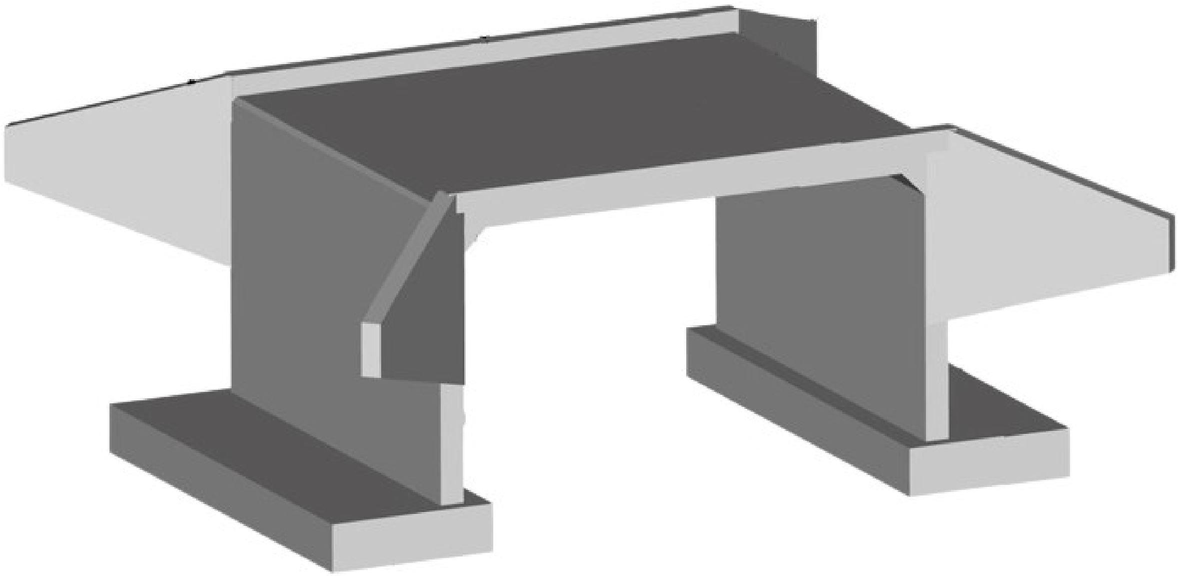

Sustainable Bridge Construction

Methods to reduce the climate footprint from concrete slab frame bridges

Bachelor's thesis in the Engineering Programme Civil and Environmental Engineering

Mohamad Omar Alzokani

Department of Architecture and Civil Engineering
Division of Structural Engineering

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
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EXAMENSARBETE ACEX20

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Cover: Trafikverket (2020a), baTMan, Brokonstruktionstyper, Plattrambro

Department of Architecture and Civil Engineering
Göteborg 2022

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ABSTRACT

Greenhouse gas emissions threaten our climate by contributing to global warming. Furthermore, infrastructure and bridge construction are associated with a significant part of these emissions. Considering the Swedish Transport Administration's long-term goals to reach climate neutrality by 2045, the potential for affecting the climate footprint from bridge structures should be investigated, which is considered significantly high throughout its life cycle.

The study investigates the carbon dioxide CO_2 emissions from the structural parts for one of Sweden's most common bridge types, the slab frame bridge. The study indicates the emissions from the material production and transportation phases, to achieve the study's purpose, a case study has been carried out on slab frame bridge 100-140-1 in Halvor's link. A comparative analysis has been conducted for various concrete and reinforcement products, where optimised alternatives have been investigated to promote sustainable material selection. After that, the study analyses the possibility of using environmentally friendly products that initially do not serve the exact required strength and exposure classes in bridge design. Finally, to promote sustainable decision-making, the study discusses the importance of implementing preliminary climate impact results at the early stages of the design.

The life cycle analysis for the bridge's structural parts and the comparative analysis showed the possibility of reducing a significant amount of CO_2 emissions by promoting more sustainable material selection. The investigations showed that it is possible to use other environmentally friendly products only if it is possible to modify the products to fulfil the exact bridge requirements i.g. strength- and exposure classes. Implementing preliminary climate impact results at the early design phase would enable more sustainable decision-making, in which more optimised designs would be achievable.

Keywords: Slab frame bridge, Life cycle analysis, Carbon dioxide emissions, Material selection, Concrete, Reinforcement.

Hållbart brobygge

Metoder för att minska klimatavtrycket från plattrambroar i betong

Examensarbete inom högskoleingenjörsprogrammet
Samhällsbyggnadsteknik

MOHAMAD OMAR ALZOKANI

Institutionen för arkitektur och samhällsbyggnadsteknik
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SAMMANFATTNING

Utsläppen av växthusgaser hotar vårt klimat genom att de bidrar till den globala uppvärmningen. Infrastrukturbyggande i allmänhet och brobyggande i synnerhet står för en betydande del av dessa utsläpp. Trafikverket har som långsiktigt mål att uppnå klimatneutralitet till 2045 och med anledning av detta bör möjligheterna till en reduktion av brobyggandets belastning på klimatet undersökas.

I studien undersöks koldioxidutsläppen från konstruktionsdelarna för en av Sveriges vanligaste brotyper, plattrambron. Studien undersöker utsläppen från materialproduktion och transportfaserna; för att uppnå studiens syfte har en fallstudie genomförts på plattrambro 100-140-1 i Halvor's länk. En jämförande analys har genomförts för olika betong- och armeringsprodukter, där optimerade alternativ har undersökts för att främja ett hållbart materialval. Därefter analyseras i studien möjligheten att använda miljövänliga produkter som ursprungligen inte uppfyller de exakta krav på hållfasthets- och exponeringsklasser som krävs för brokonstruktionen. För att främja ett hållbart beslutsfattande, diskuteras slutligen vikten av att genomföra preliminära klimatkonsekvensbedömningar i ett tidigt skede av konstruktionsarbetet.

Livscykelanalysen av brons konstruktionsdelar och den jämförande analysen visade, att genom att främja ett mer hållbart materialval, kunde man reducera koldioxidutsläppen knutna till brokonstruktionen med en betydande mängd. Undersökningarna visade att det är möjligt att använda andra miljövänliga produkter endast om det är möjligt att ändra produkterna så att de uppfyller de krav som krävs för bron, t.ex. hållfasthets- och exponeringsklasser. Genom att tillämpa preliminära klimatkonsekvensbedömningar i designfasen skulle det bli möjligt att fatta mer hållbara beslut, som leder till mer optimerade konstruktioner.

Nyckelord: Plattrambro, Livscykelanalys, Koldioxidutsläpp, Materialval, Betong, Armering.

Table of Contents

Preface

This thesis is the final part of the Engineering Programme Civil and Environmental Engineering at Chalmers University of Technology and comprises 15 credits. The work has been carried out in cooperation with the bridge department at Ramboll, Sweden.

I want to thank all the involved people who helped me achieve this degree project. A special thanks to the supervisors at the bridge department at Ramoll, Anna Svensson Höök, and Christoffer Jonsson, for providing information, guidance, and sharing their experiences. I would also thank Madelene Staf from PEAB for providing the thesis with information and valuable insights. A special thanks to the examiner of this thesis, Mario Plos, for your thoughts and guidance through this work.

I would also like to give a special thanks to my wife, Nawar Obeid. Thank you for standing beside me and motivating me; this thesis would not have seen the light without you.

Mohamad Omar Alzokani, Gothenburg, June 2022.

List of Designations

A1	Raw material supply phase
A2	Transportation phase
A3	Manufacturing phase
A4	Transportation to the construction site phase
A1-A3	Material production phase
A4-A5	Construction production phase
AMA	Allmän Material- och Arbetsbeskrivning ” General description of materials and work”
AP	Acidification potential
CO_2	Carbon dioxide
kg CO_2-eq	Carbon dioxide equivalents as a functional unit
EP	Eutrophication potential
EPD	Enviromental Product Declaration
GGBS	Ground Granulated Blast furnace Slag
GWP bionic	Global warming potential from removals of CO_2 into biomass
GWP fossil	Global warming potential from fossil fuels
GWP luluc	Global warming potential from land-use and land-use changes
GWP total	Global warming potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
ODP	Ozone depletion potential
SCM	Supplementary Cement Material
Vct	Water to Cement ratio

List of suppliers and products

Concrete Suppliers

1- Swerock AB

- Swefrys 45
- ECO 1 Sweexp55

2- Betongindustri AB

- Frost BI Anläggning FA
- BIO-1

3- Skanska

- Frost beständig betong med Anläggning FA

Cement Suppliers

1- Cementa AB

- Anläggningscement FA
- Velox CEM I 52,5 N

Steel Suppliers

1- Tibnor AB

- Reinforcing Bar
- Cut and bent rebar

2- CELSA steel service AB

- Steel reinforcement products for concrete

1 Introduction

1.1 Background

Our communities are constantly expanding with increased transport demands, and infrastructure is vital in meeting those demands. As a result, increased transport volumes require an extension of the transport infrastructure, with the need to construct new bridges and other infrastructure units (Uppenberg *et al*. 2017).

From a Life Cycle Analysis (LCA) perspective, climate impact from the construction of roads and railroads caused around 5-10 % of the total climate impact in Sweden (Uppenberg *et al*., 2017). Consequently, the Swedish Transport Administration (2022b) has set long-term goals and plans to reduce this impact and to reach climate neutrality by 2045 from constructing, operating, and renovating infrastructure. However, to reach this long-term goal, Trafikverekt has set additional sub-goals, which are, in short, to reach a 30% emission reduction by 2025 and 50% by 2030, compared to 2015.

According to Uppenberg *et al*. (2017), bridge structures are crucial in today's concern over climate impact due to their association with high resource consumption and their significant emissions of greenhouse gases. A large part of these emissions comes from the production of steel and cement used in construction. However, some approaches that concern the material selection and promoting sustainable decision making early in the design phase would increase the potential for affecting the climate footprint of bridge construction.

1.2 Aim and Objectives

The aim of this thesis is to explore and analyse opportunities to reduce the climate impact from the structural parts of slab frame bridges. The thesis conducts a life cycle analysis concerning the carbon dioxide (CO_2) emissions from a typical slab frame bridge's structural element during the material production and transportation phases. The thesis also analyses different reinforcement and concrete products to promote alternative solutions for more optimised material selection. Furthermore, the thesis will also investigate the influence of current standards and practices on the possibility of fostering long-term sustainability for construction.

To reach the aim of this study, the following objectives have been identified:

1. To quantify the amount of CO_2 emissions produced by the structural parts of a typical slab frame bridge during the material production and transportation phases.
2. To quantify the CO_2 emissions produced by other reinforcement and concrete product options during the material production and transportation phases.
3. To estimate the possible reduction in carbon footprint from a slab frame bridge through an optimised material selection.
4. To examine the influence of current practice and standards on the possibility of fostering long-term sustainability for the construction.

1.3 Limitations

- The LCA was limited to only include the CO_2 emissions and covered only the emissions caused by the material production and transportation phases.
- This study examined only the reinforcement and concrete used in the bridge's structural elements, excluding the effect of CO_2 emissions from, for example, the roadway pavement and the casting mould.

1.4 Methodology

Various methods were used to collect information in order to achieve the study's purposes. The first part was a series of literary studies that includes a detailed description of the LCA's components and the process that should be considered for executing one. The literary study also included a detailed description of the different materials used in the bridge's structural elements, from how they are produced, which resources they mainly consume and their contribution to CO_2 emissions.

The second part was the case study, where an LCA covering the material production and transportation phases was conducted on slab frame bridge 100-140-1 in Halvor's link. This part has quantified the CO_2 emissions from the bridge's structural elements, using various Environmental Product Declarations (EPDs) for calculation. Therefore, this step aimed to demonstrate a slab frame bridge's climate impact on the environment.

The third part of this study conducted a comparative analysis between various reinforcement and concrete products on the Swedish market to quantify the amount of CO_2 emissions produced by each product using various EPDs. The products used in this analysis fulfil bridge 100-140-1 requirements from the strength and exposure classes, and the analysis have focused only on the material production and transportation phases. Moreover, ecological (ECO) concrete products that do not fulfil the bridge requirements were also under investigation; however, these products are noted in detail in the discussion part. Moreover, the findings from this step have enabled us to calculate the reduction potential in CO_2 emissions by promoting other more sustainable product alternatives.

For the fourth part, "*To examine the influence of current practices and standards on the possibility of fostering long-term sustainability for the construction*" a literature study was conducted to investigate the Swedish standard SS 137003:2021 that regulates the use of the supplementary cementing materials. This allowed us to suggest how influencing such a standard could foster long-term sustainability. The literature study also investigated the importance of implementing preliminary climate impact results at the early design stages to promote sustainable decision-making.

2 Life Cycle Assessment

This part includes a comprehensive view of the theoretical basis of the life cycle analysis, covering concepts, definitions, standards and requirements to understand the performance of a life cycle analysis.

2.1 International standards

According to Rydh *et al*. (2002), the International Organisation for Standardisation (ISO) has developed standards in the environmental field compiled in the ISO 14 000 series to overcome the need to objectively compare the climate footprint of different activities and products. The standards address the environmental management systems, environmental auditing, environmental performance, and life cycle analysis.

The international standard ISO 14040:2006 (The international organization for standardization, 2006a) offers, according to Wendin (2019), guidance and structures for implementing an LCA study; it also specifies detailed requirements and guidelines for the LCA's different phases: objectives and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation, see Figure 1. Furthermore, the standard acts as quality assurance concerning documentation, and it reduces subjectivity in system limitations during the study. Following the standard's rules and guidance also increases the study's credibility and inspires confidence in communicating the results.

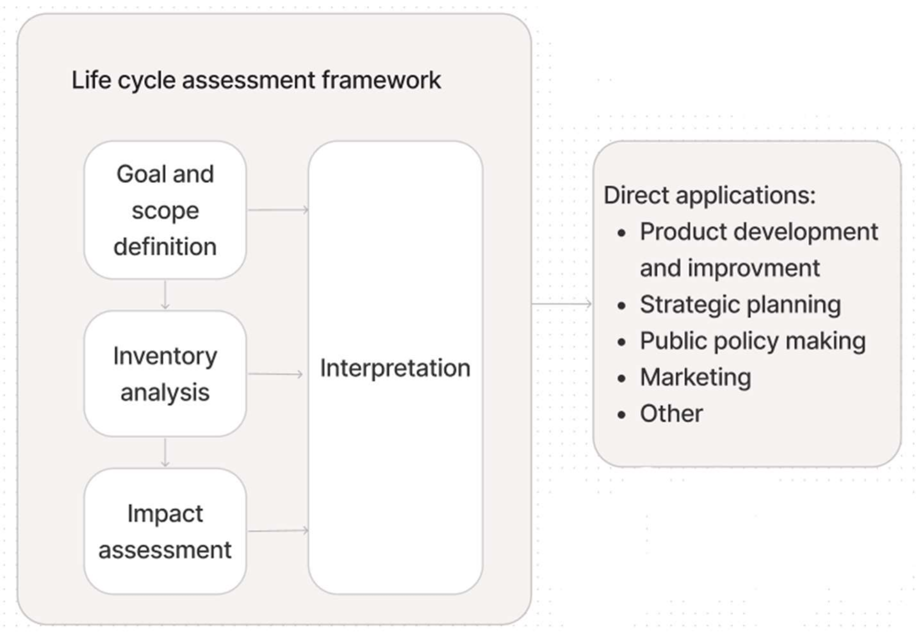


Figure 1 Life cycle assessment framework, based on ISO 14044: 2006 (2006b).

2.2 Life Cycle Analysis

Life Cycle Analysis (LCA) is a process that aims to map a product's environmental impact by assessing the various aspects of the product life cycle (Wendin M, 2019). LCA outlines the energy and materials used in a product's lifecycle at every level concerning its emissions to the environment and nature to help identify and minimise greenhouse gas emissions.

2.2.1 Goal and scope

In the first phase of the LCA, the goal and scope of the analysis must be determined (Rydh *et al*. 2002); in short, the goal definition must describe why to implement the LCA and what the results are used for. However, before starting an LCA, the consequences of the expected result should be evaluated; in this way, it is possible to define which results are more interesting and how extensive the study must be executed. The scope definition of the study identifies what the LCA should focus on to meet the goal objectives, ultimately, by defining the matter to be studied and the system's functions; the function or system to be studied is then limited to the parts with the most significant environmental impact.

Furthermore, suppose the LCA goal is to compare different systems; in this case, a common denominator is required as a functional unit (Rydh *et al*. 2002). However, increasing the system's comparability requires the unit to be specified for three different characteristics: quantity, durability, and quality. In short, the quantitative part of the functional unit is used to calculate how large the required matter and energy are to fulfil the system's function. The durability of the technical and actual service life should be considered when a system's function is optimised. Finally, the qualitative characteristics can be defined with, for instance, reliability, user-friendliness, aesthetic value and price. The choice of functional unit and performance of the studied system can significantly impact the results.

The system's boundaries must be defined when the analysis's purpose, objectives, and functional unit are shaped (Rydh *et al*. 2002). However, system boundaries determine which processes are included in the LCA study to reduce the complexity of the analysis. Therefore, the study is limited to the parts judged to be relevant to the intended application.

2.2.2 Life cycle inventory (LCI)

The life cycle inventory, LCI, is the second phase in LCA (Rydh *et al*. 2002); it includes data collection to quantify relevant inflows and outflows of the studied system. The inflow and outflow of matter or energy are then quantified with so-called data categories. Each data category indicates which environment is affected, such as emissions to air and water and resource use. However, the definition of goal and scope affects what is to be inventoried and what type of data is to be collected, where both the system and its outgoing products must be described in detail.

According to Rydh *et al*. (2002), the inventory analysis usually includes the following activities:

- Determination of the material composition and formulating a process tree for the system and its boundaries.
- Data description and collection about the product system's various activities and in-depth process units.
- Calculation of material balance for each process unit of the process tree.
- Analysing of mass flow and inventory data for each process unit.

- Assessing the reasonability of the results and improving the data quality if necessary.

2.2.3 Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment, or LCIA, is the third phase of the LCA (Dongyan et.al, 2020). LCIA is a phase to evaluate potential environmental impacts by converting the LCI results into specific impact indicators. Conducting LCIA includes three mandatory parts. The first is to select impact categories for the analysis; ultimately, the major impact categories are divided into three general groups regarding impacting subjects, specifically, ecosystem impacts, human health impacts and resource depletion. The second is called classification, where the LCI results are assigned to different impact categories. The third is characterisation, where potential impact indicators are assigned. However, normalisation, grouping and weighting are optional elements, see Figure 2.

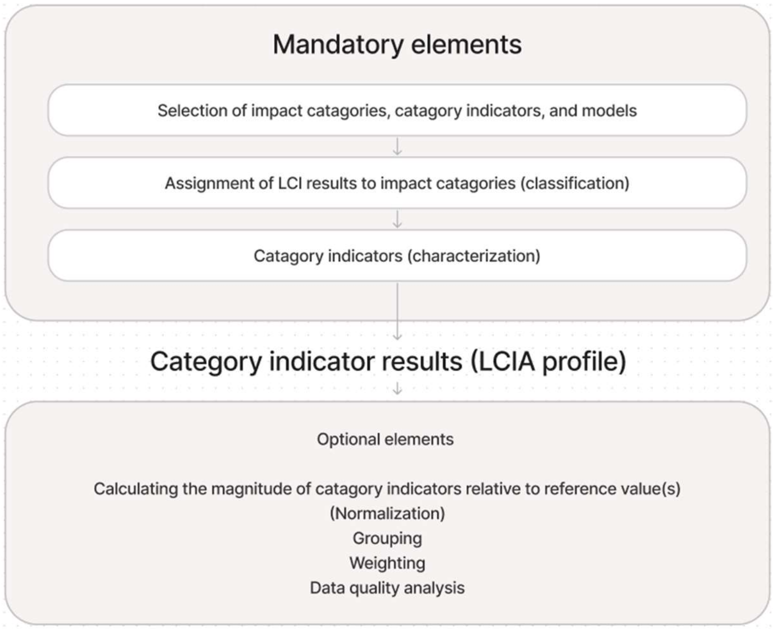


Figure 2 Elements of the LCIA procedure. Based on ISO 14044:2006 (2006b).

2.2.3.1 Choice of environmental impact category

For the purpose and boundary setting of the LCA, the environmental impact categories are selected (Rydh *et al*. 2002). The evaluated emissions, resource use and impact from the various processes included in the system are weighed together into different environmental impact categories (Ahlgren *et al*. 2020). Such calculations are based on scientific chain models of cause-and-effect in natural systems. However, the cause-and-effect models used in LCIA are often very simplified (Baumann & Tillman, 2004). The most common environmental categories and indicators are described briefly in Table 1.

Table 1 Core environmental impact indicators, based on (SS-EN 15804:2012+A2:2019).

Impact category	Indicator	Functional unit
Climate change - total	Global warming potential total (GWP-total)	Kg CO_2 eq.
Climate change - fossil	Global warming potential fossil fuels (GWP-fossil)	Kg CO_2 eq.
Climate change - biogenic	Global warming potential biogenic (GWP-biogenic)	Kg CO_2 eq.
Climate change - land use and land use change	Global warming potential land use and land change (GWP-luluc)	Kg CO_2 eq.
Ozone Depletion	Depletion potential of the stratospheric ozone layer (ODP)	Kg CFC 11 eq.
Acidification	Acidification potential, Accumulated Exceedance (AP)	Mol H^+ eq.
Eutrophication aquatic marine	Eutrophication potential, fraction of nutrients reaching marine end compartment (EP)	Kg PO_4 eq.

The selected environmental impact category for LCIA in this thesis is climate change, mainly considering emissions that indicate a global warming potential using kg CO_2 eq as a functional unit, while the remaining categories will be treated briefly. Below is a description of a few environmental impact categories.

Climate Change-total

Climate impact is included in most environmental impact assessments and is expressed as global warming potential (GWP), with the unit carbon dioxide equivalents (kg CO_2 eq) as a functional unit (Ahlgren *et al*. 2020). However, the total global warming potential (GWP-total) is the sum of three sub-categories of climate change as described below (SS-EN 15804:2012+A2:2019):

- **Fossil global warming potential (GWP-fossil):** This indicator accounts for GWP from greenhouse gas emissions and removals to any media originating from the oxidation or reduction of fossil fuels or materials containing fossil carbon utilising their transformation or degradation (SS-EN 15804:2012+A2:2019).
- **Biogenic global warming potential (GWP-biogenic):** This indicator accounts for GWP from removals of CO_2 into biomass from all sources except native forests, as transfer of carbon, sequestered by living biomass, from nature into the product system declared as GWP-biogenic. This indicator also accounts for GWP from transferring any biogenic carbon from previous product systems into the product system under study. (SS-EN 15804:2012+A2:2019).
- **Land use and land-use change global warming potential (GWP-luluc):** This indicator accounts for greenhouse gas emissions and removals originating from changes in the defined carbon stocks caused by land-use and land-use changes associated with the declared/functional unit. This indicator includes biogenic carbon exchanges resulting, e.g. from deforestation or other soil activities, including soil carbon emissions (SS-EN 15804:2012+A2:2019).

