Conversion of quarries into hubs for intermediate storage

Upgrading and treatment of excavated materials - opportunities and challenges

Master's Thesis in Infrastructure and Environmental Engineering

ANTON PEHRSSON
ELIAS ZETTERHOLM

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

Chalmers University of Technology
Gothenburg, Sweden 2025
www.chalmers.se

Master's thesis 2025

Conversion of quarries into hubs for intermediate storage, as well as upgrading and treatment of excavated materials – opportunities and challenges

ANTON PEHRSSON
ELIAS ZETTERHOLM

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology
Gothenburg, Sweden 2025

Conversion of quarries into hubs for intermediate storage, as well as upgrading and treatment of excavated materials – opportunities and challenges
ANTON PEHRSSON
ELIAS ZETTERHOLM

Supervisor: Joakim Claesson, Swedish Transport Administration
Supervisor: Carolina Borre, Swedish Transport Administration
Supervisor and Examiner: Jenny Norrman, Geology and Geotechnics at Chalmers University of Technology

Master's Thesis 2025
Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Typeset in LaTeX
Printed by Chalmers Reproservice
Gothenburg, Sweden 2025

Conversion of quarries into hubs for intermediate storage, as well as upgrading and treatment of excavated materials – opportunities and challenges
ANTON PEHRSSON
ELIAS ZETTERHOLM
Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology

Abstract

The construction industry is a major contributor to greenhouse gas emissions and resource consumption, with a growing demand for sustainable practices in material management. This thesis explores the potential of converting rock quarries into multifunctional hubs for the intermediate storage, upgrading, and treatment of excavated materials within the Gothenburg region. Through a qualitative methodology comprising literature review, site visits, and stakeholder interviews, the study identifies technical, legislative, and logistical opportunities and challenges involved in such conversions. Key findings highlight synergies in technical equipment, the potential for reducing transportation distances and emissions, and the importance of developing viable business models. The thesis also presents three scenario-based analyses that explore different levels of integration and their respective regulatory, technical, and environmental implications. Results suggest that while such transformations offer significant circular economy benefits, they require careful navigation of environmental legislation, stakeholder collaboration, and market demand for recycled materials. The study contributes holistically to the broader objective of sustainable infrastructure by proposing practical strategies for enhancing circular mass management and production through the repurposing of quarries.

Keywords: Circular economy, mass management, excavated materials, intermediate storage, quarry conversion.

Omvandling av täkter till nav för mellanförvaring, samt uppgradering och behandling av schaktmassor – möjligheter och utmaningar
ANTON PEHRSSON
ELIAS ZETTERHOLM
Institutionen för arkitektur och samhällsbyggnadsteknik
Avdelningen för geologi och geoteknik
Chalmers tekniska högskola

Sammanfattning

Bygg- och anläggningssektorn står för en betydande del växthusgasutsläpp och resursförbrukning i samhället. Denna studie undersöker potentialen i att omvandla bergtäkter för att även kunna mellanlagra, behandla och uppgradera schaktmassor i Göteborgsregionen. Studien bygger på två delar: en kvalitativ analys och en scenariobaserad analys.

Den kvalitativa analysen, som omfattar platsbesök, intervjuer och litteraturstudie, identifierade både utmaningar och möjligheter med en sådan omställning. Utmaningarna inkluderar begränsade ytor, ekonomisk lönsamhet, olika tolkningar av lagstiftning, avsaknad av cirkulära krav från beställare, samt produktifiering av schaktmassor klassade som avfall. Möjligheterna innefattar synergier med befintlig utrustning och infrastruktur, förlängd livslängd på täkten, minskade transportkostnader och reducerat behov av nyexploatering.

Resultaten från den kvalitativa analysen ligger till grund för den scenariobaserade analysen, i vilken tre scenarier har utvecklats och analyserats med olika nivåer av integrering av mellanlagring, behandling och uppgradering av schaktmassor på täkter. Scenario 1 innebär enkel mellanlagring med låg kostnad och personalbehov. Scenario 2 inkluderar lagring, behandling och uppgradering av AMA-klassificerat material, och drar nytta av de tekniska synergier som identifierats på bergtäkten. Scenario 3 är likt scenario 2, men omfattar ett mer utvecklat system med hantering av en större variation av material, upp till icke-farligt avfall (IFA). Scenarierna analyseras utifrån aspekter såsom tekniska, miljömässiga och regulatoriska. Analysen visar att alla tre scenarier har styrkor och kan vara lämpliga beroende på förutsättningarna.

Slutsatsen är att en omställning mot en mer cirkulär masshantering både är nödvändig och möjlig, men inte utan utmaningar. Bergtäkter har en unik möjlighet att ta en ledande roll för att främja cirkulär masshantering och produktion. Nyckelfaktorer för att möjliggöra detta är enhetlig och förutsägbar tolkning av lagstiftningen, ett starkare samarbete mellan intressenter, samt cirkulära krav från beställare.

Nyckelord: Cirkulär ekonomi, masshantering, schaktmassor, mellanlagring, omvandling av täkter.

Acknowledgements

This Master Thesis of 30 credits was completed at the Department of Architecture and Civil Engineering at Chalmers University of Technology in the spring of 2025.

We would like to express our sincere gratitude to our supervisor and examiner, Jenny Norrman at Chalmers, for her immensely valuable guidance and support throughout the course of this thesis. We are also deeply grateful to our supervisors at the Swedish Transport Administration, Joakim Claesson and Carolina Borre, whose insights and encouragement were much valuable.

We wish to thank Jan Englund and Paulina Johansson at Skanska for their generous support and expertise. Their contributions played a key role in shaping the aim and purpose of this study and in providing thoughtful, constructive feedback. In addition to our contacts at Skanska, we would like to thank the teams at Swerock and Sortera for facilitating site visits, engaging in valuable discussions, and generously sharing their knowledge.

Finally, we would like to express our gratitude to all the interviewees who participated in this study and shared their knowledge, experiences, and insights into working with excavated materials. Their input has significantly enriched this thesis, its findings, and has highlighted future challenges and opportunities for further research in the field of circular mass management and quarry operations.

Anton Pehrsson and Elias Zetterholm, Gothenburg, May 2025

Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AMA	General material and work description *Allmän material och arbetsbeskrivning*
CO_2	Carbon dioxide *Koldioxid*
CPR	Construction Products Regulation *Byggproduktreglering*
EC	Environmental Code *Miljöbalk*
EPA	Environmental Protection Agency *Naturvårdsverket*
EPD	Environmental Product Declaration *Miljövarudeklaration*
GHG	Greenhouse gas *Växthusgas*
IFA	Non-hazardous waste *Icke farligt avfall*
KM	Sensitive land *Känslig mark*
MKM	Less sensitive land *Mindre känslig mark*
MLC	Mass Logisitcs Center *Masslogistikscenter*
MRR	Less than slight risk *Mindre än ringa risk*
SDG	Sustainable Development Goals *Hållbarhetsmål*
SGS	Swedish Geotechnical Society *Svenska Geotekniska Föreningen*
SGU	Swedish Geological Investigation *Sveriges Geologiska Undersökning*
TrV	Swedish Transport Administration *Trafikverket*

Glossary

Below is the glossary that has been used throughout this thesis listed in alphabetical order:

Construction rock *Entreprenadberg*	Rock material that is generated in connection with tunnel work, the construction of underground chambers, or rock excavation.
Excavated material *Massor*	Soil, rock, sediment or other substances removed from the ground during construction, mining or other projects.
Intermediate storage *Mellanlagring*	Temporary storage of materials, such as rock or excavated materials, until the material is ready for the intended use.
Mass management *Masshantering*	Management of volumes of materials that are removed, excavated, from land and soil.
Waste *Avfall*	Substance or object that the holder disposes of, intends to dispose of, or is required to dispose of.

Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

Today's construction industry plays a major part in creating emissions that contribute to increased global warming and climate change (Lai et al., 2023). Among these emissions, greenhouse gases (GHG) are particularly significant, with carbon dioxide (CO_2) being by far the most dominant GHG, accounting for 97% of total GHG emissions. Notably, the combined CO_2 emissions from the construction, engineering, and architecture sector represent 32% of Europe's total annual emissions (Carvalho et al., 2019). Together, these three sectors also consume approximately 40% of Europe's total annual energy and are responsible for generating 25% of all annual waste. Globally, construction and demolition waste has the largest impact on the generated gross waste stream, a figure that continues to rise as a result of increased global urbanisation trends (Zhang et al., 2022).

Large-scale construction projects, such as roads and railways, typically generate substantial volumes of excavated materials (Hale et al., 2021). Despite their prevalence, the rate of reuse of such materials has been limited. In 2019, only 7% of Europe's total use of 4.2 billion tonnes of granular materials, including excavated materials, was involved in circular processes (Larsson & Gammelsæter, 2023). The lack of circular flows and processes regarding these materials is often connected to complex material management, which involves extensive testing and classification to comply with national standards and regulations. As part of the European Waste Management Act, excavated materials are subject to a hierarchical classification, making their handling more extensive in comparison to other material streams (Haas et al., 2020).

In addition to regulatory challenges, the transportation of construction materials, including virgin, recycled, or excavated materials, poses significant environmental and logistical concerns. When the distance between the material source and its endpoint becomes too great, both economic and environmental impacts increase, largely due to increased CO_2 emissions and their indirect financial costs to society (Larsson & Gammelsæter, 2023). Larsson and Gammelsæter (2023) further notes that transportation costs of certain materials can exceed the value of the material after just 30 kilometres.

While the on-site reuse of excavated materials has proven to be successful across different construction projects in Europe, it has yet to be implemented on a larger scale (Haas et al., 2020). With the increasing trend of global urbanisation, and with ageing infrastructure, the demand for granular materials for construction purposes will most likely increase over time (Larsson & Gammelsæter, 2023). In response, a shift toward more sustainable and circular practices in the management and distribution of excavated materials is becoming increasingly needed. The city of Gothenburg has ambitious targets for the year 2030, aiming to source 50% of its purchased rock and excavated materials through circular processes and to reuse 100% of surplus excavated materials that are technically and environmentally suitable (Gothenburg City, 2023). Achieving these ambitious targets requires substantial investments in circular mass management and the circular production of aggregates. One such approach involves the use of intermediate storage to temporarily hold reusable excavated materials until later use or refinement.

However, securing space for such storage remains a significant challenge, particularly in densely developed urban areas (Larsson & Gammelsæter, 2023).

Quarries typically operate with machinery such as sieves, crushers, and loaders (Patyk et al., 2019), much of which is also well suited for the treatment and upgrading of excavated materials (Andersson-Sköld et al., 2022). Consequently, several quarries in the Gothenburg region are today located close to areas where the materials are being utilised. This highlights the strategic strengths in the positioning of quarries in a Gothenburg context since shorter transport distances enable a decreased environmental footprint and increased financial value. As a result, converting areas within quarry sites to store, treat, and upgrade excavated materials presents a promising opportunity for quarry operators. Such an approach could play a vital role in supporting circular mass management and promoting circular production practices in the construction sector.

1.2 Aim

This thesis aims to analyse how quarries can be converted to hubs for intermediate storage, with upgrading and treatment of excavated materials. Consequently, it investigates the technical and legislative framework necessary to facilitate such a transition. Additionally, the study examines the contextual factors and surrounding preconditions under which a full or partial implementation of this approach would be most favourable.

To achieve this aim, the following objectives have been formulated:

- Identify: 1) the technical equipment required for the upgrading and treatment of materials at the quarry site, and 2) the permits necessary for integrating intermediate storage with the upgrading and treatment of excavated materials.
- Explore various scenarios for integrating intermediate storage with upgrading and treatment of excavated materials, considering both a full and partial implementation of the quarry.
- Present the economic and environmental impacts on a holistic level, as well as the stakeholder dynamics, associated with the different scenarios of intermediate storage with upgrading and treatment of excavated materials.

1.3 Limitations

Given the considerable variation in both scale and characteristics of quarries across Sweden, this study focuses on rock quarries of sufficient capacity to supply materials to large-scale infrastructure projects within the Gothenburg region. The selection of this geographical scope is motivated by the presence of the Swedish Transport Administration (TrV) as a key stakeholder in such projects. This limitation also allows for a more focused understanding of how TrV works and manages material classifications, properties, and contamination levels related to excavated material in their projects. Moreover, the high density of active quarries in the Gothenburg region provides a representative sample for analysis and enables practical opportunities for site visits.

2 Rock-quarrying

A rock quarry is a site where rock is extracted through blasting and subsequently processed for use in various applications, such as roads, railways, and buildings (EPA, n.d.). As rock quarrying depends on the extraction of a finite natural resource, it is classified under Swedish law as an environmentally hazardous activity. As such, quarry operations require either a permit or a notification to the appropriate authority, depending on the scale and nature of the activity. The level of regulatory instance also varies based on whether the quarry requires groundwater pumping (Svevia, n.d.). Furthermore, the geographical location of a quarry must be carefully assessed and justified to minimise environmental impact and limit potential disturbances to surrounding areas and communities (EPA, n.d.).

Quarry operations are typically granted permission to extract a specified volume of rock within a defined time frame, usually ranging from 15 to 25 years (Svevia, n.d.). Once either the maximum permitted volume has been extracted or the operational period has expired, the quarry enters a post-treatment phase aimed at site rehabilitation. The specific type and conditions for the post-treatment are defined in the quarry's permit and may vary in focus depending on regulatory and environmental objectives (Environmental Cooperation Sweden, 2006). For instance, post-treatment measures may focus on ecological restoration, to rehabilitate the landscape and promote local biodiversity (Svevia, n.d.).

2.1 Operational steps and technical equipment

The procedure of rock quarrying is comprehensively described by Svevia (n.d.) and illustrated in Figure 2.1. The quarrying process begins with the removal of surface layers to expose the underlying rock. Once the rock is uncovered, holes are drilled for explosives, which are used to blast the rock apart. The resulting loose material is then collected and fed into a crusher, followed by a dry sieve that sorts the rock into predefined fraction sizes. This sorted material is stored in piles on-site. When needed, loaders transfer the desired fractions onto clients' trucks for transportation off-site.

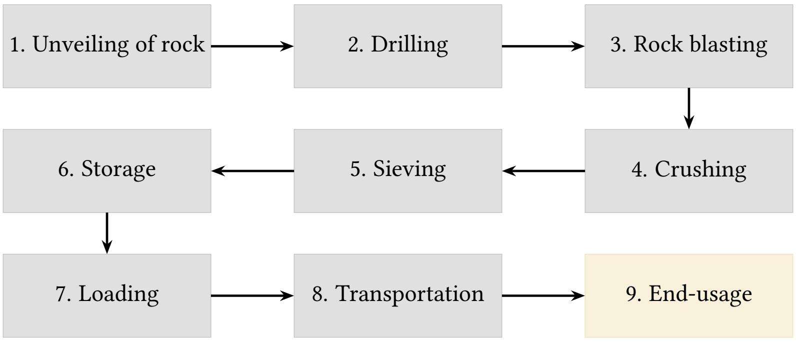


Figure 2.1: Example of quarry operation procedure. Inspired by a figure from Svevia (n.d.).

2.2 Geographical locations - Gothenburg

Within the Gothenburg region, multiple rock quarries are located at varying distances from the city centre, as illustrated in Figure 2.2. Their proximity to both aggregate consumers and urban construction sites is strategically important, particularly given that transportation costs become less efficient beyond approximately 30 kilometres (Larsson & Gammelsæter, 2023).

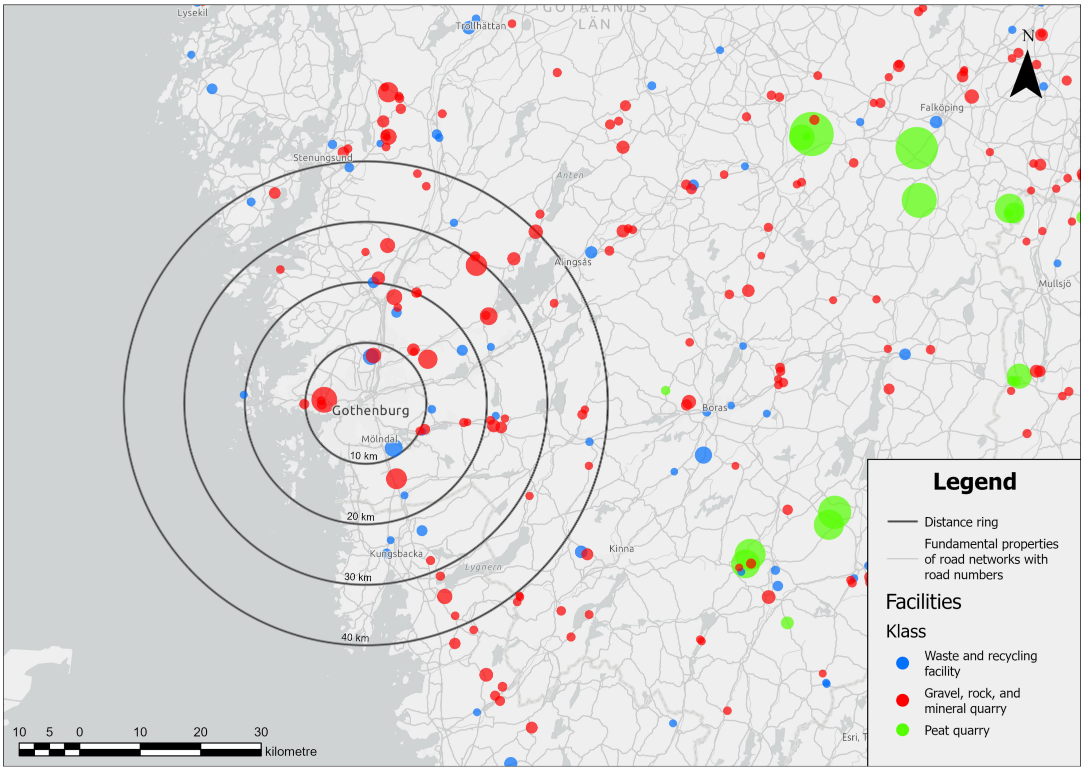


Figure 2.2: Map of quarries, waste and recycling facilities in the Gothenburg region with circles showing distance (10, 20, 30 and 40 kilometres) from the city centre. The size of nodes resembling quarries in the map scales with the quarry area.

3 Theory

3.1 Sustainable development

The concept of sustainability and sustainable development has become increasingly popular in the past two decades (Purvis et al., 2019). Sustainability has been developed alongside a critique of the side effects of economic growth. In addition to the economy, it also incorporates environmental and social aspects of development and growth. Economic, social, and environmental aspects are often referred to as the three pillars of sustainability, where excluding one of the pillars may result in long-term negative effects on all aspects, not only the one excluded. This idea of sustainability is sometimes visualised as pillars, sometimes as concentric circles, or as a Venn diagram (Figure 3.1).

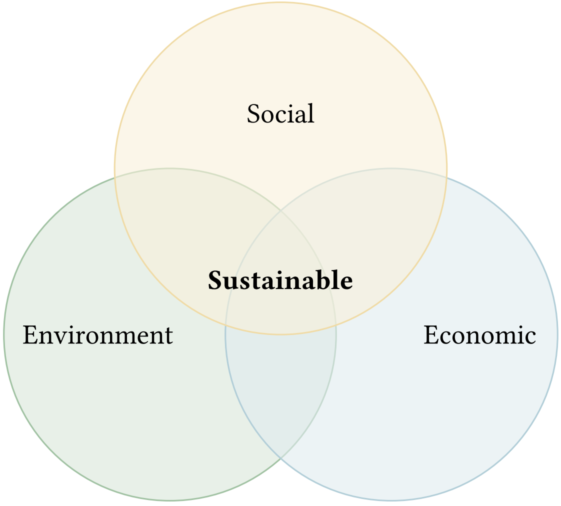


Figure 3.1: Sustainability and its three pillars: social, environmental, and economic, illustrated as a Venn diagram.

3.2 Circular economy and mass management

The primary challenge to sustainable development is the linear flow of materials and energy within the economy (Korhonen et al., 2018). This unidirectional flow depletes the system it operates in while simultaneously generating waste and emissions. To address the limitations of the linear economy, the circular economy has emerged as a more sustainable alternative. It seeks to reduce resource and energy demand by extending the lifespan and maximising the value of materials. This approach considers the entire life cycle of a product—pre-use, use, and post-use phases (Zhang et al., 2022). The circular economy is often formulated through the hierarchy of actions with Rs. The most common 3R principle includes Reduce, Reuse, and Recycle. It has evolved into more comprehensive models such as the 4R, 5R, and 6R frameworks. These expanded approaches provide deeper insights into how circular economy principles can be implemented to enhance sustainability.

