A2018-21 Utveckling av LCA och LCCA för geotekniska konstruktioner

Ida Samuelsson

2022-10-21, BIG webbinarie

Kort info om mig

- Doktorand avd. Jord- och bergmekanik KTH
- Geotekniker på Tyréns sen 2007

Dagordning

- Introduktion till projektet
- Metoderna LCA och LCCA
- Forskningsläget idag inom LCA och LCCA för geoteknik
- Fallstudie
- Pågående arbeten
- Framtida utmaningar

Projektbeskrivning – bakgrund, mål och metodik

- Projekt med doktorand fram till lic. och en seniorforskningsdel hos Tyréns.
- LCA och LCCA används idag och är under snabb utveckling inom tex väg- och järnvägsområdet, men det saknas tillämpad forskning för geotekniska konstruktioner.
- Utveckla arbetet och ta fram en modell relaterat till geokonstruktioner omfattandes både LCA och LCCA.
- Projektet utförs så att nuvarande ramverk och vägledningar för LCA och LCCA tillämpade på geokonstruktioner utvecklas.

1. Litteraturstudie, forskningsläget idag – konferensartikel 1
2. Fallstudie – Rapport Tyréns och konferensartikel 2
3. Metodik i ämnet – tidskriftsartikel 1 (pågående)
4. Praktisk tillämpning – Rapport Tyréns (pågående)

Livscykelsteg

- Materialutvinning och användning sekundära material
- Produktion
- Konstruktion
- Användning
- Sluthantering

www.boverket.se

Metoderna - LCA och LCCA

- LCA - Livscykelanalys, en produkts eller process potentiella miljöpåverkan under dess livscykel
- LCCA – Livscykelkostnadsanalys, en produkts eller process potentiella kostnad (pengar) under dess livscykel
- Standarder och vägledningar:

  Generella:
  - ISO 14040:2006 LCA
  - ISO 14044:2006 LCA

  Byggnadsverk:
  - ISO 15686-5:2017 LCC
  - EN 15804:2012+A2:2019/AC:2021 byggdelar
  - Trafikverkets vägledning för LCC-beräkningar
  - Trafikverkets vägledning för LCA-beräkningar

Metodik

Definiera mål och omfattning

Inventera

Bedöma miljöpåverkan

Tolka resultatet

- Systemgränser – vilka aktiviteter och processer ingår i respektive livcykelskede
- Mål – jämförelse? hitta de aktiviteter i processen med störst påverkan?
- Funktionell enhet – det som utvärderas ska ha samma funktion
- Vilka livscykelsteg ska ingå

Livscykelsteg - EN 15804:2012+A2:2019/AC:2021

A1-A3	A4-A5	B1-B7		C1-C4	D
Production	Construction	Use		End of life	Benefits and loads beyond the system boundary
A1 Raw material supply	A4 Transport	B1 Use	B5 Refurbishment	C1 De-construction demolition	Reuse- Recovery-Recycling-potential
A2 Transport	A5 Construction-installation process	B2 Maintenance	B6 Operational energy use	C2 Transport	
A3 Manufacturing		B3 Repair	B7 Operational water use	C3 Waste processing	
		B4 Replacement		C4 Disposal	

Livscykelsteg - LCCA

Investering		Drift och underhåll		Avveckling	
Production	Construction	Use		End of life	Benefits and loads beyond the system boundary
A1 Raw material supply	A4 Transport	B1 Use	B5 Refurbishment	C1 De-construction demolition	Reuse- Recovery-Recycling-potential
A2 Transport	A5 Construction-installation process	B2 Maintenance	B6 Operational energy use	C2 Transport	
A3 Manufacturing		B3 Repair	B7 Operational water use	C3 Waste processing	
		B4 Replacement		C4 Disposal	

Metodik

Definiera mål och omfattning → Inventera → Bedöma miljöpåverkan → Tolka resultatet

- Resurser som används under livscykeln
- Utsläpp som de genererar – emissionsfaktorer
- Data
  - Experter
  - Databaser: Ecoinvent, Klimatkalkyl, Geokalkyl m fl.
  - EPD

EPD

- EPD – Environmental Product Declaration (miljövarudeklaration)

CEMENTA
HEIDELBERGCEMENTGroup

LCA: Results

Disclaimer:
EP-freshwater: This indicator has been calculated as "kg P eq" as required in the characterization model (EUTREND model, Struijs et al., 2009b, as implemented in ReCiPe; http://eplca.jrc.ec.europa.eu/LCDN/developerEF.xhtml).

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; ND = MODULE OR INDICATOR NOT DECLARED; MNR = MODULE NOT RELEVANT)

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	ND	ND	ND	ND	MNR	MNR	MNR	ND	ND	ND	ND	ND	ND	ND

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT according to EN 15804+A2: 1 metric t CEM II/A-V 42.5 N

Core Indicator	Unit	A1-A3
Global warming potential - total	[kg CO_2-Eq.]	6.80E+2
Global warming potential - fossil fuels	[kg CO_2-Eq.]	6.80E+2
Global warming potential - biogenic	[kg CO_2-Eq.]	1.94E-1
GWP from land use and land use change	[kg CO_2-Eq.]	1.26E-1
Depletion potential of the stratospheric ozone layer	[kg CFC11-Eq.]	8.39E-6
Acidification potential, accumulated exceedance	[mol H^+-Eq.]	1.21E+0
Eutrophication, fraction of nutrients reaching freshwater end compartment	[kg P-Eq.]	5.39E-2
Eutrophication, fraction of nutrients reaching marine end compartment	[kg N-Eq.]	4.30E-3
Eutrophication, accumulated exceedance	[mol N-Eq.]	3.84E+0
Formation potential of tropospheric ozone photochemical oxidants	[kg NMVOC-Eq.]	1.04E+0
Abiotic depletion potential for non-fossil resources	[kg Sb-Eq.]	1.39E-4
Abiotic depletion potential for fossil resources	[MJ]	1.39E+3
Water (user) deprivation potential, deprivation-weighted water consumption (WDP)	[m^3 world-Eq deprived]	2.68E+1