However, the most substantial greenhouse gases that make the earth significantly warmer are water vapour, carbon dioxide, methane and nitrous oxide (NATURVÅRDSVERKET, 2022). Using the GWP indicators help with weighing and calculating the climate-impact different gases retained by relating them to carbon dioxide, i.e. in the unit kg CO_2 equivalents per functional unit (Ahlgren *et al*. 2020). Different greenhouse gases have different lengths of residence and influence the atmosphere's radiation balance; therefore, choosing a time horizon is necessary. Usually, 100 years is chosen. In short, to measure the contribution of gas to the greenhouse effect, all emissions are multiplied by a global warming potential (GWP) based on a hundred-year value (Boverket, 2021). The factor is different for each greenhouse gas, see Table 2, and GWP indicates the total contribution to global warming for the gas under investigation.

Table 2 Global Warming Potential (GWP) for climate impact, based on (IPCC2007).

Greenhouse gas	**Global Warming Potential (GWP)**
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (NO_2)	298

Ozone Depletion

Ozone (O_3) occurs naturally in the atmosphere and protects the earth from harmful UV rays. Emissions of ozone-depleting compounds can lead to the thinning of the protective ozone layer; thus, increased UV radiation entails an increased risk of skin cancer, eye damage and effects on the immune system (Wendin M, 2019). The contribution of particular compounds to ozone depletion is characterised by the ozone depletion potential (ODP). The ODP of a compound, as customarily defined, is the ratio of the global loss of ozone from that compound at steady-state per unit mass emitted relative to the loss of ozone due to emission of a unit mass of a reference compound, usually taken as CFC-11 (Pitts, Jr & Finlayson-Pitts, 2000).

Acidification

The acidification potential (AP) estimates the emissions that increase the acidity of water and soils (Ahlgren *et al*. 2020). Caused by acidifying substances such as Sulfur dioxide ($SO_{x)}$, Nitrogen oxides ($NO_{x)}$ and Hydrogen chloride (HCl) emissions and is expressed as proton release (H^+) or sulphate dioxide equivalents ($SO4^{2-}$). These substances react with air water, creating a weak acid solution. Sulphate dioxide emissions occur mainly in the combustion of sulphate-containing fuels, such as coal and heating oil (NE, n.d.). Upon deposition of this acid solution, the hydrogen ion balance in the receiving recipient can change, which can thus cause acidification (Ahlgren *et al*. 2020). Acidification affects lakes, streams, and forests regionally and buildings, statues, and similar objects. In the same way, as for climate impact, the total contribution to acidification can be estimated as the sum of the emissions multiplied by characterisation factors (Zetterberg *et al*. 2001).

Eutrophication

Eutrophication potential (EP) estimates the quantity of the nutrient enrichment in sea, lakes and waterways and is often included in LCA studies (Ahlgren *et al.* 2020); usually, it is expressed in phosphate or nitrogen equivalents. However, eutrophication is caused by excessive levels of nitrogen and phosphate in soil or water. These nutrients can end up in the environment via emissions to the air (Sverigesmiljömål, 2021) of, for example, nitrogen oxides from car traffic, shipping and power plants.

In the Swedish marine environment, eutrophication is, above all, one of the most severe threats (Sverigesmiljömål, 2021). In both seas and lakes, eutrophication causes, among other things, overgrowth and algal blooms, which leads to a lack of oxygen on the bottoms, where plants and animals suffocate. If it is poisonous algae that cause the flowering, the health of both humans and animals can be threatened. When calculating eutrophication potentials, phosphate ion equivalents ($PO4^{3-}$) are used as a reference for calculating the characterisation factors (Abrahamsson, 2019). Multiplying the studied substance by its characterisation factor enables to obtain the corresponding effect on eutrophication that $PO4^{3-}$ has.

2.2.3.2 Classification

Classification is defined as sorting the parameters from the inventory analysis according to the type of environmental impact they contribute to (Baumann & Tillman, 2004). However, some parameters can contribute to several different environmental impact categories (Rydh *et al.* 2002). For example, nitrogen oxides (NO_x) can contribute to the greenhouse gas effect, acidification, and ground-level ozone formation. It is possible to decide which environmental impact categories (classes) are relevant to the analysis and which data categories are placed in each class.

2.2.3.3 Characterisation

Characterisation is defined as multiplying the inventory data by its specific characterisation factor according to its environmental impact category (Rydh *et al.* 2002). The goal of the characterisation is to assess which emissions lead to a significant environmental impact by relating their effect to each other. For all characterisation factors, all potential environmental impact is calculated, for instance, if a substance is released into the environment or if a resource is consumed.

For example, substances contributing to the greenhouse gas effect are calculated using the GWP characterisation factors, an indicator of CO_2-equivalents (Wendin M, 2019). As an illustration, methane is a 25 times more potent greenhouse gas than carbon dioxide, which gives methane a characterisation factor of 25. In short, 1 kg of methane can potentially cause a significant climate impact as 25 kg of carbon dioxide.

2.2.3.4 Normalisation

Normalisation means calculating the characterisation result relative to reference values (Stranddorf S, et.al, 2005). The different impact potentials and consumption of resources are expressed on a standard scale by relating them to a common reference to facilitate comparisons across impact categories. Global normalisation factors are not mandatory for ISO 14044 (Sala *et al.* 2017), although it helps better understand the sense of LCIA results and support decision-making.

2.2.3.5 Weighting

Weighting is an optional element within LCA, and it is performed to facilitate the interpretation of LCI results (Wendin M, 2019). Weighting helps evaluate the LCI results in comparison with their relative contribution from different environmental impact categories with the help of weighting factors (Rydh *et al*. 2002). The more critical the considered environmental impact, the higher the weighting factor assigned (Wendin M, 2019)

Weighting is based on subjective values, making weighting a subjective method (Wendin M, 2019). The method weighs different types of environmental impact against each other based on (Rydh *et al*. 2002), for example, an individual or a society's political or moral values. Weighting can be used, for example, to make it easier for decision-makers to prioritise which environmental effects are most important and which are less important to take into account (Wendin M, 2019).

2.2.4 Interpretation

Interpretation of LCA results is one of the most critical phases of life cycle analysis that should fulfil the goal definition and the different applications of the study (Rydh *et al*. 2002). The interpretation phase aims to analyse the study's results, evaluate and explain its limitations, and arrive at conclusions and recommendations (ISO 14 040:2006a).

2.3 The life cycle of a construction

The construction life cycle is mainly divided into three stages: the construction phase, operation phase, and demolition phase (Boverket, 2019). These stages are divided into so-called information modules that describe the processes that occur during the life cycle, see Table 3.

Table 3 Construction Life Cycle, Based on (Boverket 2019).

A1-A5 Construction phase		
A1-A3 Material production phase	A1	Raw material extraction
	A2	Transport
	A3	Manufacturing
A4-A5 Construction production phase	A4	Transport to the construction site
	A5	Construction process
B1-B7 Operation phase	B1	Usage
	B2	Maintenance
	B3	Reparations
	B4	Replacement
	B5	Reconstruction
	B6	Operational energy
	B7	Operational water use
C1-Ca Demolition phase	C1	Demolition
	C2	Transport
	C3	Residue processing
	C4	Disposal

The construction phase (A1-A5) is divided into two phases, the material production phase (A1-A3) and the construction production phase (A4-A5). In short, the material production phase comprises the production of the construction products from raw material and other resources as well as transport and manufacturing. Furthermore, the construction production phase involves the transportation of finished products to the construction site and the completion of the building. The operation phase of construction (B1–B7) includes the construction's use and maintenance. Finally, the demolition phase (C1-C4) comprises the processes required to demolish and transport the building parts for reuse, recycling or disposal when the construction has reached the end of its service life.

2.4 Environmental Product Declaration (EPD)

Intending to intercommunicate a product's environmental impact, the International EPD System has developed the Environmental Product Declaration (EPD) according to the international standard ISO 14025. Therefore, to compare the various environmental impact of products and services with other products and services as long as they have similar product groups and system boundaries (the international EPD system 2022).

The EPD reports the results of a life cycle analysis in a compressed format and can, in some cases, be limited to only certain parts of a product's life cycle (Boverekt, 2019). However, the EPDs for construction comply with the standard for sustainable construction works, environmental declarations and product specific rules SS-EN 15804:2012+A2:2019. Furthermore, an EPD is the most comprehensive form of environmental calculation since it is third-party reviewed and based on a life cycle analysis prepared according to product category rules (PCR) (Boverket 2019).

3 Material

The construction industry sector is one of the largest renewable and non-renewable natural resources consumers (Pacheco *et al*., 2014), consequently leading the sector to the centre of concerns regarding environmental impact. The sector consumes around 40% of both the global raw materials and primary energy (Casini M, 2022) as well as it accounts for 40% of the world's total carbon dioxide emissions from related fuel combustion.

However, with active and conscious climate management and a combination of material-related and performance-related measures (Uppenberg *et al*. 2017), it is possible to reduce the climate impact of concrete constructions. This section provides a theoretical background on the materials constituents of slab frame bridges: concrete, including its components, and reinforcement.

3.1 Concrete

Concrete is characterised by its good durability, formability, strength and is, therefore, one of our most used construction materials (Burström, 2007). Concrete can be used in different structures, such as residential buildings, bridges and harbours. What gives concrete a unique position as a building material is its many strengths (Betonghandbok Material, 2017), such as fire resistance, moisture resistance, heat inertia, sound insulation and the possibility of recycling. Concrete ingredients are abundant and often easily accessible over large parts of our globe and, therefore, cheap. The main concrete ingredients consist of a binder (mainly cement), water and aggregate (stone, gravel, sand); it may also contain various admixtures to give the specific properties of concrete either in the fresh or hardening stages.

Carbon dioxide emissions occur during the production phase of concrete and decrease during the use phase as the concrete instead absorbs carbon dioxide (Svensk Betong, 2021). However, concrete's most significant climate impact occurs in cement clinker manufacturing. A life cycle analysis of concrete shows that more than 90 percent of the carbon dioxide emissions come from the manufacturing of concrete's raw material, especially from cement clinker manufacturing, while the rest comes from concrete production and transportation of concrete products. However, one way to reduce the CO_2 emissions is by replacing parts of the cement clinkers in the concrete mixture with other binder alternatives such as fly ash, slag, silica dust, or limestone filler (Betonghandbok Material, 2017).

During the entire use phase, concrete absorbs carbon dioxide through so-called carbonation (Svensk Betong, 2019), and this is a chemical process that arises naturally and spontaneously throughout the life of the concrete. According to theoretical studies, the existing concrete structures in Sweden absorb 300,000 tonnes of carbon dioxide annually. From a life cycle perspective, that corresponds to approximately 15 to 20 per cent of the emissions that occur during the production phase.

3.1.1 Cement

Cement is a hydraulic binder characterised by hardening with reaction with water to form a product that is resistant to water (Burström, 2007). Limestone is the primary raw material together with clay for today's cement production. Raw materials are finely ground and then burned in long, gently inclined rotary ovens with burners at the lower end. The material is then discharged from the oven and cooled. They are now in balls, or small lumps form called cement clinker; cement is then obtained by grinding the cement clinker together with about 5% gypsum.

Properties of concrete in both fresh and hardened states depend on the properties of cement used (Betonghandbok Material, 2017). The chemical composition of cement influences the workability and mouldability of fresh concrete and the durability and colour of the hardened concrete surface. Different cement types can also influence the concrete's comprehensive strength and heat development.

In Sweden, standard SS-EN 197-1 applies for cement (Burström, 2007). The standard specifies the properties of the components of common cement types and in what proportions they should be combined to form different types and classes. It also specifies the mechanical, physical and chemical requirements. The standard divides cement into several different types: CEM I, CEM II, and CEM III.

3.1.2 Mixing water

The quality of mixing water used in concrete production can affect the bond time, strength development and reinforcement corrosion resistance (Betonghandbok Material, 2017). When assessing whether the water of unknown quality is suitable for concrete production, both the composition of the water and the application of the concrete produced are considered. Water, including process water for concrete production, is covered in standard SS-EN 1008. However, ordinary drinking water is always good for the concrete mixture as a thumb rule. Thus, problems may arise when using other water sorts, though analysing the water should be considered before using it.

3.1.3 Aggregates

Aggregate is a common name for granular materials intended for concrete production, and usually, it is rock material (Betonghandbok Material, 2017). According to standard (SS-EN 206), aggregate is defined as a granular material suitable for use in concrete and can be found naturally, industrially produced or recycled material.

Depending on the aggregate grains size, the terms sand, fines or stone are used, and the different grain sizes provide a special mutual relationship in the concrete mixture (Burström, 2007). The voids that exist between the largest grains, even in tight compaction, should be filled with smaller grains, whose voids are filled with even more minor grains. the remaining volume of the holding space is filled with cement paste where the grain particles are glued together, see Figure 3.

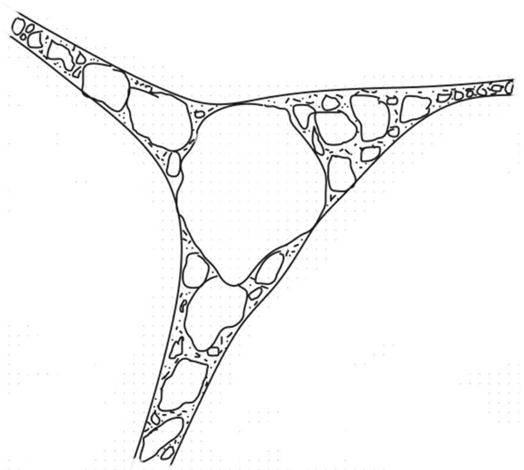


Figure 3 An ideal aggregate grain size that fills the voids to the maximum. Based on (Burström, 2007).

Typically, concrete comprises of 70% aggregate, and the remaining 30% is water, air and binding materials (Forde 2009). However, concrete's fundamental characteristics are greatly influenced by the physical properties of the aggregate, such as the size, shape, texture and strength, as well as the chemical properties, such as chemical stability. Furthermore, increasing the percentage of recycled coarse aggregates in the concrete mixtures decreases the CO_2 emissions slightly in the concrete manufacturing process (Jiménez *et al*. 2018).

3.1.4 Additives

Additives are chemicals added to the concrete mixture to acclimate its different demands (Forde 2009); additives modify the mix's properties in both the fresh and the hardened state. Using additives benefits different economic, environmental, and technical areas; moreover, they are usually classified according to their effect on the concrete. Some of the most important groups are mentioned below:

- Dispersant additive types, such as plasticisers, superplasticisers
- Set control additives, such as retarding, accelerating or hardening additives.
- Air-entrainment additives.
- Additives for particular purposes, such as water-resisting additives for underwater structures.

3.2 Supplementary cement materials (SCM)

Cement clinker as a binder accounts for a significant proportion of the climate impact in concrete production (Svensk Betong 2019). Supplementary cement materials (SCMs) allow lower climate impact from concrete production by replacing parts of the cement clinker. They can be added during cement production or when mixing concrete. However, concrete binders can be classified as follows (Betonghandbok Material, 2017):

- Hydraulic materials, such as Portland cement
- Latent hydraulic materials, such as Ground Granulated Blast furnace Slag (GGBS).
- Pozzolanic materials, such as silica fume and fly ash.

In Sweden, the primary SCMs used are silica fume, fly ash and GGBS (Betonghandbok Material, 2017). Incorporate SCMs in concrete stems from their potential to reduce greenhouse gas emissions, energy use, and waste disposal to landfill sites (Daman K, 2019). Beyond the environmental benefits, SCMs as a partial cement replacement can achieve similar or improved fresh, mechanical, and transport properties compared to concrete without SCMs. Below is a brief introduction of the primary SCMs used in Sweden.

3.2.1 Silica fume

Silica fume is a by-product from producing elemental silicon or alloys containing silicon in electric arc furnaces (Daman K, 2019). At a temperature of about 2000°C, the decrease of high-purity quartz to silicon produces silicon dioxide vapour, which oxidises and condenses at low temperatures to build silica fume. Silica fume is added to concrete in approximately 3-10% of the binder quantity without affecting the comprehensive strength (Betonghandbok Material, 2017); however, silica fume can decline the CO_2 emission as cement production decreases.

The general effects of silica fumes on concrete properties are dependent on several factors, such as the type of cement, silica fume and concrete composition (Betonghandbok Material, 2017). However, silica fume improves the cohesion and stability of fresh concrete, reducing the risk of separation during transport and handling; thus, the amount used affects workability. Silica fume increases the hardened concrete's susceptibility to plastic cracking, reduces water separation, increases plastic shrinkage, and increases pore pressure.

3.2.2 Fly ash

Fly ash is a by-product of pulverised coal-fired power and heating plants (Betonghandbok Material, 2017). During combustion, which takes place at 1000-1600°C, the coal is consumed, and mineral contaminants are left behind, combining and following the flue gases outwards. Over time they swell and change into solid form as spherical glassy particles called fly ash. Fly ash particles are separated from flue gases utilising electronic filters.

Fly ash's chemical, physical characteristics, and mineralogical composition vary between plants and within the same plant (Mindess S, 2019). Some of the contributing factors that lead to variations in fly ash properties include the mineralogical composition of the coal, degree of coal pulverisation, type of furnace, combustion temperature, oxidation conditions, and the collection, handling, and storage conditions. The coal burned is either hard coal or lignite, giving different chemical compositions. According to SS-EN 206 and SS-EN 450-1 (Betonghandbok Material, 2017), fly ash from lignite may not be used as a reactive additive for concrete, but lime-rich fly ash may be added to the cement.

Fly ash yields improved workability and reduce the water demand of fresh concrete (Mindess S, 2019). The setting time may be delayed when fly ash is used as cement replacement, and bleeding and segregation are reduced because of its lubricative effect. A longer setting time may increase the vulnerability of the concrete to plastic shrinkage cracking; moreover, the use of fly ash as cement replacement affects the air-entraining ability of fresh concrete, requiring more air-entraining admixture than concrete without fly ash.

For the mechanical properties, an equivalent 28-day compressive strength, concrete containing fly ash typically achieves a lower 7-day strength than concrete without fly ash (Mindess S, 2019). However, concrete containing fly ash can achieve parity with concrete without fly ash between 28 and 90 days, depending on the fly ash content. Furthermore, an equivalent early-age strength can be achieved using accelerators, water-reducing admixtures, or modifying the mix proportions. In concrete production, the fly ash is added to approximately 5-30% of the binder amount (Betonghandbok Material, 2017). Whereas the 28-day compressive strength of concrete containing up to 25% fly ash achieves a similar or greater compressive strength than concrete without fly ash (Mindess S, 2019).

3.2.3 Ground Granulated Blast furnace Slag

GGBS is a by-product of iron production (Betonghandbok Material, 2017), where oxygen is removed from iron ore during raw iron production, mainly utilising coal and coke. However, iron ore contains other minerals that must be removed, and this is achieved with slag-forming materials such as limestone and dolomite, which are added to absorb impurities. The slag is then drained and rapidly cooled with either water or air, whereas rapid cooling with water produces a grit-like material called granulated blast furnace slag. The slag is ground to a fineness equivalent to cement or slightly finer, and the finished product is called ground granulated blast furnace slag or GGBS.

The chemistry and morphology of GGBS depend on the ore, fluxing stone, impurities in the coke, and the iron-making process, particularly the cooling rate (Mindess S, 2019). For example, molten slag that is quickly cooled predominantly yields amorphous, and the resulting GGBS particles exhibit more significant cementitious properties than molten slag that is slowly cooled.

Fresh concrete containing GGBS as partial cement replacement can have a higher slump and improved particle dispersion than concrete mixes without GGBS, irrespective of using water-reducing admixtures (Mindess S, 2019). However, if the GGBS particles are finer than the Portland cement particles, the rate of bleeding will decrease, and vice versa. The setting time of fresh concrete containing GGBS is commonly retarded, but if necessary, using chemical accelerators can minimise the delay. Moreover, the amount of air entrainment admixtures needed for concrete containing GGBS is similar to that of the concrete mix without GGBS.

For the mechanical properties, the effect of GGBS on the compressive strength of concrete can vary widely and is dependent on several factors (Mindess S, 2019) such as the GGBS activity index, the proportion of GGBS used, water-to-cementitious material ratio, physical and chemical characteristics for both the GGBS and portland cement, and the curing regime. Concrete containing GGBS may have lower strength at early ages (days 1-21) and equal or greater strength at later ages (28 days and beyond). However, in concrete production, the GGBS is added to approximately 10-60% of the binder portion (Betonghandbok Material, 2017). Whereas concrete containing up to 25% of GGBS achieves similar or greater 28-day compressive strength compared to concrete without GGBS (Mindess S, 2019).

3.3 Proportioning of the concrete materials

Concrete consists of about one-third coarse aggregate and one-third fine aggregate, and the remaining void is filled with about one-tenth of cement and one-fifth of water (Betonghandbok Material, 2017). When proportioning concrete, the composition of the concrete is usually based on the properties of the sub materials so that concrete can obtain the desired strength, durability and fresh properties. However, the concrete should be mixed, transported, cast, and hardened so that the finished product meets the standard requirements. The resistance in different exposure classes should also be considered.

New concrete recipes should be pre-tested, and workability, consistency, and the factors that influence them should be considered (Betonghandbok Material, 2017). Meeting the fresh and hardened concrete requirements should also be optimised according to the cost and environmental requirements. However, when proportioning a concrete recipe, the following should be considered:

- The hardened concrete properties must meet the required strength and durability.
- The concrete casting properties must be adapted to the casting method used to obtain a dense and homogeneous final product.
- The cement content should typically be limited as far as possible from an economic and environmental point of view; therefore, the following should be considered:
    - Using the largest grain size appropriate concerning the available aggregate, structure's dimension, reinforcement density, transportation and casting methods.
    - Composing the aggregates to a suitable gradation.
    - Using the stiffest consistency appropriate to the requirement for full workability.
- Using admixtures to improve the properties and the cost profile.
- Test samples should be produced.

3.4 Steel Reinforcement

Steel is the name given to a material with iron as its primary element (Burström, 2007). Nowadays, there are two methods of steel production, ore-based and scrap-based (Tekniskamuseet, 2021). The ore-based method extracts molten pig iron from iron ore, which requires much heat and takes place in a blast furnace. The scrap-based method uses iron scrap.

Steel properties depend on its composition; for example, its carbon content influences softness and toughness (BE Armeringshandboken, 2017). Steel can also be alloyed to achieve specific properties. Reinforcement steel is manufactured under strict quality control conditions, and the final product must have properties that satisfy applicable standards (Fanella D, 2016).

Reinforcement steel is hot rolled and has high tensile strength and is used to increase the strength of concrete structures in several ways (BE Armeringshandboken, 2017). Reinforcement absorbs tensile, compressive, and shear stresses to prevent cracking and distributes loads throughout the structure. Well-developed reinforcement techniques enable "leaner" structures by reducing the amount of concrete.

Reinforcement is anchored in concrete by friction where ribs or profiles are rolled onto the steel bar surface (Burstöm 2007), see figure 4; however, the higher the strength of the bar, the tighter the ridges are. Moreover, concrete without reinforcement fails suddenly and without warning (BE Armeringshandboken, 2017), while reinforced concrete can withstand much higher loads, allowing cracking and deformations before failure occurs.