Mass management refers to the management of volumes of excavated materials (EPA, 2024b). There is legislation concerning whether this type of material can be reused in other construction projects. The way the material can be dealt with is therefore directly dependent on the material's contamination level (Andersson-Sköld et al., 2022). Mass balance is a key part of larger construction projects to maintain sustainability. To optimise mass balance in a construction project, the goal is to maximise the use of excavated material as a resource. An optimised mass balance limits the amount of excavated material that ends up in the broader system of waste management, which creates greenhouse gas emissions and economic costs due to transportation.

The flow of resources in mass management today is similar to that of a linear economy, with only a small portion of resources being incorporated in a sustainable circular flow (Brinkhoff et al., 2020). A more sustainable situation would be to increase the circular flow of materials, which would reduce the linear flow and the amount of generated waste.

3.3 Volume of generated excavated material

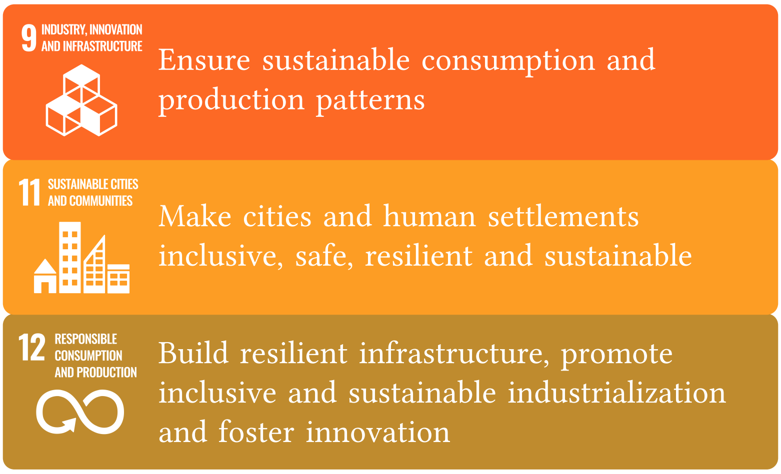
In Sweden, estimations of the amounts of excavated materials emerging through construction projects are often hard to specify (EPA, 2024a). However, based on rough estimations, data from 2018 and 2019 by the Swedish Environmental Protection Agency (EPA) shows that emerging masses of around 60-80 million tonnes annually are linked to the construction sector. The majority of this amount is construction rock. Also, in 2018, the amount of excavated soil materials registered as waste was approximately 8.9 million tonnes, of which 8.3 million tonnes was classified as IFA and 600,000 tonnes was classified as hazardous waste. Annual amounts of excavated materials also change from year to year. Economic fluctuations, such as periods of economic growth or recession, along with variations in the quantity, scale, and duration of projects, can significantly influence the dynamics of industries and sectors.

3.4 Guidelines and legislation

There are various guidelines and legislations established at multiple levels of governance. The United Nations adopted the Sustainable Development Goals (SDGs) in 2015 (United Nations, 2015). This agenda addresses a wide range of issues with 17 goals, all with specific targets and indicators to measure progress. Concerning mass management, SDGs 9, 11, and 12 all address the sustainable development of cities and their supporting infrastructure, see Figure 3.2.

The European Union has developed policies to reduce waste generation during the stages of construction and demolition (Zhang et al., 2022). The Waste Framework Directive from 2008 introduced a Waste Hierarchy (Figure 3.3). It establishes a hierarchy of priorities, starting with prevention (a non-waste option), followed by waste management strategies in the order of reuse, recycling, other forms of recovery, and finally disposal (waste options).

Prevention of waste generation is most preferred and is highly dependent on the product



Ensure sustainable consumption and production patterns

Make cities and human settlements inclusive, safe, resilient and sustainable

Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Figure 3.2: SDG 9, 11, and 12 icons from United Nations (2015) with their main goals, focusing on issues relevant to mass management.

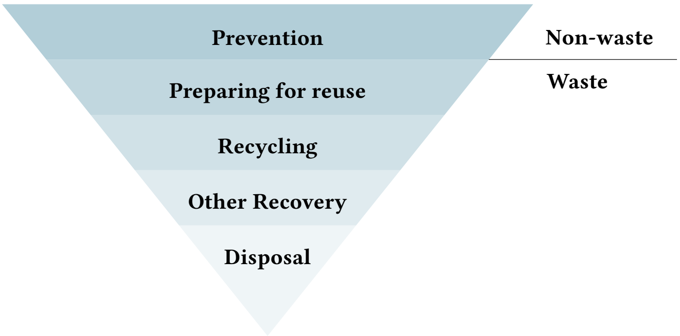


Figure 3.3: Waste hierarchy from the EU Waste Framework Directive (Zhang et al., 2022).

design (Zhang et al., 2022). One way to prevent waste generation could be to enhance the durability of materials, as it reduces the need for replacement. Zhang et al. (2022) further explains the waste hierarchy by using concrete as an example. Prefabricated concrete has been shown to prevent waste by having the potential to reduce waste concrete by 50%. Reuse refers to a product that is not waste and can be used for its intended purpose again. Concrete products, such as structural components, are typically designed for specific loads and use cases, making them difficult to reuse. Renovation and retrofitting of buildings are, therefore, seen as more suitable options. The recycling of concrete can be done by reprocessing waste concrete to make new concrete products. Other methods of recovery could be downcycling waste concrete through backfilling, which refers to filling excavated sites with materials of lower quality. The final, least preferred option of the waste hierarchy is disposal. Disposal could be considered similar to backfilling, especially when it is without purpose, but the main difference is that useful backfilling is done with a specific function.

The Swedish Environmental Code (EC) emphasises sustainable development to protect the environment and the human right to use it (EC, 1998). In chapter 15, section 1, the first paragraph, the EC states that it is the interest or intent to dispose of excavated

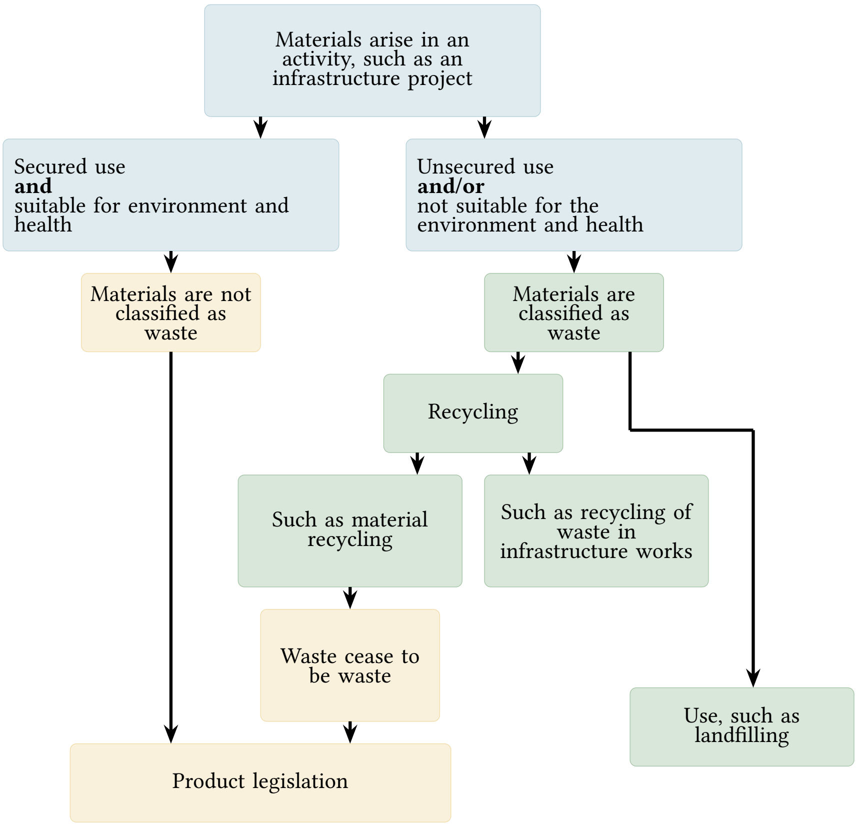


Figure 3.4: Guidelines from the Swedish EPA for how excavated material can be used based on the definition of waste. Translated illustration based on a figure from EPA (2024b).

material that decides if it is waste or not. Developing on this, the Swedish EPA adds the health and environmental component to the definition of waste (EPA, 2024b). Their guideline of how the definition of waste can be applied to excavated material is shown in Figure 3.4. In this guideline, both of the following criteria must be fulfilled for excavated materials not to be defined as waste:

- Use of the excavated material is secured.
- The excavated material is suitable for the environment and human health.

In addition to meeting the two criteria mentioned above, the intended use of the excavated masses must occur within a reasonable timeframe (EPA, 2022). Otherwise, there is a risk that the excavated material will be classified as waste (EPA, 2024b). The operator responsible for generating the excavated material determines whether it qualifies as waste (EPA, 2022). This assessment should be made at an early stage, as it is a crucial factor in determining which laws apply and how the material can be managed.

Waste can be transformed into a product through a recycling process (EPA, 2022). The product operator is responsible for assessing its compliance with legal standards and ensuring that its use does not pose a threat to the environment or human health once introduced to the market. This evaluation must also take into account the possibility that future circumstances could change and result in the emergence of an unacceptable risk.

3.5 Classification and categorisation of material properties

Swedish Building Service (n.d.) presents a classification of material properties in their general material and work descriptions, known as AMA. This reference work provides properties for the filling material of soil and rock, for infrastructure, construction and buildings. The material types of soil and rock for infrastructure construction and buildings are 1, 2, 3A, 3B, 4A, 4B, 5A, 5B, 6A, and 6B. These are classified based on the proportion of different fractions and the content of organic material (as seen in Table 3.1).

Table 3.1: AMA classifications for material types of soil and rock for infrastructure and construction (Swedish Building Service, n.d.). Translated by Andersson and Borre (2024).

Material type	**Name of soil and rock material**	**Content of (weight-%) X/Y**			**Example**	**Frost class**
		Fine 0.063 / 63 mm	**Clay** 0.002 / 0.063 mm	**Organic soil** % / 63 mm		
1	Rock type A	<10		≤2	Mica-poor granite or gneiss and other hard and strong rocks such as quartzite, dolerite, porphyry, and leptite	1
	Rock type B	<10		≤2	Mica-rich granite or gneiss and other rocks with moderate strength and poor wear resistance	1
2	Boulder and stony soils, Coarse-grained soils	≤15		≤2	Boulder, rock, gravel, sand, sandy gravel, gravelly sand, gravel till, sand till	1
3A	Rock type C	≤15		≤2	Rocks with high mica levels, clay shale, coarse-grained granites, porous sedimentary rocks, very strong transformed rocks	2
3B	Mixed-grain soils	16–30		≤2	Clayey or silty sand, gravel, sandy till, gravel till	2
	Rock type D			≤2	Rocks with high mica levels, clay shale, chalk limestone, clay-converted rock, unclassified material	3
4A	Mixed-grain soils	31–40		≤2	Same as above (high mica, shale, chalk limestone, etc.)	3
4B	Fine-grained soils	>40	>40	≤2	Clay, clay till	3
5A	Fine-grained soils	>40	>40	≤2	Silt, muddy silt, silty clay, silt till, silty clay till	4
5B	Mineral soils with organic content			2–6	Muddy clay, muddy silt	4
6A	Organic, mineral soils			6–20	Clayey mud, silty mud, sandy humus soil	3
6B	Organic soils			>20	Mud, peat, humus soil	1

The Swedish EPA has classified mass materials into four categories (A–D), as shown in Table 3.2 (EPA, 2022). This classification offers an overview of the properties and potential applications of each category and includes references to AMA classification standards.

Table 3.2: The Swedish EPA's classification of mass material (EPA, 2022).

	Construction rock	**Soil- and excavated masses**		
Material category	**A. Raw rock, loose rock**	**B. Sand and gravel**	**C. Moraine**	**D. Clay and silt**
Type of product / Endproduct	Crushed rock, i.e. material type 3A*	Stackable, single-graded sand- and gravel fractions, i.e. material type 2*	Unsorted fill material, i.e. material type 3B, 4A*	Loose soils, in some cases not packable, i.e. material type 4B, 5A*
Possible areas of use (not exhaustive)	Roads (bound/unbound layer), railway, foundation for building, concrete aggregate etc.	Roads (bound/unbound layer), railway, foundation for building, concrete aggregate, end coverage landfill (i.e. drainage layer, above sealing layer)	(Unbound), noise barrier, end coverage landfill (i.e. leveling layer under sealing layer) etc.	Additives in cultivation soil, end coverage landfill (i.e. part of sealing layer) etc.
Possible degree of impact	Untouched. Anthropogenically or geogenically impacted.	Untouched. Anthropogenically, biogenically or geogenically impacted.	Untouched. Anthropogenically, biogenically or geogenically impacted.	Untouched. Anthropogenically, biogenically or geogenically impacted.
Contamination level	Not contaminated, slightly contaminated, contaminated	Not contaminated, slightly contaminated, contaminated	Not contaminated, slightly contaminated, contaminated	Not contaminated, slightly contaminated, contaminated

*material type according to AMA

The Swedish EPA also provides guidelines following the EC for managing contaminated sites (EPA, 2009). These guidelines classify substances into two protection levels: sensitive land use (KM) and less sensitive land use (MKM). The objective of the classifications is to protect human health, the soil environment, groundwater, and surface water both on and around a site. In the sensitive case, KM, humans can reside on-site permanently for a lifetime. Consequently, there is greater emphasis on safeguarding human health. In contrast, MKM is intended for part-time residents and does not require as extensive protection of the soil ecosystem. The EPA also offers guidelines to facilitate the recycling of excavated material (EPA, 2010). These guidelines include values based on the total concentrations of substances, which help indicate when the risk of pollution from using a material is considered less than slight (MRR).

Excavated materials can also be classified based on the property of leaching (Elert et al., 2006). The Swedish EPA provides guideline values for the leaching test, which is a required test when landfill facilities receive excavated materials (EPA, 2004). The guideline values for contaminants relate to three waste categories: inert, non-hazardous (IFA) and hazardous waste. Ordinance (2001:512) on the landfilling of waste (2001) states that inert waste refers to excavated material which:

1. Does not undergo significant physical, chemical, or biological changes, nor dissolve, burn, or react in any harmful way.
2. Does not biodegrade or negatively affect other materials in a way that could harm

the environment or human health
3. Has negligible leachability, pollutant content, and ecotoxicity, posing no risk to surface or groundwater quality

Since the introduction of the European Commission's Construction Products Regulation (CPR) in 2013, all manufacturers, distributors, and importers of construction products covered by harmonised standards are required to CE-mark their products before placing them on the European Union market (Brander & Schouenborg, 2015). This marking ensures that the product can be marketed across all EU countries and signifies the manufacturer's assurance that it complies with the European Union's safety, health, and environmental protection standards (European Union, 2015). Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction (2007) must, therefore, comply with the geometrical, physical, chemical, and durability requirements of the *SS-EN 13242+A1:2007* standard.

For TrV projects, the guideline document *TDOK 2022:0063* serves as a supportive reference for TrV operators when managing and transferring masses internally between different projects (TrV, n.d.). The document provides contamination guideline values for a selection of relevant environmentally hazardous substances, presented in Appendix B.1. This document aims to better ensure environmental safety while also enabling a higher degree of utilisation and efficiency in managing excavated material between different TrV projects, particularly within the road and railway sectors. However, excess excavated material intended for external projects outside the scope of TrV may be subject to different or additional criteria, as well as extended testing requirements.

3.6 Methods for upgrading and treating excavated materials

Since the project focuses on exploring upgrading and treatment methods at the site of a quarry, all methods discussed in this section are ex-situ.

Storage time

In certain projects, materials with high water content need to be stored for a defined period prior to use. Table 3.3 presents the threshold water content values for AMA material types 3B, 4A, 4B, and 5A, along with their respective required storage time (Swedish Building Service, n.d.).

Crushing

Quarries use crushers to produce materials of varying fractions. The crushing process, as explained by Olaleye (2010), is typically performed in stages, with the primary stage involving the use of a jaw crusher. Provided that the material, such as excavated soil, blasted rock, or other recovered masses, meets the relevant technical and environmental standards for its intended application, it can be used in the crushing stages. This creates an opportunity to incorporate circular materials into the production of new aggregates.

Table 3.3: Required storage time for AMA material types based on water content. Translated version of table AMA CEB.11212/1 in Swedish Building Service (n.d.).

Material-type	Grading coefficient, Cu = d60/d10	Water content, w (%)	Storage time*, months
3B, 4A	<5	<7	Special investigation
		7–12	–
		>12	4
		>12	6
	≥ 5	<5	Special investigation
		5–10	–
		>10	<2
		>10	6
4B		<20	Special investigation
		20–35	3
		>35	–4)
5A		<7	Special investigation
		7–12	–
		>12	6
		>12	9

*Under frost-free conditions

Screening

Screening operates on the principle of allowing particles smaller than the screen openings to pass through, while larger particles remain on top, separating aggregates into different sizes (Alexandria, 2013). Screening could, therefore, be used to extract larger fractions from excavated soil for further processing and reuse. The main types of screens used for this separation include vibrating inclined, stationary inclined, vibrating grizzly, vibrating horizontal, and rotary. Vibrating inclined screens are the most commonly used type due to their reliability and the flexibility they offer in adjusting parameters such as slope, speed, and stroke. Stationary inclined screens are a simpler process which does not allow for as high flexibility. For heavy materials, screening media such as grizzly bars can withstand more intense strain as they are more rugged in their construction.

Dry and wet sieving

A traditional method for treating and upgrading excavated materials is dry sieving (SBMI, n.d.). This mechanical process separates the material into fractions based on grain and rock size. It can be used to remove finer fractions, which are generally less desirable because they tend to bind pollutants and have lower technical quality due to high capillary rise (Andersson-Sköld et al., 2022).

Wet sieving separates the excavated material into even smaller fractions (Andersson-Sköld et al., 2022). This procedure is more complex and time-consuming than dry sieving and can also involve chemical additives in the washing water for separation purposes. Standard wet sieving techniques are particularly effective for sorting gravel and sand particles larger than 0.063 millimetres (Ma et al., 2024). Mechanically, scrubbing the material removes contaminants from the surfaces of the particles, thereby reducing contamination (Andersson-Sköld et al., 2022). Chemically, unwanted contaminants attached to the fractions can be reduced. The washing water then needs treatment by measures such as regulating the pH, flotation, flocculation and filtering. When comparing the two methods, dry sieving is more effective for processing and upgrading materials with a lower proportion of fine fractions. Wet sieving is preferred when the material contains a higher proportion of fine particles.

Biological degradation

Excavated material could be treated through biological degradation (Andersson-Sköld et al., 2022). This method is particularly suitable after the excavated material has undergone either wet or dry sieving and contains non-natural organic matter, such as petroleum or hydrogen chloride. The degradation process involves adding microorganisms to the incoming material, which will feed on the contaminants and ultimately create CO_2. However, this treatment method is not suitable for excavated material with natural organic contaminants, as these are hard to treat fully. This process is very sensitive to deviations from optimal conditions for the added microorganisms regarding relevant parameters such as the pH, temperature and nutrients. Further, this treatment will not necessarily result in an upgraded technical quality of the material. Treatment through biological processes could also need specific facilities such as bioreactors or open composts.

Thermal treatment

Following the preferable pre-sorting of larger fractions from the excavated material, thermal ex-situ treatment involves heating the remaining soil to vaporise pollutants bound to the particles (SGS, n.d.-c). This process is carried out in a closed container facility, where temperatures typically range between 100°C and 800°C. The resulting contaminated gases are then directed into a post-treatment unit, where they are purified through methods such as filtration, condensation, or post-combustion. Thermal treatment is generally effective across a wide range of soil types and particle sizes, as well as with varying contamination levels. However, its efficiency is significantly reduced in materials with high clay or silt content.