RESULTS OF THE LCA - INDICATORS TO DESCRIBE RESOURCE USE according to EN 15804+A2: 1 metric t CEM II/A-V 42.5 N

Indicator	Unit	A1-A3
Renewable primary energy as energy carrier	[MJ]	3.05E+2
Renewable primary energy resources as material utilization	[MJ]	0.00E+0
Total use of renewable primary energy resources	[MJ]	3.05E+2
Non-renewable primary energy as energy carrier	[MJ]	2.03E+3
Non-renewable primary energy as material utilization	[MJ]	0.00E+0
Total use of non-renewable primary energy resources	[MJ]	2.03E+3
Use of secondary material	[kg]	2.03E+2
Use of renewable secondary fuels	[MJ]	6.55E+2
Use of non-renewable secondary fuels	[MJ]	1.07E+3
Use of net fresh water	[m^3]	6.58E-1

RESULTS OF THE LCA – WASTE CATEGORIES AND OUTPUT FLOWS according to EN 15804+A2: 1 metric t CEM II/A-V 42.5 N

Indicator	Unit	A1-A3
Hazardous waste disposed	[kg]	1.30E-1
Non-hazardous waste disposed	[kg]	4.25E+2
Radioactive waste disposed	[kg]	0.00E+0
Components for re-use	[kg]	0.00E+0
Materials for recycling	[kg]	1.29E-1
Materials for energy recovery	[kg]	0.00E+0
Exported electrical energy	[MJ]	0.00E+0
Exported thermal energy	[MJ]	0.00E+0

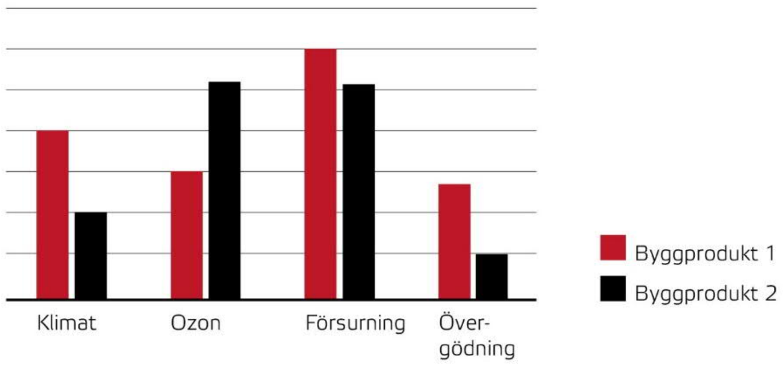
5 Environmental Product Declaration Cementa AB – CEM II/A-V 42.5 N

www.cementa.se

Metodik

Definiera mål och omfattning → Inventera → Bedöma miljöpåverkan → Tolka resultatet

- Miljöpåverkanskategorier



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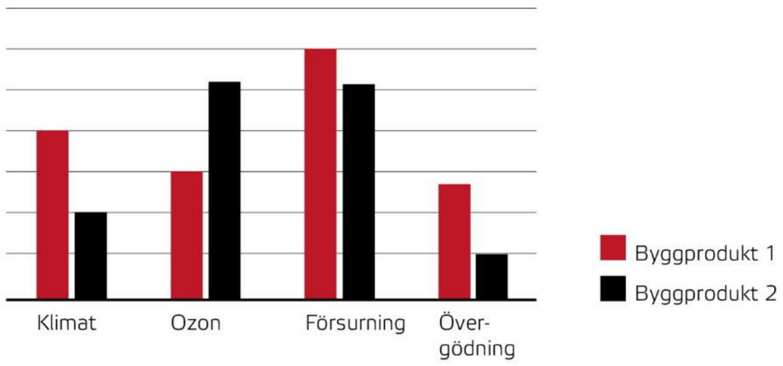
Metodik

Definiera mål och omfattning → Inventera → Bedöma miljöpåverkan → Tolka resultatet

- Resultaten ska relateras till målen för analysen
- Rekommendationer
- Känslighetsanalyser



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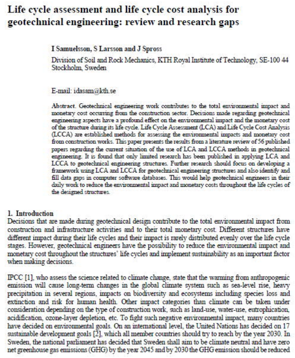
Konferensartikel 1

- *Life cycle assessment and life cycle cost analysis for geotechnical engineering: review and research gaps*
- NGM 2020
- Sammanställning av 56 artiklar inom hållbarhet varav 29 inom LCA och LCCA mellan åren 1987-2019
- Fram till år 2010 var endast 9 artiklar publicerade.
- Hållbarhet
  - Miljö - LCA
  - Ekonomi - LCCA
  - Social – ej inkluderad



Life cycle assessment and life cycle cost analysis for geotechnical engineering: review and research gaps

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Abstract. Geotechnical engineering work contributes to the total environmental impact and monetary cost occurring from the construction sector. Decisions made regarding geotechnical engineering aspects have a profound effect on the environmental impact and the monetary cost of the structure during its life cycle. Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) are established methods for assessing the environmental impacts and monetary cost from construction works. This paper presents the results from a literature review of 56 published papers regarding the current situation of the use of LCA and LCCA methods in geotechnical engineering. It is found that only limited research has been published in applying LCA and LCCA to geotechnical engineering structures. Further research should focus on developing a framework using LCA and LCCA for geotechnical engineering structures and also identify and fill data gaps in computer software databases. This would help geotechnical engineers in their daily work to reduce the environmental impact and monetary costs throughout the life cycles of the designed structures.