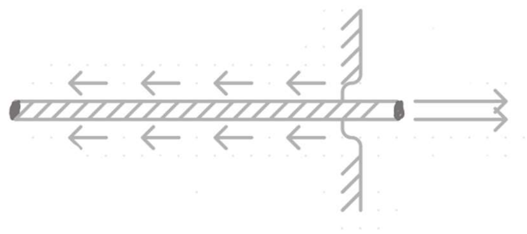


Figure 4 Anchoring by end anchors or welded crossbars. Based on (Al-Emrani et al 2011).

3.4.1 Recycled and reused reinforcement steel

Producing steel from scrap reduces energy consumption by almost 75% compared to producing steel from ore (Celsa Steel, 2021). Due to the recycling of iron scrap, the consumption of raw materials in steel production worldwide have been reduced by 90%.

Scrap steel recycling forms a large part of the feedstock or converters, particularly for electric arc furnaces, in which the scrap can form up to 100% of the charge (Soutsos & Domone, 2017). Some care may have to be taken with the composition since the scrapped steel will contain alloying elements, which may negatively affect the produced steel.

Reusing steel components of structures after demolition is feasible since, in most cases, steel properties will not have changed since it was first produced (Soutsos & Domone, 2017). However, section size may have been reduced due to corrosion, which would prevent their use, and the structure design may not be able to accommodate the component sizes available.

4 Swedish Transport Administration

The Swedish Transport Administration (Trafikverket) is an authority responsible for all modes of transport: road, rail, sea and air (Trafikverkets, 2020b). It's mission is to be responsible for long-term infrastructure planning for road traffic, rail traffic, shipping and aviation, and the construction and operation of state roads and railways.

Swedish Transport Administration's authority consists of the following:

- Responsible for long-term planning of the transport system for road traffic, rail traffic, shipping and aviation
- Responsible for the construction, operation and maintenance of state roads and railways
- Procures interregional public transport
- Maritime aid, Delegation for Maritime Aid

4.1 Climate requirements

Swedish Transport Administration requires suppliers in investment and maintenance projects to reduce the climate impact of the infrastructure (Trafikverkets, 2020b). The requirements apply to the climate impact of construction, the materials used and future maintenance. It also imposes climate requirements on reinforcing steel, concrete, cement, structural steel, and fuel in projects with less than 50 million in investment cost and all maintenance contracts.

The Swedish Transport Administration's long-term goal for infrastructure is to be climate neutral by 2045 (Trafikverkets, 2020b). It progressively translates the intermediate goals into procurement requirements for consultants, contractors and equipment suppliers. The intermediate goals are:

- 2030-2034: at least 50% reduction in climate impact in relation to the emissions in 2015, with a bonus for up to 100% reduction in climate impact in projects and railway equipment. Fossil-free fuels or electric power in all contracts.
- 2025-2029: at least 30% reduction in climate impact in relation to the emissions in 2015, with a bonus for up to half of climate impact in projects and railway equipment.
- 2020-2024: at least 15% reduction in climate impact in relation to the emissions in 2015, with a bonus for reductions up to 30% in projects and railway equipment.

4.2 AMA

AMA stands for *Allmän Material och Arbetsbeskrivning*, or in English as General Material and Work Description (Svensk Byggtjänst, n.d.). AMA is a reference material used to prepare descriptions and execute assignments in the construction industry. AMA contains thousands of descriptions of proven solutions for quality and material selection. AMA makes it easier for the industry to use the same language and concepts and provides greater certainty and clarity in the quality of the construction process (Trafikverket, 2020c)

The AMA is divided into several different areas (Svensk Byggtjänst, n.d.):

- Infrastructure (Anläggnings AMA)
- Buildings (Hus AMA)
- Plumbing & Refrigeration (VVS & Kyl AMA)
- Electrical (El AMA)

5 Case study

5.1 Slab frame bridges

Concrete slab frame bridges are formed by one main bridge deck connected to end supports (frame legs) and wing walls (Yavari M 2017). Figure 5 illustrates the different parts of a typical single-span slab frame bridge. These bridges can be built either as single spans or multi-spans, with open or closed foundation slabs on rock, packed soil, or piles. The span lengths are usually limited to 25m for reinforced concrete and up to 35m for prestressed solutions. The number of bridges constructed with spans less than 20 m is dominated by the slab frame bridges representing about 46% of the total bridge stock in Sweden (Uppenberg *et al*. 2017). The advantages of slab frame bridges include simple design, fast construction, simple details, no expansion joints, and easy maintenance (Yavari M 2017).

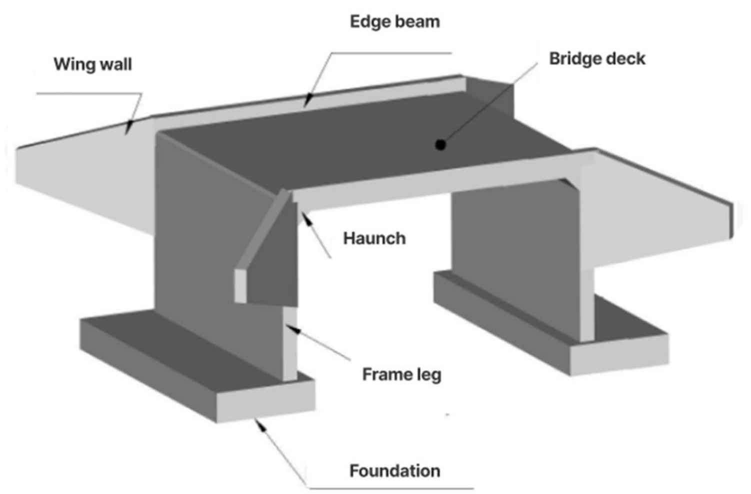


Figure 5 Different parts of a single-span slab frame bridge based on (BaTMan, 2020).

5.2 Slab frame bridge 100-140-1 in Halvor's link

Slab frame bridge 100-140-1 is part of the Halvor's link project, which will be a cross-link between road 155 and Hisingsleden (Trafikverket, 2022a), See Figure 6. The link will facilitate freight transport to and from the prominent industries on western Hisingen. The Halvor's link road plan includes the construction of a 1.3 km of new road and a walk/cycle path linking the Hisingsleden road with the Outer harbour junction *Ytterhamnsmotet* on road 155. A new traffic place, Vikansmotet, will also be built on the Halvor's link, connecting the Halvorsäng logistics centre to the national road network, see Figure 7. The connection between Vikans industrial road and road 155 will be closed, making Vikansmotet the new link to the road network.

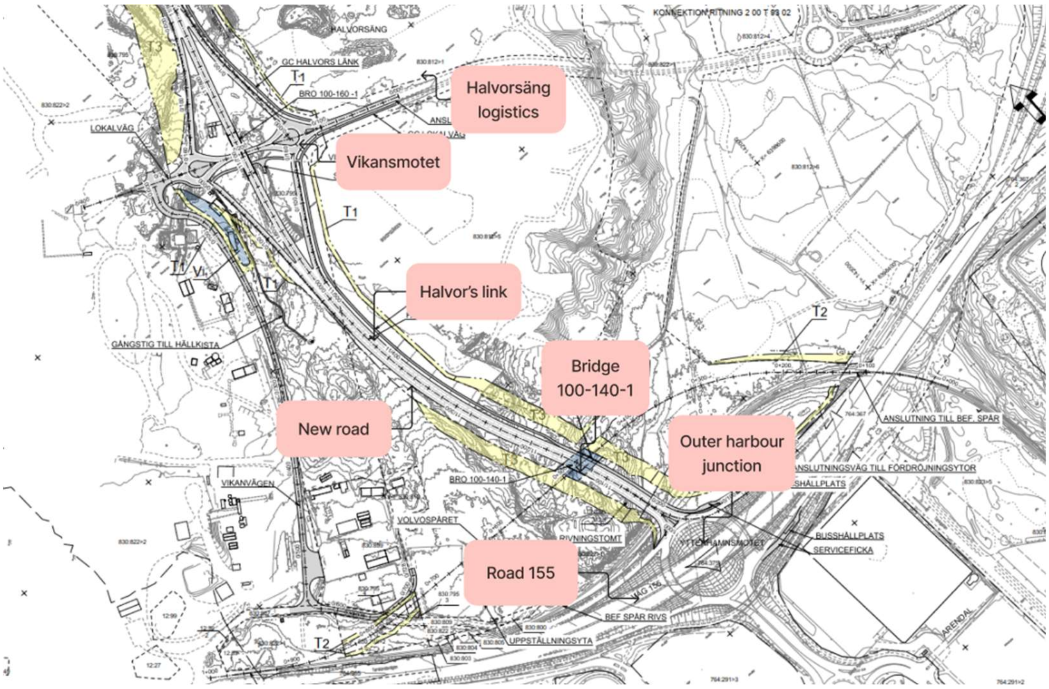


Figure 6   Bridge's location and site activities, (Trafikverket, 2018).

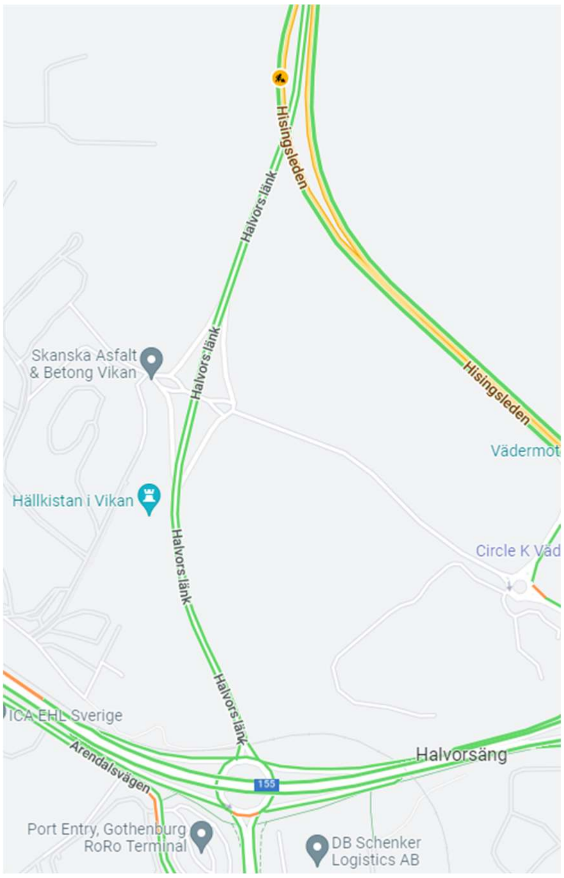


Figure 7   Map over Halvor's link, based on (Google maps).

The bridge is designed as a cast-in-place reinforced concrete slab frame bridge founded on compacted fill on bedrocks and PEAB is the contactor company responsible for constructing the bridge. As the angle between the overlying road line and the underlying railway line is 114˚, the bridge has a parallelogram shape from plane view and is divided by barriers into three lanes. The bridge length is

13.9 m, the span is 12.65 m, the total length is 20.7 m, and the total width is 21.5 m. The bridge is classified with safety class 2 as the span is less than 15m, and the lifetime is set to 80 years; thus, the lifetime class becomes L50. Figure 8 shows the bridge's cross-section, including of the three lanes, figure 9 shows the bridge's parallelogram shape from a plane view, and figure 10 shows a three-dimensional illustration of the bridge's design. The bridge's data in this subchapter is based on the construction documents developed by Ramboll (internal documents).

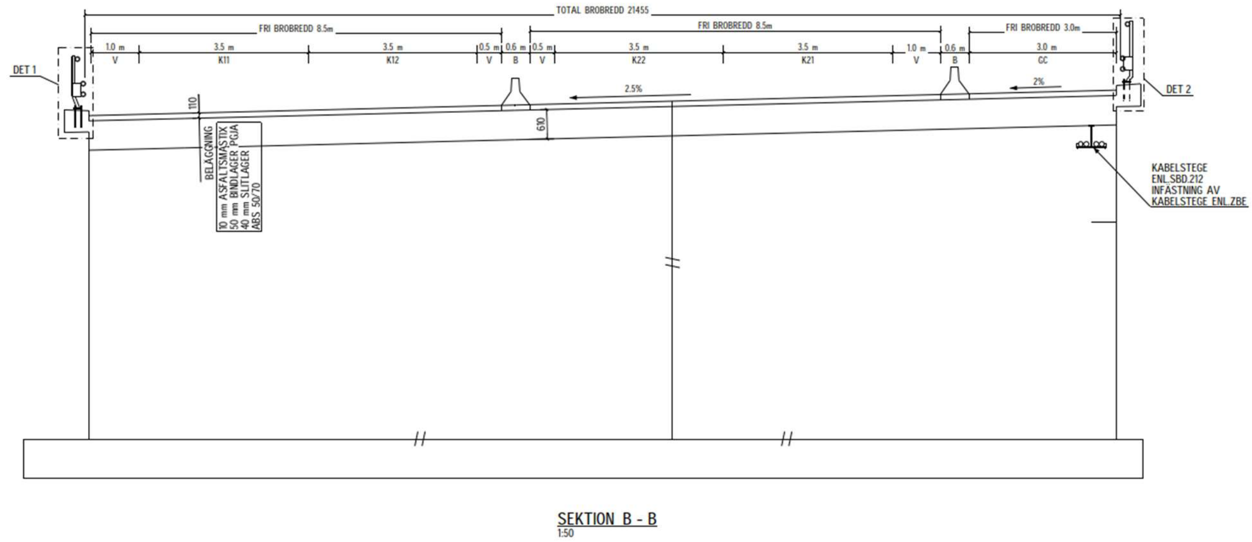


Figure 8 Cross-section view showing three lanes (Ramboll, internal documents).

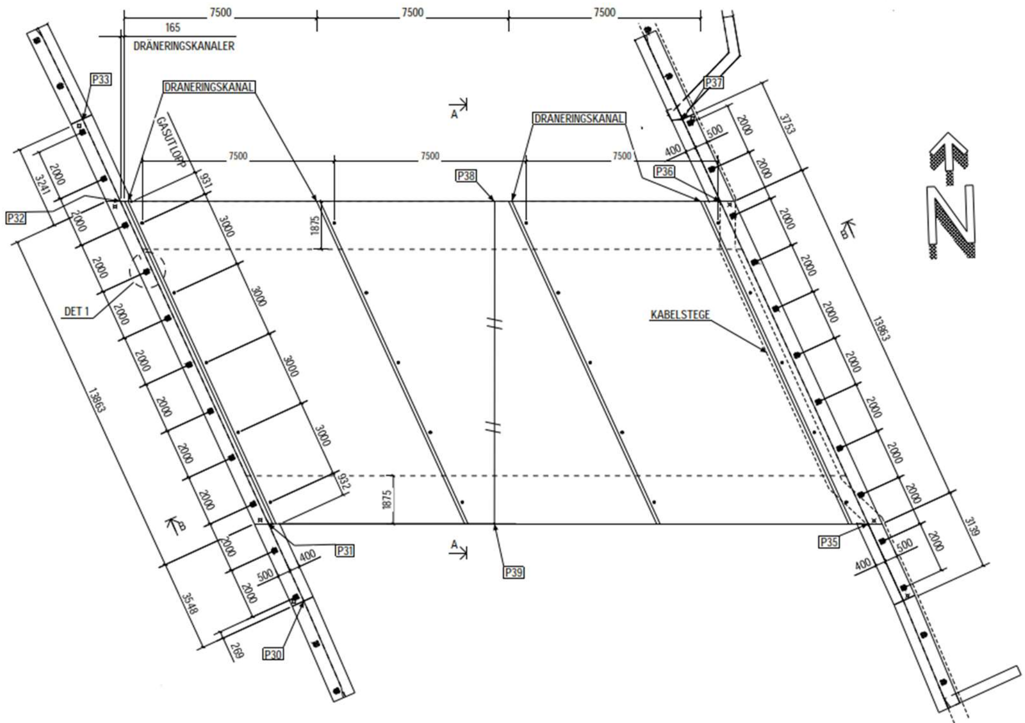


Figure 9 Plane view showing the parallelogram shape (Ramboll, internal documents).

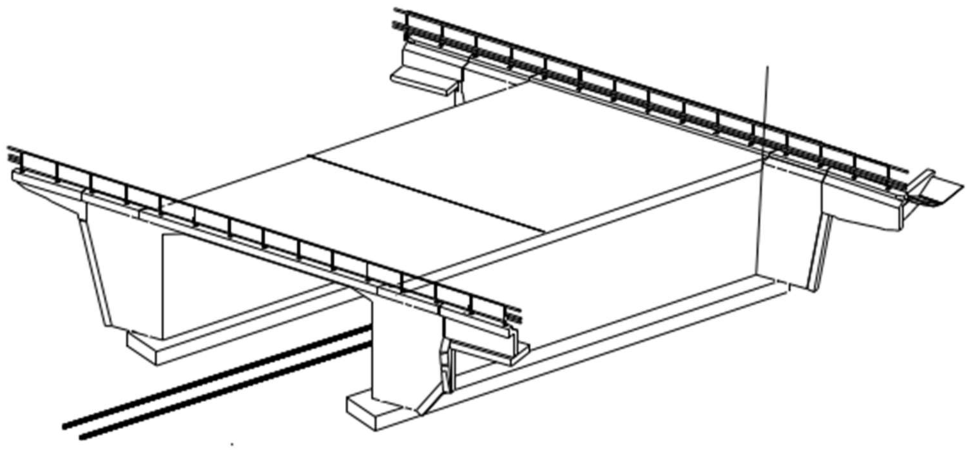


Figure 10 3D view of the bridge design (Ramboll, internal documents).

5.2.1 Applicable documents and regulations:

The governmental regulation and requirement documents used in designing the slab frame bridge and the associated descriptions and traffic operation drawings are listed in table 4 below (Ramboll internal documents).

Table 4 Applicable documents and regulations (Ramboll, internal documents).

Document	Title
TDOK 2016:0204, version 2	Requirements Bridge building
TDOK 2016:0203, version 2	Advice Bridge building
TDOK 2013:0267, version 5	Strength calculation of bridges, Requirements
TDOK 2013:0273, version 5	Design of bridges, Advice
TDOK 2013:0667, version 2	Swedish Transport Administration's technical requirements for geo-structures
TDOK 2013:0668, version 2	Swedish Transport Administration's technical advice for geo-structures
SS-EN 1990 till SS-EN 1999	Eurocode, as applicable
TSFS 2018:57	The Swedish Transport Agency's regulations and general advice on the application of Eurocodes.
AMA Anläggning 17	General description of materials and operations for civil engineering projects.
TDOK 2017:0441, version 2	The Swedish Transport Administration's modifications and additions to AMA Construction 17
2 K 07 41 01	Description of materials, execution and control (BMUK)

5.3 Life Cycle Analysis for bridge 100-140-1

5.3.1 Goal and scope

The LCA study investigates the climate impact of slab frame bridge 100-140-1 in Halvor's Link and how to influence the climate savings. The study indicates how different decisions affect the climate impact of the bridge in terms of greenhouse gas emissions. The obtained results will be used as reference material for Rambolls structural engineers in future projects.

The study will include the bridge's structural elements, which will be divided into two main categories: the bottom slabs foundation and the superstructure elements, which consists of the bridge deck, frame legs, edge beams, wing walls and the haunches. The study calculates air emissions that indicate global warming potentials using the functional unit kilogram carbon dioxide equivalents (kg CO2-eq), and the bridge's lifetime is set to 80 years.

The study investigates the climate impact of the bridge during the material production phase (A1 - A3) and transportation phase (A4), excluding the construction, the operation, and the demolition phases since they are not to be seen as relevant to the goal of the study, see Figure 11. The material production phase (A1 - A3) comprises the production of the construction products from raw materials and other resources, while the transportation phase (A4) includes transportation to the construction site.

The study also compares different material selection options for the reinforcement and concrete mixtures that could be used as a replacement in the bridge's design. The study compares various concrete and reinforcement products from different suppliers, promoting a more sustainable material selection. It is preferable to obtain the data used in the comparison analysis directly from the supplier in an environmental product declaration form. The suppliers should be part of the Swedish market, or their products should be accessible on the Swedish market.

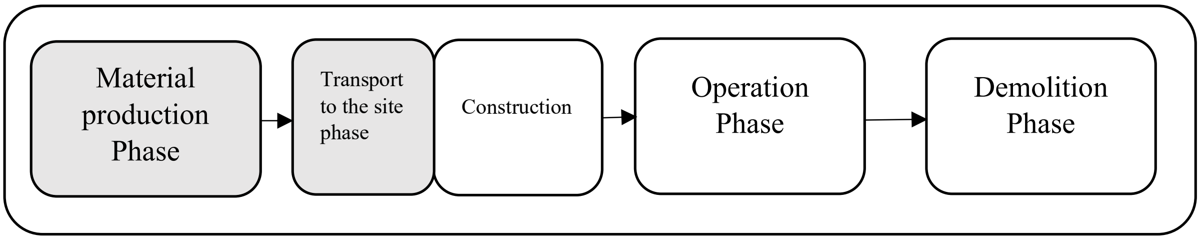


Figure 11 The phases included in the LCA (Arthur's figure).

5.3.2 Life Cycle Inventory

This chapter includes data collection to quantify relevant inflows and outflows of the studied system, i.e. the slab frame bridge 100-140-1. Inflows, such as the extraction of raw materials, production of materials, and transportation, are presented in the process tree below, see Figure 12. The outflows defined for this system have global warming potential and are obtained through various environmental product declarations.

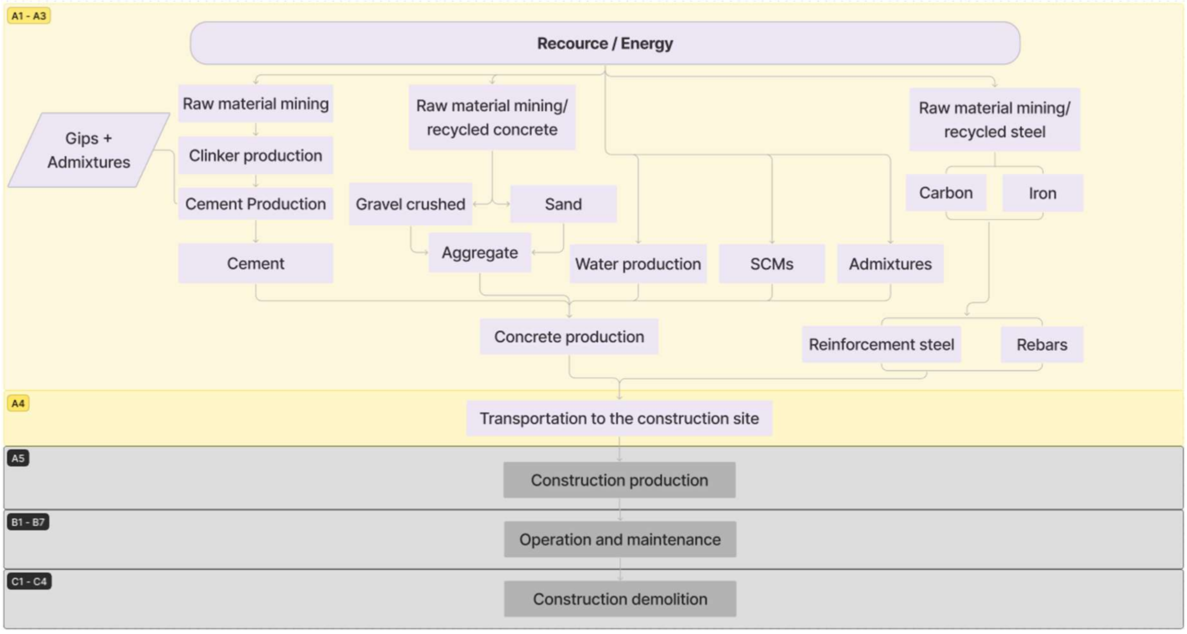


Figure 12 Process tree (Arthur's figure).

