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Assessment of sustainable mass management strategies in infrastructure projects

Application of the SCORE method in a case study of
Lundbyleden

Master's thesis in Infrastructure and Environmental Engineering

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ABSTRACT

Large infrastructure projects often result in large amounts of excavated material. This raises important questions about handling, transport and opportunities for reuse. This thesis applies the SCORE (Sustainable Choice of Remediation) tool to the Lundbyleden project in Gothenburg to help guide sustainable management of these materials. Three mass management alternatives were compared: i) sending all the material to landfill, ii) sieving to allow for some reuse of masses, and iii) a combination of sieving and washing, increasing the reuse rate even more. Each alternative was assessed for its environmental, social and economic impacts to identify which best balanced the different aspects of sustainability. Further, three scenarios were developed to investigate the impact of different perspectives (sustainability vs. circular economy) and different references (“no action” or “landfill disposal”). The results, which were supported by Monte Carlo simulations, showed that treating the material to allow for reuse of masses generally gave better sustainability results than sending it directly to landfill.

The results indicate that the most preferred alternative depends on the evaluation approach. From an environmental standpoint, sieving combined with washing had the best environmental performance, due to reduced landfill use, lower transportation impacts and greater reuse potential. On the other hand, from a circular economy perspective that considers both environmental and economic factors, sieving alone was more favourable, as it delivered environmental benefits at lower cost compared to washing.

Including all sustainability dimensions resulted in considerable uncertainty, especially since the social dimension could only be assessed with limited data. The findings should therefore be interpreted as an assessment of circular mass management, rather than a full sustainability assessment. Although SCORE effectively structured the comparison, for infrastructure projects, referring to landfill disposal provides a more practical reference than ‘no action,’ as it mirrors actual decision making.

Key words: SCORE, mass management, infrastructure projects, sustainability, circular economy, waste hierarchy, sieving, soil washing, landfill disposal, soil contamination

List of Content

ABSTRACT	II
LIST OF CONTENT	III
ACKNOWLEDGEMENT	V
NOTATIONS	VII
 1 INTRODUCTION	 1
1.1 Background	1
1.2 Aim	2
1.3 Limitations	3
 2 THEORY	 4
2.1 Mass management in infrastructure projects	4
2.2 Legislation and regulation for excavated soil	5
2.3 Technical properties of excavated material	7
2.4 Environmental properties of the excavated material	9
2.5 Sustainability assessment and Circular economy	11
2.6 Decision support methods	12
2.6.1 Cost benefit analysis	12
2.6.2 MCDA	13
2.6.3 SCORE	13
2.7 Uncertainty	15
2.8 Theoretical synthesis and implication for mass management	15
 3 CASE STUDY: LUNDBYLEDEN	 16
3.1 Site description	16
3.2 Geology	18
3.3 Technical and environmental properties of materials at the site	19
3.4 Current mass management strategy	21
3.5 Control and treatment of surface and groundwater during construction	22
 4 METHODOLOGY	 23
4.1 Literature review	24
4.2 Case Study Lundbyleden	25
4.3 The SCORE methodology	25
4.3.1 Selection of relevant criteria	26
4.3.2 Weighting and Scoring	28

4.3.3	Uncertainties and Sensitivity Analysis	29
5	MANAGEMENT ALTERNATIVES OF THE EXCAVATED MASS	30
5.1	Reference Alternative	30
5.2	Alternative 1: Landfill Disposal	30
5.3	Alternative 2: Sieving	30
5.4	Alternative 3: Sieving and Washing	31
6	RESULTS	33
6.1	Scenario 1a	34
6.2	Scenario 1b	41
6.3	Scenario 2	43
7	DISCUSSION	46
7.1	Main findings	46
7.2	The SCORE methodology for assessment of mass management alternatives	48
7.3	Further analysis	49
8	CONCLUSIONS AND RECOMMENDATIONS	50
	REFERENCES	52
	APPENDICES	54

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Göteborg June 2026

Kamal Said

Statement on the use of AI

Regarding AI use, it was used to improve the report's textual quality, focusing on grammar to ensure coherence. ChatGPT was used for editing and rephrasing to boost clarity and readability, while Grammarly was utilised for proofreading and maintaining language quality. All content, including analyses, interpretations, and conclusions, is solely the author's original work. The author has reviewed and verified all AI-assisted material and takes full responsibility for its accuracy and scientific integrity.

Notations

LIST OF ABBREVIATION

SCORE	Sustainable choice of remediation
MCDA	Multi criteria decision analysis
NPV	Net present value
CBA	Cost benefit analysis
STA	Swedish transport administration
EPA	Environmental protection agency
MLV	Most likely value
GHG	Greenhouse gas emission
KM	Sensitive land use
MKM	Less sensitive land use
FA	Hazardous waste
SC	Source contamination
RA	Remedial action
bgl	Below ground level

List of figures

FIGURE 1:THE THREE SUSTAINABILITY DOMAINS, WHERE THE MOST SUSTAINABILITY IS DEFINED BY ALL THE DOMAINS (ROSÉN ET AL., 2015).....	14
FIGURE 2:OVERVIEW AND LOCATION OF LUNDBYLEDEN PROJECT (SWEDISH TRANSPORT ADMINISTRATION, N.D.-A).	17
FIGURE 3:THE GEOLOGICAL MAP OF LUNDBYLEDEN (VEIDEKKE, 2025).	18
FIGURE 4: THE FOCUSED AREA (MINELUNDSVÄGEN) IN THE LUNDBYLEDEN PROJECT (VEIDEKKE,2026).	21
FIGURE 5 OVERVIEW OF THE WORKING PROCESS.	23
FIGURE 6: SCORE DECISION-SUPPORT FRAMEWORK BY ROSÉN ET AL., 2015). THIS FRAMEWORK IS ORIGINALLY DEVELOPED FOR THE ASSESSMENT OF THE DIFFERENT REMEDIATION PROJECTS AND THEIR IMPACT ON SUSTAINABILITY.	25
FIGURE 7: OVERVIEW OF THE SECOND MANAGEMENT STRATEGY (ALTERNATIVE 2).....	31
FIGURE 8: OVERVIEW OF THE THIRD MASS MANAGEMENT STRATEGY (ALTERNATIVE 3).	32
FIGURE 9: SUSTAINABILITY SCORE FOR ENVIRONMENTAL AND SOCIAL. ALTERNATIVE 1: EXCAVATION AND LANDFILL DISPOSAL, ALTERNATIVE 2: EXCAVATION AND SIEVING, ALTERNATIVE 3: EXCAVATION AND SIEVING COMBINED WITH SOIL WASHING.....	35
FIGURE 10 ENVIRONMENTAL AND SOCIAL EFFECTS DUE TO THE ALTERNATIVES AND REMOVAL OF SOURCE CONTAMINATION. ALTERNATIVE 1: EXCAVATION AND LANDFILL DISPOSAL, ALTERNATIVE 2: EXCAVATION AND SIEVING, ALTERNATIVE 3:EXCAVATION AND SIEVING COMBINED WITH SOIL WASHING.	36
FIGURE 11: ECONOMIC SUSTAINABILITY FOR THE ALTERNATIVES IN THE FIRST SCENARIO, WHERE ALTERNATIVE 1: EXCAVATION AND LANDFILL DISPOSAL, ALTERNATIVE 2: EXCAVATION AND SIEVING, ALTERNATIVE 3: EXCAVATION AND SIEVING COMBINED WITH SOIL WASHING.	37
FIGURE 12:WEIGHTS FOR THE DIFFERENT DOMAINS AND CRITERIA IN THE ASSESSMENT.	38
FIGURE 13:(A) PROBABILITY DISTRIBUTIONS OF SUSTAINABILITY INDICES FOR THE THREE ALTERNATIVES AND (B) PROBABILITY OF EACH ALTERNATIVE BEING IDENTIFIED AS THE MOST SUSTAINABLE ALTERNATIVE IN SCENARIO 1A.	39

FIGURE 14: SENSITIVITY ANALYSIS FOR THE ALTERNATIVES IN SCENARIO 1A, WHERE A1= ALTERNATIVE 1, A2=ALTERNATIVE 2 AND A3=ALTERNATIVE 3.....	40
FIGURE 15: SUSTAINABILITY WEIGHTS FOR SCENARIO 1B.....	41
FIGURE 16:(A) PROBABILITY DISTRIBUTIONS OF SUSTAINABILITY INDICES FOR THE THREE ALTERNATIVES IN SCENARIO 1B AND (B) PROBABILITY OF EACH ALTERNATIVE BEING IDENTIFIED AS THE MOST SUSTAINABLE ALTERNATIVE IN SCENARIO 1B.	42
FIGURE 17:SUSTAINABILITY SCORE FOR ENVIRONMENTAL AND ECONOMIC. ALTERNATIVE 1: SIEVING, ALTERNATIVE 2: SIEVING COMBINED WITH SOIL WASHING.....	44
FIGURE 18: (A) PROBABILITY DISTRIBUTIONS OF SUSTAINABILITY INDICES IN SCENARIO 2 AND (B) PROBABILITY OF EACH ALTERNATIVE BEING IDENTIFIED AS THE MOST CIRCULAR ALTERNATIVE IN SCENARIO 2.....	45

List of tables

TABLE 1: SHOWS THE MATERIAL PROPERTIES OF DIFFERENT SOIL TYPES FOR POSSIBLE MASS MANAGEMENT (SVENSK BYGGTJÄNST, 2023). _____	8
TABLE 2 GENERAL GUIDELINE VALUES FOR EXCAVATED MASSES WITH POSSIBLE CONTAMINATION CONTENTS, (VEIDEKKE,2026) _____	10
TABLE 3 THE SOIL TYPE VARIATIONS AT MINELUNDSVÄGEN (VEIDEKKE, 2025). ____	19
TABLE 4:THE MOST COMMON CONTAMINANTS AT LUNDBYLEDEN (VEIDEKKE,2026). MOST OF THE CONTAMINANTS EXCEED THE KM VALUES, WHEREAS ONE SAMPLES SHOWS THAT CONTAMINANTS ALSO EXCEED MKM-VALUES ACCORDING TO THE SITE-SPECIFIC GUIDELINE VALUES _____	20
TABLE 5 DESCRIPTION OF THE PERFORMANCE CRITERIA FOR THE ENVIRONMENTAL DOMAIN (ROSÉN ET AL., 2015). _____	26
TABLE 6: DESCRIPTION OF THE PERFORMANCE CRITERION FOR THE SOCIAL DOMAIN, ACCORDING TO (ROSÉN ET AL., 2015). _____	27
TABLE 7: BENEFITS (B) AND COSTS (C) IN THE ECONOMIC ASSESSMENT OF SCORE (ROSÉN ET AL., 2015) _____	28
TABLE 8: MARKING SCALE IN SCORE FOR THE ASSESSMENT OF THE ENVIRONMENTAL AND SOCIAL IMPACTS _____	29

1 Introduction

1.1 Background

Infrastructure projects commonly involve extensive excavation, transport, treatment, reuse, and disposal of soil and other excavated materials (OECD, 2019). The management of excavated masses is often one of the most important environmental challenges in large infrastructure projects, as large volumes of material must be handled within limited time frames, restricted construction areas and complex regulatory conditions. However, the excavated material can represent both a waste problem and a potential resource, depending on, for instance, contamination levels, geotechnical properties, project needs and reuse possibilities.

Construction waste is considered one of the largest waste streams in the European Union. Although recovery rates are often reported as high, the European Environment Agency reports that most of the recovery is based on low-grade applications, such as backfilling or use in road sub-bases, rather than full potential circular reuse (European Environment Agency, 2020).

A review by (Hale et al., 2021) states that infrastructure projects can produce surplus excavated soils that end up in landfill, despite their potential for reuse. The authors discuss that the potential for reuse is limited not only by technical factors but also by uncertainties regarding the regulatory framework, lack of sustainable mass management planning and difficulties in matching supply and demand among projects.

From a sustainability perspective, inefficient mass management can affect the environment. For instance, transport of excavated material often results in extensive fuel consumption, greenhouse gas emissions (GHG), air pollution, noise, traffic disturbances and risks related to traffic safety (OECD, 2019). Furthermore, disposal of reusable material at landfills also increases the demand for landfill capacity and creates a need for replacement with virgin aggregates. The OECD emphasises that mass management is crucial and that resource efficiency and circular economy measures need to be strengthened in infrastructure construction.

1.2 Aim

This thesis explores how to assess sustainability of different mass management alternatives in infrastructure projects, using Lundbyleden in Gothenburg as a case study.

The specific objectives are to identify and compare relevant mass management alternatives, evaluate their environmental, social and economic impacts, and assess the applicability of SCORE in this context. The comparison is based on a strategy of complete excavation and landfill disposal of all excavated material with other, potentially more sustainable, mass management alternatives using SCORE. The objectives also include examining SCORE's effectiveness as a decisions-support tool in the context of mass management and whether its framework and matrices are suitable for mass management in infrastructure projects or if some modifications are needed.

The study seeks to answer the following research questions:

1. Which mass management alternative is most sustainable according to the SCORE assessment?
2. How applicable is the SCORE methodology for assessing the sustainability of mass management alternatives in infrastructure projects?
3. Which criteria within SCORE have the greatest and least influence on the scoring and ranking of the mass management alternatives for Lundbyleden?
4. How do uncertainties, data limitations, and criteria selection influence the applicability and practical use of SCORE in infrastructure projects?
5. What adaptations are needed in SCORE to make it more applicable for sustainable mass management appraisal in infrastructure projects?

1.3 Limitations

The following limitations and assumptions related to the case study apply:

- The assessment focuses on a limited area at Lundbyleden (see chapter 3).
- The study is only assessing three alternative mass management strategies, including the one implemented at the project site, for the management of excavated mass.
- These alternatives are identified based on the assumption that the main contaminants in the soil to be excavated consist of PAHs and metals.
- The excavated soil comprises a mixture of filling material and various soil types with different grain sizes, but data availability is limited. Using the available case-specific information, consultations with external supervisors, and expert industry input, it was assumed for this case study 30% of the excavated soil is coarse-grained and 70 % is fine-grained. This distribution served as an input for the assessment, however, it should be perceived as a study-specific assumption, as actual proportion may vary based on site conditions and material characteristics.
- Factors such as transport distance, landfill availability, treatment capacity, and reuse opportunities are based on the specific conditions of the case study. Nevertheless, these factors are associated with large uncertainties.

The following limitations and assumptions related to the SCORE assessment apply:

- The SCORE assessment is based on data from literature review, the Lundbyleden case study, authors interpretation supported by inputs from projects experts and study-specific assumptions, all associated with various degrees of uncertainty.
- Not all the environmental, social and economic criteria were evaluated. The excluded criteria considered irrelevant to the case study. On the other hand, some economic and social criteria were omitted in the assessment because of limited data availability.

2 Theory

2.1 Mass management in infrastructure projects

Infrastructure projects often generate large volumes of excavated material, which must be managed in a way that is both technically feasible and environmentally safe (OECD, 2019). Depending on the material properties and contamination levels, excavated soil can either be reused as a resource, treated before reuse, or transported off-site for disposal. Therefore, mass management is an important part of infrastructure planning, as it affects transport demand, costs, waste generation, use of natural resources and environmental risks.

When excavated material is contaminated, its management becomes more complex, (European Commission, n.d.). If the contamination poses a risk to human health or the environment, remedial action may be required depending on the site conditions, land use and potential exposure pathways. In such cases, the material cannot automatically be reused, and further assessment is needed to determine whether it should be treated, reused under specific conditions, or sent to landfill.

Proper mass management can reduce the negative environmental impacts of infrastructure projects by limiting landfill disposal, reducing the need for virgin material and increasing the reuse of suitable excavated material. Treatment methods such as sieving or soil washing may improve the potential for reuse by separating or reducing contaminated fractions. In this way, mass management is closely connected to sustainable management and circular economy principles, especially when contaminated soil can be safely managed as a resource rather than as waste.

2.2 Legislation and regulation for excavated soil

The EU Waste Framework Directive provides essential guidance on waste management within the European Union (European Commission, n.d.). It establishes a waste hierarchy that prioritises prevention and reuse over recycling, recovery, and, ultimately, disposal. Consequently, excavated soil should not be immediately designated for landfill. Rather, its potential for safe reuse or treatment should be evaluated first. The potential for reusing excavated material depends on factors including contamination levels, material properties, and associated environmental risks. When material is contaminated or classified as hazardous waste, more stringent requirements govern its handling, documentation, and disposal. This consideration is particularly significant in infrastructure projects, where substantial quantities of soil and other materials are excavated, and the decision between reuse, treatment, or landfill disposal can have considerable environmental and economic impacts.

Within the context of this thesis, the Waste Framework Directive supports the consideration of treatment-based alternatives, such as sieving and soil washing, as preferable to direct landfill disposal when these methods enable safe reuse. If the material fails to meet environmental or technical standards, landfill disposal remains necessary. Thus, legislation and regulation are critical for determining how excavated material should be classified, managed, and potentially reused in sustainable mass management.

In Swedish infrastructure construction, excavated soil must be assessed to determine whether it should be treated as a resource or as waste (Swedish Transport Administration, 2023a). This reflects STA's interpretation and application of existing environmental guidance rather than legislation. According to the Swedish Transport Administration (STA), if the excavated material is secured within a reasonable time and is suitable from an environmental and technical perspective, it can be regarded as a resource rather than waste. However, even waste classified as mass can be reused in construction if it has acceptable technical properties and meets the contamination level for the intended site. The waste classified as mass can also be used as a resource if they become suitable after treatment.

Mass management is essential from a sustainability perspective. For example, the environmental benefits of using excavated mass as a resource must be weighed against the environmental impacts associated with transporting the material, including emissions and transport distance. Economic feasibility should also be considered when evaluating environmental benefits. In addition to sustainable management, the waste hierarchy is a key principle for preventing surplus masses and promoting the reuse and recovery of materials to minimise landfilling. According to the Swedish Transport Administration (2023a), to emphasise circularity and sustainable mass management, general legal frameworks for managing excavated mass should be supplemented with additional guidance.