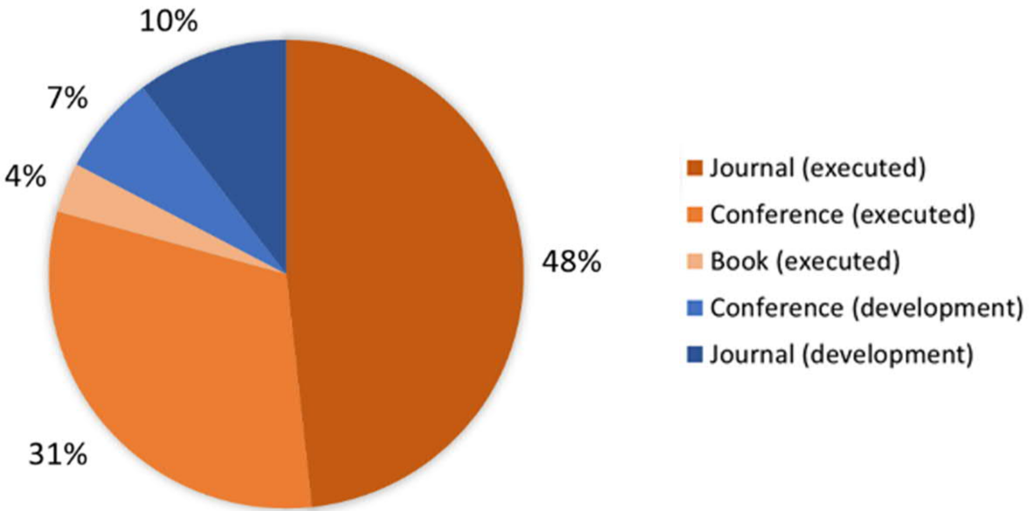
1. Introduction

Decisions that are made during geotechnical design contribute to the total environmental impact from construction and infrastructure activities and to their total monetary cost. Different structures have different impact during their life cycles and their impact is rarely distributed evenly over the life cycle stages. However, geotechnical engineers have the possibility to reduce the environmental impact and monetary cost throughout the structures' life cycles and implement sustainability as an important factor when making decisions.

IPCC [1], who assess the science related to climate change, state that the warming from anthropogenic emission will cause long-term changes in the global climate system such as sea-level rise, heavy precipitation in several regions, impacts on biodiversity and ecosystems including species loss and extinction and risk for human health. Other impact categories than climate can be taken under consideration depending on the type of construction work, such as land-use, water-use, eutrophication, acidification, ozone-layer depletion, etc. To fight such negative environmental impact, many countries have decided on environmental goals. On an international level, the United Nations has decided on 17 sustainable development goals [2], which all member countries should try to reach by the year 2030. In Sweden, the national parliament has decided that Sweden shall aim to be climate neutral and have zero net greenhouse gas emissions (GHG) by the year 2045 and by 2030 the GHG emission should be reduced

Resultat – typ av artiklar

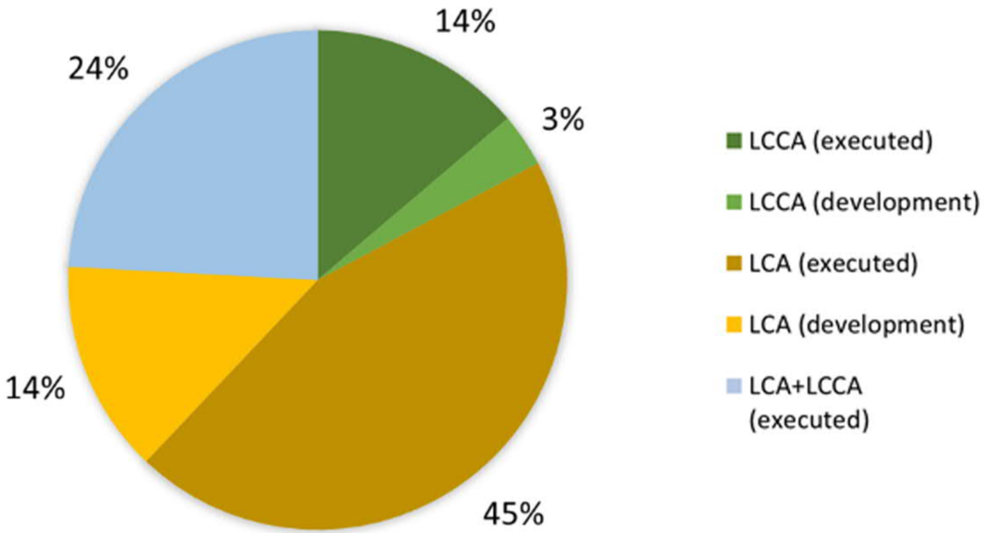
- 24 av 29 artiklar beräkning med diskussion
- 17 tidskriftsartiklar



Samuelsson I., Larsson S., Spross J. (2021) Life cycle assessment and life cycle cost analysis for geotechnical engineering: review and research gaps