The following subchapters describe and collect the product system data, material quantities and balance calculation. The data collection and material quantities used to calculate the bridge's global warming potential are received from PEAB internal documents and are not included in the appendix list.

5.3.2.1 Concrete

Existing option

Concrete of strength class C35/45 with a water to cement ratio (Vct) of 0,40 and a maximum permissible aggregate size of 27 mm is used for constructing the bridge 100-140-1. The concrete meets the requirements of the performance grade EXC3, lifetime L50, safety class 2 and the exposure class XD3/XF4. The cement used in the recipe is Velox CEMI 52,5 N produced by Cementa, and the concrete is mixed and supplied by Swerock Betong AB, Table 5 below shows the content for one cubic meter of concrete. For delivering the concrete to the construction site, diesel driven concrete mixers are used; each concrete mixer has a capacity of $6m^3$, and the one-way distance is approximately 22 km; hence the emission data used for the environmental calculation is brought from an EPD produced by Swerock Betong see Appendix 1.

Table 5 Recipe for one cubic meter of concrete.

Material	Quantity (kg)	Percentage (%)
Aggregate	1847	75,8
Cement	349	14,3
GGBS	66	2,7
Water	166	6,8
Superplasticizer	3,32	0,13
Air-entrainment	4,98	0,20
Total	2436	100

Table 6 shows the amount of concrete used for the bottom plates foundation and the superstructure elements of the bridge, i.e., the bridge deck, frame legs, edge beams, wingwalls and the haunches.

Table 6 Concrete quantity in the structural elements.

Structural elements	Concrete (m^3)
Bottom plates foundation	105
Superstructure elements	446
Total	551

Other concrete products

For other concrete options, choose ready mixed climate effective concrete products with strength class C35/45, lifetime L50, Vct 0.4 and exposure class of XF4. Table 7 below shows two concrete options used for the comparative analysis, the suppliers, and the emission data source; after that, a summary follows for each option.

Table 7 Other concrete product options.

Nr	Supplier	Product name	Emission data source
1	Betongindustri	FrostBI Anläggning FA	EPD
2	Skanska	Frost resistant concrete with Anläggningscement FA	EPD

1-FrostBI Anläggning FA by Betongindustri

The product description and emission data are brought from an EPD produced by Betongindustri AB and certified by the Norwegian EPD Foundation see Appendix 2. *FrostBI* is process-certified ready-mixed concrete and meets the requirements of European standard EN 206, Swedish application standard SS 137003 and AMA Anläggning. FrostBI is very dense to resist salt penetration, contains air-entraining admixtures to resist freezing, and it is recyclable, usually as fill material. The concrete meets the requirement of strength class C35/45, water to cement ratio Vct of 0,40, and the exposure class XC4, XS3, XD3, and XF4. Table 8 below shows the content for one cubic meter of concrete. The cement used for this concrete type is Cementa's Anläggningscement FA which replaces the cement clinker with 6-20% fly ash and an additional 0-5% GGBS.

Table 8 Recipe for one cubic meter of concrete.

Material	Quantity (kg)	Percent (%)
Anläggning cement FA	420	17,58
Aggregate	1800	75,35
Water	164	6,87
Superplasticizer	3	0,13
Air-entrainment	1,5	0,07
Total	2388,5	100

2-Frost resistant concrete with Anläggningscement FA by Skanska

The product description and emission data are brought from an EPD produced by Skanska Industrial Solutions AB and certified by the Norwegian EPD Foundation see Appendix 4. This concrete type is process-certified factory concrete and meets the requirements of European standard EN 206, Swedish application standard SS 137003 and AMA Anläggning. This type is very dense to resist salt penetration and contains air-entraining admixtures to resist freezing, and it is recyclable, usually as fill material. The concrete meets the requirement of strength class C35/45, water to cement ratio Vct of 0,40, and the exposure class XC4, XS3, XD3, and XF4. Table 9 below shows the content for one cubic meter of concrete. The cement used for this concrete type is Cementa's Anläggningscement FA which replaces the cement clinker quantity with 6-20% fly ash and an additional 0-5% GGBS.

Table 9 Recipe for one cubic meter of concrete.

Material	Quantity (kg)	Percent (%)
Anläggning cement FA	430	17,9
Aggregate	1790	74,4
Water	180	7,5
Superplasticizer	3	0,12
Air-entrainment	1,7	0,07
Total	2405	100

5.3.2.2 Reinforcement

Existing option

Steel quality K500CT is used in concrete reinforcement, whereas the steel contains around 98% recycled material and can be recycled with up to 100%. The product description and emission data used for the environmental calculation are brought from two EPDs produced by the supplier Tibnor AB and certified by The International EPD System, see Appendix 5, 6. Table 10 below the amount of reinforcement used for the bottom plates foundation and the superstructure elements of the bridge, i.e., the bridge deck, frame legs, edge beams, wingwalls and the haunches.

Table 10 Steel quantity in bridge 100-140-1.

Structural elements	Reinforcement bars (kg)	Cut and Bent bars (kg)
Bottom plates foundation	7883	3185
Superstructure elements	32699	13123
Total	40582	16308

Other reinforcement products

Choosing CELSA's *steel reinforcement products for concrete* as another reinforcement product option, whereas the product's diameter can range from 4 mm to 40 mm, yield stress, Re ≥ 500 MPa - Rm/Re ≥ 1.15, and has a density of 7700 kg/m3. This product type is certified by the Material Standards: SS 212540:2011 and EN 10080:2005 and manufactured and delivered from Halmstad-Sweden. The product description and emission data are brought from an EPD produced by CELSA Nordic and certified by The International EPD System, see Appendix 7.

5.3.2.3 Transportation (A4)

Table 11 shows the distance, vehicles, and fuel type used or could have been used to transport each concrete and reinforcement product to the construction site.

Table 11 Transportation distance, vehicles, and fuel type used to transport each concrete and reinforcement product, respectively.

Product/supplier	From	To	Distance (km)	CO_2 per m^3/tonne	Vehicle/capacity	Fuel
Swefrys 45, Swerock	Kållered	Halvor's link	22	6,06	Concrete mixer $6m^3$	Diesel
FrostBI, Betongindusti	West region	Halvor's link	15	5,04	Concrete mixer $6m^3$	Diesel
Frost resistant, Skanska	Vikans industriväg	Halvor's link	2	0,3	Concrete mixer $6m^3$	Diesel
Reinforcing Bar, Tibnor	Köping	Halvor's link	464	30,5	Truck EURO 4 30tonne	Diesel
Cut and bent rebar, Tibnor	Köping	Halvor's link	480	38,3	Truck EURO 4 30tonne	Diesel
Steel reinforcement products, CELSA Nordic	Halmstad	Halvor's link	148	7	Truck HVO100 28tonne	Diesel +21% biofuel

6 Results

The results presented in this chapter are based on the case study executed on slab frame bridge 100-140-1 and follow the theoretical framework guided by the theory part.

6.1 LCA of bridge 100-140-1

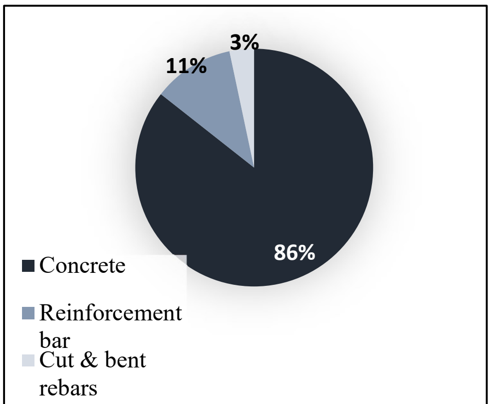
The amount of CO_2 emissions produced by the structural parts of the case study slab frame bridge in Halvor's link, Bridge 100-140-1, was quantified through an LCA including the material production and transportation phases.

6.1.1 Material production phase (A1-A3)

Table 12 shows the LCA results from the material production phase (phase A1-A3) conducted on the structural parts of the case study, Bridge 100-140-1, while Figure 13 shows the share of emissions of CO_2 equivalents for each material, respectively.

Table 12 LCA results from the material production phase (phase A1-A3).

Material Resource	**Declared unit**	**Amount per declared unit**	**kg CO_2-eq per declared unit (kg)**	**kg CO_2-eq in total (kg)**	**CO_2 emission (%)**	**Comment**
Concrete	m^3	551	314.81	173 * 10^3	85.6	EPD Appendix 1
Reinforcement bar	kg	40 * 10^3	0.553	22 * 10^3	11.1	EPD Appendix 5
Cut & bent rebars	kg	16 * 10^3	0.414	6751	3.3	EPD Appendix 6
Total				202 * 10^3	100	



The LCA results indicate that concrete accounts for the largest share, 86%, of the climate impact from phases A1-A3, corresponding to 173 * 10^3 kg CO_2-eq. Furthermore, the reinforcement bars account for the second-largest share at 11% and contribute to 22 * 10^3 kg CO_2-eq. The third-largest contributor is cut and bent rebars, with a carbon footprint of 6751 kg CO_2-eq.

Figure 13 Share of emissions of CO_2 equivalents from material production phase (phase A1-A3), for the case study bridge.

6.1.2 Transportation phase (A4)

Table 13 shows the LCA results from the transportation phase (phase A4) conducted on the structural parts of the case study, Bridge 100-140-1, while Figure 14 shows the share of emissions of CO_2 equivalents for each material, respectively.

Table 13 LCA results from the transportation phase (phase A4).

Material Resource	**Declared unit**	**Amount per declared unit**	**kg CO_2-eq per declared unit (kg)**	**kg CO2-eq in total (kg)**	**CO_2 emission (%)**	**Comment**
Concrete	m^3	551	6.06	3339	64.2	EPD Appendix 1
Reinforcement bar	kg	$40 * 10^3$	0.0305	1237	23.8	EPD Appendix 5
Cut & bent rebars	kg	$16.3 * 10^3$	0.0383	624	12.0	EPD Appendix 6
Total				5201	100	

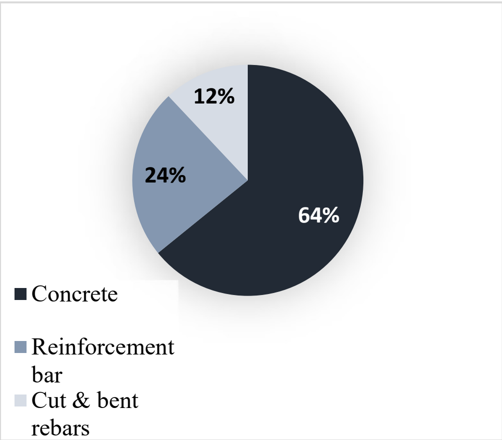


Figure 14 Share of emissions of CO_2 equivalents from transportation phase (phase A4), for the case study bridge.

The LCA results indicate that concrete accounts for the largest share, 64%, of climate impact from phase A4, corresponding to 3339 kg CO_2-eq. Furthermore, the reinforcement bars account for the second-largest share at 24% and contribute to 1 237 kg CO_2-eq. The third-largest contributor is cut and bent rebars, with a carbon footprint of 624 kg CO_2-eq.

6.1.3 Material production & transportation phases (A1-A4)

Table 14 shows the LCA results from the material production and transportation phases (phase A1-A4) conducted on the structural parts of the case study, Bridge 100-140-1, while Figure 15 shows the share of emissions of CO_2 equivalents for each material, respectively.

Table 14 LCA results from the material production and transportation phases (phase A1-A4).

Material resource	**kg CO_2-eq for phase A1-A3 (kg)**	**kg CO_2-eq for phase A4 (kg)**	**kg CO_2-eq in total (kg)**	**CO_2 emission (%)**
Concrete	173 * 10^3	3339	176 * 10^3	85.1
Reinforcement bar	22.4 * 10^3	1237	23.6 * 10^3	11.4
Cut & bent rebars	6751	624	7376	3.5
Total	202 * 10^3	5201	207 * 10^3	100

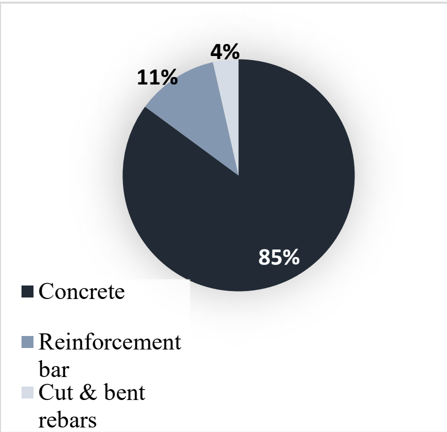


Figure 15 Share of emissions of CO_2 equivalents from the material production and transportation phases (phase A1-A4), for the case study bridge.

Combining the results from the material production and transportation phases (phase A1-A4), showed that the concrete used in slab frame bridge 100-140-1 accounts for the largest share of climate impact, at 85%, corresponding to 176 * 10^3 kg CO_2-eq. Furthermore, the reinforcement bars account for the second-largest share at 11% and contribute to 23.6 * 10^3 kg CO_2-eq. The third-largest contributor is cut and bent rebars, with a carbon footprint of 7376 kg CO_2-eq.

6.2 Comparative analysis of concrete and reinforcement products

The study compared concrete and reinforcement products on the Swedish market to quantify the CO_2 emissions produced by each product during the material production and transportation phases to promote optimized material selection.

6.2.1 Concrete products

6.2.1.1 Material production phase (A1-A3)

Table 15 shows the results from the concrete comparative analysis for the material production phase (phase A1-A3) performed on three concrete products, while Figure 16 shows the share of emissions of CO_2 equivalents for each product, respectively.

Table 15 Results from the concrete comparative analysis for the material production phase (A1-A3).

Option type	Supplier	Product name	Declared unit	Amount per declared unit	kg CO_2-eq per declared unit (kg)	kg CO_2-eq in total (kg)	Comment
Existing	Swerock	Swefrys 45	m^3	551	314.81	$173 * 10^3$	EPD Appendix 1
Other	Skanska	Frostbeständig betong med Anläggning FA	m^3	551	311.6	$171 * 10^3$	EPD Appendix 4
Other	Betongindustri	FrostBI Anläggning FA	m^3	551	303	$166 * 10^3$	EPD Appendix 2

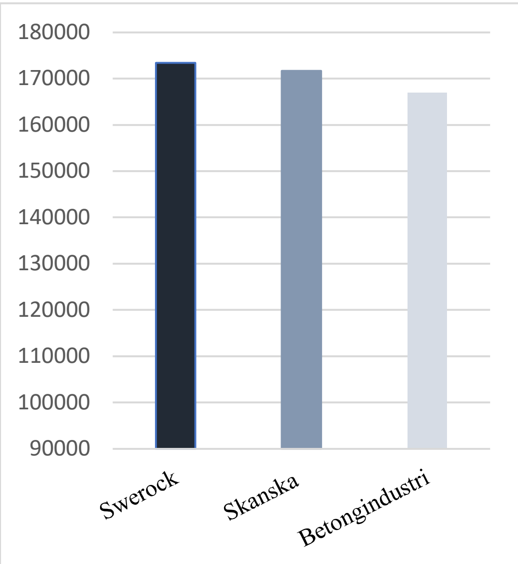


Figure 16 Share of emissions of CO_2 equivalent from the material production phase (phase A1-A3) for each concrete product, respectively.

The concrete comparative analysis for the material production phase (phase A1-A3) indicates that Skanska’s and Betongindustri’s concrete products give a slightly better results than the existing concrete product produced by Swerock. However, Skanska's concrete emits $171 * 10^3$ kg CO_2-eq and Betongindustri's concrete achieves better results by emitting $166 * 10^3$ kg CO_2-eq.

6.2.1.2 Transportation phase (A4)

Table 16 shows the results from the concrete comparative analysis for the transportation phase (phase A4) performed on three concrete products, while Figure 17 shows the share of emissions of CO_2 equivalents for each product, respectively.

Table 16 Results from the concrete comparative analysis for the transportation phase (phase A4).

Option type	Supplier	Product name	Declared unit	Amount per declared unit	kg CO_2-eq per declared unit (kg)	kg CO_2-eq in total (kg)	Comment
Existing	Swerock	Swefrys 45	m^3	551	6.06	3339.06	EPD Appendix 1
Other	Skanska	Frostbeständig betong med Anläggning FA	m^3	551	0.3	165.3	EPD Appendix 4
Other	Betongindustri	FrostBI Anläggning FA	m^3	551	5.04	2777.04	EPD Appendix 2

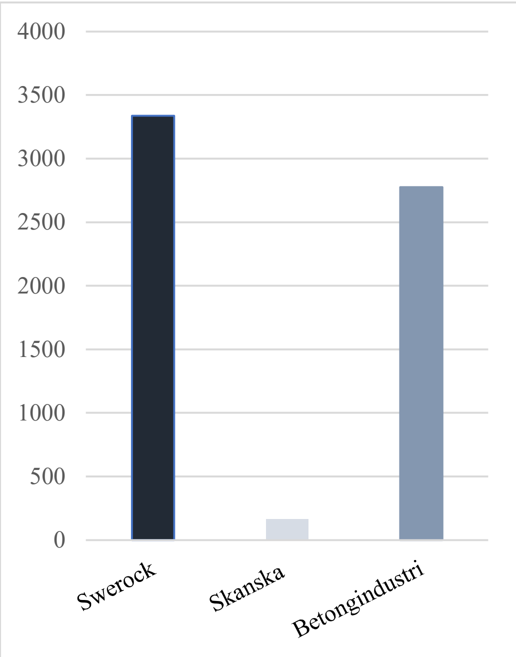


Figure 17 Share of emissions of CO_2 equivalent from the transportation phase (phase A4) for each concrete product, respectively.

The concrete comparative analysis for the transportation phase (phase A4) shows that Skanska's concrete delivers significantly better results due to the close location of the concrete factory from the construction site. However, Skanska's concrete emits 165 kg CO_2-eq. Moreover, Betongindustri's concrete achieves slightly better results than the existing concrete product by emitting 2777 kg CO_2-eq.

6.2.1.3 Material production & transportation phases (A1-A4)

Table 17 shows the results from the concrete comparative analysis for the material production and transportation (phase A1-A4) performed on three concrete products, while Figure 18 shows the share of emissions of CO_2 equivalents for each product, respectively.

Table 17 Results from the concrete comparative analysis for the material production and transportation phases (phase A1-A4).

Option type	**Supplier**	**Product name**	**kg CO_2-eq for phase A1-A3 (kg)**	**kg CO_2-eq for phase A4 (kg)**	**kg CO_2-eq in total (kg)**
Existing	Swerock	Swefrys 45	$173 * 10^3$	3339.06	$176 * 10^3$
Other	Skanska	Frostbeständig betong med Anläggning FA	$171 * 10^3$	165.3	$171 * 10^3$
Other	Betongindustri	FrostBI Anläggning FA	$166 * 10^3$	2777.04	$169 * 10^3$

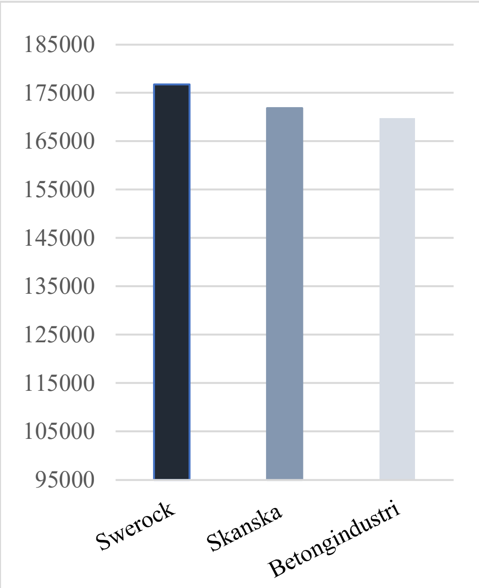


Figure 18 Share of emissions of CO_2 equivalent from the material production and transportation phases (phase A1-A4) for each concrete product, respectively.

Combining the results from the material production and transportation phases (phase A1-A4), showed that the concrete product produced by Betongindustri emits 166 * 10^3 kg CO_2-eq achieving better results than Skanska's and Swerock's concrete products which emits 171 10^3 kg CO_2-eq and 176 10^3 kg CO_2-eq, respectively.

6.2.2 Reinforcement products

6.2.2.1 Material production phase (A1-A3)

Table 18 shows the reinforcement comparative analysis results for the material production phase (phase A1-A3) performed on two reinforcement product suppliers, while Figure 19 shows the share of emissions of CO_2 equivalents for each product, respectively.

Table 18 Results from the reinforcement comparative analysis for the material production phase (phase A1-A3)

Option type	**Supplier**	**Product name**	**Declared unit**	**Amount per declared unit**	**kg CO_2-eq per declared unit (kg)**	**kg CO_2-eq in total (kg)**	**Comment**
Existing	Tibnor	Reinforcing Bar	kg	$40.5 * 10^3$	0.553	$22.4 * 10^3$	EPD Appendix 5
Existing	Tibnor	Cut and bent rebar	kg	$16.3 * 10^3$	0.414	6751	EPD Appendix 6
Existing total	Tibnor		kg	$56.8 * 10^3$		$29.1 * 10^3$	
Other	CELSA	Steel reinforcement products	Tonne	56.89	398	$22.6 * 10^3$	EPD Appendix 7

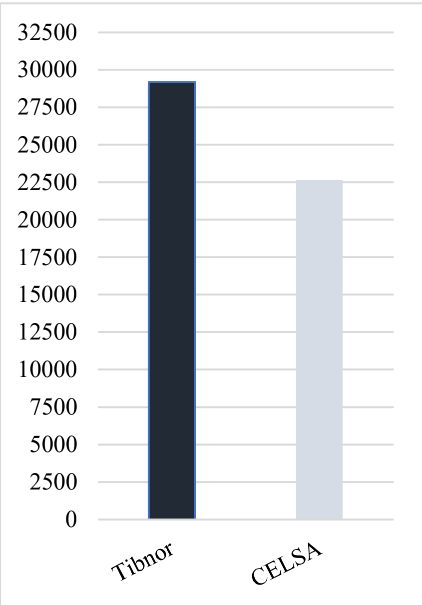


Figure 19 Share of emissions of CO_2 equivalent from the material production phase (phase A1-A3) for each reinforcement product, respectively

The reinforcement comparative analysis for the material production phase (phase A1-A3) indicates that CELSA's steel reinforcement products achieve significantly better results than the existing steel reinforcement products produced by Tibnor by emitting less 6511 kg CO_2-eq.

