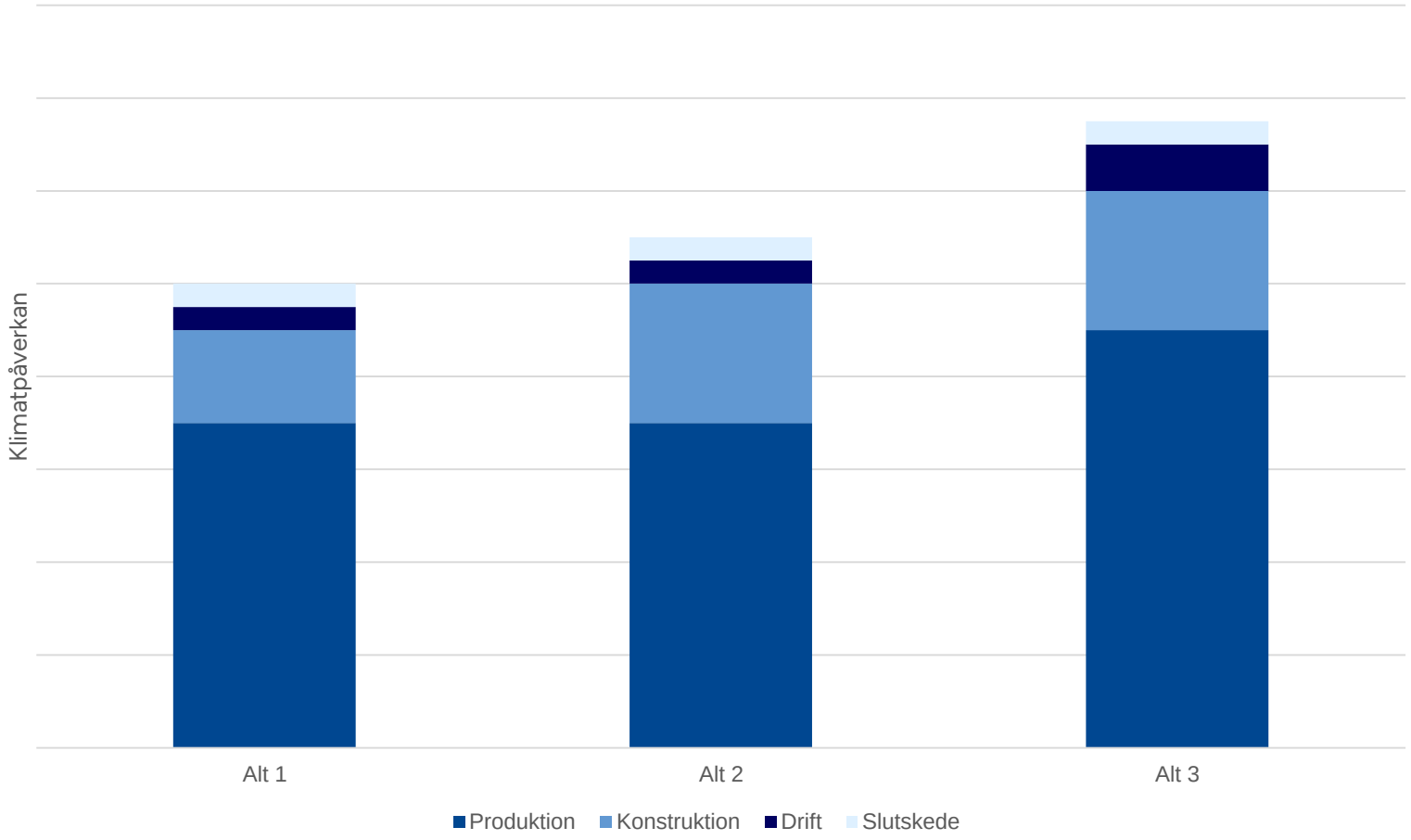


Probabilistisk LCA och LCCA för geoteknisk design i tidiga skeden

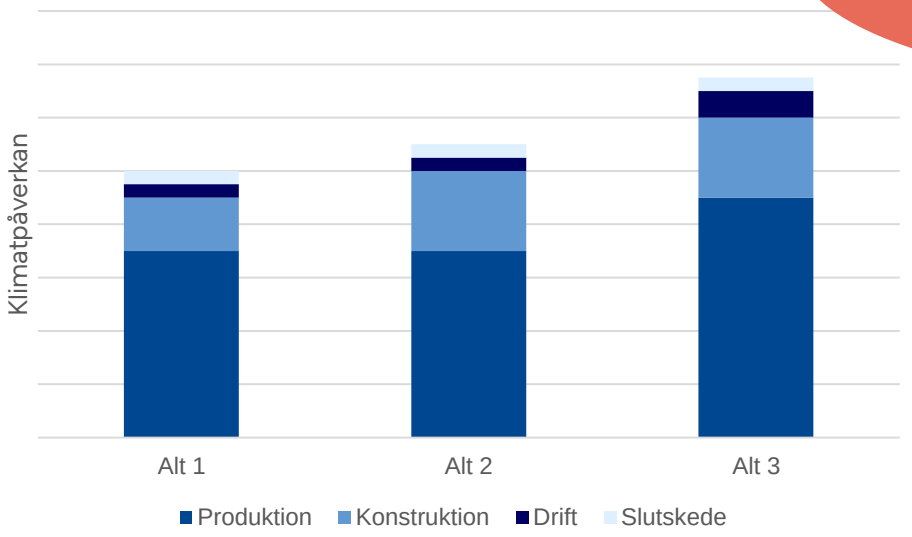
Ida Samuelsson, 2026-06-12

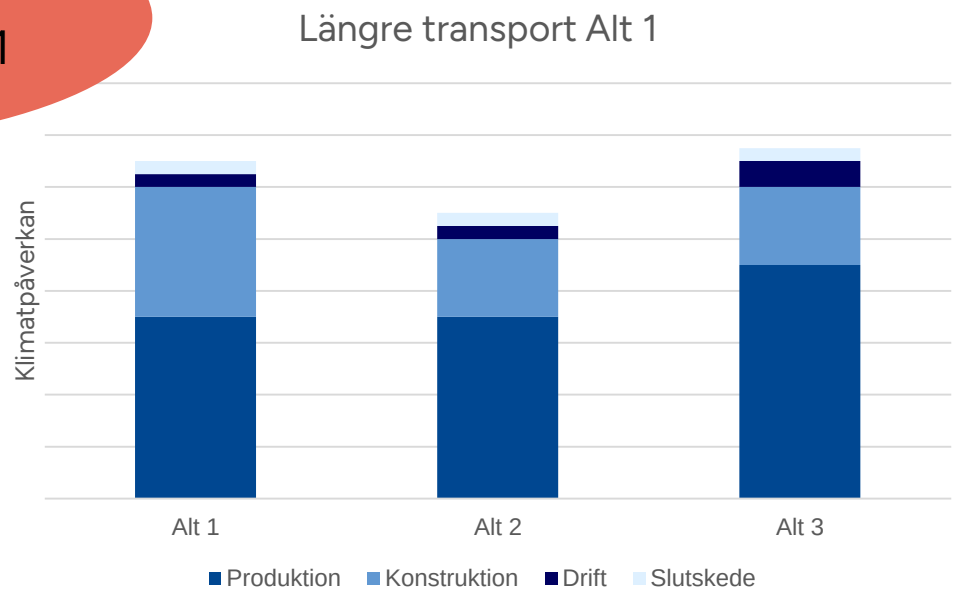
Typisk jämförelse klimatpåverkan



Typisk jämförelse klimatpåverkan

Osäkerhet i transportavstånd för Alt 1





Dagordning

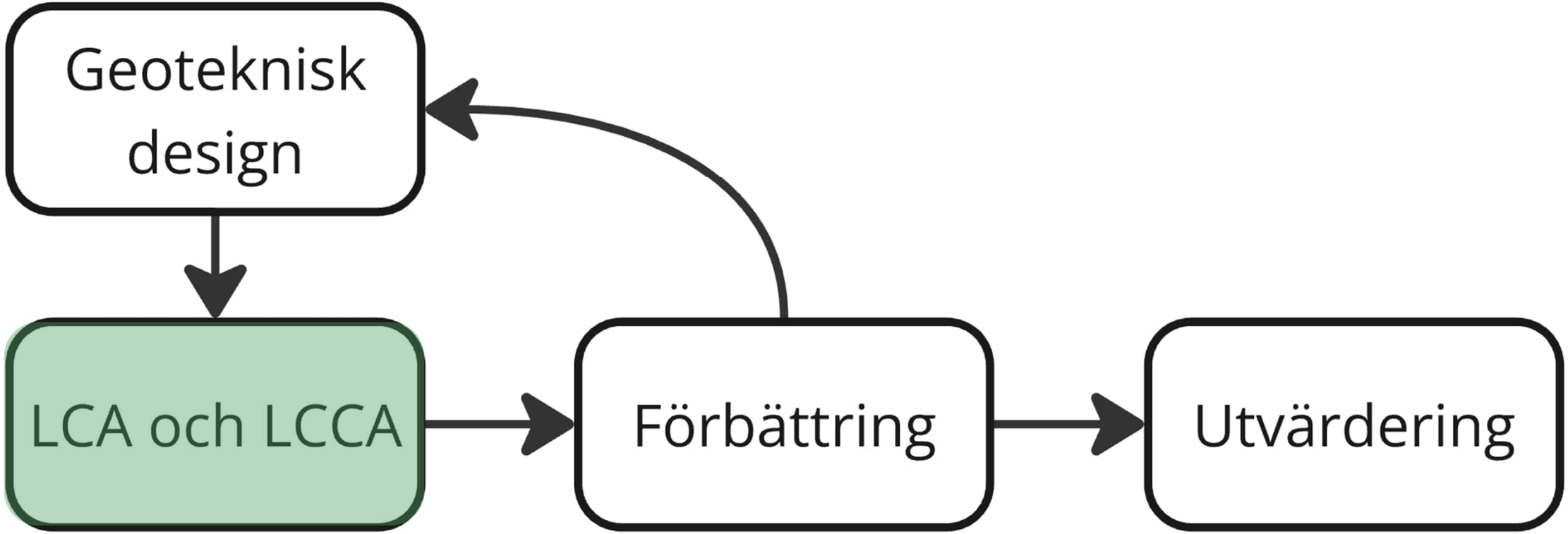
- Ramverk
  - LCA och LCCA är integrerat i den geotekniska processen
  - Inkluderar osäkerheter
  - Beslutsstöd med avseende på miljöpåverkan och LCC i valet av geotekniska alternativ
- Beräkningsexempel