2.3 Technical properties of excavated material

The management of excavated material and its potential for circular use are partly determined by material properties and technical feasibility. The technical material property parameters to consider, as shown in Table 1, include the grain size distribution of fine-grained soil, clay, and the organic content. These parameters partly determine whether a soil can be reused and for which technical purpose. Soils with coarse-grained sizes, such as sand and gravel, exhibit good drainage, high bearing capacity, and low compressibility, making them suitable for reuse. However, fine-grained soils are generally less preferable due to their low permeability and sensitivity to moisture variations. Content with low clay content ($\leq 2\%$) behaves similarly to granular material. However, material with a clay content $>2\%$ leads to increased cohesion and a potential for swelling and shrinkage. Generally, the material properties shown in the table below influence the handling, transport, and reuse options of the excavated material, and are therefore essential for mass management in infrastructure projects (Svensk Byggtjänst, 2023).

Table 1: shows the material properties of different soil types for possible mass management (Svensk Byggtjänst, 2023).

Material type	Name of soil or rock material	Content (weight %) X/Y			Example
		Fine fraction 0.063/0 mm	Clay fraction 0.002/0.063 mm	Organic content %/63 mm	
1	Rock type A	<10		≤2	Mica-poor granite or gneiss, and other hard rocks such as quartzite, and dolerite,
	Rock type B	<10		≤2	Mica-rich granite or gneiss, as well as other rock types with moderate strength
2	Block and boulder soils Coarse-grained soils	≤15		≤2	Stones, gravel, sand, sandy gravel, gravelly sand, gravelly till, and sandy till.
3A	Rock type C	≤15		≤2	Rocks with high mica content, clay shale, and coarse-grained granites,
3B	Mixed-grained soils	16–30		≤2	Clayey or silty sand Clayey or silty gravel
	Rock type D			≤2	Rocks with high mica content, clay shale, and unclassified rock material.
4A	Mixed-grained soils	31–40		≤2	Clayey or silty sand Clayey or silty gravel Clayey or silty till
4B	Fine-grained soils	>40	>40	≤2	Clay and clay till.
5A	Fine-grained soils	>40	>40	≤2	Silt, clayey silt, silty clay, silty till, and silty clay till.
5B	Mineral soils with organic content			2–6	Muddy clay and muddy silt.
6A	Organic mineral soils			6–20	Clay mud, silty mud, and sandy humus soil.
6B	Organic soils			>20	Mud, peat, and humus soil.

2.4 Environmental properties of the excavated material

Environmental properties of excavated material are also essential to determine how such material can be managed, reused, or disposed of in infrastructure projects. The key parameters include contaminant levels, leaching potential, and associated risks to the environment and human health.

Waste classification is governed by the EU Waste Framework Directive for determining whether waste is hazardous or non-hazardous. This directive is implemented in the Swedish legislation through the Waste Ordinance (Avfallsförordningen) (Swedish Government, 2020). The classification is based on the presence of hazardous substances and their properties, rather than solely on guideline values. The leaching behaviour and contaminant concentrations are important factors, as they determine the potential for pollutants to spread to groundwater and surface water and are relevant to the consideration of material reuse. Furthermore, related to the management of excavated masses, there are some materials with concentrations below the level of ‘Less than negligible risk’. This material can be reused without causing environmental or human impacts, as the contaminant levels are very low. In contrast, soil material with very high contaminant concentrations may be classified as hazardous waste (FA). Under the waste legislation, these materials are considered hazardous and require special treatment and disposal.

Generic guideline values for contaminated soils have been developed by the Swedish Environmental Protection Agency (EPA) (Naturvårdsverket, 2009). Table 2 presents the general guideline values for some contaminants such as metals and PAHs. These values are commonly used for risk assessments, but also for the classification of excavated masses regarding their level of contamination, since many landfills have permits related to these levels. The guidelines are risk-based and intended to protect multiple receptors, including human health, soil ecosystems, groundwater, and surface water. Two types of land use are considered when deriving the generic guideline values: sensitive land use (KM) and less sensitive land use (MKM). KM represents areas where contaminant exposure could be high, such as residential or recreational areas. MKM represents areas with lower exposure levels, such as industrial or commercial areas.

If the generic soil guidelines values are not representative enough for the site's actual conditions, site-specific guideline values can be applied. These guidelines specifically consider the site's specific conditions, such as soil characteristics, groundwater conditions, potential exposure pathways, and future land use. Site-specific guideline values are often applied when decisions on remediation and mass handling require a more precise evaluation of potential environmental, social, and economic impacts (Naturvårdsverket, 2009).

Table 2 General guideline values for excavated masses with possible contamination contents, (Veidekke, 2026)

<u>Substance/content</u>		KM	MKM	FA
Summa PAH, H	mg/kg TS	1	10	*
Summa PAH, M	mg/kg TS	3	20	*
Arsenic, (As)	mg/kg TS	10	25	1000
Barium, (Ba)	mg/kg TS	200	300	10000
Lead, (Pb)	mg/kg TS	50	400	2500
Cadmium, (Cd)	mg/kg TS	0,5	15	100
Cobalt, (Co)	mg/kg TS	15	35	100
Copper, (Cu)	mg/kg TS	80	200	2500
Chromium (Cr)	mg/kg TS	80	150	10000
Mercury (Hg)	mg/kg TS	0,25	2,5	1000
Zink Zn	mg/kg TS	250	500	2500

2.5 Sustainability assessment and Circular economy

The Brundtland Report describes sustainable development as fulfilling the needs of the current generation without hindering future generations from meeting their own needs (World Commission on Environment and Development, 1987). It is typically understood through three key aspects: environmental, economic and social sustainability. While these aspects are interconnected, each highlights different considerations crucial for evaluating whether an activity or decision is sustainable (Purvis et al., 2019). In mass management, this means selecting strategies that account for environmental, economic, and social impacts.

The circular economy (CE) offers a resource-centric view, meaning that it moves away from the traditional linear approach of extracting resources, using them and then disposing of waste. Instead, it emphasises keeping materials in use longer through strategies like reuse, recycling, and recovery, aiming to minimise waste and reduce reliance on virgin resources (Kirchherr et al., 2017). Although the CE is closely linked to sustainable development, the two concepts are distinct. Sustainability encompasses broader environmental, economic, and social dimensions, while the circular economy focuses specifically on the use and management of materials and resources.

This distinction matters especially for excavated soil in infrastructure projects, where large volumes of material are produced. From a CE standpoint, excavated materials should be seen as a potential resource rather than waste. Explore reuse, treatment, or recovery alternatives before landfilling, if the material meets environmental and technical standards. Relevant factors in this assessment include the volume of material landfilled, reuse potential, use of virgin materials, transportation and treatment needs, and evaluating the circularity of different mass management strategies.

2.6 Decision support methods

Decision-support methods enable systematic evaluation and comparison of various alternatives by considering multiple impacts and objectives. In sustainability assessments, it is essential to account for both monetary and non-monetary factors to support transparent, structured decision-making. This section presents Cost-Benefit Analysis (CBA), Multi-Criteria Decision Analysis (MCDA), and the SCORE methodology as key approaches for assessing different management strategies.

2.6.1 Cost benefit analysis

Cost-benefit analysis (CBA) is a decision-support tool that evaluates the positive and negative impacts of a project or alternative in monetary terms. Based on welfare economics, benefits represent gains in human well-being, whereas costs signify declines (Pearce et al., 2006). For instance, in contaminated land management, CBA helps compare the costs and benefits of various remediation projects. The measurement of cost and benefits follows net present value (NPV) equation as follows (Söderqvist et al., 2015):

$$NPV = \sum_{t=0}^T \frac{B_t - C_t}{(1 + r)^t} \quad (1)$$

where:

- NPV = net present value [SEK]
- B_t = benefit occurring at time (t), [SEK]
- C_t = cost occurring in time (t), [SEK]
- r = discount rate
- t = time period [year]

2.6.2 MCDA

Multi-criteria decision (MCDA) provides a framework for evaluating alternatives when multiple criteria must be considered. Unlike CBA, MCDA does not require all effects to be expressed in monetary terms and can therefore include monetary, quantitative (non-monetary), qualitative criteria within the assessment. This makes MCDA particularly valuable when environmental, social and economic effects cannot be captured by a single unit. This model requires definition of the alternatives and the relevant criteria that will be assessed, where each alternative's performance is assessed against each criterion. Different weights are assigned to the criteria, so that their importance is indicated, (Dodgson et al., 2009). A linear additive model is used to combine each alternative's performance across all criteria including their weights by calculating:

$$S_i = \sum_{j=1}^n W_j S_{ij} = W_1 S_{i1} + W_2 S_{i2} + \dots + W_n S_{in} \quad (2)$$

Where S_{ij} is the preference score for alternative i on criterion j and W_j is the weight for each criterion.

2.6.3 SCORE

The SCORE framework is a decision support tool designed to evaluate remediation alternatives for contaminated sites, focusing on sustainability. It employs multi criteria decision analysis (MCDA) to incorporate environmental, social and economic factors into the assessment (Rosén et al., 2015).

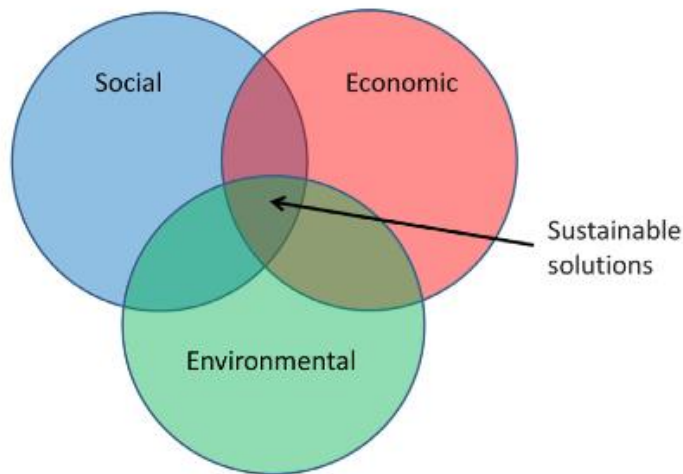


Figure 1: The Three Sustainability domains, where the most sustainability is defined by all the domains (Rosén et al., 2015).

SCORE organizes its analysis around the three sustainability dimensions: environmental, social and economic. The environmental and social components are assessed using specific criteria that reflects various potential impacts of the alternatives being considered. The economic aspect is examined from a societal standpoint through CBA, where possible, assigning monetary values to costs and benefits. Collectively, these three dimensions offer a structured way to compare alternatives based on sustainability (Rosén et al., 2015).

SCORE also allows uncertainty in the assessment, so that uncertainty in the input values is reflected in the outcome of the assessment (Rosén et al., 2015). Uncertainty analysis and Monte Carlo Simulation are described more in the next section.

In addition, the tool uses a non-compensatory approach to distinguish approach as weak or strong sustainable alternatives. In strong sustainability, negative effects cannot be offset by positive effects across different domains, criteria, and indicators. However, in weak sustainability, negative effects can be offset by positive ones (Rosén et al., 2015).

2.7 Uncertainty

Uncertainty refers to incomplete knowledge about a value or an outcome often caused by limited information, measurement errors or assumptions made during analysis. As a result, some parameters exact outcome/value may be uncertain. Instead of relying on single deterministic figures, uncertainty can be represented using probability distributions that show a range of possible values and their probabilities. Monte Carlo simulation is often used to account and consider this type of uncertainty. It involves repeatedly drawing samples from the probability distributions of uncertain inputs, then running the model with these samples for each iteration. Over many simulations, this process results distribution of possible outcomes, which provides the likelihood of different results, helping to understand how uncertain inputs affects the outcome of an event (Burgman, 2005).

2.8 Theoretical synthesis and implication for mass management

Overall, the literature indicates that sustainable mass management involves multiple objectives that do not always align. From a circular economy view, it primarily emphasises increasing reuse, minimising waste, and reducing the use of virgin materials. A broader sustainability outlook also considers social and economic impacts. Cost-Benefit Analysis (CBA) can compare costs and benefits monetarily, while Multi-Criteria Decision Analysis (MCDA) enables the simultaneous evaluation of various criteria. Uncertainty plays a critical role, as many input values rely on assumptions or limited data. SCORE integrates these aspects into a single framework, making it helpful for comparing mass management alternatives. However, since SCORE was initially created for contaminated land remediation, some of its criteria, supporting matrices, and reference options should be interpreted carefully when applied to infrastructure projects.

3 CASE STUDY: LUNDBYLEDEN

3.1 Site description

In this master's thesis, a case study of the Lundbyleden infrastructure project is presented, focusing on a small area of E1 (Etapp 1). Project E1 is one of the construction contracts, with Veidekke Entreprenad AB as a contractor. This project is a large infrastructure development on Hisingen in Gothenburg, Sweden. It covers the areas around Backaplan, Brunnsbo, and Ringömotet, and includes new road connections, the Bohusbanan railway, walking and cycling paths, and nearby junctions (Figure 2). In a broader context, the Lundbyleden is part of the so-called West Sweden Package (Västsvenska paketet), a major investment in urban development, roads, and railways, scheduled to continue until approximately 2028. The package is intended to contribute to significant development in the Western part of Sweden in the most sustainable way. This major project will facilitate mobility via public transport and private vehicles and will also create additional commuter opportunities in western Sweden (Swedish Transport Administration, n.d.).

Lundbyleden is one of the most important and heavily trafficked routes. Therefore, the networks are of national interest. The network links European routes such as E6, E20, and E45 with road 155 and the port of Gothenburg. Due to heavy traffic on this route, Lundbyleden is highly congested and perceived as difficult to navigate. To alleviate congestion on Lundbyleden, the STA in cooperation with the City of Gothenburg, is reconstructing certain streets in the Backaplan area to improve traffic flow and enhance urban development. This reconstruction aims to enhance traffic safety and reduce the risk of congestion in the area.

This thesis focuses on Minelundsvägen, part of the larger Lundbyleden project area, and was selected to assess excavated contaminated material and mass-management alternatives.

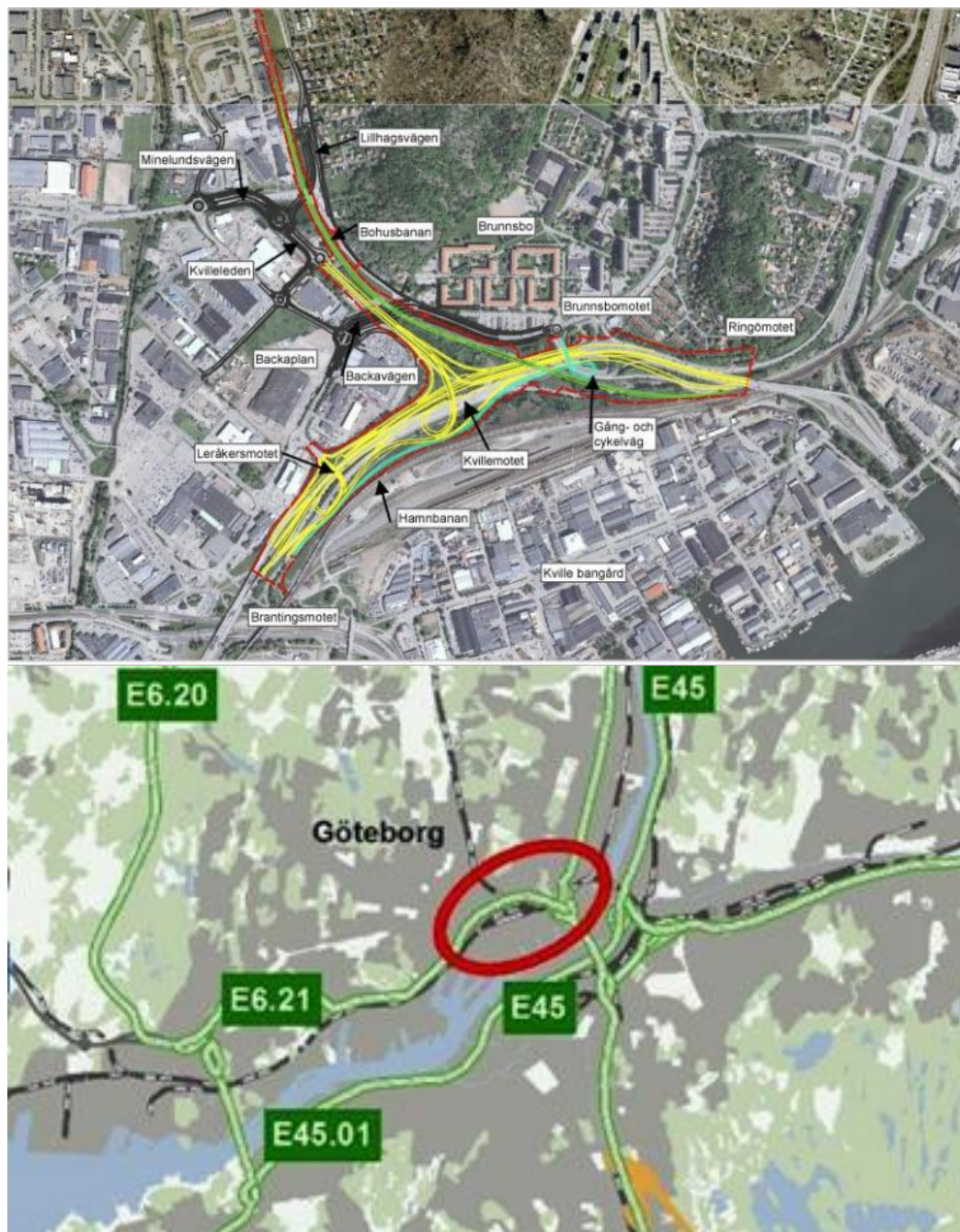


Figure 2: Overview and location of Lundbyleden project (Swedish Transport Administration, n.d.-a).

3.3 Technical and environmental properties of materials at the site

The excavated material is heterogeneous and rich in fine and mixed fractions. It consists of sandy topsoil (Sa Mu), filling clay (Fi Le), brick fragments, and former ground surface. Table 3 presents the average soil type across depth in the focus area (Minelundsvägen).

Table 3 the soil type variations at Minelundsvägen (Veidekke, 2025).