6.2.2.2 Transportation phase (A4)

Table 19 shows the reinforcement comparative analysis results for the transportation phase (phase A4) performed on two reinforcement product suppliers, while Figure 20 shows the share of emissions of CO_2 equivalents for each product, respectively.

Table 19 Results from the reinforcement comparative analysis for the transportation phase (phase A4)

Option type	**Supplier**	**Product name**	**Declared unit**	**Amount per declared unit**	**kg CO_2-eq per declared unit (kg)**	**kg CO_2-eq in total (kg)**	**Comment**
Existing	Tibnor	Reinforcing Bar	kg	$40.5 * 10^3$	0.305	1237	EPD Appendix 5
Existing	Tibnor	Cut and bent rebar	kg	$16.3 * 10^3$	0.383	624	EPD Appendix 6
Existing total	Tibnor		kg	$56.8 * 10^3$		1862	
Other	CELSA	Steel reinforcement products	tonne	56.89	7	398	EPD Appendix 7

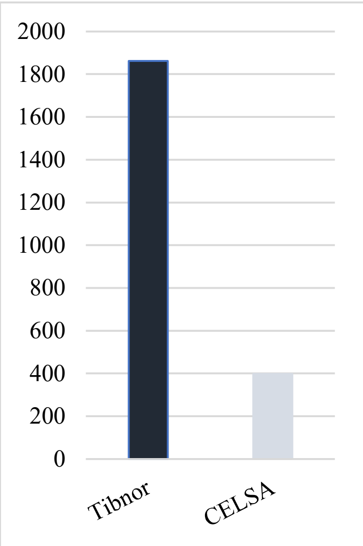


Figure 20 Share of emissions of CO_2 equivalent from the transportation phase (phase A4) for each reinforcement product, respectively

The reinforcement comparative analysis for the transportation phase (phase A4) indicates that CELSA's steel reinforcement products achieve significantly better results than the existing steel reinforcement products produced by Tibnor due to the shorter delivery distance, and the use of 28% biofuel. However, the results showed that CELSA's steel emits less 1464 kg CO_2-eq than Tibnor's steel reinforcement products.

6.2.2.3 Material production & transportation phases (A1-A4)

Table 20 shows the results from the reinforcement comparative analysis for the material production and transportation (phase A1-A4) performed on two reinforcement products suppliers, while Figure 21 shows the share of emissions of CO_2 equivalents for each product, respectively.

Table 20 Results from the reinforcement comparative analysis for the material production and transportation phases (phase A1-A4).

Option type	**Supplier**	**Product name**	**kg CO_2-eq for phase A1-A3 (kg)**	**kg CO_2-eq for phase A4 (kg)**	**kg CO_2-eq in total (kg)**
Existing	Tibnor	Reinforcement	$29.2 * 10^3$	1862	$31 * 10^3$
Other	CELSA	Steel reinforcement products	$22.6 * 10^3$	398	$23 * 10^3$

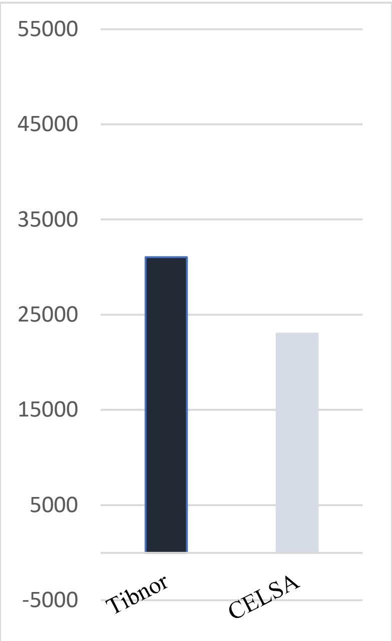


Figure 21 Share of emissions of CO_2 equivalent from the material production and transportation phases (phase A1-A4) for each reinforcement product, respectively.

Combining the results from the material production and transportation phases (phase A1-A4), showed that CELSA's steel products emit $23 * 10^3$ kg CO_2-eq achieving better results than Tibnor's reinforcement products which emits 31 10^3 kg CO_2-eq.

6.3 Optimised material selection

The study estimated the possible reduction in carbon footprint from a slab frame bridge through an optimized material selection; by analysing the results obtained from the previous subchapter. The study suggests replacing the currently used material with more sustainable material that delivers better results regarding CO_2 emissions from the material production and transportation phases (phase A1-A4). Based on the analysis, it has been found that the concrete type supplied by Betongindustri AB contributes to relatively lower CO_2 emissions than the currently used concrete type produced by Swerock. The analysis also indicated that CELSA's reinforcement products contribute to significantly lower CO_2 emissions compared to the currently used reinforcement products produced by Tibnor, See table 21.

Table 21 Results from the optimized material selection.

Option type	Material	Supplier	kg CO_2-eq for phase A1-A4 (kg)	kg CO_2-eq in total (kg)	kg CO_2-eq saved (kg)	kg CO_2-eq saved (%)
Existing solution	Concrete	Swerock	$176 * 10^3$	$207 * 10^3$	$15 * 10^3$	7.3
	Reinforcement	Tibnor	$31 * 10^3$			
Optimized solution	Concrete	Betongindustri	$169 * 10^3$	$192 * 10^3$		
	Reinforcement	CELSA	$23 * 10^3$			

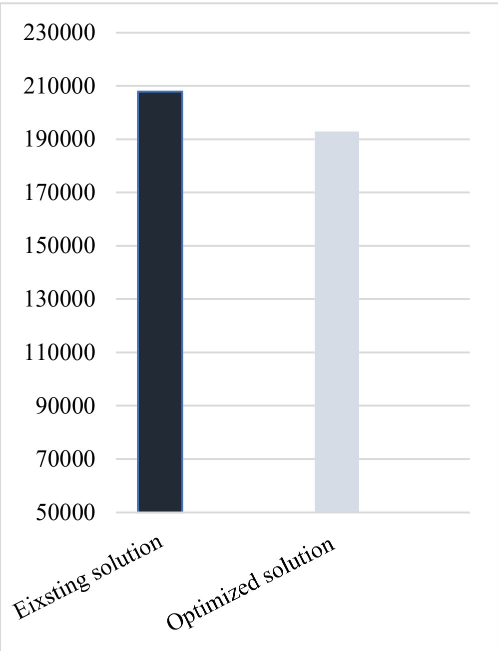


Figure 22 Results from the optimized material selection.

However, replacing the current material with more optimized solutions such as Betongindustri's concrete and CELSA's reinforcement products can reduce the climate impact by $15 * 10^3$ kg CO_2-eq, which corresponds to approximately 7.3%, from the material production and transportation phases, see Figure 22.

6.4 Fostering long-term sustainability

Two options have been investigated to examine the influence of current practices and standards on the possibility of fostering long-term sustainability for construction: implementing preliminary climate impact results at the early stages and encouraging the use of SCMs in concrete mixes. The solutions are based on theoretical studies, and a summary follows each option.

6.4.1 Implementing preliminary climate impact results at the early stages

A study has been conducted by Basbagill *et al*. (2013) to investigate the application of life-cycle assessment to early-stage building design for reducing the environmental footprint. The study demonstrates a method for applying LCA to early phase decision-making; to notify the designers about the building materials' relative environmental impact and the building elements' dimension options.

The study's framework employs a computational method that combines Building Information Modeling (BIM) software with LCA and energy analysis software to quickly estimate the environmental footprint of thousands of building designs (Basbagill *et al*., 2013). The framework is prepared for application, mainly during the early design phases when the design problem is generally not well defined, the number of design options is large, and the potential to reduce environmental impacts is greatest.

The study results show that the scope of environmental impacts is steadily reduced as decisions are made for both material selection and thickness for building elements; moreover, the results from considering the thickness of the building element could achieve up to 37% of emission reduction. However, the technique can assist in the building design process by emphasising those early phase decisions that often serve the most significant reductions in environmental footprint. In contrast, the validation of this study is limited to a single case study concerning a specific building type, size, location, and geometry (Basbagill *et al*., 2013); applying this study to bridge design requires an additional study application, although it can still be seen as relevant to thesis goal.

6.4.2 Restricting the use of the traditional concrete mix and encouraging the use of SCMs

In Sweden, the primary SCMs used are silica fume, fly ash and GGBS (Betonghandbok Material, 2017). However, incorporating the SCMs in concrete arise from the possibility of reducing greenhouse gas emissions, energy use, and waste disposal at landfill sites (Daman K, 2019). Nevertheless, SS 137003:2021 regulates the accepted binder compositions and requirements for maximum Vct and frost resistance in exposure classes XF1 to XF4 (SS 137003:2021). Whereas concrete with exposure class XF4, the maximum allowed quantities of SCMs by the regulations was 35% GGBS, fly ash.

However, a study conducted by Correia *et al*. (2020) aims to investigate the properties of concrete with GGBS, focusing on its frost scaling and chloride entree resistance. The study tested different concrete mixtures with different amounts of GGBS, efficiency factors, and air contents. The study also investigated the effects of other factors, especially the curing temperature, superplasticiser, and carbonation. However, the study results showed that it is possible to produce frost-resistant and chloride entree resistance concrete with up to 50% of GGBS by changing some mixed properties, such as increasing the air content. However, increasing the allowed quantity of SCMs than those documented in SS 137003:2021 would initially help lower the climate footprint caused by concrete production.

7 Discussion

The LCA performed in this study calculates the global warming potentials for the structural parts of a typical slab frame bridge, for both the material production and transportation phases. The rest of the construction's life cycle phases were not included due to not being seen as relevant to the study's goal. The LCA is based on inputs from the structural designers at Ramboll, the consultancy company, and the contracting engineers at PEAB, the contracting company that constructed the bridge. The environmental product declarations used in the LCA has been provided by the suppliers. Since the LCA aims to only calculate the global warming potentials for the structural parts, access to an environmental calculator was not critical; consequently, the calculations performed were based on an Excel spreadsheet developed by the author.

Due to the structure's technical lifetime and the environmental exposure, concrete with strength class C35/45 and exposure class XF4 have been used in the bridge design. The concrete products studied in the comparative analysis exactly fulfils the material requirements and choosing different concrete qualities will not suit the study's goal. Choosing a different concrete quality would either lead to a larger environmental impact or to a concrete with insufficient durability. The latter would lower the desired technical lifetime, with more maintenance and early replacement which, in turn, would make this alternative disadvantageous from both economic and environmental standpoint.

In the study, different concrete products on the Swedish market were compared, showing that only a few products were able to suit the exact requirement defined for the bridge. However, many products could be found on the Swedish market that to a near point could serve the requirements in terms of exposure and strength classes. Some of these products were more environmentally friendly than others, and this discussion mainly concerns the once having BIO or ECO in their product names.

The products named BIO or ECO deliver a significantly smaller environmental impact compared to the more common type of concrete products. The BIO/ECO products deliver better results because a large amount of the cement clinker has been replaced with different SCMs. Unfortunately, due to the difference in the product's strength or exposure classes compared to the bridge's requirements, these products could not be used directly in the bridge construction. Hence, a modification in the product's recipe is required to fulfil the desired requirements.

These modifications are commonly executed on concrete products to lower or increase the strength or exposure classes; thus, the modification's results are published internally in the form of daughter EPDs extracted from the product's original EPD, called the mother EPD. The daughter EPDs are not publicly published because they are not certified by a third party and are based on basic calculations.

One example of a product modification is the existing concrete product Swefrys 45. It is the modification results of product ECO 1 Sweexp55, which has a strength class C30/37, Vct 0.55 and exposure class XC4/ XF1. The modifications transformed the strength class to C35/45, Vct 0.4 and exposure class XF4; simultaneously, the CO_2 emissions were adjusted from 204.9 CO_2e kg/m^3 to 315 CO_2e kg/m^3. The significant change in the CO_2 emissions can be explained by the marked difference between the two products, which could have been avoidable by choosing another BIO/ECO product that initially had more comparable quality to the one needed for the bridge design.

One of these BIO/ECO products is Betongindustri's BIO-1 which has the same required strength class C35/45 and Vct 0.4, see Appendix 3. The only difference to the requirement for such a product was the exposure class of XF2. As mentioned earlier, some slight modifications could have been made to reach the desired exposure class XF4, such as increasing the amount of airborne admixtures to the recipe. Betongindustri's BIO-1 emits only 275 CO_2e kg/m^3; thus, the slight modifications required for this product would have allowed better results than the existing solution of Swerock's product Swefrys 45.

The lack of information about the modified products prevents them from being used as a replacement in the comparative analysis.

The existing reinforcement products from Tibnor used for the bridge design are, for the most significant part, scrap-based, locally produced and can be recycled with up to 100%. Therefore, the reinforcement products studied in the comparative analysis should provide the same or better conditions. Choosing CELSA's steel products as a replacement fulfils the prerequisites and achieves significantly better outcomes. CELSA's reinforcement products are 100% scrap-based iron, whereas Tibnor's reinforcement products are produced with 95% scrap-based iron. CELSA's steel production facilities and warehouses are located in Halmstad, whereas Tibnor's are located in Köping, both of which approx 150 km and 450 km away from the construction site, respectively.

Nevertheless, the emission factor from both the material production and transportation phases should be taken into account when choosing the suitable material for the structure. By calculating the total climate impact from (A1-A4), conclusions can be drawn about which supplier to choose to deliver the most environmentally friendly structures.

According to the thesis results, one can see that the CO_2 emissions from concrete bridge construction are directly related to the amounts of concrete and reinforcement used. Thus, one way to reduce emissions is by optimising the structural design to reduce material quantities. According to Uppenberg *et al*. (2017), bridge designers always intend to optimise the material quantities, for example, by shortening reinforcement to maximise the use of material or geometric optimisation based on quantities, rationality, and simplicity of the design. The optimisation possibilities are ultimately determined by the time and resources available, depending on the contracting arrangements and how stakeholders interact regarding the design.

Consequently, the optimisations are generally made against initial investment cost (Uppenberg *et al*. 2017), which often leads to sub-optimisations in terms of opportunities to create flexible and scalable solutions for future needs and design for future reuse. From an ecological standpoint, optimisation cannot only be directed towards a minimised amount of reinforcement without any specific evaluation of other possibilities but instead using all possible solutions to create more optimised decisions.

For example, the difference between a thinner structure with more reinforcement and a thicker structure with less reinforcement has been analysed for a bridge's deck and frame legs, conducted by Uppenberg *et al*. (2017). The results showed that with unchanged cross-sectional capacity, the climate impact of the bridge could be reduced by at least 15% just by adapting the cross-sectional design. Moreover, a study conducted by Alhede & Beskow (2020) concludes that the environmental impact and costs decrease with increasing the cross-section's slenderness and that it is more favourable to decrease the thickness of the structural elements and compensate with reinforcement.

However, knowing the climate impact and cost of the material would make it easier to use the LCA results at an early stage (Uppenberg *et al*. 2017), allowing the bridge designers to better understand how their optimisation decisions may affect the overall climate impact and cost of the structure. Thus, using the available technology would provide an opportunity to evaluate the effects on the final result and provide a more objective basis for optimisation decisions. However, the currently available technologies and climate calculators are hard to use because they do not include all data needed to perform an early stage LCA. They require data input to function correctly, consequently leading the designers to an undesirable additional workload. Consequently, investing in more user-friendly technologies and climate calculators would increase the possibility of implementing the LCA at an early stage.

8 Conclusion

Bridge structures in Sweden are associated with high resource consumption and significant emissions of greenhouse gases. Consequently, to achieve the Swedish Transport Administration's goals to reach climate neutrality by 2045, some approaches need to be implemented to reduce these emissions. In line with this, this thesis study has explored and analysed some options to reduce the climate impact from the structural parts of slab frame bridges.

The thesis conducted a life cycle analysis concerning the CO_2 emissions from a typical slab frame bridge's structural element, bridge 100-140-1, during the material production and transportation phases. The thesis has also analysed different reinforcement and concrete products on the Swedish market to promote alternative solutions for more optimised material selection. Furthermore, the thesis has investigated the influence of current standards and practices on the possibility of fostering long-term sustainability for construction.

The study's results showed a considerable reduction in CO_2 emissions by promoting more sustainable material selection. Furthermore, the study's investigations showed the possibility of using other environmentally friendly concrete products only if it is possible to modify the products to fulfil the bridge requirements, i.e., strength- and exposure classes, which could lead to a significant emission reduction. Moreover, the investigations also demonstrated the importance of considering preliminary climate impact results at the early design phase to enable sustainable decision-making, in which more optimised designs would be achievable.

Finally, according to the thesis's theoretical investigations, one can see that the reduction potential could be relatively high. Using the present technology in some approaches concerning material selection and early-stage sustainable decision-making would improve the prospects of affecting the climate footprint of bridge structures.

9 Further studies

The study also shows the need for further investigations on several aspects. below are some suggestions for further studies:

- More comprehensive LCA studies including all life cycle phases of bridge structures. These can cover more bridge types and analyse materials other than concrete and reinforcement, to form a basis for optimal bridge type and construction material selection.
- Studies that perform life cycle cost analysis (LCC) to investigate how sustainable decisions would affect the total life cycle cost of the structure.
- Studies that test different concrete recipes to determine the highest potential quantity of SCMs that could replace the cement clinker without affecting the strength and exposure classes of the concrete.
- Studies that test different design alternatives to reach the optimum design that satisfies both functionality and sustainability.
- Studies that test different possibilities to make the currently available technologies and climate calculators more user-friendly and develop an approach to implement them into the existing design programs.

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Appendix List

Appendix nr	Product name	Appendix form	Supplier
Appendix 1	Swefrys 45	Dotter EPD	Swerock
Appendix 2	FrostBI Anläggning FA	EPD	Betongindustri
Appendix 3	BIO-1	Product sheet	Betongindustri
Appendix 4	Frost resistant concrete with Anläggningscement FA	EPD	Skanska
Appendix 5	Reinforcing Bar	EPD	Tibnor
Appendix 6	Cut and bent rebar	EPD	Tibnor
Appendix 7	Steel reinforcement products for concrete https://celsa-steelservice.se/epd-klimatavtryck/	EPD	CELSA nordic

Dotter-EPD

Halvors länk

Swerock, Kållered betongfabrik

EPD ID: NEPD-2637-1350-SE

SWEROCK

Sammanfattande resultat

Betongkvalitet	*Densitet*	*CO2 ekv (kg)/m3 betong*
Swefrys 45	2436	315 kg
Swefrys 45	2429	371 kg

Denna EPD-beräkning kan tillsammans som bilaga till EPD med EPDid NEPD-2637-1350-SE användas som en projektspecifik EPD.

SWEROCK

Swefrys 45

Miljöpåverkan

Påverkanskategorier	Enhet	Produktion A1	Produktion A2	Produktion A3	Konstruktion A4	Konstruktion A5	Demontering och återvinning C1	Demontering och återvinning C2	Demontering och återvinning C3	Demontering och återvinning C4	A1-A3
Klimatpåverkan (GWP 100 år)	kg CO_2-ekv.	302,81	8,355	3,643	6,06	-	-	-	-	-	**314,81**
Ozonnedbrytning (ODP)	kg R11-ekv.	1,05E-06	7,91E-07	1,09E-06	1,01E-06	-	-	-	-	-	**2,93E-06**
Försurning (AP)	kg SO_2-ekv.	4,72E-01	1,25E-01	1,39E-02	1,38E-02	-	-	-	-	-	**6,11E-01**
Övergödning (EP)	kg PO_4-ekv.	1,09E-01	1,30E-02	2,36E-03	2,40E-03	-	-	-	-	-	**1,24E-01**
Marknära ozonbildning (POCP)	kg C_2H_4-ekv.	4,22E-02	3,30E-03	6,71E-04	3,41E-04	-	-	-	-	-	**4,62E-02**
Resursutarmning material (ADP)	kg Sb ekv.	5,42E-04	1,40E-07	1,44E-06	-	-	-	-	-	-	**5,43E-04**
Resursutarmning energi (ADP-fossila bränslen)	MJ	1,48E+03	7,21E+01	3,96E+00	9,67E+01	-	-	-	-	-	**1,56E+03**

Resursanvändning

Resurs	Enhet	A1	A2	A3	A4	A5	C1	C2	C3	C4	A1-A3
Förnybar primärenergi använd som energi	MJ, eff. värmevärde	1,76E+02	4,15E-01	4,40E+01	5,56E-01	-	-	-	-	-	**2,20E+02**
Förnybar primärenergi använd produkten	MJ, eff. värmevärde	-	-	-	-	-	-	-	-	-	**0,00E+00**
Total förnybar primärenergi	MJ, eff. värmevärde	1,76E+02	4,15E-01	4,40E+01	5,56E-01	-	-	-	-	-	**2,20E+02**
Icke-förnybar primärenergi använd som energi	MJ, eff. värmevärde	1,74E+03	1,12E+02	1,06E+02	9,67E+01	-	-	-	-	-	**1,96E+03**
Icke-förnybar primärenergi använd i produkten	MJ, eff. värmevärde	1,69E+01	-	-	-	-	-	-	-	-	**1,69E+01**
Total icke-förnybar primärenergi	MJ, eff. värmevärde	1,76E+03	1,12E+02	1,06E+02	9,67E+01	-	-	-	-	-	**1,98E+03**
Sekundära material	kg	6,73E+01	-	-	-	-	-	-	-	-	**6,73E+01**
Sekundära förnybara bränslen	MJ, eff. värmevärde	1,08E+02	-	8,12E-01	-	-	-	-	-	-	**1,08E+02**
Sekundära icke-förnybara bränslen	MJ, eff. värmevärde	2,69E+02	-	2,80E+00	-	-	-	-	-	-	**2,72E+02**
Vatten	m3	2,91E+00	-	1,30E-01	-	-	-	-	-	-	**3,04E+00**

Övrig miljöinformation som beskriver avfallskategorier och utflöden

Avfallskategorier	Enhet	A1	A2	A3	A4	A5	C1	C2	C3	C4	A1-A3
Farligt avfall	kg	2,40E-03	-	6,00E-02	-	-	-	-	-	-	**6,24E-02**
Icke-farligt avfall	kg	1,15E+01	-	2,90E-01	-	-	-	-	-	-	**1,18E+01**
Radioaktivt avfall	kg	6,74E-02	-	-	-	-	-	-	-	-	**6,74E-02**
Komponenter för återanvändning	kg	-	-	-	-	-	-	-	-	-	**0,00E+00**
Material för återvinning	kg	-	-	-	-	-	-	-	-	-	**0,00E+00**
Material för energiåtervinning	kg	-	-	-	-	-	-	-	-	-	**0,00E+00**
Exporterad energi	MJ per energibärare	-	-	-	-	-	-	-	-	-	**0,00E+00**

EPD-verktyg, Svensk Betong, version 3.0

A1-A2

RECEPT FÖR BETONG *(per kubikmeter)*

Nr.	Material	Mängd	Enhet
1	Ballast, kross	930	kg
2	Anläggningscement	349	kg
3	Vatten, kran	156	kg
4	Plasticerare, lösning	3,5	kg
5	Luftporbildare, lösning	7,5	kg
6	GGBS, Ecocem	66	kg
7	Ballast, natur	924	kg
8	Kalkfiller		kg
9			-
10			-
11			-
12			-
	Total	**2436**	