- Handledare KTH: Stefan Larsson, Johan Spross, Anna Björklund
- Projektgrupp: Åsa Lindgren, Ulf Wiklund
- Referensgrupp: Minna Karstunen, Olle Båtelsson, Robert Karlsson, Tabita Gröndal

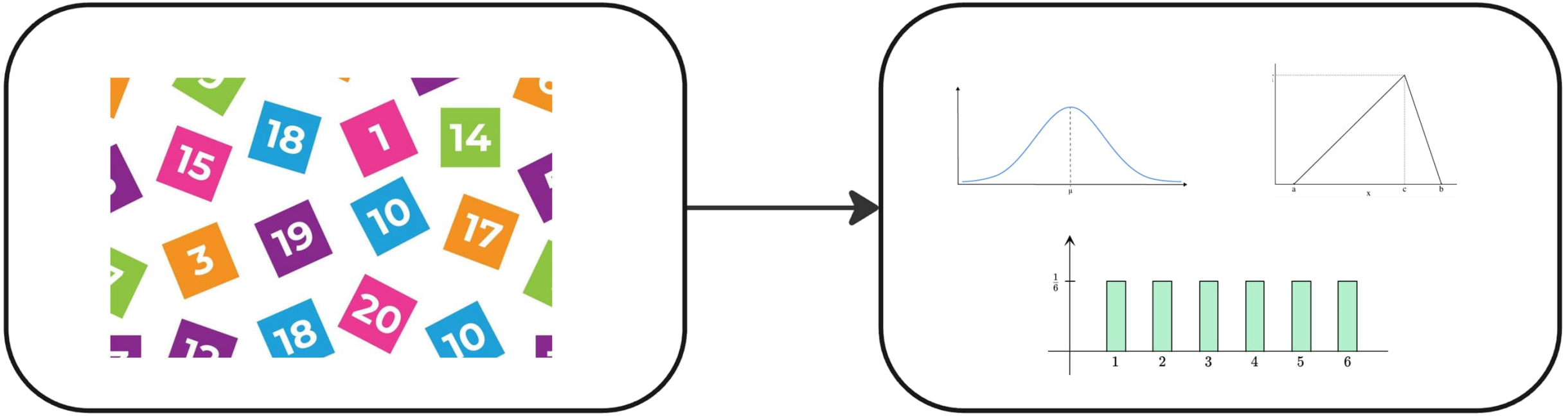
Ramverket förenklat



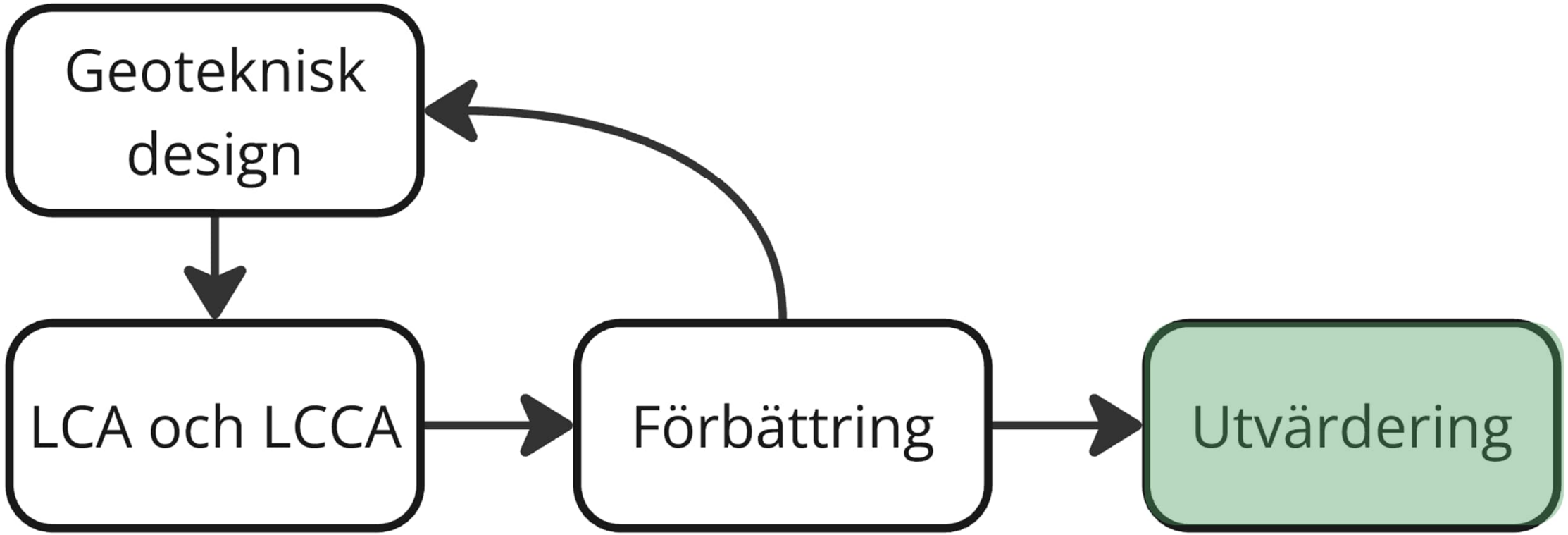
Samuelsson, I., Spross, J., and Larsson, S. (2024) Integrating life-cycle environmental impact and costs into geotechnical design.
Proceedings of the Institution of Civil Engineers-Engineering Sustainability 177(1), 19-30

Osäkra parametrar LCI

- Mängder (tex volymer, längder, vikter, avstånd)
- Emissionsfaktorer (tex kg CO_2e/m^3)
- Enhetskostnader (tex SEK/m^2)
- Miljökostnad (tex SEK/kg CO_2e) (monetariseringsfaktor)



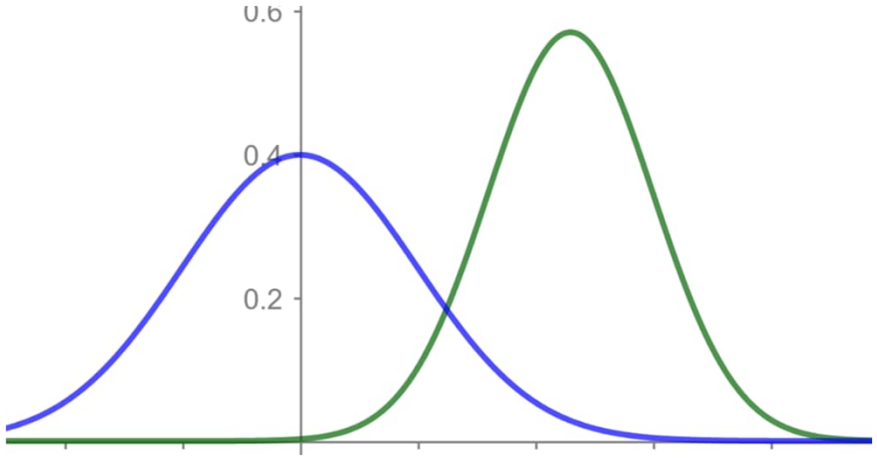
Ramverk utvärdering



Samuelsson, I., Spross, J., and Larsson, S. (2024) Integrating life-cycle environmental impact and costs into geotechnical design. *Proceedings of the Institution of Civil Engineers-Engineering Sustainability* 177(1), 19-30