Depth (m)	soil type
0.0-0.5	F, SaMu
0.5-1.5	FLe, SaMu
1.5-2.1	F, Si Le, Brick
2.1-2.4	Mu, Brick, Former asphalt

The most common contaminants in the soil at Minelundsvägen, based on samples collected during the site visit, are shown in Table 4. The tables also indicate which contaminants exceed the site-specific guideline values (MKM, KM, and FA). For instance, sample 30 taken from the area of interest (Minelundsvägen), has values that exceed the limits of both generic and site-specific guideline value of MKM for almost all contaminants, leading to lead being the biggest contaminant issue. However, the other four samples show that the contaminants encountered only exceed the KM, not the MKM values. The site-specific guideline values for Lundbyleden are presented in Table A1 in Appendix A and specify which level of contamination in the soil is considered to pose an acceptable risk at the Lundbyleden project site.

Table 4: The most common contaminants at Lundbyleden (Veidekke, 2026). Most of the contaminants exceed the KM values, whereas one samples shows that contaminants also exceed MKM-values according to the site-specific guideline values

	>MKM	>KM	>FA		
Samples from Minelund					
Sample (nr)	V10	30	60	61	T31
Depth (m)	0,0-1,0		0,1-2,0	0,2-1,7	
Soil type					
Unit	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS	mg/kg TS
Substance/Contaminant					
Sum PAH, H	1,4	13	3	2,5	
Sum PAH, M		25			
Arsenic (As)	11	13			
Barium (Ba)		1100			
Lead (Pb)	88	6100	67	94	
Cadmium (Cd)	0,82	4	0,89		
Cobalt (Co)		130			16
Copper (Cu)		1200		110	
Chromium (Cr)		850			
Mercury (Hg)		0,62	0,27	0,25	
Zink Zn		2100	420	360	

3.4 Current mass management strategy

As described in previous chapter, the excavated material at Lundbyleden contains contaminant that exceeds both the KM and MKM guideline values. While exceeding the KM values is acceptable in this infrastructure project, any soil with contaminant levels above the MKM values will need additional treatment. A total of 22,686 tonnes of mass has been removed to a depth of 2.4 meters below ground level (b.g.l), (Figure 3). Under the currently mass management strategy, the excavated mass has been sent to landfills, and no further treatment is being carried out. Disposal location vary throughout the project. However, excavations from Minelundsvägen are sent to a landfill approximately 20 km from the site. The material is subsequently treated or disposed of as waste at the landfill.



Figure 4: the focused area (Minelundsvägen) in the Lundbyleden project (Veidekke,2026).

3.5 Control and treatment of surface and groundwater during construction

During construction, the primary water management concern is dewatering excavation sites, which involves groundwater seepage, rainwater, surface runoff, and construction water. As this water may contact contaminated soil or materials, it must be treated before disposal. All water management and treatment are handled by the on-site wastewater treatment plant (WWTP), (Swedish Transport Administration, 2023b). Göta älv and Kvillebäcken are the main sensitive recipients. Water from contaminated areas must not be infiltrated into clean soil to prevent contamination.

Water must be sampled and analysed before discharge. For Göta Älv, compare measured concentrations with project-specific guideline values set by the authority (Swedish Transport Administration, 2023b). For Kvillebäcken, Table A2 and A3 (Appendix A) provide guideline values. If concentrations are too high, corrective actions are required. If guideline values are exceeded, discharge must stop, and treatment needs must be assessed before resuming release. Miljöförvaltningen in the City of Gothenburg is the supervisory authority. Any deviations would be reported and discussed with them. STA is responsible for official communication. Water must be checked, guideline values followed, and discharge is not permitted if limits in Table A2 and A3 are not met.

4 Methodology

To carry out this master's thesis, the following methodology was used (Figure 4). It started with a literature study on mass management in infrastructure construction, relevant aspects, requirements, and legislation for handling excavated soil. Subsequently, a case study of the Lundbyleden project was conducted to study the site conditions and project-specific circumstances.

To be able to carry out the sustainability assessment of the different alternatives of management techniques for excavated material, the SCORE methodology was used.

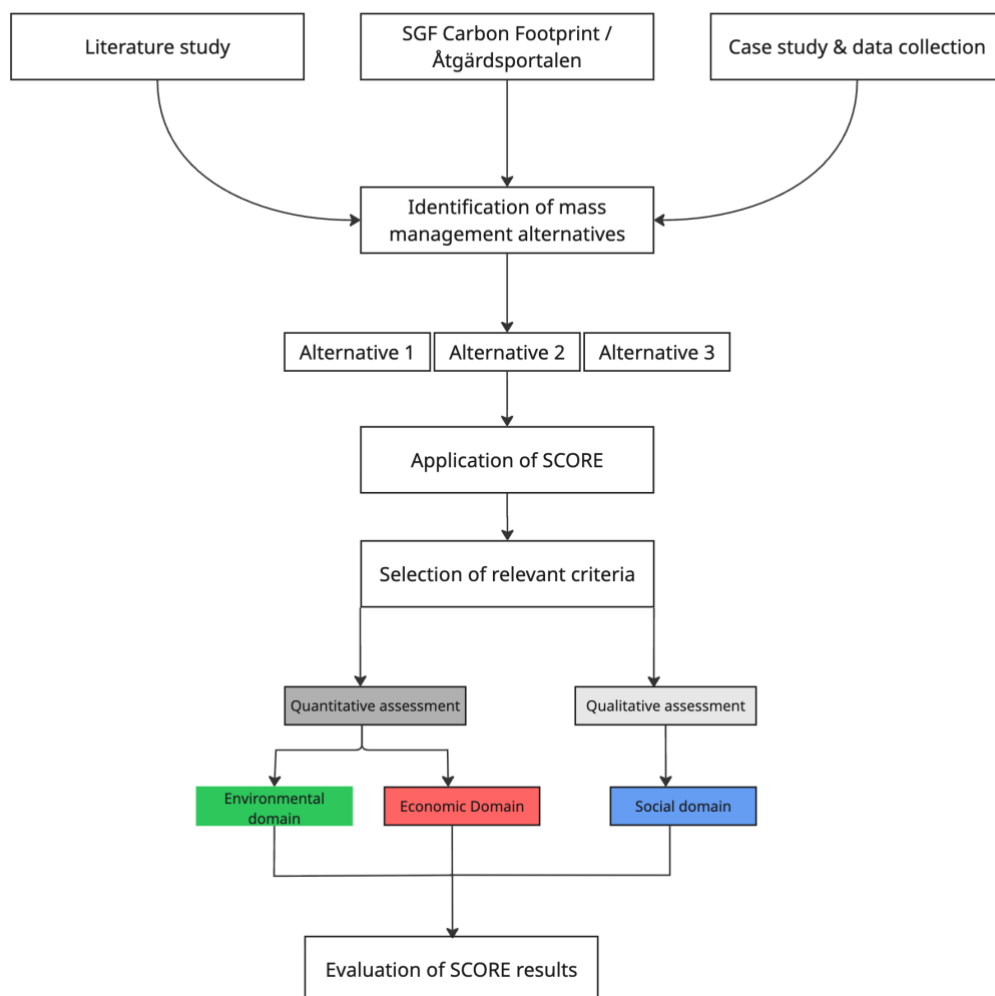


Figure 5 Overview of the working process.

4.1 Literature review

The literature study was focused on concepts essential for assessing the sustainability of handling excavated mass in infrastructure projects. This included sustainability assessment, cost-benefit analysis (CBA), multi-criteria decision analysis (MCDA), Monte Carlo simulation, and circular economy principles. These subjects were studied to understand how environmental, social, and economic impacts can be measured, how costs and benefits can be evaluated, and how uncertainties can be managed within these assessments. Understanding the circular economy was crucial for emphasising material reuse and recycling, and for reducing landfill disposal. The study also reviewed legal frameworks, such as the Waste Framework Directive, and guidelines related to waste management and excavated soil. ASEK 8.1 from the Swedish Transport Administration (2024) was also reviewed to examine how the economic value of air pollution and transport emissions, such as truck transport of excavated material, can be estimated. This theoretical background formed the basis for applying and evaluating SCORE in the Lundbyleden case.

The literature review began at the outset and continued throughout the thesis project, using search strings related to sustainable mass management, excavated soil, sustainability assessment, multi-criteria decision analysis (MCDA), cost-benefit analysis (CBA), circular economy, Monte Carlo simulation, and relevant laws and regulations. Searches were primarily performed using Google Scholar and ScienceDirect, as well as through reports and guidance documents from Swedish authorities, including the (STA) and the Swedish Environmental Protection Agency.

In addition to the literature review, the SGF Carbon footprint/åtgärdsportalen website was consulted to explore potential treatment and mass management strategies within the industry. The data collected from the website, combined with insights from the literature review and case-specific factors, helped determine appropriate mass management alternatives for evaluation.

The literature review uncovered studies on the reuse and treatment of excavated soil, circular economy in construction, sustainability assessment, and decision-support tools like CBA and MCDA. Typically, these topics were studied independently, with fewer research efforts combining them specifically for assessing the sustainability of mass management alternatives in infrastructure projects. This limited integration highlighted the need to apply and evaluate SCORE in this case study.

4.2 Case Study Lundbyleden

This case study formed part of an ongoing project at Lundbyleden in Gothenburg. An informal interview was conducted with the site manager during site visits at the end of February 2026. The collected data comprised general site information, source contamination, various contaminants, and the site's geological formation (see Section 3). To assess mass management alternatives, the team discussed several alternatives from SGF with experts during the site visits (see Section 5).

4.3 The SCORE methodology

This study applies the SCORE (Sustainable Choice of Remediation) methodology and tool to assess mass management alternatives in infrastructure projects. The methodology was implemented in Python to perform the input values with uncertainty analysis used in the assessment. The developed approach is implemented as a multi-criteria decision analysis to support sustainable decision-making by evaluating environmental, social, and economic impacts.

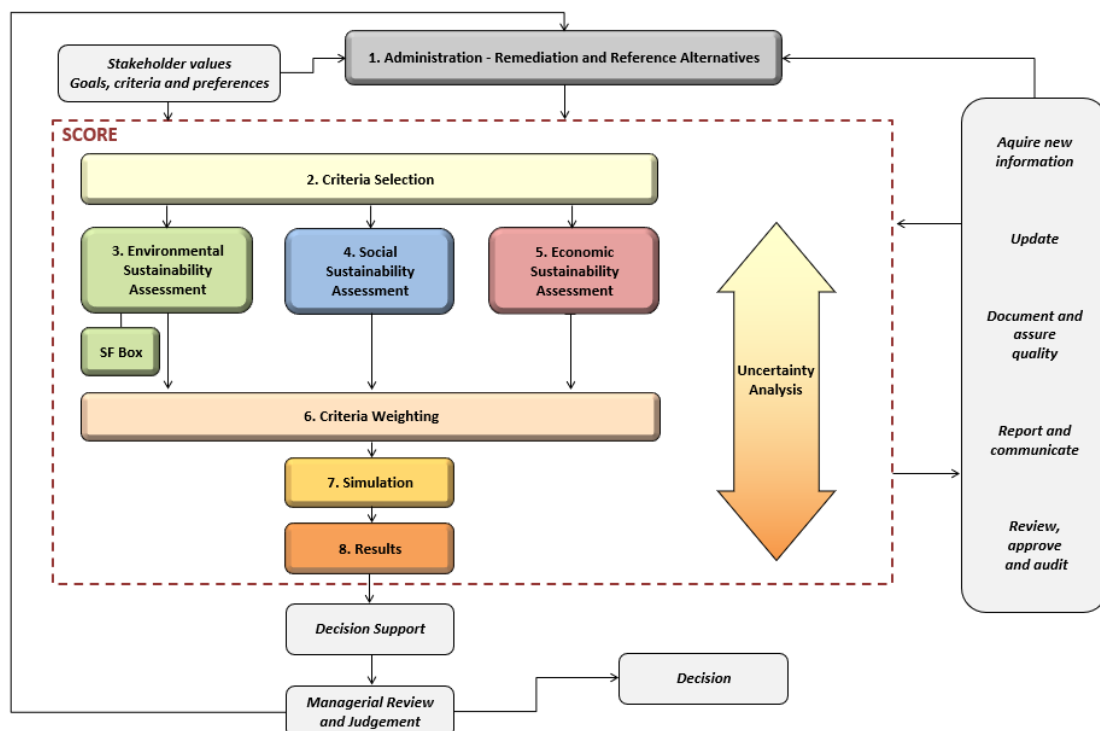


Figure 6: SCORE decision-support framework by Rosén et al., 2015). This framework is originally developed for the assessment of the different remediation projects and their impact on sustainability.

4.3.1 Selection of relevant criteria

Before selecting the relevant criteria in SCORE, the different management options for the excavated material at Lundbyleden were first identified. These options included the current method and a variety of treatment strategies. Once the alternatives were established, key criteria were chosen across the environmental, social, and economic aspects of SCORE. The selection process was based on the case study, available project-specific information, and the relevance of each criterion to Lundbyleden. Criteria were included if they were relevant for assessing the expected impacts of the different mass management alternatives. The review considered impacts related to both source contamination (SC) and remedial action (RA), considering effects both on-site and off-site—including those connected to transportation, treatment, and disposal activities.

Environmental Criteria

The environmental criteria were assessed based on available site-specific information and supporting data. The supporting data were obtained from Veidekke project documents. Additional information for the environmental assessment, such as Greenhouse gas emissions associated with transport and treatment activities, was obtained from e.i SGF Carbon Footprint. Criteria that were not assessed or deemed not relevant were marked as NR. For the scoring of the criteria (Table 5), the supporting matrices were used.

Table 5 Description of the performance criteria for the environmental domain (Rosén et al., 2015).

Key Criteria	Description
E1-Soil	Effects on the soil quality and function due to SC and/or RA.
E2-FLora and fauna	Physical impacts on ecosystems, including vegetation and wildlife, from the RA.
E3-Groundwater	Effects on groundwater quality and/or ecotoxicological risks potentially caused by the SC and/or RA.
E4-Surface water	Effects on surface water quality and/or ecotoxicological risk potentially caused by SC and/or RA.
E5-Sediments	Impacts on Sediment quality and organisms, affected by SC and/or RA.
E6-Air	Total emissions to air caused by the RA.
E7-non-renewable natural resources	The total amount and consumption of non-renewable natural resources used when performing the RA.
E8-non-recyclable waste	The amount of non-recyclable waste produced by the RA.

Social Criteria

The social criteria were assessed based on the potential social effects associated with the identified mass management approaches. Case-specific documents supported the assessed criteria presented in Table 6. A supporting matrix for SCORE were used to guide the assessment and scoring of the included criteria. Criteria that were not assessed or deemed not relevant were marked as NR.

Table 6: Description of the performance criterion for the social domain, according to (Rosén et al., 2015).

Key Criteria	Description
S1-Local environmental quality and amenity (inc physical disturbances)	Effects on e.g. recreational values, accessibility of the area or odour/noise in the area.
S2-Cultural heritage	Positive or negative effects on cultural heritage items.
S3-Health and safety	Effects on human health and safety due to the presence and/or spreading of contaminants.
S4-Equity	Effects on the vulnerable groups of the society.
S5-Local participation	Effects on local community
S6-Local acceptance	Acceptance of the remedial alternative by the local community.

Economic Criteria

Table 7 presents the costs and benefits to consider in the economic assessment, along with their respective descriptions. The SCORE assessment considers social profitability, which is evaluated through cost-benefit analysis (CBA). The societal perspective of the economic assessment was expressed in monetary terms as the Net Present Value (NPV) calculated according to Equation 1.

Direct projects related costs such as excavation, transportations, possible treatments and landfill disposal, were obtained from available documents from Veidekke. The assessment monetised environmental effects. Transport-related greenhouse gas emissions were evaluated using ASEK 8.1 from the Swedish Transport Administration (2024). The CO₂ emissions calculations focused only on the transportation of excavated materials. Due to lack of data on emissions distribution between 2025 and 2026, the 2026 ASEK value was used as a common year for all alternatives.

Costs or benefits that could not be quantified, despite their relevance, were marked with X-(Important) or (X)- (Somewhat Important). The main payer (P) for each cost item and the main beneficiary (B) for each benefit item were also assigned. In this assessment, the STA was considered the main payer, while society, the contractor (Veidekke), and the STA were considered the beneficiaries.

Table 7: Benefits (B) and costs (c) in the economic assessment of SCORE (Rosén et al., 2015)

Key Criteria for cost and benefits	sub-criteria of cost and benefits
B1. Increased properties	
B2. Improved Health	B2a. Reduced acute health risks
	B2b. Reduced non-acute health risks.
	B2c. Other types of improved health, e.g.
B3. Increased provision of ecosystem, services	B3a. Increased recreational opportunities on-site
	B3b. Increased recreational opportunities in the surroundings.
	B3c. Increased provision of other ecosystem services.
B4. Other positive externalities than B2 and B3.	
C1. Remediation costs	C1a. Design of remedial actions
	C1b. Project management
	C1c. Capital costs
	C1d. Remedial action
	C1e. Monitoring
	C1f. Project risk
C2. Impaired health due to remedial action	C2a. Increased health risks on site
	C2b. Increased health risk from transport activities
	C2c. Increased health risks at disposal sites
	C2d. Other types of impaired health, e.g. increased anxiety
C3. Decreased provision of ecosystem services due to remedial action	C3a. Decreased provision of ecosystem services on site
	C3b. Decreased provision of ecosystem services in the surroundings
	C3c. Decreased provision of ecosystem services at disposal sites
C4. Other negative externalities than C2 and C3	

4.3.2 Weighting and Scoring

After selecting relevant criteria, the environmental, economic, and social effects of the alternatives and/or changes in source contamination were assessed using scoring and weighting. Scoring was carried out by assigning each indicator a score on a -10 to +10 scale (See Table 8) against a reference alternative, where negative scores indicate a negative impact and positive scores indicate a positive impact in the environmental and economic domains. Supporting matrices were used to score and weigh the different criteria and (Norrman et al., 2019).

Table 8: Marking scale in SCORE for the assessment of the environmental and social impacts

Mark	Effect (compared to the reference alternative)
-10 to -6	Very much negative
-5 to -1	Negative
0	No effect
+1 to +5	Positive
+6 to +10	Very much positive

The following table shows how the key criteria were weighted to assess the meaning/importance of each criterion and sub-criterion. The weighting ranged from 0 to 25, where 0 indicated that the criterion was not relevant to include in the assessment and 25 indicated that the criterion was very relevant to include in the assessment (Norrman et al., 2019).