SWEROCK

Appendix 1

Swefrys 45

Miljöpåverkan

Påverkanskategorier	Enhet	Produktion A1	A2	A3	Konstruktion A4	A5	Demontering och återvinning C1	C2	C3	C4	A1-A3
Klimatpåverkan (GWP 100 år)	kg CO2-ekv.	360,12	6,981	3,643	6,04	-	-	-	-	-	**370,74**
Ozonnedbrytning (ODP)	kg R11-ekv.	1,03E-06	6,43E-07	1,09E-06	1,01E-06	-	-	-	-	-	**2,76E-06**
Försurning (AP)	kg SO2-ekv.	5,10E-01	9,36E-02	1,39E-02	1,37E-02	-	-	-	-	-	**6,17E-01**
Övergödning (EP)	kg PO4-ekv.	1,25E-01	1,00E-02	2,36E-03	2,39E-03	-	-	-	-	-	**1,37E-01**
Marknära ozonbildning (POCP)	kg C2H4-ekv.	4,72E-02	2,42E-03	6,71E-04	3,40E-04	-	-	-	-	-	**5,03E-02**
Resursutarmning material (ADP)	kg Sb ekv.	6,57E-04	1,06E-07	1,44E-06	-	-	-	-	-	-	**6,58E-04**
Resursutarmning energi (ADP-fossila bränslen)	MJ	1,69E+03	6,76E+01	3,96E+00	9,65E+01	-	-	-	-	-	**1,76E+03**

Resursanvändning

Resurs	Enhet	A1	A2	A3	A4	A5	C1	C2	C3	C4	A1-A3
Förnybar primärenergi använd som energi	MJ, eff. värmevärde	1,97E+02	3,89E-01	4,40E+01	5,54E-01	-	-	-	-	-	**2,42E+02**
Förnybar primärenergi använd produkten	MJ, eff. värmevärde	-	-	-	-	-	-	-	-	-	**0,00E+00**
Total förnybar primärenergi	MJ, eff. värmevärde	1,97E+02	3,89E-01	4,40E+01	5,54E-01	-	-	-	-	-	**2,42E+02**
Icke-förnybar primärenergi använd som energi	MJ, eff. värmevärde	1,97E+03	9,59E+01	1,06E+02	9,65E+01	-	-	-	-	-	**2,18E+03**
Icke-förnybar primärenergi använd i produkten	MJ, eff. värmevärde	1,74E+01	-	-	-	-	-	-	-	-	**1,74E+01**
Total icke-förnybar primärenergi	MJ, eff. värmevärde	1,99E+03	9,59E+01	1,06E+02	9,65E+01	-	-	-	-	-	**2,19E+03**
Sekundära material	kg	8,93E-01	-	-	-	-	-	-	-	-	**8,93E-01**
Sekundära förnybara bränslen	MJ, eff. värmevärde	1,31E+02	-	8,12E-01	-	-	-	-	-	-	**1,32E+02**
Sekundära icke-förnybara bränslen	MJ, eff. värmevärde	3,27E+02	-	2,80E+00	-	-	-	-	-	-	**3,30E+02**
Vatten	m3	2,86E+00	-	1,30E-01	-	-	-	-	-	-	**2,99E+00**

Övrig miljöinformation som beskriver avfallskategorier och utflöden

Avfallskategorier	Enhet	A1	A2	A3	A4	A5	C1	C2	C3	C4	A1-A3
Farligt avfall	kg	2,91E-03	-	6,00E-02	-	-	-	-	-	-	**6,29E-02**
Icke-farligt avfall	kg	1,39E+01	-	2,90E-01	-	-	-	-	-	-	**1,42E+01**
Radioaktivt avfall	kg	8,04E-02	-	-	-	-	-	-	-	-	**8,04E-02**
Komponenter för återanvändning	kg	-	-	-	-	-	-	-	-	-	**0,00E+00**
Material för återvinning	kg	-	-	-	-	-	-	-	-	-	**0,00E+00**
Material för energiåtervinning	kg	-	-	-	-	-	-	-	-	-	**0,00E+00**
Exporterad energi	MJ per energibärare	-	-	-	-	-	-	-	-	-	**0,00E+00**

EPD-verktyg, Svensk Betong, version 3.0

A1-A2

RECEPT FÖR BETONG *(per kubikmeter)*

Nr.	Material	Mängd	Enhet
1	Ballast, kross	900	kg
2	Anläggningscement	425	kg
3	Vatten, kran	162	kg
4	Plasticerare, lösning	3,6	kg
5	Luftporbildare, lösning	6	kg
6	GGBS, Ecocem		kg
7	Ballast, natur	932	kg
8	Kalkfiller		kg
9			-
10			-
11			-
12			-
	Total	**2428,6**	

SWEROCK

Ver. 1 2015

epd-norge.no
The Norwegian EPD Foundation

ENVIRONMENTAL PRODUCT DECLARATION

in accordance with ISO 14025, ISO 21930 and EN 15804

Ägare av deklarationen:	Betongindustri AB
Program operatör:	Næringslivets Stiftelse for Miljødeklarasjoner
Utgivere:	Næringslivets Stiftelse for Miljødeklarasjoner
Deklarations nummer:	NEPD-1712-695-SE
Publiserings nummer:	NEPD-1712-695-SE
ECO Platform registreringsnummer:	
Godkänd datum:	21.02.2019
Giltig till:	21.02.2024

FrostBI Anläggning FA

Betongindustri AB

Betongindustri
HEIDELBERGCEMENT Group

www.epd-norge.no

Appendix 2

Generell information

Produkt:
FrostBI Anläggning FA

Ägare av deklarationen:
Betongindustri AB
Kontaktperson: Jonas Axeling
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e-post: jonas.axeling@betongindustri.se

Program operatör:
Næringslivets Stiftelse for Miljødeklarasjoner
Postboks 5250 Majorstuen, 0303 Oslo
Tlf: +47 977 22 020
e-post: post@epd-norge.no

Tillverkare:
Betongindustri AB

Deklarationsnummer:
NEPD-1712-695-SE

Produktionsort:
Stockholm, 7 fabriker(se sid 6)

ECO Platform registreringsnummer:

Kvalitet-/Miljöledningssystem:
ISO 14001, ISO 9001

Org. no.:
556188-3892

Deklarationen baseras på PCR:
CEN/EN 15804:2012+A1:2013

NPCR 020 version 2.0
PCR - Part B for Concrete and concrete elements

CEN/EN 16757:2017 Sustainability of construction works
- Environmental product declarations -
Product Category Rules for concrete and concrete elements

Godkänd datum:
21.02.2019

Giltig till:
21.02.2024

Årtal för studien:
2019

Jämförbarhet:
För att jämföra olika betonger krävs att betongen relateras till en specifik funktion i en byggnad och där en funktionell enhet är deklarerad vilket kräver att modulerna A-C är deklarerade. EPDer av byggvaror är inte nödvändigtvis jämförbara om de inte uppfyller EN 15804 och ses i ett byggnadstekniskt sammanhang.

Utlåtande om ansvar:
Ägaren till EPDn ansvarar för miljöbedömningen. Företag som deklarerar sin produkt ansvarar för att tekniska specifikationen följs.

Deklarerad enhet:
1 kubikmeter betong

Miljödeklarationen är utarbetad av:
Deklarationen baseras på Svensk Betongs EPD-verktyg 3.0

Otto During

RI. SE

Verifikation:

Oberoende verifikation av deklarationen och data, i enlighet med ISO 14025:2010

☐ intern ☑ extern

Tredjepartsverifikator:

Martin Erlandsson, IVL Svenska Miljöinstiutet
(Oberoende verifikator godkänd av EPD Norge)

Godkänd

Håkon Hauan
Verkställande direktör EPD-Norge

Produkt

Produktbeskrivning:
FrostBI är processcertifierad fabriksbetong och uppfyller kraven i europeisk standard EN 206, svensk tillämpningsstandard SS 137003 samt AMA Anläggning. FrostBI är mycket tät för att motstå saltinträngning och innehåller luftporbildare för att motstå frysning. Betong är återvinningsbart, vanligtvis som fyllnadsmaterial.

Tekniska data:
Hållfasthetsklass C35/45, vct_{ekv} 0,40. Exponeringsklass XC4, XS3, XD3, XF4. Miljödata och miljöpåverkan av cement,se EPD-HCG-20160235-CAD1-EN

Produktinnehåll:
Innehåll för en kubikmeter betong

Materialer	kg	vikt-%
Anläggning FA	420	17,58
Ballast	1800	75,35
Vatten	164	6,87
Superplasticerare	3	0,13
Luftporbildare	1,5	0,07
Totalt	2388,5	100

Marknadsområde:
Sverige

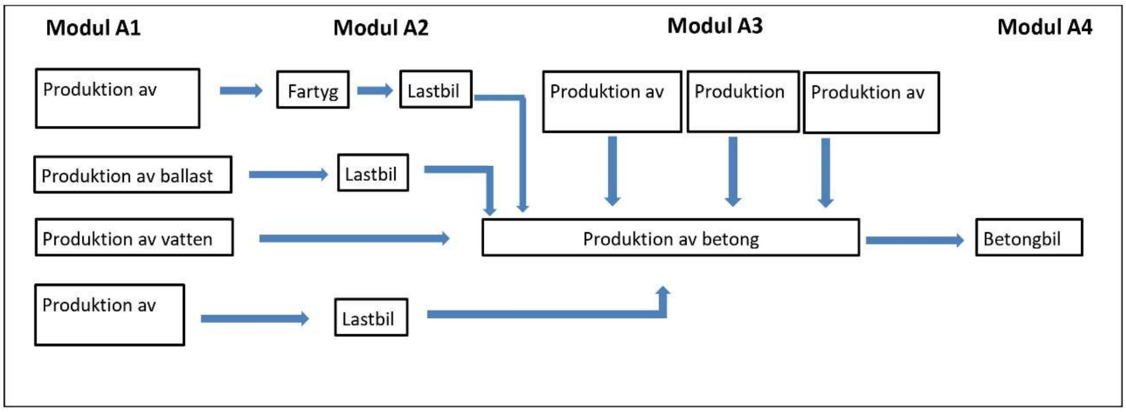
Livslängd:
Betongens livslängd i vägmiljö begränsas främst av vägsalter som orsakar armeringskorrosion. Betongens täckande betongskikt över armeringen ska dimensioneras för att förhindra korrosion. Normal teknisk livslängd (den tid under vilket byggnadsverket uppfyller avsedd funktion med "normalt underhåll") för en bro är minst 120 år. För ökad livslängd kan t.ex. beständigare armering eller impregnering väljas.

LCA: Beräkningsregler

Deklarad enhet:
1 kubikmeter betong

Systemgränser:
A1-A4

Figur 1 Processer medräknade i livscykeln



Datakvalitet:
Specifik data för använt cement "CEM II/A-V 42,5 N - MH/LA/NSR", EPD-HCG-20160235-CAD1-EN. Genomsnittligt europeiskt data för superplasticerare, "Concrete admixtures – Plasticisers and Superplasticisers" EPD från IBU 2015. Transporter inkluderar tom återtransport och är beräknade med NTM calc 3.0, 2014. Transportavstånd till kund och fyllnadsgrad baserar sig på uppmätta data. Fjärrvärme är beräknat från svenskt medelvärde av bränslemix 2015. Energidata är räknad som ett medelvärde från faktiskt förbrukning. Övrig data är från Ecoinvent v3.1 2014.

Cut-off kriterier:
Alla råmaterial och all energi som är identifierad i inventeringen är medtagen i studien. Betongens upptag av koldioxid (karbonatisering) är inte inräknad.

Allokering: Allokeringen på produktionsanläggningen baseras på årliga miljöbelastningar som delats med den totala produktionen oavsett betongkvalitet. LCA-data som används baseras på EPDer som följer EN15804 eller databasdata från ecoinvent v3.1.

LCA: Scenarier och annan teknisk information

Följande information beskriver scenarier i livscykeln

Transport från tillverkningen till byggarbetsplatsen (A4)

Type	Fyllnadsgrad inkl. retur (%)	Körtyp	Distanse km	bränsleförbruknin	värde
Betongbil 6 m^3	80% + 0% retur	frakt-utrullning-retur-tomgång-tvätt	13	liter/tkm	0.059

LCA: Resultat

Systemgränser (X = ingår, MID = ingår inte, MIR = inte relevant)

Produktskedet				Byggprocess-skedet	Användningsskedet							Slutskedet				Utanför system-gränserna
Råvaruförsörjning	Transport	Tillverkning	Transport	Konstruktions- och installationsprocessen	Användningsskedet	Underhåll	Reparation	Utbyte	Renovering	Driftsenergi	Driftens vattenanvändning	Demontering	Transport	Avfallsbehandling	Avfallshantering	Potential för återanvändning och/eller återvinning utryckt som nettopåverkan och miljönytta
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID	MID

Miljöpåverkan

Parameter	enhet	A1	A2	A3	A4	A1-A3			
GWP	kg CO_2 -ekv	296	5,21	2,26	4,58	303			
ODP	kg CFC11-ekv	3,92E-06	4,7E-07	8,35E-07	7,68E-07	5,24E-06			
POCP	kg C_2H_4 -ekv	4,87E-02	1,5E-03	4,17E-04	2,58E-04	5,07E-02			
AP	kg SO_2 -ekv	3,38E-01	6,2E-02	6,78E-03	1,04E-02	4,07E-01			
EP	kg PO_4^{3-}-ekv	1,49E-01	6,8E-03	1,68E-03	1,81E-03	1,58E-01			
ADPM	kg Sb-ekv	2,67E-05	7,0E-08	1,50E-06	0	2,83E-05			
ADPE	MJ	1,18E+03	5,6E+01	5,43E+01	7,24E+01	1,29E+03			

GWP Global warming potential; ODP Depletion potential of the stratospheric ozone layer; POCP Formation potential of tropospheric photochemical oxidants; AP Acidification potential of land and water; EP Eutrophication potential; ADPM Abiotic depletion potential for non fossil resources; ADPE Abiotic depletion potential for fossil resources

Ressursanvändning

Parameter	enhet	A1	A2	A3	A4	A1-A3			
RPEE	MJ	195	0,32	28,9	0,420	224			
RPEM	MJ	0	0	0	0	0			
TPE	MJ	195	0,32	28,9	0,42	224			
NRPE	MJ	1376	73,5	80,8	73,2	1532			
NRPM	MJ	79,8	0	0	0	79,8			
TRPE	MJ	1455	73,5	80,8	73,19	1612			
SM	kg	68,0	0	0	0	68,0			
RSF	MJ	247	0	0,420	0	248			
NRSF	MJ	357	0	1,45	0	358			
W	m^3	2,62	0	0	0	2,62			

RPEE Renewable primary energy resources used as energy carrier; RPEM Renewable primary energy resources used as raw materials; TPE Total use of renewable primary energy resources; NRPE Non renewable primary energy resources used as energy carrier; NRPM Non renewable primary energy resources used as materials; TRPE Total use of non renewable primary energy resources; SM Use of secondary materials; RSF Use of renewable secondary fuels; NRSF Use of non renewable secondary fuels; W Use of net fresh water

Appendix 2

Avfall									
Parameter	**enhet**	**A1**	**A2**	**A3**	**A4**	**A1-A3**			
HW	kg	1,92E-05	0	0	0	1,92E-05			
NHW	kg	1,06E-01	0	0	0	1,06E-01			
RW	kg	3,25E-03	0	0	0	3,25E-03			

HW Hazardous waste disposed; NHW Non hazardous waste disposed; RW Radioactive waste disposed

Utflöde									
Parameter	**enhet**	**A1**	**A2**	**A3**	**A4**	**A1-A3**			
CR	kg	0	0	0	0	0			
MR	kg	0	0	0	0	0			
MER	kg	0	0	0	0	0			
EEE	MJ	0	0	0	0	0			
ETE	MJ	0	0	0	0	0			

CR Components for reuse; MR Materials for recycling; MER Materials for energy recovery; EEE Exported electric energy; ETE Exported thermal energy

Läsexsempel: 9,0 E-03 = $9{,}0 \cdot 10^{-3}$ = 0,009

Norska tilläggskrav

Klimatpåverkan från användning av elektricitet i tillverkningsskedet (A3)
Svensk medelvärde av använd el (medelspänning) med import och export inräknad samt nätförluster.

Datakälla	Mängd	Enhet
Econinvent v3 (june 2014)	55,7	g CO_2-ekv/kWh

Farliga ämnen

- ☑ Produkten innehåller inga ämnen från REACH Kandidatlista eller den norska prioritetslistan
- ☐ Produkten innehåller ämnen som är under 0,1 vikt-% på REACH Kandidatlista
- ☐ Produktet innehåller ämnen från REACH Kandidatlista eller den norska prioritetslistan, se tabell nedan.
- ☐ Produktet innehåller inga ämnen på REACH Kandidatlista eller den norska prioritetslistan. Produkten kan karakteriseras som farlig avfall (enligt norska "Avfallsforskiften, Vedlegg III"), se tabell nedan.

Transport A4
Transport från tillverkningen till centrallager i Norge: Ej aktuell

Bibliografi

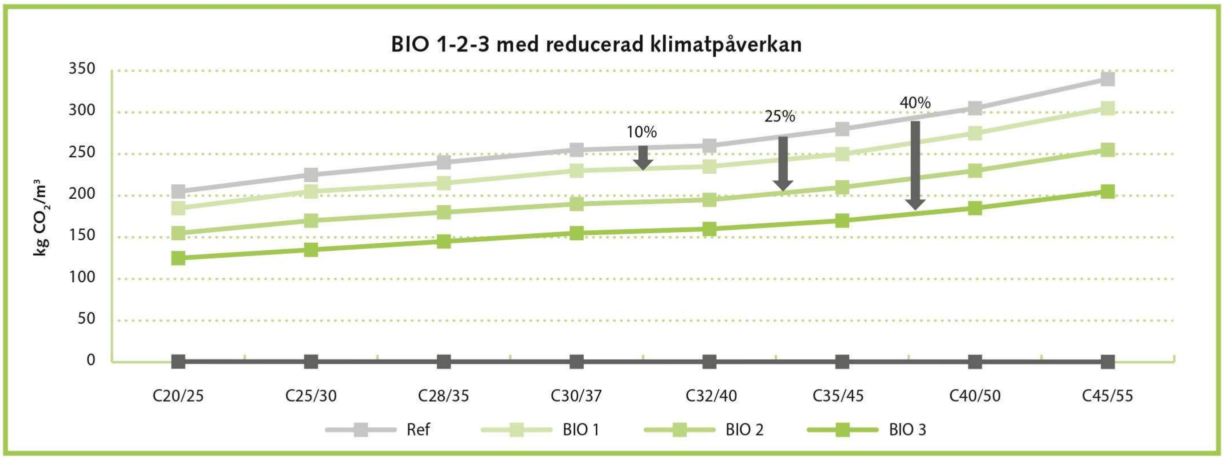
ISO 14025:2010	*Environmental labels and declarations - Type III environmental declarations - Principles and procedures*
ISO 14044:2006	*Environmental management - Life cycle assessment - Requirements and guidelines*
EN 15804:2012+A1:2013	*Sustainability of construction works - Environmental product declaration - Core rules for the product category of construction products*
ISO 21930:2017	*Sustainability in building construction - Environmental declaration of building products*
NPCR 020 version 2.0:2018	*PCR - Part B for Concrete and concrete elements, EPD-Norge, 2018*
EN 16757:2017	*Sustainability of construction works - Environmental product declarations - Product Category Rules for concrete and concrete elements*
LCI-rapport Betongindustri, 2018	*Inventering av livscykel för FrostBI C35/45 Anläggning och Anläggning FA, Betongindustri AB, 2018*
Studerade fabriker	Uppsala, Sollentuna, Täby, Värtan, Ulvsunda, Hammarby, Tumba

epd-norge.no The Norwegian EPD Foundation	**Programoperatör och utgivare** Næringslivets Stiftelse for Miljødeklarasjoner Postboks 5250 Majorstuen, 0303 Oslo Norge	+47 977 22 020 post@epd-norge.no www.epd-norge.no
Betongindustri HEIDELBERGCEMENTGroup	**Deklarationsägare** Betongindustri AB Årstaängsvägen 21 C Box 47312, 100 74 STOCKHOLM	08-625 62 00 info@betongindustri.se www.betongindustri.se
Betongindustri HEIDELBERGCEMENTGroup	**Författare till livscykelanalysrapporten** Jonas Axeling	08-625 6228 jonas.axeling@betongindustri.se www.betongindustri.se

Betongindustri
HEIDELBERGCEMENT Group

BIO – klimatförbättrad betong

Inom vårt koncept för klimatoptimerat betongbyggande, BI Optimal, ingår en optimeringstjänst i form av rådgivning inför en beställning och ett sortiment av väldefinierade klimatförbättrade betongprodukter. Produkterna erbjuds i tre nivåer av koldioxidreduktion, BIO 1, 2 eller 3. Reduktionsnivån är 10, 25 respektive 40 % jämfört med referensvärden definierade i Svensk Betongs broschyr "Klimatförbättrad betong".



Kundnytta

Den främsta fördelen med att välja klimatförbättrade BIO-produkter är att de har lägre klimatpåverkan jämfört med motsvarande standardprodukter. Att BIO-produkterna har dokumenterade koldioxidvärden är också en klar fördel eftersom det därmed blir enkelt att beräkna hur stor klimatpåverkan olika betongalternativ ger upphov till. Ytterligare en fördel är att BIO-klassad betong erbjuds inom hela sortimentet av standardbetong. Detta innebär att det inte krävs någon anpassning av specifikationen när man väljer BIO-klassad betong.

Egenskaper

Sammansättningen hos våra BIO-produkter har optimerats för begränsad klimatpåverkan genom att en del av cementet har ersatts av alternativa bindemedel. Detta medför att egenskaperna kan skilja sig något i jämförelse med motsvarande standardprodukt. I färskt tillstånd har BIO-klassad betong normalt bättre arbetbarhet medan tillstyvnandet blir något fördröjt. Hållfasthetsutvecklingen kan vara något långsammare, vilket man bör vara särskilt observant på vid vintergjutningar. Ur ett beständighetsperspektiv är BIO-klassad betong i flera avseende väsentligt bättre än motsvarande referensbetong. Framför allt är produkterna tätare vilket ger ett förbättrat motstånd mot kloridinträngning och kemiska angrepp. Det är även värt att framhålla den lägre värmeutvecklingen som kan vara en fördel vid gjutning av grövre konstruktioner. När det gäller uttorkningsegenskaper är BIO-produkterna likvärdiga eller bättre än motsvarande standardbetong.

Appendix 3

Betongindustri
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Användningsområden

Klimatförbättrad betong typ BIO 1 kan tillämpas på samma sätt som motsvarande standardprodukter. Möjligheten att tillämpa BIO 2 och 3 begränsas i viss mån av regelverken. Huvudsakligt tillämpningsområde för dessa produkter är därför i första hand olika typer av husapplikationer men det finns även andra möjligheter.