Solidification and stabilisation of excavated material

Both the methods of solidification and stabilisation aim to decrease the mobility and volatility of contaminants in a material (SGS, n.d.-b). Stabilisation of excavated material is achieved by adding chemical additives that react with the contaminants and form chemical structures in the material, which limits the risk of contaminants spreading and leaching. Examples of chemical additives are bentonite, concrete, chalk, silicates and sulphur. Solidification generally does not change the composition or chemical form of the contaminant, but instead traps it within a material with low permeability to reduce the material's hydraulic conductivity. Suitable materials for stabilisation are concrete and bentonite.

Solidification and stabilisation can also be combined, and are generally effective methods for treating homogeneous materials that are primarily composed of sand or gravel, with low amounts of organic content and clay (Andersson-Sköld et al., 2022).

Soil washing

Soil washing is a remediation method used to treat excavated materials by removing contaminated particles through physical washing or chemical leaching processes, employing several methods presented previously in Chapter 3.6 (SGS, n.d.-a). This method is commonly used to isolate pollutants such as heavy metals or sediment-bound contaminants, it can also be effective in reducing organic substances, including polycyclic aromatic hydrocarbons (PAHs). However, the effectiveness of soil washing is significantly reduced when the excavated material contains high levels of clay, silt, or organic matter. Specifically, materials containing more than 20% clay or silt pose significant challenges due to the complexity of the washing process. Similarly, if the organic content exceeds 20%, or if the material is heavily mixed with both organic and inorganic pollutants, the procedure becomes less feasible. Soil washing is most effective when applied to relatively homogeneous soil types, such as sand or gravel, and when the contamination profile is limited to a few substances. Efforts to apply soil washing for the removal of per- and polyfluoroalkyl substances (PFAS) have been met with limited success, as it remains difficult to consistently meet regulatory thresholds for PFAS concentrations in both Swedish and European contexts.

The complexity and cost of soil washing are directly influenced by the extent and type of contamination. As contamination severity increases, the number of required treatment stages rises accordingly, resulting in higher operational costs (SGS, n.d.-a). Consequently, the economic viability of soil washing tends to improve with larger volumes of excavated material, where economies of scale can justify the investment. In the Swedish context, soil washing has primarily been implemented in the post-remediation phase of contaminated sites, where soil is excavated, treated, and subsequently returned to the site of origin.

3.7 Regulations for business facilities and activities

In Sweden, business activities require different types of permits or approvals depending on the type, magnitude, and environmental impact of the activity (EPA, 2024a). The permits needed for an activity are further explained in the Environmental Assessment Ordinance. The business activities are classified as class A, B, or C. Physical businesses that have an extensive impact on their surrounding environment reach class A. Businesses with less great environmental impact, but an impact nevertheless, are class B. Both class A and class B activities require permits. An application for a class A permit is submitted to the Land and Environmental Court, while class B applications are approved by the relevant County Administration Board and its environmental assessment delegation. The C-class business activities do not need any extensive permits to operate. However, they need to report their activity to the relevant municipality. An illustration of the hierarchy of the classifications is shown in Figure 3.4. A quarry that deals and operates with excavated and granular materials needs a permit according to the Swedish EC (EC, 1998). This makes the business of a quarry generally a class B activity (EPA, 2022). However, smaller quarries related to serving household needs can be class C.

Regarding mass management, the excavated material is to be managed in compliance with the EC, as well as product and chemical legislation. However, material classified as waste must be managed in compliance with the waste legislation. Weather mechanical treatment (crushing and sieving), sorting and storing of IFA requires a permit or registration, depending on the amount managed (EPA, 2022). Class B permit is required for recycling more than 10,000 tonnes of IFA per calendar year through mechanical treat-

Table 3.4: A-C classification of an activity's environmental impacts and legal measures (EPA, 2024a).

Class	Environmental impact	Legal measure
A	High	Permit
B	Medium	Permit
C	Low	Registration

ment. Sorting of IFA requires a class C registration if the amount is 1,000 to 10,000 tonnes and a class B permit if the waste exceeds 10,000 tonnes. When storing IFA as part of collecting for a later purpose, it is possible to store IFA that requires a class C registration from 10 to 10,000 tonnes and a class B permit for amounts over 10,000 tonnes.

However, other provisions apply if the waste is intended for construction or infrastructure purposes (EPA, 2022). In this case, instead of class B, a class C registration is needed when recycling through mechanical treatment. While the provision does not explicitly require the treatment of IFA for construction or infrastructure to occur on-site, this interpretation has been applied in some cases. Sorting requires class C registration if the amount of waste exceeds 1,000 tonnes per calendar year. When dealing with more than 30,000 tonnes of waste/year, a storage facility requires a class B permit. Between 10 to 30,000 tonnes, only a class C registration is required.

3.8 Intermediate storage areas

In Sweden, the concept of an "NÖT-area", representing an area for the coordination of excavated materials between construction projects, has been explored at the request of the TrV (Lundberg et al., 2017). The Swedish acronym NÖT translates to Near, Open, and Temporary. The idea is that these areas should be temporary hubs near the place of one or several construction projects and be open to any developer. The area would, after the end of the construction projects, be terminated and repurposed. However, the stakeholder responsible for the operation and maintenance of the area has not yet been fully determined. One example of a stakeholder constellation is that the area is owned by the concerned municipality, which rents it out to an entrepreneur for operational responsibility. The concept of enabling NÖT-areas into one larger system could also mean, legally, that construction projects would be required to leave their excavated materials in these areas. This could create a more equitable competitive environment on the market between construction entrepreneurs of different sizes, whilst also enabling new business actors.

Conceptual calculations together with practical examples of areas in the Stockholm region have stated the potential positives from these areas, resulting in decreasing costs of transportation, CO_2 emissions, and increased use of circular material flows (Lundberg et al., 2017). The acknowledgement of NÖT-areas as a concept further emphasises the importance of dealing with excavated materials circularly and efficiently.

In 2015, a type of Mass Logistics Centre (MLC) emerged in connection with another urban development project in Stockholm called Norra Djurgårdsstaden (Stockholm City, 2025). This large-scale project involved the repurposing of previously industrial land for housing development, which required the management and remediation of substantial quantities of excavated materials with varying classifications. To minimise the environmental impact of sending these materials to landfill, a strategy was implemented to reduce transportation emissions, costs and related environmental harm by reusing as much of the excavated material as possible in the construction process. The establishment of the MLC aimed to enable localised mass management within the project's vicinity. Its primary objectives were to decrease the number of transports, energy use, total amount of GHG emissions, and transportation costs, all by 50 %.

The MLC was tasked with managing both incoming construction rock and contaminated excavated materials to sort, treat, and upgrade these materials for reuse. In 2025, the MLC managed around 400,000 tonnes of material and also saw an increase in the recycling rate of materials, rising from 30-40% in 2019 to 80% in 2023. This significant improvement was attributed to the technical advancement of incorporating wet sieving and treatment methods alongside the previously employed dry sieving techniques. The wet treatment enabled the effective removal of contaminants, particularly in finer fractions of materials, enhancing the overall recycling process.

Logistically, major difficulties in the existence of intermediate storage for excavated materials are if the demand and supply of excavated materials between different construction projects do not match with each other or the timeline (Hale et al., 2021). However, the absence of spaces to store larger amounts of excavated material from construction projects, together with a lack of coordination between them, has led to difficulties in utilising these materials as a resource (EPA, 2024a).

Barriers to intermediate storage are also influenced by the principles outlined in the waste hierarchy. In Sweden, if the excavated materials are to be treated and recycled, storage for up to 3 years is permissible (EPA, 2024a). Conversely, if the materials are intended for disposal only, the storage period is limited to 1 year. If these periods are exceeded, the materials are classified as waste.

Also, the location of intermediate storage is key in terms of transportation in and out of the construction site. This is to limit transport distances, hence economic costs and environmental impacts (Hale et al., 2021). Implementing such a site for intermediate storage is especially challenging in dense and urban areas (Brinkhoff et al., 2020).

3.9 Protection of the surrounding environment

Quarries, intermediate storage areas, and similar operations can significantly impact the surrounding environment. Therefore, implementing an intermediate storage facility at a quarry, along with the treatment and upgrading of materials, requires effective management of dust and water at the site. Dust emissions at quarries occur during processes such as blasting, crushing, material handling, and transportation (Saka & Hashim, 2024). Evaluating their impact requires considering environmental factors like wind speed and direction, as well as particle characteristics such as size, shape, and composition. To mitigate dust emissions, there are mainly three types of strategies. The first is engineering controls, which focus on reducing dust at the source by modifying equipment, optimising processes, or improving infrastructure. The second is water-based suppression methods, which use water to increase the weight of particles, preventing their dispersion. The final strategy is technological solutions incorporating chemical, electrical, and computational strategies to manage dust. Leachates refer to the run-off produced when rainwater infiltrates and percolates through waste materials (Renou et al., 2008). These leachates can contain high concentrations of pollutants, posing a risk to surface and groundwater. Management of this run-off involves collection, storage, and appropriate treatment to prevent environmental contamination.

4 Methodology

The methodology consists of two main components shown in Figure 4.1: A *qualitative data analysis* and a *scenario-based analysis*. The qualitative data analysis aims to summarise opportunities and challenges found in the qualitative data and list key considerations of converting, and/or implementing, a quarry to an intermediate storage site with upgrading and treatment of excavated material. The scenario-based analysis is based on the results from the qualitative data analysis, where key considerations such as legislation & permits, guidelines, technical requirements, and stakeholder needs generate key perspectives for the project's scenario development. Linguistically, generative AI-powered language models have been utilised throughout the report to enhance the clarity and structure of the text, not generating new content.

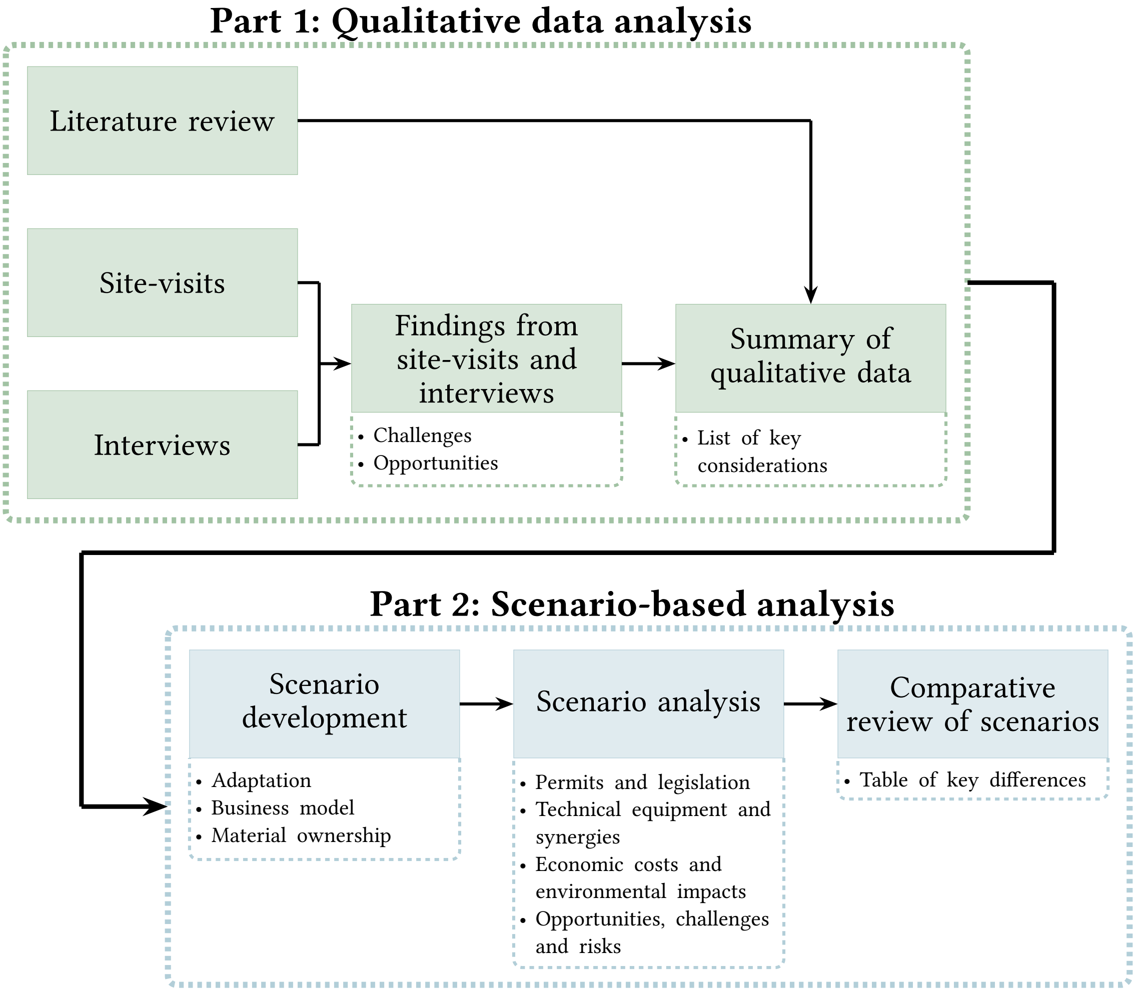


Figure 4.1: Schematic overview of the project's methodology, comprising two parts: qualitative analysis and scenario-based analysis, where the latter builds upon data collected and analysed in the former.

4.1 Part 1: Qualitative data analysis

Qualitative data was collected in three ways. First, a literature review of existing literature, relevant legislation, guidelines, and established methodologies for upgrade, treatment and intermediate storage of excavated materials ex-situ has been conducted. This review serves as a foundational knowledge base and is presented in Chapter 3.

The second source was site visits of quarries and sites that manage excavated materials in the Gothenburg region. The site visits at quarries aim to discover the overall layout, functions, and flows, providing knowledge of the quarries' operation. Visiting sites that manage excavated materials enhances the knowledge of how excavated material and waste are and can be managed today. A total of three facilities were visited during this project: two quarries in Ale and Kållered, and one reception/recycling facility in Torslanda. Information gathered during the visits was collected by asking questions, taking pictures, and making notes.

The third source was interviews with relevant people within the infrastructure and construction industry. The interview questions were divided into two different versions shown in the Appendix A.1 & A.2. One was for individuals working in quarry-related businesses on a production level, and the other was for individuals working with mass management (such as logistics, permits and environment), either at construction companies, TrV, or the County Administration. Having two sets of questions, depending on the interviewee's role, enabled a more focused and relevant dialogue. Interviewing several experts working within quarry operations, legislation, and mass management also aimed to mitigate potential biases and to capture a wider range of perspectives. Interviewees were identified through connections within TrV as well as by contacting relevant companies and authorities. Additional participants emerged through recommendations obtained during both interviews and site visits. The study included a total of 14 interviewees. The interviewees are presented in Table 4.1 with their employer and role. All interviews were conducted in Swedish, either in person or through digital meetings. In-person interviews were recorded using mobile phones, while digital interviews were recorded via the digital meeting software Skype or Microsoft Teams. All recordings were transcribed using AI-powered transcription tools. A summary of each interview was then created by reviewing both the transcription and the original recording to further ensure correctness. These summaries are presented in Appendix A.3-A.16. Only information included in these summaries was used in the report. To ensure even further accuracy and prevent misunderstandings, interviewees were provided with their respective summaries for review and approval.

Information from the interviews and site visits is summarised to highlight challenges and opportunities identified in this data collection. Combined with insights from the literature review, this information is summarised into a list of key considerations for implementing an intermediate storage facility with the possibility for treatment and upgrading of excavated material at a quarry site.

Table 4.1: List of interviewees by employer and role.

Interviewee	Employer	Role
Interviewee 1	TrV	Environmental Specialist
Interviewee 2	TrV	Environmental Specialist
Interviewee 3	TrV	Procurement and Logistics Manager
Interviewee 4	TrV	Environmental Specialist
Interviewee 5	TrV	Environmental Specialist
Interviewee 6	Renova	Environment and Investigation Manager
Interviewee 7	Skanska	Project Developer
Interviewee 8	Skanska	Climate and Sustainability Manager
Interviewee 9	Skanska	Production Manager
Interviewee 10	Skanska	Business Developer
Interviewee 11	TrV	Environmental Investigation Leader
Interviewee 12*	The County Administrative Board	Environmental Engineer
Interviewee 13	Swerock	Project Manager
Interviewee 14	Swerock	Deputy Project Manager

*Not an interview; this interviewee provided written answers to the questionnaire.

4.2 Part 2: Scenario-based analysis

The second part of the methodology is scenario-based, where different scenarios were developed and analysed. The scenarios either integrate intermediate storage with upgrading and treatment of excavated materials into the quarry or fully convert the quarry for this purpose. Key factors in the development were the qualitative research and results gathered in Part 1, such as guidelines, legislation and permits, technical requirements, and stakeholder needs. When defining scenarios, the following questions were considered:

- How is intermediate storage, treatment and upgrade adapted into the quarry?
- How does the business model operate, and what are the stakeholder dynamics?
- Who is responsible for the excavated material throughout the process?

The scenario analysis examines the advantages, disadvantages, and preconditions for viability. This is done by addressing the following questions:

- What permits are required, and which relevant legislation must be taken into account?
- What technical equipment is necessary? Are there any potential synergies with the existing quarry operation?
- What are the economic costs for stakeholders and the environmental impacts of this scenario, considering both its advantages and disadvantages?
- What opportunities, challenges, and risks does this scenario present, and how are these risks distributed among stakeholders?

Finally, the key findings and results of the scenario-based analysis are summarised in a table, providing a comparative overview of all scenarios.

5 Results Part 1: Qualitative data analysis

5.1 Findings from Site Visits and Interviews

Table 5.1 present a summary of the key challenges and opportunities. These points, which are discussed in more detail below, relate to the incorporation of intermediate storage, treatment and upgrading of excavated materials at a quarry site in the Gothenburg region.

Table 5.1: Compilation of challenges and opportunities with incorporating intermediate storage, treatment, and upgrading of excavated material at quarry site.

Challenges	Opportunities
• Limited available space • Appropriate business model • Quality of received material and sample accuracy • Lack of requirements on circularity from clients • Constructing with technical specifications • Managing excavated material and waste • Cost and design of safety measures for protecting the surrounding environment • Interpretation of legislation and guidelines • Productification of materials classified as waste	• Shifting towards circular production • Technical equipment synergy on-site • Providing additional services for customers • Prolonging the operational life of quarries • Decreasing transportation costs • Efficient use of site space • Reduce further exploitation of land

5.1.1 Challenges

Limited available space

Site visits and interviews with quarry operators highlight the challenge of spatial requirements when integrating an intermediate storage operation. This is since intermediate storage can occupy a substantial amount of space over longer periods, depending on material type, according to interviewee 7. This is also acknowledged by interviewee 12. Furthermore, quarry operators emphasised that, although quarry sites cover extensive operational areas, they make full use of the available space. As a result, even when additional space is created through rock blasting, it is often still perceived as insufficient.

Appropriate business model

Economic viability, or profitability, is a main component of realising a circular economy, according to interviewee 9. Virgin materials are currently cheaper to produce than circular ones, as they often require upgrading and treatment, which increases operational costs.

Identifying a financially sustainable model for intermediate storage is also a challenge. An intermediate storage area dedicated solely to storing excavated material, without any treatment or upgrading, could be viable under certain conditions. Since quarries have limited space, intermediate storage cannot rely on unused areas. If the operation cannot process the material, the cost of providing this service may become too high to remain financially viable for customers. If, however, the material is upgraded and treated on-site, the operation has more control and can ensure a steady flow of materials and a more dynamic use of space, according to interviewee 7. Therefore, it is crucial to develop a viable business model in which the new operation supports the quarry's sustainability.

Interviewee 4 also emphasises the importance of clearly defining responsibility for material quality as a critical element of the business model. This is especially crucial when receiving materials, since their quality can sometimes differ from the contractor's initial assessments.

Quality of received material and sample accuracy

A significant challenge in managing incoming excavated material, as highlighted by Interviewee 7, is ensuring accurate classification and documentation to comply with environmental regulations. Interviewees 2 and 4 noted that quarries accepting material classified as waste are deemed waste management operations and are therefore subject to stricter regulatory controls compared to handling materials as products or resources. Additionally, the assessment of contamination levels in incoming materials presents a considerable risk. Inconsistent sampling accuracy among contractors can lead to the inadvertent acceptance of waste, potentially compromising quarry operations. Interviewee 2 notes that the variability of incoming materials poses a concern for regulatory authorities, especially concerning effective monitoring and enforcement.