4.3.3 Uncertainties and Sensitivity Analysis

Uncertainty in the assessment was evaluated using probability distributions assigned to the input parameters. For the environmental and social criteria, the assigned P05, most likely, and P95 scores defined the distribution of possible criterion scores. For the economic assessment, probability distributions were defined based on the assigned Most Likely and P95 values for the quantified costs and benefits. These distributions were used as inputs in the Monte Carlo simulation, in which 10,000 iterations were performed. Repeated sampling propagated uncertainty in the input parameters through the assessment and produced distributions of possible outcomes for each alternative.

A sensitivity analysis was later on conducted with Spearman rank correlation coefficients to evaluate how uncertain input parameters effect the model outcomes.

5 Management alternatives of the excavated mass

5.1 Reference Alternative

In the SCORE assessment, a reference alternative was established to compare the sustainability impacts of various mass management alternatives. In this thesis, the reference was set as ‘No action,’ as illustrated in the scoring matrix. This indicates that no excavation, transportation, treatment, or disposal of materials takes place at the site.

5.2 Alternative 1: Landfill Disposal

As described in Chapter 3, the total excavation of 22 686 tonnes of mass from Minelundsvägen is sent to landfill. The excavated mass sent to the landfill contains various contaminants, as described in the case study chapter. Depending on the contamination level, the mass is either treated as waste or as a resource through additional treatments at the landfill. The contaminations vary as described in Table 5. The landfills are multiple and are located approximately 20 km (Veidekke, 2025).

5.3 Alternative 2: Sieving

Sieving was evaluated as the second option for mass management. The technique was deemed technically feasible given the excavated material's properties and the case study conditions. Sieving is a mechanical process that separates particles based on size, segregating the excavated material into different fractions. In this approach, the material passes through a 40 mm screen, resulting in a coarse fraction (>40 mm) and a finer fraction (<40 mm), (Kumpiene et al., 2017).

In the assessment, it was assumed for this case study that 30 % of the excavated material was coarse, met site-specific guideline values, and was suitable for reuse. The remaining 70 %, consisting of finer material, was assumed to exceed the site-specific guidelines and was therefore transported to landfill for disposal.

This assumption in this case study regarding the grain size and rate of reuse was based on the tendency of contaminants to be associated with finer soil particles. Finer particles generally have a larger specific surface area, providing more surface for contaminant adsorption, whereas coarser fractions may contain lower contaminant concentrations.

The assumed 30/70 distribution was therefore used as a case-study input to the assessment. The actual reusable proportion could differ depending on the material composition, contaminant distribution, treatment performance, and applicable reuse requirements.

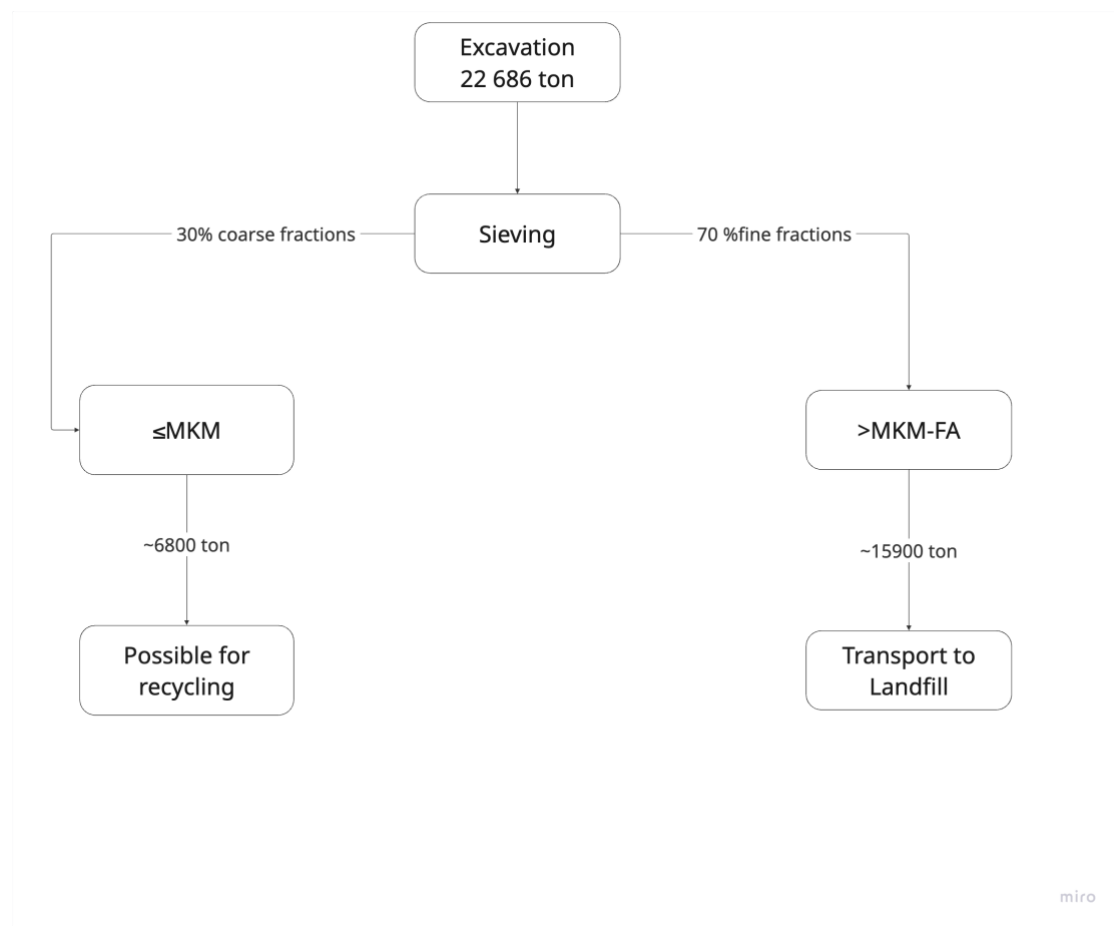


Figure 7: Overview of the second management strategy (Alternative 2).

5.4 Alternative 3: Sieving and Washing

Alternative 3 involves a two-stage treatment process that begins with dry sieving of excavated soil, followed by soil washing. Initially, the material is dry sieved at 40 mm to separate coarse and fine particles. The fraction smaller than 40 mm undergoes wet size separation at 6 mm during soil washing. The 6-40 mm fraction is washed and may be reused if its properties meet environmental and technical standards. The finer fraction (< 6 mm), however, is considered unsuitable for further treatment and is disposed of in a landfill. Contaminants removed during washing accumulate in the

fine material and sludge, which are also classified as waste and need to be sent to landfill (Li et al., 2019).

In this case study, it was assumed that 30 % of the total excavated material could be reused after the initial sieving process, while soil washing could allow an additional 15 % to be recovered for reuse. This resulted in an assumed total reuse of 45 % for alternative 3, with the remaining 55 % disposed of at landfill. These percentages were used as a study-specific assumptions in the assessment and do not represent fixed treatment efficiencies. The actual reuse rate could differ depending on soil properties, contaminant levels, washing performance, and the environmental and technical requirements for reuse.

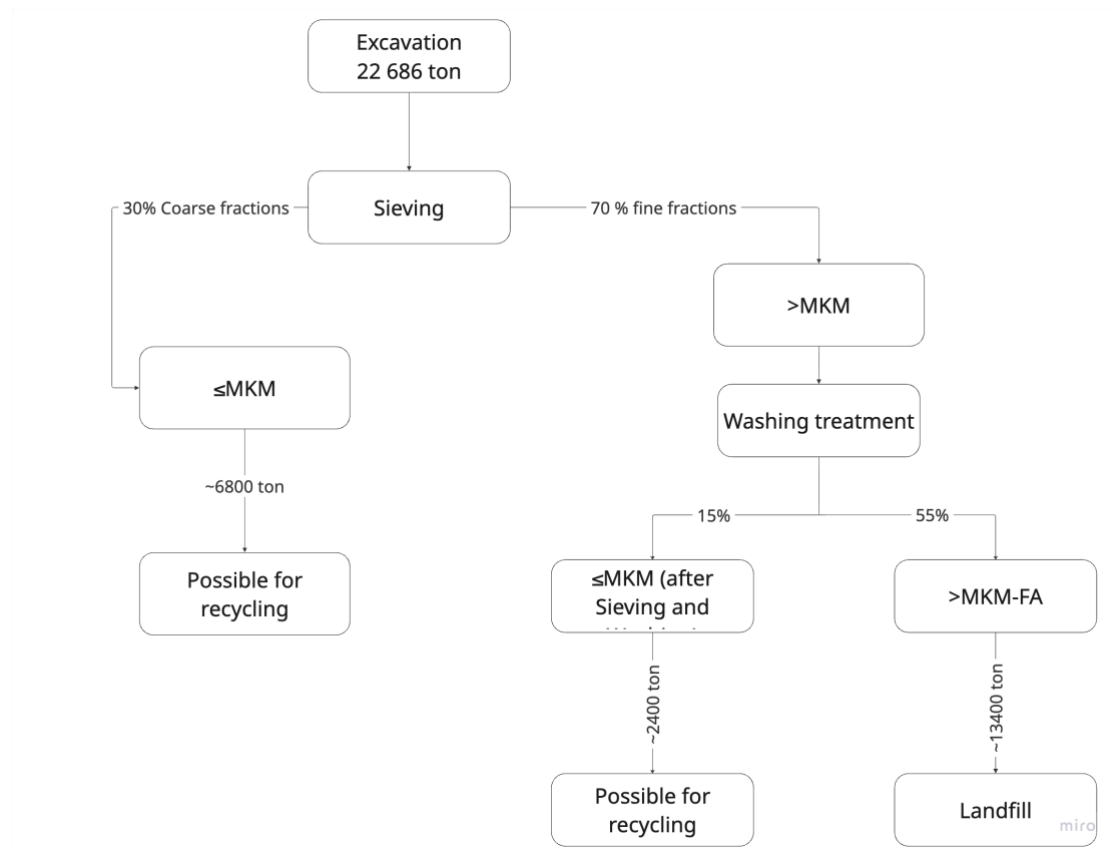


Figure 8: Overview of the third mass management strategy (Alternative 3).

6 Results

This chapter presents the results from the SCORE assessment of the three mass management alternatives considered for the Lundbyleden case study. The results are shown by three different scenarios:

- Scenario 1a: 'No action' is used as the reference alternative. The three sustainability dimensions are assigned the following weights: Environmental (55.6%), Social (6.67%), and Economic (37.8%). This scenario represents a total sustainability assessment.
- Scenario 1b: 'No action' is used as the reference alternative. The three sustainability dimensions are assigned the following weights: Environmental (64.1%), and Economic (33.3%). The social domain in the assessment of this scenario was omitted. Unlike the first scenario, this scenario represents a different perspective, an assessment based on circular economy. However, the scenario still follows same reference alternative as the first one, namely 'no action'.
- Scenario 2: Minelundsvägen's current management strategy is used as the reference alternative. The three sustainability dimensions are assigned the following weights: Environmental (64.1%), Social (2.56%), and Economic (33.3%). In this scenario, the assessment is also based on the circular economy. The scenario is focusing on circular economy benefits like less waste, reduced virgin material use, and better material recovery, while also accounting for the economic effects.

6.1 Scenario 1a

The environmental domain was weighted at 55.6%, because of its importance in the assessment. Flora & Fauna and Sediment criteria were not included in the assessment as there were none around the Lundbyleden, and therefore marked with NR (Not relevant), (see Appendix B) . There could be some flora and fauna in other areas at Lundbyleden, but not at Minelundsvägen. Since the groundwater at Lundbyleden is highly complex, not all effects could be assessed. However, the overall potential off-site effects of RA and SC on the criteria have been assessed. Air (E6) has been considered very important and, therefore, weighted the highest among the other criteria in the environmental dimension. This is because the excavated material will be transported regardless of the chosen alternative, causing long-term effects and GHG emissions. However, the need for transportation differs between the alternatives. E7, non-renewable natural resource, and E8, non-reusable waste generation, were assessed based on the proportion of the total excavated material that could be sent to landfill or reused. The scoring and the assessment of these two criteria were dependent on the assumption of the treatment efficiencies for the second and third alternatives.

The first alternative achieved the lowest performance in both the environmental and social domains, since all excavated mass is sent to landfill, implying that none of the mass is considered reusable and could therefore lead to environmental impacts. Assuming that, with the sieving strategy, approximately 30% of the mass could be reused, the alternative provides better performance (Figure 9). On the other hand, the potential rate of reuse in alternative 3 (sieving and washing) is up to 45%. As a result, the alternative performed better than the others. As shown in Figure 9, the third strategy has a less negative impact on the environment, whereas the first approach has the most negative impact. Figure 10 presents the environmental and social effects on-site and off-site.

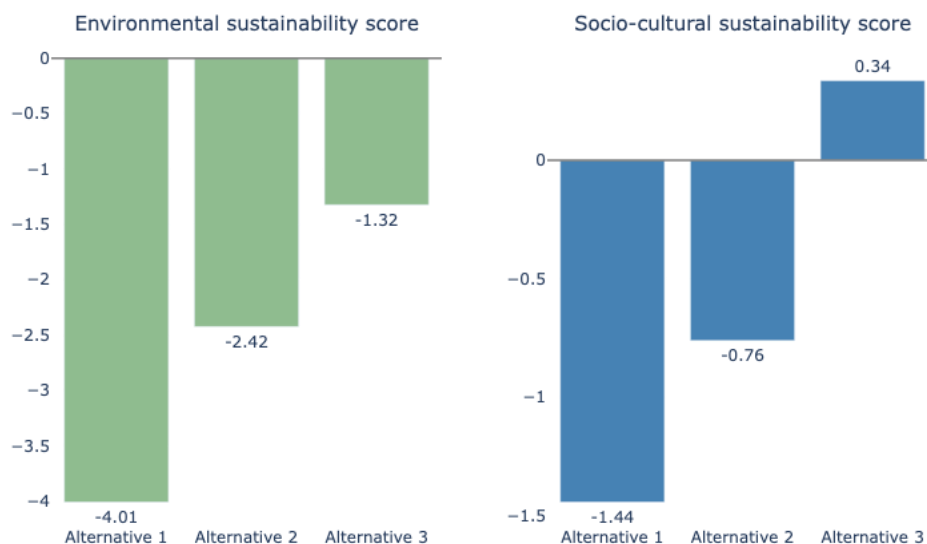


Figure 9: Sustainability score for environmental and social. Alternative 1: Excavation and Landfill Disposal, Alternative 2: Excavation and Sieving, Alternative 3: Excavation and Sieving combined with soil washing

The social domain was weighted the least (6.67%) among the domains because its criteria were difficult to assess due to insufficient data but also due to lack of relevance to the case. Only potential effects on Health & Safety and Local Environmental quality & Amenity were considered in assessing the social impacts of the management alternatives. Table B2 presents the selected criteria in the social domain and their scores, with non-relevant criteria marked as NR (Not Relevant).

S1 (Local environment quality and amenity) is very important to consider, as the surrounding local environments could be affected on-site and off-site by different management alternatives. Therefore, the criterion was assessed based on possible effects that could occur during the strategies at Minelundsvägen. S3(Health and Safety) matters are very important in infrastructure projects. Therefore, a consideration of the criterion was necessary as part of the assessment. However, in this assessment, special consideration was given to the off-site effects due to the management alternatives, as they are more conservative in these specific conditions.

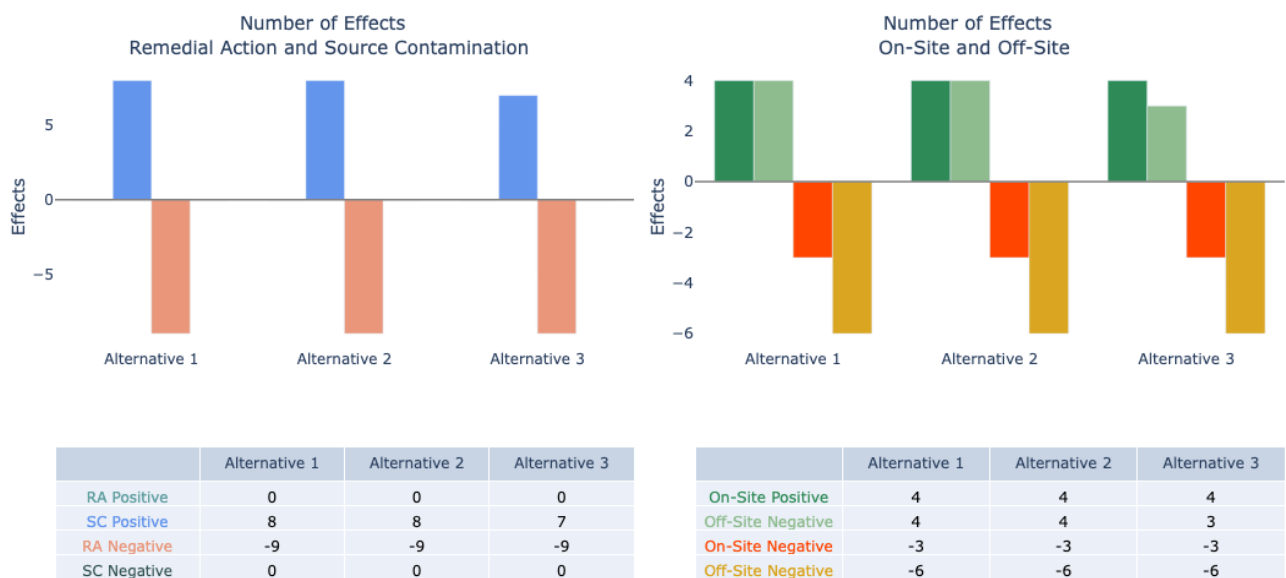


Figure 10 Environmental and social effects due to the alternatives and removal of source contamination. Alternative 1: Excavation and Landfill Disposal, Alternative 2: Excavation and Sieving, Alternative 3: Excavation and Sieving combined with soil washing.