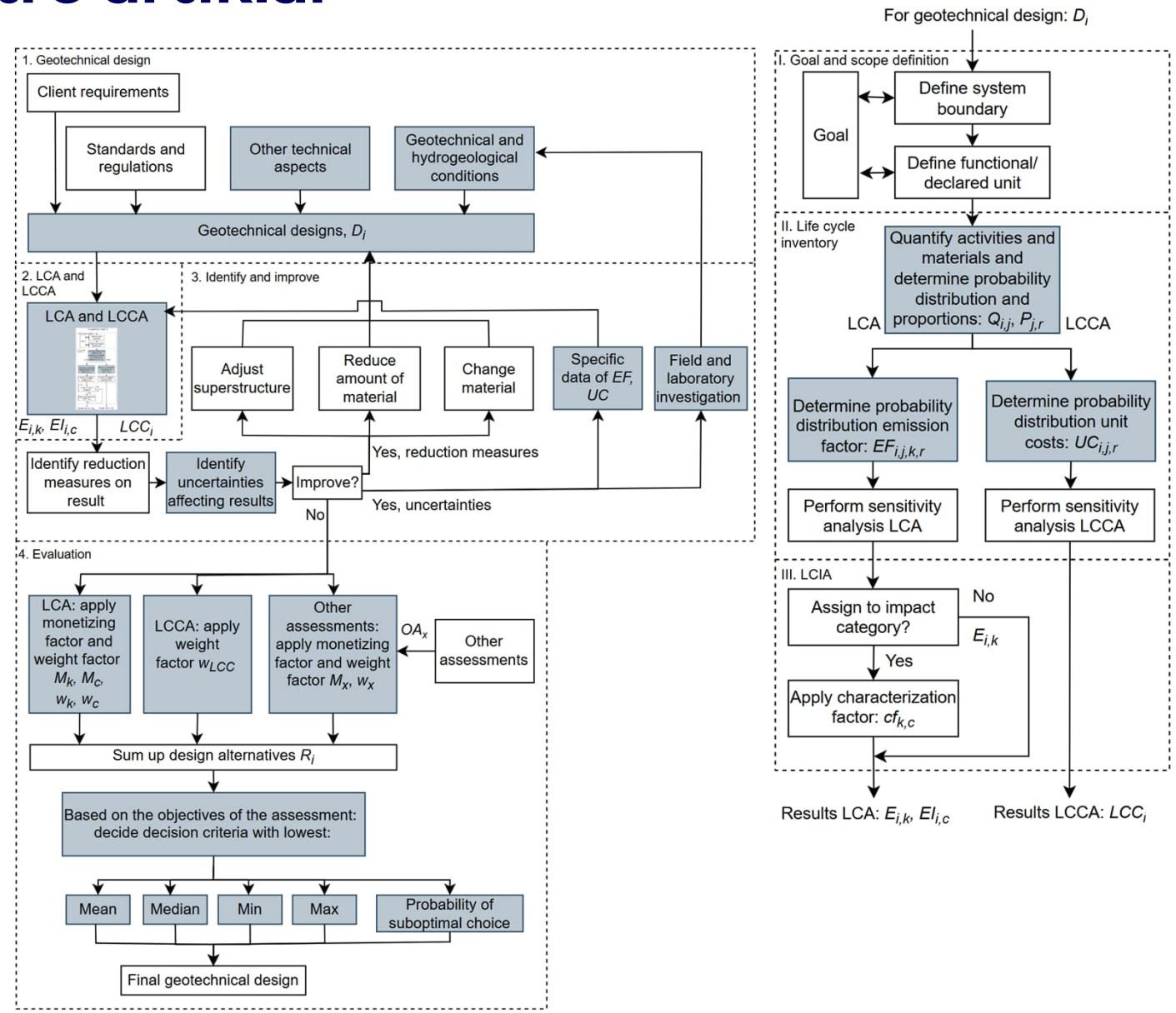
Utvärdering av resultaten

- Flera resultat med olika enheter:
  - LCA: klimatpåverkan, försurning, övergödning, landanvändning osv.
  - LCCA: LCC
- Sammanvägning: monetariseringsfaktor
  - samhällsekonomisk värdering
- Viktningsfaktor
  - projektspecifika värderingar
- Sannolikhet att välja ”fel” alternativ



Ramverksutveckling i tre artiklar

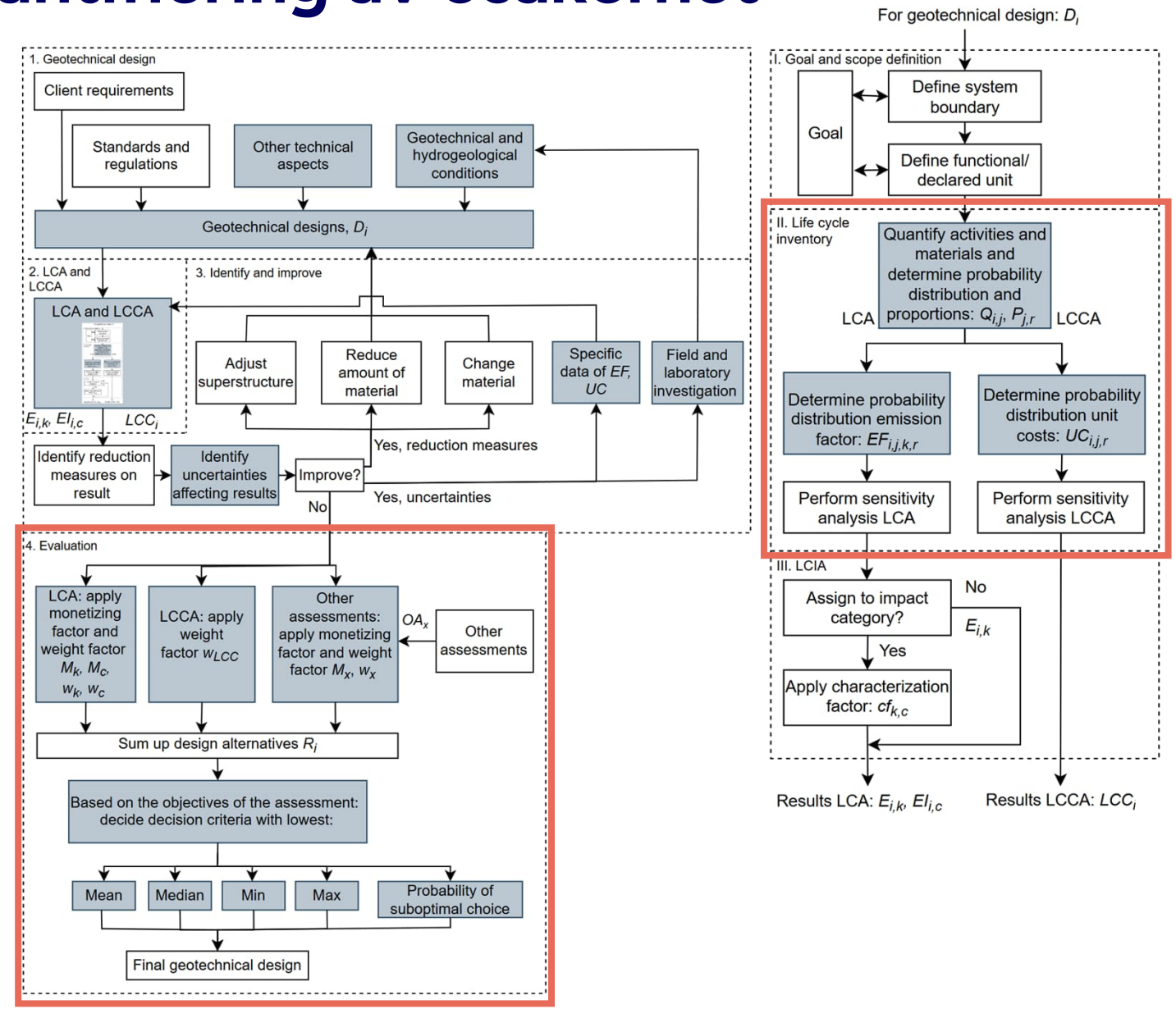
1. Integrering
2. Parameterosäkerheter
3. Kvantifiera osäkerheter och inkludera osäkerheter relaterade till val av leverantör



Samuelsson, I., Spross, J., Björklund, A., and Larsson, S. (2026)
Probabilistic evaluation of climate impact and life cycle cost of geotechnical designs (submitted)