Resultat - artikelinnehåll

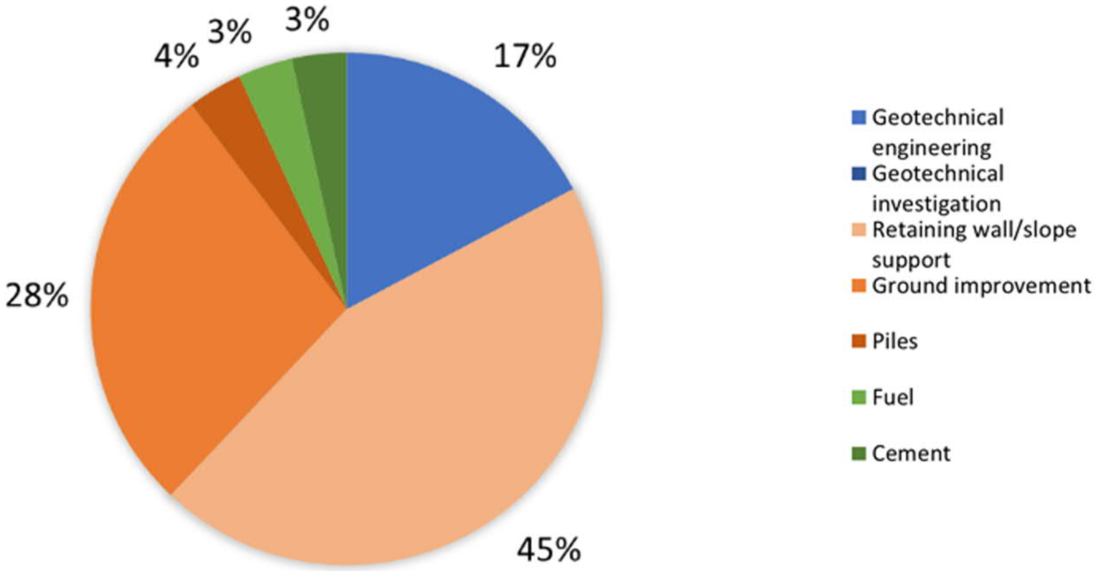
- 17 LCA, 5 LCCA, 7 både LCA och LCCA



Samuelsson I., Larsson S., Spross J. (2021) Life cycle assessment and life cycle cost analysis for geotechnical engineering: review and research gaps

Resultat - artikelämnen

- 26 av 29 artiklar om allmän geoteknik, stödmur/släntstabilisering, markförstärkning



Samuelsson I., Larsson S., Spross J. (2021) Life cycle assessment and life cycle cost analysis for geotechnical engineering: review and research gaps

Slutsatser

- Bara 29 artiklar – nytt forskningsområde
- Mer publicerad forskning om LCA än om LCCA
- Flera studier inkluderar endast fram till färdig konstruktion, saknar t.ex. drift, underhåll och sluthantering
- Fåtal miljöpåverkanskategorier används, främst klimat
- Endast ett fåtal ämnen har varit aktuella
- Kopplingen LCA och LCCA inte beskriven
- Osäkerheter i indata och underhållsskedet att hantera.

Konferensartikel 2 – Tyréns rapport

- *Assessment of climate impact and costs comparing two railway embankment fill methods*
- The Fifth International Conference on New Developments in Soil Mechanics and Geotechnical Engineering, Cypern, 2022

Assessment of climate impact and costs comparing two railway embankment fill methods

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Abstract. Emissions from infrastructure projects and construction projects have a large impact on the environment. Construction activities and materials, including geotechnical engineering works, account for a great share of that impact and the monetary costs of the projects. In railway projects, crushed bedrock is often used as fill material in the embankments, and less suitable soil is excavated and transported to a landfill causing emissions. Despite that, sustainability assessments are rarely made when comparing the crushed bedrock fill method with other alternative methods, when the geotechnical engineer is designing an embankment. This paper, therefore, shows how climate impact and monetary costs can be compared for two fill methods in a railway embankment in Sweden, namely crushed rock fill and fill made of cement-stabilized sandy till. A comparing life cycle assessment (LCA) of climate impact and a life cycle cost analysis (LCCA) of monetary costs were made for the two methods. Activities and materials used in the production and construction stages were assessed. The results show that the stabilized sandy till method had both a smaller climate impact and lower life cycle cost (LCC) than the crushed bedrock fill method.

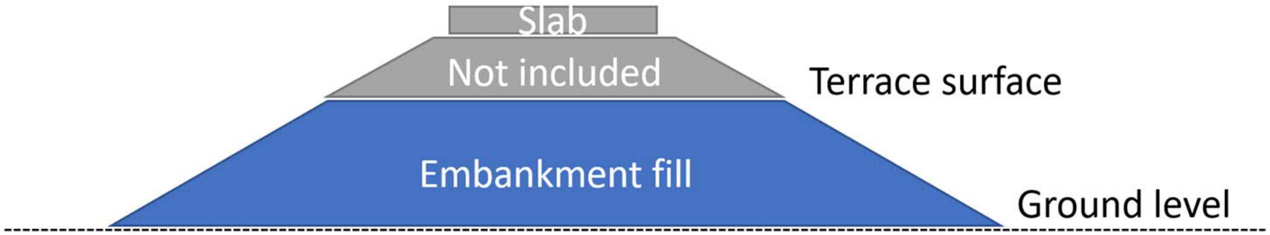
Keywords: Soil stabilization, geotechnical engineering, life cycle assessment, life cycle cost analysis, climate impact

1 Introduction

The amount of greenhouse gas (GHG) emissions in the atmosphere is rising [1]. The construction and real estate sector in Sweden accounts for about 11.7 billion kg CO_2eq, which corresponds to 21 % of the total GHG emissions in Sweden in 2019 [2]. Globally the building and construction sector account for almost 40 % of energy-related and process-related CO_2 emissions in 2018, 11 % of which resulted from manufacturing building materials and products [3]. Geotechnical engineering is an important part of the construction and infrastructure sector, and foundation works require material such as concrete, steel, and fuel, which produces GHG emissions when produced and used. Despite that, assessments of environmental impact, e.g. Life Cycle Assessment (LCA), are rarely made in the geotechnical design stage. Samuelsson et al. [4] found only 24 papers including both LCA and geotechnical engineering works. For ground improvement, only five papers included executed LCAs and only