> “The sample taken to represent the material comes from a very small portion, and an even smaller part of that sample is analysed.”
>
> *Interviewee 1*

Interviewee 1 also emphasises that how samples are collected and tested by contractors is crucial for accurately interpreting the results. For example, if samples are dried or sieved before analysis, volatile substances may be reduced or absent, leading to potentially misleading conclusions. Therefore, reliable sampling practices are essential for the effective and safe management of incoming materials at the quarry site.

Lack of requirements on circularity from clients

Another major obstacle to advancing circular processes is the limited demand from clients and customers in the market. According to Interviewee 3, TrV, a major client, typically does not impose requirements for circular management or production practices in its projects, leaving such decisions to the contractors. Rather than specifically promoting circularly produced materials, TrV focuses on overall climate impact through project-related CO_2 calculations. As a result, the emphasis often remains on the use of new materials, as they are seen as reducing both financial and operational risks for contractors, while also simplifying the procurement process.

Constructing with technical specifications

Interviewee 8 emphasises the need to shift from technical to functional requirements to enable greater circularity in material use, thereby increasing the recycling rate of excavated material. Currently, materials in construction and infrastructure projects are largely selected based on technical standards. This makes virgin materials the preferred choice, as circular products often lack the same well-defined technical specifications.

Interviewee 10 notes that certain types of projects, such as pedestrian and bicycle paths and sub-base layers, are particularly well suited for increasing the use of recycled materials. But today, rather than adhering to functional requirements that align with the intended use of the infrastructure, such projects typically follow technical requirements. These requirements often impose excessive strength parameters, enabling the road to withstand heavy motorised traffic despite its primary design for cycling and pedestrian use. Notably, the use of circular materials is not prohibited; contractors may incorporate them, provided they meet the specified standards. However, because the characteristics of circular materials are often less certain, doing so increases the contractor's exposure to risk.

Managing excavated material and waste

Interviewee 7 states that if quarrying activities are to be converted into a facility managing excavated materials, a new notification or permit under the EC is required. Interviewee 6 expands on this by explaining that small-scale storage may fall under Class C, requiring only a municipal notification, whereas larger facilities require a full permit application that includes a technical description and a comprehensive environmental impact assessment. Interviewee 12 highlights that this application comes with criteria. Depending on the circumstances, measures such as water management to prevent contaminants from spreading into the groundwater must be implemented to ensure these criteria are met. Consequently, the acceptance criteria for the materials are of vital importance. Furthermore, Interviewee 12 notes that some quarry permit processes also incorporate material recycling, either through mechanical processing for later removal or for reuse in construction activities or site restoration within the quarry. Interviewee 3 explains that managing incoming material classified as waste at a quarry site introduces a completely new set of regulatory obligations. This is because waste is regulated according to the stricter waste legislation, rather than the general rules of consideration in the EC.

Interviewee 7, involved in the permitting process for a construction company, notes that acquiring new or extended permits can be time-consuming. This is partly due to the need for comprehensive environmental impact statements and approval from the relevant authorities, with the added risk that the permit may be rejected.

Cost and design of safety measures for protecting the surrounding environment

When managing incoming excavated materials with varying compositions and contamination levels, technical measures are often necessary to minimise the risk of contaminant dispersion into the surrounding environment. During site visits, observed solutions included hardened surfaces, wastewater run-off systems, collection ponds, and on-site facilities for treating contaminated water. Implementing these solutions requires upfront investment to ensure proper site operation. Moreover, accepting a broader range of excavated materials classified as waste increases the complexity of on-site management, thereby demanding additional measures like those described.

Uncertainty in interpretation of legislations and guidelines

Interviewees dealing with excavated materials in the construction business have pinpointed that there are uncertainties regarding the interpretation of legislation. Interviewee 8 explains that the Swedish EPA has established clear criteria for when excavated materials should not be classified as waste; however, inconsistencies in regulatory interpretations continue to pose a significant barrier, and a perceived uncertainty regarding the regulations remains. This is further explained by Interviewee 3, who notes that inconsistencies in the classification of material as waste arise from differing interpretations among supervisory authorities in various municipalities, as well as from the individual handling the case. This has created a fear of making missteps and ultimately taking a risk of having to deal with costly consequences later. Therefore, better collaboration and shared expertise are needed between entrepreneurs, municipalities, and buyers, according to interviewee 5.

Interviewee 13 also highlights challenges related to recycled products, noting that municipalities may have differing views on the same product, which creates uncertainty and hinders broader acceptance and use. If municipalities then approach the customer regarding this recycled product, it creates uncertainty for the customer.

Productification of material classified as waste

Interviewee 13 explains that quarries conduct analyses and investigations, such as petrographic analysis, to determine the type of rock and its mineral composition, which in turn defines its potential uses. Consequently, introducing raw materials with unknown or poorly understood quality may restrict their application to certain products. Interviewee 14 further elaborates that, depending on the quality requirements of the final product, raw materials from the quarry, external sources, or a combination of both may be used. Interviewee 7 adds that circular materials cannot fully replace virgin materials, and only partial substitution is currently feasible.

When waste ceases to be waste through a recycling process, the material can either be sold directly or integrated into the regular production process for further use. However, as previously mentioned, a key challenge lies in differing interpretations of when waste officially becomes a product, highlighting the need for better alignment between oversight authorities and municipalities. These uncertainties can create insecurity for end customers, thereby hindering the wider adoption of recycled products.

Interviewee 14 further emphasised that the City of Gothenburg has set a target for 50% of the materials used in their construction projects to be circular. Achieving this goal will require a substantial and reliable supply of recyclable raw materials. Challenges may arise since the supply of material varies over time depending on projects and the market, which in certain periods could make it more difficult to ensure large volumes of recycled products. To this, Interviewee 13 adds that large quantities of waste are needed to even make the wanted level of recycling from the City of Gothenburg possible. The recycling rate is estimated to be low due to geographic location and the materials that can be used for construction. The estimated recycling rate for materials also varies significantly across types of materials, with some recycling rates around 70% for certain excavated materials, and others around 20%, according to interviewees 10 and 13, respectively. However, the need for the incoming flow of materials would need to be more or less consistent to ensure economic viability in this situation, according to interviewee 7.

According to interviewee 13, another challenge lies in the variability of the recycling process. Unlike quarry operations, which tend to follow standardised procedures, recycling lacks a uniform approach. This complexity arises from the diverse nature of incoming materials, each requiring specific treatments and machinery. As a result, recycling often involves case-by-case management.

5.1.2 Opportunities

Shifting towards circular production

Interviewees identified significant opportunities for integrating intermediate storage with upgrade and treatment in a quarry. Establishing such a site for handling excavated materials would allow the company to move toward a more circular approach. Quarry facilities in this study are also part of larger construction corporations which emphasise circular economy principles. More specifically, these companies are increasingly prioritising the reuse and upgrade of excavated materials, with the intent to reintroduce them into the market as valuable resources. This is especially relevant in the Gothenburg region since some respondents also highlighted the goals set for 2030 regarding recycling and circular waste strategy in the City of Gothenburg. Quarry operations show great potential and have an opportunity to contribute to this development. Additionally, interviewee 6, working in landfill operations, pointed out that quarry operators generally have a good understanding of the specific materials and material fractions demanded in the construction sector.

Technical equipment synergy on site

According to interviewees 9 and 12, quarry operations already have access to most of the necessary technical equipment and machinery to process incoming excavated materials, separating and refining them as part of the quarry's production flow. Interviewee 9 also highlights the benefits of mobile equipment, emphasising that a key principle is to minimise the transport of excavated material on site by instead bringing the equipment close to the material, rather than moving the material itself.

> “Pollutants are usually found in the smaller fractions, which could be sorted out using machinery often available at quarries.”
>
> *Interviewee 5*

Furthermore, one of the quarries visited during this project was equipped with mobile technical machinery, which the production manager on site said could be used for both rock and excavated materials. This was said to also enhance logistics and create synergies if intermediate storage, upgrade and treatment were introduced on-site.

Providing additional services for customers

Interviewees 13 and 14, who work at a larger quarry site, stated that the more services you could provide sufficiently at the place of your operation, the better. Interviewee 3 from TrV also confirms that this approach helps minimise the need for customers to travel to other locations or companies to source additional materials for their projects. Offering circular upgraded materials alongside new virgin materials at the same site could be a significant advantage for future business and help strengthen long-term relationships with customers.

Prolonging the operational life of quarries

Interviewee 6, an environmental specialist in landfill operations, highlighted the potential benefits of intermediate storage operations for quarries, especially those in the final phase of operation. Once a quarry has reached its permitted production limit, it typically seeks to repurpose the site. However, the implementation of an intermediate storage facility capable of treating and upgrading excavated materials could present a significant opportunity to extend the quarry's operational lifespan. By accepting and processing a higher volume of incoming excavated materials for refinement and sale, the quarry could continue operating for a longer period. The idea of extending the quarry's lifespan is also highlighted by interviewee 7, who noted that permits for long-term quarry operations have become increasingly difficult to obtain.

Decreasing transportation costs

Interviewee 5 from TrV emphasised the considerable potential for quarries in the Gothenburg region to serve as suitable sites for intermediate storage, treatment, and upgrading of materials. This potential is further supported by the fact that all quarries visited in this project are located within a 20-30 km transport distance from Gothenburg's city centre. According to interviewee 13, this distance is often regarded as the maximum range within which crushed material products can be transported before transport costs outweigh their value. Therefore, given the quarry's proximity to the city, these quarries offer the opportunity to reduce transportation distances for surrounding construction projects, thereby lowering both economic costs and overall environmental impacts.

Efficient use of site space

This is to organise stored materials efficiently and optimally use the available space. Strategic use of the quarry's existing benches can be used as a wall to reduce the need for wall structures. Furthermore, these benches could be used to unload excavated materials, thereby enhancing efficiency.

Reducing further exploitation of land

Interviewee 2 proposes that using existing quarry space for intermediate storage, upgrading, and treatment of excavated materials could significantly reduce environmental and noise disturbances. This approach would likely be less disruptive than developing new sites, particularly in more densely populated areas, where such activities could have a greater impact on surrounding communities. By repurposing these quarries, it may also be possible to reduce the need for additional exploitation, thereby preserving natural landscapes and reducing the overall ecological footprint. Interviewee 12 also adds that acquiring new land has become harder. To this, it is mentioned that quarries can be highly useful, especially those quarries that have been in operation for a long time and may have larger unused operational areas.

5.2 Summary of qualitative data

Quarries generally require a Class B permit. As part of this permit, there are requirements regarding environmental impacts such as vibrations, wastewater discharges from the facility, groundwater levels, and dust from operations. These impacts are continuously monitored according to a control program approved by the supervisory authority. If the set limit values are exceeded, the business must inform the supervisory authority and take corrective actions.

Permits for intermediate storage of excavated material or waste for construction or infrastructure purposes depend on the extent of storing, sorting, and treating. Class C registration is required for mechanical treatment and sorting, and a Class B permit is required for storing more than 30,000 tons per calendar year when managing non-hazardous waste. The relevant authority carries out the permit assessment. Interviewee 7 mentioned several different approaches when applying for new permits. One option is to include the newly requested permits in the existing quarry permit, while another is to submit a separate application. It is also possible to apply for a modification permit to incorporate it into the original quarry permit. The choice of application procedure when implementing depends on the circumstances.

Materials not classified as waste can be managed with greater flexibility, as they do not require a permit or registration. However, such materials must still be handled in compliance with EC and other applicable legislation. Generally, these materials can not be stored for longer than 3 years. After this period, it is considered to be waste and must be landfilled.

Intermediate storage requires space to accommodate excavated materials over time. In theory, quarries are ideal for this purpose, as they continuously generate additional space, are strategically located around the city of Gothenburg, and already possess relevant equipment and expertise. However, site visits and interviews indicate that quarries themselves frequently face space constraints. As a result, integrating intermediate storage within quarry operations presents logistical challenges. Furthermore, this suggests that intermediate storage cannot function as a secondary operation utilising leftover space; instead, it must be integrated into the core business model and contribute to the quarry's production flow and create value.

Ideally, the excavated material should be sampled before it is delivered to the facility to determine its classification. However, if sampling has not been conducted, the facility must be able to receive material for classification. Once excavated material or waste is on-site, the facility assesses how it can be processed further. This assessment must be carried out by the receiving operation, not the customer, as the facility holds the necessary expertise and experience.

Interviewees highlight that intermediate storage involving waste management poses a greater risk to the surrounding environment. As a result, the management of waste and groundwater is essential to ensure that permit limit values are not exceeded. This is achieved through the collection and treatment of wastewater. Depending on the circumstances of the quarry, collection can be facilitated by strategically placing ponds or implementing hard surfaces that direct leachate into a collection pond. One respondent also mentioned the difficulties of treating wastewater once collected. The waste comes from various sources, meaning the wastewater may contain different types and amounts of pollutants, and it is not possible to treat all of them. Therefore, there is a challenge in ensuring that the wastewater is properly treated.

To ensure control over the business and compliance with relevant guidelines and standards, it is crucial to conduct weighing and testing of both incoming and outgoing materials and waste. This monitoring process allows for the oversight of the quality of incoming materials and waste, ensuring that they are properly managed throughout the operation. This is a process that quarry businesses are already quite familiar with, as they routinely weigh and test their products. The difference here, however, is that the incoming materials may have higher levels of contamination than what these operations are typically used to managing.

Quarries already have most of the machinery needed for treating and upgrading material and waste. Typically, quarries have access to one or multiple crushers and dry sieves. The type of access does, however, vary. Unlike having stationary technical equipment on-site, one quarry adopted a business model where they rented both the crew and the necessary equipment. The primary advantage of renting equipment is its mobility, allowing it to be deployed as needed, wherever and whenever it is required. This is especially advantageous in the context of receiving excavated materials, as the receiving volume of material can vary significantly over different periods.

List of key considerations

Summary of key considerations when including intermediate storage, with treatment and upgrading of materials at a quarry:

- Materials not classified as waste can be managed with greater flexibility.
- Permit and/or registration are needed for the operations of storing, sorting, and treating waste material.
- Provide measures, such as a standardised sampling scheme and contingency plans for handling excavated materials with elevated contamination levels, to ensure compliance with the contamination limits set by the authorities.
- Monitor environmental impacts on the surrounding area.
- Two types of access to technical equipment at the quarry: stationary or mobile.
- Document the environmental and technical quality of incoming excavated materials.
- Allocated area for organising and storing incoming excavated material.
- Expertise in how excavated material and/or waste can be used as a resource.
- Appropriate business model. Enabling value for all stakeholders concerned.

6 Results Part 2: Scenario-based analysis

In this chapter, various scenarios of how intermediate storage, upgrade and treatment can be incorporated into a quarry are developed and analysed based on Chapter 5. Figure 6.1 shows an illustration of the flows of excavated material in and out of the scenario-based business model. Construction and infrastructure projects generate both excavated material and waste. While waste is typically directed to landfills, excavated material is sent to the scenario facility, which also provides construction and infrastructure projects with products. The specific flow of materials varies depending on the scenario under consideration.

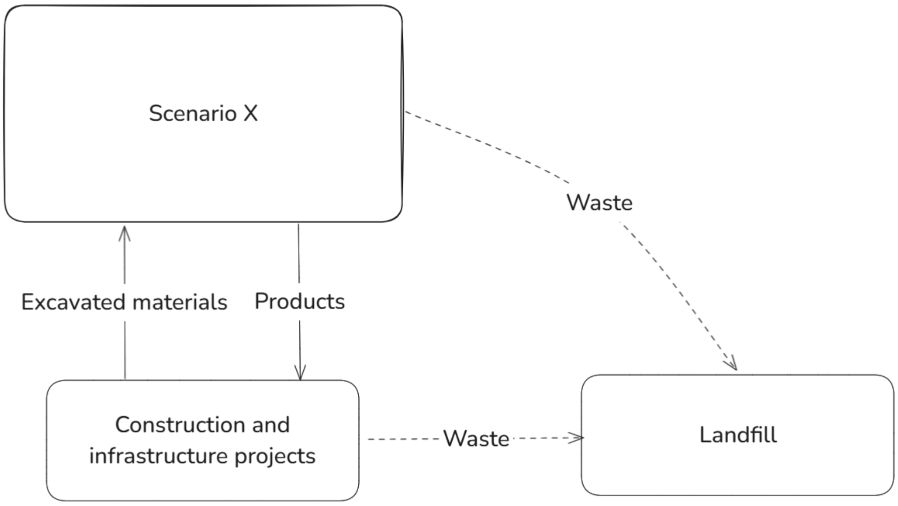


Figure 6.1: General flow of excavated materials, waste and products between construction and infrastructure projects, landfill and developed scenarios.

6.1 Scenario development

6.1.1 Scenario 1 - Intermediate storage site - ISS

The quarry expands its operation to include an intermediate storage site for excavated materials. An area designated within the site is reserved for infrastructure and construction clients to store materials temporarily during an agreed time frame specified in the contract (see Figure 6.2).

The client must ensure that these materials are not classified as waste based on the criteria in Chapter 3.4. Ownership of the materials remains with the client throughout the entire storage period. The site operators charge the clients based on the volume and duration of storage.

At the designated area for storage at the site, incoming excavated materials are organised into individual slots assigned to each client (Figure 6.2. These slots are separated using

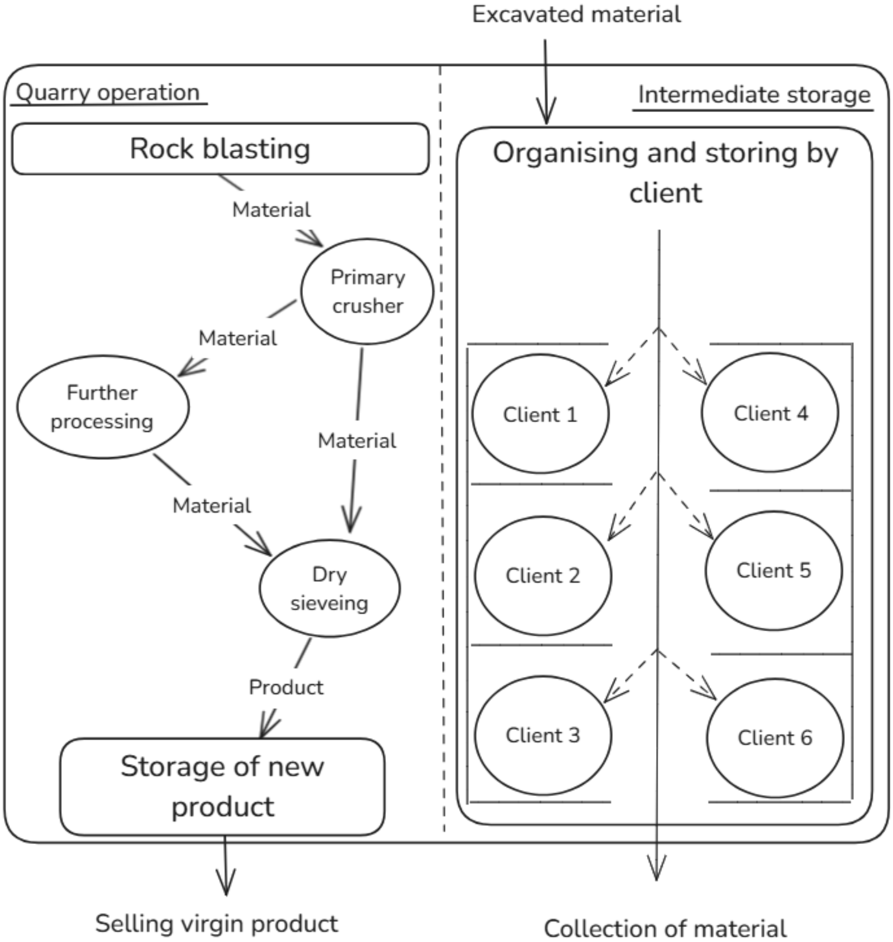


Figure 6.2: Illustration of material flow in the facility of scenario ISS.

solutions such as concrete slabs, which not only segregate materials but also optimise space by allowing the excavated material to lean against the dividing walls. The operator utilises technical equipment, such as loaders, to facilitate the loading of materials onto trucks when clients retrieve their stored materials.

6.1.2 Scenario 2 - Storage, treatment, and upgrade of AMA-classified material (STU-AMA)

The quarry extends its business to include a site of storage, treatment, and upgrading for excavated materials according to AMA classification (see Figure 6.3). There is a need for the excavated material in the market, it has secured use at the site and fulfils the environmental criteria to not be classified as waste (MRR), following Chapter 3.4.