Leverantörsval och kvantifiering av osäkerhet

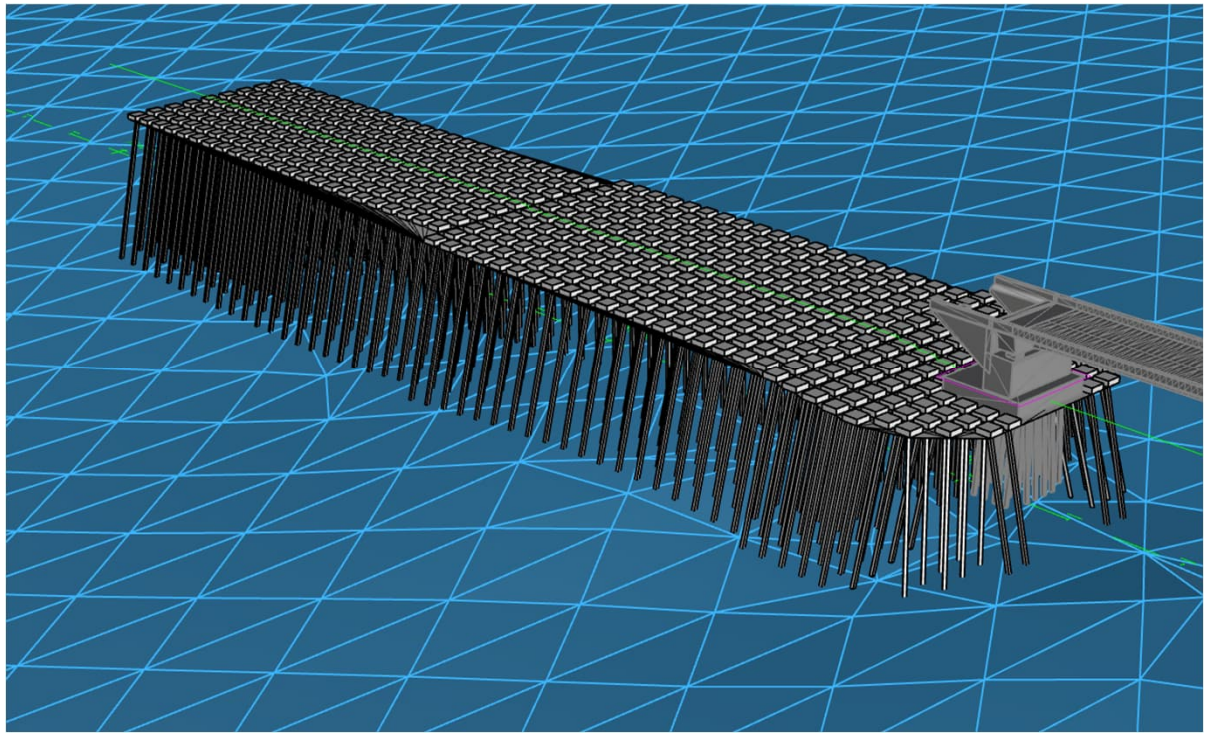
1. Livscykelinventering (LCI)
2. Åsätta sannolikhetsfördelningar
   I. Klassificera osäkerheten
   II. Välja fördelningar och parametrar
3. Propagera osäkerheten
4. Känslighetsanalys och rankning av resultatet
5. Analys av osäkerheten i beslutet



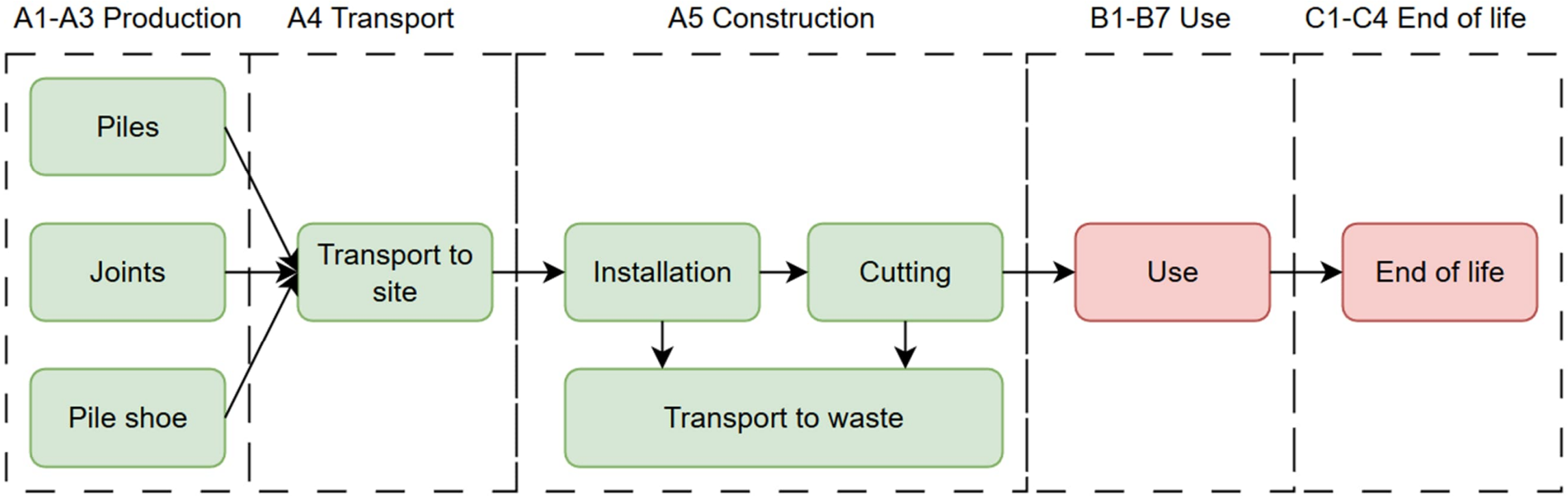
Samuelsson, I., Spross, J., Björklund, A., and Larsson, S. (2026)
Probabilistic evaluation of climate impact and life cycle cost of geotechnical designs (submitted)

Beräkningsexempel: bankpålning järnväg

- Klimatberäkning av de slagna prefabricerade betongpålarna.
- Inte bara ”längd installerad betongpåle * emissionsfaktor från Trafikverket”.



Systemgränser betongpålar (SP2)



Funktionell jämförande enhet: kg CO_2e/m påle

Samuelsson, I., Spross, J., Björklund, A., and Larsson, S. (2026)
Supplier selection under uncertainty: a probabilistic climate impact assessment in geotechnical design (manuscript)

1. Livscykelinventering mängder

Produktion (A1-A3):

- Total producerad pållängd:
  - Installerad
  - Bortslagen
  - Kapad
  - Designen – c/c-avståndet
- Antal skarvar
- Pålskor

Transport (A4):

- Sex leverantörer med olika avstånd till planerad byggarbetsplats.

Konstruktion (A5):

- Installation
- Kapning
- Transport av avfall

1. Livscykelinventering emissionfaktorer

Produktion och transport (A1-A4):

- EPDer från sex leverantörer av:
  - Pålar [kg CO_2e/m påle]
  - Skarvar [kg CO_2e/st]
  - Pålskor [kg CO_2e/st]
  - Transport [kg CO_2e/m påle/km]

Konstruktion (A5):

- Installation pålar (EPD):
  - Diesel
  - Elektrisk
- Kapning pålar
- Transport av avfall

2. Åsätta sannolikhetsfördelningar

Klassificera osäkerheten:

- Background uncertainty – relaterat till kvalitén i generisk data som inte representerar det tillverkningssätt, produktionsområde mm. som eftersöks eller är äldre data.
- Ground model uncertainty – tolkning av jordarter
- Calculation model uncertainty – antagningar och förenklingar i beräkningsmodell
- Decision uncertainty – osäkerhet i val av tex leverantör

Välja fördelningar och parametrar:

- Identifiera parametertyp: kontinuerlig eller diskret fördelning.
- Utvärdera inventerad data
- Bestämma osäkerhetsintervall
- Val av fördelningstyp (i exemplet triangel)

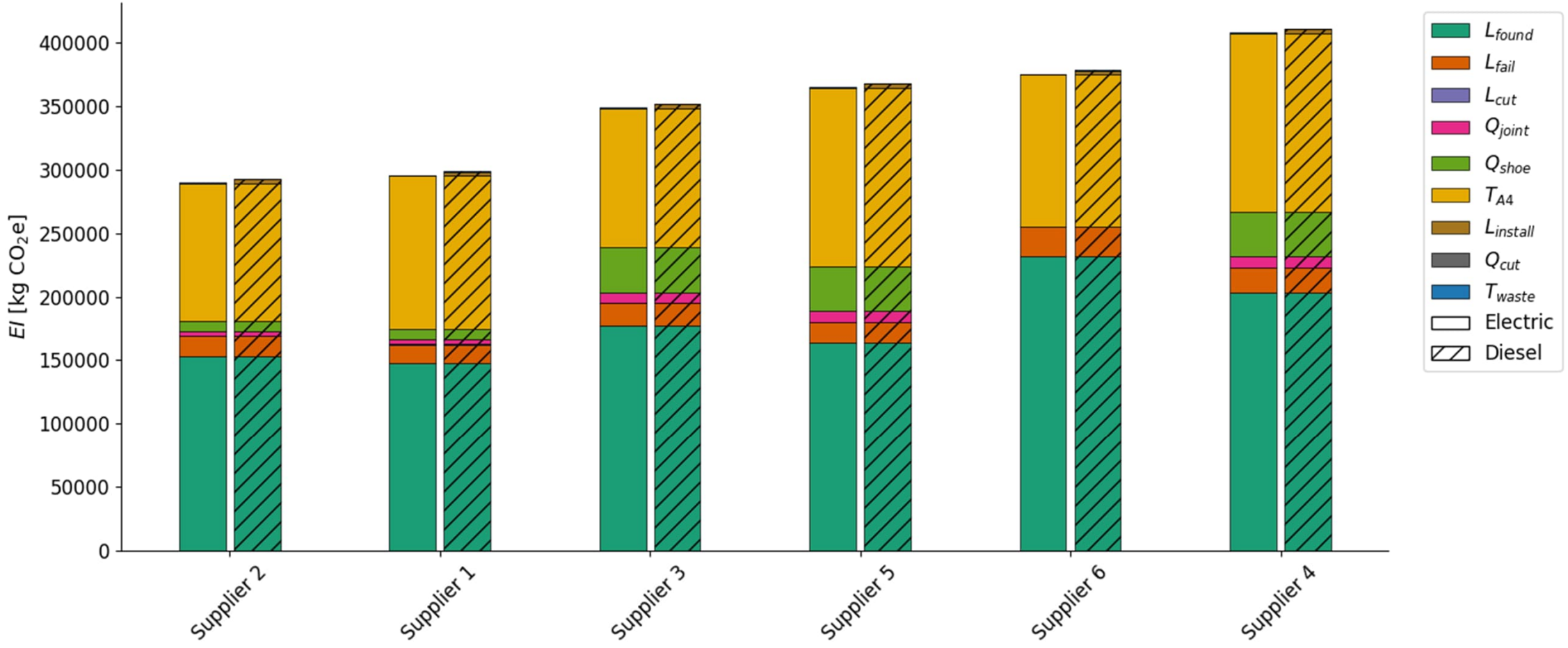
2-3. Åsätta sannolikhetsfördelningar och propagering

- Diskreta fördelningar
  - Sex leverantörer
  - Två installationssätt
- Övriga är kontinuerliga triangelfördelningar
- Monte Carlo simulering i Python för propagering av varje parameters fördelning samt slutlig klimatpåverkan.