Produktbeskrivning

Klimatförbättrad betong typ BIO 1-2-3 tillverkas med Bascement (CEM II/A-V 52,5 N) eller Byggcement (CEM II/A-LL 42,5 R). I de flesta av BIO-produkterna har vi ersatt en del av cementet med granulerad masugnsslagg. Maximal stenstorlek är 8, 16 eller 27 mm och konsistensklass S3-S5 eller SF1-SF2 (SKB). Tillgängliga BIO-klassade produkter framgår i tabell. Här redovisas även koldioxidbelastning för de olika produkterna beräknad med Svensk Betongs EPD-verktyg för produktionsskedet A1-A3.

Hantering

BIO-klassad betong gjuts och hanteras på samma sätt som vanlig betong. Produkterna inom klass BIO 2 och 3 är som regel något mindre blödningsbenägna, vilket ger ett ökat behov av att skydda betongen mot tidig uttorkning för att undvika plastiska krympsprickor. Även behovet av vinteråtgärder ökar till följd av långsammare tillstyvnande och hållfasthetsutveckling.

Tips

Kontakta oss gärna i god tid så att vi kan hjälpa dig att välja den BIO-klassade betong som passar bäst för just din applikation. Du kan även läsa mer om vårt koncept BI Optimal på www.betongindustri.se.

			Referens betong		BIO-1		BIO-2		BIO-3	
Hållfasthets-klass	Luft	vct_{ekv}	C02e/m³*	Exponerings-klass	C02e/m³*	Exponerings-klass**	C02e/m³*	Exponerings-klass**	C02e/ m³*	Exponerings-klass**
C20/25	-	-	205	XC1	185	XC1	155	XC1	125	XC1
C25/30	-	-	225	XC1	205	XC1	170	XC1	135	XC1
C28/35	-	0,6	240	XC2, XF1	215	XC2, XF1	180	XC2	145	XC1
C28/35	LU	0,55	270	XC4, XF3	240	XC4, XF3	-	-	-	-
C30/37	-	0,55	255	XC4, XF1	230	XC4, XF1	190	XC2	155	XC1
C30/37	LU	0,5	280	XC4, XF3	255	XC4, XF3	-	-	-	-
C32/40	-	0,55	260	XC4, XF1	235	XC4, XF1	195	XC2	160	XC1
C32/40	LU	0,45	300	XC4, XD2, XS2, XF2	270	XC4, XD2, XS2, XF2	-	-	-	-
C35/45	-	0,5	280	XC4, XF1	250	XC4, XF1	210	XC2	170	XC2
C35/45	LU	0,4	315	XC4, XD3, XS3, XF2	275	XC4, XD3, XS3, XF2	-	-	-	-
C40/50	-	0,45	305	XC4, XD2, XS3, XF1	275	XC4, XD2, XS3, XF1	230	XC2, XD2, XS2	185	XC2
C45/55	-	0,4	340	XC4, XD2, XS3, XF1	305	XC4, XD2, XS3, XF1	255	XC2, XD2, XS2	205	XC2

*Klimatbelastning A1-A3 [C02 ekvivalenter/m³ betong], beräknad med dmax 16 i konsistensklass S4.
**Begränsningar i gällande regelverk. Kontakta Teknisk Sälj för mer information.

Appendix 4

Ver. 1 2016

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The Norwegian EPD Foundation

ENVIRONMENTAL PRODUCT DECLARATION

in accordance with ISO 14025, ISO 21930 and EN 15804

Ägare av deklarationen:	Skanska Industrial Solutions AB
Program operatör:	Næringslivets Stiftelse for Miljødeklarasjoner
Utgivare:	Næringslivets Stiftelse for Miljødeklarasjoner
Deklarations nummer:	NEPD-1328-427-SE
Publiserings nummer:	NEPD-1328-427-SE
ECO Platform registreringsnummer:	-
Godkänd datum:	14.06.2017
Giltig till:	14.06.2022

Frostbeständig betong med Anläggning FA

Skanska Industrial Solutions AB

SKANSKA

www.epd-norge.no

SKANSKA

Generell information

Produkt:
Frostbeständig betong med Anläggning FA

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Tillverkare:
Skanska Industrial Solutions AB

Deklarationsnummer:
NEPD-1328-427-SE

Produktionsort:
Solna

ECO Platform registreringsnummer:
-

Kvalitet-/Miljöledningssystem:
ISO 14001, ISO 9001

Deklarationen baseras på PCR:
CEN Standard EN 15804 utgör kärn-PCR

Org. no.:
556793-1638

Utlåtande om ansvar:
Ägaren av deklarationen är ansvarig för den bakomliggande informationen poch bevis. EPD Norge är inte ansvarig för information om tillverkaren eller bakomliggande data för livscykelanalys eller bevis.

Godkänd datum:
14.06.2017

Giltig till:
14.06.2022

Deklarerad enhet:
1 kubikmeter betong

Årtal för studien:
2017

Deklarerad enhet med tillval:

Jämförbarhet:
För att jämföra olika betonger krävs att betongen relateras till en specifik funktion i en byggnad och där en funktionell enhet är deklarerad vilket kräver att modulerna A-C är deklarerade. EPDer av byggvaror är inte nödvändigtvis jämförbara om de inte uppfyller EN 15804 och ses i ett byggnadstekniskt sammanhang.

Funktionell enhet:

Miljödeklarationen är utarbetad av:
Deklarationen baseras på Svensk Betongs EPD-verktyg 2.8

Tillverkningsdata har inventertas av:
Mikael Hederby, Skanska

LCA-beräkningar har kontrollerats av:
Otto During, CBI

Verifikation:

Oberoende verifikation av deklarationen och data, i enlighet med ISO 14025:2010

☐ intern ☑ extern

Tredjepartsverifikator:

Martin Erlandsson, IVL Svenska Miljöinstitutet
(Oberoende verifikator godkänd av EPD Norge)

Godkänd

Håkon Hauan
(Verkställande direktör EPD-Norge)

SKANSKA

Produkt

Produktbeskrivning:

Betong för användning i anläggningsbyggande är processcertifierad fabriksbetong och uppfyller kraven i europeisk standard EN 206, svensk tillämpningsstandard SS 137003 samt AMA Anläggning. Betong för anläggning är mycket tät för att motstå saltinträngning och innehåller luftporbildare för att motstå frysning. Betong är återvinningsbart, vanligtvis som fyllnadsmaterial.

Produktinnehåll:

Innehåll för en kubikmeter betong

Ingående material:	kg	vikt-%
Anläggningscement FA	430	17.9
Ballast	1790	74.4
Vatten	180	7.5
Superplasticerare	3	0.12
Luftporbildare	1.7	0.07
Summa	**2405**	**100**

Tekniska data:

Hållfasthetsklass C35/45, vct_{ekv} 0,40. Exponeringsklasser är XC4, XS3, XD3, XF4. För information om miljödata och miljöpåverkan av cementet, se EPD-HCG-20160235-CAD1-EN.

Marknadsområde:

Sverige

Livslängd:

Betongens livslängd i vägmiljö begränsas främst av vägsalter som orsakar armeringskorrosion. Betongens täckande betongskikt över armeringen ska dimensioneras för att förhindra korrosion. Normal teknisk livslängd (den tid under vilket byggnadsverket uppfyller avsedd funktion med "normalt underhåll") för en bro är minst 120 år. För ökad livslängd kan t.ex. beständigare armering eller impregnering väljas.

LCA: Beräkningsregler

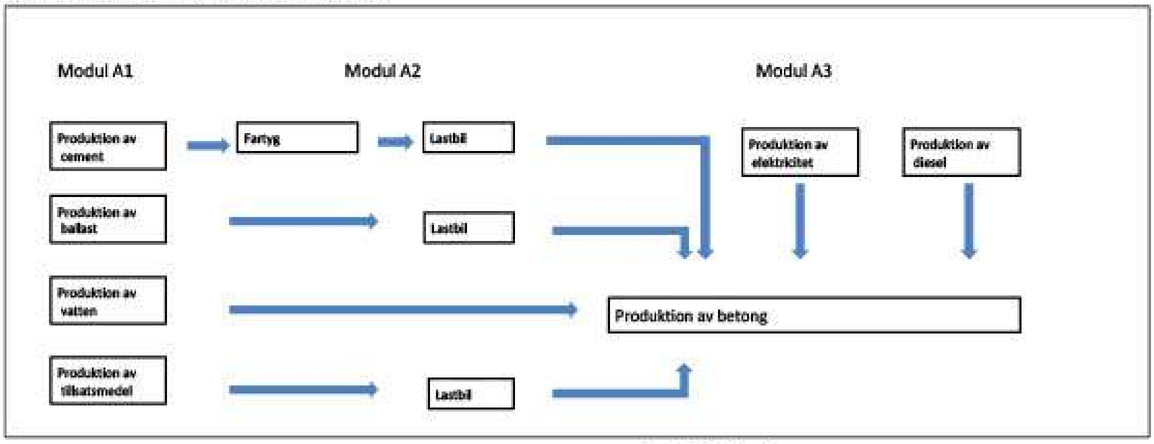
Deklarad enhet:

1 kubikmeter betong

Systemgränser:

A1-A3

Figur 1 Processer medräknade i livscykeln



Datakvalitet:

Specifik data för använt cement "CEM II/A-V 42,5 N – MH/LA/NSR", EPD-HCG-20160235-CAD1-EN. Genomsnittligt europeiskt data för superplasticerare, "Concrete admixtures – Plasticisers and Superplasticisers" EPD från IBU 2015. Transporter inkluderar tom återtransport och är beräknade med NTM calc 3.0, 2014. Data för el är från faktiskt förbrukning, räknad som medelvärde av använd el i Sverige. Övrig data är från Ecoinvent v3.1 2014.

Allokering:

Allokeringen på produktionsanläggningen baseras på årliga miljöbelastningar som delats med den totala produktionen oavsett betongkvalitet. LCA-data som används baseras på EPDer som följer EN15804 eller databasdata från Ecoinvent v3.1.

Cut-off kriterier:

Alla råmaterial och all energi som är identifierad i inventeringen är medtagen i studien.

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LCA: Resultat

Systemgränser (X = ingår, MID = ingår inte, MIR = inte relevant)

Produktskedet			Byggprocess-skedet		Användningsskedet							Slutskedet				Utanför system-gränserna
Råvaruförsörjning	Transport	Tillverkning	Transport	Konstruktions- och installations-processen	Användningsskedet	Underhåll	Reparation	Utbyte	Renovering	Driftsenergi	Driftens vattenanvändning	Demontering	Transport	Avfallsbehandling	Avfallshantering	Potential för återanvändning och/eller återvinning uttryckt som nettopåverkan och miljönytta
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MID	MID	MID	MID	MID	MID	MID	MIR	MIR	MID	MID	MID	MID	MID

Miljöpåverkan

Parameter	enhet/m³	A1	A2	A3	A1- A3				
GWP	kg CO_2-ekv	303.1	5.53	2.91	311.6				
ODP	kg CFC11-ekv	3.9E-06	5.2E-07	9.1E-07	5.29E-06				
POCP	kg C_2H_4-ekv	5.0E-02	2.0E-03	4.1E-04	5.21E-02				
AP	kg SO_2-ekv	3.45E-01	7.67E-02	7.51E-03	4.29E-01				
EP	kg PO_4^{3-}-ekv	1.49E-01	8.12E-03	1.64E-03	1.59E-01				
ADPM	kg Sb-ekv	2.67E-05	8.64E-08	9.08E-07	2.77E-05				
ADPE	MJ	1.21E+03	5.22E+01	5.52E+01	1.32E+03				

GWP Global warming potential; ODP Depletion potential of the stratospheric ozone layer; POCP Formation potential of tropospheric photochemical oxidants; AP Acidification potential of land and water; EP Eutrophication potential; ADPM Abiotic depletion potential for non fossil resources; ADPE Abiotic depletion potential for fossil resources

Resursanvändning

Parameter	enhet/m³	A1	A2	A3	A1-A3				
RPEE	MJ	192.2	0.30	28.7	221.1				
RPEM	MJ	0	0	0	0				
TPE	MJ	192.2	0.30	28.7	221.1				
NRPE	MJ	1393	75.7	90.5	1560				
NRPM	MJ	80.1	0	0	80.1				
TRPE	MJ	1469	75.7	90.5	1640				
SM	kg	69.9	0	0	69.9				
NRSF	MJ	254.1	0	0	254.1				
RSF	MJ	366.3	0	0	366.3				
W	m³	2.76	0	0.09	2.85				

RPEE Renewable primary energy resources used as energy carrier; RPEM Renewable primary energy resources used as raw materials; TPE Total use of renewable primary energy resources; NRPE Non renewable primary energy resources used as energy carrier; NRPM Non renewable primary energy resources used as materials; TRPE Total use of non renewable primary energy resources; SM Use of secondary materials; RSF Use of renewable secondary fuels; NRSF Use of non renewable secondary fuels; W Use of net fresh water.

Avfall

HW	kg/m³	1.98E-05	0	4.00E-02	4.00E-02				
NHW	kg	0.110	0	32.4	32.5				
RW	kg	3.34E-03	0	0	3.34E-03				

HW Hazardous waste disposed; NHW Non hazardous waste disposed; RW Radioactive waste disposed

Utflöde

Parameter	enhet/m³	A1	A2	A3	A1- A3				
CR	kg	0	0	0	0				
MR	kg	0	0	7.93	7.93				
MER	kg	0	0	0.15	0.15				
EEE	MJ	0	0	0	0				
ETE	MJ	0	0	0	0				

CR Components for reuse; MR Materials for recycling; MER Materials for energy recovery; EEE Exported electric energy; ETE Exported thermal energy

Exempel: 9,0 E-03 = 9,0*10-3 = 0,009

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Norska tilläggskrav

Klimatpåverkan från användning av elektricitet i tillverkningsskedet (A3)
Nationell produktionsmix från import, lågspänning (produktion av överföringslinjer, som tillägg till direkta emissionsförluster i nätet) av använd el för produktionsprocessen (A3).

Datakälla	Mängd	Enhet
Econinvent v3 (june 2014)	55.7	CO_2-ekv/kWh

Farliga ämnen

	Produkten innehåller inga ämnen från REACH Kandidatlista eller den norska prioritetslistan
X	Produkten innehåller ämnen som är under 0,1 vikt-% på REACH Kandidatlista
	Produkten innehåller ämnen från REACH Kandidatlista eller den norska prioritetslistan, se tabell nedan.
	Produktet innehåller inga ämnen på REACH Kandidatlista eller den norska prioritetslistan. Produkten kan karakteriseras som farlig avfall (enligt norska "Avfallsforskiften, Vedlegg III"), se tabell nedan.

Inomhusklimat
Produkten avses användas i en anläggningskonstruktion. Betong har normalt ingen effekt på innemiljön.

Klimatdeklaration
Klimatdeklaration är inte utarbetad för produkten.

Bibliografi

ISO 14025:2010	*Environmental labels and declarations - Type III environmental declarations - Principles and procedures*
ISO 14044:2006	*Environmental management - Life cycle assessment - Requirements and guidelines*
EN 15804:2012+A1:2013	*Sustainability of construction works - Environmental product declaration - Core rules for the product category of construction products*
ISO 21930:2007	*Sustainability in building construction - Environmental declaration of building products*
Rapport 6:2016	*Underlag för ett LCA-verktyg och 6 beräknade EPDer för betong, Otto During, CBI Betonginstitutet, rapport 6:2016, reviderad 1 mars 2017*
Inventeringsrapport	*Inventering av livscykel för frostbeständig betong med anläggningscement FA, Karolinn Jägemar, Mikael Hederby, Skanska Asfalt och Betong, 2017-05-15*

epd-norge.no The Norwegian EPD Foundation	**Programoperatör och utgivare** Næringslivets Stiftelse for Miljødeklarasjoner Postboks 5250 Majorstuen, 0303 Oslo Norge	Tel.: e-post: web	+47 23 08 82 92 post@epd-norge.no www.epd-norge.no
SKANSKA	**Ägare av deklarationen** Skanska Industrial Solutions AB Warfvinges väg 25, 112 74 Stockholm Sverige	Tel: Fax e-post: web	+46 10 44 84 891 — karolinn.jägemar@skanska.se www.skanska.se
	Författare till livscykelanalysrapporten Otto During	Tel.: e-post: web	+46-10-5166874 otto.during@cbi.se www.cbi.se

Environmental Product Declaration

In accordance with ISO 14025 and EN 15804 for:

Reinforcing Bar

from

Tibnor AB

Programme:	The International EPD® System, www.environdec.com
Programme operator:	EPD International AB
EPD registration number:	S-P-02040
ECO EPD Ref. No.:	00001190
Publication date:	2020-11-23
Valid until:	2025-11-20

TIBNOR EPD®

Company information

Owner of the EPD:
Tibnor AB, Box 600, 169 26 Solna, Sverige, +46 10 484 00 00, info@tibnor.se, www.tibnor.se

Description of the organisation:
Tibnor supplies steel and other metals to industry in the Nordics and Baltics. We are the meeting point where our know-how and expertise and that of our customers & suppliers converge to create smarter solutions. Together, we make industry in the Nordics even stronger. A subsidiary of SSAB, Tibnor has 1,100 employees across 7 countries. In 2017, we had sales of SEK 8 billion. For more information: www.tibnor.se
In Köping Tibnor AB has its main warehouse for the majority of our products, including reinforcing bar.

Product-related or management system-related certifications:
Tibnor AB: ISO 9000, ISO 14001
Tibnor AB, Köping: SBS G/004

Name and location of production site:
Tibnor AB, Köping

Product information

Product name:
Reinforcing Bar

Product identification:
Further processed concrete reinforcing based upon steel conforming to SS-EN 10080:2005 and SS 212540:2014

Product description:
Concrete reinforcing bar based upon steel conforming to SS-EN 10080:2005 and SS 212540:2014.

UN CPC code:
4126

Geographical scope:
Europe

LCA information

Declared unit:
1 kg steel reinforcing bars with packaging

System boundary:
Cradle to gate (with options)

Reference service life:
not applicable

Time representativeness:
2019

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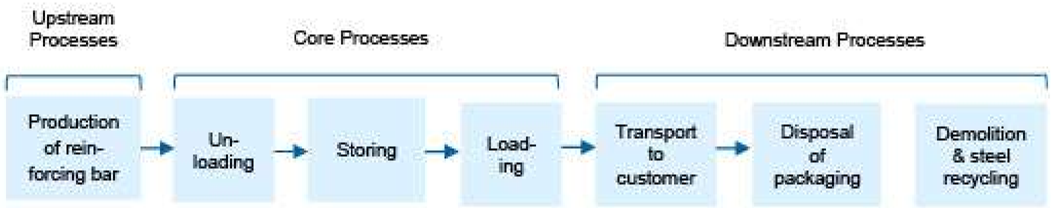
Database(s) and LCA software used:
The manufacturing process was modelled based on manufacturer-specific data. For the upstream processes of steel, supplier-specific information in the form of EPDs was used where available. Otherwise, generic background datasets were used for the upstream and downstream processes.

For the LCA modelling the software GaBi, version 9.2, Service Pack 40, distributed by thinkstep was used. The background datasets used were taken from the current versions of various GaBi databases. The datasets contained in the databases are documented online. All necessary processes within the defined system boundaries were considered.

The background datasets used for accounting purposes should not be older than 10 years. In this study, no datasets older than 10 years were used.

System diagram:



Description of system boundaries:

X = declared modules; MND = module not declared:

Production			Installation		Utilization Stage							Disposal Stage				beyond system boundary
raw material supply	transport to the manufacturer	manufacture	transport to the construction site	installation in the building	use / application	maintenance	repair	replacement	renewal	energy input for operation	water use for operation	dismantling / demolition	transport	waste management	landfilling	reuse, recovery or recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	X	MND	MND	MND	MND	MND	MND	MND	X	X	X	X	X

Cut-off criteria:
No

Estimates and assumptions:
- The collection rate for waste is 95 %

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Allocation:
No allocations were made for the modelling of production processes, as the available data do not concern other products manufactured in the plant and there are no coupling processes. Nor were any multi-input processes carried out.
Allocations in the LCA datasets used are documented accordingly in the datasets themselves.
Potential credits and avoided burdens resulting from the scrap recycling in the end of life (Module C3) are assigned to module D.

LCA scenarios and additional technical information

Transport from production place to user (module A4)
The average transport distance to the customer is 464 km by truck. Transport is mainly carried out by diesel-powered trucks, EURO 4 with an average load factor of 61 %.

Type	Capacity utilization	Type of vehicle	Average distance
Truck	61 %	EURO 4	464 km

Dismantling/demolition (module C1)
60 % of the reinforced concrete is demolished with cable excavator and wrecking ball (diesel consumption of excavator: 60.8 litres/hour; capacity approx. 15 m³/h) and 40 % is dismantled with hydraulic excavator and tongs (diesel consumption of excavator: 36.1 litres/hour; capacity approx. 20 m³/h). The ratio of reinforcing steel to concrete content is 4.8 %, corresponding to 120 kg reinforcing steel per m³ reinforced concrete (Source: German Environment Agency). Calculated diesel consumption for the demolition of 1 kg reinforcement steel is 0.0013 litres.

Type	Share	Reinforced concrete/hour	Diesel/ hour	Steel in reinforced concrete
Cable excavator and wrecking ball	60 %	15 m³	60.8 l	4.8 % = 120 kg
Hydraulic excavator and tongs	40 %	20 m³	36.1 l	4.8 % = 120 kg

Transport (module C2)
With a collection rate of 100 %, the transports are carried out by truck over 75 km and with a capacity utilization of 50 %.
Since the product is poured into concrete, it is collected as mixed construction waste.

Type	Capacity utilization	Type of vehicle	Average distance
Truck	50 %	EURO 4	75 km

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Waste processing (modules C3 and C4)

Steel rebars must be mechanically separated from the concrete surrounding them prior to recycling so that the steel can be made available to a downstream product system as secondary material. This is considered in module C3. Corresponding potentials and avoided loads are assigned to module D. The landfilling of remaining 5 % which are not collected for recycling is considered in module C4.

Waste	kg for re-use	kg for recycling	kg for energy recovery	kg to landfill
Steel scrap	-	0.95	-	0.05

Content declaration

Product

Materials	Share
Steel	100 %

Substances of very high concern

The product does not contain any substances listed in the "Candidate List of Substances of Very High Concern (SVHC) for authorisation" exceeding 0.1 % of the weight of the product.

Packaging

Reinforcing bars are fixed with slings.