The quarry extends its business to include a site of storage, treatment, and upgrading for excavated materials according to AMA classification (see Figure 6.3). The excavated materials are not classified as waste (Chapter 3.4), as there is a market demand for such materials, it has secured use at the site and fulfil the environmental criteria to not be classified as waste (MRR).

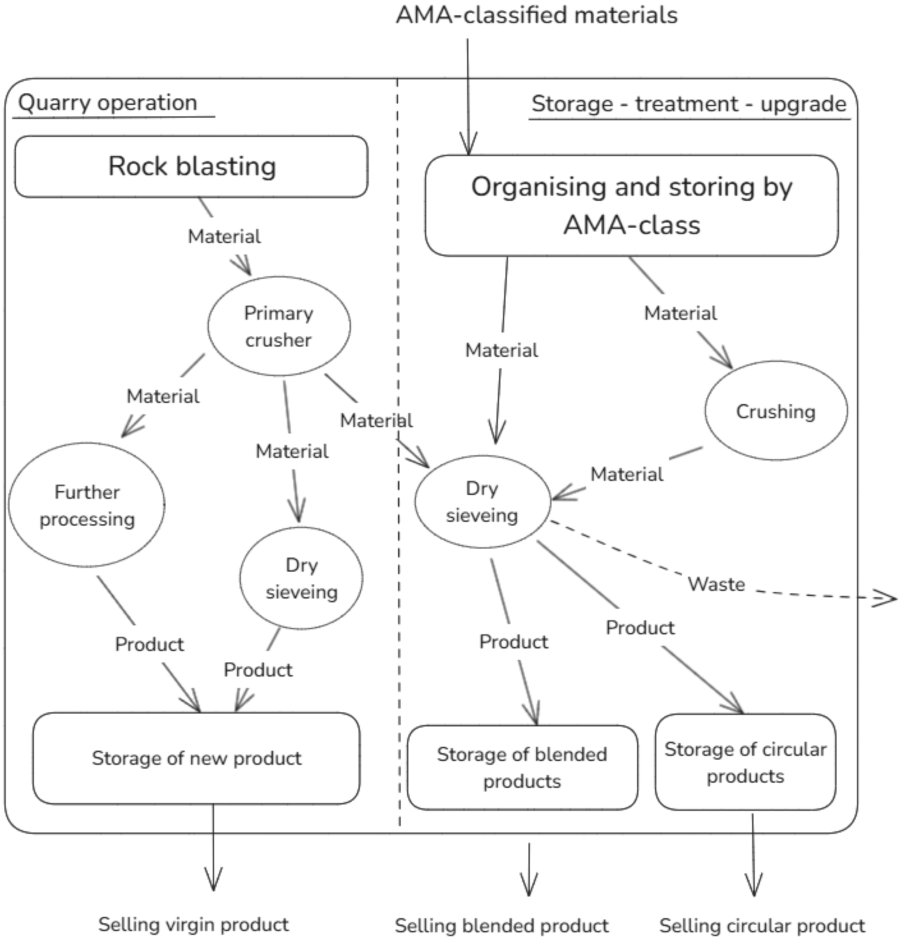


Figure 6.3: Illustration of material flow in the facility of scenario STU-AMA.

Ownership of the materials is transferred to the site operators upon arrival, after which they are stored and organised according to AMA classification in designated slots (similar to illustration in Figure 6.2). Further, the AMA-classified material could be used directly as a resource or undergo upgrading and treatment to produce fully circular products, products requiring virgin material, and blended products containing both circular and virgin material. The two operations can share dry sieves and crushers used for material treatment and upgrade, and loaders for material management. The site operator charges clients and customers based on the materials AMA-class and the potential need for treatment and upgrade.

Clients requiring intermediate storage in their project can instead engage in a material trade, where the client deposits their material at the facility to receive a receipt, allowing them to retrieve equivalent material at an agreed time. The client pays for the service and any necessary treatment of the client's material.

6.1.3 Scenario 3 - Storage, treatment, and upgrade of excavated material up to IFA (STU-IFA)

The quarry extends its business to include a site for storage, treatment, and upgrading for excavated materials up to IFA (see Figure 6.4). The business produces fully circular products, products requiring virgin material, and blended products containing both circular and virgin material. Upon arrival, the site takes ownership of the incoming excavated material and stores it in piles. The site operator evaluates the materials to determine their potential for reuse and identifies possible products that could be derived from them. If the materials are then deemed unsuitable for further processing, they are redirected to a reception facility, landfill, or another appropriate destination. The site operator charges clients based on the amount of the incoming material that can be repurposed as a resource. Handing over material with greater potential for reuse is thereby more cost-effective for the clients.

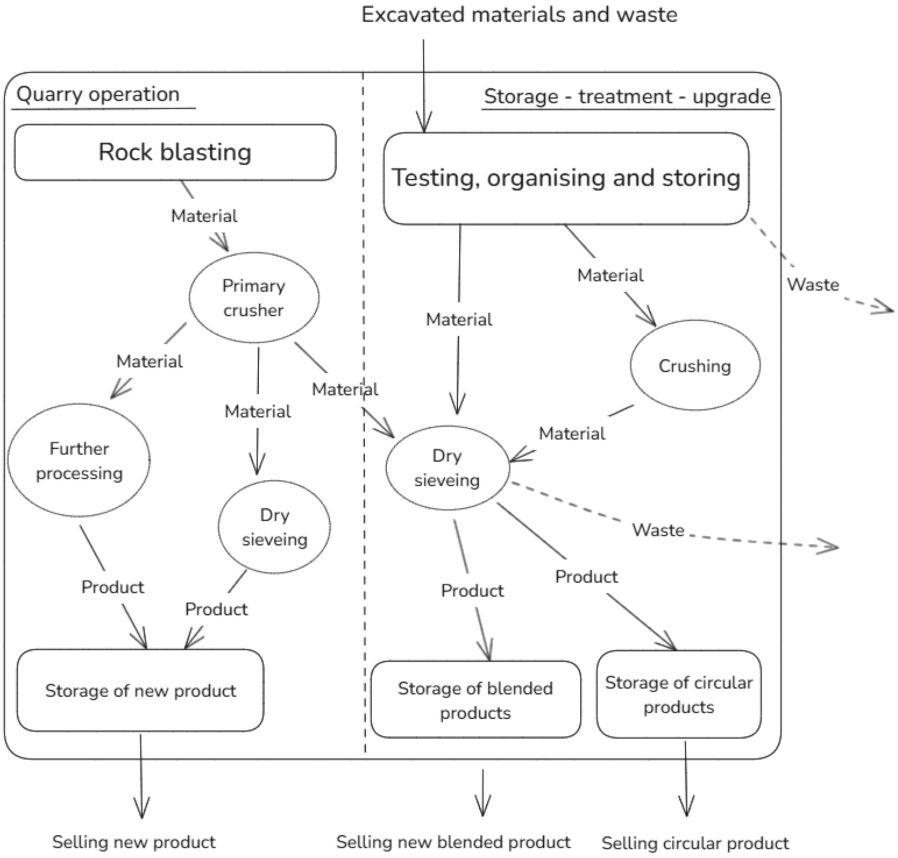


Figure 6.4: Illustration of material flow in the facility of scenario STU-IFA.

Similarly to scenario 2, clients requiring intermediate storage in their project can instead engage in a material trade, where the client deposits their material at the facility to receive a receipt, allowing them to retrieve equivalent material at an agreed time. The client pays for the service and any necessary treatment of the client's material.

6.2 Scenario analysis

The scenarios developed in Chapter 6.1 are analysed in detail by answering questions outlined in Chapter 4.2. This is followed by a comparative review summarising and examining the scenario analysis.

6.2.1 Scenario 1 - ISS

What permits are required, and which relevant legislation must be taken into account?

This operation requires a Class C notification to the municipality, as it stores materials that are considered resources rather than waste. The general rules of consideration in the EC apply. However, a Class B permit could be advantageous as it sets conditions of operation and reduces uncertainties, meaning the overseeing authority can not interfere as long as these conditions are met.

What technical equipment is necessary? Are there any potential synergies with the existing quarry operation?

Introducing an intermediate storage area within an existing quarry requires minimal changes to its operations. The main technical equipment needed includes loaders for material handling, which are typically already available on-site. Additional investment, such as concrete bricks, is required for a firm wall structure.

What are the economic costs for stakeholders and the environmental impacts of this scenario, considering both its advantages and disadvantages?

From an economic perspective, the required investment is relatively low, as most necessary equipment is already present at the quarry. The main cost involves building structural dividers for slot storage. Operationally, a self-service system is preferable, requiring minimal involvement from quarry staff. This reduces disruptions to core quarry activities, helps maintain efficiency, and keeps economic costs down.

Quarries included in this study are all within a short distance of central Gothenburg, where major construction activities are currently ongoing. The geographical location of the quarries around Gothenburg could therefore be seen as a competitive strength when clients consider options for disposal and desire shorter transport distances. This could encourage circular practices in the construction sector as contractors can temporarily store excavated material within a reasonable proximity for a maximum of 3 years. This reduces the need to send usable material to landfills, the production of virgin material and also emissions from transport.

Furthermore, utilising industrial land for intermediate storage significantly reduces the need to exploit untouched natural areas. Claiming new land for intermediate storage sites elsewhere could introduce undesired and unnecessary consequences such as air pollution, vibrations, and habitat disruption. Introducing intermediate storage to quarry sites helps minimise land use and limits environmental impacts.

What opportunities, challenges, and risks does this scenario present, and how are these risks distributed among stakeholders?

Introducing this scenario during the mid-life stage of a quarry could offer valuable benefits. By creating a new revenue stream and reducing reliance on blasting virgin material, it has the potential to extend the quarry's operational life. Adding intermediate storage within the site can also improve customer convenience, particularly for those already purchasing materials, while supporting stronger, long-term client relationships through a broader service offering. As the quarry approaches the end of its operational phase, the scenario remains appealing. Once extraction limits are met, operators are required to restore the site's natural character. In this context, repurposing the existing industrial site for intermediate storage represents a low-impact, economically sensible alternative to exploiting new land.

However, several challenges remain. Space is a key concern since storage can occupy a significant portion of the quarry, which could interfere with active extraction during periods of high demand for virgin material. There is also a risk that demand for intermediate storage may decline unexpectedly during certain periods, leading to underutilisation of the designated area. This inefficiency becomes more pronounced if concrete slabs are used, as they occupy space that would otherwise remain flexible or available for alternative uses.

Technical issues also arise, particularly in maintaining separation between storage slots. Achieving a sufficient seal could be difficult due to uneven surfaces. If leachates from the excavated materials in one slot leak into another slot, there could be cross-contamination between clients' materials. A major risk with this scenario is ensuring that pollutants from excavated material are properly contained. The site must be designed and prepared to safely store materials up to a predefined contamination level, and all incoming material must comply. Each slot may contain materials with different contamination profiles, meaning secure separation between them is essential to prevent contamination from spreading.

Technical challenges arise in ensuring proper containment and separation between storage slots. Uneven surfaces can make it difficult to achieve effective sealing, increasing the risk of leachates migrating between slots. This could lead to cross-contamination, especially when materials from different clients or with varying contamination profiles are stored on-site. To mitigate this, the site must be carefully designed and prepared to handle materials up to a predefined contamination threshold, with strict compliance requirements for all incoming materials. Ensuring secure separation between slots is critical to maintaining the integrity of stored materials and preventing environmental risks.

Financial risks also exist. For example, if the quarry offers long-term storage at a fixed price, but clients leave materials on-site for extended periods or fail to retrieve them, space could become constrained and limit new material from being brought in. Changes in market conditions may also make the business arrangement less profitable. This is particularly relevant when material is stored for extended periods, potentially up to three years, during which time more lucrative opportunities or larger volumes of material may be missed due to the fixed storage commitments. Another risk connected to space utilisation could be if the market is now demanding large quantities of newly produced rock material and is in great need of space. These risks are primarily borne by the quarry operator, especially when it comes to space management and infrastructure upkeep.

6.2.2 Scenario 2 - STU-AMA

What permits are required, and which relevant legislation must be taken into account?

This operation requires a Class C notification to the municipality, as it receives AMA-classified materials that are considered resources rather than waste. The General rules of consideration in the EC apply. However, a Class B permit is advantageous as it sets conditions of operation and reduces uncertainties, meaning the overseeing authority can not interfere as long as these conditions are met.

What technical equipment is necessary? Are there any potential synergies with the existing quarry operation?

Equipment such as loaders, dry sieves, and crushers can be shared between the two operations, particularly when mobile machinery is used. This approach enables a flexible production model, allowing for increased output of circular products when surplus materials are readily available, and a shift to virgin products when surplus materials are limited. Over time, the model can also evolve dynamically, gradually increasing the share of circular products as availability and processing capabilities improve.

Dry sieving enables the sorting of AMA-classified materials for production, treatment, and upgrading processes. As finer grain sizes contain higher levels of contamination, these can be used in products intended for applications that permit higher contamination levels. Sorting and retrieving larger grain sizes can also be used to upgrade from a lower to a higher AMA class. As an example, rock-type D (class 3B) can be upgraded to rock-type C (class 3A) by ensuring that no more than 15% of the material is below 63 millimetres (see Appendix 3.1).

What are the economic costs for stakeholders and the environmental impacts of this scenario, considering both its advantages and disadvantages?

Embracing circular production can offer meaningful benefits for quarries over the long term. By promoting the reuse of excavated surplus materials, it supports environmental goals while also contributing to operational efficiency and competitiveness. As sustainability targets become increasingly important across the industry, offering environmentally responsible solutions can strengthen a quarry's strategic position on the market. Moreover, integrating circular practices with traditional quarry operations can create valuable synergies regarding the use of technical equipment and area, which could strengthen economic viability and reduce environmental footprint. Also, provided that the quarry is close in comparison to other sites where material can be deposited and collected, having a single location for both deposit and collection could be beneficial. It would reduce both transportation costs and environmental impacts for clients.

For quarry operations looking to preserve their production of virgin materials, establishing a parallel storage, treatment and upgrading facility presents an opportunity to generate a new revenue stream. Similar to Scenario 1, implementing such a facility could also extend the operational lifespan of the quarry, especially as permits are often linked to the volume of extracted rock.

What opportunities, challenges, and risks does this scenario present, and how are these risks distributed among stakeholders?

The AMA tool is already widely adopted, and material selection for infrastructure and construction projects often relies on AMA classifications. The technical quality of materials within these classifications is clearly defined, making it feasible, for example, to use a class 3A material to produce a product of the same class without concerns of technical quality. Broad adoption of the AMA classification system as a standard tool for labelling excavated materials presents a valuable opportunity to simplify and streamline their procurement for operators.

The AMA classification of excavated materials can be determined either through testing (e.g., sieving) or based on their original use. As an example, when demolishing a road, the original AMA classification of the materials is often already known. In such cases, it may be sufficient to rely on the original classification along with an understanding of how the material may have changed over time. However, the AMA classification system does not consider contamination levels, meaning the environmental quality of incoming materials may vary. It is the responsibility of the material producer to ensure that the excavated material fulfils the level of MRR when arriving.
The convenience of several services is also an advantage. The option to both hand over and collect materials at the quarry site enhances its appeal to clients, particularly those experienced in handling AMA-classified materials.

This scenario is particularly advantageous for quarry operators when the quarry is in the middle or later stages of its lifespan. By that time, a significant land area has usually been made available through rock blasting and the extraction of virgin materials. Since the space requirements for storage and upgrading equipment can be substantial, utilising an already developed site makes practical and economic sense.

A potential outcome of this setup is that it may primarily benefit larger, well-established companies that generate excavated material in their projects, with the resources and expertise needed to classify material contamination levels and AMA classification. This could create an imbalance, where only the most capable and larger-sized contractors can take full advantage of the storage and upgrading facilities offered at the quarry site. This is since the AMA classification requires appropriate knowledge and resources in the evaluation of excavated material by the contractor. However, this scenario may also present a potential risk for quarry operators, as the responsibility for correctly classifying excavated materials according to AMA classification and ensuring MRR, is done by the contractors. Especially regarding contamination levels, standardised tests are also done at the site by the site operators. Concerns could arise if incoming materials differ from what was initially declared or expected. For the system to operate smoothly and effectively, it requires a high level of expertise and accuracy from the contractors involved.

Furthermore, designating the site as the primary location for material retrieval could provide larger industry players with a strategic advantage in enhancing their EPDs and lowering the carbon footprint of their projects. Over time, this may contribute to an uneven playing field and increased competitive imbalance within the construction sector.

Another risk with this scenario is the inconsistent flow of AMA-classified material to the site. There may be periods with little to no incoming material, causing temporary disruptions in circular production and affecting the overall efficiency of the operation. Similarly to Scenario 1, this could lead to underutilisation of the designated area. This could also be more pronounced if concrete slabs are used, as they occupy space that would otherwise remain flexible or available for alternative uses. The scenario does, however, provide flexibility within the production, which could mitigate the impacts of periods with low amounts of incoming materials.

6.2.3 Scenario 3 - STU-IFA

What permits are required, and which relevant legislation must be taken into account?

Since this scenario deals with waste classified materials within the infrastructure and construction sector, a Class B permit is required to store, sort, and mechanically treat waste.

What technical equipment is necessary? Are there any potential synergies with the existing quarry operation?

Scenario 3 needs equipment to prevent contamination from spreading to the surrounding soil, as well as measures to ensure water security and manage leachate concerns. For example, this could include hard surfaces, ditches, and ponds for water collection. Furthermore, similarly to scenario 2, equipment such as loaders, dry sieves, and crushers can be shared between the two operations.

What are the economic costs for stakeholders and the environmental impacts of this scenario, considering both its advantages and disadvantages?

This scenario involves extensive sorting and classification of incoming excavated materials and waste. Furthermore, as additional technical equipment will be required to separate materials, this translates to higher financial costs for quarry operators.

As with the previous scenarios, this setup could reduce both transportation costs and emissions. This, in turn, can improve the EPDs of clients' projects, especially when the quarry is located closer to active construction sites than alternative sources.

Compared to scenarios 1 and 2, this scenario enables a greater volume of excavated material to be used as a resource. This is because the facility is equipped to handle materials up to IFA. This could have environmental benefits, such as reducing reliance on virgin raw materials and decreasing overall waste disposal within the infrastructure and construction industry.

What opportunities, challenges, and risks does this scenario present, and how are these risks distributed among stakeholders?

By taking ownership of incoming materials, the site operator enables a more dynamic and circular business model. This contrasts with the static, client-owned storage approach seen in Scenario 1, which often results in inefficient use of space.

A potential challenge in this scenario is the increased workload associated with operating the storage, upgrading and treatment facility. The expanded business involves processing a wider variety of excavated materials up to IFA classification, which introduces greater complexity in terms of space management, sorting requirements, and overall uncertainty regarding contamination levels and the feasibility of upgrading materials for reuse. This necessitates more thorough sorting, sampling analysis, and decision-making to assess whether additional treatment is required or if the materials are unsuitable. Furthermore, accepting a broader range of materials may lead to space constraints at the site, making operational planning and capacity management more difficult. Another potential challenge for the facility is that handling waste materials may impact the quarry's EPD, particularly if both operations fall under the same permit and legal entity.

This scenario is preferable in the quarry's mid- or end-of-life. If there is an initiative to reduce the use of virgin material during the middle of the quarry's operational life, this scenario could help diversify production. This would involve removing or reducing the use of virgin materials in products where they are not required. Compared to scenario 2, this scenario could be preferable if the use of AMA classifications is not a regular practice for clients. Towards the end of the quarry's life, using both excavated material and waste to produce products could replace traditional quarry operations and focus solely on the production of circular products. However, fully converting to this model requires a substantial and steady supply of incoming excavated materials and waste to sustain the same level of product output as before the conversion.

Similarly to scenario 2, having a system at the site that allows both the deposit and retrieval of materials offers an added convenience for clients. This strengthens the long-term competitiveness of the quarry.

6.2.4 Comparative review of scenarios

Based on the scenario-based analysis, Table 6.1 provides a comparative overview of permits and legislation, technical requirements, expertise, economic costs, environmental impacts, opportunities, challenges, and risks.

Table 6.1: Comparison of key aspects in the scenario analyses.