Parameter	Symbol	Uncertainty class	Distribution	Parameter values
Quantity				
Piles	Q_{pile}	Calculation model	Triangular	$Tri(494, 549, 604)$ pcs
Installed pile length	$L_{\text{found}} = \sum L_i$	Ground model	Triangular	$Tri(L_i - 1, L_i, L_i + 1)$ m
Failure ratio	β_{fail}	Ground model	Triangular	$Tri(5, 10, 15)$ %
Surplus pile length	L_{cut}	Ground model	Triangular	$Tri(1.5, 2, 3.5)$ m
Joint	Q_{joint}	Ground model	Deterministic	$\sum L_i > 12$ pcs
Pile shoe	Q_{shoe}	Calculation model	Deterministic	Q_{pile} pcs
Transport distance A4	$D_{\text{A4,1-6}}$	Decision	Categorical	(1140, 1024, 1030, 1325, 1325, 1131) km
Proportion driven	α_{install}	Ground model	Triangular	$Tri(25, 50, 75)$ %
Cut piles	Q_{cut}	Calculation model	Deterministic	Q_{pile} pcs
Transport distance waste	D_{waste}	Calculation model	Triangular	$Tri(10, 20, 30)$ km
Emission factor				
Pile production	$EF_{\text{pile,1-6}}$	Background & decision	Categorical & triangular	Supplier specific μ with $Tri(0.95\mu, \mu, 1.05\mu)$ kg CO_2e/m
Joint production	$EF_{\text{joint,1-6}}$	Background & decision	Categorical & triangular	Supplier specific μ with $Tri(0.95\mu, \mu, 1.05\mu)$ kg CO_2e/pcs
Pile shoe production	$EF_{\text{shoe,1-6}}$	Background & decision	Categorical & triangular	Supplier specific μ with $Tri(0.95\mu, \mu, 1.05\mu)$ kg CO_2e/pcs
Transport A4-A5	EF_{tran}	Calculation model	Uniform	$U(0.01, 0.02)$ kg CO_2e/m/km
Installation	EF_{inst}	Background & decision	Categorical & triangular	$\mu\left(EF_{\text{inst,el}}, EF_{\text{inst,diesel}}\right) \in (0.35, 0.48)$ with $Tri(0.95\mu, \mu, 1.05\mu)$ kg CO_2e/m
Cutting	EF_{cut}	-	Deterministic	0 kg CO_2e/pcs

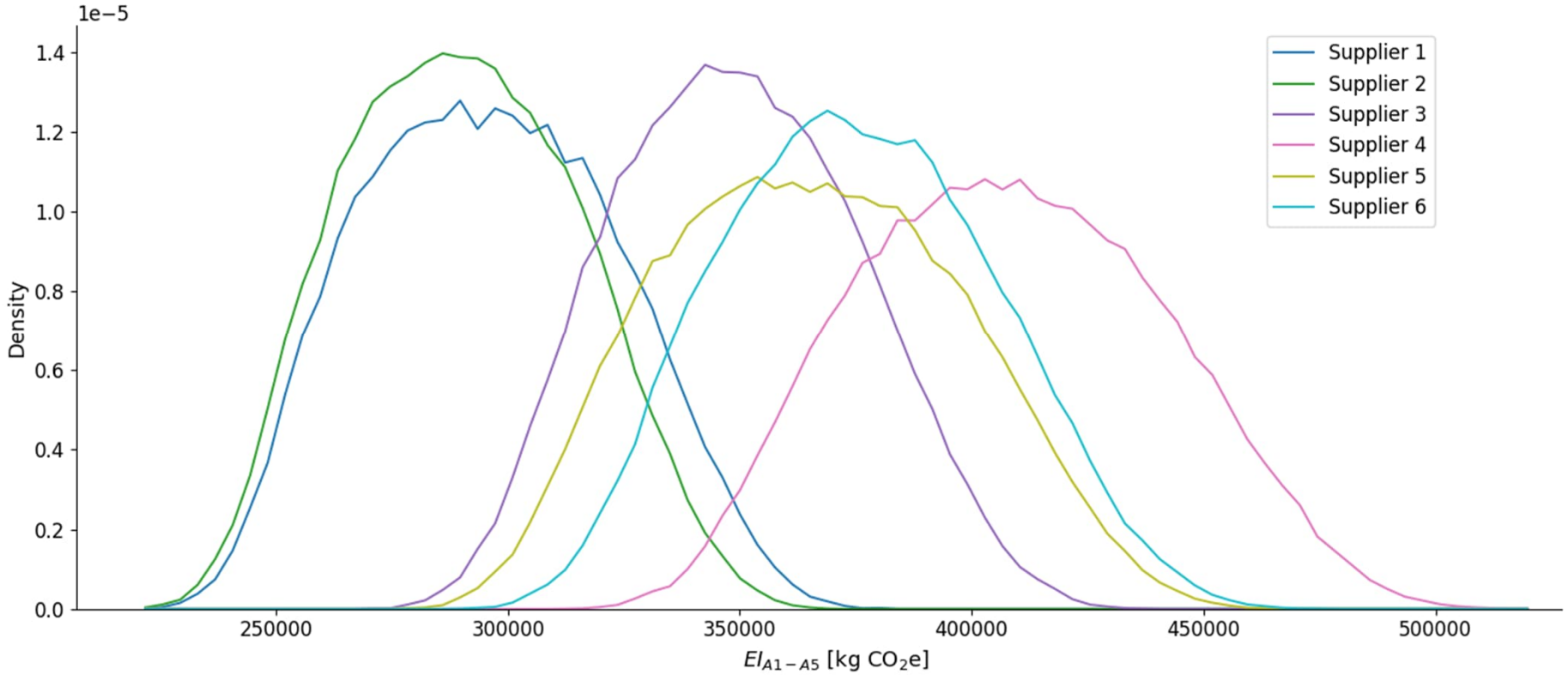
Samuelsson, I., Spross, J., Björklund, A., and Larsson, S. (2026)
Supplier selection under uncertainty: a probabilistic climate impact assessment in geotechnical design (manuscript)

Beräkning – troligaste värden



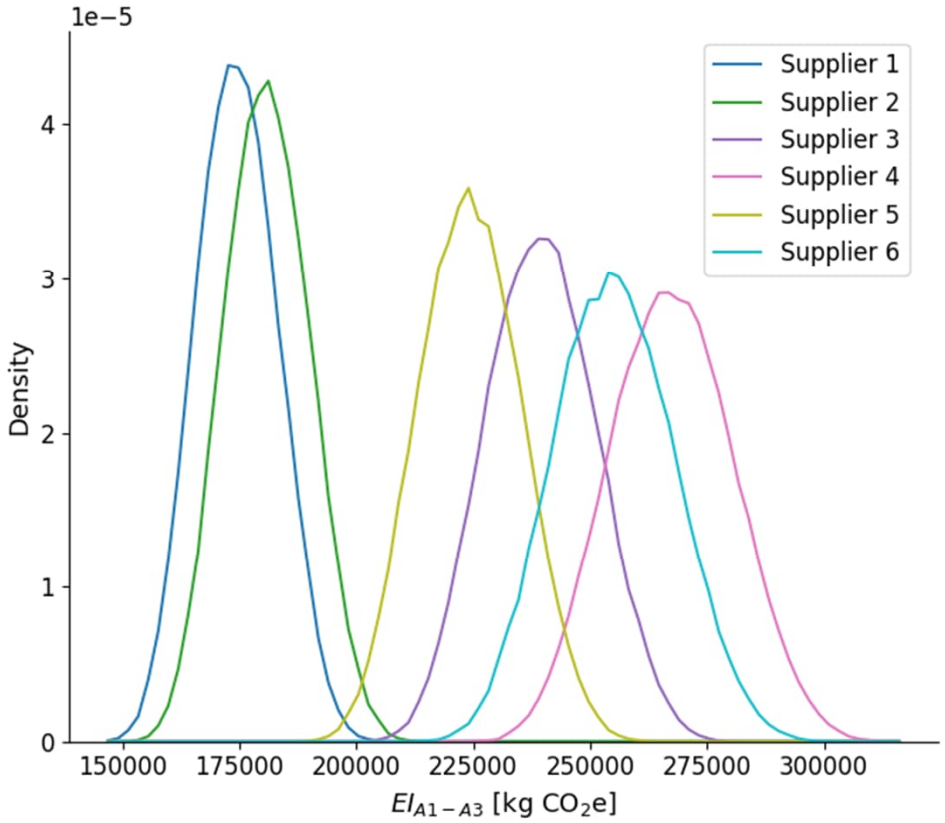
Samuelsson, I., Spross, J., Björklund, A., and Larsson, S. (2026)
Supplier selection under uncertainty: a probabilistic climate impact assessment in geotechnical design (manuscript)