The economic domain was assessed by calculating the Net present value of treatment and management costs for each alternative, using equation (1). In addition to the direct costs of treating and managing the excavated material, emissions of CO₂ from transporting it were also evaluated for each alternative. These CO₂-related costs cover only emissions from truck transport and exclude those from treatment processes like sieving or soil washing. The monetary value assigned to transport-related CO₂e emissions was derived from ASEK 8.1 by the Swedish Transport Administration

(2024). Because the exact distribution of emissions between 2025 and 2026 was unavailable, the 2026 ASEK value was applied uniformly as the valuation point for all alternatives. The costs for the different management and treatment options are based on market prices; see Appendix B. Figure 11 shows the Net present value of the three different strategies, according to SCORE. Alternative 2 is the most beneficial strategy, while the third alternative is the most expensive among the assessed alternatives due to its complex washing treatment system.

The results from the economic assessment are presented in Table B3. Criteria marked with “X” indicate cost and benefit aspects that were assessed and considered highly relevant to include in the analysis. Some criteria were considered potentially relevant to this case or to sustainable mass management in infrastructure projects more generally but could not be assessed due to limited data availability. These criteria are marked with “(X)”. Criteria marked with “NR” were considered not relevant for the assessment of sustainable mass management in this study context and were therefore excluded from the analysis.

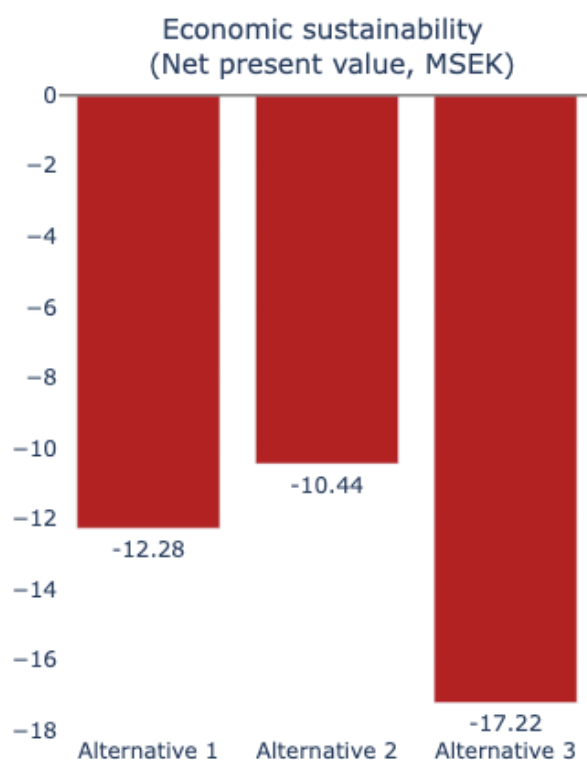


Figure 11: Economic sustainability for the alternatives in the first scenario, where Alternative 1: Excavation and Landfill Disposal, Alternative 2: Excavation and Sieving, Alternative 3: Excavation and Sieving combined with soil washing.

Figure 12 shows the weighting of the selected criteria in SCORE, reflecting their importance in the assessment. The evaluation of mass management in Lundbyleden reflects the differing significance of each criterion in this specific case. The environmental domain received the highest priority, as the Lundbyleden case concerns the management of excavated mass, where soil quality, source contamination, GHG emissions (from transportation), waste generation, and the potential for material reuse are central factors.

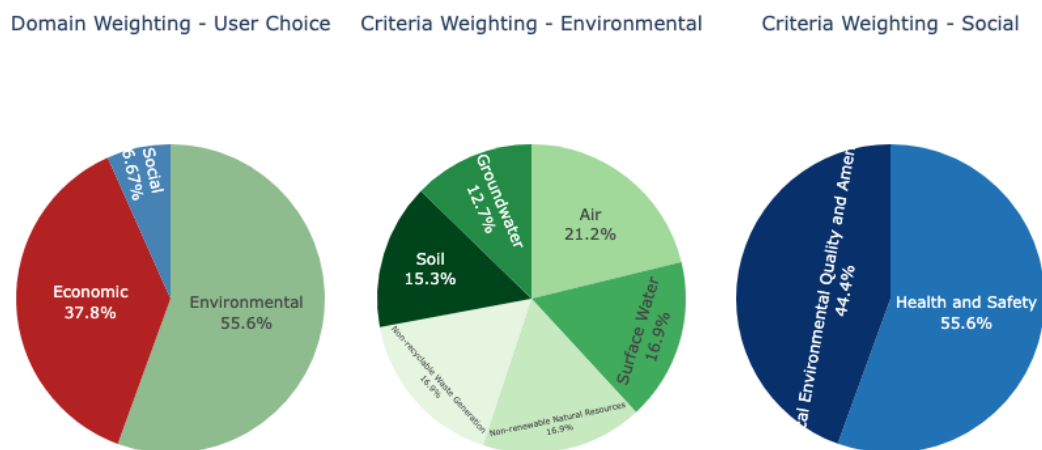


Figure 12: weights for the different domains and criteria in the assessment.

Figure 13 shows the distribution of the simulated SCORE results for the three alternatives based on 10 000 Monte Carlo iterations. Iterations were performed on the scoring values between most likely and P95 for each alternative to account for uncertainties in the scoring of criteria and sub-criteria. This allows both robustness of the ranking and the sensitivity of the results to be evaluated.

All alternatives have negative mean sustainability indices, indicating that none result in overall positive sustainability performance under the applied assumption/limitation, with clear differences among the alternatives but also due to the reference as ‘no action’. Landfill disposal have the lowest mean sustainability index (- 89.32), indicating poor performance and greater uncertainty. The sieving alternative showed improved results with a mean value of -60.23. The third alternative had the least negative mean sustainability index (- 54.74), indicating the most favourable overall performance among the three alternatives.

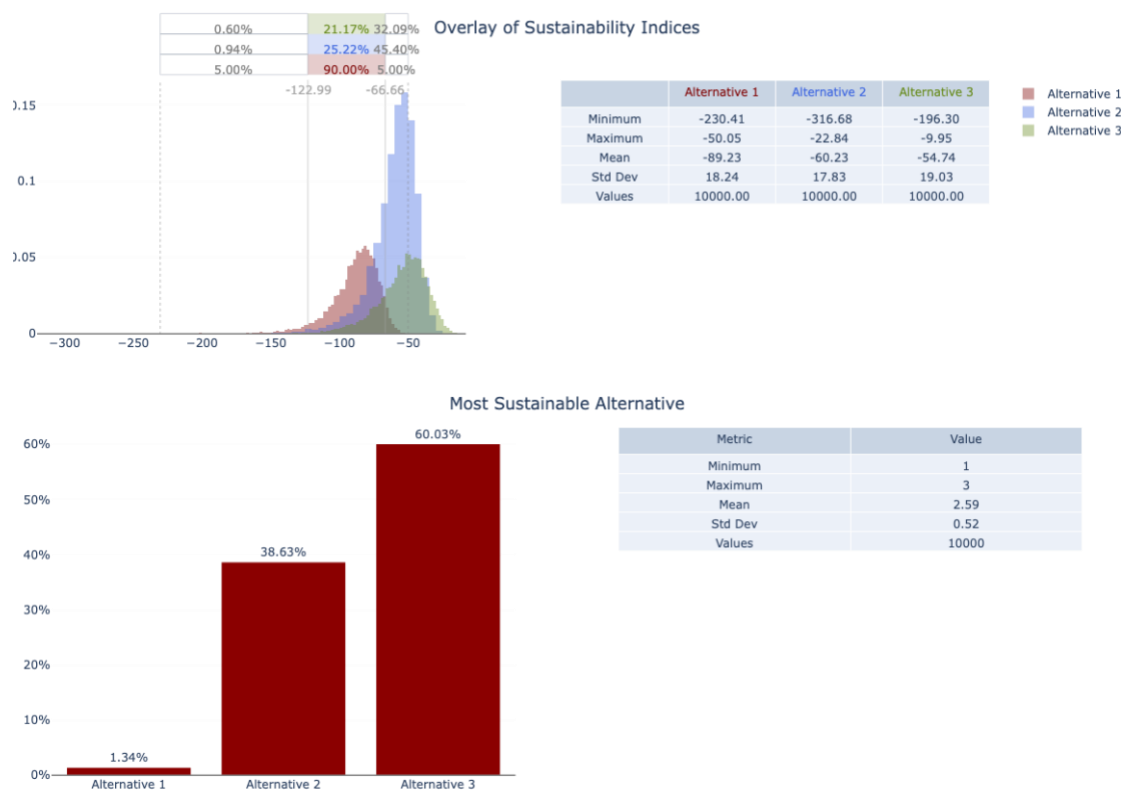


Figure 13:(a) Probability distributions of sustainability indices for the three alternatives and (b) Probability of each alternative being identified as the most sustainable alternative in Scenario 1a.

The Spearman's Rank Correlation Coefficient (Figure 14) shows that the cost criterion (C1d) mostly influences the sustainability index across all alternatives. This criterion exhibited the strongest negative correlation for Alternative 1 (-0.87), Alternative 2 (-0.86), and Alternative 3 (-0.90). The findings suggest that increased transport, and disposal costs decrease overall sustainability, highlighting that cost-related assumptions are the primary source of uncertainty in the outcomes.

Alternative 1 was clearly dominated by the cost criterion. Meanwhile, Natural Resources RA off-site, Waste RA off-site, and Air RA off-site had smaller positive impacts on variations in the sustainability index. For Alternatives 2 and 3, the influence of costs (C1d) remained significant, even though sieving and washing treatments increased their impact. This is expected because soil washing involves greater complexity and higher treatment costs. Both alternatives also affected the Natural Resources, Waste generation, and Air criteria.

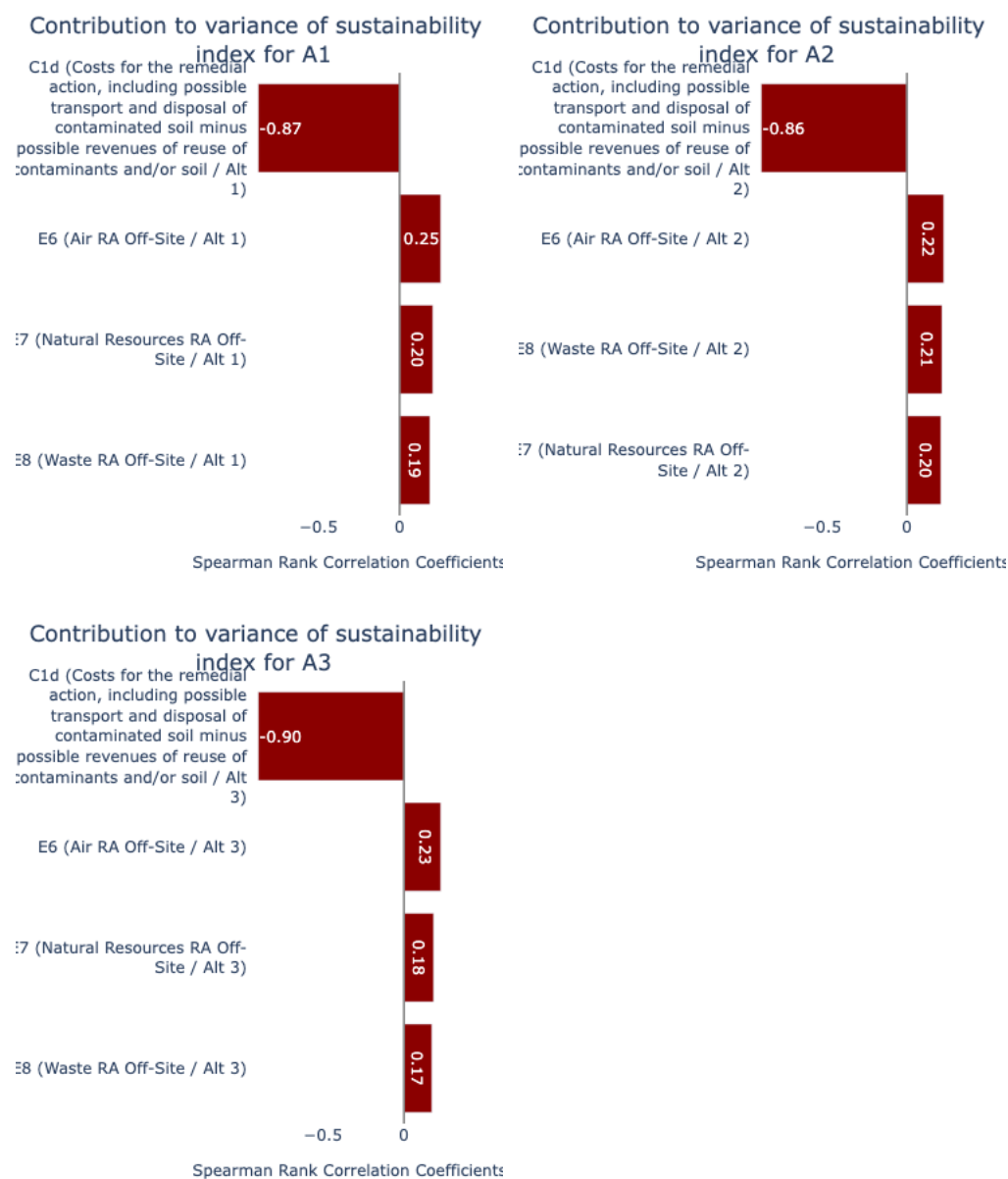


Figure 14: Sensitivity analysis for the alternatives in scenario 1a, where A1= alternative 1, A2=alternative 2 and A3=alternative 3.

6.2 Scenario 1b

In Scenario 1b, the assessment focused on the circular economy aspects of mass management. The social domain was omitted, leaving only the environmental and economic domains. The reference alternative was "No action," with the three options evaluated against a no-management baseline. The environmental assessment focused on key circular economy criteria: E6 Air, E7 non-renewable natural resources, and E8 non-recyclable waste. They highlight impacts such as transportation emissions, the need for virgin materials, waste production, and landfill disposal. The Appendix presents the scoring for the included criteria.

All alternatives had negative environmental scores (see Appendix E). Landfill disposal scored the worst (-8.15), while sieving was less negative (-4.96). Combining sieving with soil washing yielded the lowest score (-3.32). Treatment-based options outperform landfill disposal because they have greater potential to reduce waste and resource use. The environmental domain had the greatest impact (64.1%), with Air leading, followed by non-renewable resources and waste. The economic domain was weighted to 33.3%, while the social domain was omitted. However, because the application could not completely exclude a domain, it was assigned the lowest possible weight of approximately 2.6%. Transport emissions, resource use, and waste emerged as key factors, with air, resources, and waste heavily influencing the results.

Domain Weighting - User Choice Criteria Weighting - Environmental

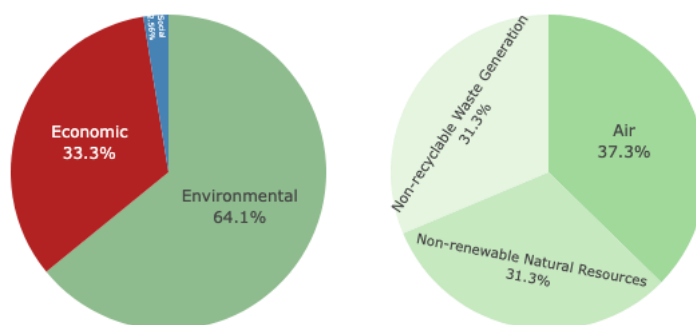


Figure 15: Sustainability weights for scenario 1b

The results showed all options had negative mean sustainability indices. Alternative 1 was lowest at -90.51, with Alternatives 2 and 3 at -61.97 and -62.06. Despite Alternative 3's environmental strength, the economic gap with Alternative 2 shrank, likely because soil washing has environmental benefits but higher costs.

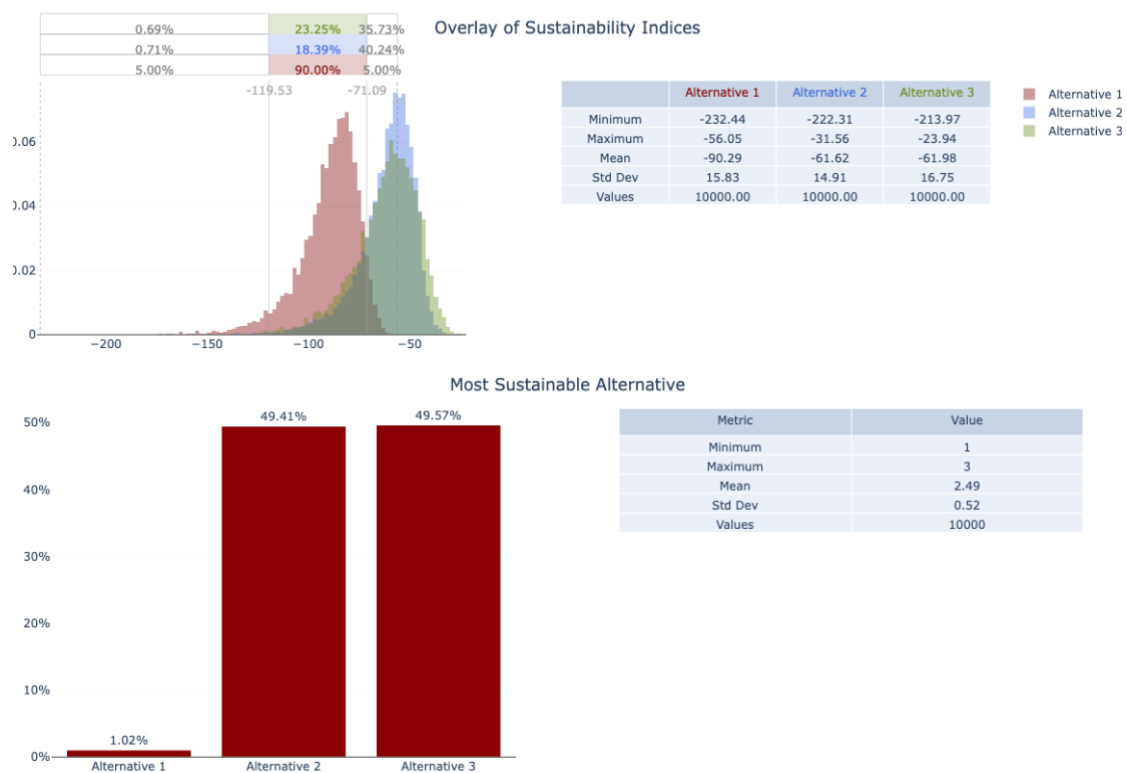


Figure 16: (a) Probability distributions of Sustainability indices for the three alternatives in scenario 1b and (b) Probability of each alternative being identified as the most sustainable alternative in Scenario 1b.

