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# Transport Optimisation and Climate Impact of Mass Handling

Case study of the Solhöjden Project

Master's Thesis in Design and Construction Project Management &  
Infrastructure and Environmental Engineering

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Gothenburg, Sweden 2026



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## Abstract

Within the construction sector, the transport and handling of excavated materials are major contributors to both project costs and climate impact. In the European Union, excavated rock and soil accounted for approximately 20% of total waste generation in 2020, highlighting a significant potential for improved resource management. Transportation over long distances and competition between receiving facilities is a key driver of both costs and CO<sub>2e</sub> emissions. Reducing transport distances through alternative routes to receiving facilities, increasing reuse of excavated materials, and using electric lorries for transportation could significantly reduce climate impact. The aim of this study is to evaluate how design changes in the Solhöjden residential project in Kungälv, developed by JM, affected excavated mass quantities, transport demand, climate impact, and cost savings per apartment resulting from reduced excavation volumes.

To achieve this aim, three different project design versions were compared. Project version 1 (PV1) represents the original design prior to redesign, PV2 includes a raised basement floor level, and PV3 involves a reduced basement. The analysis was based on Life Cycle Assessment (LCA) in OpenLCA, combined with GIS-based modelling of transport routes to receiving facilities. The input data was primarily provided by JM and included delivery notes specifying transported weights, material types, vehicle types, and receiving locations. The study used a case study approach supported by interviews to obtain project specific information that could not be derived solely from the literature.

The results show that design changes, including basement layout modifications, reduced excavation volumes and enabled construction of the project. Between PV1 and PV3, the total quantity of excavated masses decreased by approximately 28%, demonstrating substantial mass savings due to design changes. Costs related to excavation, tipping, and transportation were reduced by approximately 13,000 SEK between PV1 and PV3-RO (route optimised). Furthermore, replacing conventional lorries with electric lorries resulted in an approximate 17% reduction in total emissions, with near-zero direct emissions during operation. The study also identified that permitting processes, differences in municipal regulations, and a limited availability of receiving facilities often contribute to longer transport distances and create additional challenges in the management of excavated materials.

Keywords: Earthworks, mass handling, transportation, LCA, GIS.

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## Terminology and Acronyms

KM	Sensitive Land Use – (Känslig markanvändning) Uncontaminated materials that can be used without risk. This is the strictest guideline level and ensures that even sensitive groups can stay in the area over a lifetime without harm.
MKM	Less Sensitive Land Use – (Mindre känslig markanvändning) Containing some contamination. These materials can still be used in areas where human exposure is lower.
Inert	Non-reactive material during storage
Reinforced concrete (inert, <500)	Reinforced concrete classified as inert material with contaminant levels below 500 mg/kg dry matter. This indicates very low environmental risk and no restrictions on handling.
Reinforced concrete (<KM, <500)	Reinforced concrete that meets the KM (Sensitive Land Use) guideline, with contaminant levels below 500 mg/kg TS.
Unreinforced concrete (<KM, <500)	Unreinforced concrete, meeting KM guidelines and low contaminant levels below 500 mg/kg TS.
Asphalt (<70)	Refers to asphalt with a PAH content below 70 mg/kg (ppm).
Asphalt (<70 PAH)	Asphalt with PAH content below 70 ppm (mg/kg), meaning it is considered free from coal tar and can generally be reused.
PAH	Polycyclic Aromatic Hydrocarbons (Commonly found in contaminated soil)
Non-stackable excavated material (wet)	Soil with a high-water content, making it unstable.
Stackable excavated material	Soil that is stable enough to hold its shape.
IFA	Non-hazardous waste
PV	Project Version
E	Electric
RO	Route Optimised
ROE	Route Optimised Electric
GHG	Greenhouse Gas
CO <sub>2</sub> e	Carbon Dioxide Equivalent
EU	European Union
LCA	Life Cycle Analysis/Assessment
GIS	Geographic Information System
OpenLCA	Open-source life cycle assessments software
QGIS	Open-source geographic information system software
JM	Residential developer
Solhöjden	Apartment construction project located in Kungälv
Dalux	Digital information management system
pH	Potential of hydrogen
EIS	Earth Information System
NO <sub>x</sub>	Nitrogen Oxides

Euro 6	European Emission Standard for vehicles
EV	Electric Vehicle
ICE	Internal Combustion Engine
ICEV	Internal Combustion Engine Vehicles
HDT	Heavy Duty Truck
GWP	Global Warming Potential
HFC	Hydrogen Fuel Cell
EPA MOVES	Emission model
ICOM	Intelligent Method of Optimised Mass compensation
BIM	Building Information Modelling
MLC	Mass Logistics Centre
M&E	Mark & Energibyggarna AB
HVAC	Heating, Ventilation, and Air Conditioning
Nordic Swan Ecolabel	Environmental certification
HVO	Hydrotreated Vegetable Oil
HGV	Heavy Goods Vehicle
ORS Tools	Route plugin for QGIS
QuickMapServices	Open catalogue of basemaps for QGIS
Brattås	Receiving facility of excavated masses
Tagene	Receiving facility of excavated masses
Surte	Receiving facility of excavated masses
Monte Carlo Simulation	Statistical technique that predicts outcomes based on probability
TTW	Tank-to-Wheel
Pinpointer	Digital system focused on traceability of excavated masses
AMW	Average Material Weight





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# 1

## Introduction

### **The Construction Sector and its Environmental Impacts**

The construction sector is a major contributor to greenhouse gas (GHG) emissions, where transport and mass handling are significant cost and climate-impact factors during the earthworks phase of residential development projects (Roy et al., 2024). Earthworks activities contribute substantially to these emissions because they involve large volumes of excavated rock and soil that must be transported and handled. Since these activities rely heavily on transportation, the transportation sector also plays an important role in associated emissions. The transport sector contributes significantly to global warming, with road transport accounting for 11% of global warming in 2000 (Skeie et al., 2009). Moreover, the buildings and construction sector accounts for approximately 37% of global GHG emissions (UNEP, 2023). In addition, heavy-duty vehicles used in construction activities still largely rely on fossil fuels (Lou et al., 2024). Consequently, transport demand, transport routes, and associated CO<sub>2</sub>e emissions should be considered during the early decision-making phase of construction projects.

Large quantities of excavated material are generated each year during construction activities. In 2020, excavated rock and soil within the European Union (EU) accounted for 20% of total waste generation, corresponding to 444 million tonnes, and represented 52% of all waste generated within the construction and demolition sector (Cristóbal et al., 2024). In Sweden alone, more than 5 million tonnes of hazardous and non-hazardous excavated waste required transportation to other locations during 2026 (Hale et al., 2021). The management of these masses therefore represents both environmental and logistical challenges.

Despite the large quantities of excavated materials generated, reuse and recycling practices remain inconsistent. Recycling rates within the EU vary significantly between countries, ranging from 10% to 100% (Cristóbal et al., 2024). On average, 25% of excavated masses are landfilled, 40% are used for backfilling, and 35% are recycled. Excavated materials are also often excluded from waste reduction goals and circular economy policies, which further contributes to landfilling instead of reuse.

Several challenges affect both the handling and reuse of excavated masses (Heljedal, n.d.). Firstly, time constraints often make it difficult to identify suitable reuse opportunities. In addition, logistical challenges, such as long transport distances between excavation sites and receiving facilities, together with limited temporary storage areas for excavated materials, increase both project costs and emissions. Space constraints at construction sites further complicate temporary storage (Hale et al., 2021). Moreover, bureaucratic processes can hinder reuse between projects, resulting in reusable materials being transported to landfills instead of being reused effectively. This also highlights the relevance of evaluating alternative

transport solutions, such as electric lorries, and their potential to reduce CO<sub>2e</sub> emissions during transportation of excavated material.

### **The Solhöjden Project**

JM AB is a leading residential developer operating across Sweden, Norway and Finland, with a focus on new housing construction and long-term sustainable development (JM, 2026c). A project developer within the construction sector is responsible for planning, organising, and managing building projects from project start to completion. According to JM's Sustainability Policy in 2025, the company aims to ensure that new construction projects achieve an almost carbon neutral climate impact by 2030. In addition, the company focuses on minimising waste, increase the reuse of materials, and promoting circular material flows between construction projects and during demolition activities.

The Solhöjden residential project developed by JM, is located in Kungälv, approximately 20 km north of central Gothenburg. The project has undergone several project versions that have influenced the quantity of excavated masses, transport demand, project costs, and CO<sub>2e</sub> emissions. Previous studies have highlighted the climate impact associated with construction transport. However, many are primarily based on assumptions. Consequently, there is a lack of empirical studies comparing different design alternatives within the same project using real mass handling data. Since early design decisions can significantly influence transport and mass handling during construction (Fredriksson et al., 2021), it is therefore highly relevant to investigate how design changes can reduce excavation volumes and contribute to lower costs per apartment as well as reduced CO<sub>2e</sub> emissions.

### **1.1 Aim**

The aim of this thesis is to evaluate how design changes during the development of JM's Solhöjden project affect excavated mass quantities, climate impact, and costs associated with mass handling and related transportation. This is achieved through a comparison of three different project design versions.

The study analyses transport routes, costs, and CO<sub>2e</sub> emissions using methods including Life Cycle Assessment (LCA) in OpenLCA, supported by GIS-based visualisation of transport routes. Furthermore, the study examines how the different design versions influence excavation volumes and how the resulting mass reductions can be translated into cost savings and reduced CO<sub>2e</sub> emissions per apartment.

In addition, the thesis investigates how transport routes to alternative receiving facilities can be optimised in order to reduce both climate impact and costs. The study also evaluates the potential climate benefits achieved by replacing conventional diesel lorries with electric lorries for the transportation of excavated materials. Furthermore, the current implementation of reuse within the Solhöjden project is analysed, together with the potential improvements for increasing reuse in similar construction projects.

Finally, the study identifies the main challenges associated with the transportation of excavated materials and how mass handling in construction projects can be improved, with a particular focus on reducing both emissions and project costs.

## **1.2 Research Questions**

- 1. How do the three different project versions of the JM project Solhöjden affect the amount of masses needed to be excavated and how do these mass savings translate in terms of cost reduction per apartment?*
- 2. How can the routing of lorries to alternative receiving facilities be optimised to minimise carbon footprint and reduce project costs?*
- 3. What climate savings can be made by switching from conventional diesel lorries to electric lorries?*
- 4. How is reuse of excavated materials currently applied in the Solhöjden project, and what potential improvements exists to increase reuse in similar construction projects?*
- 5. What are the main challenges in transporting excavated material, and how can mass handling be improved in construction projects?*

## **1.3 Delimitations**

This thesis is limited to transportation activities related to mass handling during the earthworks phase of the investigated project. Furthermore, CO<sub>2</sub>e analyses are conducted using the software OpenLCA to determine and compare emissions associated with transportation during this phase. The use of GIS software is limited to the visualisation of transport routes and the calculation of transport distances.

The study focuses solely on comparisons between the different project version, as well as alternative transportation scenarios. In addition, the impact of receiving facility selection on both costs and emissions is investigated.

## **1.4 AI tools and Ethical Considerations**

AI tools, primarily ChatGPT, were used occasionally and responsibly to provide suggestions for improving the grammar and flow of the written thesis while maintaining the integrity and core meaning of the original text. When AI-generated suggestions were used to revise sentences or paragraphs, the rewritten text was reviewed by the authors to ensure that the intended meaning and purpose of the original work remained unchanged.

In addition, Scopus AI was used to identify relevant academic articles for the thesis, while ChatGPT was primarily used for brainstorming, grammar correction, and improving overall readability of the text. The use of AI tools was critically evaluated before any suggestions or inputs were implemented.

#### **1.4.1 Confidentiality**

Sensitive data was not used in order to protect company confidentiality. Instead, the data were collected from professionals and are considered representative values, particularly regarding the cost analysis. As a result, the findings may be affected to some extent due to the use of approximate rather than exact values in the calculations.

Furthermore, confidentiality regarding the interview participants was maintained by excluding names and other sensitive personal information from the study.

# 2

## Literature Review and Background

This chapter presents the literature review on management of excavated masses, including aspects related to transportation, costs, and legislative and municipal guidelines. Together, these elements provide the foundation for the subsequent results and discussion.

### 2.1 Gaps in Literature

Several gaps in the existing literature have been identified in this study. First, there is a lack of research based on real construction projects comparable to the Solhöjden project, particularly concerning the excavation of masses and their transportation. Current literature focuses mainly on larger infrastructure projects, such as the Ostlänken project in section 2.4.1 (Emissions from Earthworks).

Furthermore, there is limited direct information on how transport logistics are managed in practice, including aspects such as competition between subcontractors, for example haulage companies. Instead, this type of industry specific knowledge is primarily obtained through interviews with experts in the field. A similar gap in literature exists regarding receiving facilities, particularly in relation to variations in tipping fees and competition between them. In addition, cost data, especially tipping fees, are difficult to obtain and are seldom reported in the literature.

The availability of receiving facilities and associated transport distances is also insufficiently addressed and can vary significantly between regions. For instance, limited access to nearby receiving facilities may result in longer transport distances, which in turn increases emissions and reduces the feasibility of reuse. Although the reuse of excavated materials is widely discussed in the literature, studies focusing on practical implementation in real projects remain limited.

Moreover, the literature focuses mainly on conventional and electric passenger cars rather than heavy-duty vehicles such as electric lorries. Passenger cars represent the majority of vehicles on the road and are therefore the main contributors to daily traffic flow and typical mobility patterns, which make them central to studies. Additionally, data on passenger cars are more available, and their driving behaviour is representative of general road users (Booto et al., 2021). In contrast, there is a lack in literature of accessible and comparable data on different types of lorries, including diesel, biodiesel, and electric vehicles, which limits detailed analysis. Information on specific model years of lorries from Volvo is limited. Consequently, the study relies on specific data obtained from Volvo Trucks website and input

from an industry expert. The literature gap exists because vehicle technology develops rapidly, and detailed model data is not always publicly available.

## **2.2 Earthworks Excavation Process**

The composition of excavated material, influenced by both natural geological factors and anthropogenic processes, may include stone, rock, gravel, and clay (Magnusson et al., 2019). The earthworks excavation phase is both time consuming and costly within projects (Parente et al., 2015). At the same time, the excavated rock and soil generated during earthworks are the materials available in large surplus quantities, making them relatively inexpensive compared to other construction materials (Look, 2023). Consequently, efficiently utilising available resources becomes important to ensure that the process is carried out as optimal economically as possible (Parente et al., 2015). Furthermore, the earthworks phase establishes the foundation required to create stable conditions for subsequent building construction. As a result, careful planning and accurate estimation of this phase are essential, which is why it can be regarded as the most critical phase of a project (Smith et al., 2000).

The processes involved in earthworks are carried out sequentially, beginning with excavation of the material followed by transportation of the excavated masses (Gomes Correia et al., 2016). These operations involve repetitive tasks and usage of heavy equipment. During the earthworks phase, soil and rock materials are first excavated at the construction site and then transported to another location for placement (Look, 2023). Furthermore, several methods exist for treating and improving ground conditions at varying depths (Gomes Correia et al., 2016). These methods are applied for multiple reasons, including cost reduction and sustainability aspects.

## **2.3 Management of Excavated Materials**

The waste hierarchy is defined as the order in which waste should be managed and disposed of (European Commission, 2023b). The hierarchy consists of prevention, reuse, recycling, recovery and disposal. In the context of mass handling, soil and excavated materials should be managed in a way that minimises waste and reduces environmental impact, as illustrated in Figure 1.



Figure 1: The Waste Hierarchy Theory (European Commission, 2023a).

### 2.3.1 Strategies for Handling Excavated Materials

Excavated materials can primarily be managed through five different strategies (Magnusson et al., 2019):

1. On-site reuse

Reuse of the material directly within the same construction site for backfilling, or other construction purposes.

2. Reuse in other projects

Transportation of the material to other construction projects, thereby reducing the need for new raw materials.

3. Pretreatment prior to reuse

Treatment of the material, such as sorting or stabilisation, before it is reused in other projects.

4. Storage for future use

Temporary storage of materials either on site or at designated storage locations for future use in construction projects.

5. Disposal or use at landfill

If reuse is not feasible, the excavated material can be transported to a landfill, where it may either be used as fill material or disposed of.

These five management strategies are illustrated in Figure 2.

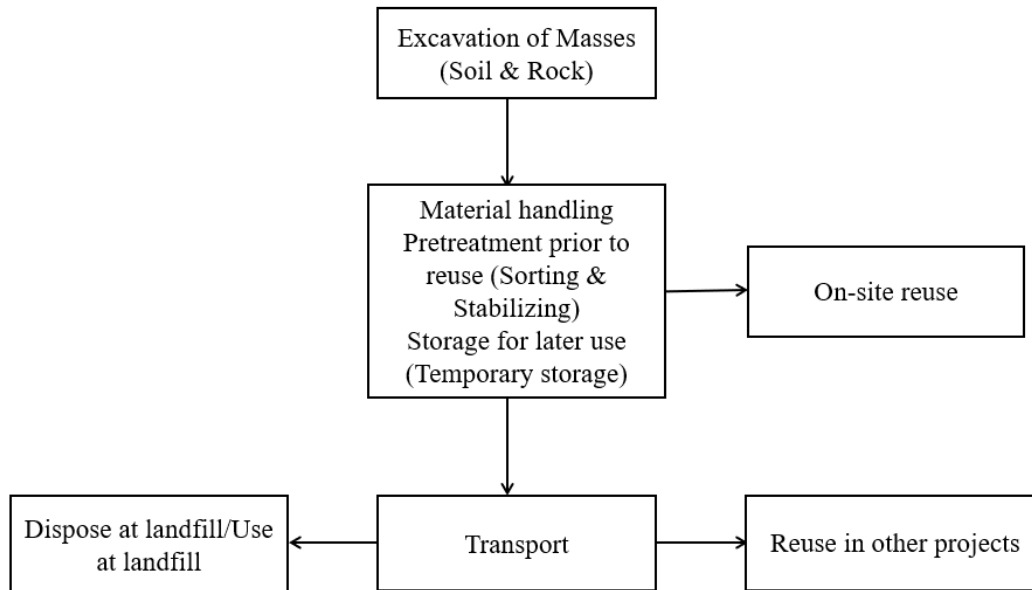


Figure 2: Excavated material management strategies. (Authors own figure).

## 2.4 Impact of Mass Handling on the Climate

This section discusses greenhouse gas emissions associated with the earthworks phase, including excavation and transportation.

### 2.4.1 Emissions from Earthworks

Optimised management of excavated soil and rock masses can reduce greenhouse gas (GHG) emissions related to transportation by 41 % (Fredriksson et al., 2021). Several measures can contribute to reducing environmental impact, including improved fill rates, return transports, and early transport planning.

The reuse of excavated rock and soil does not always occur at the same location as the excavation process. According to Fredriksson et al. (2021), “If reuse is done at the same location, there is a time lag between reuse and excavation and during this time the materials must be stored”. Transport planning is often addressed late in the project timeline, typically during the operational stage. Consequently, transportation aspects need to be considered early in the planning phase in order to ensure sufficient storage capacity for excavated materials to minimise additional handling and emissions.

Previous studies have primarily focused on excavated soil and rock in terms of recycling and mass waste management, while limited attention has been given to the interaction between site layout planning and transport planning (Fredriksson et al., 2021). This relationship therefore requires further investigation.

Heavy-duty vehicles, such as excavators and articulated haulers, consume substantial amounts of fossil fuel during the earthworks phase (Lou et al., 2024). Earthwork operations are typically carried out in the sequence of excavation, transport and compaction. During transportation, excavated materials may either be moved on site or transported off site. In cases of on-site reuse, the materials can be used for purposes such as levelling, backfilling, or landscaping. For off-site reuse or disposal, the materials must instead be transported to another construction site, a recycling facility, or a landfill.

In addition, vehicles operating during the earthworks phase can negatively affect air quality and contribute significantly to carbon emissions (Gomes Correia et al., 2016). Fuel consumption from construction equipment represent a substantial share of direct emissions, and since earthworks are included in nearly all construction projects, fuel consumption is a major contributor (Roy et al., 2024). In many construction projects, contractors have limited influence over the design phase, restricting their ability to control a large portion of the project's greenhouse gas emissions. However, fuel consumption is an area where contractors generally have greater authority.

#### **2.4.2 Reuse & Recycling Potential and Benefits**

Since soil excavation is a fundamental part of infrastructure projects, the generation of large quantities of excess excavated soil is unavoidable (Katsumi, 2015). This strongly emphasises the importance of reusing excavated materials on site or at alternative locations in order to reduce the disposal of excavated soil at landfills, which are constrained by limited capacity, finite natural resources, and limited locations allocated for landfills.