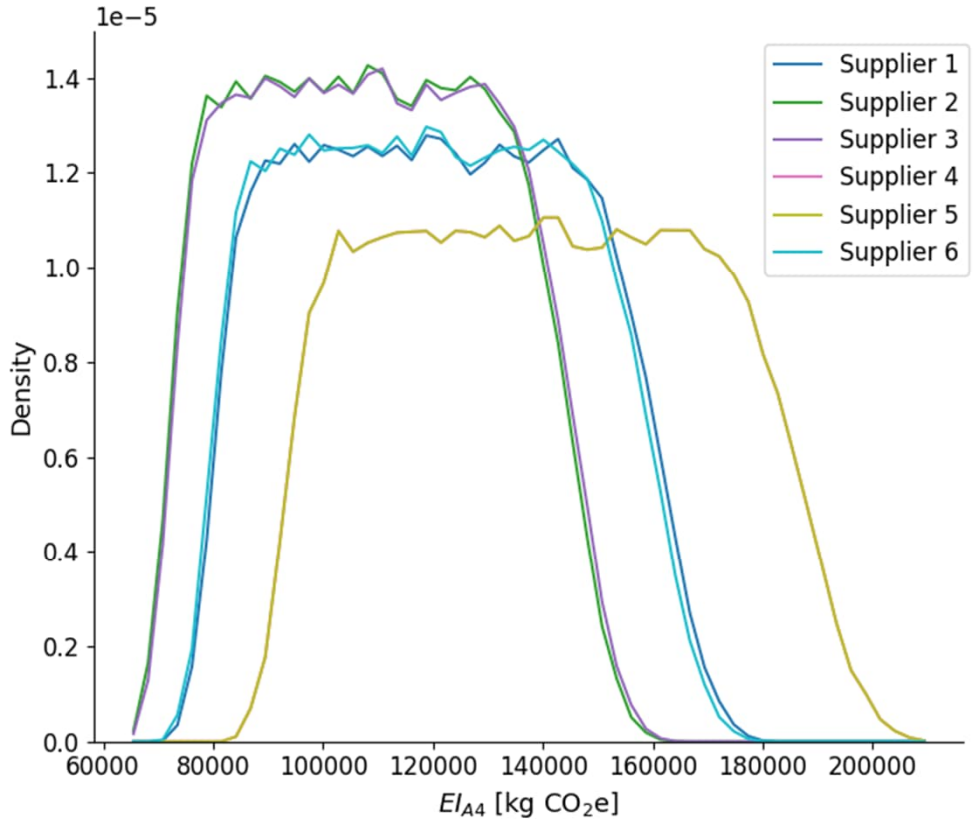
Probabilistisk beräkning A1-A5



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Probabilistisk beräkning A1-A3, A4



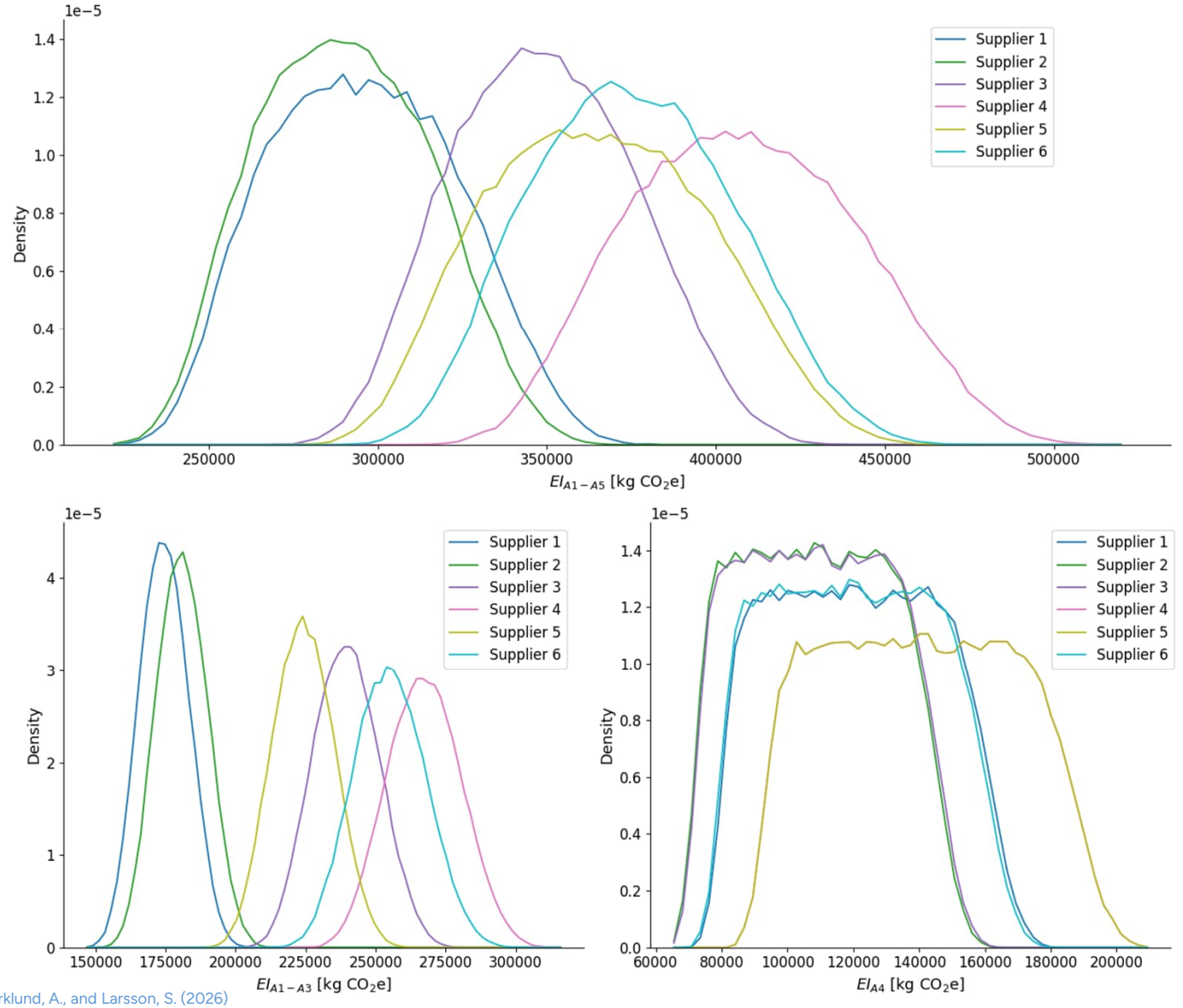


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Probabilistisk beräkning ranking