Recycled material

Provenience of recycled materials in the product:

98 %

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Environmental performance

Potential environmental impact

Parameter	Unit	A1 -A3	A4	A5	C1	C2	C3	C4	D
Global Warming Potential (GWP)	kg CO2-eq.	5.53E-01	3.05E-02	7.07E-04	3.67E-02	6.90E-03	2.40E-03	6.82E-04	-3.08E-02
Stratospheric ozone depletion potential (ODP)	kg CFC11-eq.	4.44E-08	7.67E-18	2.75E-19	6.04E-18	1.73E-18	7.98E-18	3.75E-18	9.27E-17
Acidification potential of soil and water (AP)	kg SO2-eq.	3.03E-03	1.29E-04	1.72E-07	1.32E-04	2.96E-05	1.68E-05	4.37E-06	-5.94E-05
Eutrophication potential (EP)	kg PO43--eq.	6.53E-04	3.24E-05	1.51E-08	3.14E-05	7.40E-06	4.05E-06	4.92E-07	-4.14E-06
Formation potential for tropospheric ozone (POCP)	kg Ethene-eq.	1.73E-04	-4.82E-05	3.04E-09	1.31E-05	-1.10E-05	1.86E-06	3.29E-07	-1.43E-05
Potential for abiotic depletion of non-fossil resources (ADPE)	kg Sb-eq.	-2.92E-05	2.84E-09	4.85E-11	3.06E-09	6.41E-10	2.73E-09	2.63E-10	-5.17E-07
Potential for abiotic depletion of fossil fuels (ADPF)	MJ	8.43E+00	4.18E-01	2.73E-04	5.01E-01	9.44E-02	4.67E-02	9.67E-03	-2.90E-01

Use of resources

Parameter	Unit	A1 -A3	A4	A5	C1	C2	C3	C4	D
Renewable primary energy as an energy carrier (PERE)	MJ	1.37E+00	2.42E-02	5.74E-05	2.82E-02	5.46E-03	3.48E-03	1.30E-03	1.99E-02
Renewable primary energy for material use (PERM)	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total renewable primary energy (PERT)	MJ	1.37E+00	2.42E-02	5.74E-05	2.82E-02	5.46E-03	3.48E-03	1.30E-03	1.99E-02
Non-renewable primary energy as an energy carrier (PENRE)	MJ	8.49E+00	4.20E-01	6.69E-03	5.03E-01	9.49E-02	4.83E-02	9.96E-03	-2.81E-01
Non-renewable primary energy for material use (PENRM)	MJ	6.39E-03	0.00E+00	-6.39E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total non-renewable primary energy (PENRT)	MJ	8.49E+00	4.20E-01	3.01E-04	5.03E-01	9.49E-02	4.83E-02	9.96E-03	-2.81E-01
Use of secondary materials (SM)	kg	1.13E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Renewable secondary fuels (RSF)	MJ	2.06E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Non-renewable secondary fuels (NRSF)	MJ	9.20E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of freshwater resources (FW)	m³	5.98E-03	2.82E-05	1.75E-06	3.27E-05	6.37E-06	1.36E-05	2.51E-06	-5.93E-05

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Waste production and output flows

Parameter	Unit	A1 -A3	A4	A5	C1	C2	C3	C4	D
Hazardous waste to landfill (HWD)	kg	6.54E-03	1.94E-08	2.16E-12	2.34E-08	4.39E-09	1.26E-09	1.52E-10	-3.54E-08
Non-hazardous waste disposed (NHWD)	kg	4.78E-02	6.65E-05	6.82E-05	7.69E-05	1.50E-05	1.30E-05	5.00E-02	3.29E-03
Disposed radioactive waste (RWD)	kg	2.36E-05	7.74E-07	1.13E-08	6.22E-07	1.75E-07	6.37E-07	1.13E-07	-6.69E-07
Components for Reuse (CRU)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for recycling (MFR)	kg	2.20E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.50E-01	0.00E+00	0.00E+00
Substances for energy recovery (MER)	kg	1.49E-04	0.00E+00	2.83E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Energy [Electricity]	MJ	2.09E-04	0.00E+00	1.57E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Energy [Thermal Energy]	MJ	3.92E-04	0.00E+00	2.82E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TIBNOR EPD®

General information

Programme:	The International EPD® System EPD International AB Box 210 60 SE-100 31 Stockholm Sweden www.environdec.com Info@environdec.com
Product category rules (PCR):	PCR 2012:01 Construction products and construction services, Version 2.3
PCR review was conducted by:	The Technical Committee of the International EPD® System. Chair: Massimo Marino. Contact via info@environdec.com
Independent verification of the declaration and data, according to ISO 14025:	☐ EPD process certification ☑ EPD verification
Third party verifier:	Andreas Ciroth, GreenDelta GmbH
Accredited and approved by:	The International EPD System
TIBNOR	Owner of the declaration Tibnor AB Silverdalsvägen 4 635 10 Eskilstuna Sweden https://www.tibnor.se
brands & values® sustainability consultants	Commissioner of the Life Cycle Assessment brands & values GmbH Altenwall 14 28195 Bremen Germany www.brandsandvalues.com info@brandsandvalues.com +49 421 70 90 84 33

The EPD owner has the sole ownership, liability, and responsibility for the EPD. EPDs within the same product category but from different programmes may not be comparable. EPDs of construction products may not be comparable if they do not comply with EN 15804.

TIBNOR EPD®

References

The International EPD System	General Programme Instructions of the International EPD® System. Version 3.01.
The International EPD System	PCR 2012:01 Construction products and construction services, Version 2.3
DIN EN ISO 14025	Environmental labels and declarations — Type III environmental declarations — Principles and procedures; 2009-11.
DIN EN ISO 14044	Environmental management - Life cycle assessment - Requirements and guidance (ISO 14044:2006); German and English version EN ISO 14044:2006.
DIN EN 15804	Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products; German version EN 15804:2012
GaBi 9.2	Software und Datenbank zur Ganzheitlichen Bilanzierung, LBP [Lehrstuhl für Bauphysik] Universität Stuttgart und thinkstep AG, Leinfelden-Echterdingen,1992 – 2020
German Environment Agency	Weimann, K., Matyschik, J., Adam, C., Schulz, T., Linß, E. & Müller, A. (2013). Optimierung des Rückbaus/Abbaus von Gebäuden zur Rückgewinnung und Aufbereitung von Baustoffen unter Schadstoffentfrachtung (insbes. Sulfat) des RC-Materials. Umweltbundesamt.
UN CPC	United Nations Department of Economic and Social Affairs Statistics Division: Central Product Classification (CPC), Version 2.1

Environmental Product Declaration

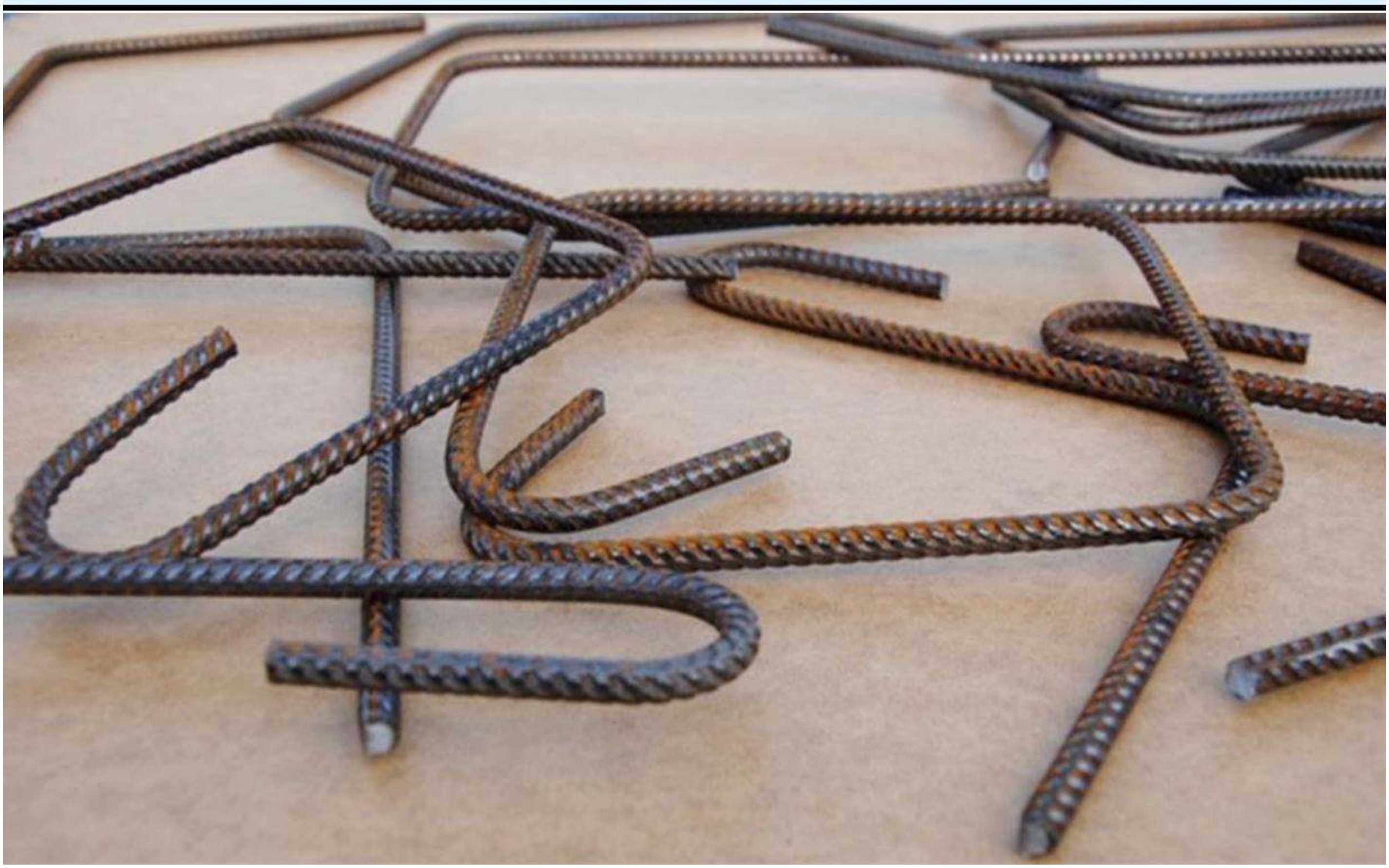
In accordance with ISO 14025 and EN 15804 for:

Cut and bent rebar

from

Tibnor AB

Programme:	The International EPD® System, www.environdec.com
Programme operator:	EPD International AB
EPD registration number:	S-P-02039
ECO EPD Ref. No.:	00001189
Publication date:	2020-08-11
Valid until:	2025-07-05



Company information

Owner of the EPD:
Tibnor AB, Box 600, 169 26 Solna, Sverige, +46 10 484 00 00, info@tibnor.se, www.tibnor.se

Description of the organisation:
Tibnor supplies steel and other metals to industry in the Nordics and Baltics. We are the meeting point where our know-how and expertise and that of our customers & suppliers converge to create smarter solutions. Together, we make industry in the Nordics even stronger. A subsidiary of SSAB, Tibnor has 1,100 employees across 7 countries. In 2017, we had sales of SEK 8 billion. For more information: www.tibnor.se
In Linköping Tibnor AB has it center for fabrication of cut & bent rebars.

Product-related or management system-related certifications:
Tibnor AB: ISO 9000, ISO 14001
Tibnor AB, Linköping: SBS A3/013

Name and location of production site:
Tibnor AB, Linköping

Product information

Product name:
Cut and bent bar in concrete reinforcing steel

Product identification:
Further processed concrete reinforcing based upon steel conforming to SS-EN 10080:2005 and SS 212540:2014

Product description:
Reinforcing steel is encased in concrete in order to improve the tensile strength of the latter in structures bearing axial or bending loads. The steel is relatively simple and comprises about 99 % iron. The reinforcing-steel products consist of cut-to-length and bent pieces starting from bars in long length or coil supplied from a steel plant. The bar surface is often ribbed in order to facilitate bonding between steel and concrete.
The cut and bent parts can be of standard shape or bespoke in accord with drawings supplied by a construction company. In many instances, parts are welded or otherwise joined together to form more complex cage arrangements tailored to the final construction. The finished parts are packed and delivered to the construction site ready to have concrete poured around them. Steel reinforcing will normally last over the life of the concrete structure. It is 100 % recyclable in the event that the structure is demolished.

UN CPC code:
4126

Geographical scope:
Europe

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LCA information

Declared unit:
1 kg steel rebars with packaging

System boundary:
Cradle to gate (with options)

Reference service life:
not applicable

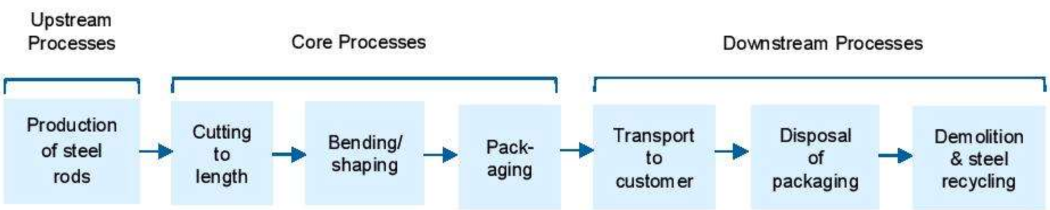
Time representativeness:
2018

Database(s) and LCA software used:
The manufacturing process was modelled based on manufacturer-specific data. For the upstream processes of steel, supplier-specific information in the form of EPDs was used where available. Otherwise, generic background datasets were used for the upstream and downstream processes.

For the LCA modelling the software GaBi, version 9.2, Service Pack 40, distributed by thinkstep was used. The background datasets used were taken from the current versions of various GaBi databases. The datasets contained in the databases are documented online. All necessary processes within the defined system boundaries were considered.

The background datasets used for accounting purposes should not be older than 10 years. In this study, no datasets older than 10 years were used.

System diagram:



Description of system boundaries:

X = declared modules; MND = module not declared:

Production			Installation		Utilization Stage							Disposal Stage				beyond system boundary
raw material supply	transport to the manufacturer	manufacture	transport to the construction site	installation in the building	use / application	maintenance	repair	replacement	renewal	energy input for operation	water use for operation	dismantling / demolition	transport	waste management	landfilling	reuse, recovery or recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	X	X	MND	MND	MND	MND	MND	MND	MND	X	X	X	X	X

Cut-off criteria:
The wooden pallets used for packaging have a mass share of 0.8 %. Due to the low mass share compared to steel and the fact that the wooden pallets are reused, no modelling was carried out. It can also be strongly assumed that the environmental impact of wood pallets will not exceed 1 %.

Estimates and assumptions:
- The collection rate for waste is 95 %

Allocation:
No allocations were made for the modelling of production processes, as the available data do not concern other products manufactured in the plant and there are no coupling processes. Multi-functional processes do not occur in the foreground system.
Allocations in the background datasets used are documented accordingly in the datasets themselves. Potential credits and avoided burdens resulting from the scrap recycling in the end of life (Module C3) are assigned to module D.

LCA scenarios and additional technical information

Transport from production place to user (module A4)
The average transport distance to the customer is 480.5 km by truck. Transport is mainly carried out by diesel-powered trucks, EURO 4 with an average load factor of 61 %.

Type	Capacity utilization	Type of vehicle	Average distance
Truck	61 %	EURO 4	480.5 km

Dismantling/demolition (module C1)
60 % of the reinforced concrete is demolished with cable excavator and wrecking ball (diesel consumption of excavator: 60.8 litres/hour; capacity approx. 15 m³/h) and 40 % is dismantled with hydraulic excavator and tongs (diesel consumption of excavator: 36.1 litres/hour; capacity approx. 20 m³/h). The ratio of reinforcing steel to concrete content is 4.8 %, corresponding to 120 kg reinforcing steel per m³ reinforced concrete (Source: German Environment Agency). Calculated diesel consumption for the demolition of 1 kg reinforcement steel is 0.0013 litres.

Type	Share	Reinforced concrete/hour	Diesel/ hour	Steel in reinforced concrete
Cable excavator and wrecking ball	60 %	15 m^3	60.8 l	4.8 % = 120 kg
Hydraulic excavator and tongs	40 %	20 m^3	36.1 l	4.8 % = 120 kg

Transport (module C2)

With a collection rate of 100 %, the transports are carried out by truck over 75 km and with a capacity utilization of 50 %.
Since the product is poured into concrete, it is collected as mixed construction waste.

Type	Capacity utilization	Type of vehicle	Average distance
Truck	50 %	EURO 4	75 km

Waste processing (modules C3 and C4)

Steel rebars must be mechanically separated from the concrete surrounding them prior to recycling so that the steel can be made available to a downstream product system as secondary material. This is considered in module C3. Corresponding potentials and avoided loads are assigned to module D. The landfilling of remaining 5 % which are not collected for recycling is considered in module C4.

Waste	kg for re-use	kg for recycling	kg for energy recovery	kg to landfill
Steel scrap	-	0.95	-	0.05

Content declaration

Product

Materials	Share
Steel	100 %

Substances of very high concern

The product does not contain any substances listed in the “Candidate List of Substances of Very High Concern (SVHC) for authorisation” exceeding 0.1 % of the weight of the product.

Packaging

Rebars are loaded on wooden pallets or fixed with slings. Depending on the type of product, the pallets are also equipped with collars. The wooden pallets are reused.

Recycled material

Provenience of recycled materials in the product:

98 %

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Environmental performance

Potential environmental impact

Parameter	Unit	A1 -A3	A4	A5	C1	C2	C3	C4	D
Global Warming Potential (GWP)	kg CO2-eq.	4.14E-01	3.83E-02	8.31E-03	3.67E-02	6.25E-04	2.40E-03	6.81E-04	-3.35E-02
Stratospheric ozone depletion potential (ODP)	kg CFC11-eq.	3.69E-09	8.03E-18	3.23E-18	6.04E-18	1.73E-18	7.98E-18	3.75E-18	8.67E-17
Acidification potential of soil and water (AP)	kg SO2-eq.	1.17E-03	1.61E-04	2.04E-06	1.32E-04	4.30E-06	1.68E-05	4.37E-06	-6.19E-05
Eutrophication potential (EP)	kg PO43–eq.	1.99E-04	4.06E-05	1.81E-07	3.14E-05	7.38E-07	4.05E-06	4.92E-07	-4.52E-06
Formation potential for tropospheric ozone (POCP)	kg Ethene-eq.	6.58E-05	-6.21E-05	2.89E-08	1.31E-05	6.08E-07	1.86E-06	3.29E-07	-1.48E-05
Potential for abiotic depletion of non-fossil resources (ADPE)	kg Sb-eq.	1.47E-07	2.97E-09	5.70E-10	3.06E-09	6.41E-10	2.73E-09	2.63E-10	-5.24E-07
Potential for abiotic depletion of fossil fuels (ADPF)	MJ	3.52E+00	4.38E-01	3.26E-03	5.01E-01	9.44E-02	4.67E-02	9.67E-03	-3.30E-01

Use of resources

Parameter	Unit	A1 -A3	A4	A5	C1	C2	C3	C4	D
Renewable primary energy as an energy carrier (PERE)	MJ	3.47E+00	2.53E-02	6.78E-04	2.82E-02	5.46E-03	3.48E-03	1.30E-03	3.57E-03
Renewable primary energy for material use (PERM)	MJ	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total renewable primary energy (PERT)	MJ	3.47E+00	2.53E-02	6.78E-04	2.82E-02	5.46E-03	3.48E-03	1.30E-03	3.57E-03
Non-renewable primary energy as an energy carrier (PENRE)	MJ	4.38E+00	4.40E-01	7.78E-02	5.03E-01	9.49E-02	4.83E-02	9.96E-03	-3.38E-01
Non-renewable primary energy for material use (PENRM)	MJ	7.42E-02	0.00E+00	-7.42E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total non-renewable primary energy (PENRT)	MJ	4.46E+00	4.40E-01	3.60E-03	5.03E-01	9.49E-02	4.83E-02	9.96E-03	-3.38E-01
Use of secondary materials (SM)	kg	1.01E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Renewable secondary fuels (RSF)	MJ	1.77E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Non-renewable secondary fuels (NRSF)	MJ	7.91E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Use of freshwater resources (FW)	m³	1.94E-01	2.95E-05	2.06E-05	3.27E-05	6.37E-06	1.36E-05	2.51E-06	-8.85E-05

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Waste production and output flows

Parameter	Unit	A1 -A3	A4	A5	C1	C2	C3	C4	D
Hazardous waste to landfill (HWD)	kg	1.03E-04	2.03E-08	2.80E-11	2.34E-08	4.39E-09	1.26E-09	1.52E-10	-3.58E-08
Non-hazardous waste disposed (NHWD)	kg	5.83E-01	6.97E-05	8.01E-04	7.69E-05	1.50E-05	1.30E-05	5.00E-02	3.29E-03
Disposed radioactive waste (RWD)	kg	3.00E-04	8.11E-07	1.33E-07	6.22E-07	1.75E-07	6.37E-07	1.13E-07	-7.96E-06
Components for Reuse (CRU)	kg	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Materials for recycling (MFR)	kg	3.12E-02	0.00E+00	6.24E-04	0.00E+00	0.00E+00	9.50E-01	0.00E+00	0.00E+00
Substances for energy recovery (MER)	kg	3.48E-04	0.00E+00	3.32E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Energy [Electricity]	MJ	5.00E-04	0.00E+00	1.84E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Exported Energy [Thermal Energy]	MJ	9.37E-04	0.00E+00	3.31E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

General information

Programme:	The International EPD® System EPD International AB Box 210 60 SE-100 31 Stockholm Sweden www.environdec.com Info@environdec.com
Product category rules (PCR):	PCR 2012:01 Construction products and construction services, Version 2.3
PCR review was conducted by:	The Technical Committee of the International EPD® System. Chair: Massimo Marino. Contact via info@environdec.com
Independent verification of the declaration and data, according to ISO 14025:	☐ EPD process certification ☑ EPD verification
Third party verifier:	Andreas Ciroth, GreenDelta GmbH
Accredited and approved by:	The International EPD System
TIBNOR	Owner of the declaration Tibnor AB Silverdalsvägen 4 635 10 Eskilstuna Sweden https://www.tibnor.se
brands & values® sustainability consultants	Commissioner of the Life Cycle Assessment brands & values GmbH Altenwall 14 28195 Bremen Germany www.brandsandvalues.com info@brandsandvalues.com +49 421 70 90 84 33

The EPD owner has the sole ownership, liability, and responsibility for the EPD. EPDs within the same product category but from different programmes may not be comparable. EPDs of construction products may not be comparable if they do not comply with EN 15804.

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References

The International EPD System	General Programme Instructions of the International EPD® System. Version 3.01.
The International EPD System	PCR 2012:01 Construction products and construction services, Version 2.3
DIN EN ISO 14025	Environmental labels and declarations — Type III environmental declarations — Principles and procedures; 2009-11.
DIN EN ISO 14044	Environmental management - Life cycle assessment - Requirements and guidance (ISO 14044:2006); German and English version EN ISO 14044:2006.
DIN EN 15804	Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products; German version EN 15804:2012
GaBi 9.2	Software und Datenbank zur Ganzheitlichen Bilanzierung, LBP [Lehrstuhl für Bauphysik] Universität Stuttgart und thinkstep AG, Leinfelden-Echterdingen,1992 – 2020
German Environment Agency	Weimann, K., Matyschik, J., Adam, C., Schulz, T., Linß, E. & Müller, A. (2013). Optimierung des Rückbaus/Abbaus von Gebäuden zur Rückgewinnung und Aufbereitung von Baustoffen unter Schadstoffentfrachtung (insbes. Sulfat) des RC-Materials. Umweltbundesamt.
UN CPC	United Nations Department of Economic and Social Affairs Statistics Division: Central Product Classification (CPC), Version 2.1

Appendix 7