The reuse of excavated materials on site is widely recognised in the literature as an effective strategy for reducing both environmental impact and project costs, compared to recycling processes that require additional treatment (Bertin et al., 2019). Therefore, when referring to the transformation of waste into new raw materials, recycling is the more suitable term.

During the earthworks phase, the recycling of excavated on-site materials contributes to reduced consumption of natural resources (Gomes Correia et al., 2016). In addition, it decreases the need for transportation of excavated masses. However, to ensure that the excavated materials meet the required quality standards, the materials must first be analysed. If the quality is insufficient, different measures, such as chemical or mechanical treatment methods, may be applied to improve the material properties.

Several benefits are associated with the reuse of excavated soil, including reduced transport distances, lower disposal costs, preserved landfill capacity, conservation of natural resources, and reduced environmental impact (Hale et al., 2021). However, whether excavated soil can be reused depends on several factors, including particle size, plasticity, pH value, and the

concentration of pollutants. Consequently, optimisation of these parameters may be necessary to make the material suitable for reuse.

Excavated soil can either be reused on site or transported for off-site reuse (Hale et al., 2021). However, on-site reuse is considered the most favourable alternative, as it provides the greatest reduction in environmental impact. This highlights the importance of implementing environmental considerations into the design and planning phases to support a sustainable built environment. Previous studies have shown that the reuse of soil and rock materials can reduce the climate impact of a project by up to 85% and, in some cases, lower the project costs by up to 30%.

An important first step in the reuse process is determining whether the excavated material is classified as waste (Hale et al., 2021). In Sweden, excavated soil is classified as waste, which results in substantial quantities being transported to landfills. However, if the excavated soil is intended for reuse at the excavation site within a relatively short timeframe, it is not classified as waste, as this classification applies when the excavated soil lacks a clearly defined future use.

By reusing excavated soil, carbon dioxide emissions can also be reduced due to the decreased need for transportation associated with disposal (Choi et al., 2017). The transportation of excavated soil represents a substantial share of infrastructure project costs, accounting for approximately 5-16% of total capital costs.

Although soil is a limited natural resource, the recycling rate of excavated soil within the construction industry remains relatively low (Choi et al., 2017). Recycling uncontaminated excavated soil offers several advantages, including reduced landfill costs and reduced demand for purchasing new soil that may otherwise require transportation over long distances.

### **2.4.3 Reuse & Recycling Barriers and Solutions**

The barriers associated with the reuse of excavated soil are mainly categorised as regulatory, organisational, logistical and economic, and material quality barriers (Hale et al., 2021). Regulatory barriers include complex regulatory frameworks, limited guidelines regarding reuse in many countries, and lengthy application processes, despite construction projects often operating under strict time constraints. Another challenge concerns the ownership of risks associated to potential future complications linked to the reused soil.

Organisational barriers include a lack of knowledge and implementation of soil reuse during early planning stages of projects (Hale et al., 2021). In addition, there is often a lack of a holistic approach for coordinating reuse, while contracts are not designed to promote the reuse of excavated materials.

Logistical and economic barriers are primarily related to the mismatch between when and where excavated soil is needed (Hale et al., 2021). As a result, temporary off-site storage is often required due to limited storage capacity at construction sites, particularly in denser cities. This challenge is further complicated by regulations within the European Landfill Directive, which limit the intermediate storage of excavated soil classified as waste to a maximum of one year, or up to three years if the material is intended for recycling. Consequently, permits are required for longer storage periods.

Additional logistical and economic challenges arise from the transportation of soil to and from treatment facilities or temporary storage locations (Hale et al., 2021). These activities contribute to increased project costs as well as higher environmental emissions. Furthermore, low landfill costs and low prices for new materials reduce the economic incentives for reusing excavated soil.

Barriers related to material quality include contamination levels due to historical land use or the origin of the soil (Hale et al., 2021). This creates a need for both environmental and geotechnical evaluation of excavated soil to determine whether they are suitable for reuse in specific applications. However, there is currently no clear guideline regarding documentation requirements prior to reuse. As a result, the simplest solution is often the use of new materials with already established geotechnical and environmental properties.

Several measures could contribute to increasing the reuse of excavated soil (Hale et al., 2021). These include regulatory changes for promoting reuse and providing decisionmakers with the necessary tools to implement reuse. Improved guidelines could further reduce the complexity associated with reuse. Where landfill disposal is the most economically appealing option due to low cost of new materials, landfill taxation could potentially increase incentives for reuse. Another possible measure is the implementation of reward systems that encourage reuse practices in construction projects and promote more sustainable approaches.

Additional important aspects include earlier identification and documentation of both supply and demand for excavated materials during the planning phase, together with improved traceability to improve coordination between projects through digital logistics systems (Hale et al., 2021). To address limited storage capacity, soil hubs could be further integrated to regulate supply and demand. Furthermore, improved documentation of environmental and technical properties through standardised testing procedures could ensure the quality and suitable applications.

One potential approach for enabling additional reuse is the transfer or sale of excavated soil between construction projects (Choi et al., 2017). However, this requires coordination between project stakeholders and the creation of economic benefits for all involved parties. Earth Information Systems (EISs) are systems that enable tracking and information sharing related to excavated soil availability and demand. Nevertheless, challenges remain regarding such exchanges, particularly the lack of mutual agreements concerning soil volumes and pricing. Furthermore, additional planning is required to coordinate between cut and fill sites,

such as optimising schedules. Several parameters must therefore be considered when planning earthmoving activities, including timing, involved parties, costs, and the volume of soil to be transported, while aiming to reduce total costs. For excavation sites, one of the most significant expenditures is hauling cost, which is strongly influenced by both transportation distance and transported soil volumes.

## **2.5 Transportation in Earthworks**

This section discusses transportation within the earthworks phase and compares electric transportation with conventional transport.

### **2.5.1 Diesel Lorries**

In 2014, the Euro 6 emission standard for diesel lorries was introduced, resulting in a significant reduction in nitrogen oxides (NO<sub>x</sub>) emissions compared to older vehicle standards such as Euro 5 and earlier models (Hoven, 2018).

Diesel lorries remain highly dominant within heavy-duty transportation, primarily because diesel engines are 30-50% more fuel efficient than gasoline engines (Cybulski & Moulijn, 2005). In addition, their higher torque and durability make them particularly suitable for heavy-duty transportation.

### **2.5.2 Comparison of Electric and Conventional Transport**

There is limited direct research comparing the earthworks phase in projects using electric vehicles (EVs) with project relying on conventional diesel vehicles. Therefore, a broader perspective on transportation and earthworks is considered in this study.

In tunnel construction projects, battery-powered machinery has been shown to reduce global warming by up to 83% compared to diesel-powered machinery (Khan et al., 2025). Similarly, internal combustion engine vehicles (ICEVs) generate higher carbon emissions than electric vehicles (EVs).

However, one major drawback of electric vehicles is the high cost associated with battery production, which can reduce the attractiveness of implementing electric vehicles within organisations (Inkinen & Hämäläinen, 2020). Additional limitations for electric vehicles include shorter driving range and insufficient charging infrastructure compared to conventional diesel alternatives. Furthermore, it is important to consider emissions throughout the entire life cycle of electric heavy-duty lorries (HDTs), rather than only during operation, since both the production and maintenance phases generate CO<sub>2e</sub> emissions.

Research have also investigated alternative fuel types for heavy-duty lorries that generate lower environmental emissions compared to conventional diesel configurations (Li et al.,

2022). These alternatives include compressed natural gas, biodiesel, batteries, hydrogen internal combustion engines (ICEs), and hydrogen fuel cells (HFCs). Among these alternatives, HFCs offer several advantages, including near zero emissions and long driving range.

Implementation of electric lorries in long-distance and heavy transportation still faces several challenges (Provost, 2025). Large batteries are required to provide sufficient energy, which increases vehicle weight and may reduce payload capacity and overall efficiency. Battery-electric lorries can weigh between 1.5 and 2 tonnes more than diesel lorries with comparable capacity.

In addition, current battery technology limits driving range, particularly when combined with insufficient charging infrastructure, especially in rural areas (Nykvist & Olsson, 2021). Long charging times may also require additional vehicles or extended downtime. Conventional diesel lorries are more suitable for operating in extreme temperatures, such as cold climates, whereas electric lorries may experience reduced performance under such conditions. Furthermore, electric lorries involve high initial investment costs, while battery degradation over time may require costly battery replacement and significant energy use.

### **2.5.3 Impact of Receiving Facility Selection**

The selection of a specific receiving facility can significantly influence fuel consumption during the earthworks phase (Roy et al., 2024). When excavated materials must be transported over long distances, transportation may account for one of the most substantial contributors to fuel consumption within a project.

Research indicates that hauling operations requires the lowest fuel consumption at speeds between 80-90 km/h (Roy et al., 2024). In contrast, dense traffic, characterised by frequent stops and starts together with lower average speed, can increase fuel consumption. In some cases, fuel consumption has been shown to increase by up to 60% under heavily congested conditions.

## **2.6 Costs of Transportation**

In infrastructure road projects, earthworks account for around 25% of total project costs, of which transportation related to large quantities of excavated materials represent 20-25% (Bhat et al., 2023). Consequently, optimising logistics planning within a project can significantly reduce overall costs.

To minimise the need for transportation, storage facilities for excavated materials have the potential to reduce the transportation demand for soil and rock masses by 23-36% compared to conventional methods (Fredriksson et al., 2021). Several factors influence transportation efficiency and are strongly connected to planning, including fill rates, traffic flow

imbalances, and the combination of cost and delivery service. Furthermore, reducing fuel consumption can substantially lower total project costs.

One factor affecting fill rates is policies that restrict the permitted weight of lorries operating within certain areas (Fredriksson et al., 2021). Such restrictions limit the maximum fill rate per trip, which can increase the number of required transports.

Another important aspect is the utilisation rate of lorries, where inefficiency related to waiting times during loading and unloading, together with long driving distances, can significantly affect project costs (Fredriksson et al., 2021). This is also closely connected to the availability of excavators, since loading and unloading depend on their operation. These factors highlight the importance and potential of improving internal logistics to reduce project costs further. In addition, the size of the lorries used for transportation is another relevant consideration, as smaller lorries may contribute to reduced fuel consumption.

Foytik & Robinson (2015) investigated how lorry emission costs can be included in traffic models. Their study combined an emissions model (EPA MOVES) with a traffic assignment model, allowing environmental costs to be included alongside conventional travel costs such as time and distance. As a result, lorry routes are selected based on both transportation time and emission costs. The result demonstrated that route optimisation and the selection of lorry type can significantly influence greenhouse gas emissions. In the studied area, total lorry emissions were reduced by 0.61%, corresponding to around 88 tonnes of emissions.

To complete an earthworks project within budget, it is necessary to establish efficient haul road networks (Liu & Lu, 2014). By implementing optimised transportation plans between cut and fill sections, project costs can be reduced. Mass diagrams are the simplest tool, while programming models can be applied to more complex hauling problems. However, due to earthmoving operations being temporary, there is a lack of established guidelines. As a result, simulation models providing planning insights needs to be adapted from the specific conditions of each individual project. Furthermore, reducing waiting times during earthmoving can improve overall resource efficiency.

In construction projects, the cost of implementing changes increases as the project progress, while the flexibility to make changes decreases over time (JD Supra, 2023). Changes are typically less expensive during the planning and design phases, due to greater flexibility. Consequently, the ability to make cost effective changes decrease throughout the project lifecycle, as illustrated in Figure 3.

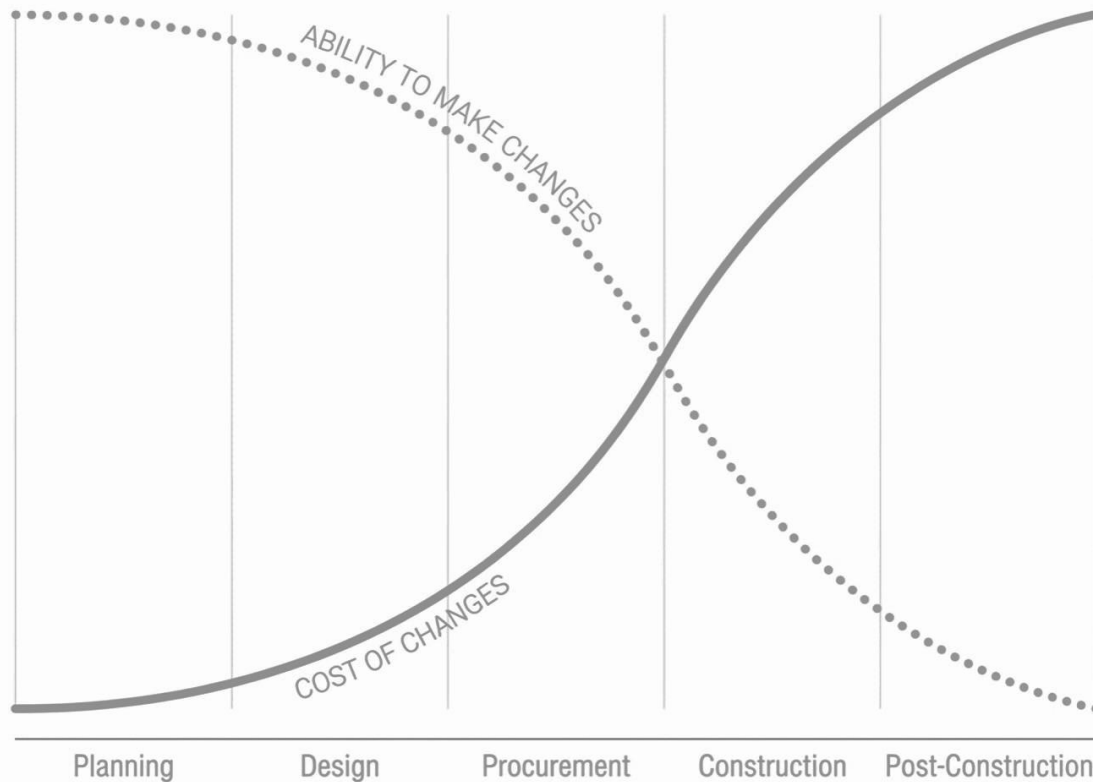


Figure 3: Ability to make changes versus cost of changes curve, Adapted from JD Supra (2023).

### 2.6.1 Design Changes and its Costs Interrelation with Mass Handling

The ICOM method (Intelligent Method of Optimised Mass compensation) enables optimisation and fill operations by minimising transport distances, thereby reducing both project costs and CO<sub>2</sub>e emissions (Villar et al., 2020). Conventional methods do not consider the type and quality of the materials available on site. In contrast, the ICOM method integrates Geographic Information Systems (GIS) for optimisation of transportation networks together with Building Information Modelling (BIM) to support accurate data management decision-making. Applications of the ICOM method in various projects have demonstrated cost reduction from between 5% to 14.1% (Villar et al., 2020).

## 2.7 Legislative and Municipal Guidelines

Traffic legislation can contribute to reduced fuel consumption for both private vehicles and lorries by lowering speed limits on roads (Inkinen & Hämäläinen, 2020). This can result in both cost savings and reduced environmental impact through lower emissions. Additional measures may include distributing HDTs outside peak traffic hours in order to reduce pollution peaks in urban areas.

The classification of excavated rock and soil as waste complicates legal procedures and reduces opportunities for effective reuse of these materials as resources (Haas et al., 2020). European legislation is not homogenous, resulting in site-specific solutions rather than a

standardised approach. National guidelines vary, but there are also logistical barriers such as storage. Temporary storage play an important role in mass handling by enabling the storage of waste materials before final disposal or recycling. Physical and chemical characterisation of the materials is required, including geotechnical quality.

The Swedish Environmental Protection Agency (2026) has reviewed and summarised court rulings related to the management of excavated masses within construction projects. The agency highlights important decisions, including rulings from both the EU Court of Justice and the Swedish Supreme Court. They emphasise that excavated materials should, whenever possible, be managed locally. If transportation is necessary, materials should only be moved over short distances, while landfilling should be considered a last resort. Similarly, Kungälv municipality (2024) emphasises that transportation distances should be minimised in order to reduce environmental impacts, for example by directing materials to nearby receiving or processing facilities.

## **2.8 Tools for Material Management**

This section provides context for the results and offers a brief background on tools used in material management.

### **2.8.1 Mass Consolidation Centre Stockholm**

In Stockholm County, 19 million tonnes of excavated materials are used annually (Stockholm Stad, 2022). To address the low level of reuse and the long transportation distances, a mass consolidation centre was established in 2018 in the Royal Seaport area. The excavated materials are reused for backfilling in newly constructed streets within nearby areas instead of being transported to landfills. Through this approach, only 20% of the excavated materials have been sent to landfills since 2018. The facility has also improved its capacity to separate soft excavated materials through the implementation of a wet screening plant. In addition, a large portion of the sorting process is conducted within a hall building, while uncontaminated rock materials can be processed and reused on site using a stone crushing plant. Since its establishment, the mass consolidation centre has handled 1,050,000 tonnes of excavated material.

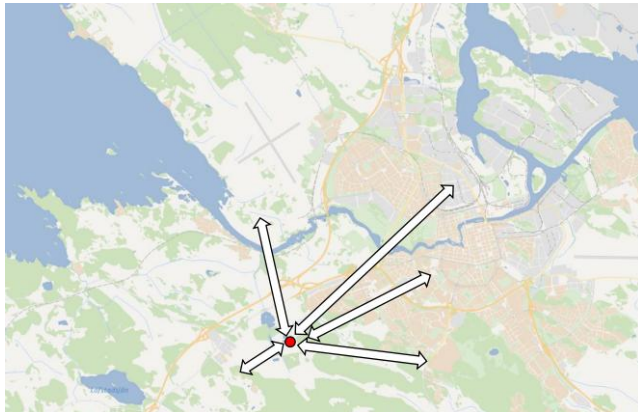
### **2.8.2 Mass Management in Norrköping City**

Norrköping municipality has developed a system for managing excavated materials that includes avoiding excavation, reusing materials locally, reusing the materials in the vicinity, storing or preparing materials for reuse, and using disposal as a last resort (Heljedal, n.d.).

According to Heljedal (n.d.), the main challenges related to mass handling today are:

1. Time constraints
2. Space constraints
3. Insufficient knowledge of soil and rock conditions
4. Waste legislation
5. Lack of coordination

Preventing excavation focuses on selecting suitable construction locations and ensuring sufficient information of the ground conditions within the area (Heljedal, n.d.). The Mass Logistics Centre (MLC) supports this system by providing temporary storage, sorting, and crushing of excavated materials for projects within the municipality, see Figure 4. In addition, the system utilises temporary storage areas that are not connected to any specific construction project.



*Figure 4: Mass Logistics Centre (MLC) Norrköping. Adapted from Heljedal (n.d.).*

### **2.8.3 Sortera Facilities**

Sortera operates a receiving facility in Torslanda, Gothenburg, that provides comprehensive handling of soil and excavated materials (Sortera, 2026). The process includes receiving, analysing, sampling, sorting, and classifying the materials, which is illustrated in Figure 5. As part of these operations, stone materials can be recovered from different types of excavation waste and subsequently processed, crushed, and screened in order to meet required quality standards.



Figure 5: Sortera Receiving facility. (Apple Maps. 2026).

## 2.9 Improvement Possibilities in Earthworks Management

Efficient allocation of heavy machinery, including excavators and dump lorries, can reduce project costs by improving productivity and ensuring that machinery is utilised where it is most needed (Parente et al., 2016). In addition, the implementation of linear programming models can contribute to reduced transportation costs and improved operational efficiency.

One of the main barriers to recycling excavated soil is the lack of communication and coordination between stakeholders, together with insufficient information sharing (Huang et al., 2022). To address these challenges, tools such as Building Information Modelling (BIM) can support improved collaboration by ensuring that stakeholders have updated and shared project information.

To ensure that excavation processes are possible, information regarding the geomorphology of the construction site must be collected (Huang et al., 2022). The integration of BIM and GIS can support this process. GIS includes a broad range of capabilities, such as distance calculations, route analysis, and identification of suitable sites.

LCA and GIS can also be integrated by utilising GIS to calculate mass balances based on geological and topographical data, which can then be incorporated into LCA analyses to estimate greenhouse gas emissions and energy consumption (Karlsson et al., 2017).

# 3 Methodology

The following chapter presents the methodology on which this report is based on, including how input data were collected and how the modelling in OpenLCA and QGIS were conducted. Figure 6 provides an overview of the methodology used to address research questions 1-3, illustrating the sources of input data, the software tools applied, and the relationships between the different analytical processes.