- Det/A1-A5: 2, 1, 3, 5, 6, 4
- A1-A3: 1, 2, 5, 3, 6, 4
- A4: 2, 3, 6, 1, 4 & 5

A1-A3 avgör parordningen men A4 påverkar relativa rankingen i paren

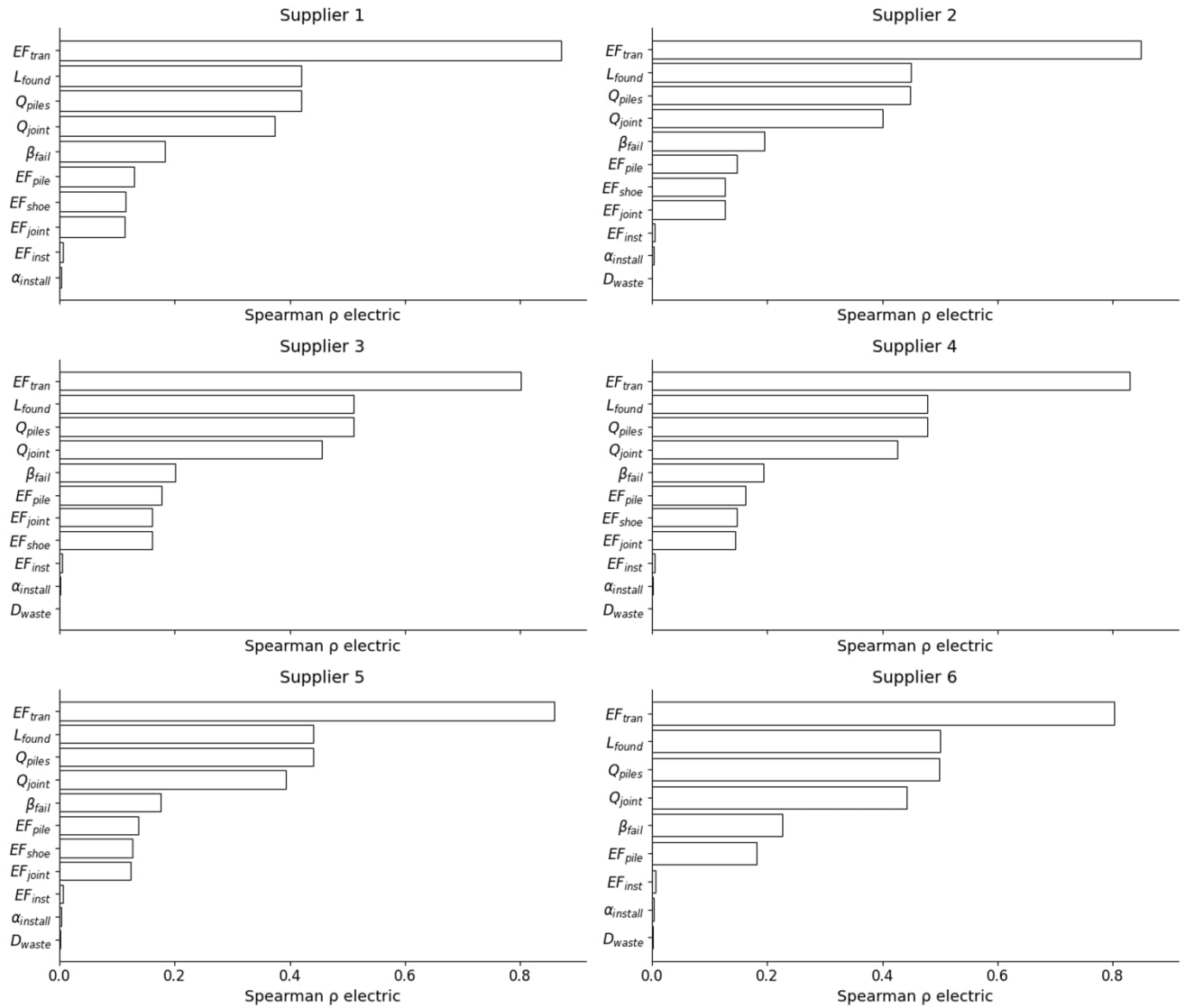


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Supplier selection under uncertainty: a probabilistic climate impact assessment in geotechnical design (manuscript)

4. Känslighetsanalys och ranking

Spearman ranking visar hur drivande en parameter är i simuleringsresultatet.

1. Emissionsfaktor transport
2. Installerad pållängd
3. Antal pålar
4. Antal skarvar

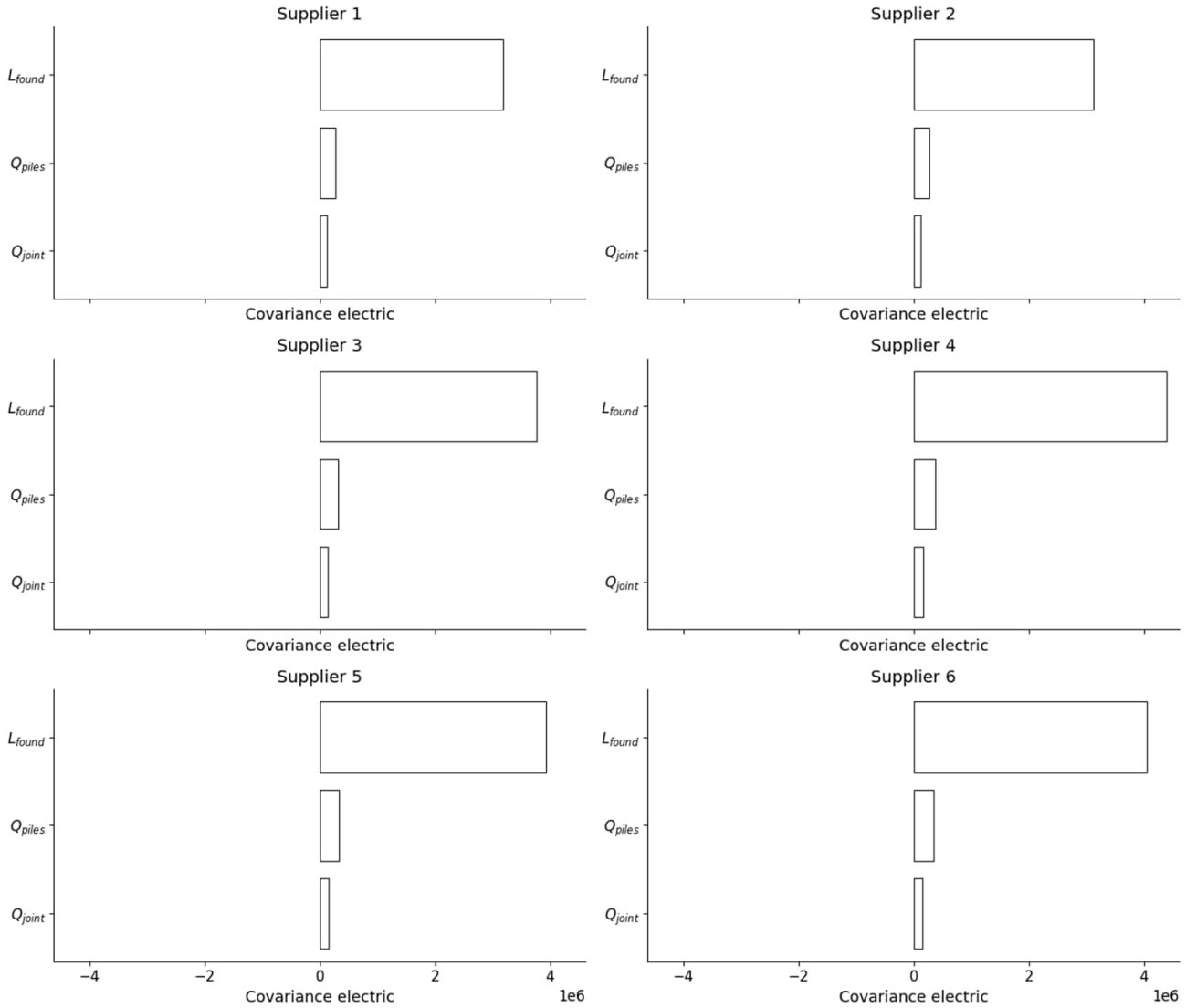


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4. Känslighetsanalys och ranking

Covarians visar hur drivande en parameter är i spridningen i resultatet.

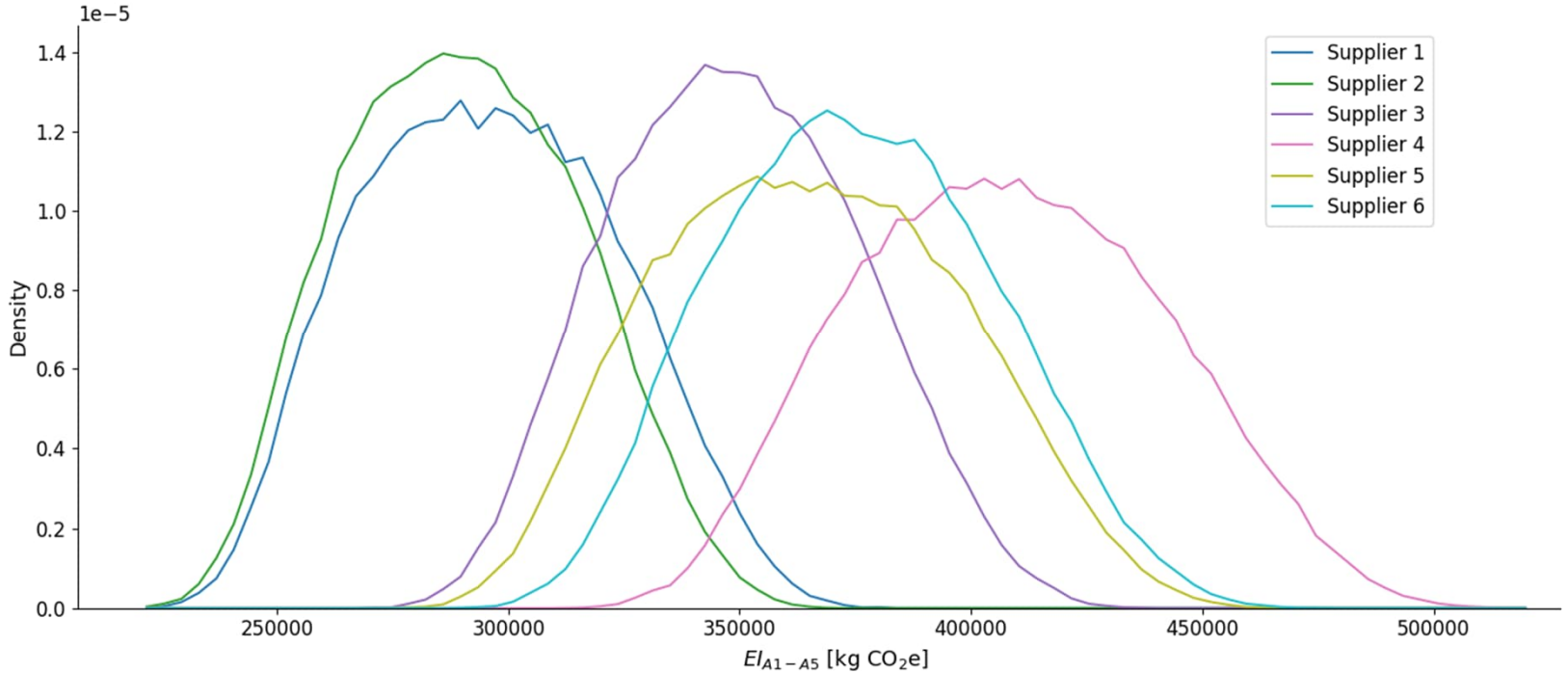
1. Installerad pållängd
2. Antal pålar
3. Antal skarvar



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Supplier selection under uncertainty: a probabilistic climate impact assessment in geotechnical design (manuscript)

5. Analys av osäkerheten i beslutet

- Kvantifiera sannolikheten att ett alternativ har en lägre klimatpåverkan $P(EI_a < EI_b)$
- Leverantör 2 har lägst klimatpåverkan i 84 % av simuleringarna, leverantör 1 i 16 % och övriga 0 % sannolikhet att ha lägst klimatpåverkan.