Introduktion

- LCA och LCCA för att beräkna klimatpåverkan och LCC för två olika bankfyllningsmetoder för en järnvägsbank.
- De två metoderna:
  - Krossat berg
  - Cementstabiliserad sandig morän



Metodik – fallstudie

- Höghastighetsjärnväg mellan Lund och Hässleholm. En sträcka på 70 km. Förstudie.
- En analys i Geokalkyl av mängden massor i projektet visade inget överskott på berg men ett överskott på 480 000 m^3 sandig morän.
- Moränen hade behövt köras bort från projektet om krossat berg användes.
- Den funktionella enheten är en bank med total volym 480 000 m^3, längd 7400 m, medelbredd 19 m och höjd 3,4 m.

Klimatpåverkan [kg CO_2eq]

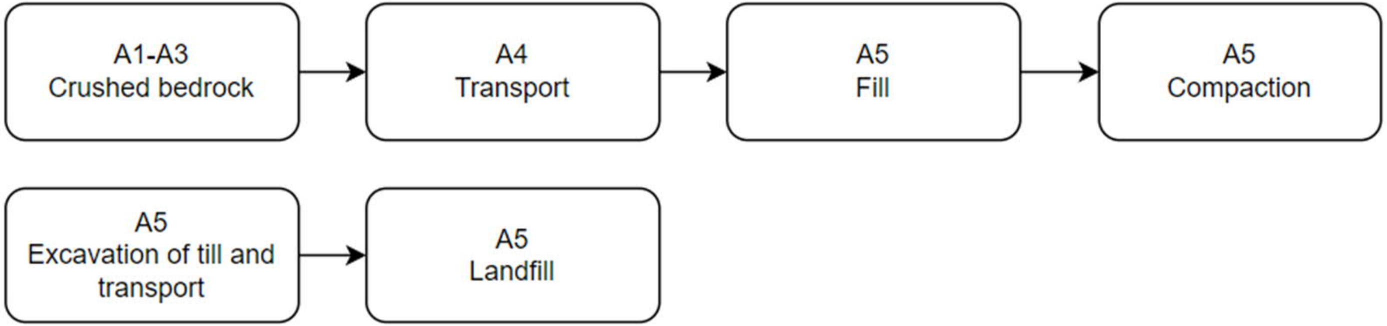
LCA

Livscykelkostnad (LCC) [miljon SEK]

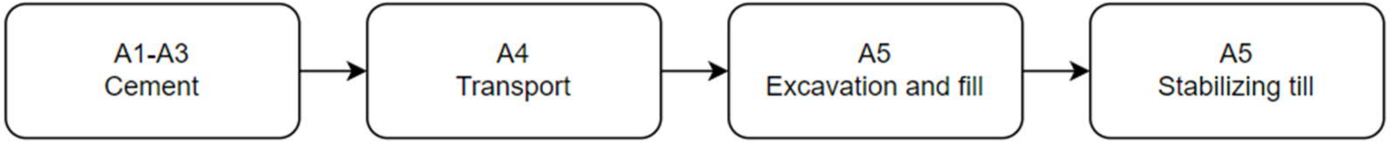
LCCA

Systemgränser

- Krossat berg



- Cementstabiliserad morän



Resultat – Livscykelinventering (LCI)

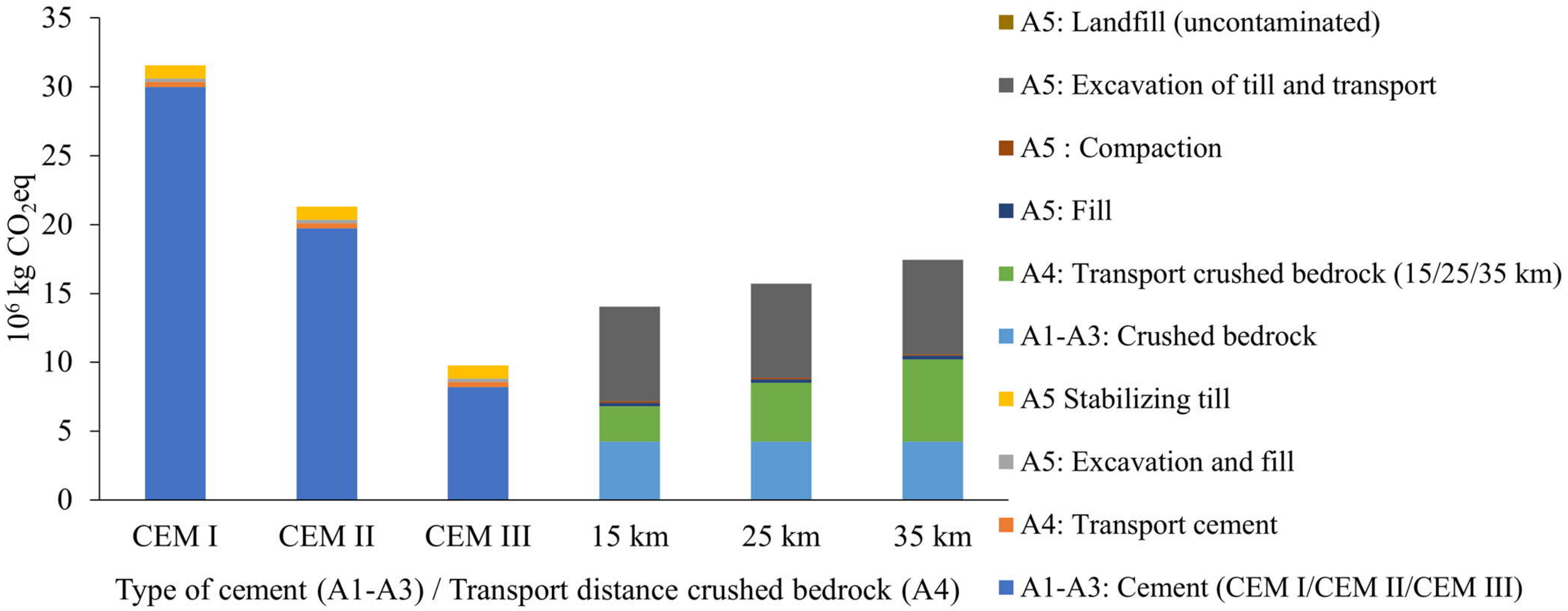
Life cycle stage	Emission factors and conversion factor	Cost
A1-A3 Crushed bedrock	0.004 kg CO_2eq/kg	120 SEK/1000 kg
A4 Transport	$CF_{Transport}$, EF_{Diesel}	38 SEK/1000 kg (25 km)
A5 Fill	$CF_{Excavator}$, EF_{Diesel}	200 SEK/m^3
A5 Compaction	EF_{Diesel}	22 SEK/m^2
A5 Excavation of till and transport	$CF_{Excavator}$, $CF_{Transport}$, EF_{Diesel}	250 SEK/m^3
A5 Landfill	0 kg CO_2eq/m^3 (uncontaminated)	200 SEK/m^3 (uncontaminated)
	–	375 SEK/m^3 (Little contaminated)
	–	1250 SEK/m^3 (Very contaminated)