Scenario	**1. Intermediate storage site**	**2. Storage, treatment, and upgrade of AMA classified material**	**3. Storage, treatment, and upgrade of excavated material up to IFA**
Permits & Legislation	Class C notification required; Class B permit can be advantageous. General rules of consideration in EC apply.	Class C notification required; Class B permit advantageous. General rules of consideration in EC apply.	Class B permit required. General rules of consideration and waste legislation in EC apply.
Technical Requirements	Loaders, and wall structures for slot-based storage.	Loaders, wall structures for slot-based storage, dry sieves, and crushers.	Loaders, dry/wet sieves, crushers; additional infrastructure including hard surfaces, drainage ditches, and water treatment.
Expertise	Management of excavated materials.	Testing and classifying according to AMA and contamination level.	Testing and classifying waste; Productification of waste.
Economic Cost	Low. Most equipment available on-site; minimal staff workload.	Moderate. Costs relate to upgrading and mobile equipment use; potential for synergies with existing operations.	High. Requires significant investment in infrastructure and processing capacity due to broader material intake.
Environmental Impact	Reduces need for landfill and transport; supports circular use of excavated material; avoids exploitation of new land.	Supports circularity and reduced emissions; limits virgin material use.	Maximises the reuse potential of excavated material and waste; highest circularity.
Opportunities	Adds a low-impact revenue stream; strengthens customer loyalty; leverages urban proximity.	Integrates circular production; extends quarry life; utilises AMA classification; flexible production of circular, virgin and mixed products.	Enables a wider circular business model; processes a broader range of materials; repositions quarry as a resource hub.
Challenges	Space competition with core operations.	Contractor expertise required for AMA and contamination classification; potentially limited participation of smaller firms.	Increased complexity in space management, sorting, and compliance with regulation; low recycling rates require vast amounts of excavated materials and waste.
Risks	Long-duration storage might limit space; potential for cross-contamination of stored materials.	Inconsistent flow of AMA-classified material; Inaccurate sampling and analysis by contractors.	Irregular excavated material and waste inflows may disrupt production; improper sorting/treatment of waste; may negatively affect the quarry's EPD.

7 Discussion

7.1 Key takeaways from interviews

Variation in perspectives, opportunities, and challenges

The interview findings have been essential in clarifying the current landscape and the challenges involved in treating excavated material as a resource. In general, interviewees from TrV responded positively when discussing the possibilities and challenges of expanding quarries to also handle incoming excavated material. They emphasised that this approach aligns with TrV's interests and would be beneficial from their perspective. Currently, contractors are responsible for managing surplus material, but TrV has expressed a growing ambition to take on more responsibility in future projects. As such, solutions that enable and simplify circular mass management are broadly seen as having strong potential. Interviewees from the quarry industry highlighted similar opportunities and challenges to those noted by TrV representatives, but placed particular emphasis on the need to establish a viable business model and address existing barriers.

Barriers for circular materials

One such barrier is the lack of demand for circular materials and mass management from clients, including TrV. Instead, the demands are primarily on climate calculations aiming to reduce aspects such as CO_2 emissions. As a result, methods such as electrification are being adopted, while potentially more costly solutions, such as recycling and procuring circular materials, are often excluded. Additionally, recycling and using circular materials are generally associated with a greater risk, which can be attributed to a lack of experience and uncertainties regarding different interpretations of legislation. A demand for circular products and mass management from clients such as TrV could therefore push the industry towards incorporating circular mass management and production to a greater extent. Another barrier is the utilisation of technical specifications rather than functional requirements. The recycling rate, which refers to the proportion of a material that can be recycled, varied across the interviews. Both interviews and site visits revealed that contractors typically procure materials based on the technical specifications provided by clients, such as TrV. However, these specifications often overlook the intended functionality of the infrastructure. As a result, the same materials are used for bicycle paths as for roads designed for cars, even though bicycle paths could make use of materials with a lower load-bearing capacity. While these technical specifications do not explicitly exclude the use of circular materials, they hinder their adoption. Shifting to functional requirements could encourage the use of materials with lower technical specifications, ultimately supporting higher recycling rates.

Interpretation of legislation and guidelines

Interviewees with hands-on experience in managing excavated materials in the construction sector highlighted significant uncertainty about how to comply with legislation, as interpretations can vary between and within authorities. A part of this uncertainty stems from the complex hierarchy of regulations and guidelines related to specific construction purposes. For example, the Swedish EPA issues guidelines intended to clarify national laws and how they should be interpreted in the context of construction. Many interviewees acknowledged that these guidelines provide reasonable clarity on the permissible handling and storage of excavated materials, provided that the materials meet the criteria required to avoid being classified as waste. Another important point is that people often mistakenly view guidelines as equivalent to national law, when in fact they are merely tools intended to support legal compliance.

Moreover, even when contractors comply with the criteria outlined in the guidelines, uncertainty often persists due to differing interpretations of legislation by local authorities. One interviewee described a case in which a contractor had met all legal requirements to temporarily store a specific volume of excavated material, classified as KM and of good quality, at a designated site for four months. Despite compliance with all relevant regulations, the contractor felt compelled to seek approval from the local municipality. This led to a prolonged administrative process, though the storage was ultimately approved. Experiences like this create hesitation among contractors to pursue circular practices for managing excavated materials. The risk, as expressed by several interviewees, is that continued uncertainty may discourage efforts toward circular mass management.

Ultimately, there is a clear need for a unified and consistent interpretation of legislation related to the management of excavated materials. Such alignment, across local authorities and regulatory bodies, would reduce legal uncertainty, support more predictable decision-making, and create a more stable foundation for implementing circular practices in construction projects.

Uncertainties in sampling of granular materials

There is considerable uncertainty surrounding the sampling and analysis of excavated materials. Since samples are taken from only a very small portion of the total material, and only an even smaller part of each sample is analysed, questions arise about how accurately these samples represent the whole. This uncertainty introduces risks, as the actual material received may contain higher levels of contamination than expected. Consequently, sample results must be interpreted with this limitation in mind.

One interviewee emphasised that laboratory test results are highly dependent on how the sample was collected and prepared. For example, if a sample is dried and sieved before analysis, volatile substances may no longer be present. Therefore, understanding the sampling method and laboratory handling procedures is crucial for effectively addressing these challenges. Adequate expertise in both sampling techniques and result interpretation is essential.

For contractors and operators handling excavated material, avoiding the classification of the material as ‘waste’ is desired. As emphasised in both theory and interviews, once material is labelled as waste, it becomes subject to stricter regulations, significantly limiting handling flexibility. Therefore, how contractors conduct material sampling is critical for maintaining accurate documentation and a clear understanding of the excavated material intended for reuse or market circulation. Improper or negligent sampling can lead to serious environmental and economic consequences. Relying solely on contractors’ assessments may be risky for quarry operators, who should consider performing their own sampling to ensure safety and compliance with legislation.

7.2 Key takeaways from site visits

Two quarry sites were visited in the city of Gothenburg as part of this project. A third planned visit to a quarry in Ramnaslätt did not take place. Including this site would have added further depth by covering a broader range of quarry sizes and ownership structures. Additionally, the Ramnaslätt site's greater distance from Gothenburg could have offered insight into how location influences the perceived or actual demand for circular materials, particularly concerning transportation logistics.

The two visited quarries represented both large- and medium-scale operations, offering valuable perspectives on the conditions surrounding a potential transition or expansion of quarry activities toward circular practices. Beyond size, it would have been beneficial to include a quarry not operated by or affiliated with a major construction company. Although beyond the scope of this study, this could have provided a more nuanced understanding of how smaller business quarries perceive circularity and the specific challenges or opportunities they face in adopting such practices.

In addition to the quarry visits, a site visit was conducted at a recycling facility in Gothenburg. This facility specialises in classifying and sorting incoming waste materials to maximise reuse and recycling. Its operational model closely aligns with the operation introduced in Scenario 3 (STU-IFA), where a broader range of classified materials is accepted and managed on-site.

Across all visited sites, there was a general awareness of the construction sector's shift toward more circular approaches. One of the quarries had already initiated development of a designated area for receiving excavated materials, while the larger quarry had been selectively accepting such materials for some time. However, the implementation of a fully organised and large-scale site for managing incoming excavated material remains in its early stages.

7.3 Sources of error and biases

The interviews and site visits were the most significant sources of potential errors and biases. The study included interviewees from several different stakeholders and professions to address and identify potential biases. The information gathered during each interview was summarised and sent to the relevant interviewee for review and approval, in order to reduce the risk of miscommunication. Feedback from the interviewees was used to eliminate misinterpretation and ensure that no confidential or unwanted information was published. Although the study includes several professional roles, the interviewees are connected to a handful of stakeholders in the construction industry. To potentially get a more nuanced picture of how more people in the quarry industry are dealing with increased circular handling in their industry, it could have been beneficial to seek out more interviewees connected to other companies, especially smaller businesses. However, for this project's aim, the results gathered from the interviews were satisfactory to get a picture of the situation across the dimensions of regulatory authorities, contractors, quarry operators, recycling operators, and TrV.

Potential biases may also have occurred in the results of interviews since some of the people interviewed were suggested by initial interviewees, meaning that these people share similar views on the issue explored, and hence making the results less diverse.

7.4 Interpretation of scenario-based analysis

7.4.1 Scenario development

The scenarios were developed both during and after qualitative data collection, drawing inspiration from site visits and conversations with interviewees. The three scenarios included in this project seek to give various approaches to implementation in varying complexity and engagement for quarry operators. This is since quarries have different preconditions and resources. Having three different scenarios aims to provide a sense of variability and adaptivity in implementing an ISS- or STU-site for quarry operators.

What could have been done is to explore even more scenarios, or stay with one predefined scenario of either a quarry in the end-of-life or in the middle. If staying with only one scenario, the project could potentially go more in-depth in operational details and logistics on-site and potentially make more hands-on calculations. However, as previously stated, since the sizing and preconditions of quarries vary, a preset conceptual quarry may be non-applicable for many quarry operators and may lose relevance.

7.4.2 Scenario analysis

The analysis of the scenarios is assessed in a context of strengths and weaknesses in accordance with different preconditions for implementing additional circular operations. The analysis is especially done through the perspective of quarry operators, seeking to repurpose parts of, or the quarry site in its entirety. This aims to provide a comparison of the different scenarios in order to better understand their opportunities and challenges.

After analysing the various scenarios, each presents its advantages and disadvantages for implementing circular mass management at a quarry site. However, Scenario 2, STU-AMA, stands out as a promising option in this study. This is primarily because the AMA classification system is already widely used in the industry for categorising construction materials. Contractors providing excavated material that is pre-classified would also reduce the need for extensive contamination testing on-site, thus streamlining the process and allowing for faster upgrading and processing of the material. However, this scenario places higher requirements on the incoming materials, which must meet MRR criteria and be classified according to AMA standards. As a result, there is significant uncertainty about the volume of excavated material in the Gothenburg region that would qualify. In this context, Scenario 3, STU-IFA, could address the challenge by accepting a broader range of materials, rather than disqualifying those that do not fully meet the stricter criteria.

That said, STU-AMA places significant reliance on the accuracy of the incoming material's classification. If the material does not meet its stated specifications, it could have serious repercussions if it enters the production chain. Therefore, quarry operators should still conduct some level of testing on incoming material. Additionally, since contamination levels may change after excavation and transport, testing is necessary to ensure the material's quality upon arrival at the quarry.

7.5 Limitations of the study

The predefined limitations focused on rock quarries with sufficient capacity to supply materials for large-scale infrastructure projects within the Gothenburg region. As intended, these limitations streamlined the study and kept the time requirements manageable while aligning the scope with the priorities and operational needs of TrV. This focus facilitated the collection of qualitative data, as interviews with TrV personnel could directly address their specific needs, strategic priorities, and interpretations of relevant legislation. One example of this is the issue of contamination. The concepts of KM and MKM are commonly applied in the construction and infrastructure sectors. TrV has developed its own guidelines that permit slightly higher levels of contamination in materials used within its facilities, justified by the lower degree of human exposure in such environments.

One interviewee emphasised the importance of limiting the study to the Gothenburg region, noting that conditions vary significantly across Sweden. Analysing another region would therefore involve entirely different circumstances. The Gothenburg region has a relatively high concentration of quarries compared to other cities in Sweden. Moreover, the types of aggregates produced at these quarries vary, as do the characteristics of excavated materials generated by construction projects. A distinctive feature of the Gothenburg area is the high presence of clay, which is generally more difficult to utilise as a resource compared to excavated materials with coarser particle fractions.

The study also encountered limitations during the collection of qualitative data, which significantly influenced the overall methodology, analysis, and results. Initially, the research included plans to use a conceptual quarry as the basis for a comprehensive economic and environmental assessment. The idea was to define a quarry with parameters typical of those meeting the study's criteria, and to combine this with data on the regional production and demand for excavated materials. This would have enabled an illustrative case of how intermediate storage, upgrading, and treatment could be integrated into such a quarry, allowing for concrete calculations of economic costs and environmental impacts. However, due to insufficient data on excavation needs and material flows in the Gothenburg region, this type of analysis was ultimately deemed unfeasible.

7.6 Previous research

While no prior studies have been found that specifically address the conversion of quarries for intermediate storage, upgrading, and treatment of excavated materials, several studies underscore the broader need to enhance circular mass management within the Swedish construction sector (Brinkhoff et al., 2020; Larsson & Gammelsæter, 2023). Notably, the report from Brinkhoff et al. (2020) also acknowledges the potential role of quarries for intermediate storage but emphasises the necessity of economic incentives and sustainable business models to make such solutions feasible.

The importance of coordinating excavated material flows to improve efficiency and reduce transport between construction sites has been highlighted in research conducted by Ecoloop (Lundberg et al., 2017). However, the intermediate storage model examined in that study is more temporary. It illustrates the establishment of a strategically located area near multiple active construction projects in Stockholm, designed to be decommissioned and repurposed once nearby construction activities conclude. Similarly to Ecoloop, the Mass Logistical Centre was established in conjunction with the Norra Djurgårdsstaden development project to enable nearby construction sites to dispose of excavated materials, including hazardous waste (Stockholm City, 2025). At this facility, received materials are sorted, treated, and upgraded for reuse.

Extensive research exists on treatment and upgrading methods for excavated materials and waste. This study draws upon Andersson-Sköld et al. (2022), SBMI (n.d.), and SGS (n.d.-a, n.d.-b, n.d.-c) to present relevant methodologies in Chapter 3. Additionally, previous work by Hale et al. (2021) and Haas et al. (2020) addresses the regulatory challenges of managing excavated materials, examining both Swedish and European frameworks.

8 Conclusion and recommendations

8.1 Conclusion

This study has examined the potential of converting rock quarries into hubs for intermediate storage, treatment, and upgrading of excavated materials, with a particular focus on the Gothenburg region. Using a dual-method approach, combining a qualitative data analysis with a scenario-based analysis, it provides a comprehensive overview of considerations for implementing such models.

The qualitative data analysis, based on site visits, interviews, and a literature review, identified several challenges, such as:

- Spatial limitations and concerns about financial viability,
- Differences in the interpretation of legislation,
- Lack of requirements on circularity from clients, and
- Productification of excavated material classified as waste.

Despite these obstacles, the study also revealed important opportunities, such as:

- Synergies with existing quarry equipment and infrastructure,
- Extending the operational life of quarries,
- Decreasing transportation costs, and
- Reduced need for exploitation of new land.

A tailored approach is essential; there is no single solution that fits all sites, and planning must account for size, available equipment, and local expertise. The scenario-based analysis outlines three models with escalating ambition and operational complexity, each viable under the right circumstances:

- Scenario 1: Intermediate storage of excavated materials with minimal quarry personnel involvement and low cost.
- Scenario 2: Integration of storage, treatment, and upgrading of AMA-classified materials, leveraging quarry synergies.
- Scenario 3: A fully developed system accepting a broader material range, including non-hazardous waste (IFA), but requiring significant investments and management.

In conclusion, the study highlights the strong potential for quarries to become strategic nodes in circular mass management and production. A shift toward more circular practices is both necessary and possible. This study identifies key enablers to support that transition:

- Unified and predictable interpretation of legislation,
- Stronger collaboration between stakeholders, and
- Circular requirements by clients.

As environmental demands on the infrastructure and construction sectors increase, quarries have a unique opportunity to take a leading role in advancing circular mass management.

8.2 Recommendations for future studies

There is significant potential for future studies on how quarries can be utilised for the storage, upgrading, and treatment of excavated materials. While this study focused specifically on rock quarries in the Gothenburg region, it opens the door to broader applications in other geographic contexts. Regions with varying urban scales and population densities may present both unique challenges and promising opportunities. For instance:

- Larger or smaller cities may face different logistical and infrastructural conditions,
- Densely or sparsely populated regions could require alternative approaches to ensure both environmental and economic feasibility.

Building on these considerations, further studies could explore in greater detail the scenarios presented in this study. A particularly valuable next step would be the development of a conceptual quarry model that reflects the common characteristics of sites in the Gothenburg area. This model could offer:

- A concrete example of how the proposed scenarios could be implemented in practice,
- A clearer understanding of the technical, regulatory, and logistical implications of each scenario.

Although the development of such a model was initially intended as part of this study, limited data availability and time constraints prevented it from being fully realised. These limitations underscore the need for:

- Access to more detailed and site-specific data,
- Extended timelines to allow for the creation of meaningful conceptual or pilot models.

In addition, future studies could explore the combination of different scenarios, which was outside the scope of this study. This would allow for the examination of hybrid models that balance ambition and feasibility. Furthermore, conducting a detailed cost-benefit analysis would enhance the understanding of:

- The economic viability of each scenario,
- Their potential impact on circular mass management and sustainability outcomes in real-world settings.

Together, these future directions can significantly advance the practical application and strategic planning needed to transform quarries into circular resource hubs.

Bibliography

Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction (2007). https://www.sis.se/produkter/byggnadsmaterial-och-byggnader/byggnadsmaterial/mineral-material-och-produkter/ssen13242a120072/

Alexandria, V. (2013). The aggregates handbook. *National Stone Association, Alexandria.*

Andersson, R., & Borre, C. (2024). Increasing coordination of excavated material between infrastructure projects: Creation of a digital platform for the coordination of excavated material at the swedish transport administration.

Andersson-Sköld, Y., Norrman, J., Patrício, J., Mirzanamadi, R., & Claesson, J. (2022). *Mass management – indicators and key figures for incentives to reduce climate impact in procurement* (tech. rep. No. 0347–6030). VTI. Retrieved February 11, 2025, from https://www.diva-portal.org/smash/get/diva2:1712788/FULLTEXT01.pdf

Brander, L., & Schouenborg, B. (2015). Ce-marking of natural stone—practical application and solutions in sweden. In G. Lollino, A. Manconi, F. Guzzetti, M. Culshaw, P. Bobrowsky, & F. Luino (Eds.), *Engineering geology for society and territory - volume 5* (pp. 309–312). Springer International Publishing.