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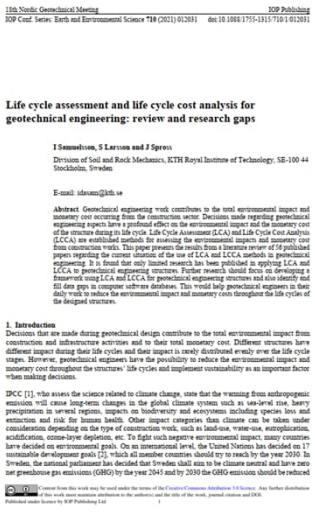
Höjdpunkter

- En strukturerad hållbar geoteknisk projektering under osäkerhet är avgörande för att inte redan i tidiga skeden begränsa möjligheten att senare kunna välja klimatsmarta grundläggningslösningar som tex kräver större utrymme.

- Ramverket är inte begränsat av ett fåtal scenarier utan kan ta med sig hela osäkerheten genom hela processen och möjliggör iterativa förbättringar.

- Både samhällsekonomiska och projektspecifika värderingar vägs in i beslutet.

Mer att läsa



10th Nordic Geotechnical Meeting — IOP Publishing
IOP Conf. Series: Earth and Environmental Science **710** (2021) 012031 — doi:10.1088/1755-1315/710/1/012031

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

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E-mail: idasam@kth.se

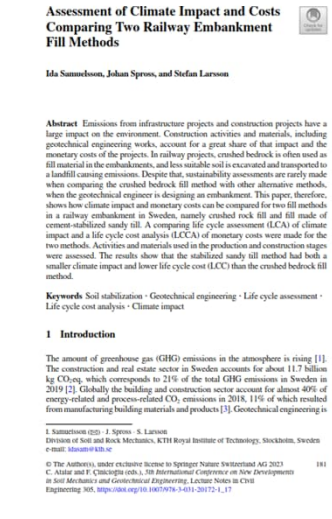
Abstract Geotechnical engineering work contributes to the total environmental impact and monetary cost occurring from the construction sector. Decisions made regarding geotechnical engineering aspects have a profound effect on the environmental impact and the monetary cost of the structure during its 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

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Assessment of Climate Impact and Costs Comparing Two Railway Embankment Fill Methods

Ida Samuelsson, Johan Spross, and Stefan Larsson

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

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Engineering Sustainability
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Integrating life-cycle environmental impact and costs into geotechnical design

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Construction and infrastructure projects account for a large share of global greenhouse gas emissions. Included in these projects are geotechnical engineering works, which cause environmental impact and costs throughout their life cycle. In the geotechnical design process, the geotechnical engineer often has design choices where different methods and materials can be used. If assessments of environmental impact and costs were to be integrated into the geotechnical design process, the geotechnical work could be made more sustainable. As a result of this, there is a need for research on integrating the assessments of environmental impact and costs into the geotechnical design process. This paper, therefore, presents a methodology showing how life-cycle assessment and life-cycle cost analysis could be integrated into the geotechnical design process. The presented methodology is then illustrated in a practical example for assessing the climate impact and costs of high-speed railway embankment fill methods.

Keywords: climate impact/cost/geotechnical engineering/LCA/LCCA/life-cycle assessment

Notation

$CIA_{i,m}$	characterisation factor of the ith emission of impact category m	$x_{i,LCI}$	converted and weighted LCI result of the ith emission of $Q_{i,e}$
CO_2, $CO_{2,LCI}$, $CO_{2,m}$	conversion factors for $E_{i,e}$, $LCC_{i,e}$, $IC_{i,e,m}$ and $OA_{i,e}$ of $Q_{i,e}$	$x_{i,q}$	converted and weighted results of other assessments $OA_{i,q}$
$CV_{i,LCI}$, $CV_{i,j}$	intermediate conversion factors needed for $EF_{i,LCI}$ and $UC_{i,j}$	$x_{i,m}$	converted and weighted LCIA result of impact category m of $Q_{i,e}$
D_i	geotechnical design i	$x_{i,j}$	converted and weighted LCC result of $Q_{i,j}$
$E_{i,LCI}$	life-cycle inventory (LCI) result; amount of the ith emission of $Q_{i,e}$		
$EF_{i,LCI}$	emission factor of the ith emission of $Q_{i,e}$		
$IC_{i,e,m}$	life-cycle impact assessment (LCIA) result; amount of impact category m of $Q_{i,e}$		
$LCC_{i,j}$	life-cycle cost (LCC) result; monetary cost of $Q_{i,j}$		
$OA_{i,q}$	other assessment results of $Q_{i,q}$		
$Q_{i,e}$	quantity i of a material or activity of D_i summed, converted and weighted result of design i		
$R_{i,j}$	unit cost for $Q_{i,j}$		
$UC_{i,j}$	weighting factors for $E_{i,LCI}$, $LCC_{i,j}$, $IC_{i,e,m}$ and $OA_{i,q}$ of $Q_{i,j}$		

1. Introduction

Globally, the building and construction sectors accounted for almost 40% of the energy- and process-related carbon dioxide (CO_2) emissions in 2018 (GlobalABC, 2019). Thus, construction and infrastructure projects must reduce their climate impact if international and national goals are to be be achieved – for example, goal 13, climate action, and the other 16 goals for sustainable development stated by the UN (2022), including environmental, economic and social sustainability (Desa, 2016).

Sustainability in geotechnical engineering is a comparatively new research area. Samuelsson *et al.* (2021) reviewed 29 scientific papers assessing sustainability in geotechnical engineering using the methods life-cycle assessment (LCA) and life-cycle cost analysis (LCCA), which are established methods for assessing the



GEOTEKNIK
ur ett livscykelperspektiv

Genom att tillämpa livscykelberäkningar där man utvärderar hela konstruktionens livscykel, från råmaterialutvinning till slutskedet, kan ett mer hållbart val av en konstruktions utformning göras. I syfte att skapa förutsättningar för att minska både konstruktionens miljöpåverkan och kostnader utvecklar man nu på avdelningen för Jord- och bergmekanik på KTH just sådana beräkningsmetoder. Här skriver forskarna på KTH om det pågående projektet som sker med finansiering från Sven Tyréns Stiftelse och Trafikverket.

TEXT: [illegible]

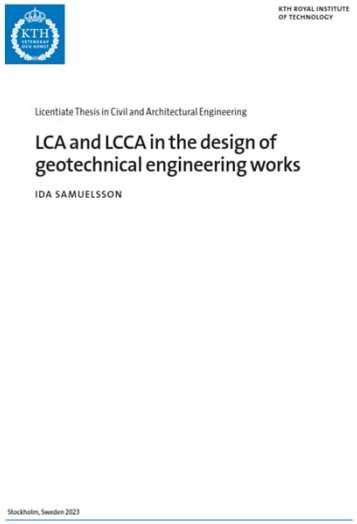
GEOTEKNIKENS ARBETE ÄR VIKTIGT FÖR HÅLLBARHETEN

Dagens praktiserande geotekniker har möjlighet att inkludera hållbarhetsaspekten i sitt dagliga arbete. Traditionellt har fokus legat på att endast använda överdimensionering av geotekniska konstruktioner, eftersom investeringskostnaden annars blir onödigt stor. Möjlighet att få hållbarare geotekniska konstruktioner finns om man använder ett livscykelperspektiv i hållbarhetsarbetet, där inte bara investeringskostnader, utan även användning och slutskedet inkluderas. Förutom kostnader är miljöpåverkan såsom klimatförändringar faktorer som geotekniken måste hantera. Exempelvis sker utsläpp av växthusgaser såsom koldioxid och metan i alla skeden av en konstruktions livstid. I Sverige står bygg- och fastighetssektorn för över 20 procent av de totala utsläppen av växthusgaser.

En minskning av utsläppen behövs för att Sveriges miljömål ska uppnås, där ett av målen är inga nettoutsläpp av växthusgaser senast år 2045. Inom byggprojekt är geotekniska konstruktioner nämligen ofta bland annat grundläggning, markförstärkning och slänstabilisering, vilka alla har en påverkan på klimatet under sin livscykel.

ETT INTEGRERAT HÅLLBARHETSARBETE INOM GEOTEKNIK

I ett doktorandprojekt på KTH:s Jord- och bergmekanik arbetar vi nu med livscykelanalys (LCA) och livscykelkostnadsanalys (LCCA) för geotekniska konstruktioner. LCA och LCCA är etablerade metoder för att utvärdera en produkts miljöpåverkan respektive livscykelkostnad (LCC). Doktorandprojektet syftar till att ta fram ett tillvägagångssätt för att integrera LCA och LCCA i den geotekniska designprocessen, vilket



KTH ROYAL INSTITUTE OF TECHNOLOGY

Licentiate Thesis in Civil and Architectural Engineering

LCA and LCCA in the design of geotechnical engineering works

IDA SAMUELSSON

Stockholm, Sweden 2023

1 **Probabilistic evaluation of climate impact and life cycle cost of geotechnical designs**
2
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