Life cycle stage	Emission factors and conversion factor	Cost
A1–A3 Cement	817 kg CO_2eq/1000 kg (CEM I)	–
	537.7 kg CO_2eq/1000 kg (CEM II)	958 SEK/1000 kg (CEM II)
	223.2 kg CO_2eq/1000 kg (CEM III)	–
A4 Transport	$CF_{Transport}$, EF_{Diesel}	90 SEK/1000 kg
A5 Excavation and fill	$CF_{Excavator}$, EF_{Diesel}	80 SEK/m^3
A5 Stabilizing till	EF_{Diesel}	171.4 SEK/m^3

- $CF_{Transport}$ = transport with lorries = 2.5 MJ/tkm, 43.25 MJ/liter diesel
- $CF_{Excavator}$ = excavator = 0.19 liter diesel/m^3 soil
- EF_{Diesel} = diesel = 2.8 kg CO_2eq/liter diesel

Samuelsson I., Spross J., Larsson S. Assessment of climate impact and costs comparing two railway embankment fill methods, submitted to ZM2022

Resultat - klimatpåverkan



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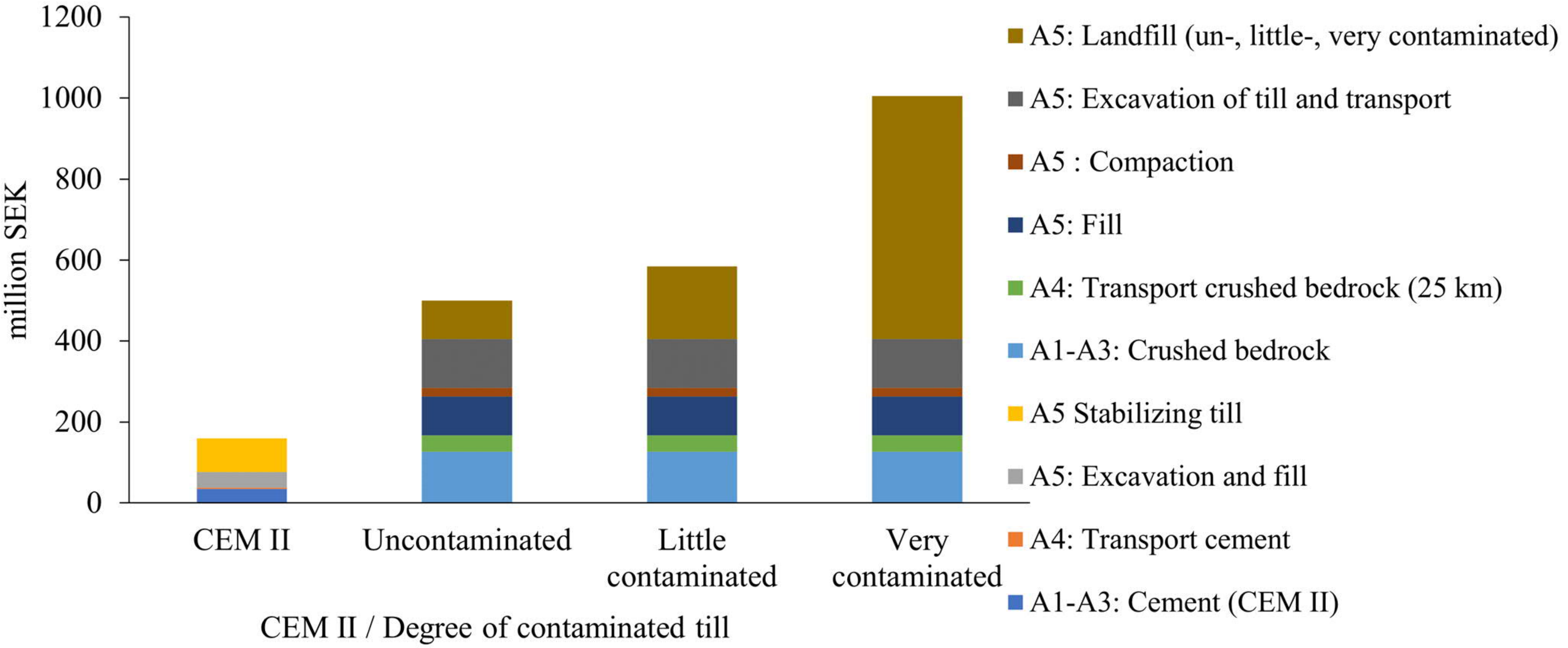
Resultat – livscykelkostnad (LCC)