Overall, Scenario 1b demonstrates that treatment-based alternatives can enhance circular economy compared to landfill disposal. However, the outcomes remain negative because all options entail excavation, transport, resource consumption, and waste management compared to the reference alternative 'No action'. Consequently, the results should primarily be understood in relative terms, highlighting which alternative has the least negative impact.

6.3 Scenario 2

In Scenario 2, the focus was again on the circular economy of mass management, but now with a new reference alternative, which shifted from “No action” to “Landfill disposal”. Because the analysis does not account for the positive effects of the new infrastructure at Lundbyleden, using “No action” as a reference is unfair: the effects of the necessary handling of masses are evaluated separately, even though the excavation will occur regardless of the strategy. In this scenario, the reference alternative was shifted to ‘Landfill disposal’, since it provides a more realistic basis in mass management in infrastructure projects.

The criteria and their domain weights match those in scenario 1b. As a result, this scenario compares two treatment options—Sieving (Alternative 1) and Sieving combined with soil washing (Alternative 2)—against the reference alternative. See appendix for the scoring of the criteria.

The environmental results (Figure 17) show that both options outperform landfill disposal. Sieving scored 4.36, while combining it with soil washing scored 6.61. Soil washing provides the greatest environmental benefits by reducing landfill waste and increasing the potential for material reuse.

The economic results (Figure 17) reveal a different pattern. Sieving yielded a positive outcome of 4.74 MSEK, whereas combining sieving with soil washing resulted in a negative outcome of -5.37 MSEK. This indicates that sieving is more cost-effective, while soil washing is more costly because of the additional treatment step.

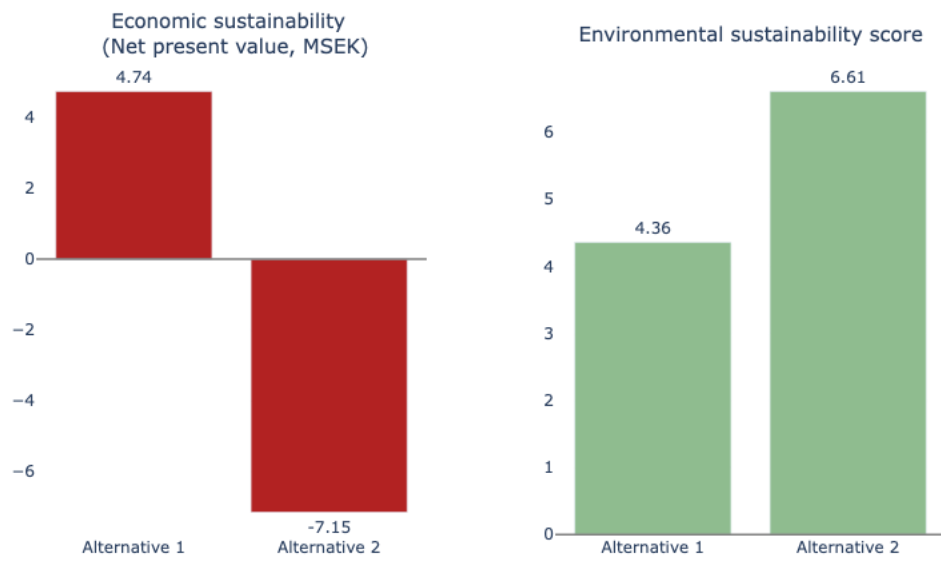


Figure 17: Sustainability score for environmental and economic. Alternative 1: Sieving, Alternative 2: Sieving combined with soil washing.

Uncertainty analysis (Figure 18) presents the option ranking is not definitive. Sieving ranked highest in 79% of simulations, while sieving with soil washing was preferred in 21%. This suggests sieving generally provides better overall performance, despite soil washing's superior environmental results, because the environmental domain carries a higher weight. A different weighting could possibly lead to different results.

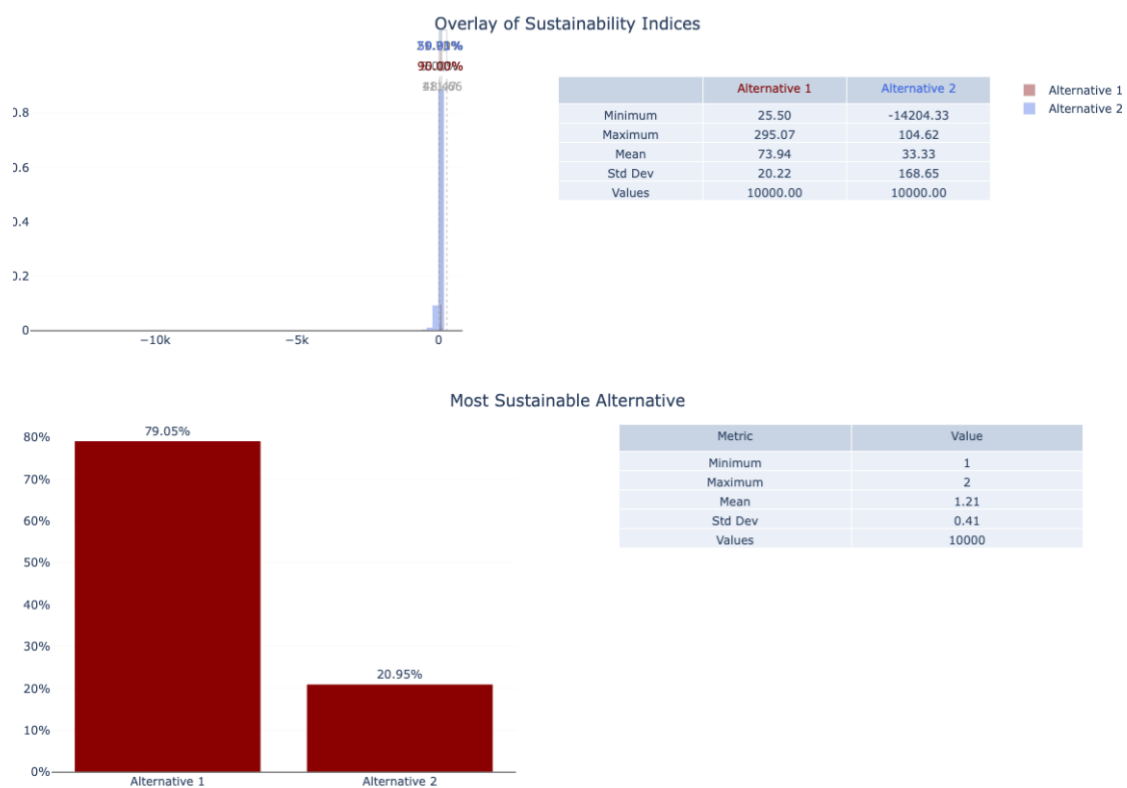


Figure 18: (a) Probability distributions of sustainability indices in scenario 2 and (b) Probability of each alternative being identified as the most circular alternative in Scenario 2.

7 Discussion

7.1 Main findings

This study evaluated different strategies for managing excavated material at Lundbyleden using SCORE, including landfill disposal, sieving, and soil washing with sieving. In the primary analysis (Scenario 1a), with “No action” as the baseline, all options produced negative sustainability indices. This outcome was expected because each involves excavation, transport, treatment, or disposal, while the infrastructure project provides broader benefits. Consequently, the results should mainly be viewed as a relative comparison among the alternatives.

In Scenario 1a, “landfill disposal” showed the lowest sustainability performance, as all excavated material was presumed to be transported off-site for disposal. Sieving alone allowed 30% recovery (reuse) of the material, whereas combining sieving with soil washing increased the projected recovery to 45% and resulted in the least negative impact on the environmental dimension.

The social assessment focused only on Health and Safety and Local Environmental Quality and Amenity, although it covered only a narrow part of the social aspect. This is because other social criteria were not considered relevant, and because data availability was limited. The economic assessment was also limited, highlighting treatment and disposal costs as the key factor in the sensitivity analysis. Because only costs could be quantified and no direct benefits (enhanced accessibility, traffic flow, and road safety) could be monetised, the economic assessment should be approached with caution. Some social criteria, such as cultural heritage, equity, and local acceptance, were not evaluated in this case study. This does not mean these factors are generally irrelevant for mass management in infrastructure projects. Instead, the available case-specific information was insufficient to evaluate their impacts or to differentiate significantly between the evaluated alternatives. Consequently, these criteria were omitted from the analysis but are recognized as potentially relevant in other infrastructure and mass management scenarios.

Scenario 1b shifted the assessment from a broader sustainability to a greater focus on the circular economy by removing the social domain from the assessment. This change heightened the emphasis on material recovery, waste management, resource use, transportation, and costs. As a result, alternatives 2 and 3 showed similar performance, suggesting that the environmental advantages of soil washing were partly offset by higher treatment costs.

However, in scenario 2, the reference alternative shifted instead to ‘landfill disposal’, unlike the other scenarios, where the reference alternative was ‘No action’. The shift offers a more realistic comparison since excavation is unavoidable in infrastructure projects (especially when excavation will occur). Both treatment options showed environmental benefits compared to landfill disposal. Soil washing provided the greatest environmental advantages, while sieving was more cost-effective. The preferred alternative thus depends on how environmental benefits are weighted against treatment costs.

The sensitivity analysis revealed that treatment costs significantly influence the assessment. However, these costs are uncertain because market prices for sieving and soil washing can differ greatly between projects. Treatment costs depend on various factors such as the volume and properties of the excavated material, contamination levels, treatment capacity, transportation distances, and the availability of treatment facilities (on-site). Therefore, cost estimates or project-specific factors could change the economic differences between options and, as a result, affect their overall ranking.

Overall, the results indicate that treatment alternatives can lessen negative impacts compared to direct landfill disposal. Nonetheless, the outcome relies on the reference alternative, criteria chosen, weighting, available data, and assumptions. SCORE helps organise the assessment but could be enhanced to better reflect positive circular economy benefits like avoided landfilling, increased reuse, and reduced virgin material consumption.

7.2 The SCORE methodology for assessment of mass management alternatives

This study demonstrates that applying SCORE can effectively help structure a sustainability assessment of various mass management alternatives in infrastructure projects. The tool enables comparison of alternatives across environmental, social, and economic domains and helps show how different criteria scoring, weightings, and uncertainties influence the outcome and ranking.

However, the study also shows that the tool is not fully adapted to infrastructure-related mass management, as it is mainly developed for remediation projects, where the choice between remediation and ‘No action’ (no remediation) often is considered for comparison. In infrastructure projects, this is often unrealistic, as excavation must be carried out for the project to be completed. Therefore, using the most extreme alternative, i.e. complete excavation and landfill disposal as a reference may give a more relevant comparison when assessing the sustainability performance of different mass management strategies.

Another limitation is that the supporting matrices for scoring different criteria was not developed to accommodate for benefits (positive impacts) but instead show how to score negative impacts for certain criteria. Criteria such as E6, E7, and E8 can only be scored negatively when using the supporting matrices, which means that more sustainable alternatives in costs and environment may still indicate negative performance. This can also be discussed in the context that the supporting matrices only use ‘No action’ as the reference alternative, meaning the alternatives are compared to nothing or against nothing.

The results can be seen through weak and strong sustainability views. Since SCORE combines different criteria into one overall index, better performance in one area can compensate for poorer performance in another, which is more in line with a weak sustainability approach. A higher SCORE does not mean good performance across all areas. The social dimension has minor influence, and some environmental impacts remained negative, even among top options. From a strong sustainability view, the negatives should be judged separately and cannot be offset by better performance elsewhere. Therefore, the ranking should be considered alongside individual criteria and dimensions.

7.3 Further analysis

Further analysis could explore the break-even points for key assumptions affecting the assessment results. For instance, it could determine the minimum reuse rate at which sieving becomes more economical than direct landfill disposal. Since the financial viability of treatment options heavily depends on treatment costs, landfill costs, transportation, and reuse potential, such an analysis could identify conditions that make treatment economically justifiable. Additionally, investigating how the ranking of sieving against soil washing shifts when weighing environmental versus economic performance differently would be valuable. Currently, soil washing has better environmental results, while sieving tends to perform better economically when economic factors are prioritised. A break-even analysis on the weighting between these aspects could pinpoint when the preferred method switches. Although not included here, these analyses could be useful for future SCORE applications by illustrating how sensitive the preferred choice is to assumptions about reuse rates, costs, and weighting.

8 Conclusions and recommendations

This thesis assessed various mass management strategies for excavated material at Lundbyleden using the SCORE methodology. It compared direct landfill disposal, sieving, and sieving combined with soil washing across different scenarios and reference options. The findings demonstrated that the ranking of these alternatives depended on the assessment perspective (CE and sustainability), the relative importance of the three-dimensional criteria, and the reference alternative.

- Treatment-based alternatives typically have a more favourable environmental impact than direct landfill disposal, as they promote higher material recovery and reuse while reducing the volume of excavated soil sent to landfills.
- Sieving combined with soil washing offered the greatest environmental advantages, mainly through higher reuse rates, reduced landfill disposal, and less reliance on virgin materials.
- Sieving proved to be more cost-effective than soil washing, making it the preferred choice in the circular economy assessment.
- The choice of reference alternative significantly influenced the results. Using ‘No action’ as a reference resulted in negative sustainability indices for all alternatives, because excavation, transport, treatment and disposal create impacts compared with doing nothing.
- ‘No action’ was deemed less appropriate as a reference for infrastructure mass management because excavation is usually unavoidable in these projects. Referencing landfill disposal offers a more realistic baseline for comparing various management strategies.
- The sensitivity analysis showed that cost is among the most influential factors in the overall ranking, indicating that uncertainties in treatment and handling costs can significantly affect the preferred alternative.
- The study also showed that the CE perspective was easier to apply to mass management because differences in reuse, landfill disposal, transport, resource use and cost could be assessed more directly. However, a CE perspective should not be considered equivalent to a complete sustainability assessment.

- SCORE provided a structured and transparent framework for comparing alternatives, but the current supporting matrices are not fully adapted to infrastructure mass management and would benefit from further development.

Recommendation for adapting SCORE to mass management

- Employ a more realistic strategy, like landfill disposal, as the reference alternative instead of only using ‘No action’.
- Adjust the supporting matrices to better reflect the positive impacts of material reuse, reduced landfill waste, lower transportation, and avoided virgin resource use.
- Create social criteria more relevant to mass management and infrastructure projects, including traffic disruptions, accessibility, local nuisances, occupational health and safety, project duration, and effects on nearby communities.

Overall, the study shows that SCORE can serve as an effective decision-support tool for comparing mass management alternatives, especially from a CE perspective. However, for wider sustainability evaluations in infrastructure projects, both the reference alternative and supporting criteria should be modified. A circular economy approach offers a more practical and measurable foundation for decision-making, but it should be supplemented with social factors if the goal is to assess sustainability more comprehensively.

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Appendices

Appendix A

Table A1: Site-specific guideline values at Lundbyleden project (Swedish Transport Administration, 2023b)

Contaminants	Site Specific guideline	Governing for site-specific guideline value	Mean	Max	Median
PAH, H	50	Protection of surface water	2,3	500	20,7
PAH, L	150	Protection of surface water	0,5	1200	18,1
PAH, M	120	Protection of surface water	2	1500	34,9
Arsenic (As)	100	Health risk related guideline value/toxicity	5,4	96,2	7,2
Barium (Ba)	50 000	Protection of surface water	103	2920	161,9
Lead (Pb)	600	Health risk-related guideline value/short-term exposure	61,3	31 000	272,3
Copper (Cu)	2500	Protection of surface water	37,3	2920	149,5
Chromium (Cr)	1800	Protection of surface water	22,3	4250	33,6
Mercury (Hg)	2,5	Protection of surface water	0,4	120	2,4
Zinc (Zn)	10 000	Protection of surface water	156	9430	352
Cadmium (Cd)	15	Protection of surface water	0,4	73	0,8
Nickel (Ni)	1200	Protection of surface water	15,4	239	18,5

Cobalt (Co)	250	Protection of surface water	7,5	49,1	8,1
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Table A2: Guidelines for discharge to the Göta River (Swedish Transport Administration, 2023b).

Parameter	Enhet	Entreprenörens larmvärde	Projektspecifikt riktvärde
Arsenik (As)	µg/l	25	50
Krom (Cr)	µg/l	15	32
Kadmium (Cd)	µg/l	0,4	0,9
Bly (Pb)	µg/l	7	14
Koppar (Cu)	µg/l	8	10
Zink (Zn)	µg/l	20	30
Nickel (Ni)	µg/l	34	68
Kvicksilver (Hg)	µg/l	0,05	0,14
Bens(a)pyren	µg/l	0,027	0,048
Polyklorerade bifenyler (PCB summa 7)	µg/l	0,001	0,003
Polyaromatiska kolväten (PAH16)	µg/l	3,5	7
Tributyltenn (TBT)	µg/l	0,001	0,0015
Oljeindex	mg/l	1	1
MTBE	µg/l	250	500
pH	µg/l	6-9	6-9
TOC	mg/l	12	12
Suspenderat material	mg/l	25	100 (50mg/l under perioden 15/4-15/6)
Turbiditet	FNU	För landarbeten:45	För landarbeten: 180
Utgående flöde i utsläppspunkt	m ³ /s	-	1,8

Table A3: Guidelines for discharge water to Kvillebäcken (Swedish Transport Administration, 2023b).

Parameter	Enhet	Larmvärde	Riktvärde
Arsenik (As)	µg/l	8	16
Bly (Pb)	µg/l	14	28
Kadmium (Cd)	µg/l	0,4	0,9
Koppar (Cu)	µg/l	8	10
Krom (Cr)	µg/l	3	7
Kvicksilver (Hg)	µg/l	0,03	0,07
Nickel (Ni)	µg/l	34	68
Zink (Zn)	µg/l	15	30
Oljeindex	µg/l	500 (250)	1000 (500 inom Göta Älvs vattenskyddsområde)
Suspenderat material	mg/l	12	25
pH	-	6,5-9	6,5-9
Fosfor*	µg/l	25	50
Kväve*	µg/l	625	1250

Appendix B

Table B1: The scoring for the environmental dimension in scenario 1a (NR-Not relevant, P05, ML & P95, meaning low, medium, and high values in the uncertainty assessment).

Key Criteria	Sub-criteria	Alternative 1			Alternative 2			Alternative 3		
		P05	ML	P95	P05	ML	P95	P05	ML	P95
E1-Soil	Ecotoxicological risks RA on-site	-6	-5	-4	-6	-5	-1	-5	-3	-1
	Ecotoxicological risks SC on-site	+5	+7	+8	+2	+4	+5	+4	+5	+7
	Soil functions RA on-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
E2-Flora and Fauna	Effectuated by RA on-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
E3-Groundwater	Effect by RA on-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Effect by RA off-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Effectuated by SC on-site	0	+2	+5	0	+1	+4	0	+3	+5
	Effectuated by SC off-site	0	+2	+5	0	+1	+4	0	+3	+5
E4-Surface water	Effect by RA on-site	-3	-2	-1	-2	-1	-1	-6	-5	-2
	Effect by RA off-site	-4	-3	-2	-3	-2	-1	-5	-4	-2
	Effect by SC on-site	+2	+3	+3	+1	+2	+2	+2	+2	+3
	Effect by SC off-site	+2	+3	+3	+1	+2	+2	+2	+3	+4
E5-Sediment	Effect by RA on-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
E6-Air	Effect on Air due to RA off-site	-10	-9	-8	-8	-6	-5	-6	-5	-3
E7-non-renewable natural resources	Natural resources effects due to RA off-site	-10	-9	-8	-6	-5	-4	-5	-4	-3
E8-non-recyclable (waste)	Waste due to RA off-site	-10	-10	-9	-8	-8	-7	-7	-7	-5

Table B2: The scoring for the environmental dimension in scenario 1b, with No-action as a reference alternative (NR-Not relevant, P05, ML & P95, meaning low, medium, and high values in the uncertainty assessment).

Key Criteria	Sub-criteria	Alternative 1			Alternative 2			Alternative 3		
		P05	ML	P95	P05	ML	P95	P05	ML	P95
E6-Air	Ecotoxicological risks RA on-site	-10	-9	-8	-6	-5	-4	-5	-4	-4
E7-non-renewable natural resources	Effected by RA on-site	-10	-9	-8	-6	-5	-4	-5	-4	-3
E8-non-recyclable (waste)	Effect by RA on-site	-10	-10	-9	-8	-8	-7	-7	-7	-5

Table B3: The scoring for the environmental dimension in scenario 2, where the reference alternative is Landfill disposal (NR-Not relevant, P05, ML & P95, meaning low, medium, and high values in the uncertainty assessment).

Key Criteria	Sub-criteria	Alternative 2			Alternative 3		
		P05	ML	P95	P05	ML	P95
E6-Air	Ecotoxicological risks RA on-site	+1	+3	+5	+2	+4	+6
E7-non-renewable natural resources	Effected by RA on-site	+1	+4	+6	+2	+6	+8
E8-non-recyclable (waste)	Effect by RA on-site	+2	+5	+8	+3	+7	+9

Table B4: Assessment of the social dimension in scenario 1a (NR = Not relevant, P05, ML & P95, meaning low, medium and high values in the uncertainty assessment).

Key Criteria	Sub-criteria	Alternative 1 (No action as a reference)			Alternative 2			Alternative 3		
		P05	ML	P95	P05	ML	P95	P05	ML	P95
S1-Local environmental quality and amenity	RA on-site	-7	-6	-5	-5	-4	-3	-6	-5	-4
	RA off-site	-8	-7	-6	-5	-4	-3	-6	-5	-4
	SC on-site	+4	+6	+7	+2	+3	+4	+3	+5	+6
	SC off-site	+3	+5	+6	+1	+3	+3	+2	+3	+5
S2-Cultural heritage		NR	NR	NR	NR	NR	NR	NR	NR	NR
S3-Health and Safety	Effects due to RA on-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
	RA off-site	-8	-5	-3	-6	-4	-2	-5	-3	-1
	Due SC on-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
	Due to SC off-site	+1	+3	+5	0	+2	+4	+2	+5	+7
S4- Equity		NR	NR	NR	NR	NR	NR	NR	NR	NR
S5-Local participation	Effects due to RA on-site	NR	NR	NR	NR	NR	NR	NR	NR	NR
S6- Local acceptance		NR	NR	NR	NR	NR	NR	NR	NR	NR

Table B5: Criteria selection for the economic dimension (NR= Not relevant, (X)=less important due to, e.g. lack of data or less relevance, X= Very Important and quantified

Benefit criteria	Sub-criteria	Alt 1	Alt 2	Alt 3
B1. Increased properties		NR	NR	NR
B2. Improved Health.	B2a. Reduced acute health risks B2b. Reduced non-acute health risks.	(X)	(X)	(X)
B3. Increased provision of ecosystem, services.	B3a. Increased recreational opportunities on-site B3b. Increased recreational opportunities in the surroundings. B3c. Increased provision of other ecosystem services.	NR	NR	NR
B4. Other positive externalities than B2 and B3.	Monetized CO ₂ e saving	X	X	X
Cost Criteria	Sub-criteria			
C1. Remediation costs	C1a. Design of remedial actions	(X)	(X)	(X)
	C1b. Cost for contracting	(X)	(X)	(X)
	C1c. Capital costs	(X)	(X)	(X)
	C1d. Remedial action	X	X	X
	C1e. Monitoring	NR	NR	NR
	C1f. Project risk	(X)	(X)	(X)
C2. Impaired health due to remedial action	C2a. Increased health risks on site C2b. Increased health risk from transport activities C2c. Increased health risks at disposal sites C2d. Other types of impaired health, e.g. increased anxiety	(X)	(X)	(X)
C3. Decreased provision of ecosystems services on-site	C3a. Decreased provision of ecosystem services on site C3b. Decreased provision of ecosystem services in the surroundings C3c. Decreased provision of ecosystem services at disposal sites.	NR	NR	NR
C4. Other negative externalities than C2 and C3	Monetized CO ₂ emissions	X	X	X

Table B6: Cost estimates for Landfill disposal

Cost item	Unit	P05 unit cost	P95 unit cost	P05 total cost, SEK	P95 total cost, SEK
Transport cost	SEK/tonne	20	50	453,600	1,134,000
Landfill disposal cost	SEK/tonne	300	1,500	6,804,000	34,020,000
Total cost	SEK			7,257,600	35,154,000
Total cost	MSEK			7.26	35.154

Table B7a: Cost estimates for sieving process

Cost item	Unit	Cost, [SEK]
Excavated material to be sieved	22,686 tonnes	—
Screening machine	1,500 SEK/hour	170,145
Excavator + driver	1,350 SEK/hour	153,130.5
Wheel loader + driver	1,250 SEK/hour	141,787.5
Material capacity	200 tonnes/hour	—
Lump sum	SEK	60,000
Total sieving cost	SEK	525,176.43

Table B7b: Total cost estimation for Sieving

Cost item	Unit	P05 unit cost	P95 unit cost	P05 total cost, SEK	P95 total cost, SEK
Share of material sent to landfill after sieving	%	70	70	—	—
Transport cost	SEK/tonne	20	50	317,604	793,800
Landfill disposal cost	SEK/tonne	300	1,500	4,762,800	23,814,000
Sieving cost	SEK	—	—	525,176.43	525,176.43
Total cost	SEK			5,605,580.43	25,132,976.43
Total cost	MSEK			5.61	25.13

Table B8: Cost estimation for Sieving combined with washing alternative

Cost item	Unit	P05 unit cost	P95 unit cost	P05 total cost, SEK	P95 total cost, SEK
Dry sieving	SEK/tonne	100	150	2,268,000	3,402,000
Soil washing	SEK/tonne	400	700	6,350,400	11,113,200
Transport cost	SEK/tonne	20	50	249,480	623,700
Landfill disposal cost	SEK/tonne	300	1,500	3,742,200	18,711,000
Total cost	SEK			12,610,080	33,849,900
Total cost	MSEK			12.61	33.85

Table B9: Summary of cost ranges for the alternatives

Alternative	Description	P05 cost, MSEK	P95 cost, MSEK
Alternative 1	Landfill disposal	7.26	35.154
Alternative 2	Sieving	5.61	25.13
Alternative 3	Sieving + soil washing	12.61	33.85

Table B10a: input parameters used to estimate transport-related CO₂e emissions for each alternative. The transported mass varies depending on the assumed reuse rates, while the transport distance, truck capacity, fuel consumption, and diesel emission factor remain constant. A fixed distance of 20 km from the project site to the landfill was used for all alternatives. A round-trip distance of 40 km was used in the calculations, focusing solely on transporting excavated material from the site to the landfill and back to the site. The truck capacity, estimated fuel consumption, and diesel emission factor are based on data provided by Veidekke (2026).

Parameter	Unit	Alternative 1	Alternative 2	Alternative 3
Excavated mass transported	tonne	22,686	15,880.2	12,474
Transport distance	km	20	20	20
Truck capacity	tonne/vehicle	30	30	30
Approximate fuel consumption	litre/km	0.4	0.4	0.4
CO ₂ e emission factor for diesel	kg CO ₂ e/litre	3	3	3

Table B10b: Estimation of CO₂e from transportation of excavated mass

Calculation item	Unit	Alternative 1	Alternative 2	Alternative 3
Number of transports	number	756.2	529.34	415.8
Total transport distance	km	30,248	21,173.6	16,632
Fuel consumption	litre	12,099.2	8,469.44	6,652.8
CO ₂ e emissions	kg CO ₂ e	36,297.6	25,408.32	19,958.4
CO ₂ e emissions	tonne CO ₂ e	36.3	25.4	20.0

Table B11: ASEK for emissions, kr/kg CO₂e

2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
2.22	2.36	2.51	2.65	2.79	2.93	3.07	3.21	3.35	3.49	3.63

Table B12: Estimated monetary cost of transport-related CO₂e emissions for 2026 using the corresponding ASEK 8.1 values.

Costs for CO ₂ (Kr)	CO ₂ e (Kg)	ASEK 2026, SEK/kg CO ₂ e	Costs 2026
Alt 1	36,297.6	2.36	85,662.336
Alt 2	25,408.32	2.36	59,963.6352
Alt 3	19,958.4	2.36	47,101.824

Appendix C: the mass management alternatives and detailed assessment of the environmental criteria, including their weighting, scoring, motivations and discussions. This appendix refers to scenario 1a, with ‘No action’ as the reference alternative.

Table C1: Description of the mass management alternatives

Alt 1	Alternative 2	Alternative 3
Excavation and landfill disposal are carried out currently at the Lundbyleden project. Only the 2.4 m above the clay layer is considered in the assessment, since clay is not of interest in reuse and sustainable mass management. Down to 2.4 m, there are different type of soils mixtures such as topsoil, bricks, dredged masses and former ground surface.	Sieving with partial landfill disposal. This approach contains only two steps. Sieving is where the coarse and fine fractions are separated. Coarse material that is cleaner can be reused. The fine fraction with attachments of contaminants will be landfilled.	Sieving and washing treatment with partial landfill disposal. The Sieving will separate coarse and fine fractions, with the intention of reusing the coarse fractions, since they are often cleaner. The contaminants often bind to the fine fractions; therefore, a washing treatment will be performed to detach the contaminants from soil particles for possible reuse. The rest of the soil that cannot be reused, after sieving and washing treatment, will be landfilled.

Table C2: The classification of on-site and off-site effects from remedial actions, along with changes in source contamination, is used in the SCORE assessment.

	On-site	Off-site
Due to remedial action	I-Effects due to the remedial action on site (during action).	II- Effects due to remedial action off-site (during action)
Due to changes in the source contamination	III- effects due to changes in source contamination on-site (after the remedial action)	IV- effects due to change in source contamination off-site (after the remedial action)
Reference: Site investigations at Lundbyleden revealed that the levels of multiple contaminants surpassed the guideline values specific to the project, as shown in Table 6.		

E1: Ecotoxicological risks

E1-I: Weighting and scoring of effects due to remedial action on site (during the remedial action).

Weight: 25	Motivation: Very important as the projects concerns mass management and management of contaminated soil, reuse and treatment and their effect on soil structure, function and contamination level.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-6	-6	-5
Most likely	-5	-5	-3
Highest possible	-4	-1	-1
Motivations and discussions: During all the remedial actions, the excavation of 22 680 ton is performed. Due to that action, the effect on the ecotoxicological risk is the same, related to excavation. some of the soil can be backfilled, if it is suitable and this will result that the soil can remain its functions. Since the washing treatment includes a water-based treatment process that may mobilize PAHs and metals, increasing the risk of temporary exposure to soil organisms.			

E1-II: Weighting and scoring of effects due to changes in source contamination on-site (after the remedial action).

Weight: 25	Motivation:		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	+5	+2	+4
Most likely	+7	+4	+5
Highest possible	+8	+5	+7
Motivations and discussions: All the approaches lead to positive impacts due to source contamination. The first alternative regardless the negative ecotoxicological risks, receives the highest scoring, since all contamination is removed from site. Alternative 2 & 3 provides also positive effects due to change in source contamination, due to their potential of treatment. However, since it is very uncertain how likely the contaminants are removed and the efficiency of the treatments. Therefore, alternative 2 receives higher scoring the alternative 3, hence the third approach is more efficient than the second one.			

E1-III: Weighting and scoring of effects due to remedial action on site (during the remedial action). Soil Function

Weight: 0	Motivation: The criteria is not included in the assessment		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions:			

E2- Flora and Fauna

Weight: 0	Motivation: As the project site does not have any flora and fauna, this criterion is considered not important in this assessment.		
Marks	Alt 1	Alt 2	Alt3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions: There are no flora and fauna located at the site; hence there's no need to include the criterion in the assessment. However, from a sustainable assessment point of view on mass management, this criterion might be interesting to reflect on.			

E3- Groundwater

	On-site	Off-site
Due to remedial action	E3-I: Effects due to the remedial action on site (during action).	E3-II: Effects due to remedial action off-site (during action)
Due to changes in the source contamination	E3-III: effects due to changes in source contamination on-site (after the remedial action)	E3-IV: effects due to change in source contamination off-site (after the remedial action)

E3-III & IV: Effects due to change in source contamination on-site & off-site

Weight: 14	Motivation: This criterion is important because contaminated mass may affect leaching, infiltration and contaminants transport. The groundwater conditions at Lundbyleden are very complex and cannot be assessed due to insufficiency in the available data. However, the groundwater criteria generally in sustainable mass management in infrastructure projects is highly relevant.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	0	0	0
Most likely	2	1	3
Highest possible	5	4	5
Motivations and discussions: Total removal of contaminant source can reduce the risk of future leaching to groundwater. The efficiency of reduction of source contaminants that could affect the groundwater in the second approach depends how effectively the sieving process is performed. If the contaminated fine fractions remain in reused material, the potential of reduction in groundwater risk may be limited. The third approach can substantially reduce contaminant concentration and leaching in the potential reused soil, providing a positive benefit for groundwater protection. However, the washing treatment and the process water need to be treated effectively in WWTP on-site.			

E4- Surface water

	On-site	Off-site
Due to remedial action	E4-I: Effects due to the remedial action on site (during action).	E4-II: Effects due to remedial action off-site (during action)
Due to changes in the source contamination	E4-III: effects due to changes in source contamination on-site (after the remedial action)	E4-IV: effects due to change in source contamination off-site (after the remedial action)
Reference: The WWTP on site will handle and treat all types of water that are produced or used on site, so that the discharge to the recipients does not exceed the guidelines as presented in Table A3. However, the assessment of these criteria will consider also consider outside the focused area and how the management approaches possibly would influence the surface water at Lundbyleden.		

E4-I: Effects on the surface water due to remedial action on-site

Weight: 20	Motivation: As the project already have a WWTP on-site that treats the surface water at the project, the criterion is considered very important. As alternative 3 also results process water from the washing treatment, the effect this could have on the focused area but also the entire project, is very important.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-3	-2	-6
Most likely	-2	-1	-5
Highest possible	-1	-1	-2
Motivations and discussions: A wastewater treatment plant at the site is active and treats the wastewater collected through the ditches and excavations. Therefore Alternative 3 gets highest scoring, since this could have an impact on site and the mobilization of contaminants, since the washing treatment of the soil produces process water. If the WWTP does not function effectively or if flooding occurs, the risk to surface water may increase. The alternatives receives negative scores since excavation and handling of contaminated soil, can cause contaminated water run-off.			

E4-II Effects on the surface water off-site due to the Remedial Action

Weight:20	Motivation:		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-4	-3	-5
Most likely	-3	-2	-4
Highest possible	-2	-1	-2
Motivations and discussions The effect on this criterion is mainly related to whether the contaminated water or run-off can reach the nearby recipients, Kvillebäcken and Göta River. The fact that alternative 3 produces process water, effects the criteria the most. If the WWTP on-site does not treat all contaminated water from the project before discharge or if it does not function well, the risk for Surface water off-site increases. However, in case the removal of contaminants does not match the guidelines in Table A2 after a treatment, the water gets released to Gryaab for additional treatment.			

E4-III: Effects on the surface water due to change in source contamination on-site

Weight:20	Motivation:		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	+2	+1	+2
Most likely	+3	+2	+2
Highest possible	+3	+2	+3
Motivations and discussions: The SC effect on surface water is positive because reducing contamination can reduce future runoff and contaminant transport to surface water. Alternative 1 provides positive score due to total removal of contamination. Alternative 2 receives a moderate positive score because sieving can reduce contamination if the contaminated fractions are separated effectively. Alternative 3 should receive highest score, due to removal efficiency of contamination and reduce in leaching potential. However, this score remains uncertain, depending on the treatment efficiency and treatment of the process water that occurs.			

E4-IV: Effects on the surface water due to change in source contamination off-site.

Weight:20	Motivation:		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	+2	+1	+2
Most likely	+3	+2	+3
Highest possible	+3	+2	+4
Motivations and discussions The effect on SC off-site is linked to SC on-site, due to transportation and leakage of surface run-off water. Depending on the treatment efficiency of the sieving, the risk that contaminated run-off water can be transported off-site, remains uncertain. However, since the alternative 3 is more efficient, in case the wastewater treatment plan is efficient in treatment of process water, the alternative should be most sustainable. Hence the source contamination is removed and the water from the remedial action is treated, the recipients are strictly considered, and therefore the risk of effects are reduced.			

E5: Sediment

Weight: 0	Motivation: Not included in the assessment, as there's no sediment at the focused area.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions: This criterion is not relevant in this case, since there are no sediments at the focused area. However, there is sediments in other parts of the project, and therefore could be interesting to study the other parts when performing the assessment.			

E6: Air

	On-site	Off-site
Due to remedial action	E3-I: Effects due to the remedial action on site (during action).	E3-II: Effects due to remedial action off-site (during action)
Due to changes in the source contamination	E3-III: effects due to changes in source contamination on-site (after the remedial action)	E3-IV: effects due to change in source contamination off-site (after the remedial action)
Reference: Calculations on the transportation of the excavated mass have been made in this criterion, where GHG emissions has been assessed. The excavated material is disposed on a landfill, located approximately 20 km from the project site. Thus, the distance, calculation based on the transportation of the excavated soil made during the project has been calculated, to quantify how much CO_{2e} these transports results. The results shows that the first approach (reference), leads to highest amount of CO_{2e}, since all the excavated soil is disposed at the landfill. The emissions can be monetized to quantify the cost of the effects on these criteria, that the management approaches will result.		

E6-II: Effects on the air due to Remedial action off-site

Weight: 25	Motivation: Very important as the mass management strategies differ significantly in transport volumes of excavated mass and machinery use, effecting CO2 emissions and air pollution.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-10	-8	-6
Most likely	-9	-6	-5
Highest possible	-8	-5	-3
Motivations and discussions: As a reference, approximately 22,686 tonnes of mass have been excavated. The excavation has been performed down to 2.5 m below ground level. In this criterion, GHG emissions from transportation of the excavated material is considered where CO2 emissions from the transportation to a landfill was calculated. The landfill is located 20 km from the project. The first approach which is already implemented at the project, results in highest CO₂e (36.3-ton CO₂e) and therefore results most impact to air The other two approaches give less impact on the criterion, since less excavated mass is transported to the landfill. The second approach results approximately 25.4-ton CO₂e, which is about 30 % less than the first approach. Alternative 3 is most sustainable in this scenario, hence the approach provides reuse of some of the excavated material and therefore less mass is disposed on landfill, resulting approximately 20-ton CO₂e and about 45 % less emissions than alternative 1.			

E7-non-renewable natural resources

	On-site	Off-site
Due to remedial action	E3-I: Effects due to the remedial action on site (during action).	E3-II: Effects due to remedial action off-site.
Due to changes in the source contamination	E3-III: effects due to changes in source contamination on-site (after the remedial action)	E3-IV: effects due to change in source contamination off-site (after the remedial action)
Reference: The soil in the depth of the first 2.4 m beneath the ground level will be excavated in all alternatives. The assessment of this criterion considers the possibility to use non-renewable natural resources such as, how much of the excavated soil after each remedial action that can be backfilled and reused. These criteria consider also the use of non-renewable natural resources during the remedial action, such as fuel for the machines and transportations of the excavated material.		

E7-II: Effects on natural resources due to Remedial action off-site

Weight: 24	Motivation: Very important, as reuse of material in mass management reduces the need for virgin material and supports sustainable mass management.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-10	-6	-5
Most likely	-9	-5	-4
Highest possible	-8	-4	-3
Motivations and discussions: This criterion is assessed based on the amount of mass that can be backfilled on site and the amount of fossile fuel that are used for excavation and transportation of contaminated soil. Based on the assessment, the first alternative has the greatest negative effect on non-renewable natural resources, as all excavated masses are transported to landfill. No material is reused, which may increase the need for virgin backfilling material (in case of need) and contribute to higher use of landfill capacity, fuel and other non-renewable resources. The 2nd alternative reduces the amount of material sent to landfill by allowing part of the excavated mass to be sieved and potentially reused, based on assumption, approximately 30 % of excavated mass can be reused. This reduces the need for virgin material compared with Alt 1, therefore the alternative is more positive. However, sieving still requires machinery, fuel and handling, and a substantial amount of material is still disposed of at landfill. The 3rd alternative has the greatest potential to reduce the use of non-renewable natural resources because the largest amount of excavated mass may be reused after treatment. It also results in the lowest amount of material sent to landfill. However, the score remains close to neutral because washing treatment may require energy, water, chemicals and additional handling in the WWTP at site, which may partly offset the resource benefit.			

E8- non-recyclable waste generation

	On-site	Off-site
Due to remedial action	E3-I: Effects due to the remedial action on site (during action).	E3-II: Effects due to remedial action off-site (during action)
Due to changes in the source contamination	E3-III: effects due to changes in source contamination on-site (after the remedial action)	E3-IV: effects due to change in source contamination off-site (after the remedial action)
Reference: In this environmental criterion, non-recyclable waste generation, contaminated soil that cannot be reused after the remedial action, will be evaluated. The assessment is based on the excavated material that exceeds the MKM guideline values in this infrastructure project and therefore transported to landfill.		

E8-II: Effects on waste due to Remedial action off-site

Weight: 25	Motivation: Very important since the project focuses on sustainable mass management by evaluating how different mass handling approaches can support reuse or non-recyclable of excavated soil in Infrastructure projects.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-10	-8	-7
Most likely	-10	-8	-7
Highest possible	-9	-7	-5
Motivations and discussions The first alternative gives highest impact on the criteria; hence all the excavated soil is transported to a landfill as waste, a volume of 22 686 ton of contaminated mass. According to the supporting matrix (Anderson et al., 2020) , this criterion should receive a very negative score. Contaminated runoff water that are produced in the process, is treated in the WWTP on site, before discharged. The 2nd approach reduces the amount of waste compared with Alt 1, since approximately 6,806 tonnes of coarse material (30 %) may potentially be reused after sieving. However, around 15,880 tonnes are still sent to landfill, meaning that waste production remains significant. On the other hand, the 3rd approach generates the lowest amount of non-reusable excavated mass, as approximately 12,477 tonnes (55%) are sent to landfill and a larger share up to 45 % of the excavated mass may potentially be reused after treatment. This means that the alternative receives highest score.			

Appendix D: the motivations and discussions for the assessed social criteria, including their weighting and scoring. It also explains which social criteria were not included in the assessment and the reasons for their exclusion. This appendix refers to scenario 1a, with ‘No action’ as the reference alternative.

S1: Local environmental quality and Amenity

	On-site	Off-site
Due to remedial action	E3-I: Effects due to the remedial action on site (during action).	E3-II: Effects due to remedial action off-site (during action)
Due to changes in the source contamination	E3-III: effects due to changes in source contamination on-site (after the remedial action)	E3-IV: effects due to change in source contamination off-site (after the remedial action)
Reference: This criterion is very important while assessing impacts on the local environment, due to remedial actions in infrastructure projects. As those types of projects may cause noise, dust and traffic disturbances. However, these types of disturbances occur regardless in infrastructure constructions and therefore change in Source contamination could at least diminish the issues but not fully abolish. Therefore, the effects due to Remedial action are more important than the one for change in source contamination.		

S1-I Effect due to Remedial action on site

Weight:20	Motivation: Important to consider how different mass management approaches in Infrastructure projects could have an impact on the local environment. The criterion is very important as discussed above.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-7	-5	-6
Most likely	-6	-4	-5
Highest possible	-5	-3	-4
Motivations and discussions: The on-site effects are most likely similar in all approaches, since the aim of the project is to build a road construction. The activities leads to road closures, reduced accessibility, noise, dust, visual disturbance and temporary disruption of movement in the surrounding area. Since these impacts are mainly caused by the road construction and excavation works rather than by the specific management technique, the alternatives are given the same most likely score.			

S1-II Effects due to Remedial action off-site

Weight:20	Motivation: The criterion is very important as discussed above.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-8	-5	-6
Most likely	-7	-4	-5
Highest possible	-6	-3	-4
Motivations and discussions: Unlike the on-site effects, this sub criteria differ in the three alternatives, since the amount transportation of the excavated material, can slightly influence the surroundings. The first alternative will have most impact on the local environmental quality off-site due to the remedial action, because of extensive physical disturbances from the transportation of the contaminated soil. Less transports are made after the other two approaches, with the assumption that the third alternative will lead to less transportation and therefore less congestion and disturbances, resulting the least scoring. There will be noises and other disturbances regardless of selection of alternative, therefore the most likely scoring is quite similar.			

S1-III: Effects due to change in SC on-site

Weight:15	Motivation: Less important since, the effects on local environment cannot fully be abolished by change in source contamination.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	+4	+2	+3
Most likely	+6	+3	+5
Highest possible	+7	+4	+6
Motivations and discussions: The disturbance due to the project itself will remain. However, from a mass management perception, the choice of strategy could influence the on-site effects on environmental quality and Amenity. The three alternatives received positive scores due to their potential of removal of source contamination, which enhances better local environment.			

S1-IV: Effects due to change in SC off-site

Weight: 15	Motivation: Less important as discussed above.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	+3	+1	+2
Most likely	+5	+3	+3
Highest possible	+6	+3	+5
Motivations and discussions All the approaches will result positive impact because of change in source contamination, hence the overall local environmental quality of the area is getting effected due to less transportation of the contaminated soil. The third approach tends to give the most impact, since less transportation and disturbance are created in the alternative, enhancing sustainability.			

S2- Cultural Heritage

Weight: 0	Motivation:		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions This criterion is not assessed in this project since, there's no restoration or preservation of cultural heritage items at site. However, this criterion could be interesting to assess in overall mass management assessment of infrastructure projects.			

S3- Health and Safety

	On-site	Off-site
Due to remedial action	E3-I: Effects due to the remedial action on site (during action).	E3-II: Effects due to remedial action off-site (during action)
Due to changes in the source contamination	E3-III: effects due to changes in source contamination on-site (after the remedial action)	E3-IV: effects due to change in source contamination off-site (after the remedial action)
Reference: This criterion is very important to assess when considering the mass management in infrastructure projects. However, the effect on this criterion off-site is more important, as they are less predictable. In Swedish constructions, health and safety due to remedial action are always considered and controllable. The aspects to consider on-site could be machinery accidents, noises and exposure risks, however the assessment could not be performed due to limited data.		

S3-I: Effects due to remedial action on-site

Weight: 0	Motivation: The criteria could not be assessed due to lack of data regarding health and safety on-site.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions			

S3-II: Effects due to RA off-site

Weight:25	Motivation: More important to consider the off-site effects that such remedial action could result, since they are more unpredictable.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	-8	-6	-5
Most likely	-5	-4	-3
Highest possible	-3	-2	-1
Motivations and discussions The 1st alternative requires the largest amount of contaminated mass to be transported off-site. It therefore has the highest potential for increased heavy traffic (although the surroundings are already congested), accident risks, emissions, dust and possible spreading of contaminants during transport. However, the actual effect depends on transport routes, distance, traffic conditions and control measures. The 2nd alternative reduces the amount of material transported to landfill compared with Alt 1, which lowers off-site traffic and accident risks. However, a substantial amount of residual contaminated material is still transported off-site, and risks remain related to dust, emissions and possible contaminant spreading. On the other hand the 3rd alternative results in the lowest amount of material transported to landfill and therefore has the lowest transport-related off-site health and safety risk. However, some risks remain due to transport of residual fractions, treatment residues or equipment. The uncertainty is high because the washing process may introduce additional residual streams that are not fully quantified.			

S3-III: Effects due to change in source contamination on-site

Weight:0	Motivation: The criteria as mentioned above could not be assessed or considered due to limited data.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions:			

S3-IV: Effects due to change in source contamination off-site

Weight:25	Motivation: More important to consider off-site effects due to change in source contamination, as they are more difficult to consider and control off-site.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	+1	0	+2
Most likely	+3	+2	+5
Highest possible	+5	+4	+7
Motivations and discussions Removing contaminated masses from the site can reduce the potential for off-site exposure through dust, runoff or other spreading pathways. However, the benefit is uncertain because the main risk reduction occurs on-site, and the extent of previous off-site exposure is not clearly known. The second alternative may reduce off-site health risks if contaminated fractions are successfully separated and removed. However, the effect is more uncertain than Alt 1 because some material may remain or be reused depending on the quality after sieving. The third alternative has the greatest potential to reduce contaminant concentrations and future spreading from reused or remaining material. Therefore, it may provide the strongest long-term reduction in off-site health and safety risks, provided that the treatment is effective and residual fractions are properly managed.			

S4- Equity

Weight:0	Motivation: The criteria could not be assessed or considered, and therefore not included in the assessment.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions: Equity was not assessed in this case study because the available information did not provide a sufficient basis for evaluating whether the mass management alternatives would result in different distributional effects between affected groups. This does not imply that equity is generally irrelevant to infrastructure mass management.			

S5- Local Participation

Weight:0	Motivation: Not included		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions: The criteria may be relevant in infrastructure projects when handling excavated materials, particularly where different mass management strategies might affect nearby communities or require stakeholder involvement. However, in this case study there was insufficient data to assess the criteria. Therefore, S5 was marked with NR for the alternatives.			

S6- Local acceptance

Weight: 0	Motivation: The criteria could not be assessed or considered, since ‘Local acceptance’ cannot directly be quantified while managing excavated soil in infrastructure projects.		
Marks	Alt 1	Alt 2	Alt 3
Lowest possible	NR	NR	NR
Most likely	NR	NR	NR
Highest possible	NR	NR	NR
Motivations and discussions Local acceptance was not assessed because the available case-specific information did not provide a basis for evaluating whether acceptance would differ between the mass management alternatives. The criterion may still be relevant in other infrastructure projects where different mass management strategies have distinguishable local effects.			

Appendix E

Table E1: The environmental and economic sustainability score in Scenario 1b. [Alternative 1: Landfill disposal, alternative 2: Sieving, and alternative 3: Sieving and washing]

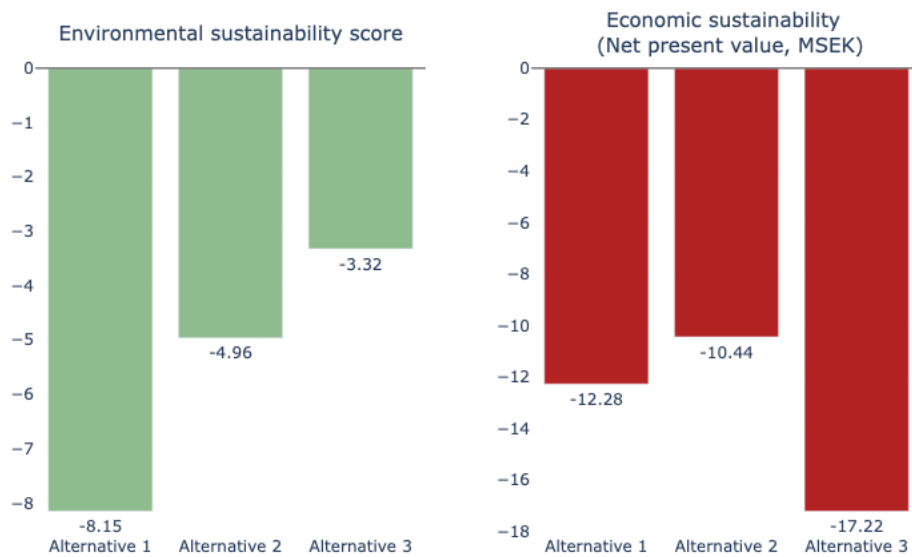


Table E2: Spearman rank's correlation coefficients for the alternatives in Scenario 1b.

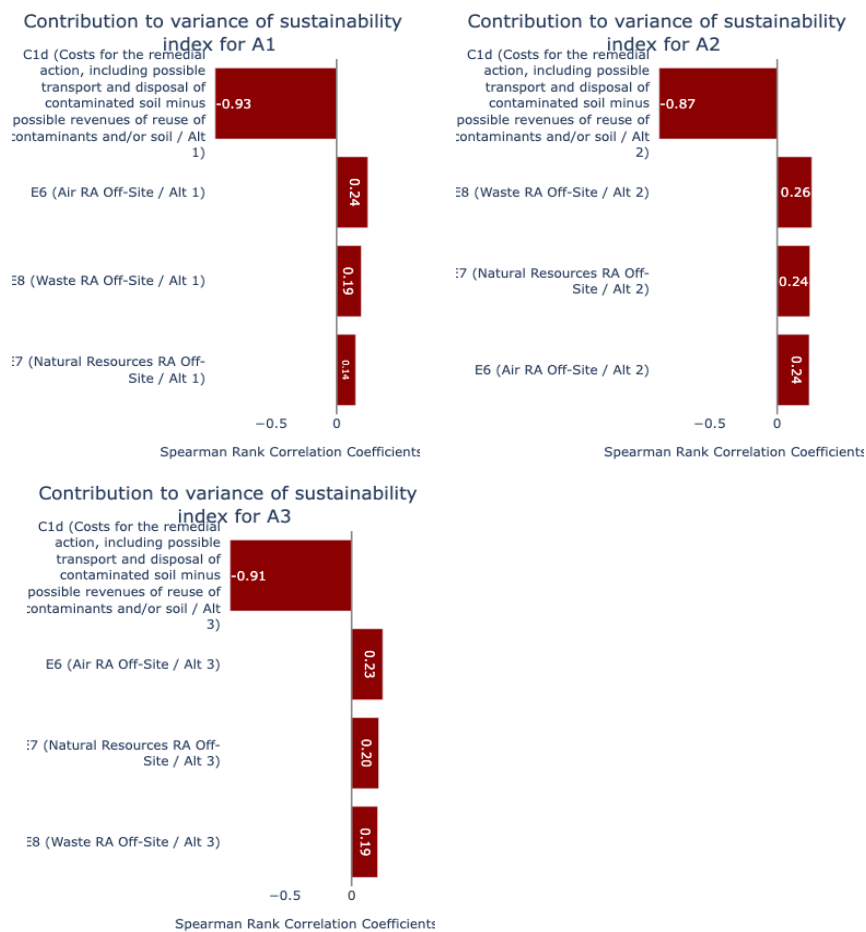


Table E3: Spearman rank's correlation coefficients for the alternatives in scenario 2.