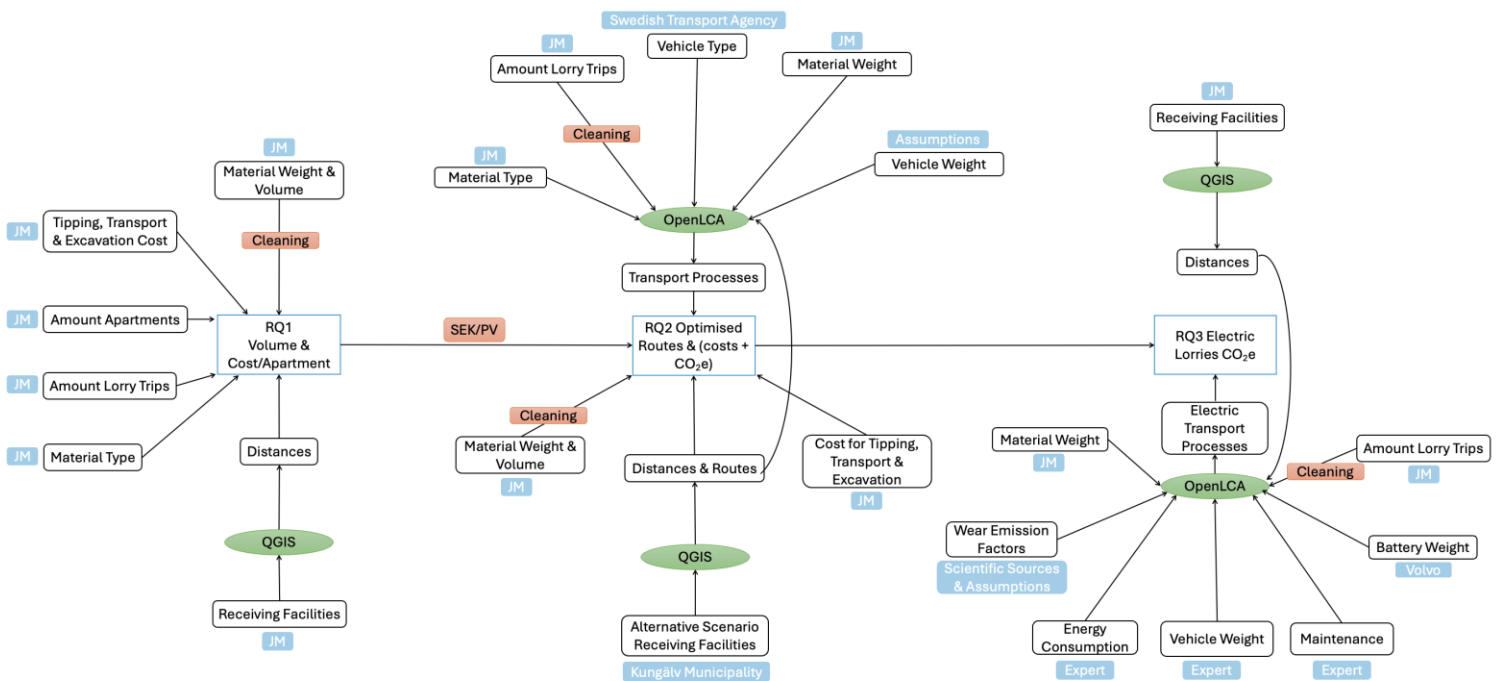


Figure 6: Overview of the methodology for research questions 1-3, showing the connections between data sources, software tools, and analytical processes (Authors own figure).

Figure 7 illustrates an overview of the methodology used to address research questions 4-5, which adopt a more discussion-oriented approach. This figure presents the sources of input data and demonstrates how the different analytical processes are connected to support the research findings.

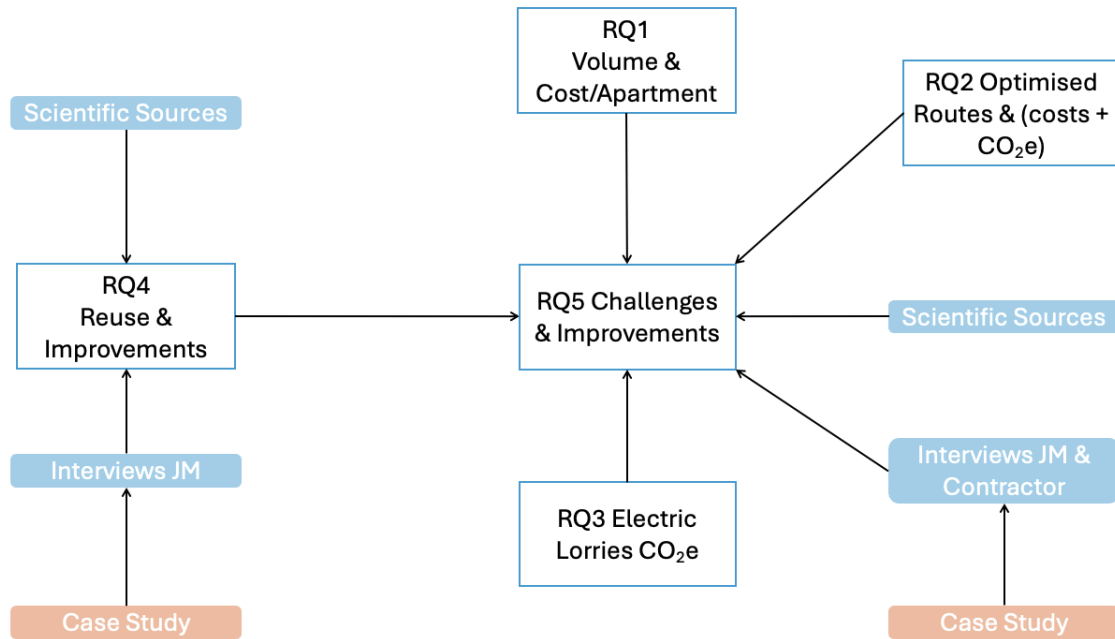


Figure 7: Overview of the methodology for research questions 4-5, showing the connections between data sources, software tools, and analytical processes (Authors own figure).

### 3.1 Literature Review Framework

This section outlines the framework used to conduct the literature review for this study. Keywords were identified in both English and Swedish to ensure a broader range of relevant literature. These keywords were then combined using the Boolean operators ‘AND’ and ‘OR’ to refine and expand the search results.

The literature review provides the theoretical basis for this master’s thesis and establishes the scientific foundation upon which the remaining sections are built. It also enables discussion and comparison between findings from the interview study and the case study, forming the basis for the study’s conclusions.

Sources were collected from academic databases including Scopus, Google Scholar, and ResearchGate. More general information was obtained through searches conducted using Google. The primary focus of the literature was to gather relevant information regarding mass handling and transportation, as this constitutes the core topic of the thesis. This was further complemented by literature addressing the impact of transportation within the construction sector, preferably with a connection to the earthworks phase.

### 3.2 Interview Study

The interview study was conducted to gain practical insights real world knowledge related to the topics addressed in this thesis and the JM project Solhöjden. This provided a practical perspective that could be contrasted with the theoretical findings from the literature review,

as the interviews contributed knowledge based on professional experience and practical work within the field.

The interviews followed a semi-structured qualitative approach, which allowed predetermined questions to be adapted and further explored depending on the interviewees' perspectives and through follow up questions. The interviewees were selected based on their professional background and area of expertise. Most participants were employed at JM, although other relevant stakeholders were included in the study. The complete list of interview questions is presented in Appendix B: Interview Questions.

### **3.2.1 Interview Bias**

The interviews were conducted with several participants, including a site manager, design manager, earthworks specialist, and other relevant stakeholders. The interview questions were adapted to each participant's professional role to obtain more relevant and detailed responses. However, this limited the possibility of direct comparison between all interviews, which may have introduced a degree of bias.

To address this limitation, the analysis focused on identifying common themes connected to the research questions rather than comparing individual interview responses.

### **3.3 Case Study Framework**

The case study is a central part of the thesis and is connected to JM's project Solhøjden, which provides real world data regarding how that project was carried out and how the three different project alternatives differ and relate to mass handling and associated transportation.

By using the digital platform Dalux, information regarding the project and the development of the layout and design through different project iterations could be collected. However, information predating the implementation of Dalux had to be collected through other sources.

Furthermore, a site visit was conducted to ensure a more holistic understanding of the project and to gain insights into how the project was carried out in practice and how the construction site was structured, despite the earthworks phase already being completed.

### **3.4 Collection of Input Data**

The Swedish County Administrative Board was contacted to obtain information regarding mass receiving facilities. However, due to limited available information, they referred the study to Kungälv municipality. A complete list of facilities permitted to receive soil classified as below KM (Sensitive Land Use) could not be established. Instead, facilities within Kungälv municipality authorised to receive excavated soil were identified, see Table 1. Decision documents related to these facilities were compiled in order to gather information

regarding, for example, the permitted quantities of excavated soil that may be handled and stored.

The excavated masses transported from Solhöjden were classified as < KM (Sensitive Land Use), meaning uncontaminated materials that can be used without risk. This represents the strictest guideline level and ensures that even sensitive groups, such as children and the elderly, can remain within the area over a lifetime without harm (Naturvårdsverket, 2009).

Some of the excavated materials were also classified as KM-MKM (Less Sensitive Land Use), indicating the presence of certain contaminants. However, these materials may still be suitable for use in areas where human exposure is considered lower. This classification is based on guideline values from Naturvårdsverket (2009).

*Table 1: Receiving facilities, in Kungälv Municipality.*

<b>Receiving Facility</b>
NCC Industri AB
Änggårde Municipal waste reception facility in Kungälv
Agnesberg Grävtjänst i Kungälv AB
Kode Gräv AB
Svevia Reception facility

Afterwards, the receiving facilities were contacted. It was found that both Agnesberg Grävtjänst i Kungälv AB and Kode Gräv AB do not receive excavated masses. One stakeholder also stated that the permit application process is highly demanding. As a result, they do not work with the reuse or handling of uncontaminated masses and perceive that the municipality complicates this type of activity.

Svevia responded that its receiving facility in Kungälv is permitted to receive soil, asphalt, concrete, and dredged masses, provided that the materials fulfil the requirements for non-hazardous waste (IFA). However, certain restrictions apply. For example, dredged masses are limited to a maximum of 1,000 tonnes per year, while the total amount of material received at the facility in Kungälv may not exceed 30,000 tonnes annually. In addition, NCC stated that masses with contamination levels exceeding the KM (sensitive land use) guideline values are not accepted.

Based on this information, the study concluded that NCC and Svevia would be selected as alternative receiving facilities for the optimised route version, instead of the facilities currently used for the transportation of excavated materials, see Table 2.

Table 2: Alternative receiving facilities.

Receiving Facility	Handling Capacity (t)	Accepted Waste Categories
NCC Industri AB	140 000 / year (inert waste)	Soil & stones Track ballast without hazardous substances Concrete Bricks Tiles & ceramics Mixtures of concrete, bricks, tiles, and ceramics
Svevia Receiving Facility	Max. 30 000	Soil Dredged material Track ballast Concrete Asphalt

The volumes of contaminated and uncontaminated masses were provided by the earthwork's specialist at JM, see Table 3. The documentation included information regarding vehicle license plates, destinations for the excavated materials, and the transported quantities per trip in tonnes, all of which were collected and analysed. In addition, acceptance receipts for contaminated transports were obtained and compiled into an Excel file.

Table 3: Transported material and their total weight.

Material	Weight (t)
Reinforced concrete (inert, <500)	71
Reinforced concrete (<KM, <500)	138
Asphalt (<70)	9
Asphalt (<70 PAH)	345
Non-stackable excavated material (<KM, wet)	2287
Soil (KM–MKM)	815
Unreinforced concrete (<KM, <500)	24
Stackable excavated material (<KM)	2895

Using the vehicle license plates together with the Swedish Transport Administration's database, it was possible to identify specifications for the vehicles, including vehicle type, fuel type, taxable weight, and emission standard.

In the Solhøjden project, all vehicles used for transporting materials were diesel lorries with the EURO 6 emission standard. The lorries consisted of Volvo and Scania vehicles. The main parameter differing between the vehicles was the taxable weight, which was either 28 or 32 tonnes.

Volvo Trucks was also contacted to obtain information regarding CO<sub>2e</sub> emissions per kilometre for different lorry model years. However, this information could not be provided. Therefore, emission factors were instead obtained from alternative sources, including publicly available data and relevant literature.

### 3.5 Input Data for Electric Lorries

Charging electric lorries from Volvo requires substantial amounts of energy, and the aim is to establish 1,700 charging stations located near highways and unloading zones (Volvo, 2024). Electric lorries can be charged from 20% to 80% battery capacity in approximately 65 minutes using a charging power of 350 kW and 750 V. This enables overnight charging between transport operations of excavated materials. However, as the battery lifetime is not specified on Volvo's website, assumptions were required. Additionally, Volvo also addresses battery recycling by collaborating with waste management contractors to explore available solutions. For example, batteries may be repurposed for secondary applications such as energy storage for solar power.

Electric lorries were investigated in this study even though they were not available as a predefined process within the OpenLCA software. Consequently, several assumptions had to be made in order to model the electric lorry process for transportation.

The modelling was based on data obtained from academic articles, together with values derived from the Ecoinvent 3.8 database. Several assumptions used in this study were developed through personal communication with a professional working with lorries from Volvo. The input data used in OpenLCA was therefore based on real world lorry data that most closely matched the use case scenario of the studied transportation. Existing input and output flows from the Ecoinvent 3.8 database process "transport, freight, lorry 16-32 metric ton, EURO6 - RER" were combined with assumptions and real-world data to create a representative model for electric lorries. Furthermore, input flows from the Ecoinvent 3.8 database process "transport, passenger car, electric - GLO" was used as a baseline and subsequently adapted using assumed values considered suitable to represent an electric lorry process.

$$\text{Total battery weight} = \text{Number of batteries} \cdot \text{Battery weight} = 4 \cdot 505 = 2,020 \text{ kg} \quad (1)$$

According to Volvo (n.d.), a single battery used in a Volvo electric lorry weighs 505 kg, and their lorries are equipped with between two and six batteries. According to personal communication with the contact person at working with lorries from Volvo (2026), lorries operating on longer routes most commonly use six batteries, while four batteries are considered sufficient for shorter transport distances within urban areas.

$$\text{Battery mass per lifetime km} = \frac{\text{Total battery weight (kg)}}{\text{Average lifetime for the battery (km)}} = \frac{2,020}{500,000} = 0.00404 \text{ kg} \quad (2)$$

Calculating the average battery lifetime in kilometres for use in OpenLCA is not straightforward. Lorries are typically operated by haulage companies for approximately 8-10 years before being replaced with newer models, even though both the vehicle and battery lifetime may exceed this period (Volvo personal communication, 2026).

The total driving distance accumulated during the vehicle's operational lifetime is also influenced by the intended use of the lorries. Vehicles operating daily over longer transport distances are likely to accumulate significantly greater mileage before replacement, whereas lorries primarily used for shorter transport distances are unlikely to reach the same total driving distances.

$$\text{Energy consumption} - \text{between } 1.1 \text{ \& } 2.1 \text{ kWh/km} \rightarrow 1.5 \text{ kWh/km} \quad (3)$$

According to personal communication with the contact person at Volvo (2026), the electric lorries typically consume between 1.1 and 2.1 kWh/km. Average energy consumption is estimated to be approximately 1.9 kWh/km for lorries operating on short distance routes, 1.5-1.6 kWh/km for long distance transport lorries, and around 1.2 kWh/km for lorries equipped with cranes that perform loading and unloading operations at construction sites in urban areas. Based on this information, an energy consumption of 1.5 kWh/km was assumed.

$$\text{Maintenance}_E = \text{Maintenance}_D \cdot 0.5 = 3.20E^{-7} \cdot 0.5 = 1.60E^{-7} \quad (4)$$

Maintenance requirements for electric lorries are assumed to be 50% lower than for diesel lorries due to the reduced number of components requiring maintenance (Volvo personal communication, 2026). Furthermore, service costs for electric lorries are generally estimated to be 30-40% lower compared to their diesel counterparts.

$$\text{Brake Wear}_E = \text{Brake Wear}_D \cdot 0.5 = 2.22E^{-5} \cdot 0.5 = 1.11E^{-5} \text{ kg} \quad (5)$$

According to Woo et al. (2022), emissions associated with brake wear from electric vehicles can be assumed to be 50% lower than those from diesel vehicles due to the use of regenerative braking.

$$\text{Road Wear}_E = \text{Road Wear}_D \cdot 1.07 = 1.91E^{-5} \cdot 1.07 = 2.04E^{-5} \text{ kg} \quad (6)$$

According to personal communication with the contact person at Volvo (2026), an electric lorry is assumed to weigh one tonne more than its diesel equivalent. This corresponds to an increase of around 7% compared to the assumed 14.5 tonne diesel lorry used in the calculations. Due to this additional weight, road wear emissions were also assumed to increase proportionally (Malmqvist, 2022).

$$\text{Tyre Wear}_E = \text{Tyre Wear}_D \cdot 1.07 = 2.20E^{-4} \cdot 1.07 = 2.35E^{-4} \text{ kg} \quad (7)$$

Due to the increased weight of electric lorries, tyre wear emissions can also be assumed to increase proportionally (Malmqvist, 2022).

$$\text{Road}_E = \text{Road}_D \cdot 1.07 = 1.05E^{-3} \cdot 1.07 = 1.12E^{-3} \quad (8)$$

The increased weight compared to the diesel lorry was also assumed to affect the road parameter, resulting in an estimated 7% increase.

$$\text{Road Maintenance}_E = \text{Road Maintenance}_D \cdot 1.07 = 2.23E^{-4} \cdot 1.07 = 2.39E^{-4} \quad (9)$$

Road maintenance were also assumed to increase proportionally with the additional weight compared to the diesel counterpart.

See Appendix A for an overview of the electric lorry input data used in OpenLCA.

### 3.6 Modelling in LCA & QGIS

The system boundary of the LCA in this thesis were to investigate the use stage of transportation, Well-to-Wheel that were associated with handling of excavated masses in Solhøjden. This consists of empty and loaded lorries, and routes distances for receiving facilities of excavated masses. Although, due to the nature of OpenLCA, some upstream processes such as electricity production, battery manufacturing, lorry production and diesel production, are indirectly included in the assessment.

The functional unit used in this study was the transportation of excavated materials generated within Solhøjden. The transport activities were modelled based on transported mass and transport distance in tonne-kilometres.

It was further assumed that the lorries were distributed around the subcontractor M&E's main office in Mölndal. At the beginning of each work shift, the lorries were assumed to travel empty from M&E's main office to Solhøjden in Kungälv, where they were loaded equally before transporting excavated masses to the receiving facilities. If multiple trips were conducted during the same shift according to the transport records, the lorries were assumed to return empty to Solhøjden between each transport. Otherwise, they were assumed to return directly from the receiving facility to the main office in Mölndal.

For LCA calculations, OpenLCA version 2.4 was used together with the Ecoinvent 3.8 cut-off unit database, released on 21 September 2021. Efforts were made to identify a more transport-oriented database more suitable to the scope of this thesis, although with limited success, resulting in the use of the Ecoinvent database. Since the database does not contain datasets specifically representing the exact transport operations carried out in Solhøjden, several assumptions were required in the LCA calculations. In addition, the lorries were assumed to be equally loaded in order to simplify the calculations due to the large amount of transport data.

For visualisation purposes, GIS maps illustrating transport routes were created in QGIS (version 3.44.7). The complementary plugins QuickMapServices and ORS Tools were also

used. QuickMapServices provided an underlying base map of Sweden, while ORS Tools enabled route generation specifically adapted for HGVs.

This approach made it possible to visualise alternative receiving facilities for excavated materials and compare them with the facilities that were actually used in the project. In addition, the Isochrones tool within ORS Tools was applied to determine the distance an HGV could travel within a predetermined timeframe using Solhöjden as the starting point. This enabled a clearer visualisation of the relative distance between the project site and each receiving facility.

The fastest available route was consistently used when calculate transport distances between receiving facilities and the lorries final destinations, as the study assumed that this most closely reflects how lorry drivers select routes in practice.

Figure 8 illustrates the transport routes visualised in QGIS, showing how excavated uncontaminated masses were transported from Solhöjden to the receiving facility at Brattås, with M&E in Mölndal as the starting location for the empty lorries (A). The transport routes used for the transportation of contaminated masses to the receiving facilities in Surte, Tagene, and Brattås (B). Finally, the transportation routes for the route optimised project version, in which the excavated masses were transported to the receiving facilities operated by Svevia and NCC (C).

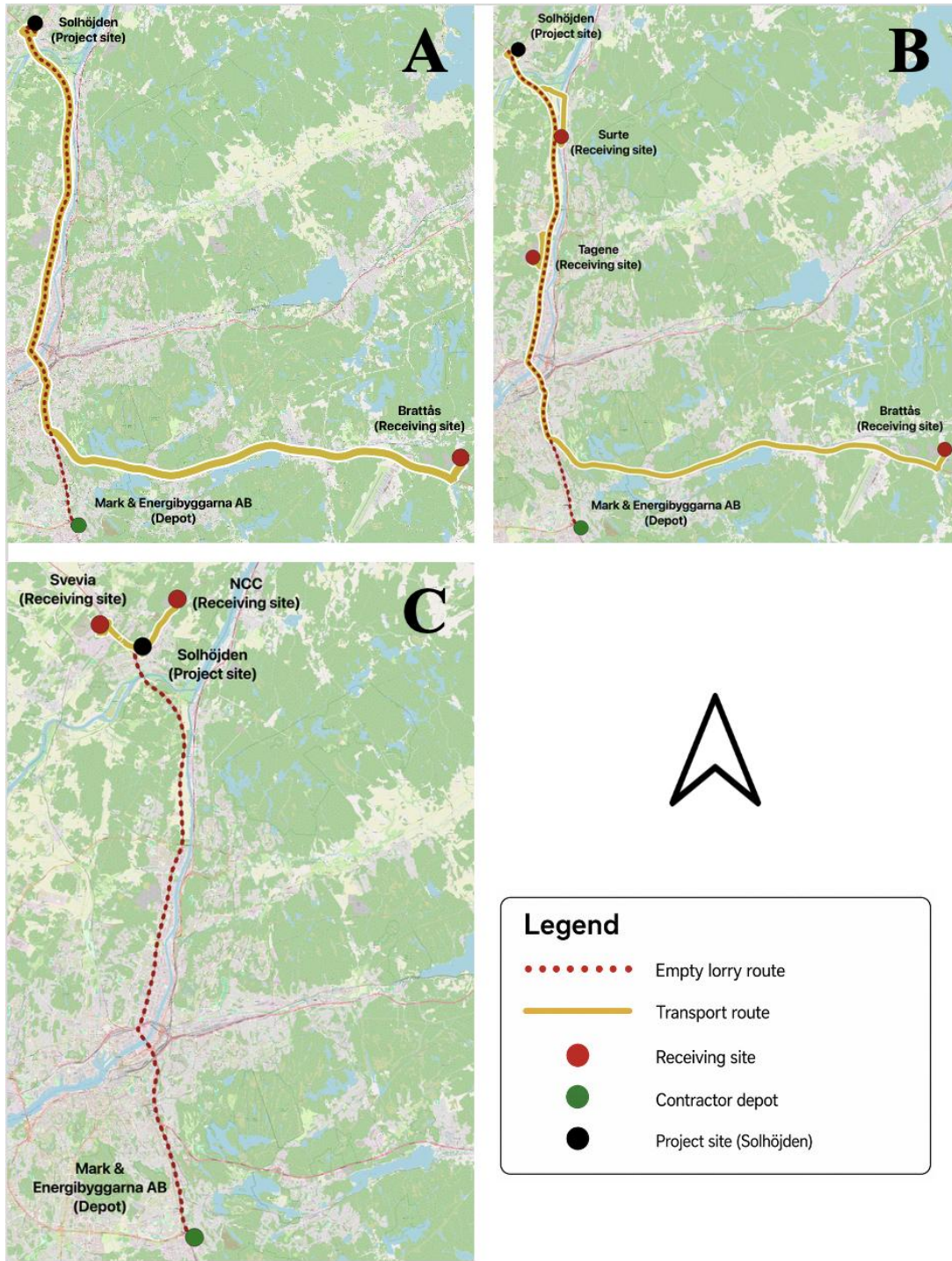


Figure 8: A: The routes used for receiving facilities of uncontaminated masses. B: The routes used for receiving facilities of contaminated masses. C: The routes used for receiving facilities for project version 3 route optimised (PV3-RO). (Authors own figure).

Transport distances were collected using QGIS together with the ORS Tools plugin, which generated the fastest route available for Heavy Goods Vehicles HGVs and provided the transport distances in kilometres, as presented in Table 4.

Table 4: Distances between locations used for transport modelling for the PV 1-3.

<b>Lorry Route</b>	<b>Distance (km)</b>
Solhöjden - Brattås	46.41
Solhöjden - Tagene	14.47
Brattås - M&E	28.17
M&E - Solhöjden	28.28
Surte - M&E	23.67
Tagene - M&E	15.93
Solhöjden - Surte	8.56

Table 5 presents the transport routes for PV3, including the number of trips and transported material quantities. The average material weight was calculated by distributing the weight equally per material, since each lorry could not exceed the maximum load limit of 40 tonnes, which resulted in an increased number of trips between PV1 and PV2.

Table 5: Transport routes, number of trips and average material weight (AMW) for PV3.

<b>Material Route</b>	<b>Trips (N)</b>	<b>AMW (t)</b>
Reinforced concrete (inert, <500) - Solhöjden - Brattås	4	17.65
Reinforced concrete (<KM, <500) - Solhöjden - Brattås	7	19.65
Asphalt (<70) - Solhöjden - Brattås	1	9.38
Asphalt (<70 PAH) - Solhöjden - Tagetipp	11	31.40
Non-stackable excavated material (<KM, wet) - Solhöjden - Brattås	73	31.32
Soil (KM-MKM) - Solhöjden - Surte	29	28.10
Unreinforced concrete (<KM, <500) - Solhöjden - Brattås	1	23.72
Stackable excavated material (<KM) Solhöjden - Brattås	86	33.66
Empty Lorry Brattås - Mark & Energibyggarne AB	71	0
Empty Lorry Mark & Energibyggarne AB - Solhöjden	91	0
Empty Lorry Surte - Mark & Energibyggarne AB	11	0
Empty Lorry Tagene - Mark & Energibyggarne AB	9	0
Empty Lorry Brattås - Solhöjden	101	0
Empty Lorry Surte - Solhöjden	18	0
Empty Lorry Tagene - Solhöjden	2	0
<b>Total</b>	<b>515</b>	

For the alternative route scenario, masses classified below KM were assumed to be transported to the receiving facility NCC Skälebräcke, as the facility does not accept materials exceeding this classification. In contrast, masses classified as KM-MKM were assumed to be transported to the receiving facility operated by Svevia, due to its capacity to handle larger quantities of these material types. The transport distances for these lorry routes, together with the corresponding material quantities, are presented in Table 6 and Table 7.

Table 6: Distances between locations used for transport modelling for PV3 route optimised.

<b>Lorry Route</b>	<b>Distance (km)</b>
M&E - Solhöjden	28.28
NCC Skälebräcke - M&E	30.85
Svevia - M&E	29.77
Solhöjden - Svevia	3.39
Solhöjden - NCC Skälebräcke	2.78

Table 7: Transport routes, number of trips and average material weight (AMW) for PV3 route optimised.

<b>Material Route</b>	<b>Trips (N)</b>	<b>AMW (t)</b>
Reinforced concrete (inert, <500) - Solhöjden - Svevia	4	17.65
Reinforced concrete (<KM, <500) - Solhöjden - Svevia	7	19.65
Asphalt (<70) - Solhöjden - Svevia	1	9.38
Asphalt (<70 PAH) - Solhöjden - Svevia	11	31.40
Non-stackable excavated material (<KM, wet) - Solhöjden - NCC	73	31.32
Soil (KM–MKM) - Solhöjden - Svevia	29	28.10
Unreinforced concrete (<KM, <500) - Solhöjden - Svevia	1	23.72
Stackable excavated material (<KM) Solhöjden - NCC	86	33.66
Empty Lorry NCC - Mark & Energibyggar AB	71	0
Empty Lorry Mark & Energibyggar AB - Solhöjden	91	0
Empty Lorry Svevia - Mark & Energibyggar AB	20	0
Empty Lorry NCC - Solhöjden	101	0
Empty Lorry Svevia - Solhöjden	21	0
<b>Total</b>	<b>516</b>	

### 3.7 Cost Calculation

For the cost calculations, the tipping fee (SEK/tonne), transport cost (3 SEK/km/tonne), and excavation cost (178 SEK/tonne), were considered, as presented in Table 8. This information was gathered from an earthwork's specialist at JM.

Table 8: Tipping fee for each material.

Tipping Fee (SEK/t)	Material
320	Reinforced concrete (inert, <500)
320	Reinforced concrete (<KM, <500)
170	Asphalt (<70)
170	Asphalt (<70 PAH)
128	Non-stackable excavated material (<KM, wet)
330	Soil (KM–MKM)
250	Unreinforced concrete (<KM, <500)
58	Stackable excavated material (<KM)

### 3.8 Uncertainty and Sensitivity Analysis

A sensitivity analysis was conducted to assess the impact of variations in material quantities. More specifically, scenarios were evaluated in which the excavated masses quantities were increased and decreased by 10% in order to examine how such variations influence the overall results. The analysis was performed using a Monte Carlo simulation with 5,000 iterations in OpenLCA to assess the uncertainty and sensitivity related to the climate impact of mass transportation for PV3.

Monte Carlo analysis is a technique that uses random sampling to evaluate how uncertainty in input parameters affect the output of a model (Johnson, 2013). Sensitivity analysis examines how variations in input parameters influence the model output and can therefore be used to identify the most influential parameters, helping to reduce uncertainty within the model.

# 4

## Case Study

The following chapter is primarily based on findings from the interview study and presents relevant information regarding JM's Solhöjden project. The complete list of interview questions is presented in Appendix B: Interview Questions. Furthermore, Table 9 provides an overview of the interview participants, including their roles and affiliated companies.

Table 9: List of Interviewees and company names.

Interviewee	Role & Company
1	Design Manager at JM
2	Contaminated land specialist at JM
3	Site Manager at JM
4	Earthworks specialist at JM
5	Site Manager at contractor M&E
6	Co-founder at Pinpointer

### 4.1 JM and the Solhöjden Project

This study investigates JM's Solhöjden project, located in Kungälv municipality north of Gothenburg. The Solhöjden project involves the construction of residential apartments in Kongahälla (JM, 2026b). In Solhöjden 137 apartments are considered. Torpe gränd forms the northern boundary of the area, while Hansgatan is located to the east and Kongahällagatan to the south, as illustrated in Figure 9. The ground surface level within the area is +6.5 m and the excavation during the earthworks phase is illustrated in Figure 10.



Figure 9: Location of the Solhöjden construction site in Kungälv. (JM, 2026a).

According to JM, excavated materials are regarded as surplus material rather than waste and are therefore managed accordingly. Excess soil that cannot be reused within the project is sometimes redirected to other construction projects, for example for the construction of noise barriers. If reuse is not possible the material is transported to a receiving facility. In certain cases, the excavated material is of sufficiently high quality, comparable to uncontaminated sand, which enables reuse in applications such as concrete production within specified limits. Furthermore, some receiving facility operators consider these materials to have economic value and may therefore choose to sell the material rather than classify it as waste.

JM does not carry out the earthworks operations itself but instead procures contractors to perform this work. In Solhøjden, M&E acted as the main contractor and further subcontracted transport companies responsible for the haulage operations. These transport companies compete with one another for transport contracts.

Several factors strongly influence competition within mass transportation, including the distance to the receiving facility, tipping fees, fuel prices, vehicle and driver availability, and project time constraints. In most cases, contracts are awarded to the contractor offering the lowest overall cost.



*Figure 10: Solhøjden during the earthworks phase. (JM, 2025d).*

## **4.2 Background of the Design Phase**

The Solhøjden project was already largely completed in terms of the early design phase when Interviewee 1 (design manager), joined the project. At that stage, the design phase had been finalised, and the construction drawings were already completed. However, the Covid-19 pandemic resulted in a market downturn and rising construction costs, meaning that the original budget and financial calculations could no longer be maintained. As a result, a cost reduction process was initiated to scale back elements identified as major cost drivers. Despite these efforts, the overall project costs did not decrease significantly.

At the same time, the project site continued to generate holding costs, creating pressure to move the project forward. According to interviewee 1, it was therefore challenging to enter

the project at a later stage and attempting to restructure it. To address the issues, the design manager contacted the structural engineer who had been involved from the beginning of the project and asked, “if we had the opportunity to start over, what would we do differently?”.

The structural system was inefficient and unnecessarily complex. Furthermore, Interviewee 1 reviewed the apartment layouts and identified that several units were excessively large and difficult to furnish efficiently.

#### **4.2.1 Design Changes to Limit Excavation of Masses**

Interviewee 1 (design manager) redesigned the project within a relatively short timeframe. According to the interviewee, replacing the architect was necessary in order to enable a more efficient redesign process. During this phase, the HVAC consultant was also replaced, while the structural and electrical consultants remained involved in the project.

Interviewee 1 explained that the basement had originally been positioned too deep below ground level, making the first step of the redesign process to raise the basement level. The interviewee further highlighted that “the waste collection vacuum system occupied significant space, and the foundation was unnecessarily large”, which contributed to increased project costs. By reducing the footprint of the waste collection vacuum system and raising both the system and the basements level, the need for sheet piling and extensive excavation works could be reduced.

Furthermore, Interviewee 1 emphasised that “the basement was excessively large, designed in a U-shape with an additional protruding wing”. The basement also included rental storage units that were considered unnecessary. Together with the architects, these storage areas were removed and corridor widths were reduced, resulting in a substantial reduction in basement floor area.

The layout of the ventilation plant room was inefficient, as the air handling unit had originally been placed within the same space. To improve efficiency, the installations were reorganised and vertically stacked throughout the building. In addition, the building orientation was adjusted, and both the entrance and elevator solutions were simplified. Finally, reducing internal walking distances further improved the overall efficiency of the building layout.

In general, there is often limited focus on optimising the earthworks phase. However, these aspects are important to address at an early stage in the planning process. Furthermore, attic solutions are generally considered more cost-effective alternatives to basements, as they can contribute to a reduction of costs associated with the earthworks phase.

### 4.2.2 The Three Design Versions

The project underwent three major design revisions that influenced the extent of the earthworks, as reported by JM. The differences between the three project versions mainly relate to the following changes:

1. In the first and original project version (PV1), no suitable sheet pile solution had been identified. To limit soil removal, the excavation was reduced, while a large vacuum waste system was included in the design.
2. In the second project version (PV2), the dimensions of the waste collection vacuum system were reduced, and the system was positioned at a higher level. In addition, the foundation level was raised, which simplified the sheet piling solution and reduced the extent of the sheet piling. However, this also reduced ceiling height within the basement.
3. In the third project version (PV3), parts of the basement were removed by eliminating plans for rentable storage units, which enabled less extensive foundation works. Furthermore, the basement corridors were narrowed while still complying with minimum requirements.

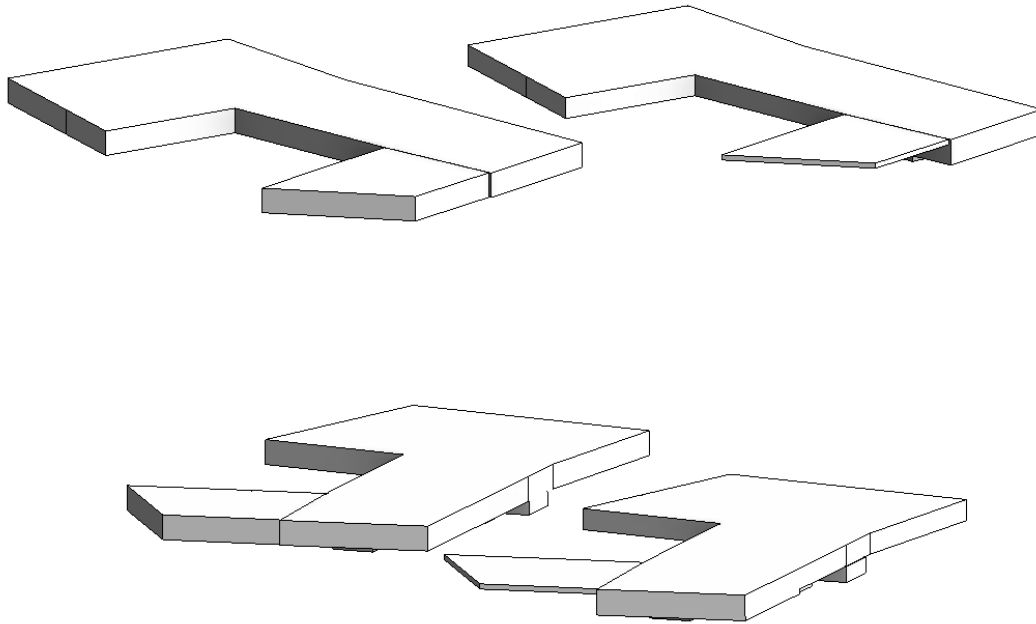
Table 10 presents the excavated volume and mass quantities for PV1-3 and PV3-RO. The density was established at 1.91 t/m<sup>3</sup> for PV3 by dividing the total excavated mass transported to the receiving facilities by the planned excavated volume. It was then assumed that the remaining project versions had the same density, which enabled the calculation of the total excavated mass for the other project versions. Since the only difference between PV3 and PV3-RO lies in the transportation routes, both alternatives have the same excavated mass and volume.

*Table 10: Excavated volume and mass for project version (PV) 1-3 and route optimised (RO).*

<b>Project Version</b>	<b>Total Excavated Volume (m<sup>3</sup>)</b>	<b>Total Excavated Mass (t)</b>
PV1	4,777	9,137
PV2	4,394	8,403
PV3	3,442	6,583
PV3-RO	3,442	6,583

PV1 consists of approximately 4,777 m<sup>3</sup> of excavated material, as illustrated in Figure 11.





*Figure 13: Volume difference between project version (PV) 2 on the left and PV3 on the right, where the measurements are taken from the centreline of the sheet pile wall. (JM, 2026f).*

### **4.3 Challenges with Mass Handling**

This section presents challenges related to mass handling and is based on findings from the interview study.

#### **4.3.1 Problems with Different Types of Masses**

According to Interviewee 2 (contaminated land specialist), the handling of wet soil is an extremely costly aspect that is often overlooked. Wet soil can generate approximately twice the handling cost compared to regular soil, yet this aspect has historically been underestimated in cost calculations. Rainfall during transportation to receiving facilities can increase the moisture content of the soil, creating significant challenges since wet masses are more difficult to stack and handle efficiently.

Another challenge concerns the handling of uncontaminated excavated materials, which are generally subject to extensive sampling and testing requirements. Proving that excavated material is entirely uncontaminated can be difficult, and if this cannot be demonstrated within the required timeframe, opportunities for reuse may already have been lost. For example, excavated materials may contain slightly elevated sulphide levels, which can prevent reuse.

### 4.3.2 Economic Challenges

According to Interviewee 2 (contaminated land specialist), subcontractors in Gothenburg submit bids, and particularly during the current economic downturn, the lowest price is always the determining factor. The interviewee further explained that contracts are commonly procured as combined solutions for both transportation and disposal.

Sustainability requirements were described as more relevant during periods of high economic activity but may become increasingly important again in future market conditions. Certifications such as the Nordic Swan Ecolabel are only applied after the earthworks phase and therefore do not affect the requirements for the excavation or transportation of excavated masses. However, optimising transport distances remains important, as approximately 30% of the carbon dioxide emissions associated with construction projects derive from the earthworks phase.

Regarding the earthworks contract, excavation and transportation activities were estimated to account for approximately 20% of the contract cost. In turn, the earthworks contract itself typically represents around 15-25% of the total project cost. Consequently, optimising excavation and transportation can have a substantial impact on the overall project economy.

The design changes between PV2 to PV3 resulted in cost savings of approximately 7 million SEK related to the foundation and an additional 15 million SEK in the structure above the basement level. As a result, the project could meet market price expectations, enabling construction to proceed.

### 4.3.3 Challenges with Reuse and Temporary Storage

According to Interviewee 2 (contaminated land specialist), no excavated materials from Solhøjden were suitable for on-site reuse. However, some excavated soil was off-site reused, where specific crushed materials were placed on top. Approximately 400-800 m<sup>3</sup> of material was reused in the construction of a road in Gothenburg following approval from the Environmental administration office. The earthworks phase is shown in Figure 14.



Figure 14: Earthworks phase at Solhøjden. (JM, 2025a).

Interviewee 2 further highlighted the challenges associated with temporary storage of excavated masses, explaining that “the permitting process is extremely time consuming”. The objective is always to reuse as much material as possible. However, in the Gothenburg and Kungälv municipality area, excavated masses mainly consist of clay, which is difficult to store due to its plasticity.

#### **4.3.4 Bureaucracy Challenges**

Contaminated soil must be thoroughly documented in accordance with the Swedish Environmental Protection Agency to ensure that the movement and final destination of the material can be fully traced within the country. A major challenge is the limited number of receiving facilities, which often results in very long transport distances. Furthermore, obtaining permits for quarry operations is extremely difficult due to requirements from the county administrative boards and municipalities. In addition, permits for receiving hazardous waste are difficult to obtain, and many municipalities are unwilling to accept hazardous waste within their county.

Interviewee 2 (contaminated land specialist) emphasised that transport distances are considered a secondary factor, meaning that materials may be transported long distances if necessary. However, the interviewee noted that transportation impacts are increasingly being considered. Furthermore, many municipalities have started to adopt more comprehensive sustainability goals, which further influence transport planning.

According to Interviewee 2, there are generally no situations where excavated materials are transported longer distances for reuse instead of being sent to a closer receiving facility “unless there is a clear economic benefit for doing so”. Long transport distances can create additional logistical challenges, as lorries become occupied for extended periods, reducing operational efficiency. Ordering additional lorries could also result in inefficiencies, since several vehicles may arrive simultaneously and result in unnecessary downtime.

#### **4.3.5 Logistical Obstacles**

According to Interviewee 4 (earthworks specialist), one of the primary challenges concerns logistics at the construction site. The layout of the construction site is illustrated in Figure 15. Larger lorries are generally preferred, although they may create challenges related to the limited available space on site. The interviewee further explained that it is important to have return loads and maintain a high excavation pace to maximise lorry utilisation, as lorries often spend time waiting in queues, which generates additional costs.

The first step in selecting a transport destination is ensuring that the receiving facility has the required permit approval from the Country Administrative Board. Thereafter, the receiving facility is selected based on the lowest combined cost for transportation and tipping fees.

Additional factors, such as acceptable waiting times during transportation, are also considered.



Figure 15: Earthworks phase at Solhöjden. (JM, 2025a).

Interviewee 4 further explained that tipping fees can vary substantially between receiving facilities. In general, receiving facilities attempt to charge the highest possible price while simultaneously monitoring competitors' pricing. Facilities located closer to the construction project often charge higher fees compared to more distant alternatives. Furthermore, the available time for negotiation can influence pricing, since short procurement timeframes may allow receiving facilities to demand higher prices. It is also important to consider that not all receiving facilities are permitted to accept all types of excavated masses.

According to Interviewee 4, design decisions related to floor elevations, basement layout, and ground levels largely determine the quantity of excavated soil that must be transported off site, with up to 97% of this being influenced during the early design phase. Essentially, most decisions influencing the extent of excavation are determined during the early design phase, with the design manager being responsible for these decisions.

Additional challenges are related to procurement processes, particularly if transport provider is not procured at competitive prices. According to Interviewee 4, the agreed conditions with transport providers may also significantly affect project performance, particularly if the contractor is unable to provide the required number of lorries for transporting excavated materials. This may reduce the excavation rate and consequently increase project costs.

Further logistical challenges may occur when several lorries arrive simultaneously at the construction site in the morning, resulting in long waiting times before loading can begin. According to Interviewee 4, transport companies may demand compensation if waiting times exceed agreed limits in the contract. Challenges may also arise at the receiving facility, where operators may sell more disposal capacity than is actually available at the site. In addition, disputes may occur regarding whether the excavated masses should be classified as wet rather than dry material, since wet masses result in higher tipping fees.

Finally, Interviewee 4 highlighted that the actual quantities of excavated masses may exceed the initially estimated amounts due to various unforeseen factors. This may create additional challenges if sufficient disposal capacity has not been reserved in advance at the receiving facilities.

#### **4.3.6 Practical on-site Challenges**

Interviewee 5 (the contractor's site manager), who is responsible for procurement, production, follow-up, and related project activities, explained that JM requests bids from contractors and receives a fixed price for the entire project, including drawings and quantity take-offs. In some cases, the destination of the excavated material is predefined, otherwise, the receiving facility is selected by the contractor, in this case M&E.

To improve transport efficiency, crushed material is occasionally transported on return trips instead of using empty lorries. In certain cases, transport routes are selected based on geographical considerations, for example to avoid specific roads and maintain efficient traffic flow. Haulage contractors often use established transport systems and may deliver materials to receiving facilities with which they already have business connections.

The main challenge in handling excavated materials is ensuring a continuous and efficient workflow so that operations can proceed without unnecessary interruptions. In addition, limited space on site is often a significant constraint. In Solhöjden, clearly defined boundaries for the excavation works helped structure the process. Further, "it is generally preferable to transport excavated materials away and return crushed material using the same truck", as stated by Interviewee 5. However, this approach was not applied in Solhöjden.

At present, haulage contractors determine the types of vehicles used, and according to Interviewee 5, there are currently no electric lorries capable of operating for a full working day, as transports are often heavy and cover long distances. Instead, HVO diesel is the most common alternative used to meet environmental requirements. The choice of vehicle is largely guided by regulatory and project requirements, and since there are no explicit requirements for electric lorries, they are not used.

Further, a potential alternative to reduce the number of transports would be to coordinate with nearby construction projects that could make use of the excavated masses. Instead of transporting materials to landfills, they could be redirected to other sites where they are needed. However, such coordination is difficult, as it requires matching project schedules and conducting material testing before reuse.

Regarding whether the excavated materials from Solhöjden could have been sent to nearby reception facilities such as NCC or Svevia, NCC did not have the capacity to receive the materials at the time and instead indicated that they would need to be transported to Tjörn,

which is a significantly farther away than Brattås. In addition, the site manager at M&E stated that there was “no awareness of Svevia’s reception facility”.

#### 4.4 Site Visit Solhöjden

A site visit was conducted on 2026-03-04, during which the site manager answered questions regarding the earthworks phase. The planned occupancy is scheduled between August and October 2026, meaning that the construction had progressed significantly at the time of the visit. Additionally, photographs from the groundworks phase taken by the site manager were provided (see Figure 16 & Figure 17).



*Figure 16: Picture from the start of the project in Spring 2025. (JM, 2025c).*

Interviewee 3 (site manager) stated that the groundworks phase lasted from February to May in 2025. During the excavation works, an existing concrete foundation was discovered and had to be removed. Overall, the groundworks phase progressed smoothly, with only minor deviations that affected the pilling works. Towards the end of the excavation phase, only small amounts of material remained, which were subsequently transported off site.



*Figure 17: Foundation work, including concrete piles and steel sheet piling. (JM, 2025b).*

#### **4.5 Limitations in Real Time Traceability of Mass Handling**

Pinpointer is a digital system for mass handling focused on traceability, providing full visibility over material flows, contamination levels, vehicle types, fuel types, and transport routes, according to interviewee 6 (Pinpointer co-founder). The system aims to optimise logistics and act as a key tool for contractors and construction projects.

According to Interviewee 6, digital tracking and material handling are becoming increasingly important as new regulations and requirements emerge. The Swedish Transport Administration (Trafikverket) has introduced rules requiring closer monitoring in certain areas, and a new consultation proposal suggests broader traceability requirements across the industry.

Stricter regulations are expected to further drive digitalisation of mass handling. According to (Pinpointer AB, 2026), upcoming requirements include proposals from the The Swedish Environmental Protection Agency (Naturvårdsverket) regarding excavated material management, as well as increased demands for digital documentation of material origin, classification, transport, and reception. In addition, Trafikverket already requires BEAst 4.0 in procurements, while clients such as Svevia, NCC and Skanska pass these requirements on to suppliers and subcontractors. Regulatory authorities may also require digital logs during inspections.

The system is increasingly in demand across the construction industry. At facilities such as receiving facilities and sorting plants, it supports detailed tracking of materials in detail, for example by identifying batches and verifying whether materials such as stone have been separated from a fraction. This improves traceability and control, while reducing the need for follow up work, which in turn can improve cash flow in projects.

As demand increases, clients are requesting greater visibility into internal material flows within projects, for example the ability to prove that a certain percentage of material is reused. In the current system 1.0, each transport is registered only with its origin (the excavation site) and its destination (the receiving facility). The forthcoming “System 2.0” introduces geotagging technology, enabling more precise identification of both loading and unloading location. Further, demand for HVO has increased due to requirements from the Swedish Transport Administration. Currently, there are no requirement for electric lorries, and no indications that this will be introduced.

#### **4.5.1 Implementation of Pinpointer at JM**

Pinpointer is also used in practice within the construction sector, for example at JM, where it enables real time traceability in mass handling. According to Interviewee 2 (contaminated land specialist), full real time traceability is essential for efficient mass handling.

The process begins by registering the project, by defining the location, volume, and material type, to support optimised planning. Equipment operators and lorry drivers then use an application that generates notifications when a delivery is completed, allowing each ton of material to be tracked. This data can be used to improve processes and reduce environmental impact.

Interviewee 2 further highlights the importance of handling excess materials quickly, making matching services for excavated material highly valuable. Limited space on site makes storage impractical, meaning decisions must be taken rapidly. At the same time, permits, sampling, and bureaucratic procedures can delay reuse and complicate mass handling. In addition, the system allows monitoring of lorry fill rates, which is important from both a cost and sustainability perspective. Even small inefficiencies, such as lorries departing at 80-90% capacity instead of close to full load, can significantly increase the number of transports required.

# 5

## Results of LCA Modelling & Cost Analysis

This chapter presents the results from the OpenLCA modelling in terms of CO<sub>2e</sub> emissions, together with a comparison of the different project versions and their corresponding design changes, as shown in Table 11.

*Table 11: Project version (PV) iterations and their key changes.*

<b>Project Version</b>	<b>Key Design Changes</b>
PV1	Original version before re-design
PV2	Raised basement floor level
PV3	Reduced basement
PV3-RO	Transport route optimisation

### 5.1 Comparison of Emissions

The original version represents the transportation operations that were carried out in the Solhøjden project for PV3, while PV3-RO illustrates a route optimised alternative in which different receiving facilities, namely Svevia and NCC, were selected instead.

Figure 18 demonstrates that, for PV3, the largest share of CO<sub>2e</sub> emissions originates from the transportation of stackable excavated material, accounting for 36.4% of total emissions, followed by non-stackable excavated material, which accounts for 29.4%. In contrast, for PV3-RO, the highest contributions originate from the empty transport route between M&E and Solhøjden, representing 33.6% of total emissions, and the empty return route between NCC and M&E, accounting for 28.6%. Thus, the categories contributing most to emissions in PV3 are the transportation of stackable and non-stackable excavated materials, whereas the largest contributors in PV3-RO are the empty transport operations between M&E to Solhøjden, and NCC to M&E. Full data are presented in Appendix C.

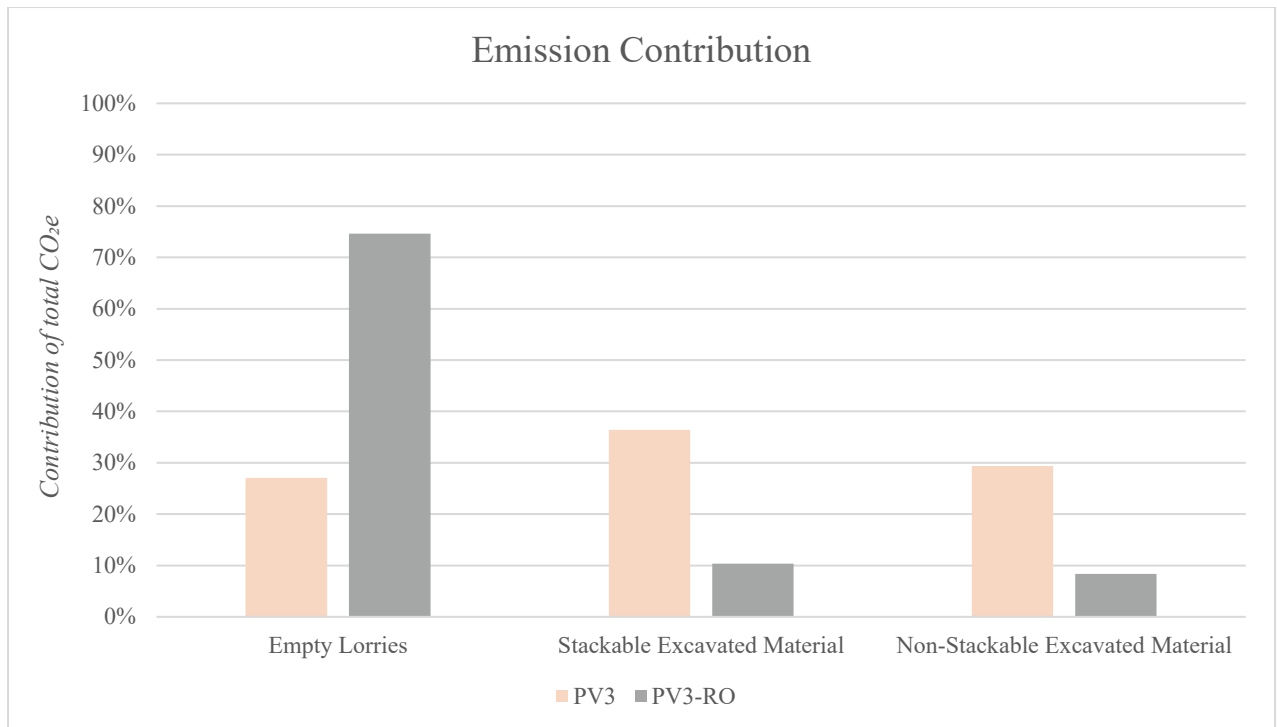


Figure 18: Relative contribution of the main emission categories to total CO<sub>2e</sub> emissions in project version 3 (PV3) and the route-optimised scenario (PV3-RO).

These findings indicate that when the distance to the receiving facilities is significantly reduced, empty return trips between the construction site and the contractors' main office become a substantially larger contributor to total emissions. Consequently, it is not surprising that empty haulage operations account for a considerable share of the carbon emissions in PV3-RO, particularly since the selected receiving facilities were located closer to the construction site. The distance between M&E and Solhöjden is approximately 28.3 km, which still represents a substantial transport distance.

## 5.2 Electric & Diesel Lorries Direct Contributions

A transition from conventional diesel lorries to electric lorries, which are currently not utilised in the transport operations, could theoretically result in a substantial reduction in CO<sub>2e</sub> emissions.

The direct contribution of Tank-to-Wheel (TTW) emissions differs significantly between electric and diesel lorries. Although, electric lorries generate higher emissions during the production phase compared to conventional diesel lorries, the total emissions were still approximately 17% lower for the electric alternative.

As presented in Table 12, the direct contribution from the two largest emission categories was substantially lower for the electric lorry alternative. The electric lorries generated approximately 0.2% of the direct emissions produced by the diesel lorries for these transport categories.

Table 12: Direct contribution (DC) emissions for project version 3 (PV3) and its electric lorry (E) counterpart for the two largest emission categories.

Material	PV3 - DC (kg CO <sub>2</sub> e)	PV3-E - DC (kg CO <sub>2</sub> e)
Stackable excavated material	22,400	45
Non-stackable excavated material	18,100	36

### 5.3 Comparison between Project Versions

The results indicate that total emissions decreased by approximately 21 t CO<sub>2</sub>e between PV1 and PV3, corresponding to a reduction of around 20%. Furthermore, the transportation of stackable excavated material, which represents the largest emission category, generated approximately 41 t CO<sub>2</sub>e in PV1, compared to 38 t CO<sub>2</sub>e in PV2 and 31 t CO<sub>2</sub>e in PV3.

Overall, the results demonstrate a reduction of approximately 10 t CO<sub>2</sub>e between the initial design version PV1 and the final design PV3 implemented in Solhøjden. This corresponds to an approximate reduction of 24.4% in CO<sub>2</sub>e emissions related to the transportation of stackable excavated material, as illustrated in Figure 19.

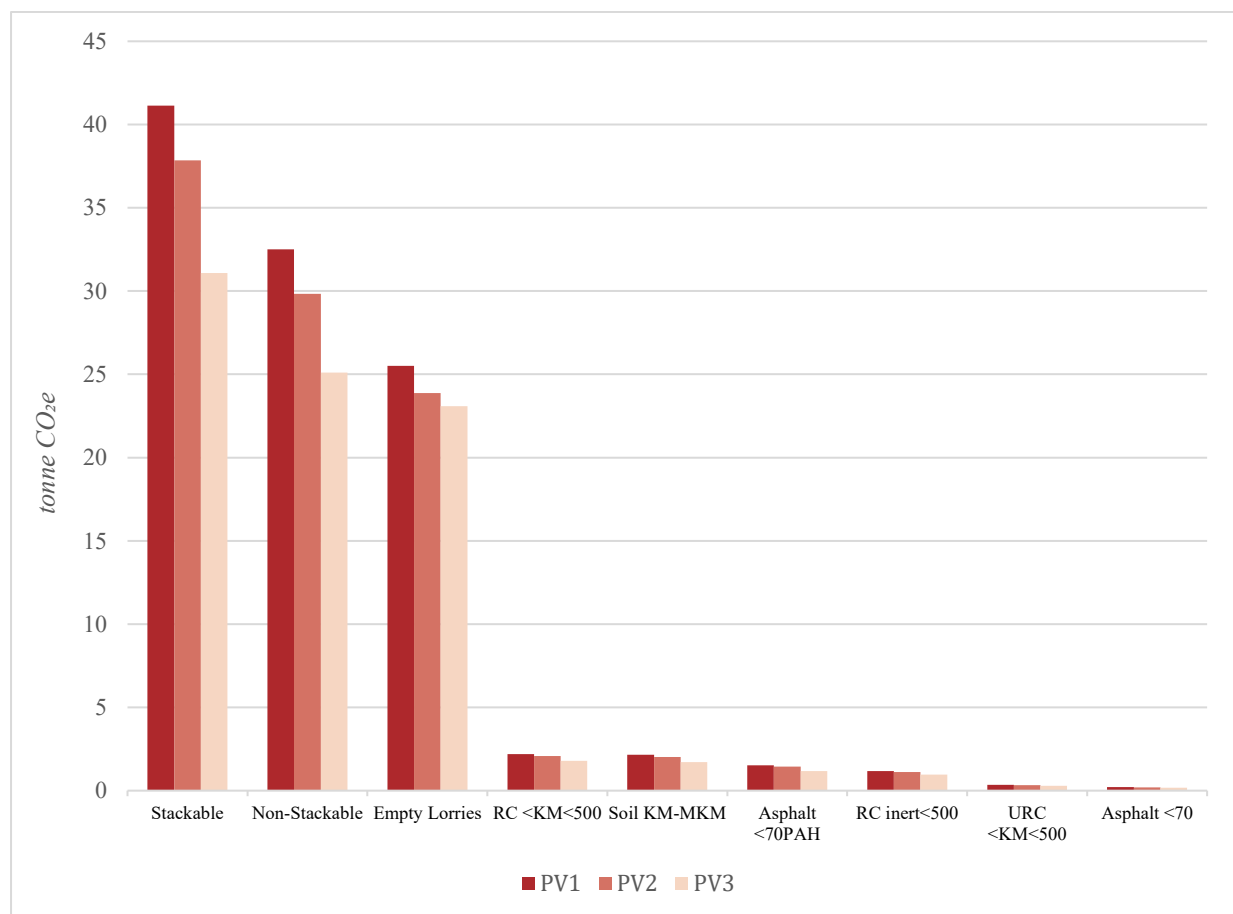


Figure 19: Comparison of CO<sub>2</sub>e emissions across the three project versions (PVs) for different material categories, including empty lorry transportation, reinforced concrete (RC)<KM<500, reinforced concrete inert <500, and unreinforced concrete (URC)<KM<500.

The total transport emissions amounted to 107 t CO<sub>2e</sub> for PV1, 99 t CO<sub>2e</sub> for PV2, 85 t CO<sub>2e</sub> for PV3, 71 t CO<sub>2e</sub> for PV3-E, 18 t CO<sub>2e</sub> for PV3-RO, and 15 t CO<sub>2e</sub> for PV3-ROE, as illustrated in Figure 20.

The results demonstrate a reduction of 33.5% between PV1 and PV3-E, while the reduction between PV1 and PV3 corresponds to 20%. Furthermore, an 85.7% reduction in CO<sub>2e</sub> emissions was observed between PV1 and PV3-ROE. In addition, emissions decreased by 82.1% between PV3 and PV3-ROE.

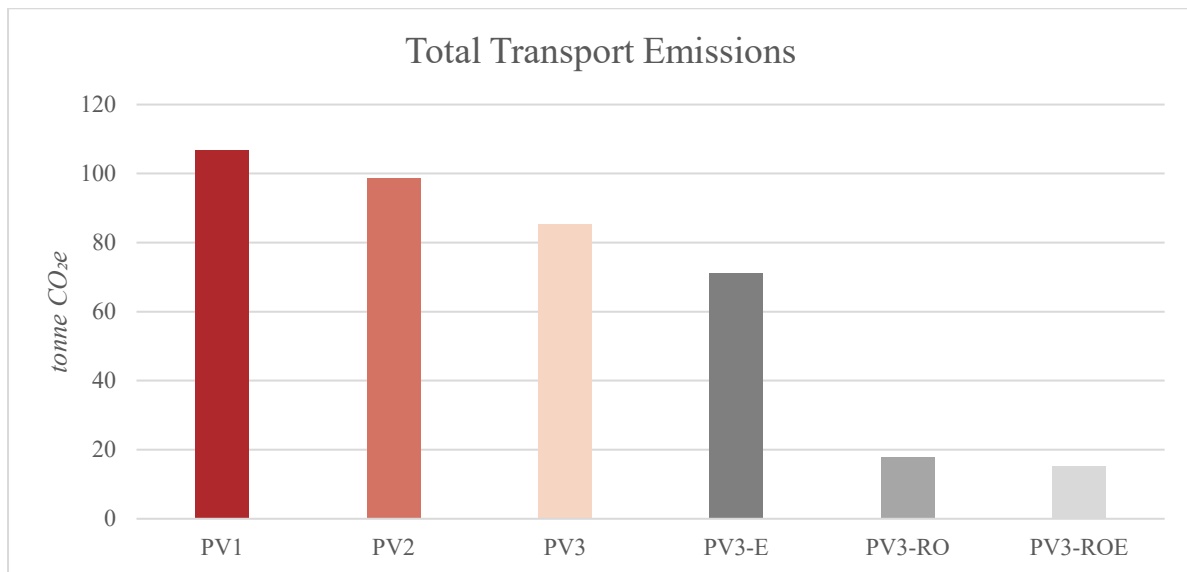


Figure 20: Total transport emissions in tonnes of CO<sub>2e</sub> for the different project versions (PVs), including the electric (E), route optimised (RO), and route optimised electric (ROE) alternatives.

#### 5.4 Cost Savings Associated with Reduced Excavated Masses

The total cost difference related to excavation, tipping, and transportation amounted to 1.1 million SEK between PV1 and PV3, 1.8 million SEK between PV1 and PV3-RO, and 730,000 SEK between PV3 and PV3-RO, as illustrated in Figure 21.

These results demonstrate that substantial cost reductions can be achieved through shorter transportation distances, as observed in PV3-RO. Furthermore, the redesign process carried out during the design phase resulted in significant cost savings related to the earthworks, corresponding to 1.1 million SEK between PV1 and PV3.

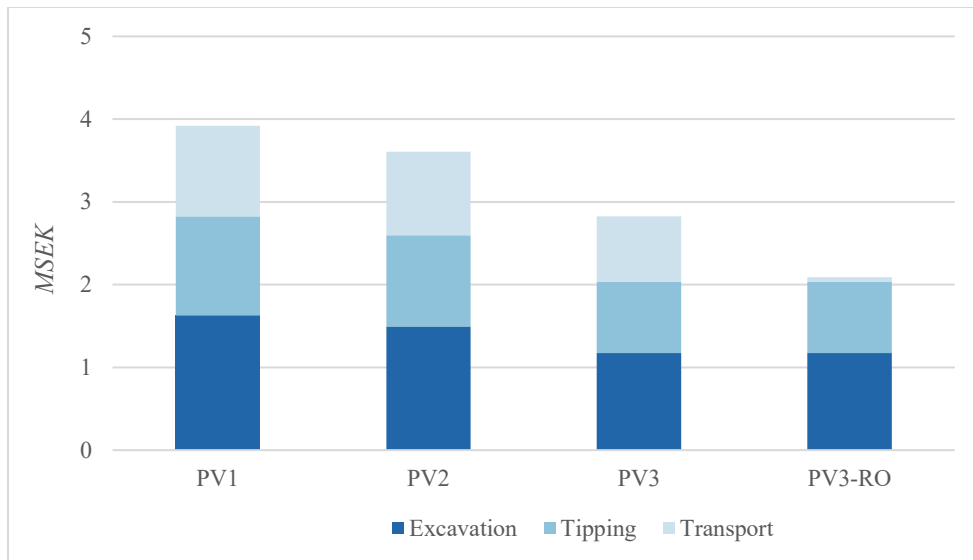


Figure 21: Cost comparison for excavation, tipping, and transportation across the different project versions (PVs), including the route optimised (RO) alternative, presented in million SEK.

### 5.5 Cost and CO<sub>2</sub>e Reduction per Apartment

The cost per apartment was reduced by 8,000 SEK between PV1 and PV3, by 13,000 SEK between PV1 and PV3-RO, and by 5,000 SEK between PV3 and PV3-RO. These results highlight the importance of the earthworks phase in achieving cost efficiency from the design phase.

Figure 22 and Figure 23 show the contribution of cost and CO<sub>2</sub>e per apartment, which is a common way to indicate how much the changes have affected the project. Although, when using this measurement, it is not taken into consideration the different sizes of apartment, so the reduction is simply indicating the change per apartment.

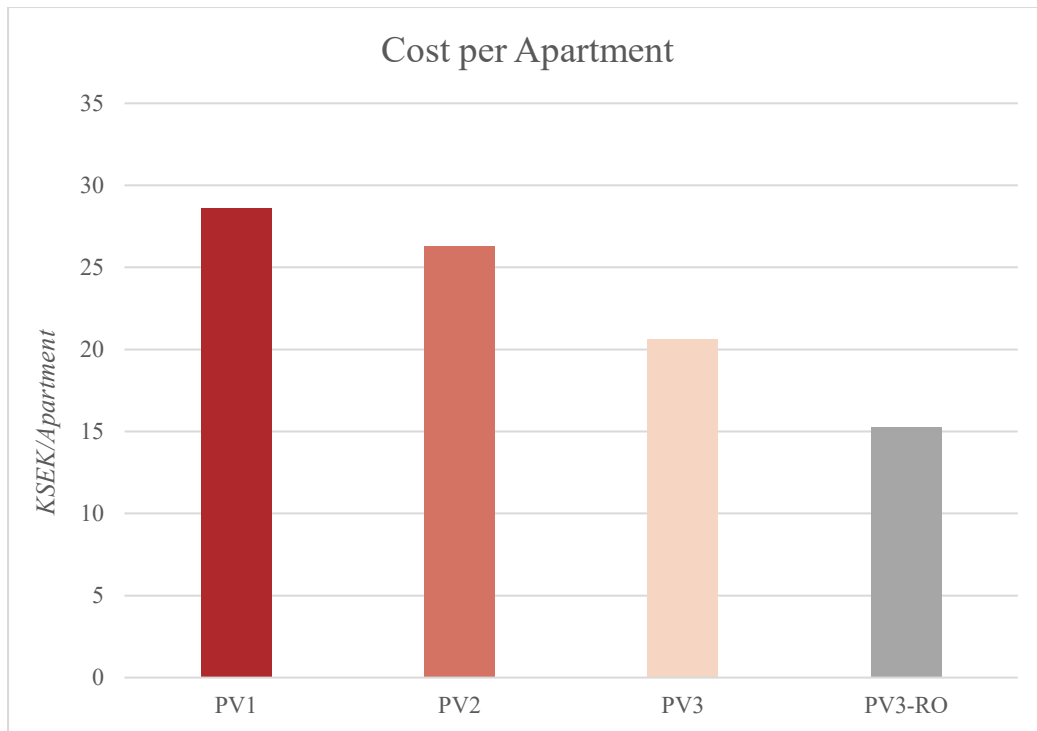


Figure 22: Total cost contribution per apartment in thousand (K) SEK from excavation, transport, and tipping for the different project versions for three project versions (PVs), including route optimised (RO).

The reductions in CO<sub>2</sub>e emissions per apartment amounted to around 156 kg CO<sub>2</sub>e between PV1 and PV3, 668 kg CO<sub>2</sub>e between PV1 and PV3-ROE, 261 kg CO<sub>2</sub>e between PV1 and PV3-E and 512 kg CO<sub>2</sub>e between PV3 and PV3-ROE.

This indicates that shortening the transport distance in the route optimised version, compared to the other project scenarios, has a significant impact on reducing carbon emissions, as PV3-RO has 79% lower CO<sub>2</sub>e emissions compared to PV3. The electric version further has a reduction potential of 15% compared to PV3-RO.

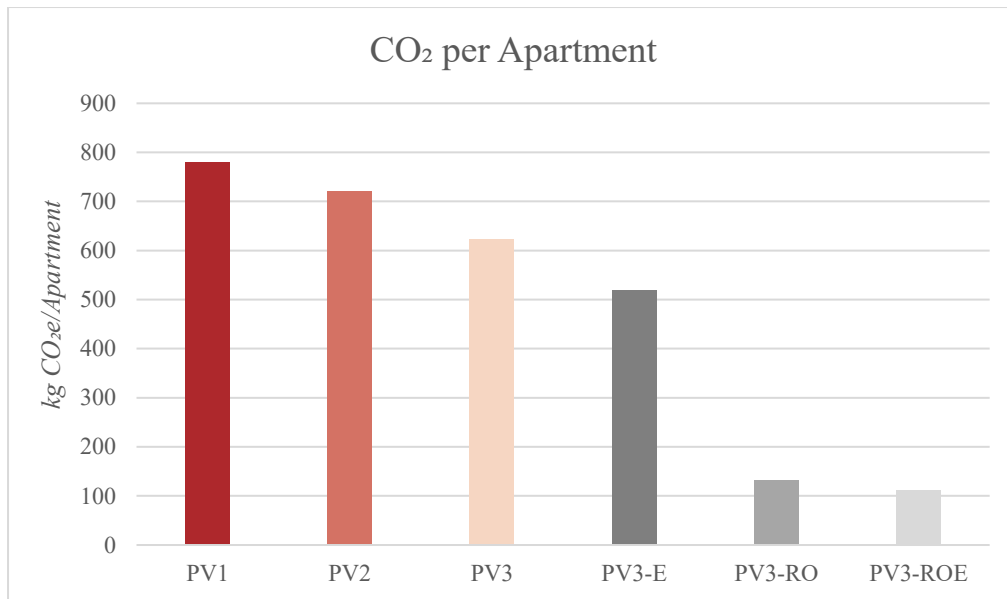


Figure 23: Kg CO<sub>2</sub> contribution per apartment of transportation for the different project versions (PVs), including electric (E), route optimised (RO) and route optimised electric (ROE).

## 5.6 Uncertainty and Sensitivity Analysis results

A sensitivity and uncertainty analysis was conducted to evaluate the robustness of the results if a change of plus, minus 10% were done to the input parameter in OpenLCA of transported material and how that change affects the total kg CO<sub>2</sub>e emissions compared to our original version.

The results from the Monte Carlo analysis in Figure 24 show a median value of approximately 85 t CO<sub>2</sub>e for PV3. Raising the transported masses by 10% increases the emissions up to around 89 t CO<sub>2</sub>e, almost a 4.5% difference. Reducing the transported masses by 10% decreased the median to around 80 t CO<sub>2</sub>e, indicating a near 6% difference. Furthermore, the 5<sup>th</sup> and 95<sup>th</sup> percentiles for PV3 range from approximately 79 t to 94 t CO<sub>2</sub>e, indicating that 90% of the simulation values lies within this interval.

For PV3 +10%, the same percentiles range from around 83 t to 99 t CO<sub>2</sub>e, highlighting an increase of approximately 5%. The 5<sup>th</sup> and 95<sup>th</sup> percentiles for PV3 -10% range from about 75 t to 90 t CO<sub>2</sub>e, a decrease close to 4-5% compared to PV3. The variability of the results is indicated by the standard deviation of approximately 5.1 t CO<sub>2</sub>e for PV3, 5.4 t CO<sub>2</sub>e for PV3 +10%, and finally 4.8 t CO<sub>2</sub>e for PV3 -10%. The whiskers in Figure 24 highlights the range of the data, showcasing the full variability of the results and the larger variation in the upper values whereas the lower values have less variability.

The uncertainty and sensitivity analysis indicates that the results are relatively robust, as the median values varied by only approximately 6% despite a 10% variation in transported mass. Furthermore, the relatively low standard deviations suggest limited variability in the simulation results.

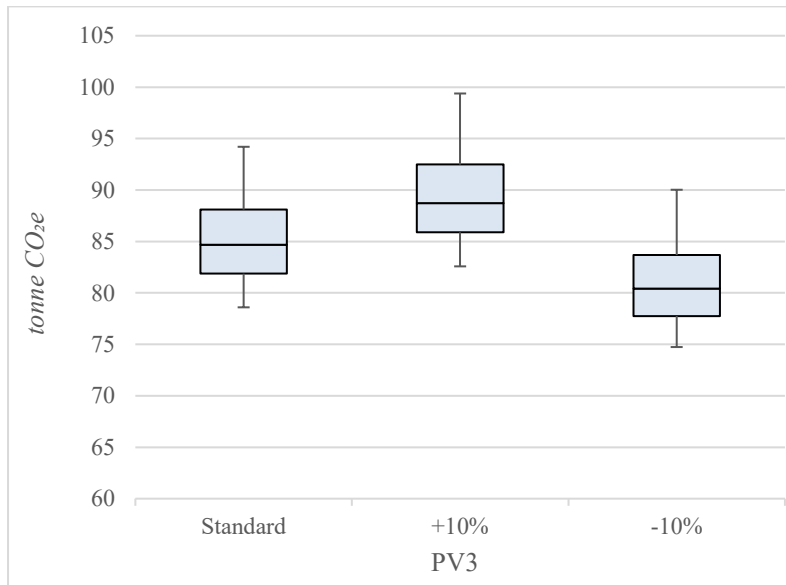


Figure 24: Uncertainty and sensitivity analysis for project version 3 (PV3) created from a Monte Carlo simulation in OpenLCA.

# 6

## Discussion & Conclusions

This chapter presents the discussion and main conclusions of the study, which are connected to the research questions.

### 6.1 Design Changes and its Influence on Project Survival

The design optimisations in subsection 4.2.2, (The Three Design Versions) helped reverse the initially negative cost trend. Moving from PV2 to PV3 significantly reduced costs in both the foundation and upper structure, while excavated masses decreased from PV1 to PV3 (9,137 to 6,583 tonnes), showing substantial mass savings.

These results shows that early design decisions, such as floor levels and basement depth, largely determine excavation volumes, with up to 97% being set at an early stage. This supports previous findings, the greatest potential to reduce transport, costs, and environmental impact lies in the initial design phase. The results support Figure 3 in section 2.6, (Costs of Transportation), which shows early changes are more effective much easier and more economically beneficial. In Solhöjden, design adjustments improved project feasibility and enabled construction to start.

#### 6.1.2 Impact of Early Design Changes

The results demonstrate that even relatively small cost reductions per apartment can generate substantial total savings at the project level. In Solhöjden, costs were reduced by 8,000 SEK per apartment between PV1 and PV3, and by 13,000 SEK between PV1 and PV3-RO (route optimised). Route optimization reduces transportation distances, which consequently lowers transport costs. However, these savings do not necessarily benefit JM or the contractor directly, since transport companies may adjust prices. According to the interview findings, nearby receiving facilities may increase their prices when transport distances are reduced.

The comparison between PV1 and PV3 further demonstrates that design changes affecting excavation volumes reduce both costs and emissions throughout the value chain, highlighting the importance of early design decisions. Interviewee 2 (contaminated land specialist) explained that earthworks account for approximately 15-25% of the total project cost, while excavation transportation represents around 20% of the earthworks cost. This further reinforces the importance of early optimisation, as illustrated in Figure 3.

Furthermore, studies such as Villar et al. (2020) demonstrate that the implementation of GIS and BIM can reduce project costs by 5% and 14.1% by incorporating the ICOM method. Similarly, Huang et al. (2022) emphasise the advantages of integrating BIM and GIS in order

to overcome coordination barriers, improve route analysis, and facilitate the collection of information related to ground conditions. These findings highlight the importance of digital tools during early design phases to support cost reductions, improve stakeholder coordination, and contribute to a more efficient and streamlined project process.

## **6.2 Optimisation of Lorry Routing**

The following section discusses the impact of receiving facility selection, lorry size, and cost as a primary driver of lorry routing decisions.

### **6.2.1 Receiving Facility Selection**

The results indicate a clear relationship between receiving facility selection, emissions, and cost. As shown in Figure 20 in section 5.3, changing to a nearby receiving facility has a substantial impact on transport emissions, reducing carbon dioxide equivalent emissions by approximately 79% from PV3 to PV3-RO. This finding highlights the importance of optimising transport distances. However, as shown in Table 2.C (Appendix C), empty lorries account for the largest share of emissions in the optimised scenario, representing more than 74% of total transportation emissions compared to approximately 27% in PV3. Consequently, further emission reductions require minimising empty trips, which is considerably more challenging and requires further investigation.

Reducing the distance to the receiving facility significantly lowers transportation costs in the results, while excavation and tipping costs remain unchanged. In practice, however, tipping fees would likely be affected by market competition. If one receiving facility lowers its price, this may lead to increased price elsewhere, meaning that a more distant facility could still be the most cost-effective option overall. As a result, JM may not necessarily save money from shorter transport distances, as the financial benefit may instead be captured by receiving facility operators through higher tipping fees.

Furthermore, Interviewee 4 emphasised that the time available for negotiating tipping fees has a considerable influence on the final cost. Early planning of excavated mass disposal may therefore contribute to lower overall costs, including in cases where receiving facilities located farther from the construction site are selected due to favourable transport and tipping fees. Nevertheless, even if more distant facilities are marginally cheaper, the results clearly demonstrate that emissions remain significantly higher when the receiving facility is not located close to the project area.

Fuel consumption is another important factor to consider when selecting receiving facilities. Roy et al. (2024) highlight that transportation can account for the largest share of fuel consumption during the earthworks phase. This emphasises the importance of selecting receiving facility located close to the project site while also avoiding congested traffic commonly associated with larger cities. According to Roy et al. (2024), congestion can increase fuel consumption by up to 60%.

Overall, the results show that using nearby receiving facilities, such as Svevia or NCC in Kungälv, could reduce transport emissions by approximately 79% compared to the receiving facility selection implemented in practice. Although the analysis does not account for factors such as traffic congestion, travel speeds, and time of day operations, these variables would likely further increase the difference between the alternatives. This is particularly relevant for routes to Brattås, where lorries must travel through heavily trafficked roads in Gothenburg.

Moreover, NCC lacked available capacity at the time of the Solhöjden project and indicated that the material would instead need to be transported to Tjörn, resulting in a considerably longer transport distance than Brattås. In addition, the contractor was not aware of Svevia's receiving facility. Together, these findings suggest that local alternatives were limited, either due to capacity constraints or insufficient information regarding receiving facilities.

Another disadvantage of selecting receiving facilities located far from the project site is the difficulty in organising and planning for lorry loading operations. As highlighted by Interviewee 2, longer transport distances occupy lorries for extended periods, making the excavation process more difficult to manage and increasing the risk of downtime. This may also require additional lorries to maintain productivity, further complicating logistics.

### **6.2.2 Impact of Lorry Size**

The size of the lorries is another factor that must be considered. According to Interviewee 4 (earthworks specialist), high-capacity lorries are generally preferred. However, their size can become a limitation on construction sites with restricted space. Larger lorries reduce the number of trips required to transport material to receiving facilities, thereby lowering transportation emissions and potentially reducing costs by minimising queue times during loading, which is considered critical.

Furthermore, Liu & Lu et al. (2014) highlight that reducing waiting times in earthmoving operations can improve overall resource efficiency. In contrast, smaller lorries offer greater flexibility on construction sites where space is limited. Additional advantages include the possibility of distributing a larger number of lorries across the transport route, thereby reducing the risk for stop in excavation due to lorries being delayed by congestion. Smaller lorries may also enable the use of weight restricted routes and can contribute to lower fuel consumption compared to larger vehicles, as noted by Fredriksson et al. (2021).

### **6.2.3 Cost as a Primary Driver**

According to Interviewees 2 (contaminated land specialist) and 5 (the contractor's site manager), cost is the primary factor influencing subcontractor procurement decisions, while the distance to the receiving facility is generally considered secondary. During periods of economic uncertainty, sustainability considerations tend to receive lower priority, despite the

potential climate benefits that could be achieved by selecting closer receiving facilities rather than less expensive alternatives located farther away.

Furthermore, the destination of excavated masses is often either predetermined during procurement or decided by the subcontractor responsible for excavation and transportation. As a result, the most economically advantageous option is typically selected. In practice, this often means that subcontractors prioritise lower tipping fees over shorter transport distances, leading to longer transportation routes and consequently higher transport emissions.

### **6.3 Electric Lorries Climate Savings**

The comparison between transportation using electric lorries and conventional diesel lorries shows a reduction in GHG emissions of approximately 17%. However, as previously highlighted, the majority of emissions associated with electric lorries originate from the production phase, while direct operational emissions are close to zero. In contrast, operational emissions constitute a substantial share of the climate impact associated with conventional diesel lorries. Consequently, further improvements in the production processes of electric lorries are necessary to achieve greater emission reductions and increase the environmental benefits of electrification. At the same time, the growing use of HVO diesel may reduce the difference in climate impact between electric and diesel lorries to some extent, at least until the production of electric lorries becomes more sustainable.

When comparing the modelled electric lorry with the conventional Euro 6 diesel lorry, a clear difference in emissions can be observed. However, it is important to consider how future developments, such as the introduction of Euro 7 standards, may influence these results. Since the database used in OpenLCA is based on historical data, recent advancements in both diesel technology and lorry electrification may not be fully reflected in the assessment. Further, incorporating HVO diesel in future databases could significantly reduce overall climate impact of the case study.

Moreover, government incentives and subsidies will likely be required to encourage contractor and haulage companies to transition from diesel-powered to electric lorries. Since the lowest transport cost is currently the deciding factor, financial incentives are essential. Measures are also needed to enable local handling of excavated materials and reduce long transport distances.

### **6.4 Reuse in the Study**

Studies in subsection 2.4.2 (Reuse & Recycling Potential and Benefits) explains that soil and rock can reduce the climate impact of construction projects by up to 85% and, in some cases, lower costs by up to 30%. When managed effectively, reuse can therefore generate both environmental and economic benefits. However, the extent of these benefits depends largely

on the effectiveness of planning and the ability to reuse materials close to their point of excavation.

According to Interviewee 2 (contaminated land specialist), excavated materials are generally not transported longer distances for reuse if a closer receiving facility is available, unless there is a clear economic incentive. This challenge could be addressed through regional coordination, where surplus materials are more effectively matched with nearby construction projects rather than being transported over longer distances. Furthermore, digital exchange platforms, real time tracking of masses, and temporary storage hubs could also help prioritise shorter transport routes. Lastly, this issue can be reduced through incentives, such as transport fees, carbon taxes, or procurement requirements favouring nearby receiving facilities.

In the literature, excavated materials are commonly described as waste, whereas JM refers to it as surplus materials. This distinction in terminology reflects a more circular approach, where the material is viewed as reusable rather than something to be disposed of. Consequently, JM can redirect surplus material to other projects, such as the construction of noise barriers, thereby supporting more efficient and sustainable material management. No reuse of excavated material occurred within the Solhøjden project itself due to its relatively small scale. However, for larger infrastructure projects, reuse is essential.

Furthermore, Interviewee 2 (contaminated land specialist) highlighted that the Nordic Swan Ecolabel currently excludes the earthworks phase from its sustainability requirements. Given that approximately 30% of carbon dioxide emissions originates from earthworks, this represents a significant opportunity for improvement. Expanding certification requirements to include earthworks could encourage the industry in achieving CO<sub>2</sub> reductions during this phase. In the absence of such requirements, sustainability efforts may instead focus on comparatively minor carbon dioxide reduction measures in later construction phases in order to satisfy minimum certification requirements.

## **6.5 Challenges and Improvements of Mass Handling**

A similar approach to that described in subsection 2.8.1 (Mass Consolidation Centre Stockholm), where excavated materials are reused locally instead of being transported to landfill, could have significant potential in the Gothenburg region. Large infrastructure projects such as Västlänken generate substantial volumes of excavated materials, often creating logistical and environmental challenges related to transportation and disposal. Establishing a mass consolidation centre in connection projects of this scale could increase local material reuse and reduce transport distances. Furthermore, by centralising the sorting, treatment, and redistribution of materials, such a facility in the Gothenburg region could reduce the amount of material sent to landfill while contributing to a more circular system, similar to the outcomes observed in Stockholm County.

Facilities such as Sortera (see subsection 2.8.3) demonstrate how integrated solutions can manage excavated materials through receiving, sampling, analysis, sorting, and material classification. However, due to the relatively high costs, such solutions are not always selected by companies. Conventional disposal alternatives are often less expensive in the short term, making them more attractive when project budgets are constrained. In addition, there are relatively few facilities of this type, and both their capacity and efficiency could potentially be improved through implementation of more advanced machinery and technologies.

Another potential improvement for JM would be to reduce the weight of contaminated soil and improve material sorting. Machinery designed for this purpose is already available and widely used in countries such as England, where materials such as wood waste and other construction debris can be separated. However, according to interviewee 4, disposal costs in Sweden are relatively low, meaning that sorting and processing of the material is not always economically viable.

Subsection 2.8.2 (Mass Management in Norrköping City) highlights several challenges associated with mass handling and demonstrates how a Mass Logistics Centre (MLC) can contribute to more efficient material management. By providing temporary storage that is not tied to a specific project, an MLC increases flexibility and enables available materials to be matched with future demand. If similar facilities were established in Gothenburg, several practical challenges could potentially be reduced. One common issue is the need to rapidly transfer materials to another project in order to avoid temporary storage at the construction site. This often creates time pressure and logistical difficulties. With access to centralised storage facilities, materials could instead be stored for longer periods until a suitable reuse opportunity is identified, reducing the need for inefficient decisions. Another challenge is the limited availability of space. Excavated materials require extensive storage areas, which can be difficult to accommodate in dense urban environments such as Gothenburg. This further highlights the importance of centralised storage facilities.

### **6.5.1 Regulatory Barriers and Transport Inefficiencies**

Lengthy permitting processes and differences in regulations between municipalities can create significant challenges for the management of excavated materials. While these regulations are intended to protect the environment and ensure safety, inconsistencies in their application can lead to unintended consequences. For example, when approval processes are particularly slow or complex in one municipality, materials may instead be transported to other municipalities where permits are easier to obtain. This can result in longer transport distances, higher costs, and increased fuel consumption and emissions. It may also reduce opportunities for local material reuse, making the process less sustainable. Consequently, inconsistent regulations can create unfair differences between municipalities and complicate project planning.

As mentioned in subsection 4.3.4 (Bureaucracy Challenges), the limited number of receiving facilities often results in longer transport distances, as excavated materials must be transported farther from the project site. According to Interviewee 2 (contaminated land specialist), one contributing factor is difficulty of obtaining permits for quarries from municipalities and County Administrative Boards, resulting in limited number of receiving facilities. In addition, fewer facilities may increase the market power of the remaining operators, which can result in higher prices and fewer alternatives for contractors.

Furthermore, some receiving facilities are only permitted to accept specific types of material. As a result, excavated materials cannot always be transported to the nearest receiving facility or delivered as mixed materials in a single load. Instead, materials may need to be sorted and transported to multiple facilities. While sending mixed materials to a single facility is simpler, restrictions often prevent this approach. Consequently, material management becomes more complex and highly dependent on regulatory conditions.

Temporary storage also presents a challenge when permitting processes are lengthy. If permits for temporary storage cannot be obtained within the required project timeframe, both planning and implementation may be delayed.

### **6.5.2 Uncertainty with Wet Soil and Contaminated Masses**

Soil and uncontaminated masses can introduce significant uncertainty in both cost estimations and the planning of material reuse. As highlighted by Interviewee 2 (contaminated land specialist), rainfall during transportation can cause excavated soil to be classified as wet soil at receiving facilities, resulting in tipping fees that are approximately twice as those for dry soil. In addition, delays in obtaining documentation to verify that excavated soil is uncontaminated may prevent the material from being reused.

These uncertainties complicate both cost estimation and reuse planning, as factors such as weather conditions and soil classification are difficult to predict in advance. As shown in Table 3, the largest material category in the project was the uncontaminated stackable material, amounting to 2,895 tonnes, followed by uncontaminated wet material at 2,287 tonnes and contaminated soil at 815 tonnes. The corresponding tipping fees were 58 SEK/t for uncontaminated dry soil, 128 SEK/t for uncontaminated wet soil, and 330 SEK/t for contaminated soil. If all uncontaminated material in the project had been classified as contaminated soil due to insufficient documentation or testing, the additional tipping costs would have amounted to approximately 1.25 million SEK. This demonstrates the substantial financial impact that changes in material classification can have in a project.

## **6.6 Future Research**

This section discusses the potential for future research within mass handling, including the use of real time traceability tools for excavated materials, impact of time-of-day on transportation, and opportunities to improve model reliability.

### **6.6.1 Future Use of Real Time Traceability**

The results indicate that digital tools such as Pinpointer have the potential to improve the efficiency of mass handling by enabling faster decisions, according to Interviewee 6 (co-founder at Pinpointer). This is particularly valuable when storage capacity is limited and excavated materials must be managed within short timeframes. The findings also suggest that improved planning of lorry loads can reduce unnecessary transportation, resulting in both lower costs and reduced emissions. Consequently, digital tools may help address practical and regulatory challenges in mass handling, which future research could explore further.

In section 4.5 (Limitations in Real Time Traceability of Mass Handling), stricter regulations for mass handling were considered. In practice, these regulations are likely to drive further digitalisation of mass handling. While this will require additional administrative work for contractors and haulers, digital logs can help reduce disputes regarding delivered volumes, transport distances, and disposal fees. Furthermore, the increased documentation regulations may enhance transparency between clients and contractors.

### **6.6.2 Time of Day Effects on Transport**

There are additional transport-related aspects that could be valuable to investigate in future research. For example, traffic conditions vary throughout the day, with peak congestion in the Gothenburg area typically occurring during weekday rush hours between 07:30-09:00 and 15:30-17:30 (Göteborg Stad, 2024). During these periods, the risk of delays and extended travel times increases significantly. Consequently, avoiding the transport of heavy materials during peak traffic hours could improve efficiency.

Traffic congestion and unnecessary stops have several disadvantages. First, vehicles consume fuel or energy while moving inefficiently, resulting in increased greenhouse gas emissions without generating productive output. Second, longer travel times increase transport costs due to higher energy consumption and labour. Third, delays reduce efficiency and may negatively affect project schedules. However, this aspect was not examined within the scope of the study and therefore requires further investigation.

### **6.6.3 Model Parameters**

Using a more recent version of OpenLCA could have provided more reliable results, as the Ecoinvent 3.8 database is based on data from 2021 and earlier. Since then, significant developments have occurred, particularly regarding electric vehicles, including electric lorries. However, it remains uncertain to what extent the underlying data in newer databases differs from earlier versions. Furthermore, access to more detailed emissions data for Volvo and Scania lorries would likely have improved the accuracy and reliability of the results.

## 6.7 Conclusions

This section provides a structured summary of the conclusions in relation to each research question:

1. *How do the three different project versions of the JM project Solhöjden affect the amount of masses needed to be excavated and how do these mass savings translate in terms of cost reduction per apartment?*
  - Design modifications, including adjusting basement depth and layout, as well as a reduction in the waste collection vacuum system, decreased excavation volumes and made the project economically viable.
  - Between PV1 and PV3 the total excavated masses decreased by approximately 28%, indicating substantial mass savings due to design changes.
  - Costs associated with excavation, tipping, and transport were reduced by approximately 8,000 SEK per apartment between PV1 and PV3, and by 13,000 SEK between PV1 and PV3-RO (route-optimised), highlighting how both design modifications and reduced transport distances can contribute to lower overall project costs.
2. *How can the routing of lorries to alternative receiving facilities be optimised to minimise carbon footprint and reduce project costs?*
  - Selecting a receiving facility in the vicinity of Solhöjden can reduce CO<sub>2e</sub> emissions by approximately 79% from PV3 to PV3-RO.
  - In PV3-RO, empty return trips account for the largest share of emissions, contributing more than 74% of total CO<sub>2e</sub> emissions.
  - Transport costs to receiving facilities are theoretically reduced by approximately 93% from PV3 to PV3-RO.
  - High-capacity lorries are preferable, as they reduce the number of trips required to receiving facilities and thereby lowering CO<sub>2e</sub> emissions.
3. *What climate savings can be made by switching from conventional diesel lorries to electric lorries?*
  - A transition from conventional diesel lorries to electric lorries results in a clear reduction in total emissions of approximately 17%, with near zero direct emissions.

- Government incentives and subsidies will likely be required to encourage contractors and haulage companies in transitioning from diesel-powered to electric lorries.
4. *How is reuse of excavated materials currently applied in the Solhöjden project, and what potential improvements exists to increase reuse in similar construction projects?*
- No reuse of excavated material was implemented within Solhöjden, primarily due to its relatively small scale.
  - Potential improvements include the establishment of mass consolidation facilities in the Gothenburg region, which could reduce amount of material sent to landfill and increase opportunities for reuse. As construction projects are highly time sensitive, coordination between cut and fill sites requires thorough planning and precision.
5. *What are the main challenges in transporting excavated material, and how can mass handling be improved in construction projects?*
- Decisions regarding the management of excavated material are currently primarily driven by the lowest costs for transport and disposal.
  - Lengthy permitting processes for establishing receiving facilities, together with regulatory differences between municipalities, can complicate the management of excavated material.
  - The limited number of receiving facilities often results in long transport distances, as materials frequently need to be transported to more distant locations.
  - Wet soil and uncontaminated masses can introduce additional complexity into cost calculations.
  - Receiving facilities tend to charge the highest possible price while simultaneously monitoring competitors' pricing. Facilities located closer to the construction project often charge higher fees compared to more distant alternatives.
  - Potential improvements include digital exchange platforms, real time tracking of material flows, and temporary storage hubs, which could facilitate shorter transport distances and more efficient logistics.

# References

- Apple Maps. (2026). *Sortera Receiving facility*. [Photograph].
- Bertin, I., Lebrun, F., Braham, N., & Le Roy, R. (2019). Construction, deconstruction, reuse of the structural elements: the circular economy to reach zero carbon. *IOP Conference Series: Earth and Environmental Science*, 323, 012020. <https://doi.org/10.1088/1755-1315/323/1/012020>
- Bhat, F. A., Roy, D., Sahu, P. K., Choudhari, S. C., & Bahurudeen, A. (2023). Earthwork Logistics Optimisation in Road Construction Project. *Lecture Notes in Civil Engineering*, 2, 179–191. [https://doi.org/10.1007/978-981-99-2556-8\\_14](https://doi.org/10.1007/978-981-99-2556-8_14)
- Booto, G. K., Aamodt Espegren, K., & Hancke, R. (2021). Comparative life cycle assessment of heavy-duty drivetrains: A Norwegian study case. *Transportation Research Part D: Transport and Environment*, 95, 102836. <https://doi.org/10.1016/j.trd.2021.102836>
- Choi, H., Park, M.-H., Jeong, D.-M., & Kim, J.-H. (2017). Soil Recycling Among Construction Sites by Optimising Schedule and Costs for Earthmoving. *Journal of Asian Architecture and Building Engineering*, 16(2), 439–446. <https://doi.org/10.3130/jaabe.16.439>
- Cristóbal, J., Foster, G., Caro, D., Yunta, F., Manfredi, S., & Tonini, D. (2024). Management of excavated soil and dredging spoil waste from construction and demolition within the EU: Practices, impacts and perspectives. *The Science of the Total Environment*, 944, 173859. <https://doi.org/10.1016/j.scitotenv.2024.173859>
- Cybulski, A., & Moulijn, J. A. (2005). Structured Catalysts and Reactors. In *Chalmers Research (Chalmers University of Technology)*. Chalmers University of Technology. <https://doi.org/10.1201/9781420028003>
- European Commission. (2023a). *The Waste Hierarchy Theory*. [Photograph].

[https://environment.ec.europa.eu/sites/default/files/styles/oe\\_theme\\_medium\\_no\\_crop/public/2021-01/SC656%20waste\\_hierachy%20FINAL.jpg?itok=NDTT2mU3](https://environment.ec.europa.eu/sites/default/files/styles/oe_theme_medium_no_crop/public/2021-01/SC656%20waste_hierachy%20FINAL.jpg?itok=NDTT2mU3)

European Commission. (2023b). *Waste Framework Directive*. European Commission.

[https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive\\_en](https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en)

*Excavated material management strategies. [Photograph]. (Authors own figure). (2026).*

Foytik, P., & Robinson, R. M. (2015). Integrating Truck Emissions Cost in Traffic

Assignment. *Transportation Research Record Journal of the Transportation Research Board*, 2503(1), 119–127. <https://doi.org/10.3141/2503-13>

Fredriksson, A., Nolz, P. C., & Seragiotto, C. (2021). A mixed method evaluation of economic and environmental considerations in construction transport planning: The case of Ostlänken. *Sustainable Cities and Society*, 69, 102840.

<https://doi.org/10.1016/j.scs.2021.102840>

Gomes Correia, A., Winter, M. G., & Puppala, A. J. (2016). A review of sustainable approaches in transport infrastructure geotechnics. *Transportation Geotechnics*, 7, 21–28. <https://doi.org/10.1016/j.trgeo.2016.03.003>

Haas, M., Galler, R., Scibile, L., & Benedikt, M. (2020). Waste or valuable resource – a critical European review on re-using and managing tunnel excavation material.

*Resources, Conservation and Recycling*, 162, 105048.

<https://doi.org/10.1016/j.resconrec.2020.105048>

Hale, S. E., Roque, A. J., Okkenhaug, G., Sørmo, E., Lenoir, T., Carlsson, C., Kupryianchyk,

D., Flyhammar, P., & Žlender, B. (2021). The Reuse of Excavated Soils from Construction and Demolition Projects: Limitations and Possibilities. *Sustainability*, 13(11), 6083. <https://doi.org/10.3390/su13116083>

Heljedal, M. (n.d.). *Mass Management in Norrköping City*. Retrieved March 19, 2026, from

[https://nordrocs.org/wp-content/uploads/nordrocs2024/K2\\_Heljedal.pdf](https://nordrocs.org/wp-content/uploads/nordrocs2024/K2_Heljedal.pdf)

Hoven, L. (2018). *A comparison of the impacts of Euro 6 diesel passenger cars and zero-emission vehicles on urban air quality compliance*. Scopus.com.

<https://www.scopus.com/pages/publications/85053859536?origin=resultlist>

Huang, T., Kou, S., Liu, D., Li, D., & Xing, F. (2022). A BIM-GIS-IoT-Based System for Excavated Soil Recycling. *Buildings*, 12(4), 457.

<https://doi.org/10.3390/buildings12040457>

Inkinen, T., & Hämäläinen, E. (2020). Reviewing Truck Logistics: Solutions for Achieving Low Emission Road Freight Transport. *Sustainability*, 12(17), 6714.

<https://doi.org/10.3390/su12176714>

JD Supra. (2023). *Navigating The Five Phases in the Lifecycle of a Construction Project* | JD Supra. <https://www.jdsupra.com/legalnews/navigating-the-five-phases-in-the-7755211/>

JD Supra. (2026). *Ability to make changes vs cost of changes curve (Created with Google Gemini, 2026)*. [Photograph]. Adapted from JD Supra. <https://jdsupra-html-images.s3-us-west-1.amazonaws.com/e337e113-0cd6-491e-a7cd-d09da9cd855d-2023-10-11-17-24-51-613-6526da6375613ff8efc8694e.png>

JM. (2025a). *Earthworks phase at Solhöjden*. [Photograph].

JM. (2025b). *Foundation work, including concrete piles and steel sheet piling*. [Photograph].

JM. (2025c). *Picture from the start of the project in Spring 2025*. [Photograph].

JM. (2025d). *Solhöjden during the earthworks phase*. [Photograph].

JM. (2026a). *Location of the Solhöjden construction site in Kungälv*. [Photograph].

JM. (2026b). *Nyproduktion av hållbara bostäder med bra lägen*. Wwww.jm.se.

<https://www.jm.se/vastra-gotaland-lan/kungalv-kommun/kongahalla/solhojden/>

JM. (2026c). *Nyproduktion av hållbara bostäder med bra lägen*. Wwww.jm.se.

<https://www.jm.se/om-oss/nyhetsrum/2026/jm-ars-och-hallbarhetsredovisning-2025/baa370e7-1b5e-4eb4-91f1-413fbb99159b/>

JM. (2026d). *Schematics of project version 1 (PV1)*. [Photograph].

JM. (2026e). *Schematics of project version 3 (PV3)*. [Photograph].

JM. (2026f). *The volume difference between project version (PV) 2 to the left and 3 to the right, where measurements are taken from the centreline of the sheet pile wall.*

[Photograph].

Johnson, P. E. (2013). Monte Carlo Analysis in Academic Research. In *Oxford Handbooks Online*. Oxford University Press.

<https://doi.org/10.1093/oxfordhb/9780199934874.013.0022>

Karlsson, C. S. J., Miliutenko, S., Björklund, A., Mörtberg, U., Olofsson, B., & Toller, S.

(2017). Life cycle assessment in road infrastructure planning using spatial geological data. *The International Journal of Life Cycle Assessment*, 22(8), 1302–1317.

<https://doi.org/10.1007/s11367-016-1241-3>

Katsumi, T. (2015). Soil excavation and reclamation in civil engineering: Environmental aspects. *Soil Science and Plant Nutrition*, 61, 22–29.

<https://doi.org/10.1080/00380768.2015.1020506>

Khan, A. U., Huang, L., & Bruland, A. (2025). Transitioning to zero emission construction: A comparative study of diesel and electric loaders and trucks in Norwegian tunnel construction. *Tunnelling and Underground Space Technology*, 164, 106847–106847.

<https://doi.org/10.1016/j.tust.2025.106847>

Kungalv kommun. kungalv.se. (2024). *Schaktmassor och avfall vid anläggningsändamål - kungalv.se*. Kungalv.se.

<https://www.kungalv.se/foretagande/tillstandsguide/schaktmassor-och-avfall-vid-anlaggningsandamal/>

- Li, S., Djilali, N., Rosen, M. A., Crawford, C., & Sui, P. (2022). Transition of heavy-duty trucks from diesel to hydrogen fuel cells: Opportunities, challenges, and recommendations. *International Journal of Energy Research*, 46, 11718–11729. <https://doi.org/10.1002/er.8066>
- Liu, C., & Lu, M. (2014). Optimising Earthmoving Job Planning Based on Evaluation of Temporary Haul Road Networks Design for Mass Earthworks Projects. *Journal of Construction Engineering and Management*, 141(3). [https://doi.org/10.1061/\(asce\)co.1943-7862.0000940](https://doi.org/10.1061/(asce)co.1943-7862.0000940)
- Look, B. G. (2023). *Earthworks Theory to Practice - Design and Construction*. CRC Press.
- Lou, B., Rasmussen, F. N., Degago, S. A., Juvik, E. S., & Bohne, R. A. (2024). A BIM-based carbon footprinting of earthworks in road construction process. *Environmental Impact Assessment Review*, 110, 107731. <https://doi.org/10.1016/j.eiar.2024.107731>
- Magnusson, S., Johansson, M., Frosth, S., & Lundberg, K. (2019). Coordinating soil and rock material in urban construction – Scenario analysis of material flows and greenhouse gas emissions. *Journal of Cleaner Production*, 241, 118236. <https://doi.org/10.1016/j.jclepro.2019.118236>
- Malmqvist, E. (2022, October). *Particles from electric vehicles*. Airclim.org; Air Pollution & Climate Secretariat. <https://www.airclim.org/acidnews/particles-electric-vehicles?>
- Mass Logistics Centre (MLC) Norrköping. [Photograph]. Adapted from Heljedal. (n.d.). [https://nordrocs.org/wp-content/uploads/nordrocs2024/K2\\_Heljedal.pdf](https://nordrocs.org/wp-content/uploads/nordrocs2024/K2_Heljedal.pdf)
- Naturvårdsverket. (2009). *Riktvärden för förorenad mark Modellbeskrivning och vägledning*. <https://www.naturvardsverket.se/globalassets/media/publikationer-pdf/5900/978-91-620-5976-7.pdf>
- Naturvårdsverket. (2025). Naturvårdsverket.se. <https://www.naturvardsverket.se/vagledning-och-stod/avfall/masshantering-och-anvandning-av-massor-i-anlaggningsarbete/>

- Nykvist, B., & Olsson, O. (2021). The feasibility of heavy battery electric trucks. *Joule*, 5(4), 901–913. <https://doi.org/10.1016/j.joule.2021.03.007>
- Parente, M., Correia, A. G., & Cortez, P. (2016). Metaheuristics, Data Mining and Geographic Information Systems for Earthworks Equipment Allocation. *Procedia Engineering*, 143, 506–513. <https://doi.org/10.1016/j.proeng.2016.06.064>
- Parente, M., Gomes Correia, A., & Cortez, P. (2015). *Modern optimisation in earthwork construction L'optimisation moderne dans les travaux de terrassement*. <https://repositorio.inesctec.pt/server/api/core/bitstreams/806cc6b0-18f2-42eb-a73d-49445a6b11a3/content>
- Pinpointer AB. (2026). *Pinpointer – Digital masshantering*. Pinpointer. <https://www.pinpointer.se/lagkrav-2026>
- Provost, A. (2025, November 12). *The Weight of Electrification — Why Electric Trucks Tip the Scales Differently*. ACEA:intelligence. <https://www.aceaintelligence.eu/post/the-weight-of-electrification-why-electric-trucks-tip-the-scales-differently>
- Roy, A., McCabe, B. Y., Saxe, S., & I. Daniel Posen. (2024). Review of factors affecting earthworks greenhouse gas emissions and fuel use. *Renewable & Sustainable Energy Reviews*, 194. <https://doi.org/10.1016/j.rser.2024.114290>
- Skeie, R. B., Fuglestedt, J., Berntsen, T., Lund, M. T., Myhre, G., & Rypdal, K. (2009). Global temperature change from the transport sectors: Historical development and future scenarios. *Atmospheric Environment*, 43(39), 6260–6270. <https://doi.org/10.1016/j.atmosenv.2009.05.025>
- Smederöd, C. (2024, March 28). *Vägarbete stänger körfält på E6 vid Olskroksmotet*. Vårt Göteborg. <https://vartgoteborg.se/p/vagarbete-stanger-korfalt-pa-e6-vid-olskroksmotet/>
- Smith, S. D., Wood, G. S., & Gould, M. (2000). A new earthworks estimating methodology.

*Construction Management and Economics*, 18(2), 219–228.

<https://doi.org/10.1080/014461900370843>

Sortera. (2020). Sortera.se. <https://www.sortera.se/om-oss>

Sortera. (2026). *Göteborg Torslanda*. Sortera.se.

<https://www.sortera.se/masshantering/mottagning-av-fororenade-massor/goteborg-torslanda>

Stockholm Stad. (2022, June 20). *How the Mass Consolidation Centre works*. Stockholm

Royal Seaport 2030. <https://www.norradjurgardsstaden2030.se/articles/how-the-mass-consolidation-centre-works>

UNEP. (2023, September 12). *Building Materials And The Climate: Constructing A New Future*. UNEP - UN Environment Programme.

<https://www.unep.org/resources/report/building-materials-and-climate-constructing-new-future>.

Villar, Y., Menéndez, M., Fernández, Z., & Bernardo, A. (2020). Sustainable earthworks: Optimisation with the ICOM method. *Energy Reports*, 6, 404–419.

<https://doi.org/10.1016/j.egy.2020.08.060>

Volvo. (n.d.). *Batterier och laddning*. Volvotrucks.se. Retrieved April 21, 2026, from

<https://www.volvotrucks.se/sv-se/trucks/electric/faq/faq-batteries-charging.html#accordion-9508c82ee1-item-0d5b0b1513>

Volvo. (2024). *Vanliga frågor om batterier och laddning*. Volvotrucks.se.

<https://www.volvotrucks.se/sv-se/trucks/electric/faq/faq-batteries-charging.html>

Volvo. (2026). *Personal communication with author*.

Woo, S.-H., Jang, H., Lee, S.-B., & Lee, S. (2022). Comparison of total PM emissions emitted from electric and internal combustion engine vehicles: An experimental analysis. *Science of the Total Environment*, 842, 156961.

<https://doi.org/10.1016/j.scitotenv.2022.156961>

# Appendices

## Appendix A: Calculations of electric lorries in OpenLCA.

Inputs/Outputs – Electric Lorry V2 Electric

Inputs										
Flow	Category	Amount	Unit	Costs/Revenues	Uncertainty	Avoided waste	Provider	Data quality entry	Location	Description
lorry, 16 metric ton	C:Manufacturing/29:Manufacture of mo	3.20000E-7	Item(s)		lognormal: gmean=		market for lorry,			Calculated value
maintenance, lorry 16 metric ton	G:Wholesale and retail trade; repair of r	3.2E-7*0.5	Item(s)		lognormal: gmean=		market for maint			Calculated value
battery, Li-ion, rechargeable, prisms	C:Manufacturing/27:Manufacture of ele	0.00404	kg		lognormal: gmean=		market for batte			Based on curren
electricity, low voltage	D:Electricity, gas, steam and air conditio	1.50000	kWh		lognormal: gmean=		market for electr			Consumption inc
road	F:Construction/42:Civil engineering/421	0.00105*1.07	m <sup>2</sup> a		lognormal: gmean=		market for road			Calculated value
road maintenance	F:Construction/42:Civil engineering/421	(2.23185020417881E-4)*1.07	m <sup>2</sup> a		lognormal: gmean=		market for road r			Calculated value

Outputs										
Flow	Category	Amount	Unit	Costs/Revenues	Uncertainty	Avoided product	Provider	Data quality entry	Location	Description
Transport with electric lorry V2 EI 0: Master Thesis Project Version 3 El		1.00000	km		none					
brake wear emissions, lorry	E:Water supply; sewerage, waste mana	0.0000221658341968912*0.5	kg		lognormal: gmean=		market for brake			Road freight s
road wear emissions, lorry	E:Water supply; sewerage, waste mana	0.0000190849740932642*1.07	kg		lognormal: gmean=1		market for road v			Road freight s
tyre wear emissions, lorry	E:Water supply; sewerage, waste mana	0.000219613523316062*1.07	kg		lognormal: gmean=		market for tyre v			Road freight s

Figure 1.A: Input data over electric lorry modelling in OpenLCA.

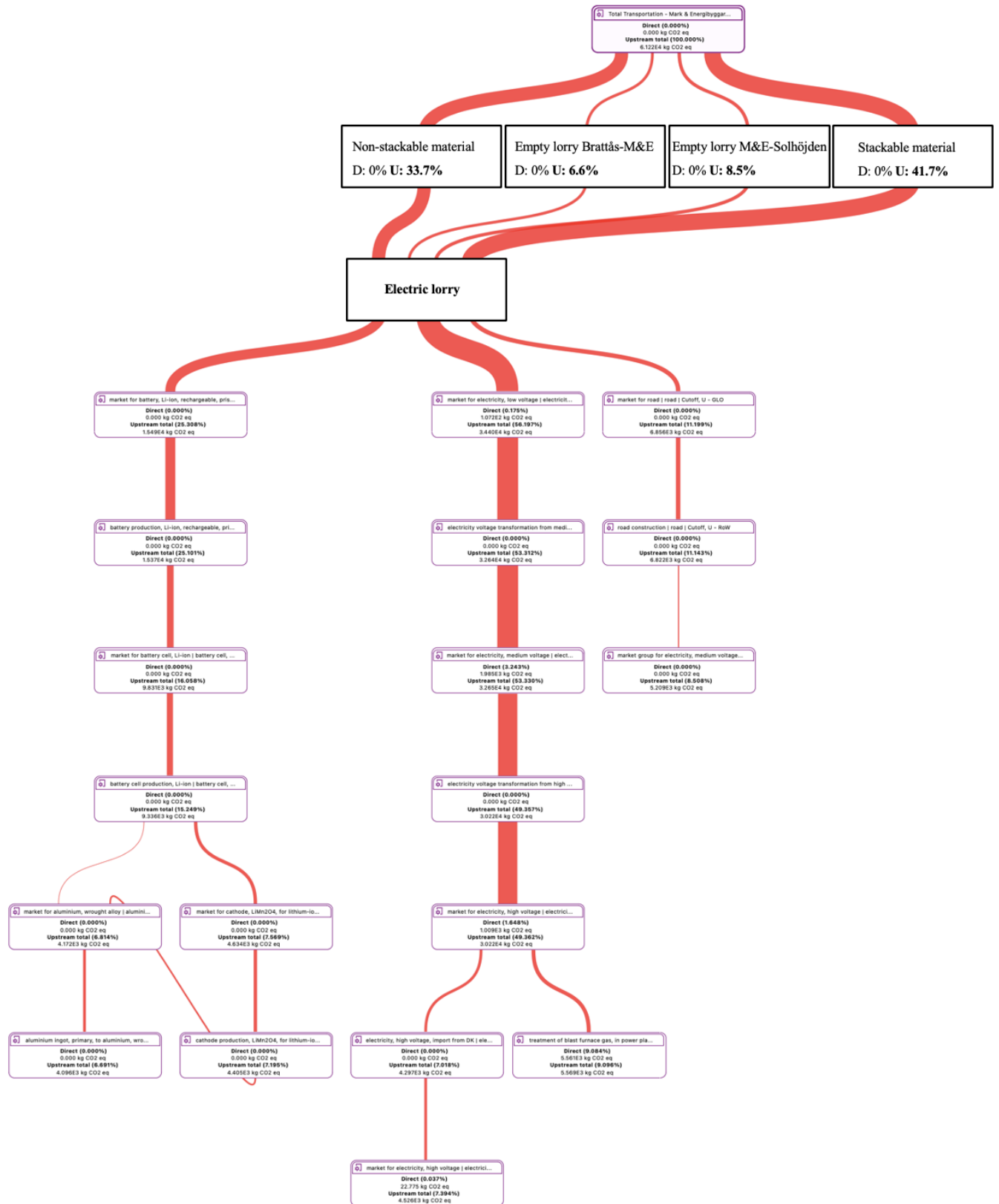


Figure 2.A: Sankey Diagram of total direct (D) and upstream (U) transportation emissions for the electric lorry, Adapted from OpenLCA (2026).



## **Appendix B: Interview Questions**

### **Interview 1: (Design manager at JM):**

1. May we record this interview?
2. Could you please describe your role in the Solhöjden project and your responsibilities within the design process?
3. What were the main reasons the project went through several project versions?
4. How did the design changes affect the excavation volumes in the project?
5. How were decisions made regarding the reuse of materials within the project site versus transporting them off site? Was any material from other projects reused at Solhöjden during the groundworks phase?
6. To what extent did you consider transport distances or the selection of receiving facilities during the design phase?
7. What key lessons from Solhöjden could be applied to future projects in relation to mass handling?
8. What were the main factors or cost-saving measures that influenced the economy of the earthworks phase?
9. Who holds responsibility for mass handling decisions during the design process? The design manager, contractor, cost estimation team, or sustainability function?
10. Were there early-stage discussions on considering impact on climate and cost when making decisions regarding mass handling and transportation?
11. Was there any planning for the reuse of materials from other projects at Solhöjden during the earthworks phase?
12. Is there anything we have not asked that you consider important for understanding mass handling in the Solhöjden project?

### **Interview 2: (Contaminated land specialist at JM)**

1. May we record this interview?
2. Could you describe your role in the Solhöjden project and your area of responsibility? How long have you worked at JM?
3. Was Pinpointer used in the project? Could you explain what Pinpointer is and how it is used?
4. What do you consider to be the main challenges in the groundworks phase regarding transport and excavation?
5. How is the transport destination for excavated material selected (e.g. nearest facility, cost, contractual agreements, environmental requirements)?
6. What does the current process for handling surplus or waste material in the project look like?
7. What types of material arise (e.g. contaminated soil, uncontaminated soil, KM/MKM classifications), and how does this affect transport and the choice of receiving facility?

8. What are the main environmental challenges related to mass handling?
9. To what extent is reuse prioritised over disposal, and what are the reasons for this?
10. Are there established collaborations with specific receiving facilities?
11. How are transport distances and volumes documented?
12. Are there cases where material is transported longer distances for reuse instead of being sent to a closer disposal site?
13. What proportion of the project cost is made up of mass handling and transport?
14. What do you believe is the main barrier to optimising transport from a climate perspective?

**Interview 3: (Site manager at JM)**

1. May we record this interview?
2. Could you describe your role in the Solhøjden project and your responsibilities?
3. When did the project start, and how long did the foundation phase take?
4. What do you consider to be the main challenges in the groundworks phase regarding transport and excavation?
5. Were there any unforeseen events during the groundworks phase that had not been accounted for in the design?
6. Did the project follow the planned schedule during the groundworks phase, or was it completed faster or slower than expected?
7. Do you feel that mass handling and logistics were sufficiently considered during the design phase?
8. What was the biggest challenge related to mass handling?
9. Did any logistical issues arise that increased the need for transport?
10. Would it be possible to obtain photos from the groundworks phase that we could use in our report?

**Interview 4: (Earthworks specialist at JM)**

1. May we record this interview?
2. Could you describe your role in the Solhøjden project and your area of responsibility? How long have you worked at JM?
3. What do you consider to be the main challenges in the groundworks phase regarding transport and excavation?
4. How is the transport destination for excavated material selected (e.g. nearest facility, cost, contractual agreements, or environmental requirements)?
5. At what stage of the project are the key decisions regarding mass handling and transport solutions made, and who is primarily responsible for these decisions?
6. To what extent does the design phase (e.g. elevation planning, basements, or ground levels) influence the volume of material that needs to be transported off site?
7. What is typically the largest cost driver in mass handling, and approximately what proportion of the total project cost do mass handling and transport represent?
8. How much variation is there in reception fees between different receiving facilities?

9. What does the current process for handling disposal material look like in the project?
10. What are the main sustainability and economic challenges related to mass handling?
11. Do you believe that coordination between different construction projects could improve the reuse of materials, and if so, what are the main obstacles?
12. Is there anything we have not asked that you consider important for understanding mass handling in the Solhøjden project, or in general?

**Interview 5: (Site manager at M&E)**

1. May we record this interview?
2. Could you describe your role and your professional background?
3. How does the setup work? Does JM contract you for a fixed price, after which you decide which transport company to use and where the excavated materials are transported?
4. How do you select the receiving facility for excavated materials?
5. What do you see as the main challenges in handling excavated materials from your perspective?
6. Were you able to coordinate transports in order to reduce empty runs?
7. Do you plan transports at specific times of the day to avoid peak traffic?
8. How do you view the future use of electric trucks?
9. What are the main challenges related to coordination on the construction site? Is it easy to time the transport of excavated materials?
10. Do you see any opportunities for improvement when it comes to reducing the number of transports?
11. Which factors have the greatest influence on transport distances (e.g. cost, availability of receiving facilities, environmental requirements)?
12. How do you handle unforeseen changes, such as variations in material volumes?
13. What are the main cost drivers in mass handling (e.g. transport, disposal fees, time, etc.)?
14. We identified the following receiving facilities near Solhøjden (NCC and Svevia); would it have been possible to transport the materials there?

**Interview 6: (Co-founder at Pinpointer)**

1. May we record this interview?
2. Could you describe your role and your professional background?
3. Could you explain what Pinpointer is and how it works?
4. How did the idea for Pinpointer originate? What challenges in the industry were you aiming to address?
5. What are the advantages of using digital tools such as Pinpointer compared to more traditional methods?
6. How are transport distances and material volumes documented within the system?
7. How are transport destinations for excavated materials selected (e.g. nearest facility, cost, contractual agreements, or environmental requirements)?

8. Which receiving facilities do you typically use?
9. How could Pinpointer be further developed to facilitate material transport?
10. Have you encountered any challenges or limitations with the system?
11. Is there anything else related to digital tracking or mass handling that you consider important to highlight?
12. We identified the following receiving facilities near Solhöjden (NCC and Svevia); would it have been possible to transport the materials there?

## Appendix C: Emission Contributions between PV3 & PV3-RO.

Table 1.C: Carbon equivalents emissions from PV3.

<b>Project Version 3</b>	<b>kg CO<sub>2</sub>e</b>	<b>Contribution</b>
Stackable Excavated Material	31,074	36.4%
Non-Stackable Excavated Material	25,098	29.4%
Empty Lorry Brattås - Solhöjden	10,988	12.9%
Empty Lorry M&E - Solhöjden	6,033	7.1%
Empty Lorry Brattås - M&E	4,689	5.5%
Reinforced Concrete <KM <500	1,794	2.1%
Soil KM-MKM	1,710	2.0%
Asphalt <70PAH	1,181	1.4%
Reinforced Concrete inert<500	965	1.1%
Empty Lorry Surte - M&E	610	0.7%
Empty Lorry Surte - Solhöjden	361	0.4%
Empty Lorry Tagene - M&E	336	0.4%
Unreinforced Concrete <KM <500	287	0.3%
Asphalt <70	179	0.2%
Empty Lorry Tagene - Solhöjden	68	0.1%
<b>Total</b>	<b>85,371</b>	

Table 2.C: Carbon equivalents emissions from PV3 route optimised (PV3-RO).

<b>Project Version 3 Optimised</b>	<b>kg CO<sub>2</sub>e</b>	<b>Contribution</b>
Empty Lorry M&E - Solhöjden	6,033	33.6%
Empty Lorry NCC - M&E	5,135	28.6%
Stackable Excavated Material	1,862	10.4%
Non-Stackable Excavated Material	1,504	8.4%
Empty Lorry Svevia - M&E	1,396	7.8%
Soil KM-MKM	677	3.8%
Empty Lorry NCC - Solhöjden	658	3.7%
Asphalt <70PAH	277	1.5%
Empty Lorry Svevia - Solhöjden	167	0.9%
Reinforced Concrete <KM <500	131	0.7%
Reinforced Concrete inert<500	71	0.4%
Unreinforced Concrete <KM <500	21	0.1%
Asphalt <70	13	0.1%
<b>Total</b>	<b>17,944</b>	



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