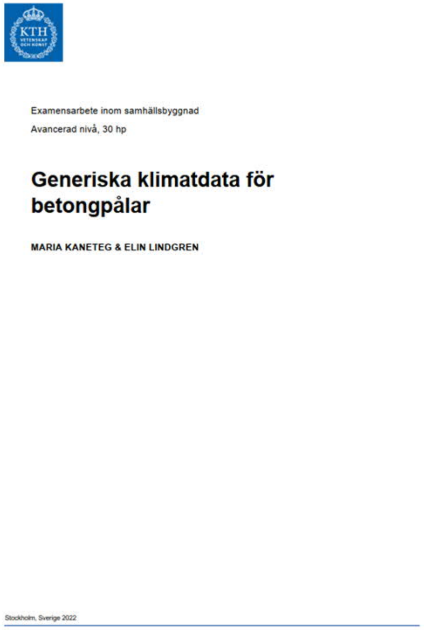
Samuelsson I., Spross J., Larsson S. Assessment of climate impact and costs comparing two railway embankment fill methods, submitted to ZM2022

Slutsatser

- Användning av stabiliserad morän istället för krossat berg kan minska både klimatpåverkan och kostnaderna i produktions- och konstruktionsskedet.
- Att bedöma klimatpåverkan och livscykelkostnad med LCA och LCCA är möjligt när man jämför bankfyllningsmetoder.
- Resultatet från LCA och LCCA kan hjälpa geoteknikern att göra val som minskar klimatpåverkan och livscykelkostnaden i projektet.

Generiska klimatdata för betongpålar

- Examensarbete för generiska klimatdata för betongpålar
- Klimatpåverkan i olika delar i livscykeln (A1-A5)
- Beräkning och intervjuer
- Boverkets klimatdatabas, Klimatkalkyl

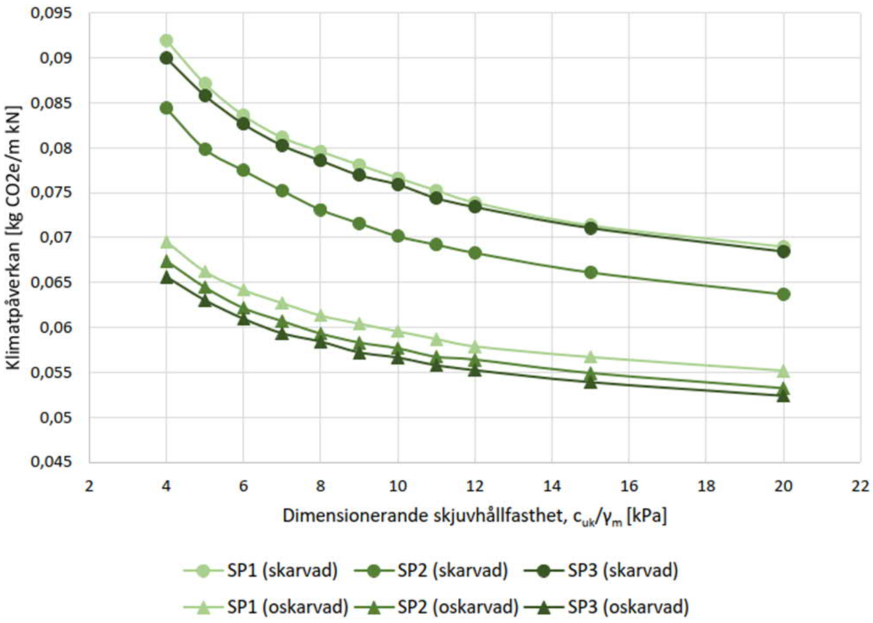

Examensarbete inom samhällsbyggnad
Avancerad nivå, 30 hp

Generiska klimatdata för betongpålar

MARIA KANETEG & ELIN LINDGREN

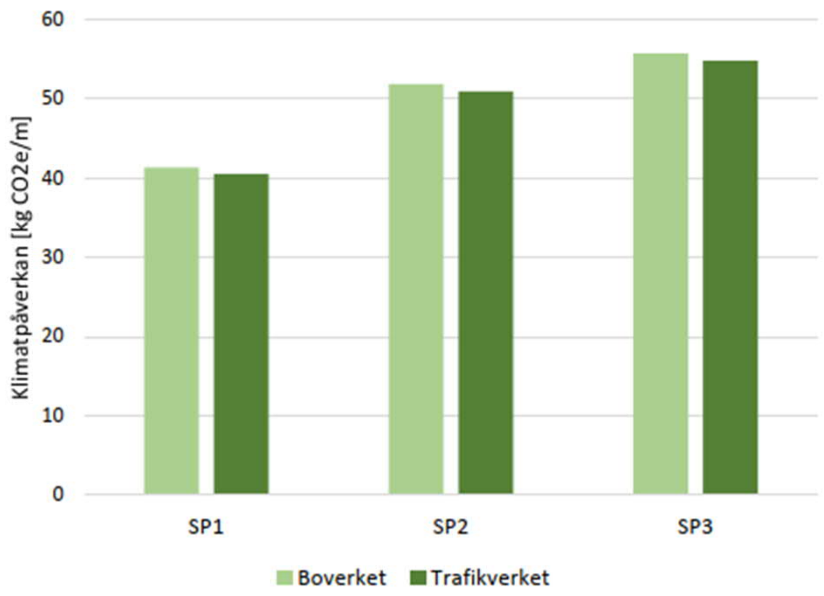
Stockholm, Sverige 2022

Resultat – hänsyn till bärförmåga



Figur 5. Klimatpåverkan för oskarvade och skarvade SP1, SP2 och SP3 med hänsyn till bärförmåga, avstånd på 10 mil till byggarbetsplats.

Resultat – jämförelse klimatdatabaser

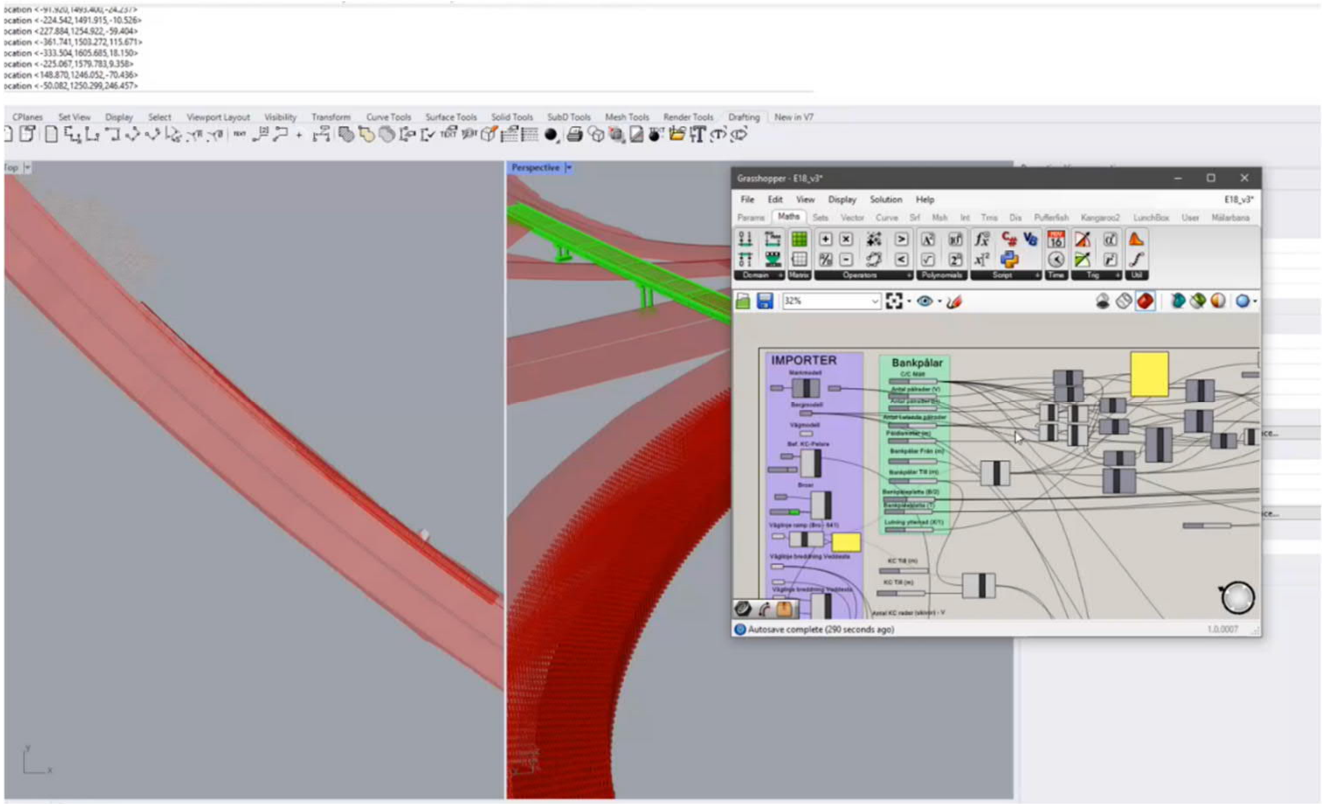


Figur 13. Generisk klimatpåverkan för prefabricerade betongpålar med användning av Boverkets respektive Trafikverkets klimatdata för ett avstånd på 10 mil till byggarbetsplats.

Pågående arbete - tidskriftsartikel

1. En metodik som visar hur LCA och LCCA kan integreras i den geotekniska designprocessen för att kunna välja den mest hållbara designen.
2. Metodiken fokuserar främst på fasen där en ytterligare reduktion av LCA- och LCCA-resultaten kan göras.
    1. Identifiera
    2. Förbättra
        1. Ändra konstruktionen
        2. Reducera mängden material
        3. Ändra materialtyp
    3. Jämföra
3. Metodiken testas i en fallstudie.

Pågående arbete – parametrisk design



Fortsatta utmaningar

- Klargöra hur osäkerheter ska beaktas vid utförandet av LCA och LCCA inom geoteknik. Det gäller osäkerheter i indata samt i framtida underhåll och slutskede.
- Sannolikhetsbaserad utvärdering.

A1-A3	A4-A5	B1-B7		C1-C4	D
Production	Construction	Use		End of life	Benefits and loads beyond the system boundary
A1 Raw material supply	A4 Transport	B1 Use	B5 Refurbishment	C1 De-construction demolition	Reuse- Recovery-Recycling-potential
A2 Transport	A5 Construction-installation process	B2 Maintenance	B6 Operational energy use	C2 Transport	
A3 Manufacturing		B3 Repair	B7 Operational water use	C3 Waste processing	
		B4 Replacement		C4 Disposal	

Tack!

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