Brinkhoff, P., Norin, M., Garçã, R., Larsson, L., Jansson, R., Grandin, J., & Lindberg, J. (2020). *Circular management of materials in construction and infrastructure projects* (tech. rep.). SBUF and NCC Sverige AB. Retrieved February 18, 2025, from https://vpp.sbuf.se/Public/Documents/ProjectDocuments/35c59f93-0182-4624-9803-f1ad7dcf424b/FinalReport/SBUF_13487-slutRapport%20Cirkul%C3%A4r%20hantering%20av%20massor_2020-02-14%20(2).pdf

Carvalho, J. P., Bragança, L., & Mateus, R. (2019). Optimising building sustainability assessment using bim. *Automation in Construction*, *102*, 170–182. https://doi.org/https://doi.org/10.1016/j.autcon.2019.02.021

EC (1998). https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/miljobalk-1998808_sfs-1998-808/#K1

Elert, M., Fanger, G., Höglund, L. O., Jones, C., Suér, P., Wadstein, E., Bjerre-Hansen, J., & Groen, C. (2006, December). *Leachate tests for risk assessment of contaminated sites: Main report and supporting report 1a.* Naturvårdsverket. https://www.naturvardsverket.se/globalassets/media/publikationer-pdf/ovriga-pub/hallbar-sanering/riskbedomning/620-5535-6.pdf

Environmental Cooperation Sweden. (2006). Rehabilitation of quarries – a pre-quarry guidance. Retrieved May 5, 2025, from https://www.miljosamverkansverige.se/wp-content/uploads/rapport-efterbehandling-av-takter-vagledning.pdf

EPA. (n.d.). Quarrying permit. Retrieved February 27, 2025, from https://www.naturvardsverket.se/vagledning-och-stod/branscher-och-verksamheter/takter/takttillstand/

EPA. (2004). The swedish epa's code of statutes: The swedish epa's regulations nfs 2004:10 on landfilling, criteria and procedures for the acceptance of waste at landfill facilities. Retrieved February 20, 2025, from https://www.naturvardsverket.se/4ac5fa/globalassets/nfs/2004/nfs-2004-10k.pdf

EPA. (2009, December). Risk assessment of contaminated sites: Model description and guidance. Retrieved February 11, 2025, from https://www.naturvardsverket.se/globalassets/media/publikationer-pdf/5900/978-91-620-5976-7.pdf

EPA. (2010, February). Recycling of waste in construction works: Handbok. Retrieved February 12, 2025, from https://www.naturvardsverket.se/4ac65d/globalassets/media/publikationer-pdf/0100/978-91-620-0164-3.pdf

EPA. (2022). Handling of excavated materials and other naturally occurring materials that can be used for construction purposes. Retrieved February 25, 2025, from https://www.naturvardsverket.se/4ac555/contentassets/510ee48eff174af79e11cadc4e8cecf8/skrivelse-uppdrag-om-hantering-av-schaktmassor-m2021-00191.pdf

EPA. (2024a, June). Notification and permit requirements according to the environmental assessment ordinance. Retrieved February 20, 2025, from https://www.naturvardsverket.se/vagledning-och-stod/miljobalken/anmalnings--och-tillstandsplikt-enligt-miljoprovningsforordningen/

EPA. (2024b, December). Handling and use of excavated materials in construction work. Retrieved February 14, 2025, from https://www.naturvardsverket.se/vagledning-och-stod/avfall/atervinning-av-avfall-i-anlaggningsarbeten/

European Union. (2015, September). Ce marking of construction products step by step. Retrieved February 24, 2025, from https://ec.europa.eu/docsroom/documents/12308/attachments/1/translations/en/renditions/native

Gothenburg City. (2023). City of Gothenburg Waste Plan 2021-2030 the gothenburg region reduces waste and local annex for the city of gothenburg. Retrieved March 14, 2025, from https://goteborg.se/wps/portal/start/kommun-och-politik/sa-arbetar-goteborgs-stad-med/hallbarhet-och-agenda-2030/cirkulara-goteborg

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/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). https://doi.org/10.3390/su13116083

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological economics*, *143*, 37–46.

Lai, K. E., Abdul Rahiman, N., Othman, N., Ali, K. N., Lim, Y. W., Moayedi, F., & Mat Dzahir, M. A. (2023). Quantification process of carbon emissions in the construction industry. *Energy and Buildings*, *289*, 113025. https://doi.org/https://doi.org/10.1016/j.enbuild.2023.113025

Larsson, K., & Gammelsæter, E. (2023). Circular materials in infrastructure: The road towards a decarbonised future. Retrieved February 12, 2025, from https://www.sweco.se/wp-content/uploads/sites/3/2023/01/UI_Report-by-Sweco_Circular-materials-in-infrastructure.pdf

Lundberg, K., Frosth, S., Meurman, F., Johansson, M., Robinson, T., & Ecoloop AB. (2017, August). *Energy-efficient and circular material management at swedish transport administration through external collaboration – case study söderström* (Final report). Trafikverket. https://www.optimass.se/wp-content/uploads/2019/07/slutrapport-energieffektiv-och-cirkulacc88r-masshantering.pdf

Ma, S., Song, Y., Liu, J., Kang, X., & Yue, Z. Q. (2024). Extended wet sieving method for determination of complete particle size distribution of general soils. *Journal of Rock Mechanics and Geotechnical Engineering*, *16*(1), 242–257.

Olaleye, B. (2010). Influence of some rock strength properties on jaw crusher performance in granite quarry. *Mining Science and Technology (China)*, *20*(2), 204–208.

Ordinance (2001:512) on the landfilling of waste (2001). https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/forordning-2001512-om-deponering-av-avfall_sfs-2001-512/

Patyk, M., Bodziony, P., & Kasztelewicz, Z. (2019). Analysis of quarrying equipment operating cost structure. *Inżynieria Mineralna*, *21*(1/2), 311–318.

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: In search of conceptual origins. *Sustainability science*, *14*, 681–695.

Renou, S., Givaudan, J., Poulain, S., Dirassouyan, F., & Moulin, P. (2008). Landfill leachate treatment: Review and opportunity. *Journal of hazardous materials*, *150*(3), 468–493.

Saka, M. B., & Hashim, M. H. b. M. (2024). Critical assessment of the effectiveness of different dust control measures in a granite quarry. *Journal of Public Health Policy*, *45*(2), 212–233.

SBMI. (n.d.). Berg bygger för dig som vill veta mer. Retrieved June 10, 2025, from https://old.sverigesbergmaterialindustri.se/images/pdf/om_bergmatind/BERG_BYGGER.pdf

SGS. (n.d.-a). Soil washing ex situ – in-depth study. Retrieved April 14, 2025, from https://atgardsportalen.se/jordtvatt-es-fordjupn/

SGS. (n.d.-b). Stabilisation and solidification – in-depth study. Retrieved May 6, 2025, from https://atgardsportalen.se/stabilisering-solid-fordjupn/

SGS. (n.d.-c). Thermal treatment ex situ – in-depth study. Retrieved April 14, 2025, from https://atgardsportalen.se/termiskbeh-es-fordj/

Stockholm City. (2025). Facts MLC brief description of the mass logistics center. Retrieved March 7, 2025, from https://masslogistikcenter.se/sv/fakta-mlc

Svevia. (n.d.). How a rock quarry works. Retrieved May 5, 2025, from https://www.svevia.se/vart-erbjudande/grus-och-kross/sa-fungerar-en-bergtakt

Swedish Building Service. (n.d.). Ama online - construction 23. Retrieved February 14, 2025, from https://ama.byggtjanst.se/navigera/anlaggning-23

TrV. (n.d.). Environmental classification and assessment of soil masses.

United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. Retrieved February 18, 2025, from https://sdgs.un.org/sites/default/files/publications/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

Zhang, C., Hu, M., Di Maio, F., Sprecher, B., Yang, X., & Tukker, A. (2022). An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in europe. *Science of The Total Environment*, *803*, 149892. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.149892

A Interview study

A.1 Questionnaire for individuals within quarry enterprises

Quarry-Specific

- What types/classes of materials do you receive at the quarry? – How much incoming material do you process annually?
- How much, and which, new materials are produced at the quarry today? – What are the future projections?
- How long is the quarry operation expected to continue?
- What are the transport distances for incoming and outgoing materials? – What is your market area?
- What types and models of machinery do you currently use at the quarry, and what are their primary functions? – How many of each type of machine are on site today? – What is the cost of each machine type according to your business model?

Intermediate Storage at the Quarry

- Do you have any prior experience with material handling and intermediate storage? – If so, from where?
- Do you have any experience with operations or projects where quarries have been used as intermediate storage sites?
- Is the concept of using a quarry for intermediate storage of interest to you? – Why or why not?

Opportunities

- What benefits do you see in expanding quarry operations to also include intermediate storage of materials?
- Do you see any potential for synergies between current quarry operations and potential intermediate storage?
- Do you perceive a market need or opportunity for offering intermediate storage of materials?
- Do you believe such an expanded quarry operation would influence market demand and needs? If so, how?

Challenges

- What potential technical, environmental, and regulatory challenges and risks do you see with intermediate storage of materials at a quarry site?
- What legal or contractual frameworks need to be considered for intermediate storage at a quarry operation?
- What types of investments or changes would be necessary to enable intermediate storage of materials at a quarry site?
- How would this expanded and combined operation affect current operational processes and logistics at the quarry?

- What resources or competencies do you think need to be developed or strengthened to succeed with such an expanded operation?

A.2 Questionnaire for Individuals within in Mass Management

Intermediate Storage at the Quarry

- Do you have any prior experience with intermediate storage of materials? If so, from where?
- Do you have any experience with operations or projects where quarries have been used as intermediate storage sites?
- Is the concept of using a quarry for intermediate storage of interest to you? – Why or why not?

Opportunities

- What benefits do you see in expanding quarry operations to include intermediate storage of materials?
- Do you perceive a market need or opportunity for offering intermediate storage of materials?
- Do you believe such an expanded quarry operation would influence market demand and needs? If so, how?

Challenges

- What potential technical, environmental, and regulatory challenges and risks do you see with intermediate storage of materials at a quarry site?
- What legal or contractual frameworks need to be considered for intermediate storage at a quarry operation?
- How would this expanded and combined operation affect current operational processes and logistics?
- What resources or competencies do you think need to be developed or strengthened to succeed with such an expanded operation?

A.3 Summary, Interviewee 1

The interviewee works with mass management in small and medium-sized projects as an environmental specialist at the investment department at the TrV.

Quarries operate under a permit that typically includes gravel or rock extraction and post-extraction restoration of the site. The intermediate storage and processing of masses introduce new activities, such as reception, sorting, and further handling. These additional activities constitute a new environmentally hazardous operation and must be managed through permits under the EC.

The materials brought into quarry operations for intermediate storage and upgrading may be contaminated. This creates requirements for handling materials with contamination levels, which differ from the quarry's current operations. The existing activities primarily handle functional rock that is not inherently contaminated, but they do generate pollutants that require some form of water management or control within the quarry operations. If the new operation involves higher levels of contamination, stricter requirements will apply to the management of water within the facility. Water monitoring related to quarrying activities is currently often focused on residues from explosives rather than contaminated materials. Introducing contaminated materials could create a need for expanded monitoring and possibly some form of treatment system to manage the polluted water.

It is also essential to know the origin of the materials and which parameters should be assessed. The interviewee highlights the importance of having expertise in analysing sample results. The sample taken to represent the material comes from a very small portion, and an even smaller part of that sample is analysed. The laboratory test results are entirely dependent on how the sample was taken, which is why it is important to know how the sample was collected and handled at the laboratory. For example, if a sample has been dried and sieved before analysis, no volatile substances will be present. This information is crucial for interpreting the results correctly.

The incoming materials need to be processed into products before they can be resold on the market. It is, therefore, important to determine which of the incoming materials are classified as waste and which are not, as well as which materials are considered waste when leaving the facility.

Environmental legislation is based on the concept of risk. Reference values, such as MRR, are not laws but guidelines developed by the Swedish EPA. However, in risk assessments, fixed values from MRR (as well as KM or MKM) are often treated as if they were legally binding.

The interviewee sees advantages and opportunities with intermediate storage, as it could save taxpayers' money. Currently, surplus materials are often handed over to contractors. If TrV were to retain control over these materials in procurement, it could simplify the reuse of surplus materials in other TrV projects.

A.4 Summary, Interviewee 2

The interviewee works as a coordinating environmental specialist at the TrV and has previously worked at two different county administrative boards for a total of 25 years. They have also served as an environmental expert in the environmental permitting delegation for 20 years, making decisions on quarry-related cases and assessing issues linked to quarry operations.

The interviewee observes a growing trend of wanting to use quarries for intermediate storage of materials, particularly in southern Sweden and densely populated areas. Challenges include finding suitable spaces within quarries and authorities' concerns about the composition and variability of the materials being stored. In northern Sweden, interest is also increasing, mainly driven by the need to sort and recycle materials more efficiently.

One key advantage of using quarries for intermediate storage is that it takes place within an already established industrial site, reducing the need to allocate new land. Additionally, it may cause less noise and environmental disturbances compared to setting up new storage areas. However, there are logistical and regulatory challenges. Materials cannot be stored for more than 3 years before being classified as landfill waste, meaning there must be a plan for their further use. Another issue is the classification of the materials, since if considered waste, they require permits or notifications, whereas by-products can be handled more flexibly. Processing methods such as sorting and washing can help reclassify waste into usable products, but this also leads to stricter permit requirements.

County administrative boards and other authorities base their assessments on legislation, guidelines from the Swedish EPA, and legal precedents. TrV have its own interpretations and guidelines, but these generally carry little weight in decisions made by the County Administrative boards.

The demand for intermediate storage is highest in urban areas with significant construction activity. In smaller towns and rural areas, the need is lower due to fewer extensive construction projects.

A.5 Summary, Interviewee 3

The interviewee works with procurement within TrV. There, the interviewee has multiple roles, one of which involves working with road procurements and road projects, as well as acting as a category leader to develop a strategy for the land category in collaboration with other operational areas.

In their role at TrV, the interviewee procures contracts for projects. TrV rarely purchases materials itself. Instead, it is usually the contracted entrepreneur responsible for purchasing materials such as ballast for the project.

TrV does not impose requirements for circular products but rather mandates a climate calculation, aiming to optimise aspects such as mass balance to minimise CO_2 impact. The primary requirements focus on the amount of CO_2 emissions rather than specific demands for circular materials.

In most cases, surplus materials generated in projects are transferred to the contractors. However, the interviewee mentions that they are testing the procurement of reception facilities that can accept surplus materials in certain projects. In rare cases, they have successfully coordinated project timelines so that surplus materials from one project are utilised in another project that requires them, though this is stated to be very uncommon.

Regulatory issues and environmental legislation are also discussed. The interviewee notes that the regulations are interpreted differently and can be complex. Whether a material is classified as waste or not depends entirely on the municipality, the individual, and the specific case officer handling it.

The interviewee sees potential in intermediate storage, upgrading, and treatment of materials at quarries, as these measures could reduce uncertainty about who can receive surplus materials. Additionally, TrV as a client could potentially lower transportation costs while also benefiting from the environmental advantages of a more circular process.

The interviewee also highlights challenges in obtaining permits, particularly regarding the storage and sorting of materials classified as waste at the facility.

A.6 Summary, Interviewee 4

The interviewee is an environmental specialist with expertise in waste legislation and has previous experience with contaminated land management from the consulting sector. The interviewee is currently working at TrV's Investment and Maintenance Division, where they work strategically on developing internal procedures and methods for mass management.

Regarding the upgrading and treatment of excavated materials, the interviewee describes that waste management is more strictly regulated compared to products and resources. When recycling waste, the level of regulatory review must be determined based on the waste's risk of contamination. If the waste contains contamination levels, its recycling for construction purposes must be reported. However, if it is classified as a product or resource, no such reporting obligation exists, and instead, the rules of consideration in the EC apply.

The interviewee mentions that some supervisory authorities interpret regulations differently, but from their perspective, the definition of waste is clear. Excavated masses are not waste but a resource that should be used as much as possible within other parts of the construction, nearby projects, or continued applications. Even if the material changes ownership, it remains a resource rather than waste, provided that an operator has a need for it and that it is technically and environmentally suitable.

Regarding the classification of masses, the interviewee refers to TrV's own threshold values (L1 and S1). These values are based on the same calculation model as the Swedish Environmental Protection Agency's general guideline values (KM and MKM) but are specifically adapted to assess environmental suitability for the types of facilities managed by TrV.

To enable intermediate storage and treatment of waste at a permitted quarry, the interviewee states that a modification of the quarry permit would be required, detailing the new extended operations. Key considerations at this stage would include the types of waste and contamination levels intended for handling, as well as the treatment methods. This is necessary to establish environmental monitoring conditions that prevent the spread of contaminants.

Before excavation, soil investigations are conducted, but it is always challenging to confirm that conditions align with assessments. The interviewee sees challenges in determining who is responsible for the material. For example, if a customer deposits material (at a quarry operation with intermediate storage and treatment) based on their own technical and environmental assessments, who holds responsibility if the material later proves to deviate from those assessments? Another challenge is the potential market disruption for quarry operations and the risk that TrV could favour one quarry over another. Therefore, it is essential to establish a viable business model for the operation.

The interviewee sees an advantage as quarries are geographically well-suited locations.

Currently, TrV does not impose requirements for circular products in projects. The interviewee highlights that contractors perceive TrV's material requirements as strict, which poses challenges for recycling and the continued use of excavated masses.

A.7 Summary, Interviewee 5

The interviewee is an environmental specialist at TrVs Investment Department and works with environmental issues in investment projects. They also have a background in working with matters related to operations, such as quarries and mines, as well as with material management, environmental assessments, and decisions regarding permit applications.

Quarry operations have a clearer understanding of the material being extracted and the potential consequences of the operations. In contrast, with intermediate storage, there are more unknown factors in advance, as it is not clear exactly which excavation materials will be brought in. For intermediate storage, an assessment is needed of the environmental impact and the pollutants the operation is prepared to manage. This preparedness could, for example, include a system for handling leachate. It is important to ensure that the materials being brought in meet the quality that is accounted for in the preparedness.

Running a quarry operation that also stores and upgrades materials has the advantage of reducing transport and promoting more circular material handling. The interviewee also sees advantages in increasing acceptance among buyers to accept waste, as there is currently a fear regarding the quality of waste materials.

Pollutants are usually found in the smaller fractions, which could be sorted out using machinery often available at quarries. Contaminant levels in coarse materials, such as track ballast, tend to be overestimated when looking at the overall contamination, as the material is typically assessed and analysed based on its finer fractions. According to the Swedish EPA, contamination should be assessed based on the material as a whole.

Even if the operation involving intermediate storage and upgrading of materials only requires notification, obtaining a permit can be seen as a safeguard. A permit means that conditions are set for operating the business, whereas a notification allows the permit authority to continue imposing requirements.

Quarry operators are responsible for ensuring that the materials produced and those recycled comply with regulations.

Entrepreneurs' willingness and incentives to accept and handle materials need to be strengthened. Currently, there is uncertainty about accepting materials due to a lack of knowledge, with a preference for clean materials to reduce risks. The materials themselves are often free, but expertise is needed to ensure the material is acceptable. This means that entrepreneurs, municipalities, and buyers must collaborate. Entrepreneurs also need expertise in assessing the quality and environmental aspects of the materials according to relevant guidelines.

Geographical context is important as conditions vary depending on the location in Sweden.

A.8 Summary, Interviewee 6

The interviewee works as an Environment and Investigation Manager. The interviewee has previous experience with intermediate storage of excavated materials, primarily related to landfills. Landfill sites receive large volumes of excavated materials for treatment, recycling, and product development, although the majority is ultimately disposed of. Before disposal, leaching tests, total content analyses, and deposition tests must be conducted to determine contamination levels. If further chemical analyses are required, materials are temporarily stored for additional testing. The company also operates mass storage centres where stone is sorted, washed, and repurposed into new products. As incoming materials are classified as waste, the company's existing permits allow for their handling, an important distinction given that waste management falls under a different regulatory framework.

The interviewee's landfill consists of separate areas for non-hazardous waste and an inert waste landfill, the latter allowing for higher capacity. Proper landfill design is crucial, including capping and drainage layers for safety. The volume of incoming materials varies, and at one site approaching capacity, fewer excavated materials are accepted to conserve remaining landfill space. It is common for projects to store materials temporarily for leaching tests rather than conducting these tests independently.

At one of their landfill sites, and within the framework of the landfill permit, another contractor operates within the same area, blasting and crushing rock for resale while simultaneously creating additional space for the landfill operation. The cost of disposal varies significantly depending on material quality and contamination levels, and landfill tax is applied. However, certain exceptions exist, such as for excavated materials from contaminated sites, which are tax-free.

Regarding quarry operations, Interviewee 6 notes that quarries are depleted once the permitted extraction volume is reached. To extend operational lifespan, quarries could accept excavated materials while simultaneously extracting, crushing, and processing stone. If permits were expanded to include waste handling, similar to landfill operations, quarries could leverage their expertise in aggregate production and market demands.

Technical challenges in waste-classified intermediate storage include hardened surfaces, stormwater management, sedimentation dams, filtration systems, and advanced monitoring. The interviewee anticipates a growing need for material storage, especially in alignment with Gothenburg's waste management plan, which aims for 50% of aggregate materials to be recycled by 2030. Reducing transportation distances through localised storage sites near projects is also a priority. However, the availability of virgin materials in and around Gothenburg remains high, keeping prices low and reducing demand for recycled alternatives. This may change as quarries are gradually depleted.

From a legal perspective, permits or notifications are required based on environmental impact classifications (A, B, or C). Small-scale storage may fall under the "C classification," requiring only a municipal notification, while larger facilities necessitate a full permit application, including a technical description and an extensive environmental impact assessment. Local zoning plans also regulate landfill operations, primarily by volume rather than time restrictions.

To optimise intermediate storage in quarries, the interviewee highlights the need for increased expertise in contamination levels and waste classification, as quarries traditionally lack experience in handling materials with varying contamination grades.

A.9 Summary, Interviewee 7

The interviewee primarily works with permitting issues related to the company's material production and management, with experience in oversight matters on a case-by-case basis. Previous experience with intermediate storage of materials in connection with quarry operations has mainly been for land restoration at the end of a quarry's lifecycle, involving backfilling and reshaping the site. However, the interviewee sees significant potential in utilising quarries for the intermediate storage of incoming materials, particularly as quarry permits have become increasingly difficult to obtain. Such an approach could extend the lifespan of quarries and improve resource efficiency and circularity.

Several challenges are associated with intermediate storage at quarries, including the need for a consistent flow of materials to ensure economic viability. Storage occupies substantial space and can extend over long periods, depending on material type and intended reuse. A potential solution is to allow projects to retrieve similar-quality materials rather than being restricted to retrieving exactly what was initially dropped off. Another challenge is ensuring accurate classification and documentation of incoming materials to comply with environmental regulations. Additionally, uncertainty regarding whether projects will repurchase deposited materials can disrupt material flow and result in excess stockpiles. Ownership structures and customer agreements play a crucial role in managing this issue effectively.

Customer demand ultimately drives production, and while circular materials cannot fully replace virgin materials, a partial substitution is feasible. The company already produces materials based on market demand and maintains stockpiles of commonly used fractions. Successful cases exist where incoming MRR materials have been processed into marketable products.

Currently, quarrying operations are only granted time-limited permits for the extraction of rock materials. Once the permit period has expired, all operations must be discontinued, and the quarry site must be restored. In cases where the land is leased, continued access to the site may no longer be possible after operations cease. If quarrying activities are to be terminated and converted into a soil material-handling facility, a new notification or permit under the EC is required. Land access must also be ensured through either a lease agreement or land ownership. Quarrying operations are always classified as "Category B activities" under the EC, regardless of whether the permit includes recycling. Pumping is subject to permit requirements if it involves the abstraction of groundwater. Technical challenges related to the intermediate storage of materials with varying environmental classifications include the need for hardened surfaces and effective water drainage systems, such as ditches leading to a water collection area, to reduce the risk of contamination spread. Technical requirements also increase with the level of contamination in the material.

Lastly, waste classification remains a critical issue, with inconsistent interpretations among regulatory authorities and municipalities regarding acceptable contamination levels. These variations contribute to legal uncertainties and complicate the management of temporary material storage at quarries.

A.10 Summary, Interviewee 8

The interviewee is working with sustainability in road and infrastructure projects, and emphasises the need for systematic approaches to minimise climate impact and achieve long-term corporate goals. While there is a growing awareness among clients and contractors regarding reducing carbon footprints, technical material requirements, primarily dictated by AMA standards, remain the dominant priority. The interviewee highlights the importance of shifting towards functional requirements to facilitate greater circularity in material use, though regulatory authorities often hinder such initiatives by focusing strictly on technical specifications.

Regarding the intermediate storage of materials, the interviewee has experience in regulatory applications, oversight discussions, and preparatory work related to storage and material reuse. The primary benefits of establishing intermediate storage near quarries are improved logistics, optimised transportation efficiency, and the integration of recycled materials into production. This approach could significantly reduce environmental impact and enhance EPD, aligning with TrV's incentive models.

However, challenges persist, particularly concerning waste classification. The Swedish EPA has established clear criteria for when excavated materials should not be classified as waste, yet inconsistencies in regulatory interpretations remain a barrier. Despite TrV's development of specific guidelines (TDOK.00:63), practical implementation varies, leading to legal disputes and delays. The interviewee attributes this to discrepancies in regulatory expertise and differing contamination thresholds at the municipal level. A more standardised and consistent approach is necessary to facilitate circular material management and reduce unnecessary regulatory constraints.

In practice, there are successful examples of large-scale intermediate storage of excavated materials where the materials have been evaluated and utilised as resources rather than treated as waste. For instance, in one case, the company successfully collaborated with TrV and the environmental authorities to obtain approval for storing 100,000 tons of material near a quarry. However, transferring materials between projects still necessitates formal risk assessments and often regulatory approval, creating great uncertainty in decision-making without consulting supervising authorities.

This analysis underscores the need for regulatory harmonisation, functional-based requirements, and improved dialogue between industry stakeholders and regulatory authorities to enhance the efficiency of circular material flows in infrastructure projects.

A.11 Summary, Interviewee 9

The interviewee works with reception facilities for excavated materials and also with virgin rock materials as a Production Manager. In this role, the interviewee is responsible for three facilities that handle excavation reception and, in some cases, resource park operation.

The business aims to reduce landfill disposal and increase the circular use of materials through a combination of inert landfills and the restoration of rock quarries. Inert landfills receive excavated material with higher levels of contamination, while excavated material with lower levels of contamination is used to remediate the quarry.

Of the materials that the facility (quarry visited during site visit) received during the past year, the majority consisted of excavated material used for quarry restoration. Additionally, smaller amounts of concrete and asphalt are processed, with the asphalt being sent to asphalt plants for recycling. All incoming material is classified as non-hazardous waste and categorised according to industry standards MRR, KM, MKM, and IFA, with KM and MKM being the most common classifications.

Production planning is based on budgets and forecasts, with the annual product distribution typically remaining stable. The quality of the material determines its applications, where high-quality rock can be used as aggregate for concrete and asphalt, while lower-quality material is used for substructures and other simpler purposes.

The operation uses mobile crushers, which are rented as needed. A primary crusher breaks down the material from a blast charge into manageable material for the secondary crusher. Many of the machines can be used for both rock material and excavated masses, with screens adapted to the material type. A key principle is to minimise material handling and the number of times material is moved by placing the right material directly in the right location, rather than using intermediate storage.

Excavation hotels, where material is temporarily stored for future reuse, pose challenges. Customers often underestimate the costs and responsibilities associated with intermediate storage, including the risk of contamination or the failure to retrieve the material as planned.

A central issue is to create profitability in the circular economy. Today, it can cost just as much to receive a useful excavated material as it does to receive a more difficult-to-handle material like clay. A good pricing model could increase recycling by basing prices on the material's recycling potential.

Contaminants such as plastic, geotextiles, and roots can be separated using methods like wind screening and water baths, while chemical contaminants primarily end up in fine fractions. Sampling is a critical part of the process, but reliability varies since customer samples often need to represent large material quantities.

The future requires better alignment between recycled materials and the construction industry's demands. Currently, there is a tendency to require virgin materials even in cases where recycled alternatives would be sufficient, which hinders progress toward more circular solutions.

A.12 Summary, Interviewee 10

The interviewee works as a business developer within the marketing function of a construction company, with a national role focused on transitioning towards reuse and recycling. Their responsibilities include asphalt and aggregate production, concrete manufacturing, and rental services for construction equipment such as site huts, cranes, and lifts.

With approximately 15 years of experience in material handling, the interviewee highlights the growing importance of intermediate storage of excavated materials in the construction industry. One concrete example is the "Hamnbanan" project in Gothenburg, where internal collaboration enabled material handling through the use of company-owned sites. The term "excavation hotel" is used to describe storage sites where materials are "checked in" and later reused. This model requires careful planning and appropriate permits to avoid the materials being reclassified as landfill after three years.

Intermediate storage typically refers to keeping untouched masses in place, although minor processing, such as sorting, may occur. If more extensive treatment is needed, this must be ordered separately by the project. The interviewee notes that the company is increasingly interested in developing quarries for both the storage and upgrading of materials, particularly as a way to optimise underutilised land. However, regulations on storage duration and environmental considerations, such as sampling to prevent the spread of contaminants like PFAS or invasive species, pose challenges.

Material processing usually involves screening rather than washing, as clay-rich soil in regions like Västra Götaland County makes washing technically difficult and economically unfeasible. "It probably costs more than it's worth," the interviewee states. The current estimated recycling rate is around 70% for certain excavated materials and up to 50% for concrete. Asphalt is considered particularly valuable - "almost like gold" - while excavated soil still requires development for effective reuse.

Certain types of projects are considered especially suitable for increasing the proportion of recycled materials. These include "lower classes of specified materials in industrial processes," such as pedestrian and bicycle paths, sub-base layers, and coarse concrete. The interviewee emphasises that projects with higher strength requirements often revert to conventional materials. There is a need to challenge existing building practices and ask whether the highest material class is always necessary.

Moreover, there is currently a lack of systematic data on how much incoming material is reused versus landfilled. The sector is in a transitional phase where new solutions are being tested, often depending on individual project champions. "Right now, it's a bit uncomfortable and a bit of a hassle" to work with recycled materials, but with clear client requirements and better visibility of recycled products, this could change. The interviewee likens the behaviour shift to introducing new consumer habits: "Imagine if we could just buy this recycled stone instead… like they did in Kungälv."

Finally, while the demand for virgin materials remains, the interviewee stresses that recycling must not be overlooked. The key is to find the right balance - knowing when, to whom, and how to offer recycled materials and creating conditions where they are seen as an equally valid alternative.

A.13 Summary, Interviewee 11

The respondent works at the TrV, in the Planning Department, as an investigation leader focusing on mass management and contaminated areas. The respondent works nationally and strategically to create direction and guidance to support TrV in various matters.

The respondent has experience from projects that have used temporary storage, which does not require a permit if carried out within the scope of the project. They also have experience from projects where masses were stored on another property, where the storage duration should not exceed three years. In this project, it was possible to adjust this time limit after dialogue with the municipality. These two types of storage differ from storage with the purpose of accumulation.

The respondent has not been involved in projects where a quarry has been used for the interim storage of masses. However, they see advantages in utilising quarries, provided they are located close to the project.

Storage does not exclude treatment. Whether storage also involves treatment depends on the level of contamination, volume, and purpose. If the material is usable from a contamination perspective, there may only be a need for storage, while material with a higher level of contamination may require screening and removal of small particles.

A challenge with the storage and treatment of masses is that the activity generates dust and noise. This can make the activity undesirable for nearby residents and create challenges when it comes to finding suitable space for the operation. Conducting the activity may require a permit depending on the volume and type of materials handled. The time aspect is also a challenge, as permits require relatively long preparation times and handling time by the supervisory authority. Therefore, it could be advantageous to conduct this type of activity at a quarry. In such cases, it involves receiving masses within the scope of existing permits and potentially applying for permission to accept additional types of masses.

Materials should not be mixed, for example, by combining contaminated material with less contaminated material to reduce the contamination level. Masses with contamination levels comparable to background levels do not require the same oversight as more contaminated masses. Having the same level of control over all masses regardless of contamination level can be very costly; different levels of contamination may require different types of control within the operation.

The respondent refers to TrVs' Legal interpretation and application of legislation for mass management and EPAs' Mass Management and Use of Masses in Construction Work, which states that if the masses have a purpose within a reasonable time and can be used without posing a risk to the environment, they can be considered a resource. There are differing interpretations regarding this document, for example, about what constitutes a purpose and what defines a risk. If the supervisory authority has different opinions and interpretations, uncertainties arise, which can lead to new material being seen as a simpler alternative.

Space is an important issue. An advantage of using quarries is the utilisation of areas that are already in use.

A.14 Summary, Interviewee 12

Interviewee 12 is working with environmental questions at the County Administrative Board in the region of Western Götaland, where the city of Gothenburg is located. This interview was answered in written text as below:

The advantage of expanding the purpose of quarry operations is that it does not necessarily have to be limited to the intermediate storage of excavated materials. In many quarry permit processes, the recycling of materials is also included, either through mechanical processing for later removal or for use in construction purposes or site restoration within the quarry itself.

Benefits of such co-location include the existing facility control of the quarry, which material management can take advantage of, for instance, the use of sedimentation ponds, water control systems, knowledge of noise dispersion, and dust control measures. Additional benefits arise from the ability to use the same machinery and work vehicles for both quarrying and waste operations, as well as the opportunity to make use of return transports, i.e., exporting rock while importing materials.

Finding suitable locations for stockpiling materials can be challenging, as it may require significant space. In this context, quarries can be highly useful, especially those that have been in operation for a long time and may have larger unused operational areas. Quarries with long histories also tend to have higher levels of public acceptance, which can be an advantage when co-locating activities.

Whether there will be a future market demand is perhaps primarily a question for the operators themselves. However, given the benefits described above, as well as the presence of large-scale construction and infrastructure projects in metropolitan regions, there may be a need. In urban projects, space is often limited at the actual project site.

Regarding the technical, environmental, and regulatory challenges related to the intermediate storage of materials at quarries, the conditions of the site/quarry must be suitable for handling such materials. For example, some rock quarries also involve water operations, including the extraction of groundwater. In such cases, measures must be in place to prevent contaminants in the materials from spreading into the groundwater. The acceptance criteria applied to the materials are thus of vital importance.

Material handling primarily takes place in rock quarries and not to the same extent in gravel pits. In the latter, the risk of contamination spreading to groundwater is higher due to the soil's permeability.

A previously mentioned advantage was the shared and existing facility control. However, this can also pose a challenge, as the control and precautionary measures were implemented based on the original quarrying activities. It requires knowledge of how material handling might affect those measures, for instance, whether the design of sedimentation ponds and other water purification systems is suitable for the types of contaminants that might be present in the materials being handled.

Another risk that often needs to be taken into account is the spread of invasive alien species. In such cases, using the same machinery for material handling as for other operations can be a disadvantage.

Quarry operations are required to provide financial security in case the state needs to assume responsibility for site restoration - for example, in the event of bankruptcy. Measures may also be needed specifically for the material handling aspect. Therefore, financial security should be structured in such a way that it also covers these types of measures. While this may not pose a major challenge, the costs will, of course, be influenced by market demand and the availability of receiving facilities.

Knowledge in material handling and waste legislation needs to be continuously strengthened and updated. The field is evolving rapidly - both in terms of technology and legislation. Special attention should be given to the issue of invasive species.

A.15 Summary, Interviewee 13

The interviewee is a Project Manager and is responsible for a production facility that includes both quarrying and recycling operations.

The facility has been receiving construction rock for a long time, but has received a larger amount in recent years due to large projects in the market. In addition to construction rock, the facility primarily accepts excavated material, asphalt, and concrete (demolition and fresh). The forecast is that the amount of construction rock will decrease as the projects generating this material are in their final stages.

Waste entering the facility should ideally be sampled before it arrives so that the waste class can be determined. However, if it is not sampled, the facility also has the capacity to receive waste for classification.

The assessment required to determine how the received material can be used for further processing cannot be made by the customer, but must be made by the receiving facility. The type of contamination, the effort required to process it, and the business itself are decisive factors in the facility's assessment.

The facility has a simple washing plant for cleaning crushed stone.

The products produced by the quarry for asphalt must today be made from virgin raw materials to ensure quality. To produce this type of product, analysis and investigations of the quarry are needed to determine the type of rock and mineral composition (petrographic analysis), thus determining what the rock material can be used for. Introducing a raw material whose quality is not well understood cannot currently be recycled to the same extent.

When sorting excavation material, larger stones can be sorted out by throwing the material over grizzly bars. Depending on whether the material is sufficiently dry, a mechanical sieve can also be used. This is done to remove the small particles where contaminants are located.

One challenge is that the recycling process varies. There is no standardised process, it is a more complex machine that must be handled case by case.

The market area largely depends on the product. When it comes to rock products, including construction rock, the cost of the product is relatively low. This means that transportation costs by truck quickly account for a larger portion of the total cost. According to the interviewee, this is occurring if the transportation distance is above 20-30 km for crushed rock material. Recycling materials are more dependent on the distance to a facility that can accept them. Materials transported by train, however, can be transported over longer distances.

The interviewee sees benefits in accepting and processing materials at the quarry. A short-term benefit is that transportation is reduced.

The business is essential. Everything is of interest as long as there is a business to build upon.

The biggest challenge is the productification of waste and knowing where investments should go. For example, the concrete industry has historically struggled to incorporate recycling into its products. The development of recycled concrete in concrete should ideally begin with simpler constructions.

Gothenburg's goal of recycling 50 % by 2030 presents significant challenges. If the recycling rate is 20 % (a figure for calculation purposes), large quantities of waste are needed to even make this level of recycling possible. The recycling rate is estimated to be low due to geographic location and the materials that can be used for construction.

The interviewee mentions challenges related to municipalities having different views on the same recycled product. If municipalities then approach the customer regarding this recycled product, it creates uncertainty for the customer.

A.16 Summary, Interviewee 14

The interviewee is the Deputy Project Manager for the company's quarrying and recycling operations in the West Region. The interviewee is also responsible for the region's permit officers, who ensure that the necessary permits and decisions to operate the business are in place.

The company works extensively with circular material management and has the capability to handle external materials for recycling at most of the quarries in the region, just like several of their industry peers. A major focus in the industry today is to create common working methods that will help increase the use of recycled materials in construction and civil engineering projects.

The facility is permitted to receive a specific amount of waste per year, and in some years, a larger amount of construction rock.

They offer recycled products under the ECO-Ballast brand. The goal moving forward is to scale this up, which requires flexibility in production.

Once the material has arrived on site, an assessment is made to determine whether the material is recyclable based on its technical and environmental properties. The goal is to further process as much as possible and reduce the amount that needs to be landfilled. The appropriate treatment method depends on the material's properties but may involve sorting or mechanical processing such as crushing and sieving. Materials that are not deemed recyclable are stored for transport to an approved receiving facility.

Depending on the final product's quality requirements, either raw materials from the quarry and/or external raw materials can be used. When waste ceases to be waste through a recycling process, the material can either be sold directly or incorporated into the regular production process for further processing. This can, for example, involve sorting out stone from excavation materials, which can then be crushed in the same way as rock material.

The catchment area may be larger for receiving materials than for selling ballast products, as receiving depends on the facilities available and what they are permitted to accept.

The interviewee sees advantages in accepting and recycling external materials at the facility. From the customer's perspective, it is beneficial to be able to both drop off and pick up materials at the same location. Co-location of these operations also enables efficient logistics, where resources can be shared. It is very much about resource efficiency and extending the life cycle of materials already in circulation. It also extends the lifespan of the quarry and conserves its natural resources.

The City of Gothenburg has set a goal that 50% of the materials used in construction will be circular. This will require a large supply of recyclable raw materials. This supply varies over time depending on projects and the market, which in certain periods could make it more difficult to ensure large volumes of recycled products.

Another challenge is differing views on when waste becomes a product, where the responsibility of oversight and municipalities need to be more aligned. Uncertainties about the assessment of when waste has ceased to be waste can create insecurity for the end customer and thus hinder the use of recycled products.

B Guidelines

B.1 TDOK 2022:0063

Land Area **Substance (mg/kg TS)**	L1 Small area <500 m^2, no hard surface, low human exposure	L2 Small area <500 m^2, hard surface, low human exposure, no protection of soil environment	S1 Large area >500 m^2, no hard surface, moderate human exposure	S2 Large area >500 m^2, hard surface, low human exposure, no protection of soil environment
Arsenic	40	75	40	75
Barium	300	900	300	900
Lead	350	350	120	250
Cadmium	12	36	8	20
Cobalt	35	105	35	100
Copper	200	600	200	600
Chronium, total	150	450	150	450
Mercury	7.5	7.5	1.2	3.0
Nickel	120	360	80	180
Vanadium	200	600	200	600
Zinc	500	1500	500	1500
PCB-7*	0.50	0.50	0.10	0.25
PAH-L*	15	45	10	20
PAH-M*	40	60	30	60
PAH-H*	10	30	10	20
Benzene	0.10	0.12	0.02	0.05
Aliphatic >C10-C12	500	1000	500	1000
Aliphatic >C12-C16	500	1000	500	1000
Aliphatic >C16.C35	1000	2500	1000	2500
Aromatic >C8-C10	50	150	50	150
Aromatic >C10-C16	15	45	15	45
Aromatic >C16-C35	40	90	18	40
Diuron	0.20	0.24	0.04	0.10

* PCB-7 = Polychlorinated Biphenyls. PAH-L = Polycyclic Aromtaic Hydrocarbons - Low. PAH-M = Polycyclic Aromtaic Hydrocarbons - Medium. PAH-H = Polycyclic Aromtaic Hydrocarbons - High.

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY