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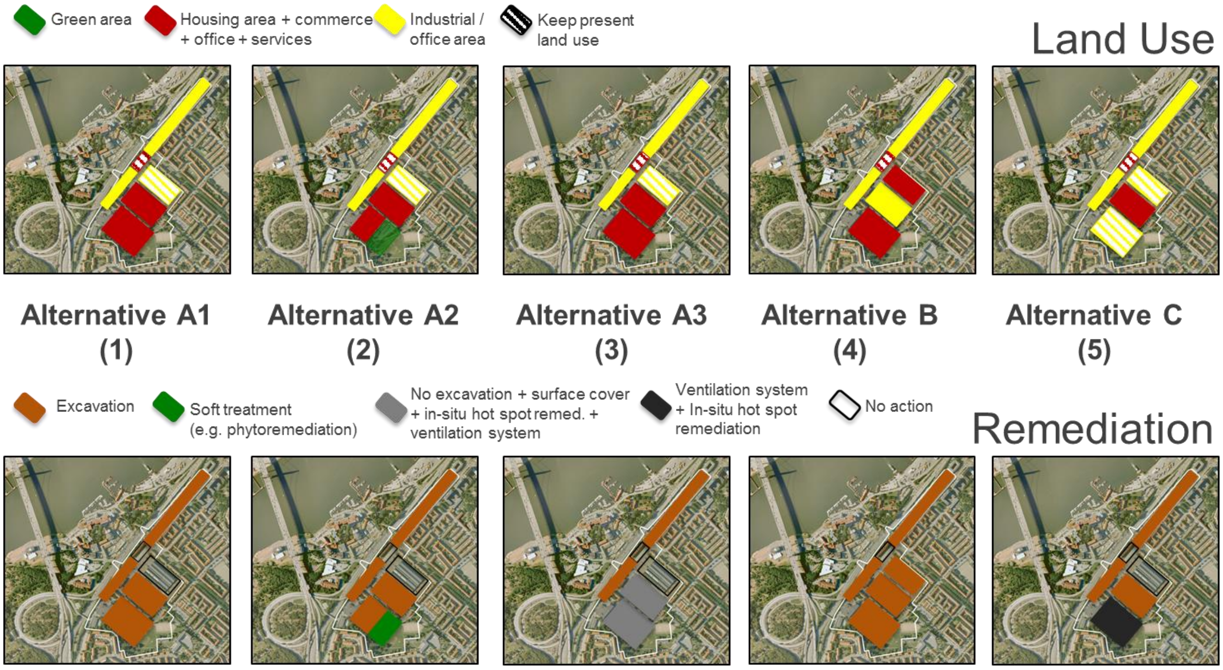

Assessment of alternatives of urban brownfield redevelopment

Application of the SCORE tool in early planning stages

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

RITA GARÇÃO

Department of Civil and Environmental Engineering
Division of GeoEngineering
Engineering Geology Research Group
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2015
Master's Thesis 2015:15

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Examensarbete 2015:15/ Institutionen för bygg- och miljöteknik,
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Cover:
Alternatives combining remediation and future land use at Fixfabriken site. Illustration: Rita Garção

Department of Civil and Environmental Engineering. Göteborg, Sweden, 2015

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ABSTRACT

Urban renewal through the redevelopment of brownfields areas (underused sites) can benefit from sustainability assessment in early planning stages, by bringing economic, social and environmental aspects into the decision-making process. In the context of the research project Balance 4P, the SCORE tool is applied in the early planning phase for sustainability assessment of an urban brownfield redevelopment project at the case study site Fixfabriken, in Göteborg, Sweden. SCORE is a multi-criteria analysis tool to evaluate remediation strategies, which combines a cost-benefit analysis (CBA) and a semi-quantitative evaluation of environmental and social effects. However, the SCORE tool has been developed for assessing remediation alternatives in the risk valuation process in the late planning phases, when typically a substantial amount of information is available. This report evaluates the possibilities for application of SCORE in the early planning phase and presents the sustainability assessment results of redevelopment alternatives at the Fixfabriken site. Obstacles experienced during the assessment are due to large uncertainty about the sub-surface conditions and about the future urban development. Furthermore, the consequences of the different future land-uses are difficult to assess with the current SCORE design. To enhance SCORE application to provide valuable input to the decision-making process on redevelopment alternatives, two recommendations for future modifications of the economic domain of the tool are presented: 1) to replace the monetary CBA by a semi-quantitative assessment in order to make an economic assessment less time consuming, requiring fewer detailed data, and thus being more likely to be used by developers; 2) to include one new benefit item (increase of property value after redevelopment) and one new cost item (demolition and construction costs when redeveloping) to allow for including the consequences of the future land-use into the economic assessment. However, further work is necessary to fully evaluate these possibilities.

Key words: urban brownfield redevelopment; sustainability assessment; cost-benefit analysis; multi-criteria analysis; SCORE; Balance 4P; soil contamination.

Utvärdering av alternativ till förnyelse av tidigare exploaterad mark.
Användning av SCORE-verktyget i tidiga planeringsskeden

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

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SAMMANFATTNING

Planering av förnyelse av tidigare exploaterad mark kan vinna på hållbarhetsutvärderinar av förnyelsealternativ under tidiga planeringsskeden eftersom ekonomiska, sociala och ekologiska aspekter då kan inkluderas tidigt i beslutsprocessen. Inom forskningsprojektet Balance 4P har SCORE-verktyget tillämpats i ett tidigt skede i planeringsprocessen i en fallstudie, Fixfabriken i Göteborg, Sverige. SCORE är ett multikriterieanalysverktyg som kombinerar kostnads-nyttoanalys (CBA) och en semikvantitativ bedömning av ekologiska och sociala effekter. SCORE är ursprungligen utvecklad för att stödja hållbarhetsanalyser av saneringsalternativ i riskvärderingsprocessen, d v s i ett skede när man har tillgång till relativt stor mängd av detaljerad information om föroreningssituationen på platsen.

Detta arbete utvärderar möjligheten att tillämpa SCORE i tidiga planeringsskeden, och presenterar den hållbarhetsutvärdering som utförts i fallstudien Fixfabriken. Svårigheter att genomföra SCORE-analysen har framförallt varit kopplade till den osäkerhet om de aktuella förhållandena på platsen och om den framtida stadsutvecklingen. Dessutom är konsekvenserna av framtida markanvänding svåra att bedöma med SCOREs nuvarande utformning. För att lättare kunna tillämpa SCORE i tidiga planeringsskeden ges två förslag på utveckling eller anpassning i den ekonomiska delen av hållbarhetsanalysen: 1) att använda en semikvantitativ bedömning av kostnader och nyttor i stället för en kvantitativ; 2) att den ekonomiska analysen utökas för att även innehålla kostnader och nyttor kopplade till själva exploateringen. Kompletterande arbete behövs dock för att till fullo bedöma de möjligheterna.

Nyckelord: förnyelse av tidigare exploaterad mark; hållbarhet; bedömning; kostnads-nyttoanalys; multikriterieanalys, SCORE; Balance 4P; markföroreningar.

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Preface and acknowledgements

This master thesis is developed to obtain the Master of Science degree, by concluding the Master Program in Infrastructures and Environmental Engineering at Chalmers University of Technology, in Sweden. The work was held at the GeoEngineering Division of the Department of Civil and Environmental Engineering. The main work was developed between June 2014 and December 2014, with the final revisions concluded in April 2015. The master thesis seminar took place in May 2015.

I am grateful to Jenny Norrman from Chalmers University of Technology, my examiner and supervisor, for her support, for guiding me and for the valuable discussions and challenges raised during my work and the writing of this thesis, as well as reviewing my report. Thank you also to Jenny for giving me the opportunity of working in the project Balance 4P, which later on enabled the writing of this master thesis. I am also thankful to my co-supervisor, Yeheniya Volchko from Chalmers, for her encouragement and contributions in the writing of this thesis. Additionally, I would like to thank Lars Rosén for his comments on my thesis. Thank you also to my colleague Nathali Cuotto for being my opponent and for her contributions for the discussion held during my master thesis seminar.

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Finally, thank you Leonardo for his support and enthusiasm, and my children Vicente and Rafael for their endless love. Thank you also to my family, friends and my present and former colleagues, even when absent, for somehow they became part of the process.

Göteborg, May 2015

Rita Garção

Preface by the supervisors

This Master's thesis was initiated as a part of the research project BALANCE 4P: Balancing decisions for urban brownfield regeneration – people, planet, profit and processes, funded by the SNOWMAN network (SN04-01). The overall aim of BALANCE 4P has been to deliver a holistic approach that supports sustainable urban renewal through the redevelopment of contaminated land and underused sites (brownfields), by integrating subsurface aspects and urban planning. An important part of the work has been to work with case studies in Sweden, Belgium and the Netherlands. For the Swedish case study site, Fixfabriken, a number of workshops have been carried out as well as a number of assessments of redevelopment alternatives, in order to apply and evaluate possibilities to lift forward subsurface aspects in the early planning stages. The work within this thesis is part of the work with the Fixfabriken case study, where the SCORE-tool is applied and evaluated with regard to its suitability for application in early planning stages.

Rita has worked enthusiastically and goal-oriented in an independent way with a quite challenging assignment. Data has been scarce, information has been needed from several different types of sources, and the preconditions have changed during the course of the work. Nevertheless, Rita has finalized the work and produced an impressive report containing a massive amount of information and important input not only to the work in BALANCE 4P and to the Fixfabriken project, but also to the work with the SCORE-tool conducted within the research group.

We wish you all the best in the future!

Göteborg, June 23, 2015

Jenny Norrman	Yevheniya Volchko
Main supervisor	Assisting supervisor

Notations

Acronyms

B4P / Balance 4P – The research project “Balance 4P - Balancing decisions for urban brownfield redevelopment - people, planet, profit and processes”

CBA – cost-benefit analysis

FA – farlig avfall (hazardous waste)

KM – känslig markanvändning (sensitive land use)

MCA / MCDA – multi-criteria analysis / multi-criteria decision analysis

MKM – mindre känsliga markanvändning (less sensitive uses)

MSEK – millions of Swedish crowns

NPV – net present value

PAH - Polycyclic aromatic hydrocarbons

PV – present value

SADA - Spatial Analysis and Decision Assistance software

SCORE - Sustainable Choice Of Remediation tool

SEPA – Swedish Environmental Protection Agency (Naturvårdsverket)

TCE – trichloroethylene

TPA – total petroleum hydrocarbons

USEPA - United States Environmental Protection Agency

1 Introduction

This chapter provides the background to the thesis, presents the aim and objectives, delimits the scope of the work, as well as presents the structure of the report.

1.1 Background

Urban development and urban redevelopment are necessary now and in the coming years, all over the globe. On one hand, world population has been growing and it is expected that more and more people will live in urban areas. According to UN (2014), continuing population growth and urbanization are projected to add 2.5 billion people to the world's urban population by 2050, with nearly 90 per cent of the increase concentrated in Asia and Africa. On the other hand, there is lack of space in the urban environment, and there has been misuse of areas within or in the vicinity of cities, due to former or current activities that in a way or another have negative impacts on the welfare of the local communities and on the environment. These are often called urban brownfield areas (CABERNET, 2006), which quite commonly are contaminated, leading to an increase of the costs of urban redevelopment. A cautious approach is advisable and limited budgets can be a barrier to undertake the desirable actions. Moreover, different stakeholders with diverse interests make, quite often, the planning and decision-making processes even more complex. For these and other reasons, it is necessary to find adequate and liable solutions, considering the three domains of sustainability, namely economic, social and environmental ones. To deal with this, studies to support decision-making need to be done which have a scope and level of detail adequate to the stage of planning or implementation of each project. Otherwise less supported decisions will be made, thus affecting resources in an improper way.

Quite often, redevelopment of brownfield sites has remediation as a major part of the interventions. Therefore, a holistic perspective including all the works and assessing its effects on economic, environmental and social domains should be part of the process. It has also been shown that more efficient and sustainable solutions are likely to be achieved in early stages of the planning process (SuRF-UK, 2010).

Worldwide, several tools and methods are available and have been developed and used to assess sustainability at different stages of the planning and implementation process of urban development including remediation, to serve the purpose of supporting sustainable assessment and decision-making. Those may include environmental impact assessment of plans, programs and projects; cost-benefit analysis; multi-criteria analysis (MCA) / multi-criteria decision analysis (MCDA); among others. Specific tools applicable to contaminated sites and urban brownfield areas have also been developed or tested (COBRAMAN, 2009; Kok, 2014; Rosén *et al*, 2015; SURF-UK, 2010), such as the Sustainable Choice Of Remediation (SCORE) MCDA-method based tool. SCORE, still under development, presently allows supporting assessment of the sustainability of remediation alternatives relative to a reference alternative. It has been applied to several case studies (Rosén *et al*, 2015; Volchko *et al.*, 2014).

1.2 Aim & Objectives

The aim of this master thesis is to apply the Sustainable Choice Of Remediation - SCORE tool (Chalmers, 2014) to a context, which it was not originally developed for. SCORE has so far been applied to assess the most sustainable remediation alternative in contaminated sites projects. In this study, it is applied to an earlier stage of the brownfield redevelopment process – at the planning stage, considering alternatives of both different remediation approaches and future land uses. This work is part of the research project "Balance 4P - Balancing decisions for urban brownfield regeneration - people, planet, profit and processes", financed by the SNOWMAN Network. In B4P, SCORE is one of several tools that are applied to the Fixfabriken case study.

Based on the experience of applying the SCORE tool (Chalmers, 2014), the goal is to give recommendations on potential adjustments of the tool, to enable its use to similar processes as the case study, i.e., at early stages of the planning process.

In order to fulfil the overall objective, the main tasks included are the following:

- Characterization of the Fixfabriken site, regarding its natural conditions, anthropogenic use and environmental contamination.
- Generation of alternatives for the site, which include different options of soil remediation and of urban redevelopment;
- Performance of a CBA, to assess the societal profitability of the alternatives;
- Assessment of the sustainability of the alternatives, by integrating economic, environmental and social domains in the SCORE tool;
- Suggestions for improvements and adjustments to the SCORE tool to enable application of SCORE to urban redevelopment in early stages of the planning process.

1.3 Limitations

This master thesis focuses on one case study, Fixfabriken site.

For remedial strategies and land use a limited number of alternatives are considered, and assessed based on the information available until August 2014. More recent data of the local conditions is not included. It is important to stress that alternatives are developed for research purposes and have informative character for the authorities dealing with urban planning and environmental protection, rather than aiming to be the most adequate solutions to the site.

It is documented that SCORE has been designed and used to remediation projects, and that is not tailored to be used to land-use planning processes. The contributions to eventually use the tool to a similar process as that of the case study are mainly explorative and require further investigation, development, implementation and testing, which is out of the scope of this thesis. Furthermore, the suggestions are exclusively focused on the economic domain.

1.4 Structure of the report

This Master thesis begins with an introductory chapter (Chapter 1) contextualizing the subject of urban brownfield redevelopment and how the work included in the thesis embraces this issue. Chapter 2 provides a general view of how the subject has been considered, namely projects and tools addressing the subject, as well as key-concepts on this.

Chapter 3 and Chapter 4 are focused on the method used. Chapter 3 presents a concise theoretical description of MCA as decision-support tool in sustainability and a more detailed description of the SCORE tool (Chalmers, 2014) that supported the work done in the thesis. Chapter 4 describes the working process and methods developed.

Chapter 5 addresses the Fixfabriken case study site conditions: the natural ones, the expected soil contamination, archaeology at the site, the present land uses and diverse constraints to future development. Chapter 6 identifies and describes the reference alternative and some of the possible future alternatives of remediation and redevelopment of the case study site. Chapter 7 focus on the application of the SCORE tool, on the detailed description of the CBA performed and concise information of the assessment made of the environmental and social domains for the Fixfabriken site. Results considering the uncertainty and sensitivity analysis are presented.

Chapter 8 highlight feedback from the application of the tool to the case study. The chapter continues suggesting adjustments to the tool in order to allow its application to process of urban brownfield redevelopment in early stages. Chapter 9 discusses how the case study was conducted and how the SCORE tool performed. Chapter 10 concludes and provides recommendations.

Appendices complement the main text of the report, providing the description and economic assessment of an initial set of alternatives (Appendix 1), as well as discussing additional potential alternatives, that were excluded (Appendix 2). Detailed information on the methods used when performing the CBA, and results obtained are presented in Appendices 3, 4, 5, 6, 7, 8, 9 and 10. Additional information on the motivation while assessing environmental and social domains is included in Appendix 11.

2 Urban Brownfield Redevelopment

This chapter presents a short review of some key concepts in urban brownfield redevelopment. Furthermore, an idea of the diversity of platforms that have been focusing on this field, and of some of the instruments, tools and methods that are available are given.

2.1 Key Concepts

Several key concepts need to be pointed out, namely, brownfield, redevelopment / regeneration / revitalization / renewal, sustainable development, risk management and source-pathway-receptor contaminant linkage, remediation and sustainable remediation.

Sustainable development

Brundtland Commission initially defined sustainable development as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (UN, 1987). It comprises a balance between environmental, social and economic domains (SURF-UK, 2010), as represented in Figure 2-1.

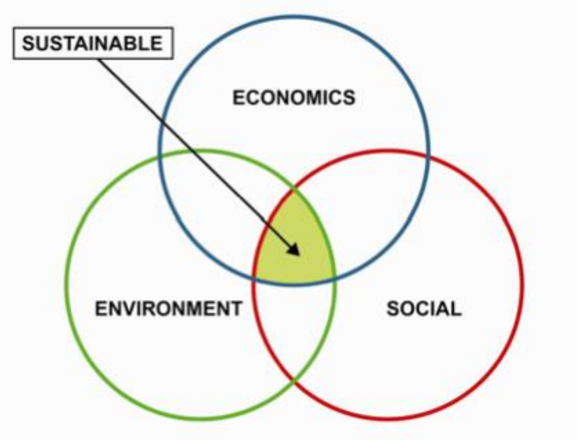


Figure 2-1 Sustainable development as a balance between environmental, social and economic domains (SURF-UK, 2010).

Brownfield areas and redevelopment

The definition of brownfield areas varies across the world and even in Europe. Based on different concepts from European countries, the Concerted Action on Brownfield and Economic Regeneration Network, which also stands for CABERNET, defines brownfields as areas that "*have been affected by the former uses of the site and surrounding land; are derelict and underused; may have real or perceived contamination problems; are mainly in developed urban areas; and require intervention to bring them back to beneficial use*" (CABERNET, 2006).

Different terms appear connected to the improvement of the environmental state of brownfield areas and its use, namely redevelopment, regeneration, revitalization and renewal, which quite often also include remedial actions. In the present report, the word redevelopment is used.

Redevelopment of urban brownfields allows confining and reverting eventual contamination problems, take advantage of land already used, thus preventing / reducing the urban sprawl and the need to uptake greenfield or virgin land that can be left untouched or to other purposes.

Risk management, remediation and sustainable assessment

Risk management aims to mitigate identified risks, thus eliminating or reducing it to acceptable levels. In contaminated sites, risk management aims to mitigate risks to human health and to the environment, by means of breaking the source-pathway-receptor contaminant linkage, as shown in the conceptual model in Figure 2-2. Breaking the contaminant linkage, or remediation, can be achieved by: 1) removing or modifying the source; 2) interrupting the pathway; 3) modifying the behaviour of the receptor, or relocating the receptor, either human or sensitive species (Bardos *et al.*, 2011).

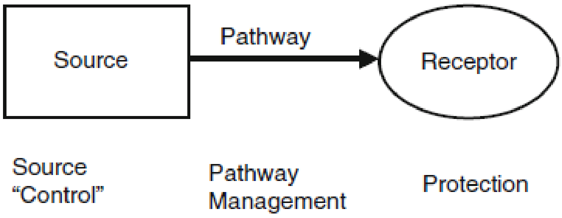


Figure 2-2 Source-pathway-receptor model. Risk management interventions (Bardos et al., 2011).

Sustainable Remediation Forum UK (SuRF – UK) defines assessment of sustainable remediation as "*the practice of demonstrating, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is greater than its impact and that the optimum remediation solution is selected through the use of a balanced decision-making process*" (SuRF-UK, 2010).

Tools that enhance the benefits of the process and lead to sustainable choices towards a sustainable development of the urban areas and surroundings should support the redevelopment initiatives and the decision process. Robust and integrated decision-making is necessary when it comes to redevelopment of brownfield areas (Pollard *et al.*, 2004).

2.2 Networks and projects

Due to the relevance of the subject, different research networks / platforms and projects have been focusing to a higher or lower extent on brownfields, namely the European ones or based in one European country: BERI - Brownfield European Regenerative Initiative, CABERNET - Concerted Action on Brownfield and Economic Regeneration Network, CLARINET - Contaminated Land Rehabilitation Network for Environmental Technologies, COBRAMAN - Manager Coordinating

Brownfield Redevelopment Activities, EUBRA - European Brownfield Revitalisation platform, EUGRIS - European Groundwater and Contaminated Land Remediation Information System, LUDA - Improving the quality of life in Large Urban Distressed Areas, MAGIC - Management of Groundwater at Industrially Contaminated Areas, Brownfield Working Group integrated in NICOLE - Network for Industrially Contaminated Land In Europe, NORISC - Network Oriented Risk-assessment by In-situ Screening of Contaminated sites, PROSIDE - Promoting Sustainable Inner Urban Development, REFINA - Research for the Reduction of Land Consumption and for Sustainable Land Management, REKULA - Restructuring Cultural Landscapes, RESCUE - Regeneration of European Sites in Cities and Urban Environments, REVIT - Revitalising Industrial Sites, SUBR:IM - Sustainable Brownfield Regeneration: Integrated Management (NICOLE Brownfield Working Group, 2011) (COBRAMAN, 2009), SuRF – Sustainable Remediation Forum UK, TIMBRE - Tailored Improvement of Brownfield Regeneration in Europe, HOMBRE - Holistic Management of Brownfield Regeneration, and, more recently, BALANCE 4P - Balancing decisions for urban brownfield regeneration - people, planet, profit and processes (Kok, 2014).

BALANCE 4P research project has the overall aim of "*deliver a holistic approach that supports sustainable urban renewal through the redevelopment of contaminated land and underused sites (brownfield)*"[1]. In the project, partners from three European countries, namely from Sweden, The Netherlands and Belgium, are collaborating towards specific objectives, including:

> "*1) application and assessment of methods for design of urban renewal/land redevelopment strategies for brownfields that embrace the case-specific opportunities and challenges;*
>
> *2) sustainability assessment of alternative land redevelopment strategies to evaluate and compare the ecological, economic and social impacts of land use change and remedial technologies; and*
>
> *3) development of a practice for redevelopment of contaminated land in rules and regulations to enable implementations.*" (SNOWMAN NETWORK Knowledge for Sustainable Soils, 2015).

Within the B4P project three case studies are developed, Fixfabriken, in Göteborg, Sweden, being one of them.

2.3 Instruments, tools and methods

Different tools are available to support assessing the sustainability. Beames *et al* (2014) suggest classifying existing decision support systems (DSS) for assessing sustainability into: 1) sustainable technology appraisal DSS, and 2) sustainable site redevelopment appraisal DSS. The first is the most common type, and is used to find the most sustainable remediation technology alternative out of the feasible ones. The second type supports other parts of the decision process, by considering impacts due to site re-use, and therefore suitable for supporting assessments of brownfield redevelopment (Beames *et al*., 2014). As this type of tool can be used in an early stage

---

[1] For more information on B4P project see: http://www.chalmers.se/en/projects/Pages/Balance-4P.aspx

of a land redevelopment process, more sustainable decisions can be made, thus most benefit is expected (SURF-UK, 2010).

Beames *et al* (2014) state that a future development of sustainability appraisal is needed. By combining those two different types of DSS tools, it will be possible for both remediation and post remediation (or future land-use) impacts to be considered together.

Presently, a range of tools and methods can be used for undertaking a sustainability assessment. Coverage of the environmental, social and economic domains varies, as well as the type of assessment (quantitative, semi-quantitative or qualitative) and the scope of analysis within each domain (narrow or wide) (SURF-UK, 2010). Sustainability assessment applied to the stage of remediation, a stage that is often necessary for improvement of brownfield areas, might be supported by: environmental impact assessment and strategic environmental assessment, environmental risk assessment, social impact assessment, health impact assessment, cost-benefit analysis (CBA), multi-criteria analysis (MCA) and multi-attribute techniques (MAT), life cycle analysis (LCA), sustainability appraisal, stakeholder analysis, engagement techniques, efficiency performance evaluation, and carbon metrics based tools (Pollard *et al.*, 2004; SuRF UK, 2010; Beames *et al.*, 2014, EC, 2014; EC, 2014a; EC, 2014b; Beames *et al.*, 2015). COBRAMAN (2009) identifies tools considered useful when proceeding with brownfield redevelopment and Kok (2014) presents an extensive overview of instruments, tools or methods developed and applied in Europe, suggesting that can be applied in brownfield redevelopment.

Examples of some specific tools are: 1) MCA based tools: SCORE (Rosén *et al*, 2013), SAMLA for contaminated sites (SGI, 2014) and Flandres MCA for BATNEEC, the latest including environmental, technical and financial aspects; 2) Life cycle-based evaluation methods: REC-risk reduction, Assessment of environmental merit and costs (Cappuyns, 2013); 3) Carbon footprint calculator, CO_2 calculator: the Swedish Carbon footprint calculator to remedial actions (SGF, 2014), Soil Remediation Tool (SRT), SiteWise^{TM}Tool and CO_2 calculator by Tauw (Cappuyns, 2013).

The research project Balance 4P tested different instruments to generate and to assess redevelopment alternatives in urban brownfields. To generate alternatives, stakeholder consultation and SEES-tool (System Exploration Environment and Subsurface) (Deltares, 2014; Maring *et al.*, 2015) were used, whereas assessing alternatives was done by performing qualitative Social Impact Analysis (SIA), Semi-quantitative mapping of changes in Ecosystem Services (ESS), CBA and MCA tools, more specifically SCORE (SNOWMAN, 2015). As presented in this master thesis, SCORE is tested as being of potential use for sustainable site redevelopment / scenario appraisal, rather than exclusively for sustainable remediation technology appraisal, as it is currently designed for.

3 SCORE Multi-Criteria Analysis based tool

This chapter introduces briefly MCDA. Furthermore, it presents and describes the tool to support decision-making SCORE and its theoretical background.

Multi-criteria analysis (MCA) has been used to support environmental decision-making and sustainability assessment. By applying an MCA, the degree to which a project fulfills a set of performance criteria is assessed. Both qualitative and quantitative information are possible to be integrated in a MCA. On the other hand, MCA methods include qualitative, semi-quantitative and quantitative approaches. When numerical values are attributed as scores and weights of criteria, multi-criteria decision analysis (MCDA) designation is often used, see Rosén *et al.* (2015).

SCORE (Sustainable Choice of REmediation) is an MCDA tool. As described in Rosén *et al.* (2015), SCORE is designed and used specifically to sustainability assessment and support to decision-making when choosing between a set of remediation alternatives, where:

- remediation alternatives are assessed against a reference alternative;
- the assessment is based on how each alternative performs on the key criteria in the economic, environmental and social domains;
- qualitative and quantitative estimations of criteria are integrated;
- scorings are used in the environmental and social domains, whereas quantifications of monetary costs and benefits are considered in the economic domain, expressed in millions of Swedish crowns (MSEK);
- scorings and quantifications of the criteria and the relative importance (weights) of these criteria are taken into account to calculate a normalized score for each alternative, by using a linear additive approach;
- compensation between different components of the system (both sustainability domain and criteria levels) is considered in the assessment, leading to classification of the alternatives as having a weak or strong sustainability;
- a full uncertainty analysis of the results, using Monte Carlo simulation, is provided, as well as a sensitivity analysis of the outcomes.
- the structure allows preferences and opinions of involved stakeholders to be openly integrated into the analysis, by means of weighting of sustainability domains and criteria.

More detailed information about SCORE framework and conceptual model, key performance criteria, in particular to economic domain, sustainability assessment, uncertainty and current practice are further on provided.

3.1 SCORE framework and conceptual model

SCORE decision support framework in Figure 3-1, is focus on providing support to decision-making by comparing the performance of a set of remediation projects alternatives against a reference alternative. For detailed explanation of the framework, see Rosén *et al.* (2015).

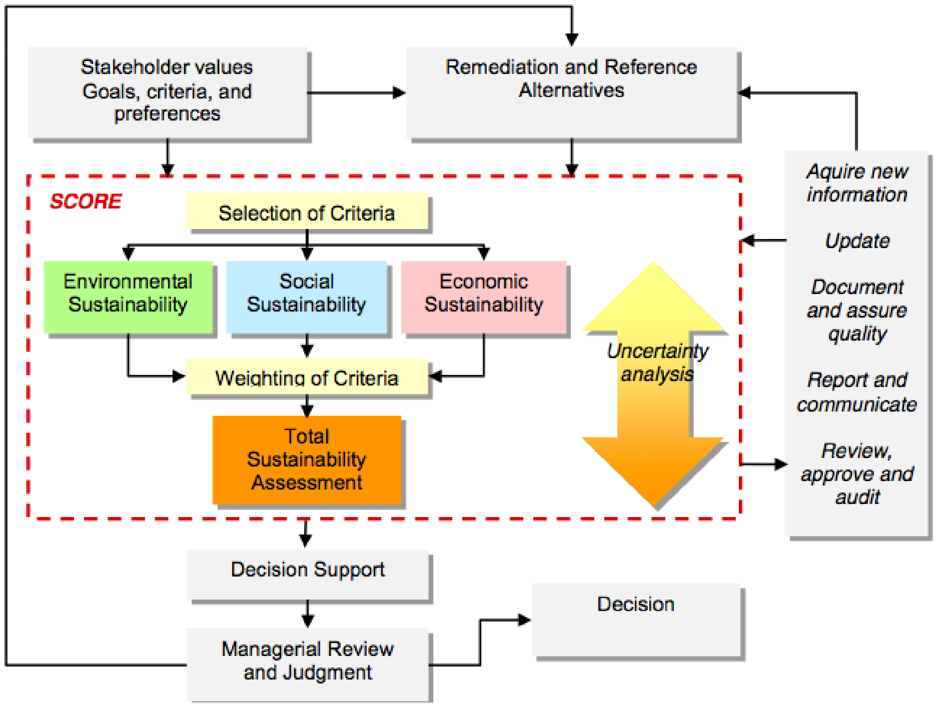


Figure 3-1 The SCORE decision support framework, in Rosén et al. (2015).

The conceptual model of SCORE, represented in Figure 3-2, is based on the cause-effect chain concept that is commonly used in risk assessment.

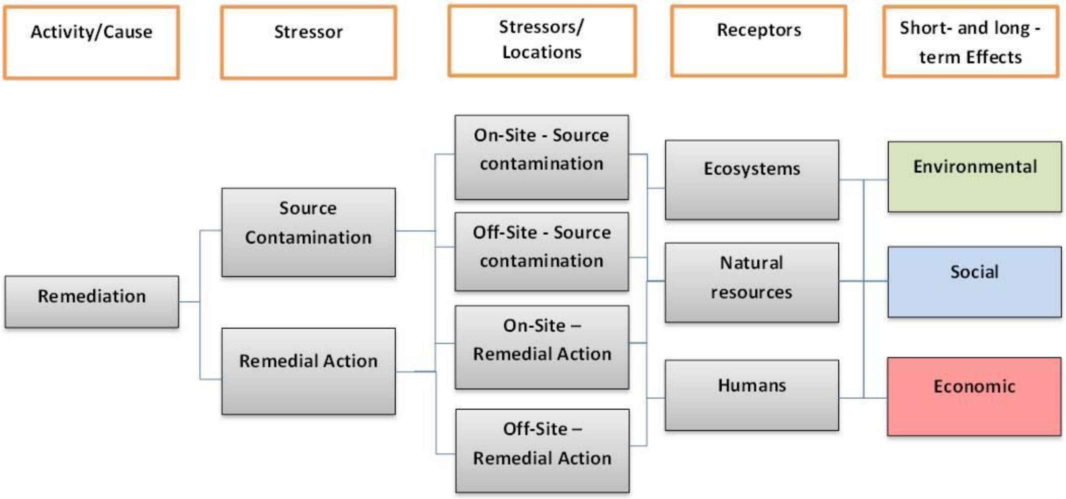


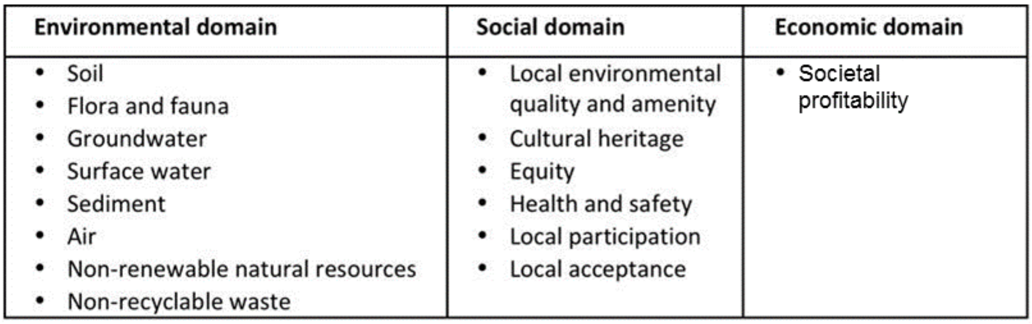
Figure 3-2 The SCORE conceptual model, in Rosén et al. (2015).

The cause of the effects is the remediation action at a particular site; the main stressors are the change in the source contamination and the occurrence of the remedial action; their effects can happen at different locations, on-site and / or off-site; the receptors that can be affected by the remediation are ecosystems, humans and / or natural resources; long and short term effects include environmental, social and economic ones.

3.2 Key performance criteria

Key performance criteria for each sustainability domain that are capable of representing all key sustainability aspects in remediation projects and avoid double-counting of effects have been identified as explained in Brinkhoff (2014) and are presented in Table 3-1.

Table 3-1 Key criteria used during the assessment with SCORE (Rosén et al., 2015).



Environmental domain	Social domain	Economic domain
• Soil • Flora and fauna • Groundwater • Surface water • Sediment • Air • Non-renewable natural resources • Non-recyclable waste	• Local environmental quality and amenity • Cultural heritage • Equity • Health and safety • Local participation • Local acceptance	• Societal profitability

Environmental domain comprises eight key criteria and social domain includes six, described respectively in Table 3-2 and Table 3-3. The identification of the sub-criteria is available in Rosén *et al.* (2015). Recently, a specific tool was developed to assess the key performance criteria Soil of the environmental domain, see Volchko (2014).

Table 3-2 Description of the environmental domain key criteria (Rosén et al., 2015).

Key criteria	**Description**
E1. Soil	Ecotoxicological risk due to the soil contamination (reflects the effects on the soil ecosystems due to the change in source contamination and/or to impacts of the remedial action) and soil function component (takes into account the effects of the remedial action on soil's capability of providing good pre-conditions for organisms, taking into account factors such as soil texture, pH, organic content, availability of nitrogen and carbon, and water retention capacity).
E2. Flora & fauna	Physical impacts from the remedial action on e.g. trees, birds and mammal habitats.
E3. Groundwater	Effects on groundwater quality and ecotoxicological risks in the discharge zone to e.g. wetland areas potentially affected by the source contamination and/or the remedial action.
E4. Surface water	Effects on surface water quality and ecotoxicological risks in the water zone of surface water bodies and streams potentially affected by the source contamination and/or remedial action.
E5. Sediment	Effects on ecotoxicological risks for organisms in sediments potentially affected by the source contamination and/or remedial action.
E6. Air	Total emissions to air, including greenhouse gases, acidifying substances, and particulate matter, due to the remedial action.
E7. Non-renewable natural resources	Total use of non-renewable natural resources, such as fossil fuels, virgin soil and rock material for backfilling, and occupation of new land for disposal, due to the remedial action.
E8. Non-recyclable waste	Total production of non-recyclable waste due to the remedial action.

Table 3-3 Description of the social domain key criteria (Rosén et al., 2015).

Key criteria	**Description**
S1. Local environmental quality (LEQ) and amenity, including physical disturbances	Effects on e.g. recreational values, noise or/and the accessibility of the area.
S2. Cultural heritage	Effects on cultural heritage items due to destruction, preservation or restoration, but not with regard to the increased access to those items that can be expected from a change in SC and subsequent change in land-use (this is scored in S1).
S3. Health and safety	Effects on human health and safety due to exposure and spreading of contaminants in soil, dust, air, water and due to accidental risks (e.g. traffic).
S4. Equity	Effects on vulnerable groups in the society.
S5. Local participation	Effects on how the local community is affected with regard to local job opportunities or other local activities. This criterion does not relate to participation of the local community in the remediation decision process.

Economic domain includes one key performance criterion, the societal profitability, which is obtained by performing a cost-benefit analysis (CBA). The CBA is preceded by a preliminary assessment of the level of importance of each economic item (either benefits or costs), in order to prioritize the ones to be monetized.

Within the CBA, positive and negative consequences of the alternatives are expressed in monetary terms, respectively as benefits (*Bi*) and costs (*Ci*), considering a certain time horizon (*t*) during which a certain effect last, and a selected social discount rate (*r*). The monetization of each benefit and cost item is expressed in present value (PV), and then the Net Present Value (NPV) is calculated, see the following Equations, from Söderqvist *et al.* (2015).

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

Where $B_t \equiv B1_t + B2_t + B3_t + B4_t$ and $C_t \equiv C1_t + C2_t + C3_t + C4_t$

$$PV(B_i) = \sum_{t=0}^{T} \frac{1}{(1+r_t)^t} B_{it}$$

$$PV(C_i) = \sum_{t=0}^{T} \frac{1}{(1+r_t)^t} C_{it}$$

$$NPV = \sum_{i=1}^{4} PV(B_i) - \sum_{i=1}^{4} PV(C_i)$$

NPV, the sum of all the benefits and costs inform on if an alternative entails a positive or a negative societal profitability, respectively if the sum is positive or negative. For a complete description, see Söderqvist *et al.* (2015).

Four main benefits and four main costs are part of SCORE to assess the key performance criterion of the economic domain, see description in Table 3-4.

Table 3-4 Description of the economic domain items (Söderqvist et al., 2015).

Benefits / Costs Items	**Description**
B1. Increased property value on site	Difference between the property value after the remediation and the property value due to the flow of expected profits in the situation before remediation.
B2. Improved health	Reductions in health risks, either acute ones (B2a) such as poisoning, or non-acute ones (B2b) such as exposure to carcinogenic substances, are a possible consequence of the remediation. Also include other types of improved health (B2c), as mitigating anxiety caused by the contamination.
B3. Increased provision of ecosystem services	Recreational opportunities are one ecosystem service often influenced positively by remediation. New or improved areas for recreation might be created on the remediated site (B3a) and / or in the surroundings (B3b). Other improvements (B3c) might be improved capacity of water systems affected by the site to support agricultural services.
B4. Other positive externalities than B2 and B3	Examples might include: the creation of knowledge by developing a new remediation technique; agglomeration economies that might be caused through the establishment of a new activity at the site; and an increase in cultural values through restoring industry buildings or other cultural heritage.
C1. Remediation costs	Costs for carrying out the remediation, including costs with: site investigations and design of remedial actions, including institutional controls (C1a); project management, technical support and working environment (C1b); referring to potential loans financing the remedial action and depreciation of human-made capital such as machines (capital costs) (C1c); mobilization (establishment of facilities and preparation of the site for performing the remedial action), remediation work and demobilization (C1d); monitoring during and after remediation (C1e); project risks associated with the remediation method (e.g., it turns to be inappropriate or inefficient), authorities (e.g., remediation permits are delayed), public opinion, project organization and financial structure, technical basis for assessment and liability issues (e.g., contaminant unexpectedly affects an adjacent lot) (C1f).
C2. Impaired health due to remedial action	Includes costs of increased health risks due to remedial action on site (C2a), transports to and from the site (C2b) and at disposal sites (C2c) where contaminated material are disposed temporarily or permanently. Can be caused by, e.g., noise and emissions, and heavy transports that imply a reduced traffic safety. Other types of impaired health due to remedial action are also possible, e.g., public distrust in the chosen option, psychosocial conditions creating anxiety among visitors and neighbours (C2d).
C3. Decreased provision of ecosystem services due to remedial action	Includes costs of decreased provision of ecosystem services due to remedial action, e.g. reduced recreational opportunities, on site (C3a), transports to and from the site (C3b) and at disposal sites (C3c). Can be caused by, e.g., emissions from remediation work and transport.
C4. Other negative externalities than C2 and C3	Example might be the reduction of cultural values through impairment or destruction of cultural heritage at the site.

Brinkhoff (2014) developed a method and tool for project risk assessment (cost item C1f) for the developer.

3.3 Sustainability assessment process

Before starting the MCDA, alternatives complying with constraints such as time, budget, technical feasibility, legal aspects, and public acceptability, are defined, as well as the reference alternative. The SCORE assessment follows several main steps.

In selection of criteria, key criteria and sub-criteria from environmental and social domains are selected for consideration in the assessment. In the economic domain, benefits and costs expected to be relevant are included to be monetized. Eventual exclusion of criteria or cost-benefit items from the assessment must be clearly motivated.

A semi-quantitative (ordinal) performance scale is used when scoring the effects in the environmental and social domains. By using a guidance matrix for each criterion, one of the following levels are assigned: Very positive effect: +6 to +10; Positive effect: +1 to +5; No effect: 0; Negative effect: -1 to -5; Very negative effect: -6 to -10. A short motivation for the score chosen needs to be done, contributing to a higher transparency of the assessment of these two domains. The scorings are subjective and are based on available data, expert judgment, questionnaires and interviews.

The items of the economic domain classified as relevant should be monetized as many as possible. The relevant items not able to monetize need to be assessed qualitatively as very important or somewhat important items, and further on included in a qualitative discussion concerning not quantifiable items.

Weighting of criteria ($w_{k,D}$) and sub-criteria ($w_{j,k}$) of the environmental and social domains is attributed with respect to their relative importance, see the following Equations, from Rosén *et al.* (2015).

$$w_{k,D} = \frac{I_{k,D}}{\sum_{k=1}^{K} I_{k,D}} \qquad\qquad w_{j,k} = \frac{I_{j,k}}{\sum_{j=1}^{J} I_{j,k}}.$$

The parameters that are part of the equations are: to calculate $w_{k,D}$, the importance I of each key criterion k in domain D, given by the numerical value attributed when weighting; to calculate $w_{j,k}$, the importance I of each sub-key criterion j in key-criterion k, once again given by the numerical value attributed when weighting.

To each domain D, a sustainability index H is calculated for each alternative i. The weighted sum of the scorings follows a simple linear additive approach, see next Equation (Rosén *et al.*, 2015). Z is the score of the sub-criterion j.

$$H_{D,i} = \sum_{k=1}^{K} w_{k,D} \sum_{j=1}^{J} w_{j,k,D} Z_{j,k,D}$$

A normalized sustainability SCORE is calculated for each alternative taking into account the three domains, namely the environmental sustainability score (H_E), the social sustainability score (H_S) and the economic sustainability (NPV), see following equation (Rosén *et al.*, 2015). The weight of each domain is represented by W.

$$H_i = 100 \left[\begin{array}{l} W_E \dfrac{H_{E,i}}{Max\left[Max\left(H_{E,1..N}\right); \left|Min\left(H_{H,1..N}\right)\right|\right]} + W_{SC} \dfrac{H_{S,i}}{Max\left[Max\left(H_{S,1..N}\right); \left|Min\left(H_{S,1..N}\right)\right|\right]} \\ + W_{NPV} \dfrac{NPV_i}{Max\left[Max(NPV_{1..N}); \left|Min(NPV_{1...N})\right|\right]} \end{array} \right]$$

The normalized score scale has a minimal value of -100 and a maximum one of + 100. Whenever an alternative has a positive score, it entails more positive effects than negative, therefore leading towards sustainable development. The normalized score can be used to rank the alternatives (Rosén *et al.*, 2015).

3.4 Uncertainty Analysis

The effects of the remedial alternatives are not possible to assess exactly, as there is uncertainty when scoring criteria in the environmental and social domains and when quantifying the economic domain. Uncertainty includes epistemic uncertainty (results from lack of knowledge) and aleatory uncertainty (natural variability). Uncertainty is also a consequence of human subjectivity when scoring the criteria.

SCORE treats the uncertainty by following a Monte Carlo simulation approach, where statistical distributions represent the uncertainties in both scores and quantitative metrics.

When scoring for environmental and social domains, beta distributions represent uncertainties. The distribution is assigned taking three steps: 1) for each sub-criterion within the environmental and social domain, selection of the possible range of scoring; 2) estimation of the most likely score within the range assigned previously; 3) assigning the uncertainty level of the assessment of the most likely effect as low, medium or high.

When monetizing cost and benefit items for economic domain, log-normal distributions are used to calculate uncertainties. The process includes two steps: 1) assigning of the most likely value (MLV) of the present value (PV) of each benefit and cost items; 2) assigning the uncertainty level of the estimation of the MLV as low, medium or high, see Rosén *et al.* (2015). SCORE presents the probabilistic distribution with the credibility (or certainty) of the interval between LCL (lower credibility limit or lowest reasonable PV) and UCL (upper credibility limit or largest reasonable PV) equal to 90%. For additional information about uncertainty in the CBA, see Söderqvist *et al.* (2015).

3.5 Current application

To enable the practical application of SCORE, a computer tool embedded in Excel was developed and has been used to assess the sustainability of several remediation projects case studies (Volchko *et al.*, 2014).

Presently, SCORE is designed to assess alternatives of remedial actions with a fixed future land-use. Thus, it was not developed to compare different future land-uses to support decision-making in land-use planning processes, see Rosén *et al.* (2015). The existent design enables assessing the economic domain by performing a CBA, whereas a semi-quantitative approach is used for the environmental and the social domains. SCORE is till at an experimental phase.

4 Method

This chapter presents the working process followed and the main methods used in this master thesis.

4.1 Working process

The main methodological steps are shown in Figure 4-1. The diagram in the middle includes the several steps undertaken. Tasks within boxes in grey and bold are the ones done by the author, whereas the ones in light grey correspond to tasks shared between the author and the other researchers in Balance 4P. The tasks within the white boxes are the ones where the intervention of the author was by far less relevant. On the left side, the timeframe clarifies that the thesis took place between June and December 2014. On the right side, the interveners are identified shortly.

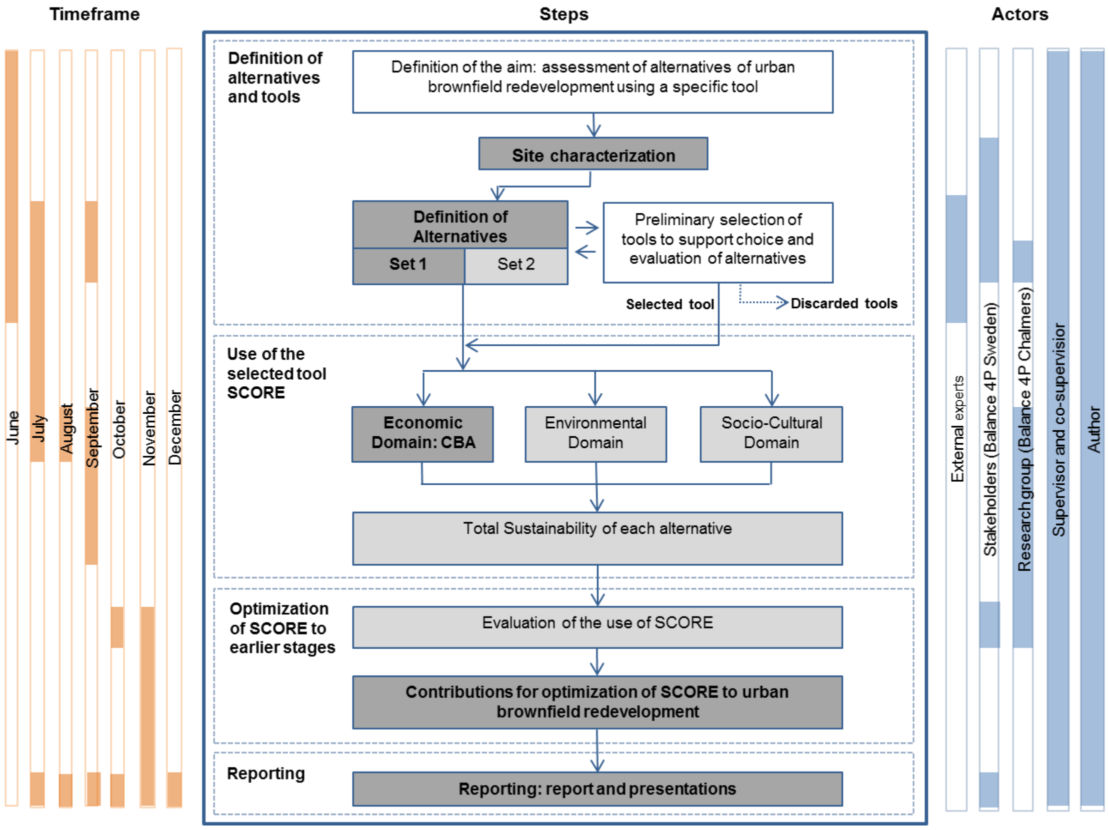


Figure 4-1 Working process, considering the timeframe, steps and actors involved.

4.2 Methods used

Characterization of the Fixfabriken site is based on: visit to the site; site specific data from technical reports, maps and interviews with experts in soil contamination and in the archaeological domain.

Selection of alternatives is initiated by defining that each alternative includes both remediation and urban redevelopment. Additionally, relevant aspects to support suggestions of possibilities of alternatives are identified. As shown in Figure 4-2, choice of alternatives takes into account the local conditions and development restrictions, as well as stakeholder´s preferences (surveys and interviews) and possibilities of differentiated land uses and remedial approaches. Future land uses include new residential areas, new and existing industrial / office areas, and the tram hall, either at the present location or relocated. The identified possibilities are either rejected either selected to the following steps.

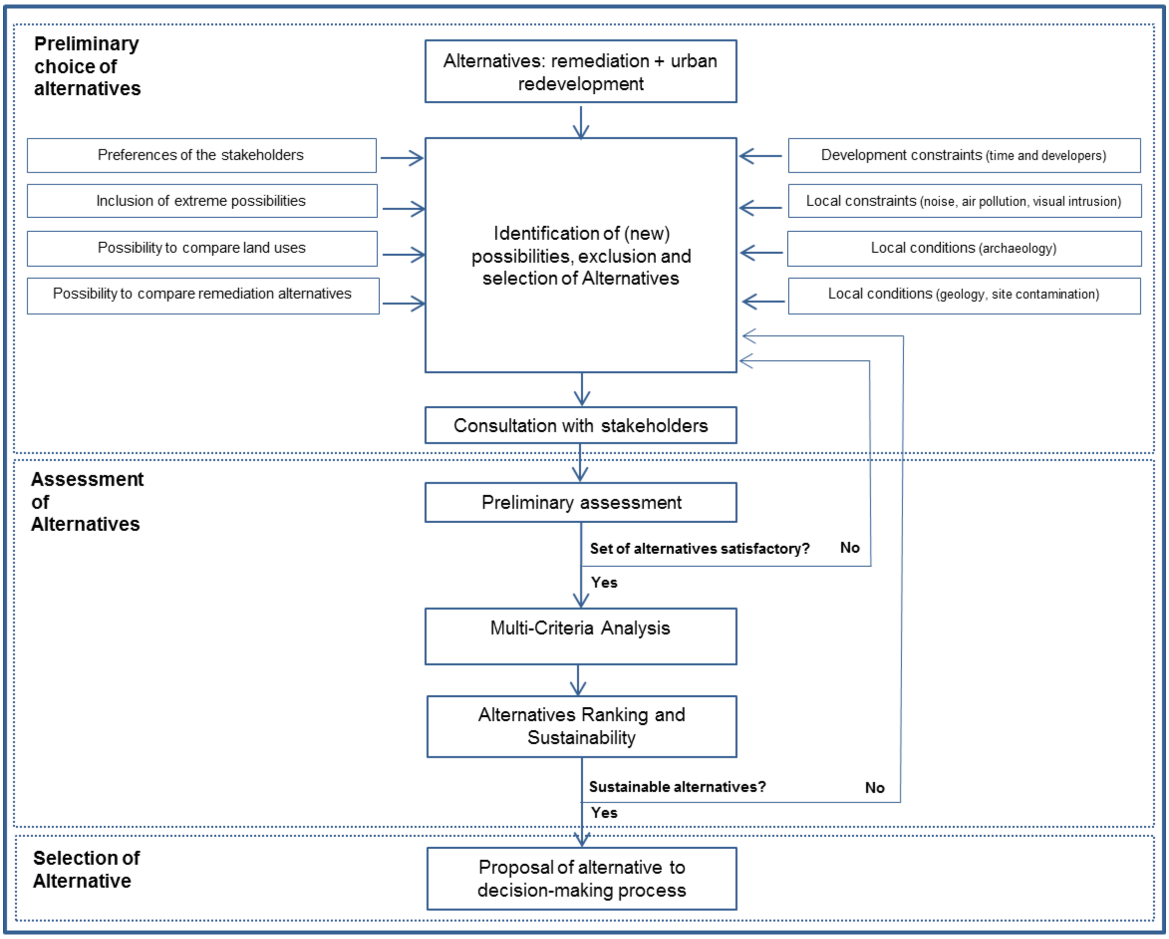


Figure 4-2 Approach for selection and assessment of alternatives.

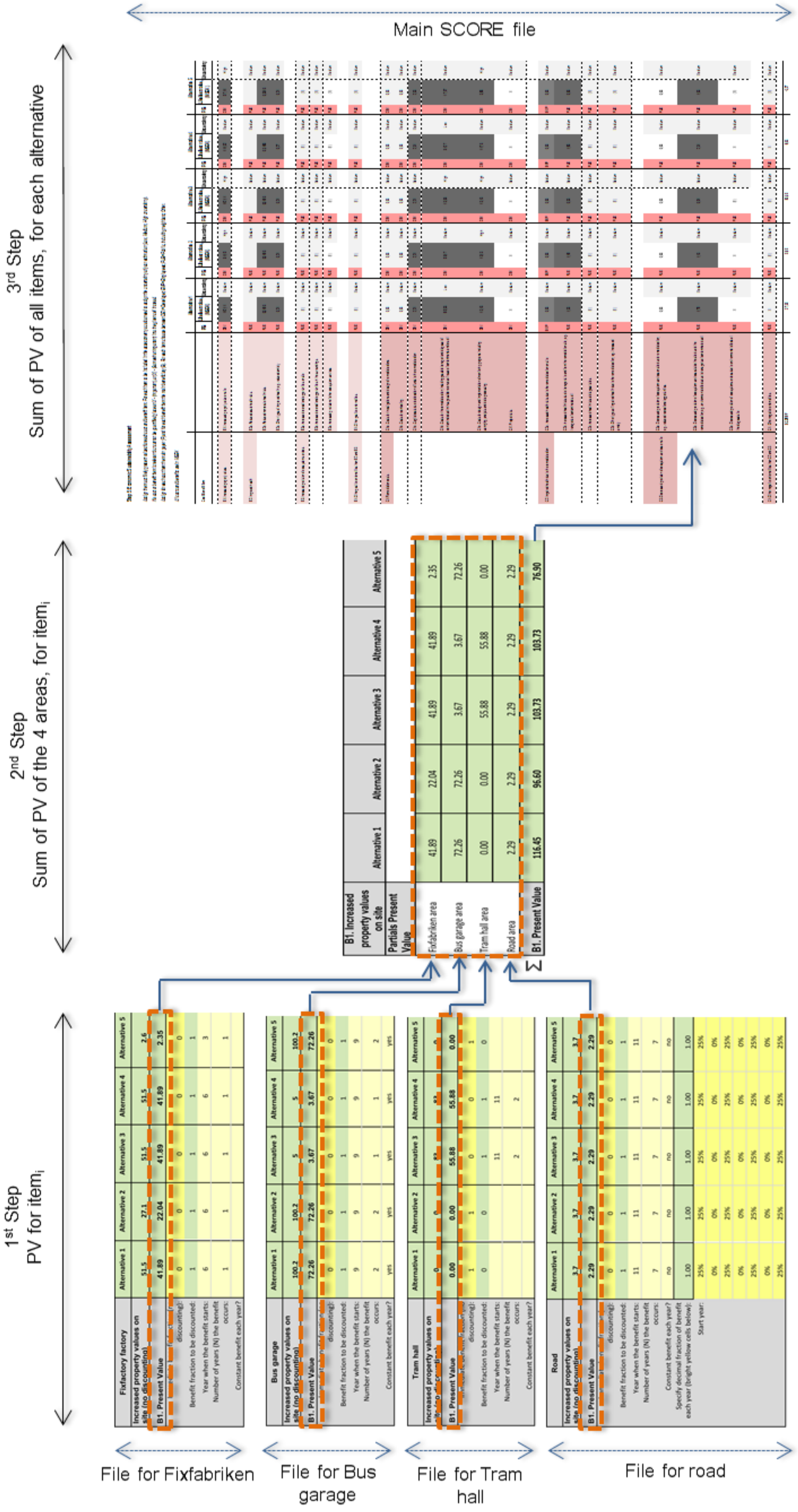
To the Fixfabriken site case study two sets of alternatives of remediation and future land-uses are defined and assessed, namely a preliminary set of alternatives, Set 1, and a new set of alternatives, Set 2. The assessment of Set 1 starts by the economic domain. When a lot of work had already been done, namely the economic assessment concluded, it is recognized that the alternatives as defined are not feasible, and that some of the assumptions of the alternatives are not adjusted to the local conditions. For instance: the excavation depth was probably too significant and it influenced substancially the results; the treatment approach was not adequate to the assumed specific soil distribution fractions at the site. At the same time, opportunity to “redo work” is taken and new alternatives are defined within the Balance 4P research group, resulting in Set 2. A full assessment is then performed to this latest set, focusing on the three domains of sustainability, economic, environmental and social ones, which is supported by the SCORE tool (Chalmers, 2014) presented in Chapter 3.

Assessment of the economic domain of the redevelopment of the alternatives is performed through a Cost-Benefit Analysis (CBA). Different benefit and cost items are monetized and expressed in the Present Value (PV), thus enabling calculating the Net Present Value (NPV) and therefore the societal profitability of the different alternatives. The SCORE tool is used to identify the items to consider, and a previous master thesis (Landström & Östlund, 2011) where an initial version of the tool was used to a different case study, is a support for some of the specific methodologies to monetize cost and benefit items.

In this process, not all the cost and benefit items are monetized, e.g. due to time constraints. Not taking into account the results of the non-monetized items might be problematic if there are many items not monetized, especially if it happens more in one of the sides, the cost side or the benefit side, or if there are items not-monetized classified as very important items. It is therefore necessary to keep in mind the items not monetized and how can they affect the assessment. It is relevant to consider if NPV is positive or negative, as well as if scoring and even eventually if the ranking of the alternatives can be affected at the end of the assessment.

The excel-based SCORE tool supports the calculation of the PV of each item per alternative and of the NPV (societal profitability) per alternative. As described in Chapter 5, the Fixfabriken site can be divided into four different parts, with independent timeframes for the development. Consequently, to this specific case study, the monetization of the economic items is conducted in three steps, as shown in Figure 4-3:

- 1st step, on the left side of Figure 4-3: using one file for each one of the four areas within the site, a partial PV is calculated to each area separately for each one of the economic items that are going to be monetized;
- 2nd step, on the centre of Figure 4-3: for each specific item, the total PV of that item for each alternative is calculated by summing the partial PV from each applicable area in each specific alternative;
- 3rd step, on the right side of Figure 4-3: the total PV of each item of each alternative is inserted in the summary table of the Economic Sustainability Assessment in SCORE. By summing the several PVs of the monetized items, the NPV in each alternative, also called societal profitability, is obtained.



B1. Increased property values on site	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Partials Present Value					
Fixfabriken area	41.89	22.04	41.89	41.89	2.35
Bus garage area	72.26	72.26	3.67	3.67	72.26
Tram hall area	0.00	0.00	55.88	55.88	0.00
Road area	2.29	2.29	2.29	2.29	2.29
B1. Present Value	116.45	96.60	103.73	103.73	76.90

Figure 4-3 Application of SCORE to Fixfabriken case study in 3 steps.

A qualitative assessment of the environmental and social domains is done in collaboration with researchers from the Balance 4P project, using SCORE.

When integrating the three domains in SCORE, the final result allows assessing relative contribution of each alternative to sustainable development. Uncertainties are calculated based on the Monte Carlo simulation method. When no sustainable alternatives are found, the process restarts. This iterative process comes to an end when the alternatives are assessed as sustainable, thereby allowing support to decision-making process. Both the alternatives ranking and the uncertainty of the result are valuable information when making a proposal.

Limitations on the application of this methodology to redevelopment of urban brownfield areas in early stages of the planning process are identified based on feedback from the stakeholders, and on the experience and difficulties encountered when performing the assessment using the SCORE tool. This supports the need to consider improvements or adjustments to the SCORE tool, in order to make it applicable in early planning phases where limited information is available.

Along the work developed a literature review was done, which took into account scientific articles, technical books and reports. Due to the connection of this work to Balance 4P research project and the SCORE tool, specific literature and experiences related to this were also considered.

5 Case Study. Characterization of the Fixfabriken Site

This chapter provides information about the site chosen as a case study, Fixfabriken in Göteborg: general information on the site, on the local geology, hydrogeology, topography, archaeological relevance, contamination issues, present land uses and additional local restrictions.

5.1 General information on the site

The case study Fixfabriken site has an area of approximately 10 ha and is located in Majorna, Göteborg, in a quite central area of the municipality. There is an on-going process of developing a new detailed plan of that area, carried out by the Urban Planning Office (Stadsbyggnadskontoret) at the Municipality of Göteborg. The future land uses are not yet defined in detail. Furthermore, Fixfabriken site is one of the case studies included in the Balance 4P project.

According to the land uses showed in Figure 5-1, the site is divided into four different parts: (1) the Fixfabriken industrial area, at the south / southwest boundary; (2) the Bus garage; (3) the Tram hall, at the east side; and (4) along the boulevard Karl Johansgatan, which corresponds to the north / northeast boundary, also mentioned in a simplified way as Road area. Figure 5-1 and Figure 5-2 give an idea of the present uses.

Figure 5-1 Existing land uses at Fixfabriken area. Reference alternative.

Fixfabriken factory

Tram hall

Bus garage

Karl Johansgatan area

Figure 5-2 Photos from Fixfabriken site, including the four different parts of the site (Google Maps).

Fixfabriken factory has industrial activities since the 40s. The companies HSB Göteborg and Balder now own Fixfabriken factory, who aims to redevelop it.

Municipality owns the Bus garage property.

The Tram hall is operated by Göteborgs Spårvägar, which has a permit to be operating in the coming years. The municipality owns the property. Recently the company showed to the municipality its interest to keep operating the tram hall further after this deadline.

The Karl Johansgatan area includes the area that stands in between the highway E45 and the road Karl Johansgatan, which is the main road serving the local neighbourhood. It also includes the road Karl Johansgatan itself. Road infrastructures and traffic generate adverse effects, namely noise, air pollution and visual intrusion. Land use at the area includes two petrol stations, a residential area, parking lots, crossings and small green areas in between.

5.2 Local natural conditions

A description on the local natural conditions includes the geology, hydrogeology and topography of the site and surroundings.

5.2.1 Geology

Figure 5-3 shows an extract of the Geological Map. The site is located inside the dashed black square, in an area with glacial and postglacial clay (in yellow), normally on top of glacial till, that overlays bedrock (in reddish). Local glaciofluvial deposit (sand and gravel, in green) exists such as on the west and southwest of the site, which corresponds to the so called Sandarna area (SWECO, 2012a).

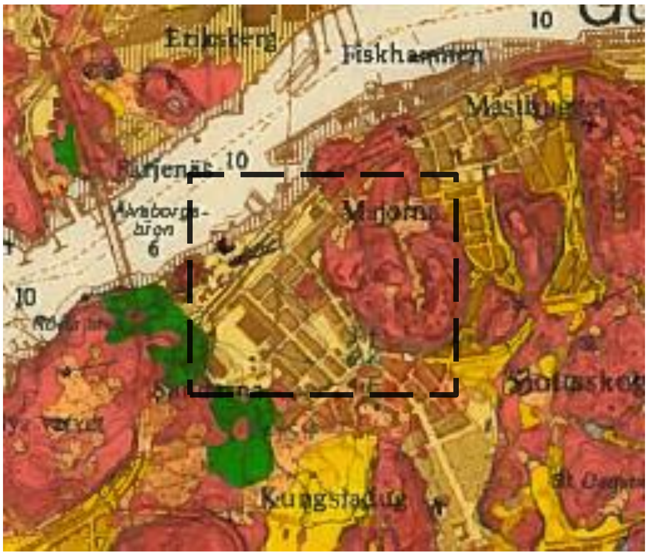


Figure 5-3 Geological map of the Göteborg region (SGU, 1985).

It can be considered that a typical soil profile in the area has the following layers (Sweco, 2012): Asphalt; Filling (sand, gravel and stones); Clay; Till (in general) and sand and gravel (in the southern part of the site); Bedrock. Clay occurs around 20 m above sea level, and along the Göta älv river valley the clay layer has a thickness of about 10 to 15 m (Golder Associates, 2010).

5.2.2 Hydrogeology

Based on the topography, groundwater is expected to flow in direction to the river (Golder Associates, 2010).

The area is likely to have a first upper unconfined “aquifer” in the top layers above the clay, and a second confined aquifer between the clay and the bedrock. In the vicinity of the area, it does not exist an aquifer of importance for water supply purposes (SWECO, 2012a).

Based on field investigations from June 2010, the groundwater table is detected between 1.05 and 1.61 m below the surface level at the Bus garage area. Very wet clay is detected 3 – 3.5 m below the ground surface (Golder Associates, 2010).

5.2.3 Topography

The site is located in between a hill and a plain area, with the highest elevation on the west and south western sides, at the Fixfabriken factory part, and the lowest at the Tram hall and the northern part of the street Karl Johansgatan.

All the areas are relatively flat (terraced), with some height differences in between: several meters difference between the adjacent road to Fixfabriken area and the ground level in the bus garage; 1.5-2 m of height difference between the ground levels in the bus garage and the tram hall (Golder Associates, 2010).

5.3 Soil contamination

The information on soil conditions at the site was mainly provided by Christian Carlsson, specialist in soil contamination, from the Real Estate Office at the municipality of Göteborg, and reports of environmental surveys in the area.

A summary of the contamination at the site is presented in Figure 5-4. The expected contamination is divided into different categories: known contamination but uncertain boundaries; likely contamination; and unlikely contamination. The expected contaminants are chlorinated solvents, hydrocarbons (mainly fuels) and metals. The thickness of the filling material is also shown in the figure. As Figure 5-4 illustrates, a significant part of the area has soil with known contamination or soil that is likely to be contaminated.

Additional information on soil contamination is provided while characterizing the land uses within the site, see Section 5.5.

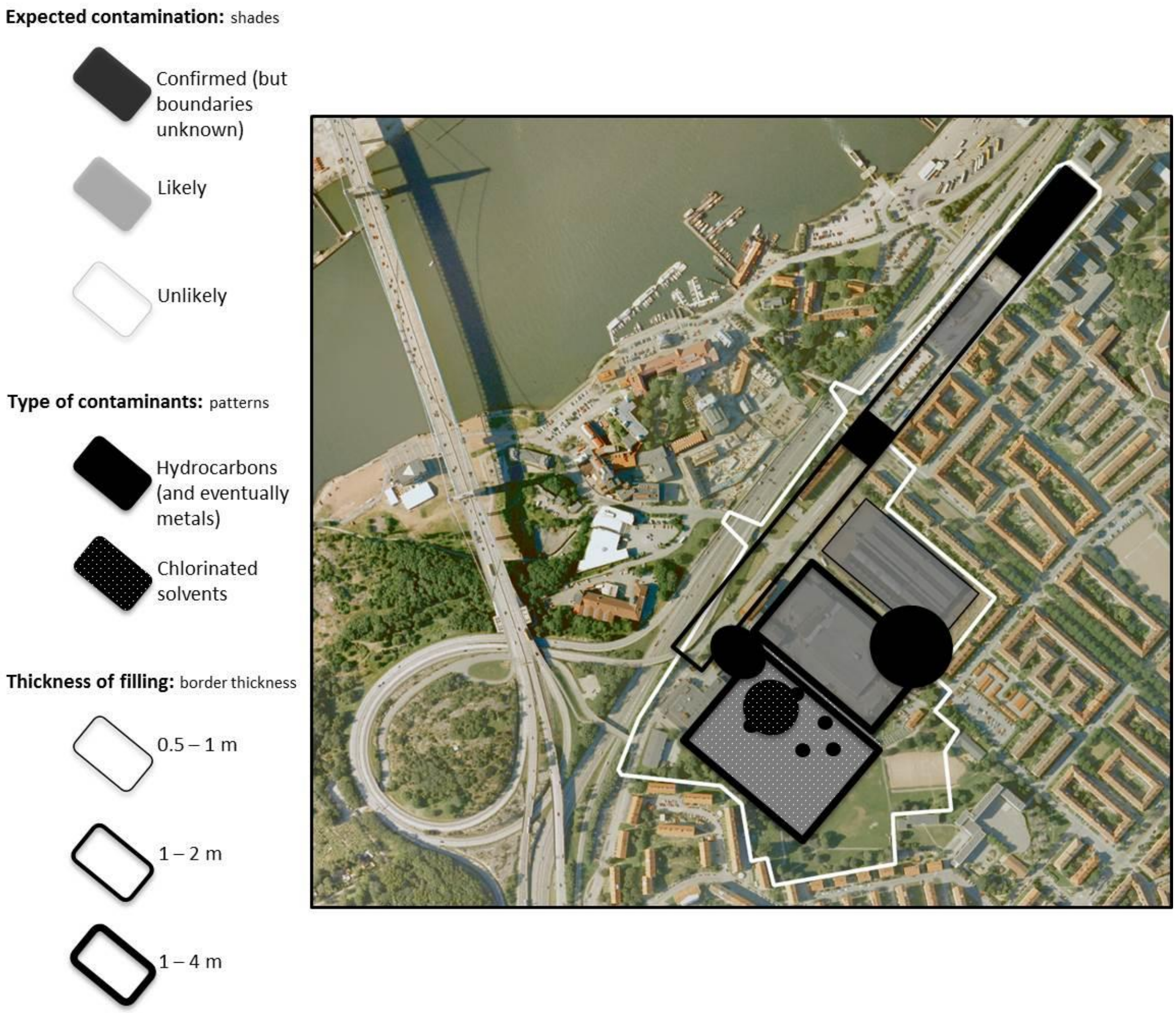


Figure 5-4 Overview of the soil contamination at the Fixfabriken area.

5.4 Archaeology

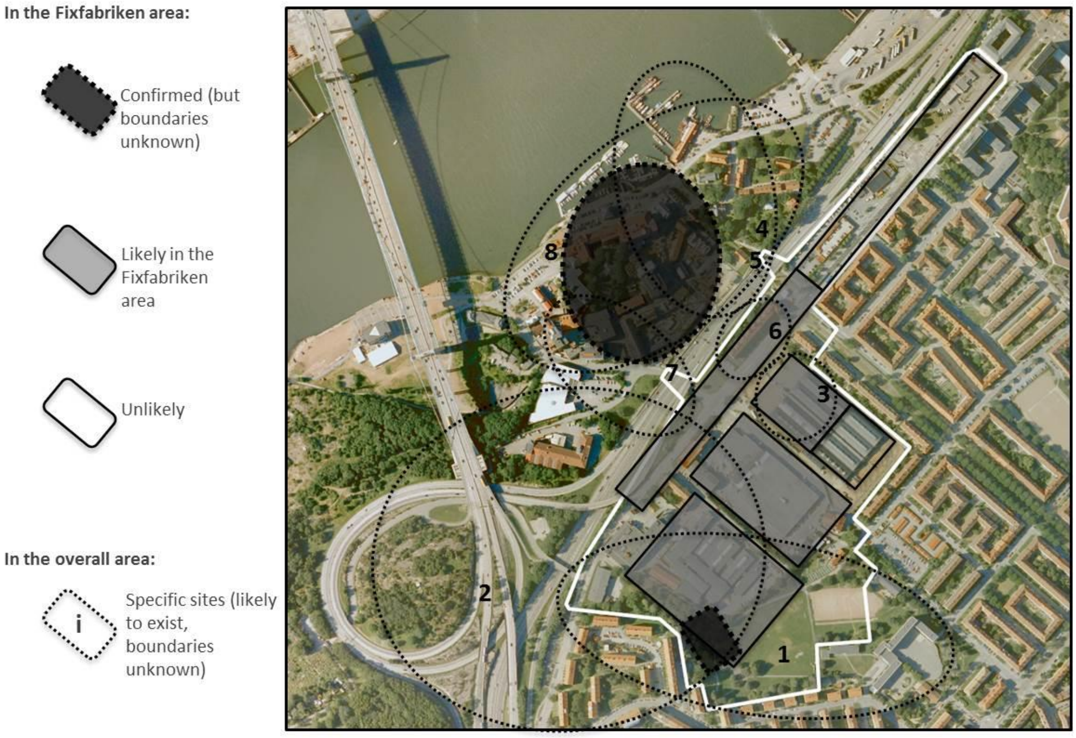
Mats Sandin, archaeologist from the County Administrative Board (Länsstyrelsen of Västra Götaland) provided most of the information on historical and archaeological background. Additional available information of the area is also considered.

People are known to exist in the Göteborg area as early as 12000 years ago (10000 B.C.). By the time of 6000 B.C., people lived in the area called Sandarna, just adjacent to the Fixfabriken industrial area. Archaeological excavations were done in 1912, 1930, 1942, and more recently in 2007, locating different tools and objects. Excavations showed that the area has been used for a long time, with settlements being overlaid from different times. The oldest settlement from 6000 years B.C. is from the Early Stone Age (number 1 in Figure 5-5), and is covered by a layer of sand and gravel of about 3 m thick. On the top of this layer a more recent settlement was found, from the Late Stone Age, from around 3000 years B.C. (Göteborgs Stad. Park och natur). The geographical limits are unknown (Sandin, 2014).

Additionally, historical facts and different clues contained in documents and findings raise the suspicion of remains of other archaeological sites around or partially within the Fixfabriken area, namely from the fourteen to the eighteen century A.C. Some of the possibilities are: military camp area from 1500s-1600s A.C. in the south / southern areas of Fixfabriken (2); an old dam from 1500s-1600s A.C. in the north area of the tram terminal, including the boulevard (3); old harbour and activities related from 1500s-1 700s A.C. (4), the Swedish East India Trade Company from 1700s-1800s A.C. (5), brick production for the castle, from 1500s-1600s A.C. (6) and, the city Älvsborgsstaden from the sixteen century A.C. (7), located in the area between the boulevard (or even including it) and the margins of the river Göta. There is also real evidence of Gamla Älvsborg (7), with a castle and fortress, from the 1300-1600s A.C., since excavations have detected archaeological remains (Sandin, 2014).

An overview of the archaeological heritage is presented in Figure 5-5. The areas are classified depending on the likelihood of archaeological remains to exist: known archaeological sites, although the physical boundaries are unsure; likeliness that archaeological remains exist; and low probability of remains to exist. The mentioned potential archaeological sites are represented despite of the uncertainty.

As Figure 5-5 shows, a significant part of the area can be considered as likely to have archaeological remains. The already confirmed Stone Age Sandarna archaeological site includes at least the southern part of the Fixfabriken area, although the exact boundaries of the site are unknown.



1 – Early stone age culture ”Sandarna settlement” (6000 B.C.) and prehistoric settlements from neolithic age (late stone age); 2 - Military camp (1500s-1600s A.C.); 3 - Damm (1500s-1600s A.C.); 4 - Old harbour and related activities (1500s-1700s A.C.); 5 - Swedish East India Trade Company (1700s-1800s A.C.); 6- Possible brick production for the castle (1500-1600s A.C.); 7 - City Älvsborgsstaden (1500s A.C.); 8 - Gamla Älvsborg (1300-1600s A.C.).

Figure 5-5 Overview of the archaeology sites at the Fixfabriken area (adjusted by Sandin, 2014.

5.5 Land uses and constraints

The description mainly focuses on the previous and present land uses and the resulting known or expected contamination in the different parts of the Fixfabriken site.

5.5.1 Fixfabriken factory

The Fixfabriken factory was built in the late 40s and no previous activity is known at the place. Since its construction, several activities that pose a risk of contamination have taken place (Carlsson, 2014).

At the Fixfabriken factory, several products have been manufactured over the years. At present, fittings for doors and windows are manufactured (SWECO, 2012a). In the factory there are both workshop and surface treatment works (Carlsson, 2014). Over a fairly long period, since Fixfabriken started to operate and until the 1980s, large amounts of trichloroethylene, a chlorinated solvent, was used as a degreasing agent for washing of metal parts (SWECO, 2012b).

Fixfabriken is classified to risk class 1, i.e. the highest risk class, in the MIFO database administered by the County Administration. The high class is due to (1) the use of hazardous materials (between 4 and 5 ton of cyanide/year as well as several tons of trichloroethylene - approximately 3 tons are estimated to be released to the air yearly), (2) the complex geology that make the area vulnerable to spreading of contaminants, and (3) the sensitive uses in the nearby areas such as housing (Länsstyrelsen Västra Götalands Län, 2013). Trichloroethylene, or "TCE", is a contaminant with high toxicity, which easily spreads far away from the contaminant source (Carlsson, 2014). It is a chlorinated hydrocarbon and a dense non-aqueous phase liquid (DNAPL), which typically makes the spreading difficult to predict and also often difficult to remediate. For additional information on DNAPL and on TCE, see Englöv (2007), USDHHS (2014) and Sale (2011).

Field investigations by soil and groundwater sampling and investigation of the soil layers, in 2012, were done in drilled boreholes outdoor. Contaminants analysed include metals, oils (including aliphatic and aromatic hydrocarbons and specifically poly-aromatic hydrocarbons - PAH), volatile compounds, polychlorinated biphenyl (PCB) or cyanide, depending on the sample analysed (soil, water or asphalt). Five of the soil samples revealed PAH and aromatics contamination at levels higher than the Swedish generic guideline values for industrial areas (less sensitive uses - MKM), and in one of those samples the PAH concentration exceeded the guideline value for hazardous waste. Three additional samples do not fulfil the Swedish generic guideline values for sensitive uses for PAH. Lead was also found in one soil sample at levels exceeding the guideline values for less sensitive uses and chrome in one sample exceeding the guideline values for sensitive use (KM). No chlorinated solvents were found, neither traces from the specific metal plating operation at the site were detected in this investigation. The overall conclusion was that no significant soil or groundwater contamination was found, although some samples from the loading area showed minor contamination. This is frequently encountered in industrial and urban areas, and it was concluded that the contamination resulted not from the specific industrial activity (Fixfabriken), but probably was caused by spilling from trucks or cars (SWECO, 2012a).

A later investigation focused on analyses of gas samples in 8 boreholes, collected below the part of the building where chlorinated solvents were used most intensively. For each sample point both the content of chlorinated solvents in the pumped gas and partly the content of degradation products of this solvent are reported. The results show that there are traces of chlorinated solvents and that trichloroethylene is present in highest concentration. There is also a clear level of degradation product dichloroethene. It was concluded that the contamination have spread mainly along and in the pipe network (SWECO, 2012b).

In this second investigation, 2 layers of concrete were detected, of about 15 cm each, although thicker in some parts (45 cm). In some parts, a layer of at least 20 cm of filling with a content of sand and stone was detected. In one of the points clay was found at about 55-60 cm from the basement concrete. The report states that it is likely that the remains of TCE occur mainly in the filling materials that are below the concrete floor in the basement and above the underlying clay. Since leakage from sewer pipes appears to be the most likely propagation path, trenches are most likely contaminated (SWECO, 2012b). Nevertheless, the present spreading conditions are unknown / difficult to predict.

Appendix 4 presents additional information on the contaminants at this specific area.

5.5.2 Bus garage

The bus garage was constructed in the late 70s and includes several on-site activities that are likely to cause soil contamination. There are or have been e.g. garages, car washes, truck service, and temporary boiler house. The bus garage is constructed on top of filling material with a thickness varying between 1 and 4 m. The filling material is likely to include waste in some parts, and poses a risk of contamination. In the south-eastern part the filling material is approximately 3 m thick (Carlsson, 2014).

In the south-eastern part of the bus garage, a leakage of diesel was detected in 2005. The leakage occurred in a pressurized transmission line between a fuel tank and the garage. From there, the diesel had spread to the soil and to the wastewater system. Subsequent remediation was done with pumping of a total of 11 m^3 of diesel out of the ground. Remediation of soil was conducted but only to a limited extent. Soil investigations concluded that approximately 1500 m^2 were polluted by the leakage. The investigations also detected pollution in the filling material not derived from the leakage. The filling material included waste bricks, scrap metal, wood and asphalt (Carlsson, 2014).

In 2010, an investigation was conducted at the bus garage site close to areas that pose greater risk of contamination, namely at areas of handling and storage of oil and diesel, at the northern and south-eastern parts. Contaminants analysed were petroleum hydrocarbons in the form of aliphatic and aromatic hydrocarbons (including PAH - polycyclic aromatic hydrocarbons) in samples of soil and groundwater. Contamination was found in the soil and groundwater samples but at levels below the guideline values for the current land use (less sensitive use - MKM). Concrete samples were also collected and analysed, all samples showing values below the limits of hazardous waste. The conducted investigation does not include the area that was previously remediated and which may have some residual contamination (Golder Associates, 2010). Despite of complying with the guideline values for less sensitive use, some contaminants have concentration levels above the ones allowed for a sensitive use, namely aliphatic (H - high molecular weight) in two of the soil sampling points, PAH-M (of medium molecular weight) in one sample and PAH-H (of high molecular weight) in two sampling points.

According to the samples collected when investigating the soil at the bus garage area, the filling material has a thickness between 0.5 m and 1.5 m. No waste was detected in the filling. Below the filling material there is clay, dry crust clay, silty gravelly clay or silty sandy clay (Golder Associates, 2010).

Appendix 4 presents additional information on the contaminants at this specific area.

5.5.3 Tram hall

The existing tram hall was built in the 40s and entails risk of contamination due to the present and past activities e.g.: garages and workshops, boilers systems, laundry and electric transformers (Carlsson, 2014).

The southern part of the tram hall is confirmed contaminated due to a diesel leakage that took place at the neighbouring bus garage area (Carlsson, 2014). Additionally, it is expected that there is filling material in parts of the area with a thickness of 0.5-1 m, which might carry some contamination (Carlsson, 2014).

5.5.4 Karl Johansgatan boulevard area

Along the street Karl Johansgatan which forms the northeast boundaries of the area, and in the neighbouring areas, several activities have been conducted that can pose risks of soil contamination: petrol stations, cleaning operations, workshops, warehouses, a former bus garage and traffic. Two petrol stations in operation (Shell and Preem) and a former petrol station (Hydro) along the Karl Johansgatan are the main concerns in terms of risk of soil contamination with hydrocarbons, but also metals (Carlsson, 2014).

Known contamination exists both in the Shell petrol station in operation since the 50s on the northern limit, and at the area of the former Hydro petrol station on the northern border of the residential area that operated between 30s until 2010. Remediation operations were conducted at the Hydro petrol station area although contamination remains in the soil down to several meters from the surface (Carlsson, 2014). Some contamination (mainly hydrocarbons and metals) is likely to exist also at the Preem petrol station area, which is operating since the 60s (Carlsson, 2014).

Filling material is likely to be present, which typically is contaminated to a varying degree, depending on the origin of the filling material. The depth of the filling is probably of 1-2 m, although it can be thicker more locally (Carlsson, 2014).

5.5.5 Other areas

Around the Fixfabriken area, the Mölnlycke sewing thread factory has been operating. In the 90s, a leakage from an oil-fired boiler was detected. Despite remediation was carried out in the area there is still suspicion of remaining contamination. As so, Mölnlycke sewing thread factory is registered in Länsstyrelsen as area with risk class 3 (moderate risk) (Carlsson, 2014). Other activities or properties not described here might also pose risk of soil contamination. Example is the content of the filling materials or the traffic areas (Carlsson, 2014).

6 Alternatives of urban redevelopment for the Fixfabriken Case Study Site

This chapter presents the reference alternative and a description of the alternatives to assess, which includes both the intended future land uses and the remedial process to allow safe use of the site and the surroundings.

6.1 Reference alternative

The reference alternative corresponds to the present situation (Figure 5-1), keeping a relatively underused area within an attractive part of Göteborg. The Fixfabriken site mainly includes industrial land use and transport infrastructure, see also Section 5.1 and Section 5.5.

6.2 Alternatives to assess

In all the alternatives to be assessed for the Fixfabriken site case study, it is assumed that redevelopment at Fixfabriken factory part is the one to start first. Thought, this doesn't take place immediately, but in year 2 or 5, as additional studies, project development and licensing process are required. Interventions in the other parts of the site start later, in year 8 or 10, due to ongoing commitments with companies operating there, namely bus garage operators, tram hall and petrol station companies.

To the Fixfabriken site case study two sets of alternatives, Set 1 and Set 2, are defined and assessed. Additional possibilities of alternatives not assessed are mentioned in Appendix 2.

The preliminary set of alternatives, Set 1, focus on conventional approach when constructing and dealing with contaminated areas, by removing the contaminants from the site and by demolishing and constructing new buildings. After initiating the assessment, this set is omitted in the process as it became evident that the alternatives as were defined are not feasible. The description of the preliminary alternatives and the assessment performed are included in the Appendix 1 for information purposes.

A new set of alternatives, Set 2, is therefore chosen to be assessed. Here, additional possibilities when redeveloping urban areas and when dealing with contaminated sites are included, namely: more in-situ remediation possibilities; lower disturbance of the sub-surface conditions; and more differentiation of the residential use, by specifying different type of residential use and height of those new buildings. This new set of alternatives, described in the next sections and assessed in Chapter 7, includes five alternatives: A1 (1), A2 (2), A3 (3), B (4) and C (5), see Figure 6-1. Those were defined by the author and by the research team of the Balance 4P project, and based on the initial assessment of preliminary alternatives (Appendix 1).

The notation for the alternatives A1, A2, A3, B and C reflects the stronger similarity of land use of same alternatives (alternatives A1, A2 and A3, specially A1 and A3). The degree of land use change relative to today varies from one alternative to another. Alternative C keeps existing land uses as much as possible, preserving existing buildings, whereas in alternative B all the parts include new land uses and new construction.

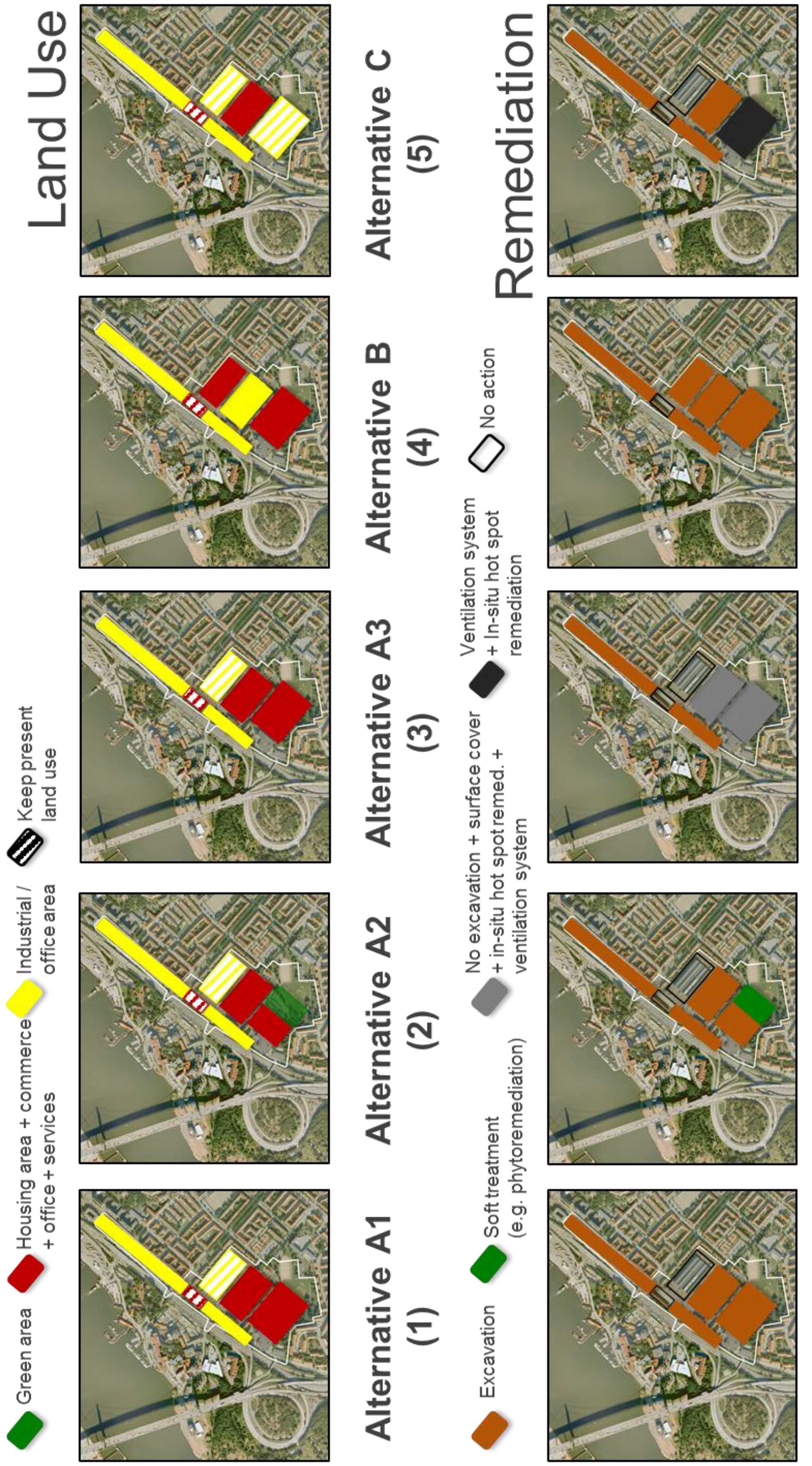


Figure 6-1 Overview of the five alternatives of land use and remediation at Fixfabriken.

The remediation strategies are chosen depending on the future land uses and on the options made regarding keeping buildings as they are (some parts of the site in alternatives A1, A2, A3 and C), keeping the existent foundations even if demolishing the buildings (some parts of the site in alternative A3), keeping buildings (Fixfabriken in alternative C), or constructing new ones from the scratch (some parts of the site in all the alternatives, but especially in A1, A2 and B). In the majority of the situations with no change of the existent industrial land use and existing buildings, a no remediation action is considered to those specific places (e.g., tram hall in alternatives A1, A2, A3 and C). The remediation strategies include a dig and dump approach (at least one part of the site in all alternatives, but specially in alternatives A1, A2 and B), soft remediation in a small green area within the site (A2), ventilation and hot-spot in-situ remediation (parts of the site in A3 and C), and additional surface covering of not excavated surfaces with future residential land use (parts of the site in A3).

Along this chapter, both notations to identify the alternatives, e.g. A(1) and 1, are used. On the contrary, the remaining chapters only refer to the numerical identification.

6.2.1 Alternative A1 (1)

The Fixfabriken factory is demolished and the existing filling material beneath the buildings and the superficial part of the underneath layer are excavated. New buildings for residential use with some commercial areas in the ground floors are then constructed. This is assumed to start during year 5 and carried out during 2 years. Housing heights are 4-7 floors, with a mix of rental and condominium apartments. The excavated contaminated materials are not further treated but are transported off-site to final disposal, possibly with some treatment at the disposal site.The Bus garage is demolished and the existing filling material beneath the buildings and the superficial part of the underneath layer are excavated. New buildings for residential use, with commerce/offices/services at the ground floor, are then constructed, starting in year 8. It is assumed that the development occurs in two stages. The total redevelopment period is 3 years. Housing heights are 4-7 floors, with a mix of rental and condominium apartments. The excavated contaminated materials are not further treated but are transported off-site to final disposal, possibly with some treatment at the disposal site.

The Tram hall is kept as it is. No remediation action is taken, unless any extreme hot-spots are found in the coming investigations.

The existing petrol stations at the street Karl Johansgatan are demolished, and the present small residential area is kept. New buildings for industrial and office use are then constructed, starting in year 10. It is assumed that the redevelopment occurs in several stages, during 8 years. No action is taken in the remaining area along the street Karl Johansgatan. Regarding remediation action, the filling materials beneath the places to be reconstructed are dug out. The excavated contaminated materials are not adequate to be used on-site and are transported off-site to final disposal, possibly with some treatment at the disposal site.

The timeframe estimated for alternative 1 is presented in Table 6-1.

Table 6-1 Timeframe for the remediation (R) and construction (C) for alternative 1

ALTERNATIVE 1 (A1)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C/R	C									
Tram hall																			
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

6.2.2 Alternative A2 (2)

The Fixfabriken factory is demolished. The northern part of the Fixfabriken factory is developed in the same way as the one described in alternative 1. On the other hand, the southern part of Fixfabriken factory area becomes a green area to preserve and emphasize the historical importance of the site. The upper soil layers are remediated through soft techniques (e.g. phytoremediation), i.e. no excavation unless any extreme hot-spots are found in the coming investigations. This allows a lower disturbance of the underneath layers, and thus a lower probability of affecting, e.g., the known archaeological remains from the Early Stone Age culture “Sandarna settlement” (6000 B.C.), see Section 5.4 that is focused on the archaeology at the site.

The Bus garage, the Tram hall and the Karl Johansgatan areas are handled in the same way as described in alternative 1.

The timeframe estimated for alternative 2 is presented in Table 6-2.

Table 6-2 Timeframe for the remediation (R) and construction (C) for alternative 2

ALTERNATIVE 2 (A2)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C/R	C									
Tram hall																			
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

6.2.3 Alternative A3 (3)

The future land uses and the remediation strategy are quite different from alternatives 1 & 2. Whereas alternatives 1 & 2 use excavation, this alternative focuses on no excavation, but instead manages health risks by using surface cover, hot-spot in-situ remediation and active ventilation of new constructions to prevent vapours in-door. The interventions in each area are further on mentioned.

When the Fixfabriken factory is demolished, foundations and sub-surface structures are left untouched to disturb the sub-soil as little as possible. The buildings are instead ventilated to manage health risks. Around buildings, in-situ and soft techniques (e.g.

phytoremediation) are potentially applied in combination with surface cover. New buildings are constructed on top of existing sub-soil structures. The ground floor is used as commercial space. Two floors of apartments are built on top of these for residential use, with a mix of rental and condominium apartments. Further, 20% of the apartments are subsidized for low-income families. Development starts approximately in year 5, and is carried out during 2 years.

The Bus garage is demolished without digging out the existent filling materials beneath the buildings. New buildings are constructed on top of the surface with piling where needed, to disturb the sub-soil as little as possible, and on top of existing sub-soil structures. The ground floor is ventilated to manage contamination and used as commercial space. Three to four floors of apartments are built on top of these for residential use, with a mix of rental and condominium apartments and 20% of the apartments are subsidized for low-income families. Around buildings, in-situ and soft techniques (e.g. phytoremediation) are potentially applied in combination with surface cover. Development starts in year 7, and is carried out during 2 years.

The Tram hall and the Karl Johansgatan area are treated in the same way as described in alternative 1.

The timeframe estimated for alternative 3 is presented in Table 6-3.

Table 6-3 Timeframe for the remediation (R) and construction (C) for alternative 3

ALTERNATIVE 3 (A3)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C										
Tram hall																			
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

6.2.4 Alternative B (4)

The Fixfabriken factory is handled in the same way as described in alternative 1.

The Bus garage is demolished and the existent filling materials beneath the buildings and the superficial part of the underneath layer is excavated. A new tram hall is constructed, starting in year 8, and during 2 years. The excavated soil is handled in the same way as described in alternative 1. Different future land uses is thus the main difference between alternative 1 and alternative 4.

The Tram hall is demolished and the existent filling materials beneath and eventually the superficial part of the underneath layer is excavated. New buildings for residential use (a mix of rental and condominium apartments), with commerce/offices/services at the ground floor, are then constructed, starting in year 10. It is assumed that the redevelopment occurs in 2 different stages, in a total of 3 years. The excavated contaminated materials are not adequate to be used on-site and are transported off-site to final disposal, possibly with some treatment at the disposal site.

The Karl Johansgatan area is handled in the same way as described in alternative A1.

The timeframe estimated for alternative 4 is presented in Table 6-4.

Table 6-4 Timeframe for the remediation (R) and construction (C) for alternative 4

ALTERNATIVE 4 (AB)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C										
Tram hall										R	C/R	C							
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

6.2.5 Alternative C (5)

This alternative preserves as much as possible the existing constructions e.g., the Fixfabriken factory and the tram hall.

Buildings and uses (industrial and offices) at Fixfabriken factory are kept as they are. Buildings are renovated to assure an adequate indoor air quality, by active ventilation. The space is used as incubator for new businesses and social entrepreneurs. Depending on further investigation of the soil contamination in the area, in-situ remediation might be carried out if there are any hot-spots / left source areas. This is assumed to occur during year 2 and carried out during 1 year.

The Bus garage is developed in the same way as described in alternative 1, but with housing heights of 7-15 floors, with a mix of rental and condominium apartments. In addition, 20% of the apartments are subsidized for low-income families.

The Tram hall and the Karl Johansgatan areas are handled in the same way as described in alternative 1.

The timeframe estimated for alternative 5 is presented in Table 6-5.

Table 6-5 Timeframe for the remediation (R), construction (C) and / or adjustments (A) for alternative 5

ALTERNATIVE 5 (C)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory		A																	
Bus garage								R	C/R	C									
Tram hall																			
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

7 Application of SCORE at the Fixfabriken Site

This chapter presents the sustainability assessment of the selected alternatives to the Fixfabriken site case study, considering the economic, social and environmental domains, by using the SCORE tool.

7.1 Economic domain (CBA)

The quantitative economic assessment is based on the methods used by Landström & Östlund (2011) and on the specific literature on SCORE: Anderson *et al.* (2015), Rosén *et al.* (2015) and Söderqvist *et al.* (2015).

The timeframe is considered in the Present Value (PV) SCORE calculations of a benefit or cost item in each specific area of the case study site. When proceeding with the calculations, it is necessary to define which fraction of benefit or cost has immediate effects and which needs to be discounted. As a rule, the beginning and the ceasing of the action, determines the year when the benefit or the cost starts and the number of years during which the cost or benefit last. However, in some specific situations, the start of a certain action of the redevelopment process is the beginning of a long period of costs or benefits, for example, when monetizing benefits of improving non-acute health conditions. Furthermore, how the economic benefits or costs occur during the years also depends on the timeframe. The most common situation is to have constant benefits and costs each year, despite for some situations no constant costs or benefits are expected. That is the case of the road Karl Johansgatan to all the alternatives assessed, where the remediation and redevelopment occur in more than one stage, and consequently large variations along the years occur.

The discount rate considered in the calculations is 3.5%, as suggested in Söderqvist *et al* (2014). The Net Present Value (NPV) is the sum of the PV of each monetized economic item, following the method illustrated in Figure 4-3 and described in Section 4.2.

The several major steps are further on presented.

7.1.1 Identification and preliminary assessment of costs and benefits

First, cost and benefit items included in the SCORE tool (Chalmers, 2014) are classified with regard to importance. Table 7-1 shows the estimated relevance of each item to each alternative. The type of assessment, quantitative or qualitative, is identified for each item. Whenever monetization is performed, the appendix with information on the method is indicated in the table. Table 3-4 in Section 3.2 provides a description of the meaning of each economic item.

Table 7-1 Relevance of each cost and benefit items in the Fixfabriken site, to each alternative. X = important, (X) = somewhat important, 0 = not relevant; A (Appendix)

Benefit Items	Sub items	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Monetized?	Method
B1. Increased property values	B1. Increased property value on site	X	X	X	X	X	Yes	A3
B2. Improved health	B2a. Reduced acute health risks	(X)	(X)	(X)	(X)	(X)	No	-
	B2b. Reduced non-acute health risks	(X)	(X)	(X)	(X)	(X)	Yes	A4
	B2c. Other types of improved health	(X)	(X)	(X)	(X)	(X)	Yes	A5
B3. Increased provision of ecosystem services	B3a. On site	(X)	(X)	(X)	(X)	(X)	No	-
	B3b. In the surroundings	(X)	(X)	(X)	(X)	(X)	No	-
	B3c. Others	(X)	(X)	(X)	(X)	(X)	No	-
B4. Other than B2 and B3	B4. Other positive externalities	0	0	0	0	0	No	-
Cost Items	**Sub items**	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**	**Alt 5**	**Monetized?**	**Method**
C1. Remediation costs	C1a. Costs for investigations and design	X	X	X	X	X	Yes, in C1d and C1e	In C1d and C1e
	C1b. Costs for contracting	(X)	(X)	(X)	(X)	(X)	Yes, in C1d and C1e	In C1d and C1e
	C1c. Capital costs due to allocation of funds	(X)	(X)	(X)	(X)	(X)	Yes	A6
	C1d. Costs for the remedial action	X	X	X	X	X	Yes	A7
	C1e. Costs for monitoring programs	X	X	X	X	X	Yes	A8
	C1f. Project risks	X	X	X	X	X	No	-
C2. Impaired health due to the remedial action	C2a. On site	(X)	(X)	(X)	(X)	(X)	Yes	-
	C2b. Due to transports	(X)	(X)	(X)	(X)	(X)	Yes	A9
	C2c. At disposal sites	(X)	(X)	(X)	(X)	(X)	No	-
	C2d. Other due to remediation	(X)	(X)	(X)	(X)	(X)	No	-
C3. Decreased provision of ecosystem services	C3a. On site	0	0	0	0	0	No	-
	C3b. Outside the site	(X)	(X)	(X)	(X)	(X)	Yes	A10
	C3c. At the disposal site	X	X	(X)	X	(X)	No	-
C4. Other costs than C2 and C3	C4. Other negative externalities	X	(X)	(X)	X	(X)	No	-

7.1.2 Assessment of costs and benefits

Important items in the Fixfabriken case study were monetized as far as possible. Additionally, other items classified as somewhat important are also considered, whenever an estimation was possible. Each benefit and cost is detailed below and the specific methods, calculations and results are presented in the correspondent Appendices.

Benefit B1. Increased property values

“B1. Increased property value on site” is considered of importance to all the alternatives. Monetization is performed based on the methodology used in the Hexion case study (Landström & Östlund, 2011) and on additional assumptions, see Appendix 3.

Benefit B2. Improved health

“B2a. Reduced acute health risks” is considered as (somewhat) important, due to the previous use of cyanide, see Section 5.5.1. On the other hand, no arsenic is expected at the site. No monetization is made.

“B2b. Reduced non-acute health risks” is assumed to be (somewhat) important and is monetized in the Fixfabriken case study by applying a methodology based on the one used in the Hexion case study (Landström & Östlund, 2011), see Appendix 4.

“B2c. Other types of improved health, e.g. reduced anxiety” is estimated to be somewhat important. Monetization is performed based on Landström & Östlund (2011), and presented in Appendix 5.

Benefit B3. Increased provision of ecosystem services

“B3a. Increased recreational opportunities on site” is classified as of somewhat importance, as it can be assumed that small green areas along the site and a sport facility will be created. No monetization is made.

“B3b. Increased recreational opportunities in the surroundings” is assumed as having somewhat importance, as a more appealing site will probably lead to a greater use of the neighbouring green areas. No monetization is made.

“B3c. Increased provision of other ecosystem services” is considered as “somewhat important”. An extensive ecosystem services identification and assessment is not part of this master thesis. SNOWMAN NETWORK (2015) identifies for the Fixfabriken site: 1) relevant urban ecosystem services, e.g. air quality regulation, aesthetic values and recreation and ecotourism, 2) relevant soil ecosystem services, such as regulation and maintenance of fresh water and of water purification and waste treatment. No monetization is made.

Benefit B4. Other positive externalities than B2 and B3

Even though some alternatives are less invasive in the Fixfabriken factory area, which is expected to have the most archaeological importance, it is too soon to include it as part of benefit B4. As so, all the alternatives are evaluated as of importance “0”. A benefit of this kind would be the integration of the archaeology in the local redevelopment, if enhancing e.g. public awareness and preservation of those remains.

Cost C1. Remediation costs

“C1a. Costs for investigations and design of remedial actions” and “C1b. Costs for contracting” are assumed, respectively, of importance and of somewhat importance.

As mentioned in Table 7-1, C1a. and C1b. are included in the calculations of C1d and C1e.

“C1c. Capital costs due to allocation of funds to the remedial action” is assumed as somewhat important. Monetization considers the values obtained for the Hexion case study (Landström & Östlund, 2011) and additional assumptions, as described in Appendix 6.

“C1d. Costs for the remedial action, including possible transport and disposal of contaminated soil minus possible revenues of reuse of contaminants and/or soil” is considered as of importance. Cost estimation, see Appendix 7, is partially based on the approach used in the Hexion case study (Landström & Östlund, 2011).

“C1e. Costs for design and implementation of monitoring programs including sampling, analysis and data processing” is assumed as important and monetized based on the Hexion case study (Landström & Östlund, 2011) and additional assumptions, see Appendix 8.

“C1f. Project risks” includes different risk cost categories (Brinkhoff, 2014). No monetization is done, though it is considered of being of importance.

Cost C2. Impaired health due to the remedial action

It is assumed that there are no risks to the workers during the remedial action taking place at Fixfabriken site, as it is known that the soil is contaminated and so proper health and safety procedures will be in place. Such procedure includes e.g. the use of individual protection equipment by the workers. Thus, “C2a. Increased health risks due to the remedial action on site” is estimated to be equal to 0 SEK.

“C2b. Increased health risks due to transports to and from the remediation site, e.g. transports of contaminated soil” is classified as of somewhat importance. It is monetized using the method applied for the Hexion case study (Landström & Östlund, 2011) and additional assumptions, see Appendix 9.

“C2c. Increased health risks at disposal sites” is expected to have a somewhat importance, due to the disposal of contaminated soil elsewhere. No monetization is made.

“C2d. Other types of impaired health due to the remedial action, e.g. increased anxiety” is of somewhat importance. No monetization is made.

Cost C3. Decreased provision of ecosystem services

“C3a. Decreased provision of ecosystem services on site due to remedial action, e.g. reduced recreational opportunities” is assumed to be of no relevance, as presently there are, nearly, no recreational opportunities at the site. No monetization is made.

“C3b. Decreased provision of ecosystem services outside the site due to the remedial action, e.g. environmental effects due to transports of contaminated soil” is classified as somewhat important, and monetized as described in Appendix 10, based on Landström & Östlund (2011) and additional assumptions.

“C3c. Decreased provision of ecosystem services due to environmental effects at the disposal site” is classified as important or as somewhat important depending on the extent of soil expected to be received by a disposal site. No monetization is made.

Cost C4. Other negative externalities than C2 and C3

“C4. Other negative externalities” may refer to the reduction of cultural values through impairment or destruction of cultural heritage. In the Fixfabriken case study it is assumed that excavation necessary to remediation and further construction are potential threats to archaeological remains on-site. In these situations, this cost is classified as important, otherwise it is considered as somewhat important. No monetization is made.

7.1.3 Results of the CBA

The PV calculated to each benefit and cost item to each alternative, as well as the NPV are included in Table 7-2, in MSEK. Depending on the item, uncertainties are stated as high or medium. The distribution of costs and benefits between the public (PUB), employees (EMP) and the developers (DEV) is also presented in Table 7-2.

As can be seen in Table 7-2, the NPV is positive to nearly all the alternatives, with alternative 3 having the highest NPV. The exception is alternative 5, with a negative value of - 2.85 MSEK.

7.2 Environmental domain

The qualitative environmental assessment in Fixfabriken site case study was done with researchers from the Balance 4P project at Chalmers. The key criteria are weight as shown in Figure 7-1.

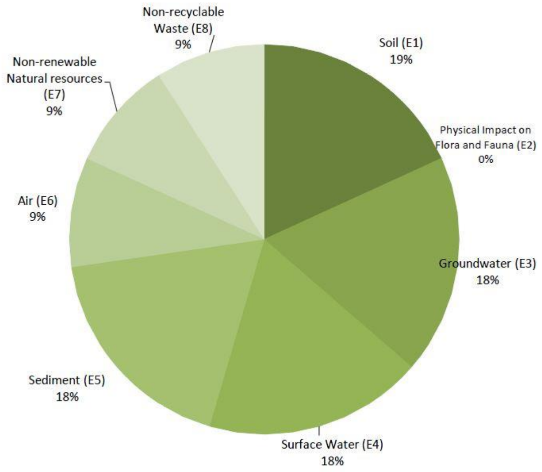


Figure 7-1 Weighting of the key criteria in the environmental domain

In the environmental domain the key criteria Soil, Groundwater, Surface Water and Sediment (around 18% each) have a higher weighting compared to the ones of the key criteria non-recyclable waste, non-renewable natural resources and air (9% each). Flora and Fauna are considered as no relevant as no faunistic neither floristic values are known in the area or surroundings.

Table 7-2 Results of the CBA, in MSEK, and level of importance of the non-monetized items, to each alternative (based on Chalmers University of Technology (2014))

Main items	Sub-items	Alternative 1			Alternative 2			Alternative 3			Alternative 4			Alternative 5		
		P/B	**Mode (MSEK)**	**Unc**	**P/B**	**Mode (MSEK)**	**Unc**	**P/B**	**Mode (MSEK)**	**Unc**	**P/B**	**Mode (MSEK)**	**Unc**	**P/B**	**Mode (MSEK)**	**Unc**
B1. Increased property values	B1. Increased property value on site	DEV	112,1	M	DEV	84,45	H	DEV	112,1	H	DEV	111,3	M	DEV	57,11	H
B2. Improved health	B2a. Reduced acute health risks	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
	B2b. Reduced non-acute health risks	PUB	0,35	M	PUB	0,35	M	PUB	0,35	M	PUB	0,35	M	PUB	0,38	M
	B2c. Other types	PUB	0,21	M	PUB	0,21	M	PUB	0,21	M	PUB	0,27	M	PUB	0,21	M
B3. Increased provision of ecosystem services	B3a. On site	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
	B3b. Off site	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
	B3c. Others	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
B4. Other positive externalities	B4. Other positive externalities	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
C1. Remediation costs	C1a. Costs for investigations and design	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M
	C1b. Costs for contracting	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M
	C1c. Capital costs due to allocation of funds	DEV	2,24	M	DEV	2,24	M	DEV	2,24	M	DEV	2,94	M	DEV	2,33	M
	C1d. Costs for the remedial action	DEV	65,93	L	DEV	58,17	M	DEV	43,08	H	DEV	84,27	L	DEV	47,07	M
	C1e. Costs of monitoring programs	DEV	13,43	M	DEV	13,43	H	DEV	13,43	H	DEV	14,70	M	DEV	9,68	H
	C1f. Project risks	DEV	X	M	DEV	X	M	DEV	X	M	DEV	X	M	DEV	X	M
C2. Impaired health due to the remedial action (increased health risks)	C2a. On site	EMP	0,00	M	EMP	0,00	M	EMP	0,00	M	EMP	0,00	M	EMP	0,00	M
	C2b. Due to transports	PUB	1,33	M	PUB	1,16	M	PUB	0,33	M	PUB	1,69	M	PUB	0,80	M
	C2c. At disposal sites	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
	C2d. Other types	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
C3. Decreased provision of ecosystem services due to remedial action	C3a. On site	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M
	C3b.Off site	PUB	1,08	M	PUB	0,88	M	PUB	0,31	M	PUB	1,43	M	PUB	0,67	M
	C3c. At the disposal site	PUB	X	M	PUB	X	M	PUB	(X)	M	PUB	X	M	PUB	(X)	M
C4. Other negative externalities than C2 and C3	C4. Other negative externalities	PUB	X	M	PUB	(X)	M	PUB	(X)	M	PUB	X	M	PUB	(X)	M
NPV		**28,66**			**9,13**			**53,28**			**6,91**			**-2,85**		

Note: * sub-items C1a and C1b are included in C1c and C1d.

Table 7-3 Environmental Sustainability Assessment: Semi-quantitative assessment to each alternative

Key criteria	**Sub-criteria**	**Alternative 1**			**Alternative 2**			**Alternative 3**			**Alternative 4**			**Alternative 5**		
		Range	**Score**	**Unc**	**Range**	**Score**	**Unc**	**Range**	**Score**	**Unc**	**Range**	**Score**	**Unc**	**Range**	**Score**	**Unc**
E1: Soil	Ecotoxicolog. risk RA On-site	NP	**0**	L	NP	**0**	M	NP	**0**	L	NP	**0**	L	NP	**0**	L
	Ecotoxicolog. risk SC On-Site	NN	**7**	M	NN	**6**	H	AS	**2**	M	NN	**9**	L	NN	**4**	M
	Soil Functions RA On-Site	AS	**1**	L	AS	**3**	M	AS	**1**	L	AS	**1**	L	AS	**1**	L
E2: Physical Impact on Flora and fauna	Flora and fauna RA On-Site	NR			NR			NR			NR			NR		
E3: Groundwater	RA On-Site	NP	**0**	H	NP	**0**	H	NP	**0**	H	NP	**0**	H	NP	**0**	H
	RA Off-Site	NP	**0**	H	NP	**0**	H	NP	**0**	H	NP	**0**	H	NP	**0**	H
	SC On-Site	NN	**6**	M	NN	**5**	H	NN	**2**	H	NN	**8**	M	NN	**4**	H
	SC Off-Site	NN	**6**	M	NN	**5**	H	NN	**2**	H	NN	**8**	M	NN	**5**	H
E4: Surface Water	Surface Water RA On-Site	NR			NR			NR			NR			NR		
	Surface Water RA Off-Site	NP	**0**	M	NP	**0**	M	NP	**-1**	M	NP	**0**	M	NP	**-1**	M
	Surface Water SC On-Site	NR			NR			NR			NR			NR		
	Surface Water SC Off-Site	NN	**3**	H	NN	**3**	H	NN	**1**	H	NN	**4**	H	NN	**2**	H
E5: Sediment	Sediment RA On-Site	NR			NR			NR			NR			NR		
	Sediment RA Off-Site	NP	**0**	M	NP	**0**	M	NP	**-1**	M	NP	**0**	M	NP	**-1**	M
	Sediment SC On-Site	NR			NR			NR			NR			NR		
	Sediment SC Off-Site	NN	**3**	H	NN	**3**	H	NN	**1**	H	NN	**4**	H	NN	**2**	H
E6:Air	Air RA Off-Site	NP	**-7**	M	NP	**-6**	M	NP	**-1**	M	NP	**-8**	M	NP	**-3**	M
E7: Non-renewable Natural resources	Natural Resources RA Off-Site	NP	**-5**	H	NP	**-4**	H	NP	**-1**	H	NP	**-6**	H	NP	**-3**	H
E8: Non-recyclable Waste Generat.	Waste RA Off-Site	NP	**-7**	M	NP	**-6**	M	NP	**-1**	M	NP	**-9**	M	NP	**-4**	M

The semi-quantitative assessment of each key criterion and sub-criterion for environmental domain is presented in Table 7-3. Motivation behind it is included in Appendix 11. From Table 7-3 it can be seen that the very positive effects are within the environmental criteria “E1. Soil” and “E3. Groundwater”, whereas the very negative effects occur in “E6. Air”, “E7. Non-renewable natural resources” and “E8. Non-recyclable waste generation”. Still as shown in Table 7-3, the most affected alternative both positively and negatively is alternative 4, followed by alternative 1 and then alternative 2. Alternatives 3 and 5 only account with low magnitude of effects (positive or negative effects).

7.3 Social domain

The qualitative social assessment in Fixfabriken site case study was done with researchers from the Balance 4P project at Chalmers. The key criteria are weight as shown in Figure 7-2.

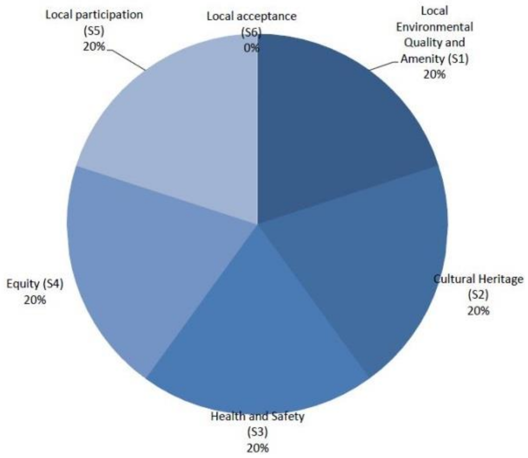


Figure 7-2 Weighting of the key criteria in the social domain

The weighting in the social domain is equally distributed among all the social key criteria considered as being applicable. Only local acceptance is not included, as this criterion should be assessed having an idea of the perspective of the local community about the area and the intervention.

The semi-quantitative assessment of each key criterion and sub-criterion for social domain is presented in Table 7-4. Motivation behind it is included in Appendix 11.

From Table 7-4 it can be seen that the very positive effects are within the social criteria “S1. Local Environmental Quality and Amenity”, “S3. Health and Safety”, and “S4. Equity”, exclusively due to the removal of the contamination source. On the other hand, the very negative effects occur in “S1. Local Environmental Quality and Amenity”, “S2. Cultural Heritage” and “S3. Health and Safety”, due to the remedial action itself.

Still as shown in Table 7-4, the most affected alternative both positively and negatively is alternative 4. All the alternatives are equally affected by some of the very positive effects.

Table 7-4 Social Sustainability Assessment: Semi-quantitative assessment to each alternative

Key criteria	Sub criteria	Alternative 1			Alternative 2			Alternative 3			Alternative 4			Alternative 5		
		Range	**Score**	**Unc**	**Range**	**Score**	**Unc**	**Range**	**Score**	**Unc**	**Range**	**Score**	**Unc**	**Range**	**Score**	**Unc**
S1: Local Environm. Quality and Amenity	RA On-Site	NP	**-4**	H	NP	**-4**	H	NP	**-1**	H	NP	**-6**	H	NP	**-3**	H
	RA Off-Site	NP	**-5**	H	NP	**-5**	H	NP	**-2**	H	NP	**-7**	H	NP	**-4**	H
	SC On-Site	NN	**8**	H	NN	**8**	H	NN	**8**	H	NN	**7**	H	NN	**8**	H
	SC Off-Site	NN	**8**	H	NN	**8**	H	NN	**8**	H	NN	**8**	H	NN	**8**	H
S2: Cultural Heritage	RA On-Site	AS	**-5**	M	AS	**-2**	M	AS	**-1**	M	NP	**-8**	L	AS	**0**	L
	RA Off-Site	NR			NR			NR			NR			NR		
S3: Health and Safety	RA On-Site	NP	**-6**	M	NP	**-5**	M	NP	**-2**	M	NP	**-8**	M	NP	**-3**	M
	RA Off-Site	NP	**-6**	M	NP	**-5**	M	NP	**-2**	M	NP	**-8**	M	NP	**-3**	M
	SC On-Site	NN	**8**	L	NN	**8**	H	NN	**8**	H	NN	**8**	L	NN	**8**	H
	SC Off-Site	AS	**0**	H	AS	**0**	H	AS	**0**	H	AS	**0**	H	AS	**0**	H
S4: Equity	RA On-Site	AS	**0**	H	AS	**0**	H	AS	**0**	H	AS	**0**	H	AS	**0**	H
	RA Off-Site	AS	**0**	H	AS	**0**	H	AS	**0**	H	AS	**0**	H	AS	**0**	H
	SC On-Site	NN	**7**	M	NN	**6**	M	NN	**4**	M	NN	**8**	M	NN	**5**	M
	SC Off-Site	NN	**5**	M	NN	**4**	M	NN	**2**	M	NN	**6**	M	NN	**3**	M
S5: Local participat.	RA On-Site	NN	**0**	M	AS	**0**	M	NN	**0**	M	NN	**0**	M	NN	**0**	M
	RA Off-Site	NN	**1**	M	NN	**1**	M	NN	**1**	M	NN	**1**	M	NN	**1**	M
	SC On-Site	AS	**4**	M	AS	**4**	M	AS	**4**	M	AS	**4**	M	AS	**4**	M
	SC Off-Site	AS	**4**	M	AS	**4**	M	AS	**4**	M	AS	**4**	M	AS	**4**	M
S6: Local acceptance	RA On-Site	NR			NR			NR			NR			NR		
	RA Off-Site	NR			NR			NR			NR			NR		
	SC On-Site	NR			NR			NR			NR			NR		
	SC Off-Site	NR			NR			NR			NR			NR		

7.4 Sustainability assessment by SCORE

The three domains are assumed as having the same importance, thus they are weighted equally.

The NPV to each alternative (CBA in economic domain) and the scorings of the criteria (environmental and social domains) performed by / in SCORE, considering the level of uncertainty defined, are used in the calculations in SCORE. Thus, through Monte Carlo simulation using 10000 trials, the environmental and social sustainability scores, the economic sustainability (NPV, in MSEK) and/or the normalized total sustainability score are obtained.

Figure 7-3 shows the sustainability scores for environmental and social domains, the NPV for the economic domain, as well as the normalized total sustainability score, which integrates the three domains.

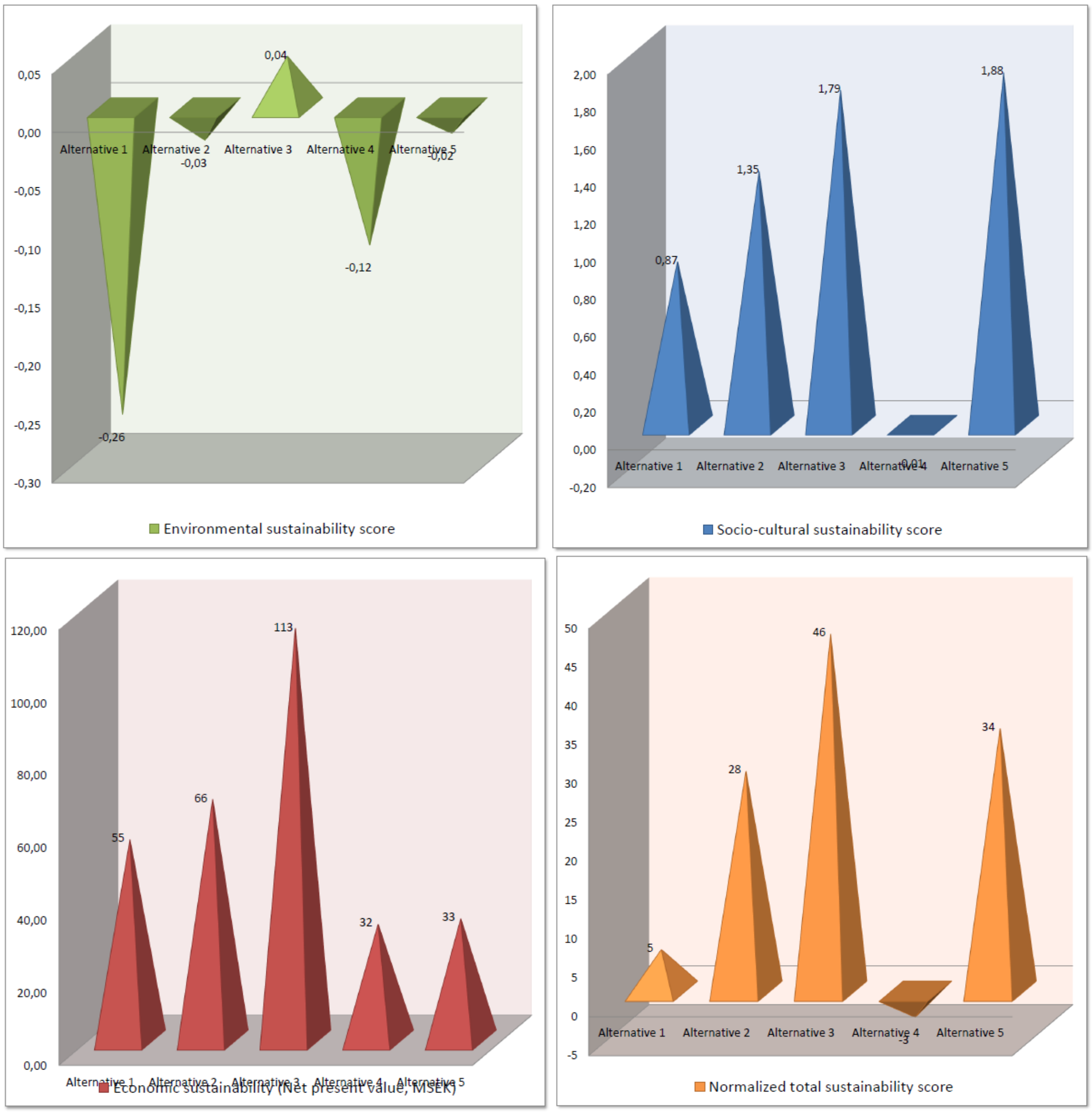


Figure 7-3 Economic sustainability, Environmental sustainability score and Social sustainability score and Normalized Total Sustainability.

According to Figure 7-3, the NPV that measures the economic sustainability of alternatives varies between 32 MSEK (alternative 4, with values very close to the ones of alternative 5) and 113 MSEK (alternative 3).

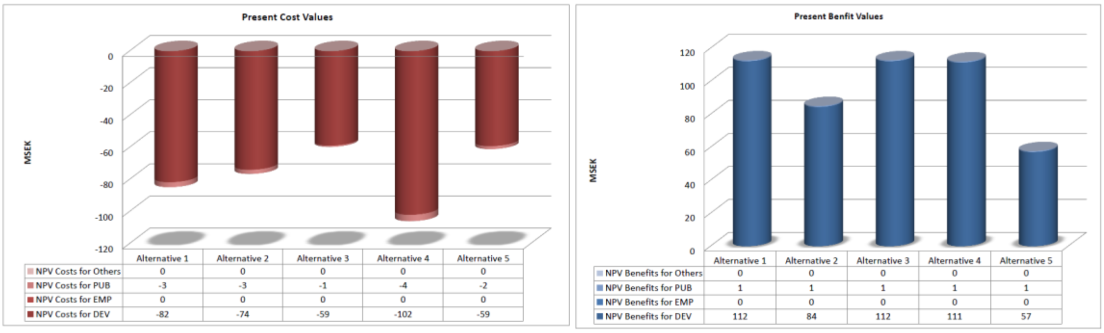
All five alternatives show an environmental sustainability score close to zero, between - 0.26 and 0.04, being alternative 1 the less favourable, followed by alternative 4. Alternative 3 shows a slightly positive environmental sustainability score.

Social sustainability score is positive to all the alternatives, varying between 0.01 and 1.88. Alternative 4 has the lowest score and alternative 5 the highest, followed by alternative 3.

The normalized total sustainability score varies between –3 (alternative 4) and 46 (alternative 3) within the scale of normalization between -100 and +100. Alternatives 2 and 5 have scores of 28 and 34, respectively. Therefore, to all the alternatives, except for alternative 4, there are more positive than negative effects. Alternative 3 is the only alternative with positive result in all the three domains, whereas alternative 4 is the most unfavourable or 2nd most unfavourable alternative in all domains.

Only alternative 3 has strong sustainability on domain level, meaning that in this one there is no compensation between the different domains. On the other hand, no alternative has strong sustainability on the key criteria levels, thus some criteria with a negative performance are compensated by positive impacts in other key criteria.

A Distributional Analysis of the Present Cost Values and the Present Benefit Values is shown, respectively on the left side and on the right side of Figure 7-4.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
NPV Costs for Others	0	0	0	0	0
NPV Costs for PUB	-3	-3	-1	-4	-2
NPV Costs for EMP	0	0	0	0	0
NPV Costs for DEV	-82	-74	-59	-102	-59

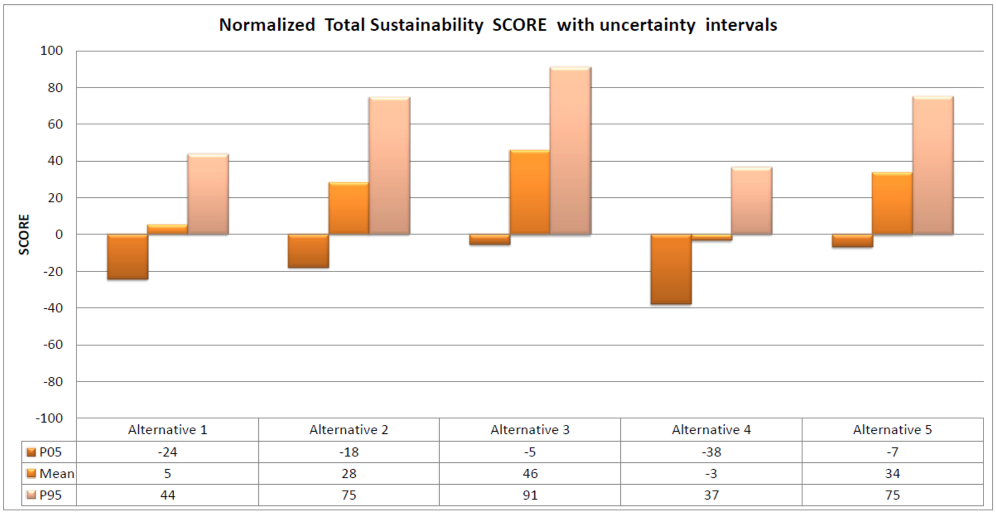
	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
NPV Benefits for Others	0	0	0	0	0
NPV Benefits for PUB	1	1	1	1	1
NPV Benefits for EMP	0	0	0	0	0
NPV Benefits for DEV	112	84	112	111	57

Figure 7-4 Distribution of the NPV costs and NPV benefits among the different stakeholders.

As it can be seen in Figure 7-4, both benefits and costs are concentrated on the developers. Other parts than the developers also have benefits and costs. In fact, some of the zeros are not true zeros, as the values from Table 7-2 are rounded when presented in Figure 7-4. In general, the public bear a greater cost than benefit in the distribution analysis.

7.5 Uncertainty and Sensitivity Analysis

The normalized total sustainability SCORE with uncertainty intervals is shown in Figure 7-5 and the probability distribution for sustainability indices for each of the alternatives in Figure 7-6.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
P05	-24	-18	-5	-38	-7
Mean	5	28	46	-3	34
P95	44	75	91	37	75

Figure 7-5 Normalized Total Sustainability. Inclusion of uncertainty interval.

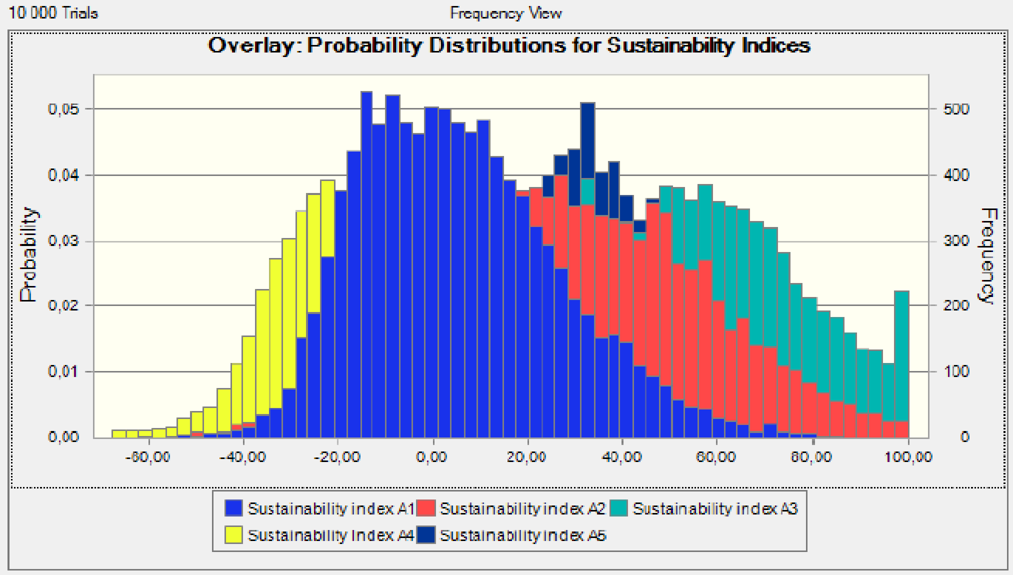


Figure 7-6 Probability distribution for sustainability indices for the five alternatives.

According to Figure 7-5 and Figure 7-6, alternatives 2 and 3 have the highest uncertainties and alternative 1 has the lowest uncertainty. On the other hand, the mean value in Figure 7-5 (which corresponds to the normalized total sustainability score presented in Figure 7-3) has its highest value in alternative 3 and its lowest value in alternative 4. The uncertainty in the results of alternative 1 includes both positive and negative values, whereas the confidence interval of the alternative 3 focuses mainly in positive values, distributed between negative values close to zero and very high positive values.

Figure 7-7 illustrates which items from the economic domain or criteria/sub-criteria from the environmental and social domains influence the end result of the MCA most.

Figure 7-7 Sensitivity analysis for the five alternatives.

For all the alternatives, the economic item that measures the increased property value on site (B1) is the one affecting the result the most. In most of the other situations, the calculations are sensitive to criteria belonging to the environmental domain, e.g.: surface water off-site and sediments off-site, when changing the source contamination in the site; natural resources off-site, due to the remedial action and deposition off-site. The social domain is also represented in alternatives 1, by criterion cultural heritage on-site, when remedial action takes place. For alternatives 2, 5 and especially for alternative 3, the result is sensitive to the economic item "C1d. Remediation costs".

Figure 7-8 shows how the results change by weighting the environmental, social and economic domains differently. Sensitivity analysis took into account four different combinations of weighting each domain, where each one is classified as been somewhat important, important and/or very important.

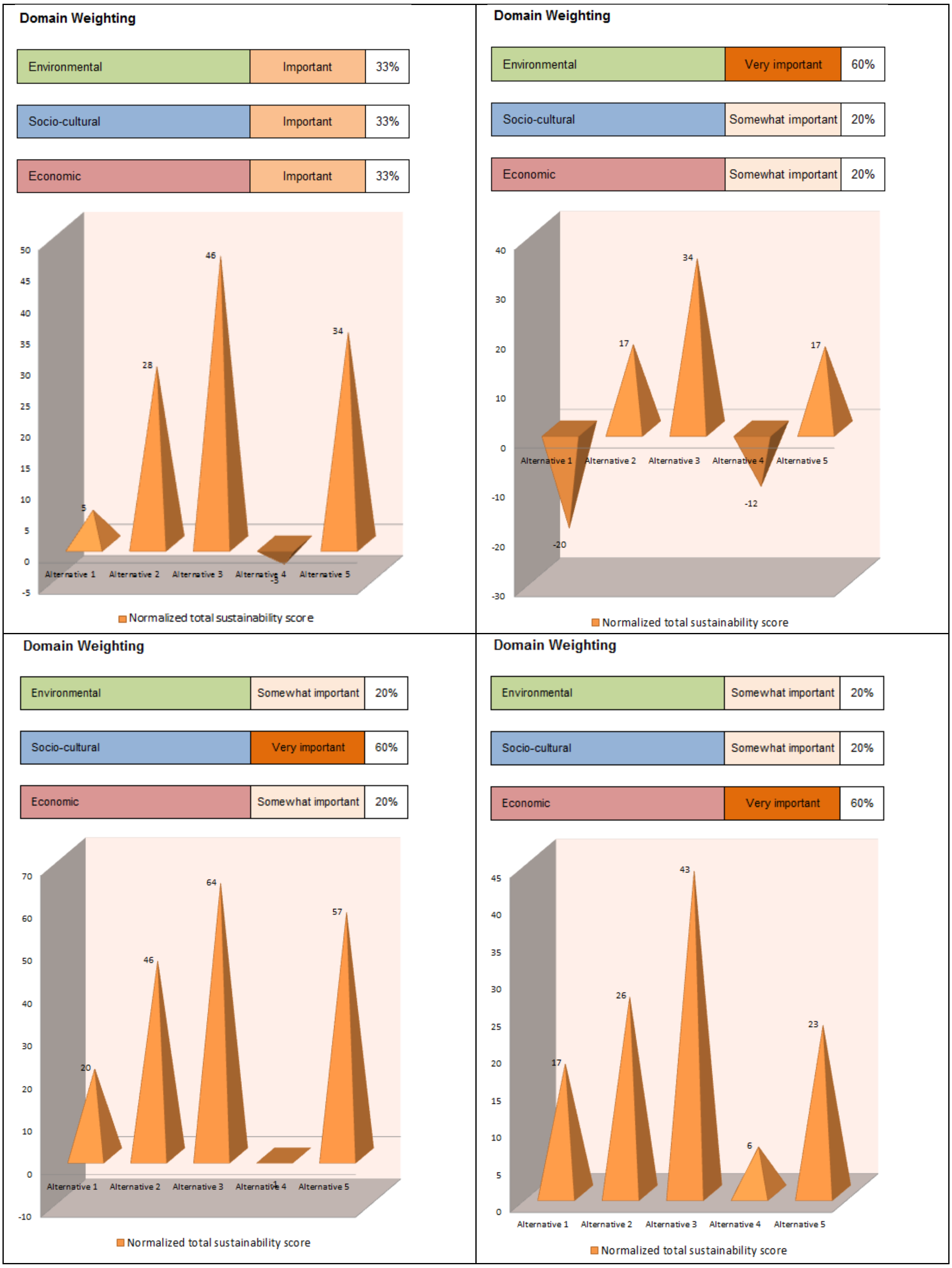


Figure 7-8 Sensitivity analysis with different weights in the environmental, social and economic domains.

As illustrated in Figure 7-8, alternative 3 shows the highest score even if the weight of the different domains is changed. It also shows that, independently on the weighting of the domains, alternatives 2 and 5 are among the three most favourable alternatives. From an environmental perspective, the worst choice is alternative 1, whereas from both a social and economic perspective, the alternative to avoid is alternative 4.

8 The use of SCORE in an early planning stage

This chapter describes the feedback from the user and the stakeholders from applying SCORE to Fixfabriken case study, and suggests adjustments in order to enable its application to early planning stages.

8.1 Feedback from stakeholders and from the user

Feedback from stakeholders was obtained in a workshop held on the 13th of October 2014, organized by Balance 4P. The workshop included presentation of the B4P project, and specifically the application of several tools for the Fixfabriken site, namely: the qualitative tool Social Impact Analysis (SIA), focused on the social domain; the Semi-quantitative mapping of changes in Ecosystem Services (ESS), applied to the environmental domain; and the quantitative and semi-quantitative tool SCORE, focused on all three domains of sustainability. Based on that, the representatives of the municipality of Göteborg had the opportunity to discuss the application of the SCORE tool (Chalmers, 2014) to early planning stages. Despite the interest of having an assessment of different alternatives at such an early stage covering the three domains, namely the environmental, social and economic ones, the stakeholders highlighted some aspects as problematic:

- It was considered that too much effort is put into the assessment, especially considering the significant uncertainty of the outcomes obtained. Therefore, the stakeholders agreed that less demanding approaches seem to be more promising to be used in early stages of urban redevelopment, when typically uncertainty is very large;
- The stakeholders interpreted the economic domain as having a very large weight compared to the environmental and social ones. However this perception is not correct, as the scale of assessment of the economic domain is different from the scale of the environmental and social domains;
- The stakeholders considered that the quantification of the economic domain through a CBA seems to represent a too advanced step to such an early stage of the planning process.

From a user perspective, the following can be said:

- The SCORE tool is easy to use. Both diagrams that are self-explanatory and help menus of different types in the SCORE tool (Chalmers University of Technology, 2014), as well as the SCORE Guide and Manual (Anderson, 2014), provide guidance to the user along the different steps;
- A significant amount of information and data is necessary as input in the application, especially when performing the assessment of the economic domain, by means of the CBA. Therefore, it is suitable for processes in a more advanced stage of development and not so much in early stages, as significant amount of information is not likely to be available until later stages;
- When detailed data is not available, substancial assumptions need to be made, thus the uncertainty of the results might be significant;
- SCORE is able to include the assessment of up to five alternatives, which in some situations might seem too few. However, selecting and assessing new alternatives through an iterative process, which is also proposed in the SCORE

methodology, easily surpasses this. A similar approach was used in the Fixfabriken case study;

- SCORE is set to assess a site where the timeframe for the interventions taking place is the same. However, prior calculations allow considering several parts with different timeframes, therefore enabling the assessment of the whole site, once again, as done in Fixfabriken case study;
- When monetizing the economic domain, care needs to be taken, as items not monetized are not considered explicitly in the results. Therefore, literature on SCORE makes a recommendation: items not monetized with a potential influence in the societal profitability (by switching between a negative and a positive value) and ranking of the alternatives need to be highlighted and considered when supporting decision-making;
- Scorings and weightings in SCORE, as well as in other similar methods, always include a portion of subjectivity. Assignment of scores needs to be done by a group of experts where the knowledge and the competences required are covered. Furthermore, the weight given to each domain is also dependent on the particular concerns and perspectives of the users. On the other hand, this makes it useful to test different perspectives. Furthermore, motivation of the weighting and scoring can be documented, and later on reviewed, contributing to transparency in the process;
- The score of some sub-criteria of environmental and social domains have compensation between negative and positive effects in the sub-criteria itself, which can be documented for transparency and reviewing purposes;
- When the process includes redevelopment of brownfields, simultaneous change in land use and different approaches to deal with site contamination might make it difficult to draw conclusions.

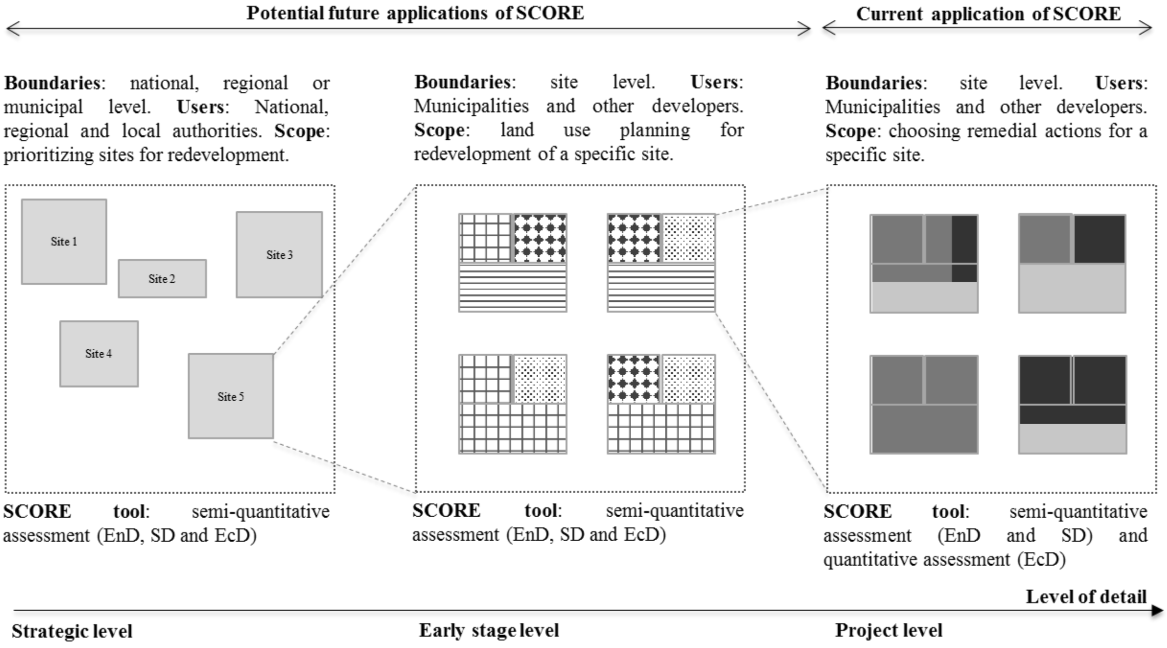
Additionally, the SCORE tool should allow:

- The user to choose the numbering of alternatives. For instance in the Fixfabriken case study, it was useful to mix letter and number to easily see which alternatives are more similar to each other, which not could be done in SCORE.
- A good understanding of the results, being advisable to adjust the outcome in all the graphs, so that values are expressed not to the unit but to decimal or centesimal. Otherwise, values lower than 1 will always appear as 0. At the present, this is the case of most of the graphs and tables expressed in MSEK, namely the distributional analysis of present costs and benefits values for the different stakeholders that might be misleading when interpreting the results.

A recommendation to future users is that, when assessing the economic domain, more effort should be put on the items classified as very important. Furthermore, focus on items that are likely to have a higher cost or benefit item value, therefore influencing more the results and the rankings of the alternatives, is advisable. The economic domain is evaluated only considering the monetized cost and benefit items, and the not monetized items are not part of the calculations. This is a limitation when looking at the result, especially when a non-monetized item is identified as important. Additionally, experienced users or experts should be part of the assessment team of all three domains when using SCORE.

8.2 Possibilities for application of SCORE in early planning stages

So far, SCORE (Chalmers, 2014) has been applied to remediation projects as it was developed for, see right side of Figure 8-1. As suggested in Figure 8-1 (in the left side and at the centre) the SCORE tool has additional potential applications to support decision-making of other scopes.



Boundaries: national, regional or municipal level. **Users**: National, regional and local authorities. **Scope**: prioritizing sites for redevelopment.

Boundaries: site level. **Users**: Municipalities and other developers. **Scope**: land use planning for redevelopment of a specific site.

Boundaries: site level. **Users**: Municipalities and other developers. **Scope**: choosing remedial actions for a specific site.

SCORE tool: semi-quantitative assessment (EnD, SD and EcD)

SCORE tool: semi-quantitative assessment (EnD, SD and EcD)

SCORE tool: semi-quantitative assessment (EnD and SD) and quantitative assessment (EcD)

Figure 8-1 Current and potential additional applications of SCORE, with EnvD – environmental domain, SD – social domain, EconD – environmental domain.

Time, human and monetary resources are scarce, and many underused and / or contaminated areas exist. Therefore, defining which sites within a larger area should be intervened first, and not only which alternatives should be undertaken for a certain specific site, could be a field of application to SCORE. The tool could be developed for use on a strategic level (left side in Figure 8-1), at a national, regional or municipal level, to prioritize sites for redevelopment. At this stage, the alternatives for each site are not much detailed. Furthermore, it is here proposed a semi-quantitative assessment to all the domains, see Section 8.2.2. Depending on the goal of the assessment, it seems suitable to both redevelopment or only to remediation purposes, which might obly including new key criteria to assess the re-use, see Section 8.2.1.

At the early stage level (centre part of Figure 8-1), application to assess different possibilities of redevelopment of a chosen site is considered, including mainly land use planning, and possibly general considerations about the remedial strategy. This could be used at the site level, to choose redevelopment possibilities. At this stage, the alternatives cannot have much detail, due to the early stage of planning and the probable lack of data. A semi-quantitative assessment to all the domains is therefore proposed, see Section 8.2.2. To allow comparison of redevelopment strategies of a specific site, adjustments in the SCORE tool need to be done, see Section 8.2.1.

The Fixfabriken site case study is in a land use planning stage, which is compatible with the early stage level in Figure 8-1.

8.2.1 Incorporation of additional items

In order to allow application of the SCORE tool to redevelopment projects, additional activities need to be included. Figure 8-2 presents a suggested adaptation of the current conceptual model of SCORE. Demolition and/or construction works that are part of a redevelopment project are suggested as additional activities, in the bottom part of the figure. Remediation is kept in the model, as remedial actions are normally an important part of urban brownfield redevelopment projects, but only a part of the full redevelopment activities.

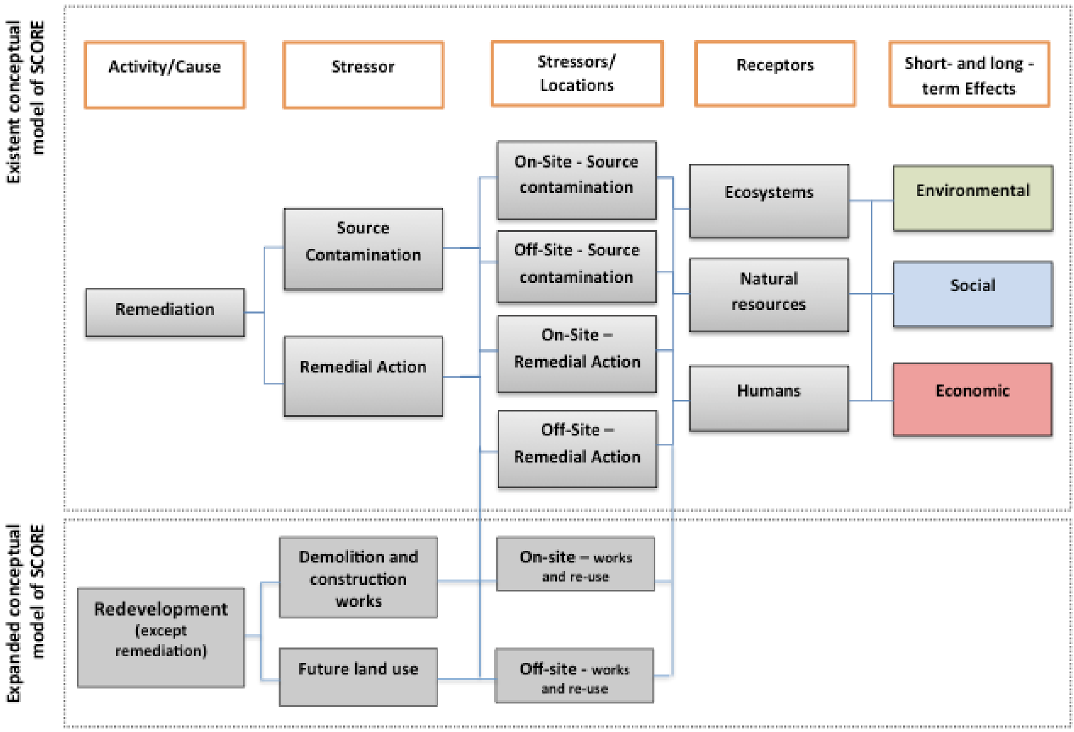


Figure 8-2 Conceptual model of an expansion of SCORE, adapted from Rosén et al (2015)

Those new activities require additional and adjusted items at the three domains, for allowing integration of the new activities in SCORE assessment. Here, focus is on suggesting adjustment of the economic domain.

8.2.2 Replacement of the CBA by a semi-quantitative method

A simplification of the economic domain assessment seems advisable to potentiate the application of SCORE to early stages of urban redevelopment of brownfield areas. Therefore, the replacement of the CBA by a semi-quantitative method is suggested here.

Figure 8-3 shows the existent key criteria for each of the domains (on the top), and suggests new key criteria for economic domain (on the bottom), thus allowing the replacement of the CBA by the semi-quantitative assessment.

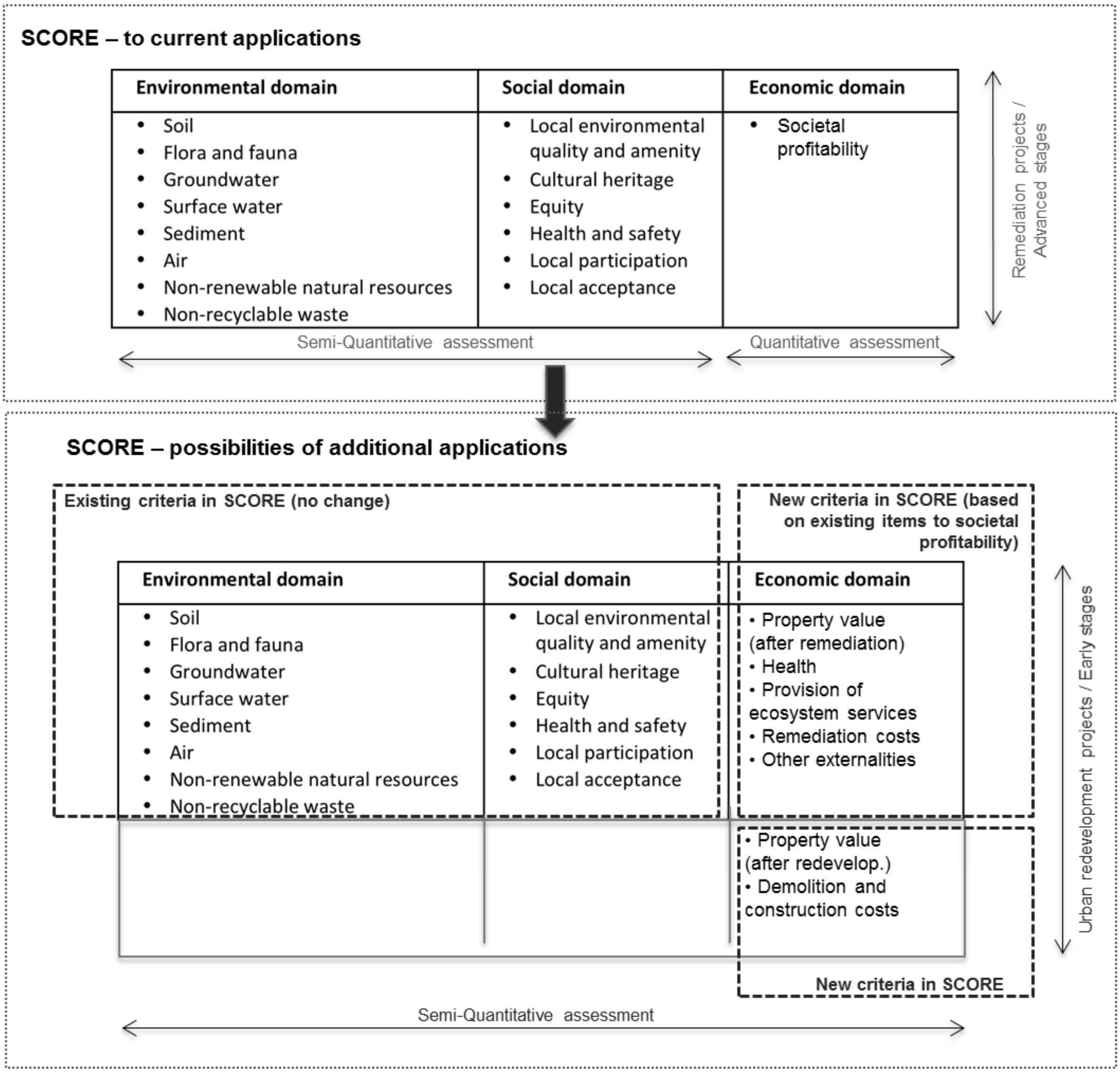
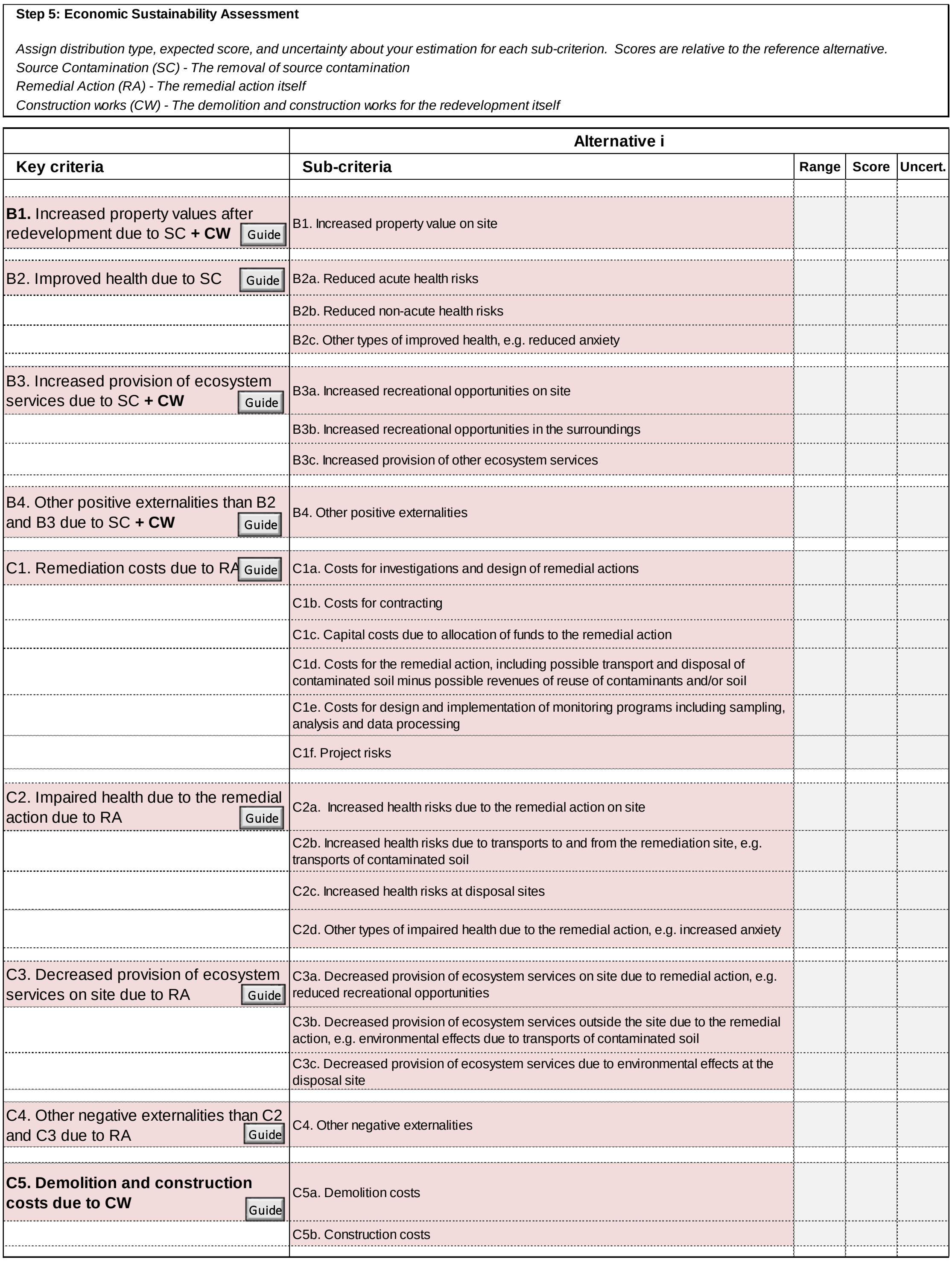


Figure 8-3 Key performance criteria for each sustainability domain in SCORE, to advanced stages (on the top) and to early stages of urban planning (on the bottom), adapted from Rosén et al (2015).

The majority of the key criteria suggested to the economic domain corresponds to the type of cost and benefit items included in the CBA today as a part of SCORE. To allow the assessment of activities that are specific from redevelopment interventions others than the remedial works, two additional key criteria are included in Figure 8-3. Probably additional ones can be identified.

The suggested criteria could then be integrated in a new excel spreadsheet in the SCORE tool, as suggested in Table 8-1, for proceeding with the semi-quantitative assessment of the economic domain in SCORE. The structure of the spreadsheet is the same as the one used for the environmental and social domains, where the range, the score and the uncertainty of each criterion have to be defined. As mentioned, the key criteria suggested are based on the cost and benefit items that presently support the CBA that is part of SCORE. The B1 key criterion is an expansion of the benefit item B1, and C5 key criterion is a completely new criterion.

Table 8-1 Economic Sustainability Assessment matrix for a semi-quantitative assessment in early stages of urban redevelopment of brownfield areas



Step 5: Economic Sustainability Assessment

Assign distribution type, expected score, and uncertainty about your estimation for each sub-criterion. Scores are relative to the reference alternative.
Source Contamination (SC) - The removal of source contamination
Remedial Action (RA) - The remedial action itself
Construction works (CW) - The demolition and construction works for the redevelopment itself

	Alternative i			
Key criteria	**Sub-criteria**	**Range**	**Score**	**Uncert.**
B1. Increased property values after redevelopment due to SC **+ CW**	B1. Increased property value on site			
B2. Improved health due to SC	B2a. Reduced acute health risks			
	B2b. Reduced non-acute health risks			
	B2c. Other types of improved health, e.g. reduced anxiety			
B3. Increased provision of ecosystem services due to SC **+ CW**	B3a. Increased recreational opportunities on site			
	B3b. Increased recreational opportunities in the surroundings			
	B3c. Increased provision of other ecosystem services			
B4. Other positive externalities than B2 and B3 due to SC **+ CW**	B4. Other positive externalities			
C1. Remediation costs due to RA	C1a. Costs for investigations and design of remedial actions			
	C1b. Costs for contracting			
	C1c. Capital costs due to allocation of funds to the remedial action			
	C1d. Costs for the remedial action, including possible transport and disposal of contaminated soil minus possible revenues of reuse of contaminants and/or soil			
	C1e. Costs for design and implementation of monitoring programs including sampling, analysis and data processing			
	C1f. Project risks			
C2. Impaired health due to the remedial action due to RA	C2a. Increased health risks due to the remedial action on site			
	C2b. Increased health risks due to transports to and from the remediation site, e.g. transports of contaminated soil			
	C2c. Increased health risks at disposal sites			
	C2d. Other types of impaired health due to the remedial action, e.g. increased anxiety			
C3. Decreased provision of ecosystem services on site due to RA	C3a. Decreased provision of ecosystem services on site due to remedial action, e.g. reduced recreational opportunities			
	C3b. Decreased provision of ecosystem services outside the site due to the remedial action, e.g. environmental effects due to transports of contaminated soil			
	C3c. Decreased provision of ecosystem services due to environmental effects at the disposal site			
C4. Other negative externalities than C2 and C3 due to RA	C4. Other negative externalities			
C5. Demolition and construction costs due to CW	C5a. Demolition costs			
	C5b. Construction costs			

Economic scorings must estimate the economic effects (costs and benefits) on the societal level. The development of scoring guides is advisable, clarifying what is being assessed, avoiding double-counting and supporting users when scoring. Table 8-2, Table 8-3, Table 8-4 and Table 8-5 provide a suggestion of guidance to some of the key criteria part of the semi-quantitative approach to the economic domain, as proposed in this master thesis.

The key criterion B1 reflects increased property values after redevelopment and is relevant to on-site effects with respect to removal of source contamination and construction works (Table 8-2).

Table 8-2 Suggested scoring guide to the Key criterion B1. Increased property values after redevelopment due to removal of source contamination and construction works

Very negative effect: -6 to -10	**Negative effect: -1 to -5**	**No effect: 0**	**Positive effect: +1 to +5**	**Very positive effect: +6 to +10**
Significantly decrease of property values after redevelopment	**Decrease of property values after redevelopment**	**No change in property values after redevelopment**	**Increase of property values after redevelopment**	**Significantly increase of property values after redevelopment**
Not applicable, as it is not expected that a planned alternative is going to make the situation worse than what it is.	Not applicable, as it is not expected that a planned alternative is going to make the situation worse than what it is.	Not applicable, as it is not expected that a planned alternative is going to make the situation worse than what it is.	Example: -Site contamination levels comply with future land uses. Fulfilment of redevelopment good-practices. - Demand in the area for the future land uses. - Construction of better quality than the existing one.	Example: -Site contamination levels comply with future land uses. Fulfilment of redevelopment good-practices. - Significant demand in the area for the future land uses. - Construction of high quality / high level standards. Mixed uses, valuing residential uses over industrial ones. -Buildings in height

The key criterion “B2b. Reduced non-acute health risks”, is relevant to on-site effects with respect to removal of source contamination (Table 8-3).

Table 8-3 Suggested scoring guide to the Key criterion B2b. Reduced non-acute health risks due to removal of source contamination

Very negative effect: -6 to -10	**Negative effect: -1 to -5**	**No effect: 0**	**Positive effect: +1 to +5**	**Very positive effect: +6 to +10**
Substantial increase in non-acute health risk levels	**Increase in non-acute health risk levels**	**No effects on non-acute health risk**	**Reduction of non-acute health risk levels**	**Substantial reduction of non-acute health risk levels**
Example: -High contamination in the site or existence of carcinogenic contamination sources located in an uncontaminated portion of the site without protection, causing substantially increased non-acute risks for human health. Levels don't comply significantly with the guideline values for the future land uses. Number of users of the site in the future is very significant. -No decrease of the carcinogenic contamination of the site and simultaneously significant increase of the number of users in the site.	Example: -Contamination in the site or existence of carcinogenic contamination sources located in an uncontaminated portion of the site without protection, causing substantially increased non-acute risks for human health. Levels don't comply with the guideline values for the future land uses. Number of users of the site in the future is non-negligible. -No decrease of the carcinogenic contamination of the site and simultaneously increase of the number of users in the site.	Example: -No change in the carcinogenic contamination of the site.	Example: -Reduction of carcinogenic contaminant concentrations and carcinogenic contaminant mass in the site. -Cutting the exposure pathway of carcinogenic contaminants allowing reduction of exposure to users. -No change in the carcinogenic contamination of the site and simultaneously decrease of the number of users in the site.	Example: -Substantial reduction of carcinogenic contaminant concentrations and carcinogenic contaminant mass in the site. -Cutting the exposure pathway of carcinogenic contaminants allowing reduction of exposure to users.

The key criterion "C1d. Costs for the remedial action, including possible transport and disposal of contaminated soil minus possible revenues of reuse of contaminants and/or soil" is relevant to on-site effects with respect to the remedial works (Table 8-4).

Table 8-4 Suggested scoring guide to the Key criterion C1d. Costs for the remedial action, including possible transport and disposal of contaminated soil minus possible revenues of reuse of contaminants and/or soil, due to removal of source contamination

Very negative effect: -6 to -10	**Negative effect: -1 to -5**	**No effect: 0**	**Positive effect: +1 to +5**	**Very positive effect: +6 to +10**
Very substantial costs for the remediation.	**Substantial costs for the remediation.**	**No remediation costs.**	**Not applicable**	**Not applicable**
Example: -Very extensive remedial works -Need to handle a significant amount of contaminated soil and transport it to landfill for industrial wastes -Very complex geological conditions and extent spreading of the contamination	Example: -Less extensive remedial works, with lower spreading of the contamination and lower concentrations of contaminants	Example: -No remedial action -Costs of remediation are balanced by benefits in using soil remediated to refill on site.	Not applicable	Not applicable

The key criterion C5b, construction costs due to construction works, is relevant to on-site effects with respect to construction works (Table 8-5).

Table 8-5 Suggested scoring guide to the Key criterion C5. Demolition and construction costs due to construction works

Very negative effect: -6 to -10	**Negative effect: -1 to -5**	**No effect: 0**	**Positive effect: +1 to +5**	**Very positive effect: +6 to +10**
Substantial construction costs in the site.	**Some construction costs in the site.**	**No construction costs in the site.**	**Not applicable**	**Not applicable**
Example: -Extensive construction works, with buildings footprints / areas with high % of the property size and with buildings with several floors height.	Example: -Less extensive construction works, with buildings footprints / areas with low % of the property size and with buildings with few floors height.	Example: -No construction works.	Not applicable	Not applicable

9 Discussion

This chapter discusses the development of the Fixfabriken case study and the application of SCORE in early planning stages.

9.1 Case study Fixfabriken site

A challenge in the assessment of the alternatives at the Fixfabrken site is that the alternatives consider the different four parts within the site, and include a lot of combinations of remediation and redevelopment possibilities. Thus, the evaluation turned out to be complex and rather time consuming. Additional insights are discussed in the next sub-sections.

9.1.1 Uncertainties of the case study

By the time of the development of this master thesis, significant uncertainties associated with the present subsurface conditions at the Fixfabriken site exist, namely the soil conditions and the archaeology within the site. More detailed investigations of the contamination at the site and of the archaeological remains, that meanwhile were carried out during 2014, are not taken into account in this work. This new data can affect the selection of feasible remedial actions and favour specific options when redeveloping the site, namely avoiding interference or incorporating the archaeological remains. Therefore, more complete information can support more adjusted and realistic alternatives. If the new data lead to a significant change in the assumptions, then the results are likely to change considerably as well.

The alternatives assessed in this work are just part of the many possible options of future land use and remediation strategies at the Fixfabriken site. At the stage of generation of alternatives of urban redevelopment in Fixfabriken, there is a great level of uncertainty both regarding the future urban redevelopment and the remediation options that are suitable to the site. This can be illustrated by changes of the planning options during the writing of this master thesis, namely the different intentions of the stakeholders for the tram hall. On the other hand, remedial actions assessed by this master thesis include different possibilities, some of them probably entailing difficulties regarding: uncertainty about its feasibility, reliability and end result, especially when considered in an early planning stage; acceptability by developers and even by local and environmental authorities. As mentioned in Section 1.3, it is not the intention of this work to suggest the most adequate solutions to the site, but instead to investigate the potential for SCORE as a tool for sustainability assessment in early planning stages.

A decrease of the uncertainty when performing assessment of alternatives can be achieved by: 1) asking the stakeholders for more information on the redevelopment (size of the areas to intervene); 2) by getting expert judgment to better understand the local conditions, the possibilities of remediation, etc. (soil fractions, remedial approaches including technical solutions and costs, property value); 3) gathering additional data about the soil conditions (recent field investigations), to name the most important ones. Any adjustments will affect the results in different ways, depending on the specific items.

9.1.2 Assessment of economic domain

Role of assumptions

The results obtained in the economic domain are dependent on the assumptions made when conducting the CBA, as well as uncertainties in data. Part of the assumptions are based on another case study, and therefore not specific to the Fixfabriken case study (see Appendices 3-10). This is particular the case of the economic items C1c, C1d, C1e and, to a certain extent, B1 and C3b. The B1 item (increased property value) primarily reflects the increase in property value due to remediation, but does not completely reflect the increase due to another future land use. Thus, no differentiation is made to take into account e.g. different heights of the buildings, neither differences in the quality of construction. Additionally, C1d is significantly influenced by the uncertainties associated with the subsurface conditions and the redevelopment. The sustainability assessment (see Section 7.5) shows that the result is very sensitive to these economic items, B1 and C1d, each being the most significant benefit and cost, respectively, in the Fixfabriken case study. Validation of the associated assumptions and better input data of the C1d and the B1 items can decrease the uncertainties of the results.

The remediation costs are dependent on the amount of soil to remediate. Thus, assumptions related to e.g. the size of the area to remediate, the depth of excavation, the contamination levels distributions, as well as the unitary costs of each remediation technology, will have a large influence on the result. Due to the uncertainty of exactly which areas are going to be intervened, and to reduce the complexity of the analysis of the results, simplifications were done by assuming that all four parts of the site have the same size. Furthermore, excavations are assumed to be carried out to the same depth all over the site. The unitary costs of each remediation approach depend on the complexity of the situation and on the size of the area where it is implemented. Therefore, it is unclear if more site-specific data would lead to lower or higher costs, and consequently, to higher or lower societal profitability of each alternative, compared to the literature data now considered.

When comparing “C1d. Remediation costs” and “B1. Increased property values on site”, with the not monetized cost and benefit items, C1d and B1 are expected to have the most significant present value, respectively on the cost and on the benefit side.

Extent of monetization and consequences

The economic domain is evaluated by only considering the monetized cost and benefit items. For the Fixfabriken case study, it was possible to monetize 37.5% of the benefit items (3 out of 8) and 43% of the cost items (8 of 14). The benefit items that are not monetized, correspond to items that are likely to be “not important” or “somewhat important”, and thus likely to have a small influence on the final results. On the contrary, not monetized cost items includes some items that are considered as very important, thus possibly having a significant influence on the results. This is possibly the case of the economic item “C1f. Project risks”, that might change the ranking of the alternatives. It is likely that the NPV decreases, if all benefits and costs are monetized, as the non-monetized costs are expected to be higher than the non-monetized benefits. A decrease of the NPV might result in a negative societal profitability to alternatives 2 and 4, and not only 5.

CBA results

Looking at the results obtained when performing the CBA, there is a positive NPV for all alternatives, except for alternative 5. Alternative 3 is the one with the highest estimated NPV, followed by alternative 1. In the assessment performed, the positive values might be “overestimated” due to the influence of the benefit item B1. The difference between the values of the 5 alternatives (Table 7-2) mainly reflects the differences with regard to both remediation and the urban redevelopment. That is, keeping or changing the existent buildings and infrastructures, and by removing or leaving the soil as it is. Some comments can be made to the results:

- Alternative 3 appears as the most favourable alternative: a low cost of remediation combined with the highest extent of residential areas as future land use, thus high increase in property value and high NPV.
- Alternative 5 has the lowest property value as new residential future land use is confined to only one of four areas of the site, thus resulting in a lower NPV.
- Alternative 1 and 3 differ with regard to remediation approach. The traditional dig and dump is assumed to be more costly than the on-site possibilities of both acting on the contaminant source and on the contaminant pathways.

However, the uncertainties regarding the local conditions, the suitability of the in-situ solutions, as well as the costs of the remediation and no monetization of some economic items, calls for caution in these results. If including “C1f. Project risks” in the assessment, and depending on how high is, alternative 3 may no longer be the one with the highest societal profitability.

Comparison of the CBA outcomes from alternative set 1 and set 2

As presented and motivated in Section 4.2, Section 6.2 and Appendix 1, an initial set of alternatives (alternative set 1) was considered of which the economic domain was assessed. Afterwards, set 1 was excluded without looking at the two additional domains, which is not in accordance with the SCORE method recommendations.

The outcome from the CBA performed to alternative set 1 and set 2 is not easily comparable, as different assumptions and different options of redevelopment, including the remediation, were taken into consideration, resulting consequently in important differences in the NPV, especially on the cost side.

The most significant assumption is the amount of soil to manage when proceeding with excavation, which depends on the site conditions, namely spreading of contamination in the soil, and construction requirements, such as the area to be intervened, here assumed to be 2.5 ha per part of the site. In set 1, a layer of soil with an average of 3 m is considered to be excavated, whereas in set 2 that layer has an average thickness of 1.5 m, thus significantly reducing the excavation costs for the alternatives in set 2. It is uncertain if this adjustment provides a more realistic assumption. Nevertheless, it shows the importance of realistic assumptions. As stated, the amount of soil to handle influences C1d, but also C2b and C3b. On the other hand, the methods of some specific items were adjusted from alternative set 1 to alternative set 2, namely C1d, C1e and C3b, which also affect the results, although not as significantly.

Despite that it is not easy to compare the alternatives from the different sets, the following can be stated. Alternative 4 from set 1 and alternative 4 from set 2 have the same type of future land use and remedial approach of dig and dump, being the thickness of the layer of soil to excavate the only difference. NPV is -73.86 MSEK for alternative 4 from set 1 and 6.91 MSEK for alternative 4 from set 2, which reflects the influence of the amount of soil to handle in the costs, if excavating a soil layer thickness of 3 m or 1.5 m. It is therefore expected that all the alternatives in set 1 would have a higher performance if the amount of soil to handle would be smaller. Still, the remediation approaches in set 2 seem to be more interesting from an economic perspective, than the treatment train chosen in set 1.

Distributional analysis

The distributional analysis shows that both benefits and costs are mainly associated with the developers (Section 7.4). The public is also affected both positively and negatively, whereas negative effects during remedial works can only affect employees if no cautionary measures are taken. Alternative 3 has the lowest costs affecting the public, due to a lower need of transport to and from the site. Furthermore, alternative 3 is the only alternative that simultaneous has one of the highest benefits to the developers, and one of the lowest costs to the developers. For the costs and benefits monetized, alternative 3 seems to be the alternative with the most more fair distribution of costs and benefits.

On the other hand, the non-monetized economic items include benefits affecting exclusively the public, whereas costs are shared between the developers and the public, (Table 7-2, Section 7.1.3). The item “C1f. Project risks” is probably the most significant cost, which is on the developers’ side. The highest cost can be expected for alternative 3, where a less conventional approach to deal with a contaminated site is proposed at an area with future sensitive land-use. Therefore, higher difficulties in achieving a more demanding end-result and probably low acceptability from licensing and environmental authorities can be expected.

Additionally, some costs and benefits from the redevelopment are not integrated in the assessment, namely the estimation of all the construction costs, thus increasing the limitations of the results of the distributional analysis of the economic domain.

9.1.3 Assessment of the environmental and social domains

When assessing the environmental and social domains, the Fixfabriken site is assessed as one area instead of four different areas as done for the economic domain. In certain sub-criteria, negative effects are compensated by positive effects, thus the score for the sub-criteria is a mix of those. This makes it potentially difficult to understand the meaning of a certain score and it becomes important to document the motivation when scoring each criterion.

The lack of specific experts (e.g. cultural heritage and public health) in the scoring group is likely to affect the results of the social domain. By including experts, the level of uncertainty can potentially be reduced and more correct scores could be given. It is however difficult to predict how different the results could be, and how the ranking would be affected.

The social key criterion S6 – Local acceptance is not included in the assessment. If some alternatives are to face strong opposition, or on the contrary, a significant preference, then the results might change. That is the case if alternative 3 is to be scored as having a very negative effect, representing a very low local acceptance, and no score is attributed to the other alternatives. In such a situation, alternative 3 ceases to have the highest social sustainability score, and instead becomes the one with the lowest value.

Assessment of the social and environmental aspects are focused only on the remediation stage, namely on the consequences of removing the contaminant source and of performing the remedial works. This has limitations for the social domain, as the redevelopment of the Fixfabriken site includes different future land uses and diverse perspectives for the urban planning. There are other types of social aspects related to urban planning that are not included in the SCORE analysis, e.g. community cohesion, residential stability, or attractive public realm (Dempsey *et al.*, 2011).

9.1.4 Aggregated sustainability assessment

As alternative 3 shows the highest score in the environmental and economic domains, and is very close to the highest score in the social domain, this alternative is the one in the top of the ranking, even if the weight of the different domains is changed (Figure 7-8, Section 7.5). Therefore, stakeholders with different interests should be likely to accept the result. However, this alternative assumes a less conventional remediation strategy, i.e. the risks are managed by cutting the exposure pathway in combination with removal of the contamination source exclusively at the hot spots. Therefore, acceptance by local authorities and environmental authorities might be more difficult compared to more conventional approaches such as dig-and-dump. This would probably also be reflected in “C1f. Project risks”, potentially lowering the total score and changing the ranking of the alternatives. Additionally, and for the same reasons, alternative 3 might raise objections from the local population, which would come reflected by scoring the social key criterion “S6. Local acceptance”. In such a situation, alternative 3 would switch to fourth place instead of first place, and alternatives 2 and 3 become the best ones.

Furthermore, if all the consequences of the redevelopment and of the future land uses were to be accounted in the assessment, the ranking of the alternatives could change. A potential change of the normalized total sustainability score from positive to negative, and vice-versa, is possible for alternatives with values close to zero (i.e. alternatives 1 and 4).

9.2 Application of SCORE in early stages

9.2.1 Aspects of the redevelopment not included in the assessment

Some aspects that are part of the redevelopment alternatives are not included in the assessment: the demolition works of the existing buildings and infrastructures, the construction works of new ones, as well as the increase of the property value due to the future land uses. Therefore, in the CBA, both the total benefits and costs due to the redevelopment of the case study site are underestimated, as there are no specific items for other redevelopment costs and benefits than those related to the remediation. Due to the high level of uncertainty in the early planning stage, and without additional data and calculations, it is difficult to guess how different the NPV would be from the one calculated. NPV might increase, at least for the alternatives providing more housing areas, as the benefits from selling the new buildings are probably higher than the costs of constructing those new buildings. An increase on the NPV will probably make that even alternative 5 has a positive societal profitability.

By including specific items for the redevelopment of the site, the ranking of the alternatives in the economic assessment can probably be different from the one calculated, thus affecting the final result. Furthermore, the approach does not allow distinguishing between different densities of construction, both building footprint (area) and the height of buildings, neither the possibilities of having underground constructions (e.g. garages) or not, which also affects the economic assessment. Those and other aspects, such as the type of residential use, if subsidized housing to low-income families or luxurious housing, are also likely to affect significantly the social domain.

9.2.2 Semi-quantitative assessment of economic domain in early stages

Monetization of the existing economic items and of additional ones at this early stage is associated with a lot of uncertainties, as well as being time consuming. Therefore, a semi-quantitative assessment might be considered as advantageous as it is less dependent on detailed data, not as time consuming, although it might require more expertise. As a consequence, more economic aspects (if scoring key-criteria instead of monetizing economic items) are likely to be taken into account in the economic assessment.

Changing the economic domain assessment from a quantitative to a semi-quantitative approach can be advisable whenever the data available is scarce and the interventions are not defined in detail, for urban planning processes and even for remediation projects, in early stages.

The proposal of adjustments presented in Section 8.2.2 is explorative and require additional work that is out of scope for this thesis. For example, some of the key criteria suggested in Section 8.2.2, specifically in the Table 8-1 and in the bottom part of Figure 8-3, might be assessing very similar aspects already undertaken in the semi-quantitative assessment of the other domains. Double-counting can be avoided if scoring guides are carefully developed to clearly separate the economic assessment from the social and environmental domains. Suggestions on scoring guides presented in Section 8.2.2 of this thesis might be a starting point for this work. Without such scoring guides, double-counting might potentially occur with the suggested new key criteria B2, B3, B4, C2, C3 and C4. An example of potential double-counting is when assessing the new criterion “B2b. Reduced non-acute health risks” in the economic domain and the existent key criterion “S3. Health and safety” in the social domain. Depending on the conclusions of further work to be developed, B2b might be omitted from the economic domain, if a semi-quantitative assessment of the economic domain is conducted.

9.2.3 Further work to enable applying SCORE in early planning stages

Further work is necessary such that the contributions presented in Section 8.2 can enable applying SCORE in early stages of urban redevelopment in brownfield areas:

- Reflection about potential conflict between criteria of different domains and how this can be surpassed, namely if eventual double-counting occurs when assessing, has suggested that it can happen between e.g. the new criterion B2b (reduced non-acute health risks) in the economic domain and the already existent S3 (Health and safety) in the social domain;
- Identification of potential additional criteria for economic domain;
- Development of guidance to all the key criteria of the economic domain;
- Operationalization of the proposed approach for the economic domain in the SCORE tool:
    - by adjustments in the current design of SCORE, to make the economic domain set up more alike the ones of the environmental and social domains;
    - by including and adjusting the new key criteria;
- Further testing in existing case studies, such as to Fixfabriken site, and comparison with the method used so far;
- Feedback from the main stakeholders to assess its user-friendliness.

As mentioned before, these reflections attended only the economic domain, thus being necessary to ponder the need of adjustment of the key criteria in the environmental and the social domains.

The need of new key criteria or adjustments in the existent ones should be based on an inventory to make about the key criteria linked to assessment of sustainability in urban redevelopment of brownfields, similar to the previously done for the assessment of the sustainability of remedial actions (Brinkhoff, 2011).

10 Conclusion and Recommendations

This final chapter presents the conclusions of the work performed and suggests recommendations.

The application of the MCDA based tool SCORE, designed and tested to assess alternatives of remediation projects, to a case study of brownfield urban redevelopment in an early stage of planning, allows to evaluate the applicability of the tool to early planning stages. Focusing on the economic domain, there are different types of constraints: 1) high degree of uncertainty in these early stages, thus generating results that may be difficult to interpretate and use in a decision-making process; 2) significant effort while performing the CBA, which makes the tool less attractive to potential users and requires some level of expertise. Additionally, important aspects of the redevelopment and future land use are not part of the assessment with the present SCORE design. Examples of such items for the economic domain are costs of construction and demolitions, and benefits of increased property value taking the future land use into account.

Nonetheless, by proceeding with some adjustments, as suggested in this report, the tool has the potential to be expanded to other applications, namely to urban brownfield redevelopment in early planning stages. Adjustments include: 1) the replacement of the CBA as a quantitative method by a semi-quantitative method, which seems promising in making the process more agile; 2) adding or adjusting cost and benefit items in the CBA or key-criteria if choosing the suggested semi-quantitative method, enabling assessing the effects of the redevelopment itself.

Application of an economic assessment based on a semi-quantitative approach in early planning stages has several advantages when comparing with performing a CBA: i) less dependent on detailed data; ii) more attractive to developers as is not so much time consuming, although it might require more expertise; iii) possibility of assessing all the items and not just some, whereas in the CBA it becomes difficult to monetize all the economic items; iv) scales of the different domains are easier comparable, therefore enhancing the comprehension of the assessment by the end-users.

The contributions suggested in this master thesis require further investigation and additional work to confirm the possibility of the proposed approach, namely: a) clarifying if already detected obstacles can be surpassed; b) performance of a literature review of the key performance criteria for sustainable urban redevelopment; c) implementation of the suggestions in the tool; d) further test in case studies and comparison with previous assessment; e) involvement of stakeholders to assess its user-friendliness. If successful, the tool will contribute to more sustainable decision-making in a critical area in today's society. The lack of similar tools covering sustainability assessment of alternatives combining remediation and future land use enhances the relevance of the expansion of the SCORE tool.

Regarding the specific case study assessed, the Fixfabriken site, it is clear that the data available and considered in this master thesis, as well as the land use planning options considered, have a large uncertainty, and therefore the outcomes need to be taken into account with precaution if supporting decision-making. Nevertheless, going through an assessment process with SCORE (or similar methods) is valuable as it: I) obliges collecting information and increasing the comprehension about the site and the possible constraints and opportunities to consider when redeveloping the site; II) generates an understanding of the uncertainties and of what inputs are most uncertain, thus supporting where to focus in order to accomplish a more reliable assessment; III) allows a structured assessment of the alternatives, covering relevant and diversified items and criteria from the three domains of sustainability; IV) supports identification of, at least, some of the critical aspects for the remediation and redevelopment, that are likely to require special care, which then should be taken into account in the following planning stages; V) makes it possible to test how interesting some alternatives might be. It is worth to highlight that, while applying SCORE to the Fixfabriken site, it become clear that economic items such as B1 and C1d influence significantly the outcomes of the SCORE assessment. Therefore, it is convenient improving the monetization of, respectively, the increase of the property value and the remediation costs, and taking those aspects into the next planning stages.

If a more realistic outcome for the Fixfabriken would be desired, it is recommended to reduce the degree of uncertainty as much as possible, by validating and adjusting the assumptions, through additional data and expertise. Scoring of the criteria with the participation of the stakeholders is likely to increase the compliance of the project to the requirements along the process.

11 Bibliography

Anderson, R. et al (2014). SCORE Tool: Multi-¬Criteria Decision Analysis for Assessing the Sustainability of Remediation Alternatives at Contaminated Sites – Guide and Manual. Report 2014:5. Gothenburg: Chalmers Reproservice.

Bardos, P. et al (2011) Chapter 20. Sustainability and Remediation. In Swartjes, F. (Ed.), Dealing with Contaminated Sites, Springer, 889-948.

Beames, A., Broekx, S., Heinout, H., Lookman, R., Boonen, K., Van Geert, Y., Dendoncker, K. & Seuntjens, P. (2015). Accounting for land-use efficiency and temporal variations between brownfield remediation alternatives in life-cycle assessment. Journal of Cleaner Production (2015), 1-9.

Beames, A., Broekx, S., Lookman, R., Touchant, K., & Seuntjens, P. (2014). Sustainability appraisal tools for soil and groundwater remediation: How is the choice of remediation alternative influenced by different sets of sustainability indicators and tool structures? Science of the Total Environment, 954–966.

Brinkhoff, P. (2014). Economic Project Risk Assessment for Sustainable Choice of REmediation (SCORE) in Construction Projects. Thesis for the Degree of Licentiate of Engineering. Gothenburg: Chalmers University of Technology.

Brinkhoff, P. (2014a). Oral information about the landfills in the Göteborg region.

Brinkhoff, P. (2011). Multi-Criteria Analysis for Assessing Sustainability of Remedial Actions. Applications in Contaminated Land Development. A Literature Review. Report No. 2011:14. Göteborg: Chalmers University of Technology.

CABERNET Coordination Team (2006). Sustainable Brownfield Regeneration: CABERNET Network Report. Nottingham: University of Nottingham.

Cappuyns, V. (2013). Environmental impacts of soil remediation activities: quantitative and qualitative tools applied on three case studies. Journal of Cleaner Production 52, 145-154.

Carlsson, C. (2014). Program för Fixfabrikområdet. Historisk inventering med avseende på förorenad mark. Utkast. Göteborgs Stad. Fastighetskontoret.

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

Chalmers University of Technology (2013, November 21). Projects. Balance 4P - Balancing decisions for urban brownfield regeneration - people, planet, profit and processes. Retrieved November 26, 2014, from Chalmers website: http://www.chalmers.se/en/projects/Pages/Balance-4P.aspx

COBRAMAN (2009). Report about concepts and tools for brownfield redevelopment activities. WP 3. Output No. 3.1.1. Bydgoszcz, Poland.

Deltares (2014, November 21). System Exploration Environment and Subsurface (SEES). Retrieved November 21, 2014, from Deltares website: https://publicwiki.deltares.nl/display/SEES/HOME+English.

Dempsey, N., Bramley, G., Power, S., & Brown, C. (2011). The social dimension of sustainable development: Defining urban social sustainability. *Sustainable Development, 19* (5), 289-300.

EC (2014). Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment. Retrieved November 13, 2014, from Eur-Lex. Acess to European Union Law: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32001L0042

EC (2014a). Environmental Impact Assessment. Retrieved 11 13, 2014, from European Commission. Environment: http://ec.europa.eu/environment/eia/eia-legalcontext.htm

EC (2014b). Review of the Environmental Impact Assessment (EIA) Directive. Retrieved November 13, 2014, from European Commission. Environment: http://ec.europa.eu/environment/eia/pdf/EIA_Directive_informal.pdf

Englöv, P, Cox, E., Durant, N., Dall-Jepsen, J., Jørgensen, T., Nilsen, J., Törneman, N. (2007). Klorerade lösningsmedel. Identifiering och val av efterbehandlingsmethod. Rapport 5663. Naturvårdsverket.

Golder Associates (2010). Avveckling av Majornas bussdepå. Miljöteknisk undersökning. Rappportnummer 10512180048.

Google Maps (n.d.). Retrieved June 2014, 15, from Google Maps: https://www.google.se/maps?source=tldsi&hl=en

Göteborgs Stad. Park och natur (n.d.). Sign at the Playground at Sandarna: The Time Path.

Kok, S. (2014). A Guide Through the Forest of Sustainable Urban Redevelopment Instruments.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Länsstyrelsen Västra Götalands Län. (2013). Informationsbrev. Id-nummer 159333.

Maring, L. *et al.* (2015). BALANCE 4P: Balancing decisions for urban brownfield regeneration – people, planet, profit and processes. Technical report I.

Naturvårdsverket (2009). Riktvärden för förorenad mark. Modellbeskrivning och vägledning. Rapport 5976. Stockholm.

NICOLE Brownfield Working Group (2011). Report Environmental Liability Transfer in Europe: Divestment of Contaminated Land for Brownfield Regeneration.

Pollard, S.J.T., Brookes, A., Earl, N., Lowe, J., Kearney, T., Nathanail, C.P. (2004). Integrating decision tools for the sustainable management of land contamination. Science of the Total Environment 325, 15–28.

Rosén, L., Back, P.-E., Söderqvist, T., Norrman, J., Brinkhoff, P., Norberg, T., *et al.* (2015). SCORE: A novel multi-criteria decision analysis approach to assessing the sustainability of contaminated land remediation. Science of the Total Environment 511 (2015): 621-638.

Rosén, L., Norrman, J., Norberg, T., Volchko, Y., Söderqvist, T., Back, P.-E., *et al.* (2013). SCORE: Multi-Criteria Analysis (MCA) for Sustainability Appraisal of Remedial Alternatives. R.R. Sirabian and R. Darlington (Chairs), Bioremediation and Sustainable Environmental Technologies—2013.

Sale, T., Newell, C. (2011). Decision Guide. A Guide for Selecting Remedies for Subsurface Releases of Chlorinated Solvents. ESTCP Project ER-2000530. Department of Defence Environmental Security Technology Certification Program.

Sandin, M. (2014). Oral information about the historical and archaeological conditions at the Fixfabrik area.

SGI Statens Geotekniska Institut (2014). SAMLA för förorenade områden. Retrieved November 19, 2014, from http://www.swedgeo.se/templates/SGIStandardPage____2868.aspx?epslanguage=EN

SNOWMAN NETWORK Knowledge for Sustainable Soils (2015). BALANCE 4P. Balancing decisions for urban brownfield regeneration - people, planet, profit and processes. Deliverable 1.4: Final Report Part 1. Project No. SN-04/01

Söderqvist, T., Brinkhoff, P., Norberg, T., Rosén, L., Back, P.-E., & Norrman, J. (accepted for publication, 2015). Cost-benefit analysis as part of a sustainability assessment of remediation alternatives for contaminated land. Journal of Environmental Management.

SuRF - Sustainable Remediation Forum UK (2010). A Framework for Assessing the Sustainability of Soil and Groundwater Remediation. London: Contaminated Land: Applications in Real Environments (CL:AIRE).

SGF Svenska Geotekniska Föreningen (2014, February 16). Carbon footprint från efterbehandling och andra markarbeten. Retrieved November 14, 2014, from Svenska Geotekniska Föreningen: http://www.sgf.net/web/page.aspx?refid=2679

SWECO (2012a). Report. Fixfabriken | Göteborg. Preliminary.

SWECO (2012b). Gasprovtagning under källargolv.

Volchko, Y. (2014). Thesis for the degree of doctor of philosophy. Assessing Soil Functions for Sustainable Remediation of Contaminated Sites. Göteborg, Sweden: Chalmers University of Technology.

Volchko, Y., Rosén, L., Norrman, J., Bergknut, M., Döberl, G., Anderson, R., *et al.* (2014). SNOWMAN - MCA. Multi-criteria analysis of remediation alternatives to access their overall impact and cost/benefit, with focus on soil function (ecosystem services and goods) and sustainability. Göteborg, Sweden: Chalmers University of Technology.

United Nations, Department of Economic and Social Affairs, Population Division (2014). World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).

UN United Nations, World Commission on Environment and Development (1987). Our Common Future. Oxford: Oxford University Press.

USDHHS, U.S. Department of Health and Human Services (2014). Draft Toxicological Profile for Trichloroethylene. Atlanta.

Appendices

Appendix 1	Description and assessment of the preliminary set of alternatives (Set 1)
Appendix 2	Alternatives not considered in the analysis
Appendix 3	B1. Increased property value on site
Appendix 4	B2b. Reduced non-acute health risks
Appendix 5	B2c. Other types of improved health, e.g. reduced anxiety
Appendix 6	C1c. Capital costs due to allocation of funds to the remedial action
Appendix 7	C1d. Costs for the remedial action, including possible transport and disposal of contaminated soil minus possible revenues of reuse of soil
Appendix 8	C1e. Costs for design and implementation of monitoring programs including sampling, analysis and data processing
Appendix 9	C2b. Increased health risks due to transports to and from the remediation site, e.g. transports of contaminated soil
Appendix 10	C3b. Decreased provision of ecosystem services outside the site due to the remedial action, e.g. environmental effects due to transports of contaminated soil
Appendix 11	Motivation to scoring in the environmental and social domains

Appendix 1 - Description and assessment of the preliminary set of alternatives (Set 1)

A1.1 Presentation of the alternatives

Five alternatives are included in a preliminary set of alternatives, Set 1: A1 (1), A2 (2), B1 (3), B2 (4) and C (5), see Figure A1-1. Those were defined by the author and the supervisor, based on different aspects, see also Figure 4-2 in Section 4.2. The notation for the alternatives reflects the stronger similarity of land use of some alternatives (alternatives A1 and A2, B1 and B2) or of remediation process (alternatives A1 and A2).

The degree of land use change relative to today varies from one alternative to another. Alternative C keeps existing land uses as much as possible, preserving existing buildings, whereas in alternatives B1 and B2 all the parts include new land uses and new construction.

The remediation strategies are chosen depending on the future land use and on the options made regarding keeping buildings (some parts of the site in alternatives A1, A2 and C) or constructing new buildings (some parts of the site in all alternatives). In the majority of the situations with no change of the existent industrial land use and existing buildings, a no remedial action is considered to those specific places. When preserving existent buildings in industrial areas with contaminants in the subsurface environment, the option of protecting the working environment is considered (Fixfabriken factory in alternative C). Furthermore, remedial options include more conventional approaches such as excavation of soil and materials that need then to be transported and taken care of off-site, as well as more complex remediation processes, “treatment trains”, which aim to handle the contaminated soil on-site. In Set 1, in-situ remediation is not proposed as it is normally more time consuming, and more uncertainties about the results are expected. Instead, speed and an end result, which is relatively easy to verify is attractive for constructions companies.

Alternative A1 (1)

The Fixfabriken factory is demolished and the existing filling material beneath the buildings and the superficial part of the underneath layer are excavated. New buildings for residential use with some commercial areas in the ground floors are then constructed, starting in year 5. Redevelopment occurs during 2 years. The excavated contaminated materials are not further treated but are transported off-site to final disposal, possibly with some treatment at the disposal site.

The Bus garage is demolished and the existing filling material beneath the buildings and the superficial part of the underneath layer are excavated. New buildings for residential use, with commerce/offices/services at the ground floor, are then constructed, starting in year 8. It is assumed that the development occurs in two stages. The total redevelopment period is 3 years. The mentioned digging of the soils is the first step of a treatment train to remediate this area on-site, consisting of digging, sieving and soil washing applied to the smaller fractions of the soil.

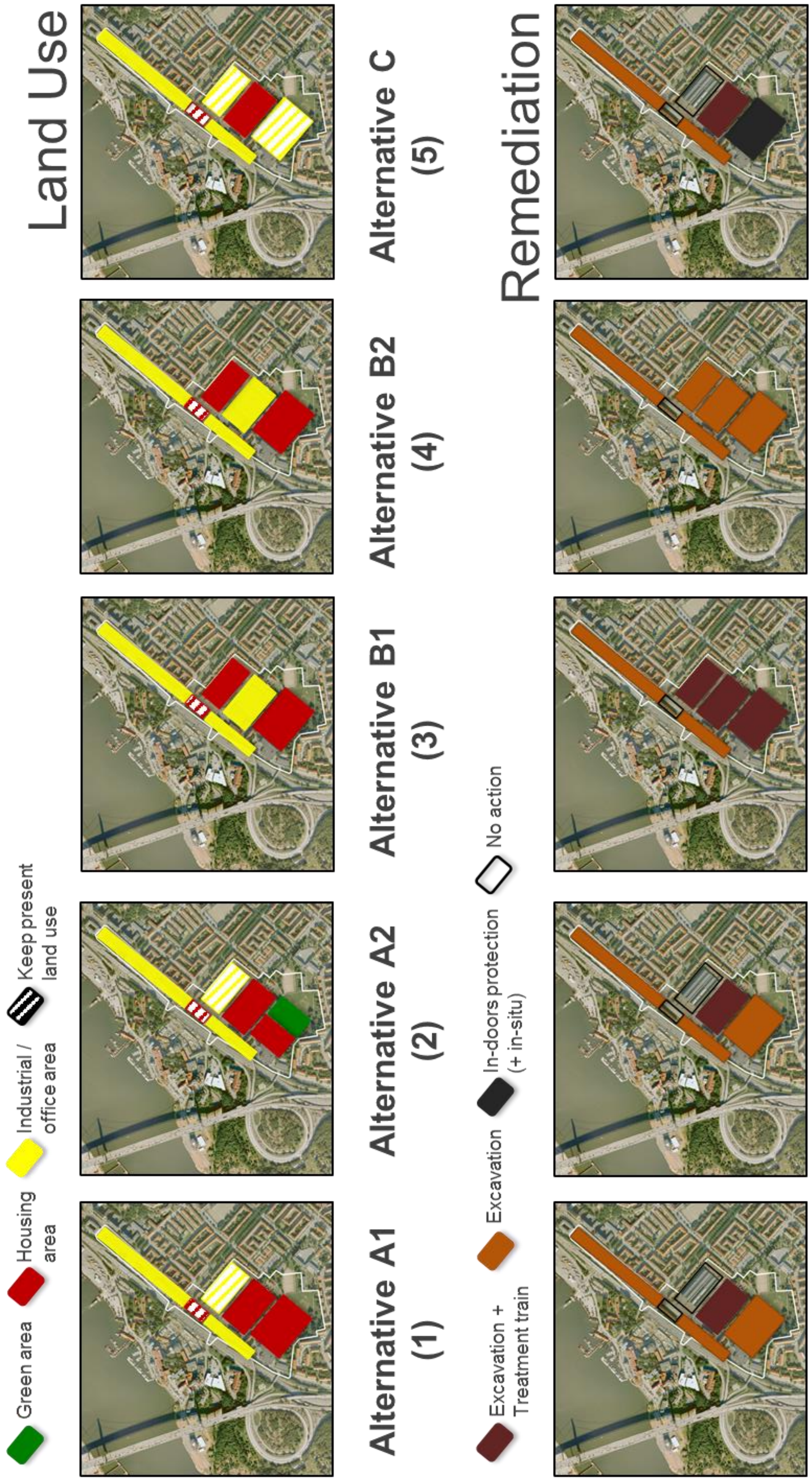


Figure A1-1 Overview of the five alternatives of land use and remediation at Fixfabriken, in alternative set 1.

At least part of the soil dug is suitable to be reused on-site, thus reducing the volume that needs to be transported off-site to final disposal.

The Tram hall is kept as it is. No remediation action is taken, unless extreme hot-spots are found in the coming investigations.

The existing petrol stations at the street Karl Johansgatan are demolished, and the present small residential area is kept. New buildings for industrial and office use are then constructed, starting in year 10. It is assumed that the redevelopment occurs in several stages, during 8 years. Regarding remediation action, the filling material beneath the places to be reconstructed is excavated. That contaminated material is not suitable for on-site reuse and is transported off-site to final disposal, possibly with some treatment at the disposal site.

The timeframe estimated for alternative 1 is presented in Table A1-1.

Table A1-1 Timeframe for the remediation (R) and construction (C) for altern. 1, set 1

ALTERNATIVE 1 (A1)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C/R	C									
Tram hall																			
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

Alternative A2 (2)

The North part of the Fixfabriken factory is developed and remediated in the same way as described in alternative 1. The southern part becomes a green area, with previous excavation to a lower depth as no buildings are then constructed there. This allows a lower disturbance of the underneath layers, thus lower probability of affecting the known archaeological remains from the Early Stone Age culture ”Sandarna settlement” (6000 B.C.) and prehistoric settlements from Neolithic Age (Late Stone Age), and eventual remains of an ancient military camp (1500s-1600s A.C.).

The Bus garage, the Tram hall and the Karl Johansgatan area are handled in the same way as described in alternative A1.

The timeframe estimated for alternative 2 is presented in Table A1-2.

Table A1-2 Timeframe for the remediation (R) and construction (C) for altern. 2, set 1

ALTERNATIVE 2 (A2)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C/R	C									
Tram hall																			
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

Alternative B1 (3)

The future land uses in the Fixfabriken factory are developed in the same way as described in alternative A1. On the contrary, the remediation strategy is quite different. Whereas alternative A1 only includes excavation, alternative B1 considers the digging followed by a treatment train to remediate this area on-site as much as possible, consisting of sieving and soil washing applied to the smaller fractions of the soil. At least part of the soil dug is suitable to be reused on-site, thus reducing the volume that needs to be transported off-site to final disposal.

The Bus garage is demolished and the existent filling materials beneath the buildings and the superficial part of the underneath layer are dug out. A new tram hall is constructed, starting in year 8, and during 2 years. The excavated soil is handled in the same way as described in alternative A1. Different future land uses is thus the main difference between alternative A1 and B1.

The Tram hall is demolished and the existent filling materials beneath and eventually the superficial part of the underneath layer is dug of. New buildings for residential use, with commerce/offices/services at the ground floor, are then constructed, starting in year 10. It is assumed that the redevelopment occurs in 2 different stages, in a total of 3 years. The mentioned digging of the soils is the first step of a treatment train to remediate this area on-site, consisting of digging, sieving and soil washing applied to the smaller fractions of the soil. At least part of the soil dug is suitable to be reused on-site, thus reducing the volume that needs to be transported off-site to final disposal.

The Karl Johansgatan area is developed in the same way as described in alternative A1.

The timeframe estimated for alternative 3 is presented in Table A1-3.

Table A1-3 Timeframe for the remediation (R) and construction (C) for altern. 3, set 1

ALTERNATIVE 3 (B1)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C										
Tram hall										R	C/R	C							
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

Alternative B2 (4)

The Fixfabriken factory is handled in the same way as described in alternative A1. Alternative B2 only differs from alternative B1 on the type of remediation actions considered, as the treatment train is missing here. Therefore, the excavated contaminated materials are not adequate to be used on-site and are transported off-site to final disposal, possibly with some treatment at the disposal site.

The Bus garage is developed in the same way as in alternative B1, except what concerns remediation action, as the treatment train is missing in alternative B2. Consequently, the excavated materials are sent to final disposal, eventually with some treatment at the disposal site, instead of being used on-site.

The Tram hall is developed as described in alternative B1, despite the treatment train to perform a most complete remediation on-site is not considered. Thus, the excavated contaminated materials in alternative B2 are not adequate to be used on-site and are transported off-site to final disposal, possibly with some treatment at the disposal site.

The Karl Johansgatan area is handled in the same way as described in alternative A1.

The timeframe estimated for alternative 4 is presented in Table A1-4.

Table A1-4 Timeframe for the remediation (R) and construction (C) for altern. 4, set 1

ALTERNATIVE 4 (B2)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory					R	C													
Bus garage								R	C										
Tram hall										R	C/R	C							
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

Alternative C (5)

Buildings and uses (industrial and offices) at the Fixfabriken factory are kept as they are. Buildings are renovated to assure an adequate indoor air quality, namely through active ventilation. Depending on further investigation of the soil contamination in the area, in-situ remediation might be carried out if there are any hot-spots / left source areas. This is assumed to start in year 2.

The Bus garage, the Tram hall and the Karl Johansgatan area are handled in the same way as described in alternative A1.

The timeframe estimated for alternative 5 is presented in Table A1-5.

Table A1-5 Timeframe for the remediation (R), construction (C) and / or adjustments to prevent human exposure to contaminants, for altern. 5, set 1

ALTERNATIVE 5 (C)	**YEARS**																		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**…**
Fixfabriken factory		A																	
Bus garage								R	C/R	C									
Tram hall																			
Road Karl Johansgatan										R	C	R	C	R	C	R	C		

A1.2 Identification and preliminary assessment of costs and benefits

First, cost and benefit items included in the SCORE tool (Chalmers, 2014) are classified with regard to importance. Table A1-6 shows the estimated relevance of each cost and benefit item to each alternative.

A1.3 Results of the CBA

Important economic items were monetized as far as possible. The Present Value (PV) calculated to each benefit and cost item to each alternative, as well as the Net Present Value (NPV) are included in Table A1-7. Depending on the item, uncertainties are classified as high or medium. The distribution of costs and benefits between the public (PUB), employees (EMP) and the developers (DEV) is also presented.

As can be seen in Table A1-7, the items affecting the most the results are B1 and C1d, to all the alternatives. The NPV is negative to all the alternatives, with the lowest value with alternative 3 (- 100.2) and the highest values with Alternative 5 (- 36.45), closely followed by alternative 1 (- 41.24).

Table A1-6 Relevance of each cost and benefit items in the Fixfabriken site, to each alternative in set 1. X = important, (X) = somewhat important, 0 = not relevant; A (Appendix)

Benefit Items	Sub items	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Monetized?	Method
B1. Increased property values	B1. Increased property value on site	X	X	X	X	(X)	Yes	A3
B2. Improved health	B2a. Reduced acute health risks	(X)	(X)	(X)	(X)	(X)	No	-
	B2b. Reduced non-acute health risks	(X)	(X)	(X)	(X)	(X)	Yes	A4
	B2c. Other types of improved health	(X)	(X)	(X)	(X)	(X)	No	-
B3. Increased provision of ecosystem services	B3a. On site	0	(X)	0	0	0	No	-
	B3b. In the surroundings	(X)	(X)	(X)	(X)	0	No	-
	B3c. Others	0	0	0	0	0	No	-
B4. Other than B2 and B3	B4. Other positive externalities	0	0	0	0	0	No	-
Cost Items	**Sub items**	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**	**Alt 5**	**Monetized?**	**Method**
C1. Remediation costs	C1a. Costs for investigations and design	X	X	X	(X)	X	Yes, in C1d and C1e	In C1d and C1e
	C1b. Costs for contracting	X	X	X	X	(X)	Yes, in C1d and C1e	In C1d and C1e
	C1c. Capital costs due to allocation of funds	(X)	(X)	X	(X)	(X)	Yes	A6
	C1d. Costs for the remedial action	X	X	X	X	X	Yes	A7
	C1e. Costs for monitoring programs	X	X	X	X	(X)	Yes	A8
	C1f. Project risks	X	X	X	X	(X)	No	-
C2. Impaired health due to the remedial action	C2a. On site	0	0	0	0	0	No	-
	C2b. Due to transports	X	X	(X)	X	(X)	Yes	A9
	C2c. At disposal sites	X	X	(X)	X	(X)	No	-
	C2d. Other due to remediation	(X)	(X)	(X)	(X)	(X)	No	-
C3. Decreased provision of ecosystem services on site	C3a. On site	0	0	0	0	0	No	-
	C3b. Outside the site	(X)	(X)	(X)	(X)	(X)	Yes	A10
	C3c. At the disposal site	(X)	(X)	0	X	(X)	No	-
C4. Other costs than C2 and C3	C4. Other negative externalities	(X)	0	(X)	(X)	0	No	-

Table A1-7– Results of the CBA, in MSEK, and level of importance of the non-monetized items, to each alternative in set 1 (based on Chalmers University of Technology (2014))

Main items	Sub-items	Alternative 1			Alternative 2			Alternative 3			Alternative 4			Alternative 5		
		P/B	Mode (MSEK)	Unc	P/B	Mode (MSEK)	Unc	P/B	Mode (MSEK)	Unc	P/B	Mode (MSEK)	Unc	P/B	Mode (MSEK)	Unc
B1. Increased property values	B1. Increased property value on site	DEV	112,1	H	DEV	84,45	H	DEV	111,3	H	DEV	111,3	H	DEV	57,11	H
B2. Improved health	B2a. Reduced acute health risks	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
	B2b. Reduced non-acute health risks	EMP PUB	0,35	M	PUB	0,35	M	PUB	0,35	M	PUB	0,35	M	PUB	0,38	M
	B2c. Other types	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
B3. Increased provision of ecosystem services	B3a. On site	PUB	0,00	M	PUB	(X)	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M
	B3b. Off site	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	0,00	M
	B3c. Others	PUB	0,00	M	PUB	(X)	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M
B4. Other positive externalities	B4. Other positive externalities	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M
C1. Remediation costs	C1a. Costs for investigations and design	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M
	C1b. Costs for contracting	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M	DEV	*	M
	C1c. Capital costs due to allocation of funds	DEV	2,23	M	DEV	2,23	M	DEV	2,94	M	DEV	2,94	M	DEV	1,39	M
	C1d. Costs for the remedial action	DEV	127,6	H	DEV	127,6	H	DEV	171,1	H	DEV	155,8	H	DEV	75,7	H
	C1e. Costs of monitoring programs	DEV	14,88	M	DEV	14,88	M	DEV	26,19	M	DEV	14,70	M	DEV	11,60	M
	C1f. Project risks	DEV	X	M	DEV	X	M	DEV	X	M	DEV	X	M	DEV	X	M
C2. Impaired health due to the remedial action (increased health risks)	C2a. On site	EMP	0,00	M	EMP	0,00	M	EMP	0,00	M	EMP	0,00	M	EMP	0,00	M
	C2b. Due to transports	PUB	2,56	M	PUB	2,56	M	PUB	3,05	M	PUB	3,42	M	PUB	1,47	M
	C2c. At disposal sites	PUB	X	M	PUB	X	M	PUB	(X)	M	PUB	X	M	PUB	(X)	M
	C2d. Other types	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M
C3. Decreased provision of ecosystem services due to remedial action	C3a. On site	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M	PUB	0,00	M
	C3b.Off site	PUB	6,40	M	PUB	6,40	M	PUB	8,63	M	PUB	8,63	M	PUB	3,75	M
	C3c. At the disposal site	PUB	(X)	M	PUB	(X)	M	PUB	(X)	M	PUB	X	M	PUB	(X)	M
C4. Other negative externalities than C2 and C3	C4. Other negative externalities	PUB	(X)	M	PUB	0,00	M	PUB	(X)	M	PUB	(X)	M	PUB	0,00	M
NPV		**-41,24**			**-68,90**			**-100,20**			**-73,86**			**-36,45**		

Note: * sub-items C1a and C1b are included in C1c and C1d.

A1.4 SCORE analysis

By using the results obtained in the CBA for the economic domain, and with no weighting neither scoring of the criteria in the environmental and social domains, a calculation of the Economic Sustainability is simulated (Chalmers, 2014). Figure A1-2 shows the economic sustainability where the different levels of uncertainties are taken into account in the calculations.

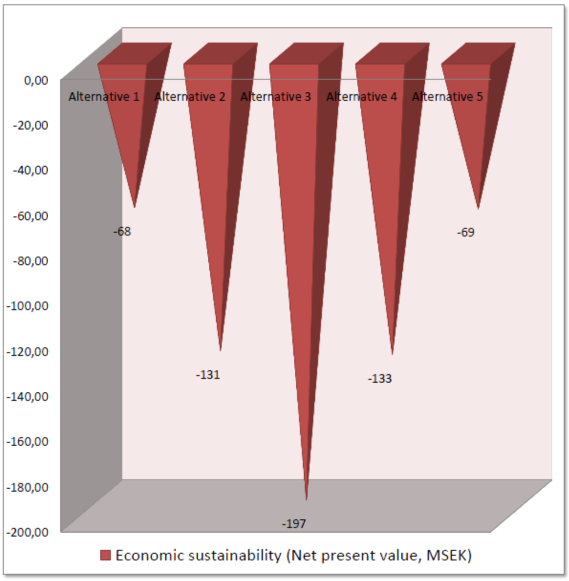


Figure A1-2 Sustainability Score: Economic sustainability for alternative set 1.

According to Figure A1-2, the NPV that measures the economic sustainability of alternatives in set 1 varies between –197 MSEK (alternative 3) and –68 MSEK (alternative 1, with values very close to the ones of alternative 5).

Continuing to look at the economic effects of alternatives in Set 1, a Distributional Analysis of the Present Cost Values and the Present Benefit Values by the different stakeholders is shown, respectively on the left side and on the right side of Figure A1-3.

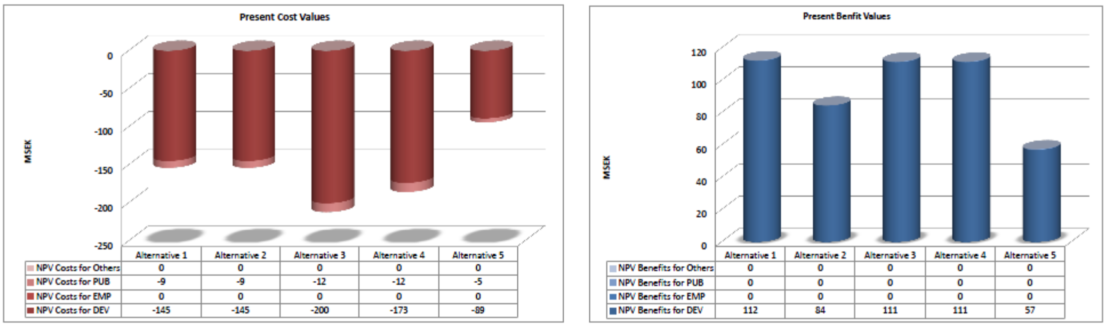


Figure A1-3 Distribution of the NPV costs and NPV benefits among the different stakeholders. Alternative set 1.

The costs are mainly focused on the developers although public is also affected. On the other hand, developers are the ones most benefiting from the redevelopment of the site. Once again, public is also a beneficiary of the process. The values of the benefits are lower than 1 MSEK, and therefore not readable in Figure A1-3.

A1.5 Discussion

Choice of remediation alternatives

The treatment train selected based on the Hexion case study (Landström, 2011), revealed not to be appropriated to the Fixfabriken case study. In a later stage of the work, it was realized that, considering available literature, and the opinion of consulted experts (Karlfeldt *et al*, 2014), soil washing is not one of the most adequate remediation technology to deal with chlorinated solvents, namely trichloroethylene (TCE) and some hydrocarbons. In fact, this treatment technology poses problems with air quality during handling of soil contaminated with volatile compounds, in open air (such as TCE). As so, a first step of in-situ treatment might be more suitable, potentially followed by excavation and, depending on the soil fractions, sieving and soil washing. In-situ approaches that might deal with the volatile compounds are in-situ thermal desorption and soil vapour extraction. Soil flushing and in-situ chemical oxidation are also possibilities (Sale, 2011; Englöv, 2007).

CBA

When performing the CBA, a negative NPV is obtained to all the alternatives, with the lowest value in alternative 3, and the highest value with alternatives 1 and 5, the difference between the five alternatives being very significant. This reflects the different options both of remediation and of urban redevelopment in each of the alternatives, by keeping or changing the existent buildings and infrastructures. The unfavourable results for alternatives in set 1 are mostly due to what ended up to be revealed as unadjusted remedial options, specifically the treatment train solution. It is also extremely dependent on the costs of remediation and on the amount of soil considered to be handled.

Some comments can be made to the results obtained:

- Alternative 1 and 2 are very much alike, except the future land use in Fixfabriken factory area. Whereas alternative 1 assumes residential use in all the area, alternative 2 assumes that half the area becomes a green area. The only difference in the monetization of the items is in benefit item B1, which becomes lower in the alternative 2.
- On a first approach, alternative 3 and 4 seem to be the less favourable as all the soil is to be remediated. However, when comparing these alternatives with the remaining 3 alternatives, it has to be considered that the alternatives 3 and 4 are the only ones with remediation and new construction occurring in all the 4 areas. This leads to a highest value in the cost item C1d due to the mobilization of a significant greater volume of soils.
- When comparing alternative 3 with alternative 4, the remediation approach is the only difference between them. The less favourable value to alternative 3 might be a consequence of less extent monetization of the benefit items compared with the

cost items. Furthermore, the costs with the remediation and treatment train on-site are higher than the saving and other benefits due to less contaminated soil being transported off-site. This results from the specific soil conditions assumed, namely the fraction distribution of the soil and the fractions considered to be efficient for the treatment train chosen. All this has to do with the high uncertainty stated. It might also reflect that the sieving and soil washing that are part of the treatment train chosen are not efficient or economically feasible, and that another treatment train / remediation approach should be considered. The excavation of a layer of soil with an average of 3 m thick is probably generating a huge amount of soil to handle that affects the costs significantly.

It is worth to mention that the identification of costs with the remediation is quite simplified. As so, costs with the improvement of the indoor-air quality in alternative 5, by implementing measures such as active / forced ventilation are not quantified, although the cost to do that is not likely to be significant. Furthermore, the sieving and soil washing costs are included, but a previous stage that is probably necessary to deal with the chlorinated solvents in Fixfabriken factory is not monetized. This is likely to affect the cost, although it can be assumed that it will occur in all the alternatives. Therefore, this is not likely to change the ranking of the alternatives in the economic domain, although the values are expected to be more negative. Additionally, when looking at the results, and specifically to item C1d, it is convenient to keep in mind that the results are quite influenced by the uncertainty of the soil contamination levels in the site, the soil fraction distribution and the requirements to apply the treatment train chosen.

Finally, as in an initial stage of the work, only a qualitative evaluation is performed to the benefit item B2c to alternative set 1, it can be said that the benefits are underestimated. However, these values are not likely to differ significantly from the ones calculated to alternative set 2 (which are around 0.20 MSEK), thus not affecting significantly the NPV of each alternative in set 1.

Assessment of additional domains

As explained in Sections 4.2 and 6.2, a qualitative assessment of the environmental and the social domains was not carried out for Set 1. By considering the environmental and social perspectives, the final ranking of the alternatives would probably be different from the one obtained at the end of the CBA. Alternatives 3 and 4 could eventually switch position regarding the less favourable alternative, as less transport of contaminated soils due to the treatment train in alternative 3 results in lower negative effects in the social and environmental domains. Even so, it is not likely that a positive normalized sustainability score would be achieved for set 1.

A1.6 Bibliography

Anderson, R. et al (2014). SCORE Tool: Multi-¬Criteria Decision Analysis for Assessing the Sustainability of Remediation Alternatives at Contaminated Sites – Guide and Manual. Report 2014:5. Gothenburg: Chalmers Reproservice.

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

CL:AIRE (2007). Technical bulletin. Understanding Soil Washing. TB13. CL:AIRE (Contaminated Land: Applications in Real Environments. UK.

Karlfeldt, K., Tossell, R., Helldén, J., Cummings, J., Newell, C. (2014). Clarifications by email correspondence about remediation technologies, requirements for performing soil washing and/or suitable approaches to deal with chlorinated solvents.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Englöv, P, Cox, E., Durant, N., Dall-Jepsen, J., Jørgensen, T., Nilsen, J., Törneman, N. (2007). Klorerade lösningsmedel. Identifiering och val av efterbehandlingsmethod. Rapport 5663. Naturvårdsverket.

Rosén, L., Back, P.-E., Söderqvist, T., Norrman, J., Brinkhoff, P., Norberg, T., *et al.* (2015). SCORE: A novel multi-criteria decision analysis approach to assessing the sustainability of contaminated land remediation. Science of the Total Environment 511 (2015): 621-638.

Sale, T., Newell, C. (2011). Decision Guide. A Guide for Selecting Remedies for Subsurface Releases of Chlorinated Solvents. ESTCP Project ER-2000530. Department of Defence Environmental Security Technology Certification Program.

Söderqvist, T., Brinkhoff, P., Norberg, T., Rosén, L., Back, P.-E., & Norrman, J. (accepted for publication, 2015). Cost-benefit analysis as part of a sustainability assessment of remediation alternatives for contaminated land. Journal of Environmental Management.

Appendix 2 - Alternatives not considered in the analysis

The alternatives presented previously are just part of the many possible options of future land use and remediation strategies at the Fixfabriken area. Below, other possibilities as well as the reason why they are discarded and not subject to further analysis are presented.

The urban redevelopment of the Fixfabriken site aims to combine different land uses, namely residential, commercial, offices and services areas as well as industrial areas. As so, alternatives with very low diversity of land uses are excluded.

One of the particularities of the area is the historical background and archaeological remains that can be an opportunity or a threat to the process of developing this urban area. No change of the sub-surface contributes at avoiding disturbance of the known and potential remains. On the contrary, interference with the sub-surface might have consequences on potential archaeological remains. The alternatives are not detailed enough to consider possible integration in the redevelopment, removal and/or relocation of remains, or adjustment of the construction works. The option of no construction in larger parts of the area is discarded, as it is probably not economically feasible from developer´s point of view. Some remediation strategies are not suitable in the areas with known or expected archaeological remains since these can be affected by digging operations and changes in the soil conditions (higher exposure to oxygen, increase in the biological activity, among others, could degrade organic material in some of the remains). However, no remediation technology is discarded exclusively based on these concerns.

Industrial land use at the Fixfabriken factory is interesting from some perspectives, in particular due to lower demands of remediation with this type of land use (the Swedish guideline values for the levels of pollutants in the soil are higher for industrial use compared with more sensitive land uses as residential use). On the other hand, the monetary value of the land is much less compared with residential areas. The option for future industrial use with construction of new buildings at Fixfabriken is discarded, as is considered not to be realistic neither interesting for the owner of the property.

Although the remediation process is more demanding in areas with future residential use than with future industrial / office use , it is assumed that the amount of soil and materials to dig does not vary so much with future land use, and that the remediation approach is quite similar.

It was initially considered to relocate the Tram hall away from the Fixfabriken site. However, the company that manages the tram hall showed interest to keep operating the tram hall as it is, eventually with some renovation. New possibilities emerged, such as keeping it exactly as it is or relocating it to the neighbouring bus garage area. The alternative of keeping the tram hall in the same location but underground was excluded due to technical / operational limitations. A temporary relocation to the bus garage area to allow the renovation / construction of a new tram hall in the present location, is also not included, partly as it can be assumed to be too costly.

Housing is not included as an alternative within the street Karl Johansgatan area. The nearby road infrastructures and traffic affect this area adversely, causing noise, air pollution, visual intrusion and even some constrains to the mobility of people, which is not a desired situation for a residential area. No changes on the present residential area located at the street Karl Johansgatan area are considered.

Not only the mentioned space and land use perspectives, but also the time dimension has been taken into account in the process of defining, selecting and excluding alternatives. As mentioned when describing each one of the alternatives, the future interventions are very likely to have different timings depending on each of the four parts in the Fixfabriken site, starting by the Fixfabriken factory and ending at the Karl Johansgatan area. The whole area is in use and new temporary uses prior to the long-term future land uses are excluded, as it is not clear when the on-going activities will be phased out. In the case of Fixfabriken factory, the intervention is expected to start as soon as possible in the coming years, thus temporary uses were not considered to be realized.

The four different parts in the Fixfabriken area have different owners and diverse deadlines, both regarding when each place is available for intervention and when construction works have to start, thus restricting possible integrated and common solutions of remediation for the overall area. Otherwise, it could potentially lead to beneficial scale economies / synergies.

At first, monitoring of natural attenuation was considered as an interesting possibility as a gentle remediation option, to areas that are not going to be intervened in the short term, and that have some contamination but not require a remediation action in the actual conditions, namely due to its less sensitive land use. This is the case of the street Karl Johansgatan area. Despite the benefits of knowing how the contamination changes over time, the costs during the process might be significant for a small-size enterprise, especially considering that at the end the action previous to the construction works will probably be the same with or without this follow-up. As so, this option was not included.

Appendix 3 - B1. Increased property value on site

A3.1 Method

Figure A3-1 shows the methodology used to monetize the benefit item B1.

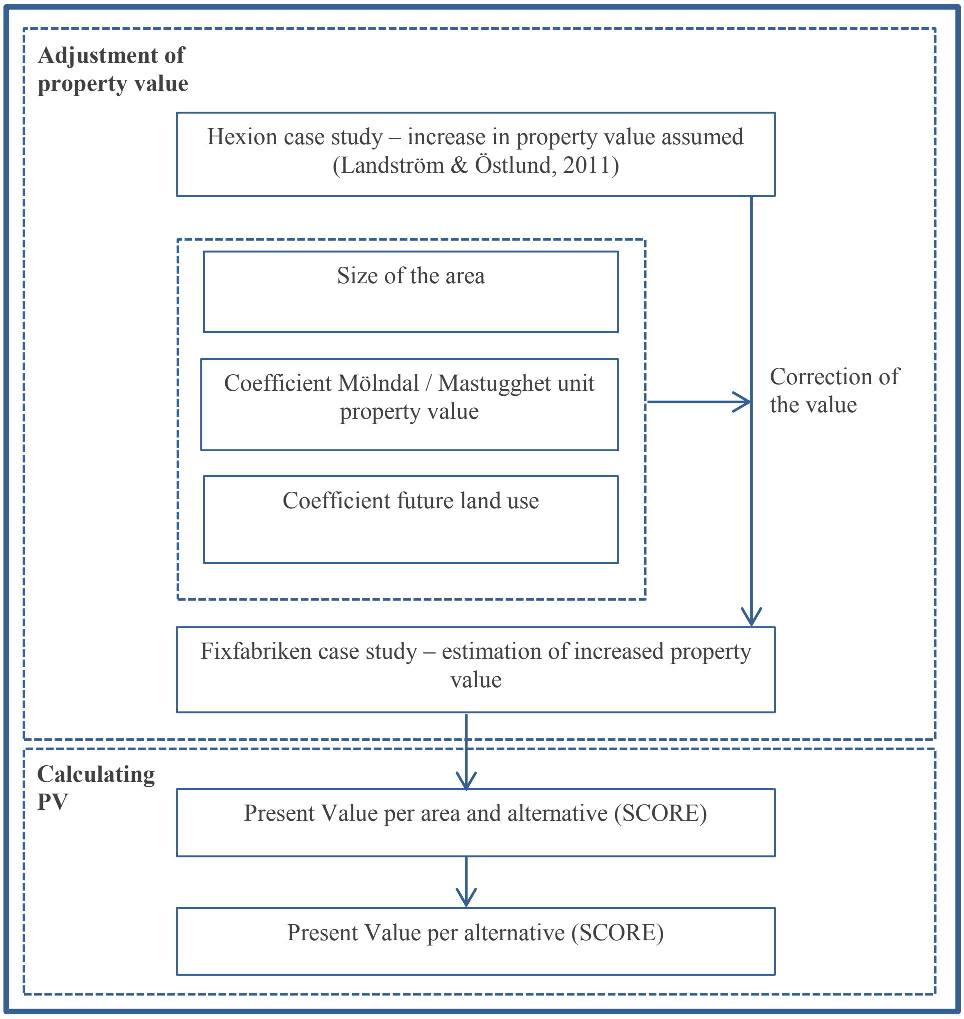


Figure A3-1 Steps followed in the increased property value assessment

The increased property value evaluated for the Hexion case study of 60 MSEK for an area of 3.5 ha, located in Mölndal (Landström & Östlund, 2011), is considered in the calculations. This value is corrected by a coefficient of 1.7, considering the difference of property value per m^2, in the centre of Mölndal close to Hexion site, and in the Masthugget area in Göteborg, where Fixfabriken site is located (Skatteverket, 2014), see Table A3-1. A limitation is that the value from Hexion case study used as a reference is probably out of date and reflects merely the consequence of the remedial action, considering a fixed future land use of mainly residential use.

Table A3-1 Property values in Mölndal and Masthugghet, based on Skatteverket

Area	Property value (thousand SEK)	Size of the property (m^2)	Value per m^2 (thousands SEK)
Mölndal	1300	800	1.6
Masthugghet, Göteborg	1900	700	2.7

To each one of the four parts of the Fixfabriken site, the increased property value is calculated for a future land use as residential or as industrial use, and assuming each one of the four parts of Fixfabriken site to have 2.5 ha each.

Whenever there is an improvement of industrial areas or green area, it is considered an increase of the property value of 5% of the value for residential use. On the other hand, a value of zero is considered when an existent industrial area is not renovated in any way. These adjustments are an attempt to reflect the influence of future land uses in the property value, although not based on previous studies and therefore significantly subjective.

Table A3-2 shows the values calculated to each area, considering its sizes and the possible future land uses at each part of the site.

Table A3-2 Increased property value in each of the 4 areas, for different future land uses

Future Land Use	Fixfabriken area (MSEK)	Bus garage area (MSEK)	Tram hall area (MSEK)	Road area (MSEK)
Residential	71.6	71.6	71.6	n.a.
Industrial	3.6	3.6	0.0	3.6

Each one of the four parts of the site are first treated separately using SCORE (Chalmers, 2014). The timeframe during which the benefit occurs is defined for each area. The benefit is assumed to occur during one year, beginning the year after the remediation is done, or during a larger period that goes between one year after the first remedial action and one year after the last remedial action within an area. For the road area, a 7 years period during which the benefit occurs is considered, when in fact it should correspond to only 4 years, one after each one of the 4 stages of remedial actions. However, this could not be reflected in the calculations. This deviation applies to all the alternatives of set 1 and set 2, to the road area, thus not affecting the ranking of the alternatives.

A3.2 Results

Table A3-3 and Table A3-4 show the increase property value per area and per alternative, expressed as PV, in MSEK, as well as the sum of the values for each alternative of set 1 and set 2.

Table A3-3 Increased property value in each of the 4 areas and for each alternative of set 1, expressed as PV (MSEK)

B1. Increased property values on site	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	58,24	30,58	58,24	58,24	3,25
Bus garage area	51,64	51,64	2,64	2,64	51,64
Tram hall area	0,00	0,00	48,20	48,20	0,00
Road area	2,23	2,23	2,23	2,23	2,23
B1. Present Value (MSEK)	**112,11**	**84,45**	**111,32**	**111,32**	**57,11**

Table A3-4 Increased property value in each of the 4 areas and for each alternative of set 2, expressed as PV (MSEK)

B1. Increased property values on site	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	58,24	30,58	58,24	58,24	3,25
Bus garage area	51,64	51,64	2,64	2,64	51,64
Tram hall area	0,00	0,00	48,20	48,20	0,00
Road area	2,23	2,23	2,23	2,23	2,23
B1. Present Value (MSEK)	**112,11**	**84,45**	**111,32**	**111,32**	**57,11**

The values calculated do not reflect all differences in the type and the density of construction, as well as the specific uses (e.g.: distinction in values for social and no-social housing; differences in values depending on buildings with different heights, and underground construction such as garages and basements). Even the exact building footprint (area) is able to affect significantly the PV for this item, and that is not reflected by this economic item.

A3.3 Bibliography

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Skatteverket (n.d.). Värdeområden för småhus 2012 - 2014. Retrieved August 28, 2014, from Skatteverket hemsida: https://www3.skatteverket.se/fa/fa_vo/secure/start.do?votyp=smahus&taxeringsar=2012

Appendix 4 - B2b. Reduced non-acute health risks

A4.1 Method

Figure A4-1 shows the methodology used to monetize the benefit item B2b.

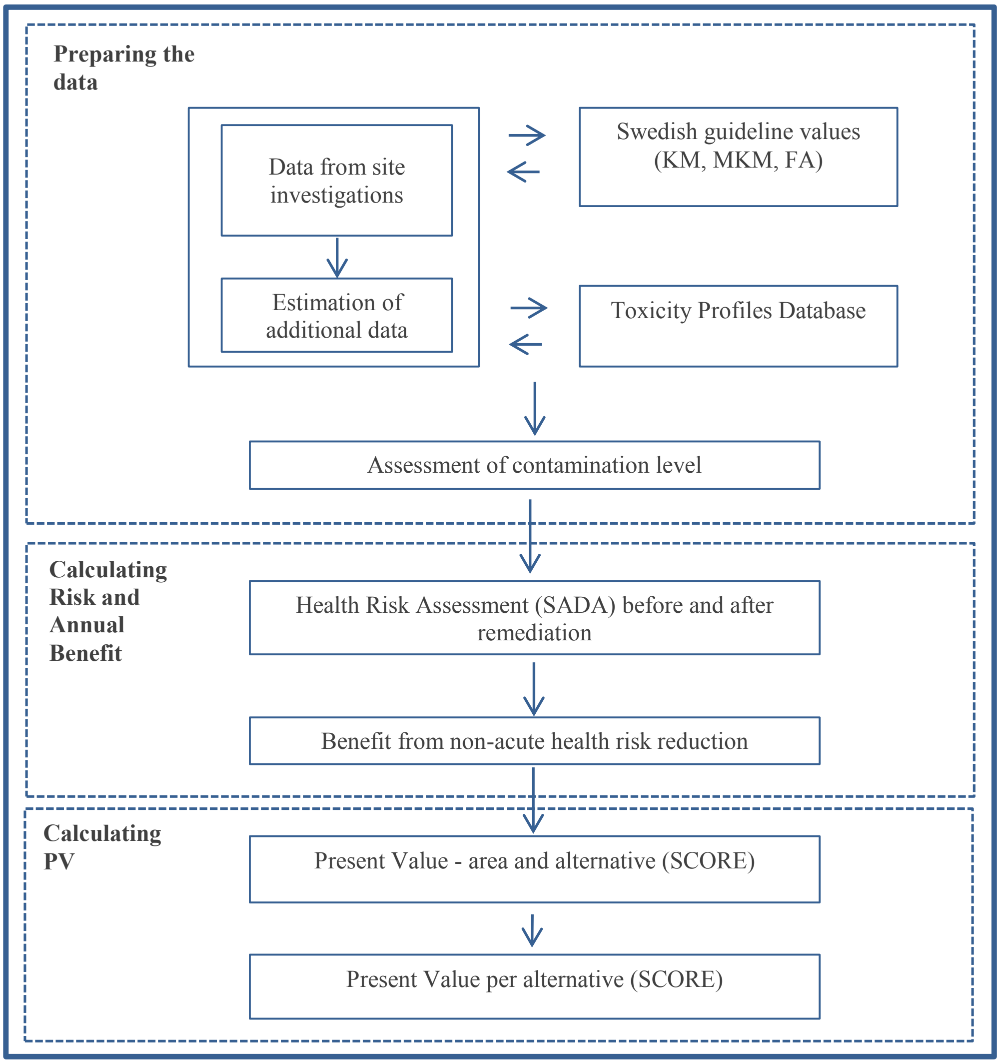


Figure A4-1 Steps followed in the assessment and monetization of the reduction of non-acute health risks, where KM, MKM and FA stands, respectively, for sensitive land uses, less sensitive land uses and hazardous waste

Included carcinogenic contaminants in the non-acute health risk assessment

The available soil contamination data was compared with the generic Swedish guideline values. Contaminants not fulfilling the guideline values for sensitive land use are selected to be included in the non-acute health risk assessment.

The USEPA's Toxicity Profiles Database (EPA's regional screening level, 2014) was used to identify which contaminants are carcinogenic. The database is not completely coherent with the classification of carcinogenic contaminants assumed by SEPA

(Naturvårdsverket, 2009). For example, SEPA classifies all PAH (Polycyclic Aromatic Hydrocarbons) as carcinogenic whereas the USEPA identifies only some of the PAHs as carcinogenic. Since the soil contamination data is processed in the SADA (Spatial Analysis and Decision Assistance) software (The University of Tennessee Knoxville, 2007), the USEPA's database was used to estimate human health risk levels. Therefore, neither PAH-L nor PAH-M were considered as carcinogenic in this study.

Each contaminant was identified using the CAS Registry Number Database (Chemical Abstracts Service from American Chemical Society, 2013), and used for matching between lab results and the USEPA database. The contaminant group "aromatics >C16-C35" from the lab results was assumed to correspond to the "Total Petroleum Hydrocarbons (Aromatic High)" in the database, although this is not completely equivalent (USEPA, 2014).

Soil contamination data from site investigations was used for the Fixfabriken factory area (SWECO, 2012a; SWECO, 2012b; Carlsson, 2014) and for the Bus garage area (Golder Associates, 2010; Carlsson, 2014). Although there was limited information on the contamination levels at the site, the available samples were considered as being representative of the contamination situation. The tram hall area and the road area are assumed to have the same contamination situation as in the Bus garage area, as all these areas have uses related to traffic and transport facilities, which is a simplification. Trichloroethylene concentrations in soil were not measured in the soil investigations. Instead these were estimated based on pore gas samples.

Table A4-1 presents both the concentrations detected in the site of each of the carcinogenic contaminants to include in the risk assessment, and the Swedish guideline values for those pollutants when in the soil. The selected carcinogenic contaminants include lead, hydrocarbons, and chlorinated solvents. The left side of Table A4-1 shows the range of contamination in soil in the different areas. Green colour means that the concentration complies with all the guideline values, the brownish that the values are above less sensitive land use guidelines but below hazardous waste when that limit exists. No data available for a certain part of the site and a certain contaminant is represented by grey.

Table A4-1 Carcinogenic contaminants levels in the different areas, and guideline values for different levels of contamination

Carcinogenic Contaminant	Range of contamination levels in soil in the different areas (mg/kg)				Swedish guideline value to soil (mg/kg)		
	Factory area	Bus garage	Tram garage	Road area	Sensitive land use	Less sensitive land use	Hazardous waste
Lead	3 - 2000	n.a.	n.a.	n.a.	50	400	2500
TPH (Aromatic High)	<1 - 64	ok	n.a.	n.a.	10	30	-
PAH High	<0.3 - 150	<0.3 – 4.1	n.a.	n.a.	1	10	-
Trichloro-ethylene	0.23 – 530 (pore gas)	n.a.	n.a.	n.a.	- (pore gas)	- (pore gas)	- (pore gas)
	1.1 – 2609 (*)	n.a.	n.a.	n.a.	0.2	0.6	-

Note: n.a. – there is no information available regarding a specific area; * - estimation based on levels in pore gas

Estimation of trichloroethylene in soil

Concentrations of the chlorinated solvent trichloroethylene (TCE) were only available as pore gas samples. Based on the equations by SEPA (Naturvårdsverket, 2009) used to calculate pore gas concentrations from soil sampling, TCE concentrations in soil (C_s) were estimated:

$$C_a = H \times C_W$$

$$C_w = C_s / [K_d + \frac{(\theta_w(1+K_{DOC}\times \mathrm{DOC})+\theta_a\times \mathrm{H})}{\rho_b}]$$

$$K_d = K_{oc} \times f_{oc}$$

$$K_{DOC} = 0.24 \times K_{OC}$$

C_a is the gas concentration in the pore gas in the soil, C_w is the concentration of pollutant dissolved in pore water, H is the Henry's constant, f_{oc} is the weight fraction of organic content in soil, see additional parameters in Naturvårdsverket (2009).

The two parameters that are compound specific are: K_{oc}, that is used to calculate distribution coefficient between soil and water (K_d); H, Henry's constant, which gives the relation between the gas phase and the aqueous phase. It is used a K_{oc} = 115 l/Kg and H = 0.28.

The calculation of the concentration of TCE is very sensitive to the organic content, which reflects the importance of the parameter f_{oc}. A conservative assumption is made, by adjusting f_{oc} from 2% to 1%, as it is expected a lower organic content in the filling material layers on the site, compared with natural soils in Sweden.

The remaining parameters were defined as suggested in Naturvårdsverket (2009).

Calculation of human health risk

Human health risk levels were calculated using the software SADA. The model considers the level of contamination (Table A4-1) and a number of exposure pathways for different land uses.

Input files with data from the Fixfabriken factory and the Bus garage area were prepared, imported to SADA and matched with the Toxicity Profiles Database (EPA's regional screening level, 2014). As the number of samples is low, and in order to make use of all samples, the ones with concentrations below the detection limit were considered to have a value nearly equal to it (depending on the number, a decimal or centesimal below). This might lead to an overestimation or an underestimation, although not expected to affect the results significantly.

Since soil and pore gas sampling had been carried out mainly close to known contamination sources, sampled data are not necessarily representative of the whole site. To mitigate possible overestimation of the contamination levels at the sites, mean values were used to assess the risk instead of UCL95 values. The human health risk is calculated for all four areas and the present land use (industrial) including all exposure pathways for this type of use: ingestion, inhalation and dermal contact.

Calculation of the benefit of health risk reduction

The annual benefit from the reduction of non-acute health risk, in each of the four areas, and per contaminant is calculated using the following formula (Landström & Östlund, 2011):

$$B_{\text{non-acute risk}} = ([(R_o \text{ x } n) / t] - [(R_1 \text{ x } n) / t]) \text{ x VSL x 2 x } P_{\text{mortality}} \text{ (SEK)}$$

R_o stands for risk levels for the reference alternative expressed as the probability of developing cancer over a lifetime. The remaining parameters and respective values are presented in Table A4-2.

Table A4-2– Parameters to calculate $B_{\text{non-acute risk}}$

Variables to calculate Bnon-acute risk	Values
R_1 (Target risk)	10^{-5}
n (number of workers)	Fixfabriken: 50; Bus garage: 70; Tram hall: 10; Road: 10
t (adult exposure duration, in years, in reference alternative)	59
VSL (Value of a statistical life) (Swedish crowns)	21000000
Pmortality	37%

It is assumed that all remediation alternatives fulfil the target risk. A rough estimation of parameter n is made and validated by Hanna Kaplan. Parameters t, VSL and $P_{\text{mortality}}$ are based on assumptions taken to the Hexion case study (Landström & Östlund, 2011).

Calculation of PV

The results obtained for the benefit of reducing the non-acute risk per contaminant in each area, are then used in the CBA calculations in SCORE (Chalmers, 2014). Here, a benefit is considered during 350 years, equivalent to several generations benefiting from the decreased non-acute health risk (Landström & Östlund, 2011).

Discounting occurs in accordance to the timeframe for the redevelopment (accumulation of the benefit in each year, starting from the conclusion of the remediation). Each of the four areas are treated separately.

A4.2 Results

Table A4-3 and Table A4-4 show the estimated risk levels for the Fixfabriken area, and for the Bus garage area, respectively.

Table A4-3 Estimated risk levels at the Fixfabriken factory area, according to SADA.

Name	**CAS**	**Conc**	**Ingestion**	**Inhalation**	**Dermal**	**Total**
Lead and Compounds	7439921	205.84	6.10E-07	4.40E-10		6.10E-07
Total Petroleum Hydrocarbons (Aromatic High)	12	19.89	5.10E-05		1.60E-04	2.10E-04
Trichloroethylene	79016	819.13	1.30E-05	3.40E-04		3.60E-04
Benz[a]anthracene	56553	111.14	2.80E-05	2.20E-09	1.20E-04	1.40E-04
Chrysene	218019	72.16	1.80E-07	1.40E-10	7.60E-07	9.40E-07
Benzo[b]fluoranthene	205992	68.61	1.80E-05	1.40E-09	7.20E-05	8.90E-05
Benzo[k]fluoranthene	207089	68.61	1.80E-06	1.40E-09	7.20E-06	8.90E-06
Benzo[a]pyrene	50328	25.96	6.60E-05	5.10E-09	2.70E-04	3.40E-04
Dibenz[a,h]anthracene	53703	1.16	3.00E-06	2.50E-10	1.20E-05	1.50E-05
Indeno[1,2,3-cd]pyrene	193395	7.82	2.00E-06	1.50E-10	8.20E-06	1.00E-05
Total			**1.80E-04**	**3.40E-04**	**6.50E-04**	**1.20E-03**

Several contaminants in the Fixfabriken factory area have a risk level higher than the target risk level of 10^{-5}, thus posing an unacceptable risk to human health.

Table A4-4 Estimated risk levels at Bus garage area, according to SADA

Name	**CAS**	**Conc (mg/Kg)**	**Ingestion**	**Inhalation**	**Dermal**	**Total**
Benz[a]anthracene	56553	0.2875	7.30E-08	5.70E-12	3.00E-07	3.70E-07
Chrysene	218019	0.3075	7.80E-10	6.10E-13	3.20E-09	4.00E-09
Benzo[b]fluoranthene	205992	0.3375	8.60E-08	6.70E-12	3.50E-07	4.40E-07
Benzo[k]fluoranthene	207089	0.16	4.10E-09	3.20E-12	1.70E-08	2.10E-08
Benzo[a]pyrene	50328	0.255	6.50E-07	5.00E-11	2.70E-06	3.30E-06
Dibenz[a,h]anthracene	53703	0.085	2.20E-07	1.80E-11	8.90E-07	1.10E-06
Indeno[1,2,3-cd]pyrene	193395	0.1625	4.10E-08	3.20E-12	1.70E-07	2.10E-07
Total			**1.10E-06**	**8.80E-11**	**4.40E-06**	**5.50E-06**

The human health risk levels calculated for the Bus garage area (and assumed for the Tram Hall and the Road area as well) are below the target risk. Thus, remediation will not provide any benefit with regard to non-acute health risks in these areas. However, spreading of chlorinated solvents from Fixfabriken factory in the surrounding area is probable. As no field investigations for TCE were performed in this area until August 2014, no data on this contaminant was available to be included in the health risk assessment. Therefore, an underestimation of the risk to Bus garage can be expected.

Another aspect contributes to an expected underestimation of the risk. It was tested if SADA risk models are coherent with the models used for the Swedish guideline values for lead, PAH-H and TCE. A no-coherent result was obtained for PAH-H, with a risk value of 3.2×10^{-4}, higher than 10^{-5}, revealing that SADA has a more conservative model than SEPA.

Table A4-5 shows the benefit of non-acute health risk reduction per area and per alternative, expressed as PV in MSEK.

Table A4-5 Monetized benefit of non-acute health risk reduction in each of the four areas and for each alternative. Expressed as PV (MSEK).

B2b. Reduced non-acute health risks	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	0,35	0,35	0,35	0,35	0,38
Bus garage area	0,00	0,00	0,00	0,00	0,00
Tram hall area	0,00	0,00	0,00	0,00	0,00
Road area	0,00	0,00	0,00	0,00	0,00
B2b. Present Value (MSEK)	**0,35**	**0,35**	**0,35**	**0,35**	**0,38**

A4.3 Bibliography

Carlsson, C. (2014). Program för Fixfabrikområdet. Historisk inventering med avseende på förorenad mark. Utkast. Göteborgs Stad. Fastighetskontoret.

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

Chemical Abstracts Service from American Chemical Society (2013, February). CAS presents "Common Chemistry". Substance Search. Retrieved July 2014, from Chemical Abstracts Service (CAS) presents "Common Chemistry": http://www.commonchemistry.org/

USEPA (2014). Frequently Asked Questions (May 2014). Retrieved July 29, 2014, from Mid-Atlantic Risk Assessment: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/faq.htm

USEPA's regional screening level (2014). Spatial Analysis and Decision Assistance. Download Latest Toxicity Profiles Database (for SADA Version 4/5). Retrieved August 18, 2014, from The University of Tennessee Knoxville. Spatial Analysis and Decision Assistance: http://www.sadaproject.net/download.html

Golder Associates (2010). Avveckling av Majornas bussdepå. Miljöteknisk undersökning. Rappportnummer 10512180048.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Naturvårdsverket (2009). Riktvärden för förorenad mark. Modellbeskrivning och vägledning. Rapport 5976. Stockholm.

SWECO (2012a). Report. Fixfabriken | Göteborg. Preliminary.

SWECO (2012b). Gasprovtagning under källargolv.

The University of Tennessee Knoxville (2007). Spatial Analysis and Decision Assistance software. Retrieved June 2014, from Spatial Analysis and Decision Assistance homepage: http://www.sadaproject.net/download.html

Appendix 5 - B2c. Other types of improved health, e.g. reduced anxiety

A5.1 Method

A qualitative evaluation is performed for alternatives in set 1 whereas a monetization was carried out for alternatives in set 2.

Figure A5-1 shows the methodology used to monetize the cost item B2c.

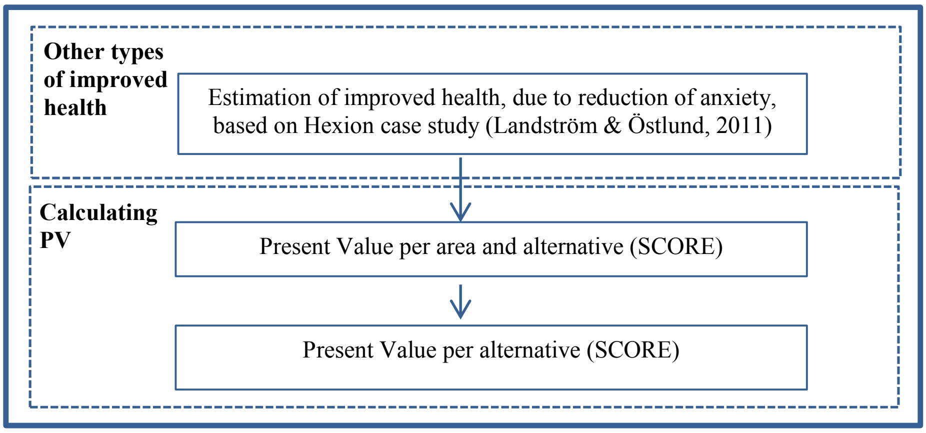


Figure A5-1 Steps followed in the estimation of improved health, due to reduction of anxiety.

Estimation of the benefits is based on Hexion case study (Landström & Östlund, 2011), where a value of 0.089 MSEK is assumed to an area of 3.5 ha. This estimation is based on a comparison of the change in property value between 2006 and 2009 in two different areas, one located at Sannegården (Göteborg), close to a site already remediated, and another at the centre part of Mölndal, close to the Hexion site. These values are probably out of date.

The mentioned value of 0.089 MSEK is applied to each of the four parts of the Fixfabriken site, which might be questionable: the areas in Fixfabriken have different sizes and the locations of Hexion and Fixfabriken sites are different.

When calculating the PV in SCORE (Chalmers, 2014), discounting in accordance with the timeframe for the redevelopment is assumed. The cost is considered to occur during the year(s) of the remedial actions.

A5.2 Results

Table A5-1 shows the benefit, per area and per alternative, expressed as PV, in MSEK.

Table A5-1 Benefit of improved health, due to reduction of anxiety, expressed as PV (MSEK)

B2c. Other types of improved health	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Present Value / area					
Fixfabriken area	0,07	0,07	0,07	0,07	0,08
Bus garage area	0,07	0,07	0,07	0,07	0,07
Tram hall area	0,00	0,00	0,00	0,06	0,00
Road area	0,06	0,06	0,06	0,06	0,06
B2c. Present Value (MSEK)	0,21	0,21	0,21	0,27	0,21

The differences in the values per area reflect different timeframes for discounting the cost as well as remedial action or not. Alternative 4 has a slightly higher benefit than the other alternatives.

A5.3 Bibliography

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Appendix 6 - C1c. Capital costs due to allocation of funds to the remedial action

A6.1 Method

Figure A6-1 shows the methodology used to monetize the cost item C1c.

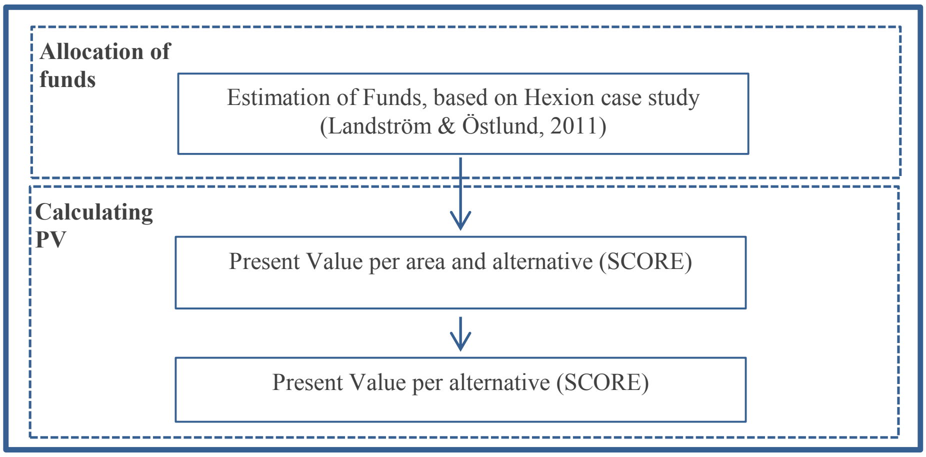


Figure A6-1 Steps followed in the estimation of the costs due to funds allocated to the remedial action.

Estimation of funds is based on Hexion case study (Söderqvist *et al*, 2014). Whenever remedial actions are undertaken, a value of 1 MSEK is assumed to each one of the four parts of Fixfabriken site, although independently of the type of remediation. Therefore, it does not reflect the specific costs of different remediation approaches, which is a limitation. Though, it enables distinguishing alternatives, as more areas with remedial actions demand more funds allocated. An additional simplification is done for the Fixfabriken factory area in alternative 5 of set 1, by not considering any remedial costs, thereby not including the eventual need of in-situ remedial actions.

When calculating the PV in SCORE (Chalmers, 2014), a discounting in accordance to the timeframe for the redevelopment is assumed. The cost is considered to occur during the year(s) of the remedial actions.

A6.2 Results

Table A6-1 and Table A6-2 show the capital costs due to allocation of funds to the remedial action, per area and per alternative, expressed as PV respectively to alternatives in set 1 and in set 2.

Table A6-1 Capital costs due to allocation of funds to the remedial action in each of the 4 areas and for each alternative in set 1, expressed as PV (MSEK)

C1c. Capital costs	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	0,84	0,84	0,84	0,84	0,00
Bus garage area	0,75	0,75	0,76	0,76	0,75
Tram hall area	0,00	0,00	0,70	0,70	0,00
Road area	0,64	0,64	0,64	0,64	0,64
C1c. Present Value (MSEK)	**2,23**	**2,23**	**2,94**	**2,94**	**1,39**

Table A6-2 Capital costs due to allocation of funds to the remedial action in each of the 4 areas and for each alternative in set 2, expressed as PV (MSEK)

C1c. Capital costs	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	0,84	0,84	0,84	0,84	0,93
Bus garage area	0,76	0,76	0,76	0,76	0,76
Tram hall area	0,00	0,00	0,00	0,70	0,00
Road area	0,64	0,64	0,64	0,64	0,64
C1c.Present Value (MSEK)	**2,24**	**2,24**	**2,24**	**2,94**	**2,33**

The differences in the values per area reflect different timeframes for discounting the cost as well as remedial action or not.

In alternative set 1, alternatives 3 and 4 have the highest capital costs, whereas alternative 5 has the lowest. In alternative set 2, alternative 4 has the highest cost and the other alternatives have very similar costs.

A6.3 Bibliography

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Söderqvist, T., Brinkhoff, P., Norberg, T., Rosén, L., Back, P.-E., & Norrman, J. (accepted for publication, 2015). Cost-benefit analysis as part of a sustainability assessment of remediation alternatives for contaminated land. Journal of Environmental Management.

Appendix 7 - C1d. Costs for the remedial action, including possible transport and disposal of contaminated soil minus possible revenues of reuse of soil

A7.1 Method

Figure A7-1 shows the general methodology used to monetize the cost item C1d.

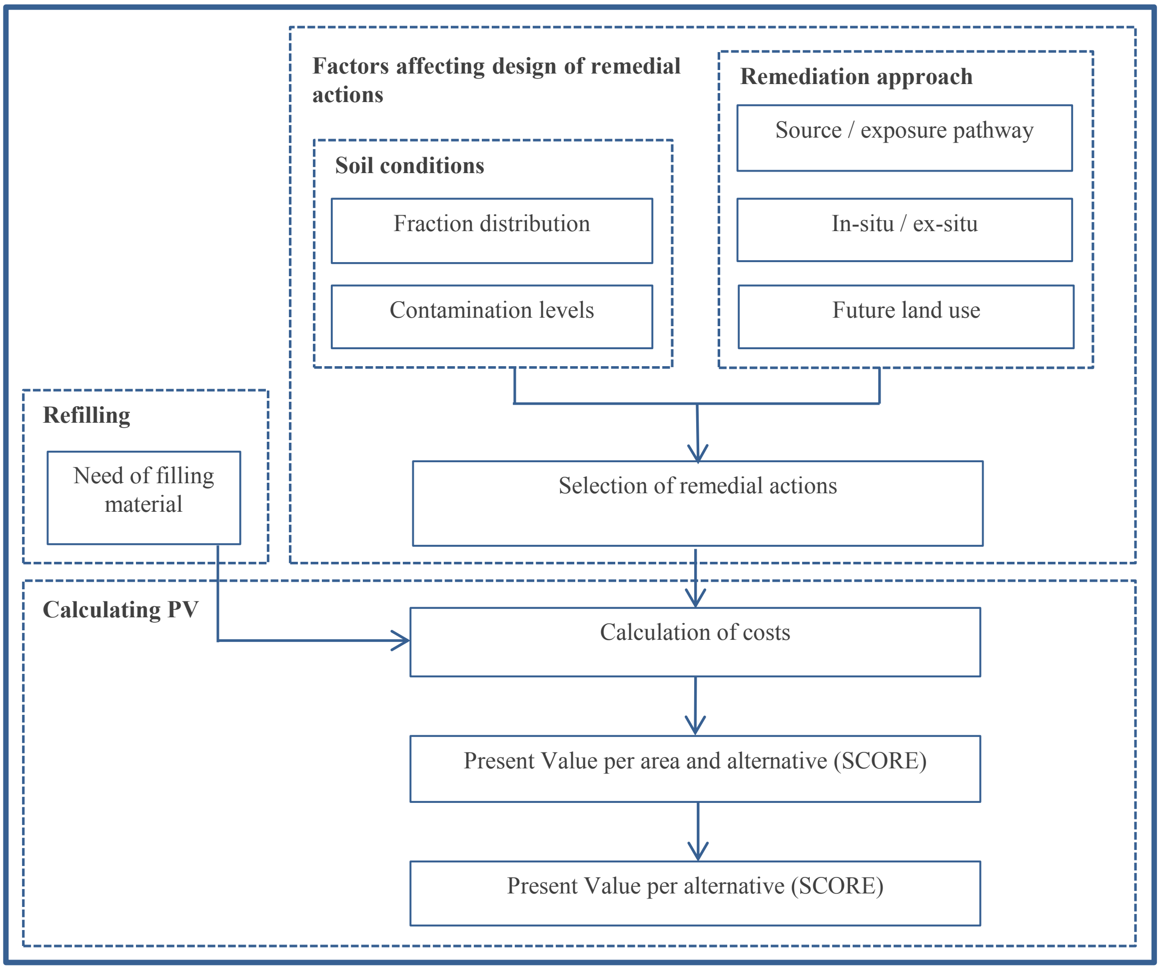


Figure A7-1 Steps followed when monetizing cost item C1d

Different methods were used in alternative set 1 and alternative set 2, as described below.

A7.1.1 Method for alternative set 1

Figure A7-2 shows the methodology used to determine the amount of soil to be managed during the remedial works.

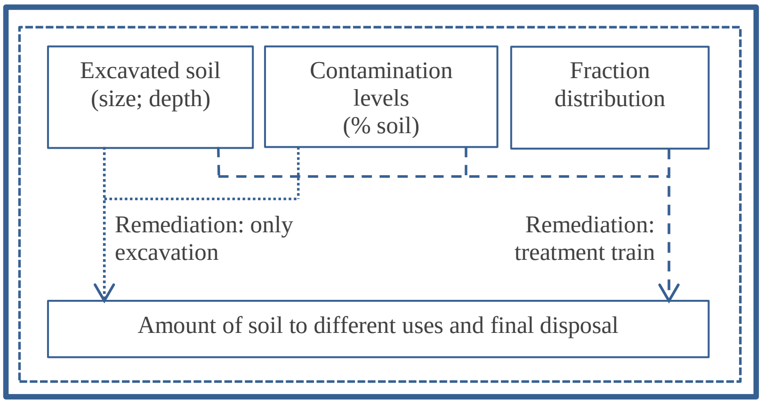


Figure A7-2 Methodology used to estimate the amount of soil to different uses and final disposal

Amount of soil to manage as a consequence of the dig and dump approach (excavation and final disposal) is estimated based on two main factors: how much soil it is excavated, and how much soil there is per level of contamination. At treatment train approach, which includes excavation, sieving and soil washing, a third factor is used when defining the management of soil within the site. That additional factor is the distribution of the fractions of the soil.

Figure A7-3 and Figure A7-4 show the conceptual model of the treatment process and the final disposal site depending on the contamination levels of the soil. Figure A7-3 shows the situation to dig and dump process (as used, for example, in the road area for all alternatives), and Figure A7-4 illustrates the situation of using a treatment train (assumed, for instance, for the bus garage area in alternatives 1, 2, 3 and 5).

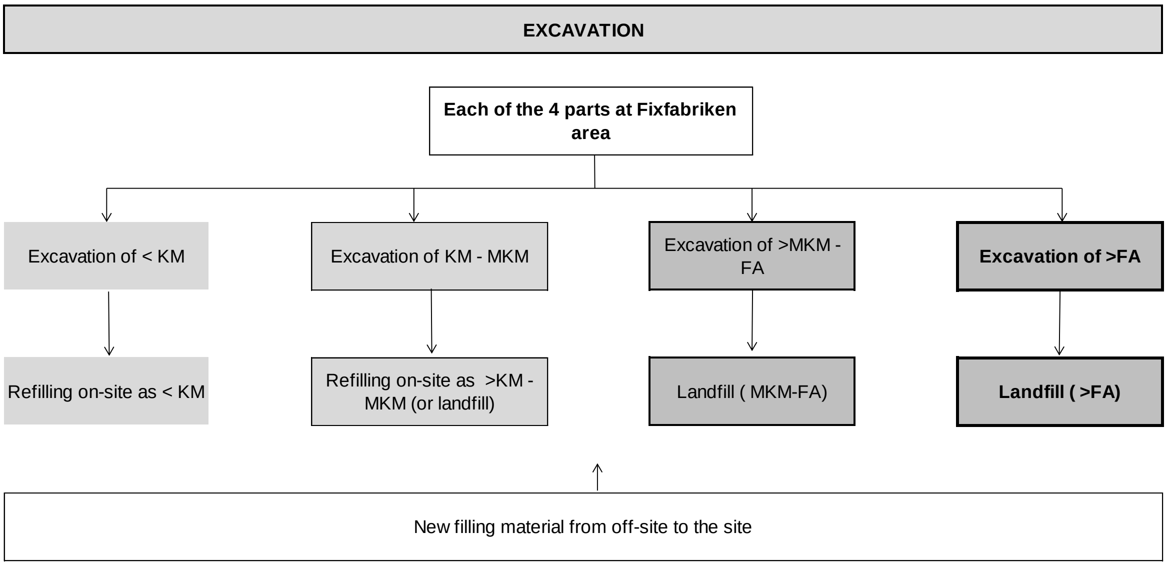


Figure A7-3 Conceptual model to the remediation alternative with excavation

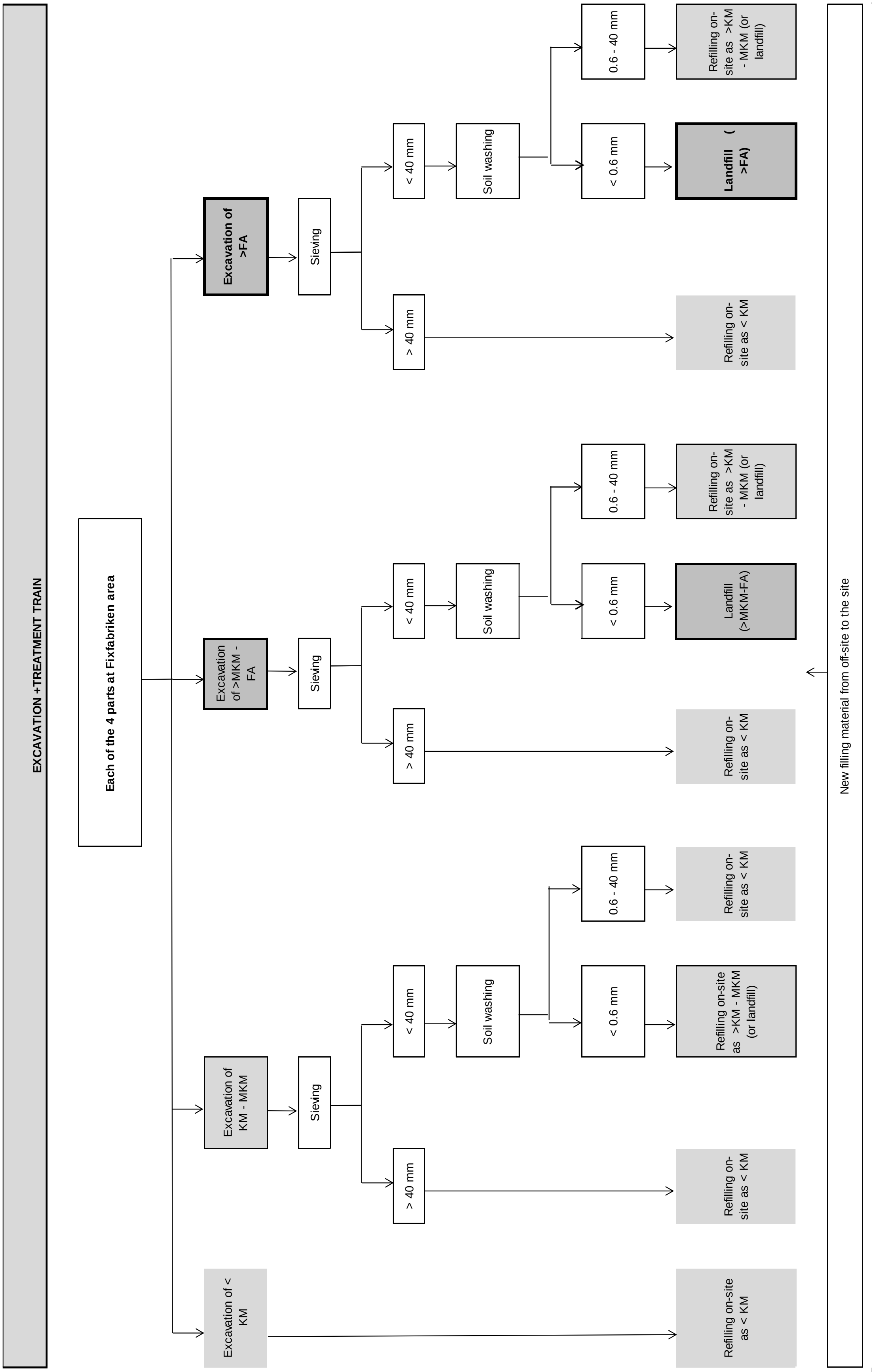


Figure A7-4 Conceptual model to the remediation alternative with excavation and treatment train

It is assumed that soil from each contamination level is excavated separately and disposed at an adequate final disposal site. When concentrations of contaminants in the soil complies with the guideline value for sensitive uses and non-sensitive uses, it can be re-used on-site to areas of future use for residential purposes and industrial use, respectively.

In the treatment train suggested, excavation is followed by sieving, with separation of coarse fractions (>40 mm), which is assumed not to be contaminated. Fractions <40 mm are washed. Contaminants are concentrated in the separated smallest fraction (<0.6 mm). During the treatment train process, there will be an increase in contaminant concentrations in the smallest fractions. However, this is not likely to be enough to increase the contamination level from >KM-MKM to >MKM-FA, or >MKM-FA to >FA, as, for instance, the concentration of pollutants is quite below the higher-limit of the range of each contamination level.

Estimation of soil fractions

The fraction ranges of <0.6 mm, 0.6–40 mm, and >40 mm, are defined as suggested for the Hexion case study (Landström & Östlund, 2011), and support the calculations for sieving and soil washing treatment processes. Udden-Wentworth grain classification and similar classification schemes are considered, being so assumed that soil of 0.6 mm corresponds to medium to coarse sands, and that 40 mm relates to gravel, between pebble and cobble (Allaby, 2013). Based on descriptions from field observations of the soil layers (SWECO, 2012a; Golder Associates, 2010), soil fractions in Fixfabriken factory area and Bus garage area are estimated, see example in Table A7-1.

Table A7-1 Example of field observations and estimation of soil fractions in Fixfabriken factory area, based on SWECO (2012)

Sample location	Borehole 1			
	Type of material		Fraction size	%
Depth (m)	0	0,3	<0.6 mm	40%
Description	**Mg:** Asphalt, Sa, Gr		0.6 - 40 mm	55%
			> 40 mm	5%
Depth (m)	0,3	1,2	<0.6 mm	100%
Description	Cl		0.6 - 40 mm	0%
			> 40 mm	0%
Depth (m)	1,2	2	<0.6 mm	70%
Description	Sa, Si		0.6 - 40 mm	30%
			> 40 mm	0%
Depth (m)	2	4	<0.6 mm	100%
Description	Cl		0.6 - 40 mm	0%
			> 40 mm	0%

Note: Mg stands for “made ground”, meaning artificial ground (landfilling materials).

Table A7-2 summarizes the estimation made of the soil fractions.

Table A7-2 Soil fractions in Fixfabriken area and in Bus garage area (also assumed for the Tram hall and Road areas), based on SWECO (2012) and Golder Associates (2010)

Different fractions	Fixfabriken (%)	Bus garage (%)
<0.6 mm	79.0%	85.2%
0.6 - 40 mm	17.4%	12.6%
> 40 mm	3.6%	2.2%

Final disposal of the excavated and / or treated soil, and refill

The size estimated for each area is of 2.5 ha, and an average layer of 3 m of soil to excavate is considered. A soil density (ρ) of 1.8 kg/m^3 is assumed.

Estimation is made on the % of the different contamination levels in each one of the four parts, as shown in Table A7-3. Fixfabriken factory area is considered as having a lower part of less contaminated soil, due to the existence of chlorinated solvents as a contaminant and the contaminant levels and health risk assessment performed, as shown in Appendix 4.

Table A7-3 Contamination fractions in Fixfabriken area and in Bus garage area (also assumed to Tram hall and Road areas)

Contamination level	Fixfabriken factory area (%)	Bus garage, Tram hall and road areas (%)
< KM (below guideline values to sensitive use)	10%	20%
KM - MKM (between guideline values to sensitive use and to less sensitive use)	35%	30%
MKM - FA (between guideline values to less sensitive use and hazardous waste limit)	35%	30%
FA (above hazardous waste limit)	20%	20%

Based on the fractions of contamination showed in Table A7-3 and on the conceptual models presented in Figure A7-3 and Figure A7-4, the amount of soil to each final use or disposal site, per area, is calculated.

The following equation is an example of how calculations are performed to remediation using dig and dump.

$$Soil\ to\ landfill_{>MKM-FA} = Soil_{\ excavated}\ (ton) \times soil_{>MKM-FA}(\%)$$

For calculating how much soil becomes available from each treatment step, an additional parameter needs to be added, which is the % of a certain fraction range. The following equation is an example of the different type of calculations performed to remediation using treatment train.

$$Soil\ to\ landfill_{>MKM-FA} = Soil_{\ excavated}\ (ton) \times soil_{>MKM-FA}(\%)\ \times fraction_{<0.6\ mm}(\%)$$

The values obtained from the calculations are presented in Table A7-4, for remedial actions of excavation and of treatment train.

Table A7-4 Amount of soil from each area and final disposal sites, depending on different remedial approaches

Only excavation

Areas within Fixfabriken site	Units	To reuse as <KM	As >KM-MKM	To landfill >MKM-FA	To landfill >FA
Fixfabriken factory area	ton	13500	47250	47250	27000
	%	10%	35%	35%	20%
Bus garage area	ton	27000	40500	40500	27000
	%	20%	30%	30%	20%
Tram hall area	ton	27000	40500	40500	27000
	%	20%	30%	30%	20%
Road area	ton	27000	40500	40500	27000
	%	20%	30%	30%	20%

Treatment train; excavation, sieving and soil washing

Areas within Fixfabriken site	Units	To reuse as <KM	As >KM-MKM	To landfill >MKM-FA	To landfill >FA
Fixfabriken factory area	ton	26093	50229	37340	21337
	%	19%	37%	28%	16%
Bus garage area	ton	34514	42988	34499	22999
	%	26%	32%	26%	17%
Tram hall area	ton	34514	42988	34499	22999
	%	26%	32%	26%	17%
Road area	ton	0	0	0	0
	%	0%	0%	0%	0%

The values of excavation, sieving and soil washing are calculated considering: the remedial action defined for each area and alternative; if any intervention is performed; if so, which is the new future land use (where residential use demand for a higher soil quality level). Afterwards, those values are used in SCORE to determine PV for item C1d. Some of the unitary costs used are the ones defined in SCORE (Chalmers, 2014), as presented in Table A7-5.

Refilling the site with soils from off-site is also considered as necessary. When excavating the ground to remediate or to enable constructing new buildings, a refill of 50% of the amount of soil excavated is assumed. Depending on the end use of the area, clean soil and/or less clean soil excavated from the site are used as refilling material. Soils from off-site are used whenever no enough adequate soil from on-site is available.

Table A7-5 Unitary costs for soil excavation and transport to off-site facility, as well as for soil refilling on-site (based on Chalmers, 2014)

Soil excavation and transport costs	**Cost (SEK/ton)**
Excavation of soil, 0-4 m	173
Excavation of soil, 4-8 m	328
Transportation to off-site facility, KM-MKM	70
Transportation to off-site facility, MKM-FA	348
Transportation to off-site facility, >FA	547
Backfill, refill	113

A7.1.2 Method for alternative set 2

Figure A7-5 shows the different remediation strategies at the site, for alternative set 2.

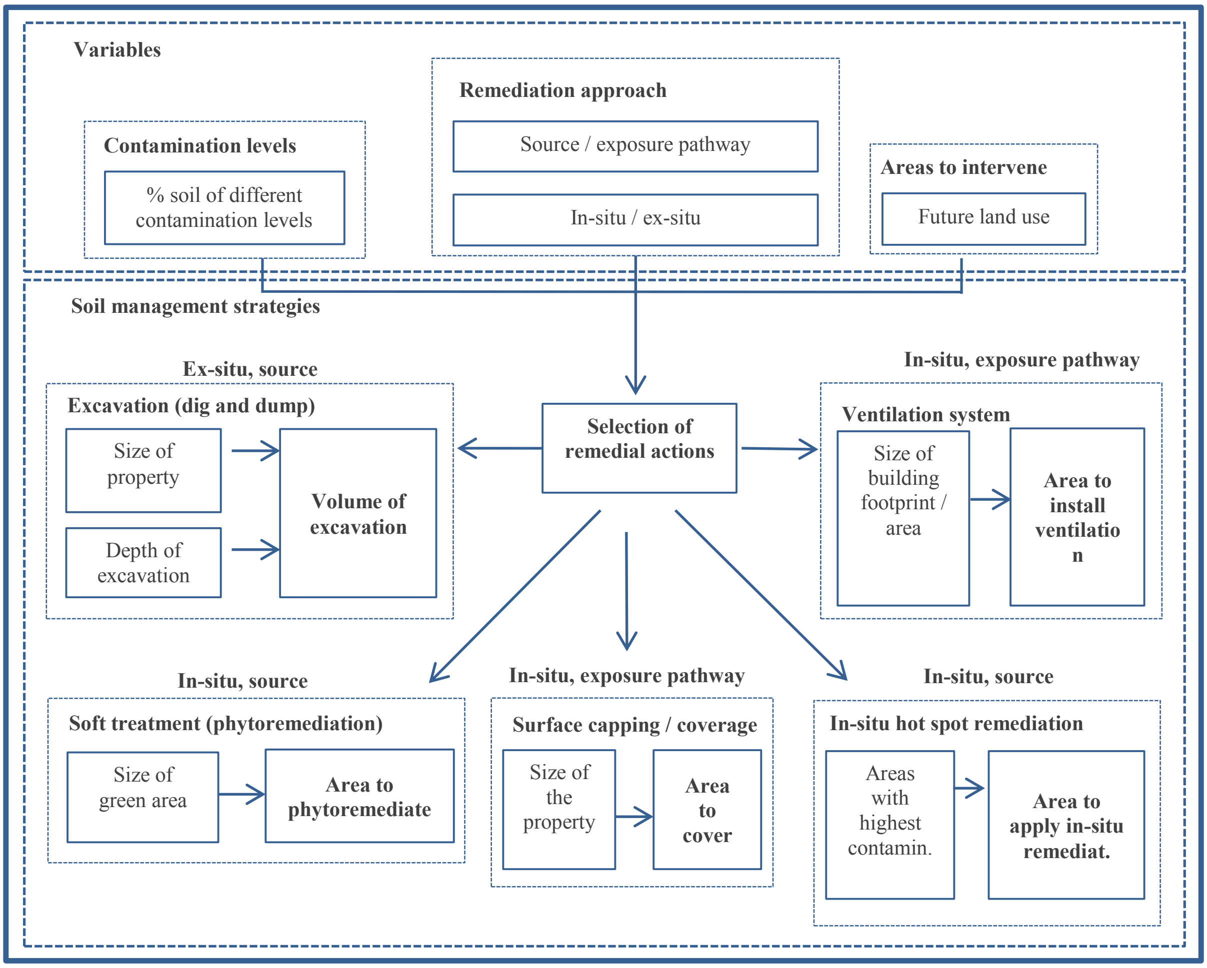


Figure A7-5 Possibilities of approaches to deal with the contamination in the site.

The conceptual model to the remediation alternative with excavation, or dig and dump, is the same as the one showed in Figure A7-3, included in Section A7.1.1.

Assumptions are similar to the ones made for alternative set 1, except the thickness of the layer of soil to excavate. An average layer of 1.5 m is considered instead.

Table A7-6 summarizes the amount of soil excavated to reuse and dispose off-site for each area. Unitary costs assumed are the ones defined in SCORE (Chalmers, 2014), as presented in Table A7-5. Refilling the site with soils from off-site is considered as described in the method used to the alternative set 1.

Table A7-6 Amount of soil from each area and final disposal sites, when excavat. soil

Areas within Fixfabriken site	**Units**	**To reuse as <KM**	**As >KM-MKM**	**To landfill >MKM-FA**	**To landfill >FA**
Fixfabriken factory area	ton	6750	23625	23625	13500
	%	10%	35%	35%	20%
Bus garage area	ton	13500	20250	20250	13500
	%	20%	30%	30%	20%
Tram hall area	ton	13500	20250	20250	13500
	%	20%	30%	30%	20%
Road area	ton	13500	20250	20250	13500
	%	20%	30%	30%	20%

Additional possibilities for managing the risk of having contamination include phytoremediation, surface capping / coverage, in situ remediation in the most contaminated spots, and ventilation, see following description.

Phytoremediation is assumed to be performed on half of the Fixfabriken factory area. A unitary cost of 546 kr/m^2 is used, which corresponds to an intervention in a small site with complex characteristics based on FRTR (2014). If applied to this specific part of the site, the cost of phytoremediation is estimated to 6.78 MSEK.

For surface capping / coverage it is assumed that 90% of the surface will be covered. A unitary cost of 355.84 kr/m^2 is assumed, which corresponds to the mean cost of two landfill caps possibilities based on FRTR (2014). Based on these assumptions, if applied to Fixfabriken part and to Bus garange part, the cost of surface capping is estimated to 7.94 MSEK per part of the site.

In-situ hot spot remediation costs are estimated based on the in-situ thermal treatment technology. When used in a specific area of the site, the technology is assumed that is used in 20% of the size of that area. A layer to treat with a thickness of 4 m is considered. The unitary cost of 361 kr /m^3 is used, considering a site with some level of complexity (FRTR, 2014). Consequently, when used in a specific area of the site, in-situ hot spot remediation is calculated to cost 7.16 MSEK per part of the site.

When ventilation is to be installed in one of the 4 parts of the site, it is assumed that the area corresponds to the building footprint (size), which is 50% of 2.5 ha of each part of the site. A unitary cost of 98.04 kr/m^2 is assumed (USEPA, 2008). Consequently, ventilation is assumed to cost 1.48 MSEK in a specific part of the site.

These are simplified assumptions, with an estimation of the costs for the different remedial approaches that are not site specific, thus a large uncertainty is expected. The technical solutions chosen, the areas to intervene, the variability of the present contamination levels in the site (some already suitable to more sensitive uses), the unitary costs, make it difficult to have realistic estimation of costs. For example, implementation of capping and ventilation is very much site specific, dependent on the contamination on the site and the intended land uses, with costs varying significantly. Afterwards, those values are used to obtain the PV (Chalmers, 2014).

A7.2 Results

A7.2.1 Results for alternative set 1

Table A7-7 includes the values of amount of soil from excavation, and to sieving and soil washing.

Table A7-7 Amount of soil to excavate, to sieve and wash, to each altern. at each area

Areas within Fixfabriken site	Alternatives	Future land use	Remediation	Volume to excavate (ton)	Total soils to sieving (ton)	Total soils to soil washing (ton)
Fixfabriken factory	**1**	KM	Exc	135000	0	0
	2	KM	Exc	135000	0	0
	3	KM	Treatment train	135000	121500	117109
	4	KM	Exc	135000	0	0
	5	No change	None	0	0	0
Bus garage	**1**	KM	Treatment train	135000	108000	105580
	2	KM	Treatment train	135000	108000	105580
	3	MKM	Treatment train	135000	108000	105580
	4	MKM	Exc	135000	0	0
	5	KM	Treatment train	135000	108000	105580
Tram hall	**1**	No change	None	0	0	0
	2	No change	None	0	0	0
	3	KM	Treatment train	135000	108000	105580
	4	KM	Exc	135000	0	0
	5	No change	None	0	0	0
Road	**1**	MKM	Exc	135000	0	0
	2	MKM	Exc	135000	0	0
	3	MKM	Exc	135000	0	0
	4	MKM	Exc	135000	0	0
	5	MKM	Exc	135000	0	0
Sum (whole site)	**1**	Several	Several	405000	108000	105580
	2	Several	Several	405000	108000	105580
	3	Several	Several	540000	337500	328268
	4	Several	Several	540000	0	0
	5	Several	Several	270000	108000	105580

If not enough soil is available on site to refill areas with future sensitive uses, additional soil <KM from off-site is required, whereas for less sensitive uses, refill doesn´t demand so high quality soil, but only >KM-MKM. Depending on the alternative, soil to be used to refill might include fractions of clean soil excavated, but also new clean soil obtained from the treatment train process. Table A7-8 shows the amount of soil needed from off-site, as well as the one that requires final disposal of contaminated soil, very contaminated soil and high levels as high as hazardous waste. For percentage values of excavated soils to go off-site, see Table A7-9.

Table A7-8 Amount of soil to use on site and to transport to different final disposal sites, to each alternative at each area

Areas within Fixfabriken site	**Alt.**	**Need of soil from off site (ton)**		**To transport off-site (ton)**				
		< KM	**>KM-MKM**	**Excedent of < KM**	**Exced. of >KM-MKM**	**>MKM - FA**	**>FA**	**Total soil**
Fixfabriken factory	1	54000	0	0	47250	47250	27000	121500
	2	54000	0	0	47250	47250	27000	121500
	3	41407	0	0	50229	37340	21337	108906
	4	54000	0	0	47250	47250	27000	121500
	5	0	0	0	0	0	0	0
Bus garage	1	32986	0	0	42988	34499	22999	100486
	2	32986	0	0	42988	34499	22999	100486
	3	0	0	10002	0	34499	22999	67500
	4	0	0	0	0	40500	27000	67500
	5	32986	0	0	42988	34499	22999	100486
Tram hall	1	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0
	3	32986	0	0	42988	34499	22999	100486
	4	40500	0	0	40500	40500	27000	108000
	5	0	0	0	0	0	0	0
Road	1	0	0	0	0	40500	27000	67500
	2	0	0	0	0	40500	27000	67500
	3	0	0	0	0	40500	27000	67500
	4	0	0	0	0	40500	27000	67500
	5	0	0	0	0	40500	27000	67500
Sum	1	86986	0	0	90238	122249	76999	289486
	2	86986	0	0	90238	122249	76999	289486
	3	74393	0	10002	93217	146837	94335	344391
	4	94500	0	0	87750	168750	108000	364500
	5	32986	0	0	42988	74999	49999	167986

The choice in the method for <0.6 mm to be separated by soil washing and to concentrate the contaminants is maybe too conservative (on the safe-side) and has consequences in the costs. A more restrict range could probably be considered, including only smallest fractions. More monitoring during soil washing process would be necessary to better check the levels of contamination obtained in each range of fractions. On the other hand, the amount of very contaminated soil would decrease, enabling a potential larger volume of soil suitable to reuse or to landfills suitable to less contaminated soils, and therefore, with lower fees.

Table A7-9 Amount of soil to different final disposal sites, in percentage

Alternatives	**% of excavated soils to go off-site**				
	Total	**to off-site facility, <KM**	**to off-site facility, KM-MKM**	**to off-site facility, MKM-FA**	**to off-site facility, MKM-FA**
1	71%	0%	22%	30%	19%
2	71%	0%	22%	30%	19%
3	64%	2%	17%	27%	17%
4	68%	0%	16%	31%	20%
5	62%	0%	16%	28%	19%

The values obtained are then used in the calculations within SCORE, considering a cost during 1 year, when the remedial works take place. These calculations are performed separately for each one of the 4 parts within Fixfabriken site.

Table A7-10 shows the cost of the remedial works per area and per alternative, expressed as PV, in MSEK, as well as the sum of the values, obtaining the PV for each alternative. This is the result of the calculations within SCORE, considering the costs during the time that the remedial works take place.

Table A7-10 Cost of the remedial action, including possible transport and disposal of contaminated soil and refill of soil, in each of the 4 areas and for each alternative, expressed as PV (MSEK), to alternative set 1

C1d. Remedial action	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	51,90	51,90	56,55	51,90	0,00
Bus garage area	45,25	45,25	40,92	35,16	45,25
Tram hall area	0,00	0,00	43,11	38,30	0,00
Road area	30,48	30,48	30,48	30,48	30,48
B1. Present Value (MSEK)	**127,63**	**127,63**	**171,06**	**155,84**	**75,73**

A7.2.2 Results for alternative set 2

The values of soil excavation for each alternative and per area are presented in Table A7-11.

Table A7-11 Amount of soil to excavate to each alternative at each area

Areas within Fixfabriken site	**Alternatives**	**Future land use**	**Volume to excavate (ton)**
Fixfabriken factory	**1**	KM	67500
	2	KM	33750
	3	KM	0
	4	KM	67500
	5	No change	0
Bus garage	**1**	KM	67500
	2	KM	67500
	3	KM	0
	4	MKM	67500
	5	KM	67500
Tram hall	**1**	No change	0
	2	No change	0
	3	No change	0
	4	KM	67500
	5	No change	0
Road	**1**	MKM	67500
	2	MKM	67500
	3	MKM	67500
	4	MKM	67500
	5	MKM	67500

Table A7-12 shows the amount of soil needed from off site, as well as the one that requires final disposal of contaminated soil, very contaminated soil and high levels as high as hazardous waste. The same approach as the one used to alternative set 1 is used here. For percentage values of excavated soils to go off-site, see Table A7-13.

Table A7-12 Amount of soil to use on site and to transport to different final disposal sites, to each alternative at each area

Areas within Fixfabriken site	Alt.	Need of soil from off site (ton)		To transport off-site (ton)				
		< KM	>KM-MKM	Excedent of < KM	Exced. of >KM-MKM	>MKM - FA	>FA	Total soil
Fixfabriken factory	**1**	27000	0	0	23625	23625	13500	60750
	2	13500	0	0	11813	11813	6750	30375
	3	0	0	0	0	0	0	0
	4	27000	0	0	23625	23625	13500	60750
	5	0	0	0	0	0	0	0
Bus garage	**1**	20250	0	0	20250	20250	13500	54000
	2	20250	0	0	20250	20250	13500	54000
	3	0	0	0	0	0	0	0
	4	0	0	0	0	20250	13500	33750
	5	20250	0	0	20250	20250	13500	54000
Tram hall	**1**	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0
	4	20250	0	0	20250	20250	13500	54000
	5	0	0	0	0	0	0	0
Road	**1**	0	0	0	0	20250	13500	33750
	2	0	0	0	0	20250	13500	33750
	3	0	0	0	0	20250	13500	33750
	4	0	0	0	0	20250	13500	33750
	5	0	0	0	0	20250	13500	33750
Sum (whole site)	**1**	101250	47250	0	43875	64125	40500	148500
	2	84375	33750	0	32063	52313	33750	118125
	3	33750	0	0	0	20250	13500	33750
	4	135000	47250	0	43875	84375	54000	182250
	5	67500	20250	0	20250	40500	27000	87750

Table A7-13 Amount of soil to different final disposal sites, in percentage

Alternatives	% of excavated soils to go off-site				
	Total	to off-site facility, <KM	to off-site facility, KM-MKM	to off-site facility, MKM-FA	to off-site facility, MKM-FA
1	73%	0%	22%	32%	20%
2	70%	0%	19%	31%	20%
3	50%	0%	0%	30%	20%
4	68%	0%	16%	31%	20%
5	65%	0%	15%	30%	20%

The values obtained are then used in the calculations within SCORE, considering a cost during 1 year, when the remedial works take place. These calculations are performed separately for each one of the 4 areas within Fixfabriken site.

The costs for each alternative of each remedial work are presented in Table A7-14. These are no discounted values.

Table A7-14 Costs of remediation of the different approaches to deal with the contamination in the site, except excavation works (no discounted values)

Alternatives	Costs of remediation (no discounted values, in MSEK)					
	Excavation, disposal and refill	In-situ hot spot remed.	Phyto-remediation	Surface capping	Ventilation	Total
Alt 1	87.91	0	0	0	0	87.91
Alt 2	71.92	0	6.78	0	0	78.70
Alt 3	26.11	7.16	0	7.94	1.48	35.53
Alt 4	114.02	0	0	0	0	114.02
Alt 5	55.92	7.16	0	0	1.48	64.56

Table A7-15 shows the remedial costs per area and per alternative, expressed as PV, in MSEK, as well as the sum of the values, obtaining the PV for each alternative for this item. Here, refilling costs are included. Table A7-15 is the result of the calculations within SCORE, considering the costs during the time that the remedial works take place, with discounting in accordance to the timeframe for the redevelopment.

Table A7-15 Cost of the remedial action, including possible transport and disposal of contaminated soil and refill of soil, in each of the 4 areas and for each alternative, expressed as PV (MSEK), to alternative set 2

C1d. Remedial action	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	26,93	19,17	13,96	26,93	8,07
Bus garage area	22,26	22,26	12,38	19,83	22,26
Tram hall area	0,00	0,00	0,00	20,77	0,00
Road area	16,74	16,74	16,74	16,74	16,74
C1d. Present Value (MSEK)	**65,93**	**58,17**	**43,08**	**84,27**	**47,07**

Due to the simplified assumptions previously mentioned, changes in the PV might change the societal profitability of each alternative, as well as the ranking of the alternatives within the CBA.

A7.4 Bibliography

Allaby, M. (2013). A Dictionary of Geology and Earth Sciences. Oxford University Press.

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

USEPA (2014). Frequently Asked Questions (May 2014). Retrieved July 29, 2014, from Mid-Atlantic Risk Assessment: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/faq.htm

USEPA (2008). Engineering Issue. Indoor Air Vapour Intrusion Mitigation Approaches. Retrieved October 3, 2014, from United States Environmental Protection Agency website: http://www.clu-in.org/download/char/600r08115.pdf

FRTR (2014). Federal Remediation Technologies Roundtable (FRTR) website. Retrieved October 3, 2014, from Remediation Technologies Screening Matrix and Reference Guide, Version 4.0. (...) 4.3 Phytoremediation.: http://www.frtr.gov/matrix2/section4/4-3.html

FRTR (2014a). Federal Remediation Technologies Roundtable (FRTR) website. Retrieved October 3, 2014, from Remediation Technologies Screening Matrix and Reference Guide, Version 4.0 (...) 4.10 Thermal Treatment: http://www.frtr.gov/matrix2/section4/4-9.html

FRTR (2014b). Remediation Technologies Screening Matrix and Reference Guide, Version 4.0. (...) 4.26 Landfill Cap. Retrieved October 3, 2014, from Federal Remediation Technologies Roundtable (FRTR) website: http://www.frtr.gov/matrix2/section4/4-27.html

Golder Associates (2010). Avveckling av Majornas bussdepå. Miljöteknisk undersökning. Rappportnummer 10512180048.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

SWECO (2012a). Report. Fixfabriken | Göteborg. Preliminary.

SWECO (2012b). Gasprovtagning under källargolv.

Appendix 8 - C1e. Costs for design and implementation of monitoring programs including sampling, analysis and data processing

A8.1 Method

Figure A8-1 shows the methodology used to monetize the cost item C1e, to alternative set 1.

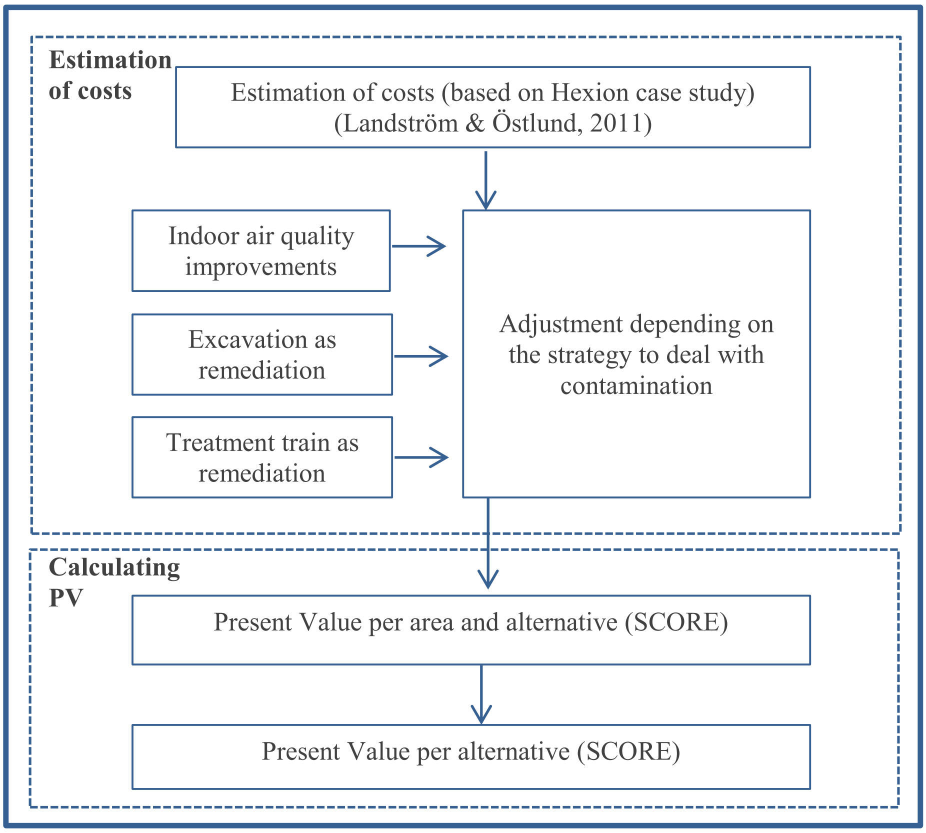


Figure A8- 1 Steps followed in the estimation of the cost of monitoring to altern. set 1

The cost used to Hexion case study is considered (Landström & Östlund, 2011). Depending on the complexity of the approach to deal with the contamination at the site, the value of 10 MSEK from Hexion case study is adjusted. Active ventilation as a strategy to deal with contamination is assumed to cost the least, and the remediation through treatment train is assumed to require monitoring the most, thus having the highest cost of monitoring, see Table A8-1. The cost is assumed to occur during the works to deal with the contamination.

Table A8-1 Costs of monitoring depending on the type of approach to deal with contamination, to alternative set 1

Type of approach to deal with the remediation	**Costs of monitoring adjusted (MSEK)**
Active ventilation	1
Excavation	5
Treatment train (excavation, sieving and soil washing)	10

Figure A8-2 shows the methodology used to monetize the cost item C1e, to alternative set 2.

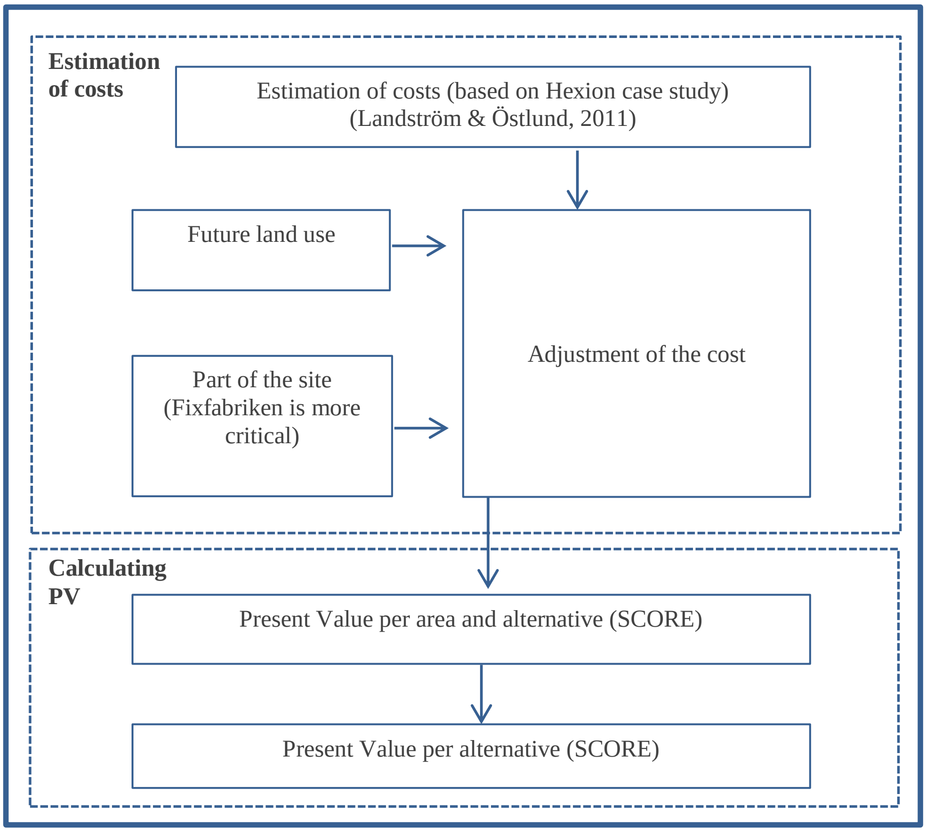


Figure A8- 2 Methodology used to estimate the cost of monitoring to alternative set 2

The cost used to Hexion case study is considered (Landström & Östlund, 2011). A slightly different procedure from the one used in alternative set 1 is followed. In alternative set 2, a base cost of 10 MSEK is adjusted depending on the future land use and on each of the four parts of the site, see Table A8-2.

Table A8-2 Costs of monitoring depending on the future land use and on the area of the site, to alternative set 2

Future land use	**Area of the site**	**Costs of monitoring adjusted (MSEK)**
Residential	Fixfabriken factory area	10
	Other areas	5
Industrial	Fixfabriken factory area	5
	Other areas	2

Complexity of each area and future land uses influence necessary studies and follow-up of the process. Fixfabriken factory part seems to be the most complex: value is 10 or 5 MSEK. Other parts of the site seem slightly less complicated: value is 5 or 2 MSEK. Future land use with residential areas demands more complete monitoring programs: 10 or 5 MSEK depending on the part of the site. Industrial areas (less sensitive uses) need less intensive monitoring works: 5 or 2 MSEK depending on the part. The cost is assumed to occur during the works to deal with the contamination. No intervention implies no monitoring, thus no costs.

The methods followed have some limitations. A possibility of improvement is using more recent budgets for the area (provided for the municipality when contracting new field investigations in 2014).

To calculate the PV for this item (Chalmers, 2014), it is assumed a discounting in accordance to the timeframe for the redevelopment.

A8.2 Results

Table A8-3 and Table A8-4 show the monitoring costs, per area and per alternative, expressed as PV, in MSEK, as well as the sum of the values, obtaining the PV for each alternative, respectively to alternatives in set 1 and in set 2.

Table A8-3 Monitoring costs in each of the 4 areas and for each alternative in set 1, expressed as PV (MSEK)

C1e. Monitoring	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	4.21	4.21	8.42	4.21	0.93
Bus garage area	7.46	7.46	7.59	3.80	7.46
Tram hall area	0.00	0.00	6.97	3.48	0.00
Road area	3.21	3.21	3.21	3.21	3.21
C1e. Present Value (MSEK)	**14.88**	**14.88**	**26.19**	**14.70**	**11.60**

Table A8-4 Monitoring costs in each of the 4 areas and for each alternative in set 2, expressed as PV (MSEK)

C1e. Monitoring	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	8.42	8.42	8.42	8.42	4.67
Bus garage area	3.73	3.73	3.73	1.52	3.73
Tram hall area	0.00	0.00	0.00	3.48	0.00
Road area	1.28	1.28	1.28	1.28	1.28
C1e.Present Value (MSEK)	**13.43**	**13.43**	**13.43**	**14.70**	**9.68**

A8.3 Bibliography

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Appendix 9 - C2b. Increased health risks due to transports to and from the remediation site, e.g. transports of contaminated soil

A9.1 Method

Figure A9-1 shows the methodology used to monetize the cost item C2b. Part of it takes into account the methodology recommended by the Swedish Road Administration (Vägverket Räddningsverket, 1998).

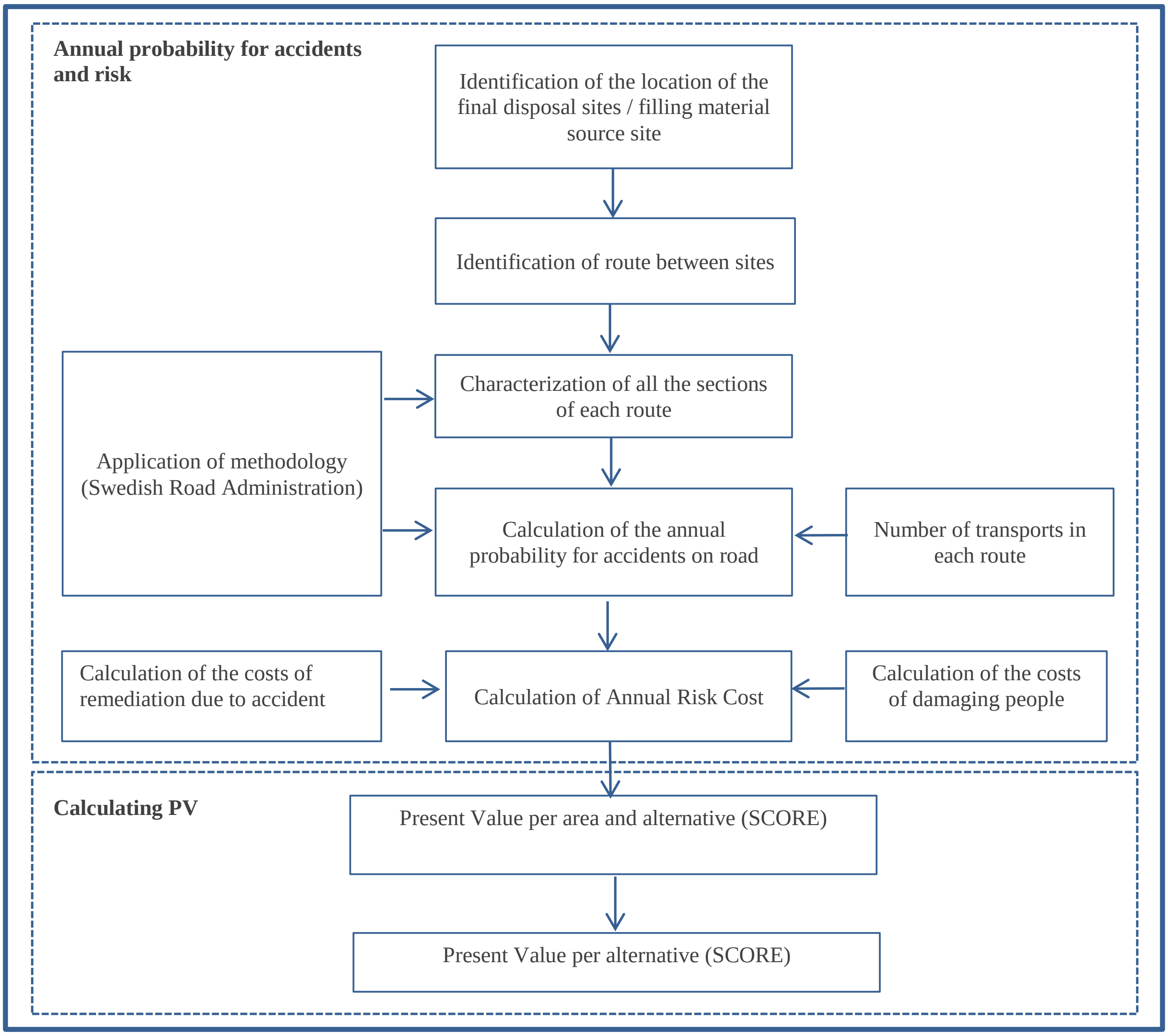


Figure A9-1 Steps followed to estimate the cost of increased health risks due to transports of soil to and from the site

Routes between Fixfabriken site and the final disposal sites / filling materials source site

Petra Brinkhoff at NCC provided information about which landfills in the Göteborg region are suitable to receive soils with different levels of contamination (Brinkhoff, 2014a). This is not necessarily valid within some years from now. For less contaminated soil, within the range >KM – MKM, a landfill in Hisingen is suitable. To more contaminated soil, within the range >MKM – FA, a landfill in Borås can probably be used. Soil classified as hazardous waste might be transported to a facility in Vänersborg or one in Skara. For the calculations, Vänerborg is considered. Figure A9-2 shows the approximated location of the landfills and the routes considered.

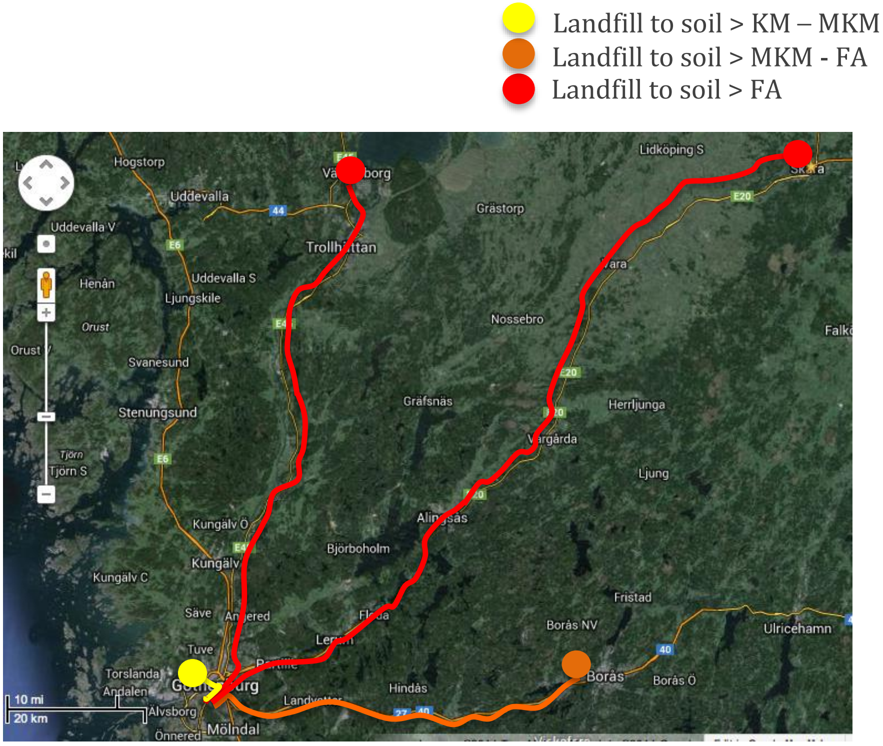


Figure A9- 2 Location of final disposal sites to excavated soil and routes to the site

Each route is divided in different sections. Eniro (ENIRO, 2014) is used, as well as Google maps (Google Maps, 2014) to obtain a possible route, as well as to classify each one of the sections that are part of the route. Table A9-1 includes general information about the off-site disposal sites and a possible source site for refilling material.

From basic information such as velocity, rural or urban road and number of lanes, number of accidents per distance (Q) can be estimated. Number of vehicles per accident (F) is dependent on the type of road. Table A9-2 and Table A9-3 present those parameters, to each route and each section of the route.

Table A9-1 Information on the routes between Fixfabriken site and the final disposal sites

	TRANSPORT TO OFF-SITE			TRANSPORT TO THE SITE
Contamination levels	**Göteborg (Hisingen) KM - MKM**	**Borås > MKM-FA**	**>FA: Vänersborg**	**Hisings-Kärra (Göteborg)**
Operator / Location	RGS 90 Sverige AB / Hisingen (Göteborg)	RGS 90 / Borås	RagnSells / Trollhättan (closer to Vänersborg)	Hisings-Kärra (Göteborg)
Address	Östra Sörredsvägen 40, Göteborg	Borås	Heljestorp 150, VÄNERSBORG	
Total distance from site (km)	8.0	64.5	100.4	13.5

Table A9-2 Detailed information on the sections within each route between Fixfabriken site and the different final disposal sites (road section 1-3)

	TRANSPORT TO OFF-SITE			TRANSPORT TO THE SITE
Location	**Göteborg (Hisingen) KM - MKM**	**Borås > MKM-FA**	**>FA: Vänersborg**	**Hisings-Kärra (Göteborg)**
Section 1	**Karl Johansgatan**	**Karl Johansgatan, Slottsskogsgatan, Jaegerdorffsmotet**	**Karl Johansgatan, Slottsskogsgatan, Jaegerdorffsmotet**	**Karl Johansgatan, Slottsskogsgatan, Jaegerdorffsmotet**
L (road length) (Km)	0.8	0.8	0.8	0.8
velocity (km/h)	50.0	50.0	50.0	50.0
Q (n. of accidents / million transport kilometres)	1.2	1.2	1.2	1.2
F (number of vehicles per accidents (1.8 in urban areas. 1.5 in rural areas)	1.8	1.8	1.8	1.8
Section 2	**Kungstensmotet**	**E45 (Oscarsleden, Skeppsgossegatan, Oskarsgatan)**	**E45 (Oscarsleden, Skeppsgossegatan, Oskarsgatan, Götatunneln)**	**E45 (Oscarsleden, Skeppsgossegatan, Oskarsgatan, Götatunneln)**
L (road length) (Km)	0.3	2.1	5.4	5.4
velocity (km/h)	50.0	90.0	90.0	90.0
Q (n. of accidents / million transport kilometres)	0.8	0.3	0.3	0.3
F (number of vehicles per accidents (1.8 in urban areas. 1.5 in rural areas)	1.8	1.5	1.5	1.5
Section 3	**Hisingsleden (159) /Lundbyleden**	**Between Andréegatan and Örgrytemötet**	**Gullbergsmotet**	**Gullbergsmotet**
L (road length) (Km)	3.1	3.44	0.51	0.51
velocity (km/h)	90	70	90	90
Q (n. of accidents / million transport kilometres)	0.37	1.2	0.4	0.4
F (number of vehicles per accidents (1.8 in urban areas, 1.5 in rural areas)	1.5	1.5	1.5	1.5

Table A9-3 Detailed information on the sections within each route between Fixfabriken site and the different final disposal sites (road section 4-6)

	TRANSPORT TO OFF-SITE			**TRANSPORT TO THE SITE**
Location	**Göteborg (Hisingen) KM - MKM**	**Borås > MKM-FA**	**>FA: Vänersborg**	**Hisings-Kärra (Göteborg)**
Section 4	**Torslandsvägen (155)**	**Kungsbackaleden (E6/E20)**	**Kungälvsleden (E6)**	**Kungälvsleden (E6)**
L (road length) (Km)	2.8	0.8	69.1	4.2
velocity (km/h)	90.0	110	90.0	90.0
Q (n. of accidents / million transport kilometres)	0.4	0.3	0.4	0.4
F (number of vehicles per accidents (1.8 in urban areas, 1.5 in rural areas)	1.5	1.5	1.5	1.5
Section 5	**Sorresdsvägen**	**Boråsleden (27)**	**Uddevallavägen (44)**	**Bäckbolsmotet, Transportgatan, Skälltorpsvägen, Södra Tagenevägen, Tagenevägen**
L (road length) (Km)	0.7	57.4	23.7	2.1
velocity (km/h)	90.0	90.0	70.0	70.0
Q (n. of accidents / million transport kilometres)	0.4	0.4	0.6	0.8
F (number of vehicles per accidents (1.8 in urban areas, 1.5 in rural areas)	1.5	1.5	1.5	1.5
Section 6	**Östra Sörredsvägen / Lilla Sörredsvägen**		**Several**	**Karlsbogårdsgatan**
L (road length) (Km)	0.3		0.9	0.4
velocity (km/h)	70.0		70.0	70.0
Q (n. of accidents / million transport kilometres)	0.8		0.8	0.8
F (number of vehicles per accidents (1.8 in urban areas, 1.5 in rural areas)	1.5		1.5	1.5

Velocity is ued to determine the parameter Q, see Vägverket Räddningsverket (1998).

The mean of the parameters Q and F are calculated by the following equation, where Q and F are represented by X_{Si}. S_i is each section of a certain route, and L the length of the section, see Table A9-4.

$$X_{S_i} = \frac{L_{S_1} \times X_{S_1} + L_{S_2} \times X_{S_2} + L_{S_i} \times X_{S_i}}{L_{S_1} + L_{S_2} + L_{S_i}}$$

Table A9-4 The calculated mean values for the different parameters, to each route between Fixfabriken site and the different final disposal sites

	TRANSPORT TO OFF-SITE			**TRANSPORT TO THE SITE**
Mean values	**Göteborg (Hisingen) KM - MKM**	**Borås > MKM-FA**	**>FA: Vänersborg**	**Hisings-Kärra (Göteborg)**
Q (n. of accidents / million transport kilometres)	0.5	0.4	0.4	0.5
F (number of vehicles per accidents (1.8 in urban areas, 1.5 in rural areas)	1.54	1.50	1.50	1.52
L (total distance from site) (km)	8.0	64.5	100.4	13.5

Number of transports

Based on the amount of soil calculated that is going to be transported from the site or the amount of filling material transported to the site, the number of transports per day during one year is calculated by the following equation:

$$Transports\ per\ day\ of\ soil_A = \frac{Amount\ of\ soil\ A\ excavated\ (ton)}{Capacity\ of\ a\ lorry\ (ton) \times 365\ (days)}$$

A lorry with a trailer of 30 ton of capacity is considered. The values of the calculations are rounded upwards to integer numbers and shown in Table A9-5 and Table A9-6, respectively for alternative set 1 and set 2. Hisingen is the final disposal site to soil >KM-MKM, Borås to soil >MKM-FA, and Vänersborg to >FA. The parts of the site to intervene in each alternative are taken into account in the overall number of transports. The number of transports from each area is summed.

Table A9-5 Number of transports per day to or from each area (alternative set 1)

Area of the site	Alternatives	Number of transports per day during one year of excavation				
		Göteborg (Hisingen)	Borås	>FA: Vänersborg	Total to off-site	Place with refilling material
Fixfabriken factory	**1**	4	4	2	10.0	5.0
	2	4	4	2	10.0	5.0
	3	5	3	2	10.0	4.0
	4	4	4	2	10.0	5.0
	5	0	0	0	0.0	0.0
Bus garage	**1**	4	3	2	9.0	3.0
	2	4	3	2	9.0	3.0
	3	0	3	2	5.0	0.0
	4	0	4	2	6.0	0.0
	5	4	3	2	9.0	3.0
Tram hall	**1**	0	0	0	0.0	0.0
	2	0	0	0	0.0	0.0
	3	4	3	2	9.0	3.0
	4	4	4	2	10.0	4.0
	5	0	0	0	0.0	0.0
Road	**1**	0	4	2	6.0	0.0
	2	0	4	2	6.0	0.0
	3	0	4	2	6.0	0.0
	4	0	4	2	6.0	0.0
	5	0	4	2	6.0	0.0
Sum (whole site)	**1**	8.0	11.0	6.0	25.0	8.0
	2	8.0	11.0	6.0	25.0	8.0
	3	9.0	13.0	8.0	30.0	7.0
	4	8.0	16.0	8.0	32.0	9.0
	5	4.0	7.0	4.0	6.0	0.0

Table A9-6 Number of transports per day to or from each area (alternative set 2)

Area of the site	**Alternatives**	**Number of transports per day during one year of excavation**				
		Göteborg (Hisingen)	**Borås**	**>FA: Vänersborg**	**Total to off-site**	**Place with refilling material**
Fixfabriken factory	**1**	2	2	1	5.0	2.0
	2	1	1	1	3.0	1.0
	3	0	0	0	0.0	0.0
	4	2	2	1	5.0	2.0
	5	0	0	0	0.0	0.0
Bus garage	**1**	2	2	1	5.0	2.0
	2	2	2	1	5.0	2.0
	3	0	0	0	0.0	0.0
	4	0	2	1	3.0	0.0
	5	2	2	1	5.0	2.0
Tram hall	**1**	0	0	0	0.0	0.0
	2	0	0	0	0.0	0.0
	3	0	0	0	0.0	0.0
	4	2	2	1	5.0	2.0
	5	0	0	0	0.0	0.0
Road	**1**	0	2	1	3.0	0.0
	2	0	2	1	3.0	0.0
	3	0	2	1	3.0	0.0
	4	0	2	1	3.0	0.0
	5	0	2	1	6.0	0.0
Sum (whole site)	**1**	4.0	6.0	3.0	13.0	4.0
	2	3.0	5.0	3.0	11.0	3.0
	3	0.0	2.0	1.0	3.0	0.0
	4	4.0	8.0	4.0	16.0	4.0
	5	2.0	4.0	2.0	8.0	2.0

Annual probability and risk cost of traffic accidents. Calculation of PV

The annual probability for accidents on road with heavy vehicle loaded with hazardous goods (contaminated soil) P_o is given by the following equation.

$$P_0 = N \times Q \times L \times 365 \times F \times 10^{-6}$$

N = Mean number of transports with heavy vehicle per day

Q = Number of accidents/million transport kilometres

L = Road length [km]

F = Number of vehicles per accidents

The annual risk costs include the consequences of spreading of soil contamination and of damage to people involved in a traffic accident. The following equation shows the mathematical formulation. The parameters included are explained in Table A9-7, as well as its values presented.

$$R = P_0 \times \left[Exc_{spread} \times Cost_{exc\ spread} + Cost_{damage\ people} \times People_{car}\right]\ (SEK)$$

Table A9-7 Parameters needed to calculate the annual risk costs. The values are based on Landström & Östlund (2011)

Parameters to calculate the Annual risk costs	**Values**
Excav$_{\mathbf{spreading}}$ (amount of soil to excavate due to spreading of material in case of accident) (ton)	30
Cost$_{\mathbf{excav\ spreading}}$ (cost of excavation actions due to spreading of material in case of accident) (SEK/ton)	165
Cost$_{\mathbf{damage\ people}}$ (cost of damage suffered by people involved in the traffic accidents) (SEK/person)	4147000
People$_{\mathbf{car}}$ (people per car)	1.5

The PV for this item is calculated (Chalmers, 2014) assuming a discounting in accordance to the timeframe for the redevelopment.

A9.2 Results

Table A9-8 and Table A9-9 present the annual risk costs due to transports to and from the site for alternative set 1 and set 2, respectively.

Table A9-10 and Table A9-11 show the costs of the increased health risks due to transports to and from the remediation site for each alternative, expressed as the PV, for alternatives in set 1 and in set 2, respectively.

Table A9-8 Annual risk costs due to transports to and from each area, alternat. set 1

Area of the site	**Alternatives**	**Annual risk cost** (MSEK)			
		To Göteborg (Hisingen)	**To Borås**	**>FA: To Vänersborg**	**From place with refilling material**
Fixfabriken factory	**1**	0.085	0.594	0.445	0.170
	2	0.085	0.594	0.445	0.170
	3	0.107	0.445	0.445	0.136
	4	0.085	0.594	0.445	0.170
	5	0	0	0	0.000
Bus garage	**1**	0.085	0.445	0.445	0.102
	2	0.085	0.445	0.445	0.102
	3	0	0.445	0.445	0.000
	4	0	0.594	0.445	0.000
	5	0.085	0.445	0.445	0.102
Tram hall	**1**	0	0	0	0.000
	2	0	0	0	0.000
	3	0.085	0.445	0.445	0.102
	4	0. 0.085	0.594	0.445	0.136
	5	0	0	0	0.000
Road	**1**	0	0.594	0.445	0.000
	2	0	0.594	0.445	0.000
	3	0	0.594	0.445	0.000
	4	0	0.594	0.445	0.000
	5	0	0.594	0.445	0.000
Sum (whole site)	**1**	0.171	1.632	1.334	0.272
	2	0.171	1.632	1.334	0.272
	3	0.192	1.929	1.779	0.238
	4	0.171	2.374	1.779	0.306
	5	0.085	1.039	0.889	0.102

Table A9-9 Annual risk costs due to transports to and from each area, alternat. set 2

Area of the site	**Alternatives**	**Annual risk cost** (MSEK)			
		To Göteborg (Hisingen)	**To Borås**	**>FA: To Vänersborg**	**From place with refilling material**
Fixfabriken factory	**1**	0.043	0.297	0.222	0.068
	2	0.021	0.148	0.222	0.034
	3	0	0	0	0.000
	4	0.043	0.297	0.222	0.068
	5	0	0	0	0.000
Bus garage	**1**	0.043	0.297	0.222	0.068
	2	0.043	20.9	0.222	0.068
	3	0	0	0	0.000
	4	0	0.297	0.222	0.000
	5	0.043	0.297	0.222	0.068
Tram hall	**1**	0	0	0	0.000
	2	0	0	0	0.000
	3	0	0	0	0.000
	4	0.043	0.297	0.222	0.068
	5	0	0	0	0.000
Road	**1**	0	0.297	0.222	0.000
	2	0	0.297	0.222	0.000
	3	0	0.297	0.222	0.000
	4	0	0.297	0.222	0.000
	5	0	0.297	0.222	0.000
Sum (whole site)	**1**	0.085	0.890	0.667	0.136
	2	0.064	0.742	0.667	0.102
	3	0	0.297	0.222	0.000
	4	0.085	1.187	0.889	0.136
	5	0.043	0.594	0.445	0.068

Table A9-10 Costs of the increased health risks due to transports to and from the remediation site, in each of the 4 areas and for each alternative in set 1, expressed as PV (MSEK)

C2b. Increased health risks from transport activities	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	1.09	1.09	0.95	1.09	0.00
Bus garage area	0.80	0.80	0.68	0.79	0.80
Tram hall area	0.00	0.00	0.75	0.88	0.00
Road area	0.67	0.67	0.67	0.67	0.67
C2b. Present Value (MSEK)	**2.56**	**2.56**	**3.05**	**3.42**	**1.47**

Table A9-11 Costs of the increased health risks due to transports to and from the remediation site, in each of the 4 areas and for each alternative in set 2, expressed as PV (MSEK)

C2b. Increased health risks from transport activities	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	0.53	0.36	0.00	0.53	0.00
Bus garage area	0.47	0.47	0.00	0.39	0.47
Tram hall area	0.00	0.00	0.00	0.44	0.00
Road area	0.33	0.33	0.33	0.33	0.33
C2b. Present Value (MSEK)	**1.33**	**1.16**	**0.33**	**1.69**	**0.80**

These results are slightly overestimated as when performing the annual risk calculations, the parameter F was included in the formula and multiplied by $\text{People}_{\text{car}}$. Therefore, PV of this economic item is slightly overestimated, as well as NPV, bringing the negative value of alternative 5 in set 2 closer to zero. This limitation in the calculations also affects the PV of alternative set 1, although does not change the negative NPV into positive ones.

A9.3 Bibliography

Brinkhoff, P. (2014). Oral information about landfills likely to be used in the Gothenburg region.

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

ENIRO. (n.d.). Retrieved June 2014, 15, from ENIRO: http://kartor.eniro.se/vägbeskrivning

Google Maps (n.d.). Retrieved June 2014, 15, from Google Maps: https://www.google.se/maps?source=tldsi&hl=en

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Vägverket Räddningsverket (1998). Förorening av vattentäkt vid vägtrafikolycka - hantering av risker vid petroleumutsläpp. Vägverket publication: 98:064.

Appendix 10 - C3b. Decreased provision of ecosystem services outside the site due to the remedial action, e.g. environmental effects due to transports of contaminated soil

A10.1 Method

Figure A10-1 shows the methodology used to monetize the cost item C3b.

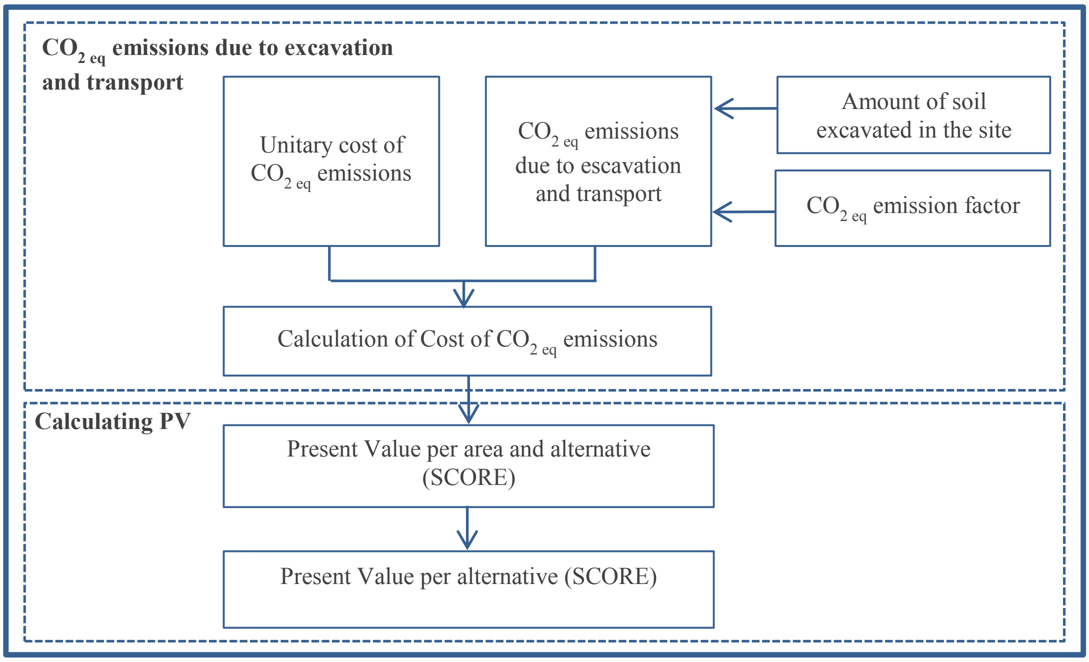


Figure A10-1 Steps followed to estimate the cost of CO2 eq emissions due to excavation in the site and further transport off-site

$CO_{2\ eq}$ emissions and total cost of $CO_{2\ eq}$ emissions values are obtained by using respectively the following formulas:

$$Total\ CO_{2\ eq\ emmited}\ (ton) = \frac{CO_{2\ eq\ emmited}}{ton_{soil}} \times soil\ excavated$$

$$Total\ Cost_{CO2\ eq\ emmited}\ (SEK) = Total\ CO_{2\ eq\ emmited} \times \frac{Cost_{CO_{2\ eq\ emmited}}}{ton_{CO_{2\ eq\ emmited}}}$$

The unitary cost of CO_2 eq emissions used in the calculations for alternative set 1 is based on the value suggested by Landström & Östlund (2011), of 3.5 SEK/kg. Later on, when proceeding with the assessment of alternative set 2, a lower value of 1.08 SEK/kg suggested by Trafikverket (2015) is used instead.

The choice of the emission factor due to excavation and transport when conducting remediation works is based on previous studies performed to other sites in Sweden, namely Almqvist *et al.* (2011) and Brycke *et al.* (2013). A value of 12 kg $CO_{2\ eq}/m^3$ of excavated soil is assumed for the calculations, which is within the range of 12-14 kg $CO_{2\ eq}/m^3$ determined to the different remediation alternatives for the Hexion case study (Almqvist *et al.*, 2011). Additionally, the selected value is close to the average value of the range 6-28 kg $CO_{2\ eq}/m^3$ estimated for the Surte site and the Limhamn site (Brycke *et al.*, 2013). Still, this has some limitations as the studies mentioned focused on case studies with distinct specificities for excavation works and off-site transport to final disposal sites. However, it can be considered that it doesn´t affect the results significantly, having the amount of soil to handle the highest influence in the costs. Assuming a density value of 1.8 ton/m^3, the emission factor for the soil excavated became 6.7 $CO_{2\ eq}/ton_{soil}$. Emissions due to the other remedial actions are not included in the calculations, but just the ones emitted during excavation and transport of soil.

The amount of soil excavated in the site is obtained while calculating the cost item C1d, as previously described in Appendix 7.

The costs for each area and each alternative are then used in the CBA calculations in SCORE (Chalmers, 2014). Discounting occurs in accordance to the timeframe for the redevelopment. Each of the four areas are treated separately, as illustrated by Figure 4-3 in the Section 4.2.

A10.2 Results

The emissions for each alternative and per area are presented in Table A10-1 and Table A10-2, respectively to alternative set 1 and set 2.

Table A10-1 CO_2 emissions due to soil excavation and transport (ton), in each of the four areas and for each alternative in alternative set 1.

CO_2 emissions due to soil excavation and transport (ton)	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Fixfabriken area	900	900	900	900	0
Bus garage area	900	900	900	900	900
Tram hall area	0	0	900	900	0
Road area	900	900	900	900	900
Total	2700	2700	3600	3600	1800

Table A10-2 CO_2 emissions due to soil excavation and transport (ton), in each of the four areas and for each alternative in alternative set 2.

CO_2 emissions due to soil excavation and transport (ton)	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Fixfabriken area	450	225	0	450	0
Bus garage area	450	450	0	450	450
Tram hall area	0	0	0	450	0
Road area	450	450	450	450	450
Total	1350	1125	450	1800	900

Table A10-3 and Table A10-4 show the cost C3b per area and per alternative, expressed as PV in MSEK, respectively for alternative set 1 and set 2.

Table A10-3 Monetized cost of decreased provision of ecosystem services outside the site due to the remedial action, in each of the four areas and for each alternative in alternative set 1. Expressed as PV (MSEK).

B2b. Reduced non-acute health risks	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	2,65	2,65	2,65	2,65	0,00
Bus garage area	2,35	2,35	2,39	2,39	2,35
Tram hall area	0,00	0,00	2,19	2,19	0,00
Road area	1,40	1,40	1,40	1,40	1,40
C3b. Present Value (MSEK)	6,40	6,40	8,64	8,64	3,75

C3b costs obtained for alternative set 1 are overestimated due to a higher unitary cost considered when performing the calculations in an early stage of this work. Nonetheless, this does not affect the ranking of the alternatives, neither changes significantly the NPV of the alternatives considered. A negative societal profitability remains unchanged.

Table A10-4 Monetized cost of decreased provision of ecosystem services outside the site due to the remedial action, in each of the four areas and for each alternative in alternative set 2. Expressed as PV (MSEK).

B2b. Reduced non-acute health risks	**Altern. 1**	**Altern. 2**	**Altern. 3**	**Altern. 4**	**Altern. 5**
Partials Present Value					
Fixfabriken area	0,41	0,20	0,00	0,41	0,00
Bus garage area	0,36	0,36	0,00	0,37	0,36
Tram hall area	0,00	0,00	0,00	0,34	0,00
Road area	0,31	0,31	0,31	0,31	0,31
C3b. Present Value (MSEK)	**1,08**	**0,88**	**0,31**	**1,43**	**0,67**

To both alternatives set 1 and set 2, an additional aspect contributes to a probable overestimation of the PV of C3b, as the value of all the soil excavated and not the value of only the soil transported off-site is used in the calculations. In all the alternatives there is at least one small amount of soil that is suitable to be reused on-site and therefore is not transported to a landfill. Nevertheless, the $CO_{2\ eq}$ emission factor used is not case-study specific, and therefore there would always be a deviation if compared with possible specific case-study $CO_{2\ eq}$ emission factor. Potential differences are not expected to change the negative societal profitability of alternative set 1, although it might change the negative societal profitability of alternative 5 in set 2 into a positive NPV.

A10.3 Bibliography

Almqvist, P., Johansson, J., König, L., Lindvert, D. (2011). Växthusgasemissioner från efterbehandling av förorenad mark. Utvärdering av verktyget VHGFM genom en fallstudie av Hexionområdet. Kandidatarbete. Chalmers Tekniska Högskola

Brycke, E., Dahlström, L., Haag, A., & Hammarberg, L. (2013). Beräkning av koldioxidemissioner från efterbehandling av förorenade mark. Kandidatarbete inom bygg- och miljöteknik våren 2013 BMTX01. Göteborg.

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.

Landström, Å., & Östlund, A.-S. (2011). Choosing sustainable remediation alternatives at contaminated sites. Application and Evaluation of a Multi-Criteria Analysis method". Master of Science Thesis. Göteborg: Chalmers University of Technology.

Trafikverket (2015). Samhällsekonomiska principer och kalkylvärden för transportsektorn: ASEK 5.2

Appendix 11 - Motivation to scoring in the environmental and social domains

Motivation to scoring of social domain, done with researchers from Balance 4P project, is in Table A11-1 and Table A11-2.

Table A11-1 Motivation to scoring in the environmental domain (E1-E3)

Key criteria	Sub-criteria	**Motivation / Comments**				
		Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
E1: Soil	Ecotoxicological risk RA On-site	No effect is expected, the uncertainty level is low. The assumption is made that the toxic soil or waste will not be stored in an uncontaminated portion of the site, no increased risks for the soil ecosystem.	No effected is expected. See alt. 1, but the level of uncertainty is medium due to phytoremediation	See alt 1	See alt.1	See alt. 1
	Ecotoxicological risk SC On-Site	Reduced contamination levels in soil will lead to substantial risk reduction.	The level of uncertainty is high (only the top layer is remediated with phytoremediation).	Slightly positive effect due to in-situ treatment. All scores are possible: natural attenuation conditions can be changed by surface cover.	Very positive effect, because reduced contamination levels in soil will lead to substantial risk reduction (low level of uncertainty).	Positive effect because the soil within future residential area is substituted with a clean material leading to reduction of the risks to the ecosystem.
	Soil Functions RA On-Site	The contaminated soil within future green areas will be substituted with a soil of good quality in accordance with the Swedish guide for installations in urban areas (MarkAMA)	See Alt 1 + positive effects on soil functions due to amendments/ phytoremediation	The area will be covered with a clean material. The soil within future green areas is expected to be of a good quality for functioning.	See alt.1	See alt. 1
E2: Physical Impact on Flora and fauna	Flora and fauna RA On-Site	No physical disturbance of any species with protection value.	No physical disturbance of any species with protection value.	No physical disturbance of any species with protection value.	No physical disturbance of any species with protection value.	No physical disturbance of any species with protection value.
E3: Ground water	RA On-Site	The extensive excavation may lead to insignificant effects on contaminant concentration in groundwater. No positive effects possible. The level of uncertainty is high because the groundwater table depth is unknown.	See alt.1	No negative effects because no change in relation to the reference alternative is expected.	See alt.1	See alt. 1
	RA Off-Site	The extensive excavation will have a small but insignificant effect on contaminant concentration in groundwater. No positive effects possible.	See alt.1	No negative effects because no change in relation to the reference alternative is expected.	See alt.1	See alt. 1
	SC On-Site	Large amounts of the contaminated soil will be removed reducing the risk for releases of contaminants to the groundwater.	The contaminated soil will be removed reducing the risk for releases of contaminants to the groundwater. High level of uncertainties due to phytoremediation (only upper soil layers are treated).	Improvement of groundwater with in-situ technique, however, the level of uncertainty is high due to unknown efficiency of the in-situ technique.	Very positive effect, because the very large amounts of contaminated soil will be removed substantially reducing the risk for releases of contaminants to the groundwater.	Improvement of groundwater, contamination levels in source are reduced with excavation and in-situ techniques. However, the level of uncertainty is high due to unknown efficiency of the in-situ technique.
	SC Off-Site	See motivation for Groundwater SC On-Site	See motivation for Groundwater SC On-Site	See motivation for Groundwater SC On-Site	See motivation for Groundwater SC On-Site	See motivation for Groundwater SC On-Site

Table A11-2 Motivation to scoring in the environmental domain (E4-E8)

Key criteria	Sub-criteria	Motivation / Comments				
		Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
E4: Surface Water	RA On-Site	-	-	-	-	-
	RA Off-Site	The Göta Alv river is a very large recipient. The effects will be insignificant. During excavation, contaminants may be released and travel with groundwater to the recipient. However, the intent is to collect and treat this water.	See alt.1	The Göta Alv river is a very large recipient. The effects will be insignificant. However, contaminants may be released and travel with groundwater to the recipient due to in-situ treatment.	See alt.1	See alt .3
	SC On-Site	-	-	-	-	-
	SC Off-Site	Large amounts of the contaminated soil will be removed reducing the risk for releases of contaminants to the groundwater and in turn their travel to surface water.	See alt.1 but some risks of release to groundwater and traveling of contaminants to surface water because in one part of the area phytoremediation handles contaminants only in the upper layers.	Some improvement in groundwater quality will lead to decreased risks associated with traveling of contaminants to surface water. Unknown efficiency of the in-situ technique	Very large amounts of the contaminated soil will be removed reducing the risk for releases of contaminants to the groundwater and in turn their travel to surface water.	See alt .3
E5: Sediment	RA On-Site	-	-	-	-	-
	RA Off-Site	If the contaminants will reach the Göta Alv river as a result of the remedial action, the high flow velocity will prevent sedimentation.	See alt. 1	See alt. 1	See alt. 1	See alt. 1
	SC On-Site	-	-	-	-	-
	SC Off-Site	The remediation will have a positive effect on the sediments.	See alt. 1	Slightly positive effect, the efficiency of the in-situ method (applied for the whole area) is not known.	Positive effects, because contamination levels in the source are reduced	Positive effects, however the efficiency of the in-situ method (applied in one part of the area) is not known.
E6:Air	RA Off-Site	Extensive transportation of excavated and refilling material from and to the site respectively.	Less than 50% of transportation than in max alternative (the area is excavated partially, one part is treated with phytoremediation assuming little transport)	Less than 10% of transportation than in max alternative. Transportation of the clean material to the site for cover (little transportation of the waste)	Transportation is more than 50% of max alternative. However, the area will be half refilled because some space is reserved for foundations (less transportation of the clean material to the site than in max alternative)	Less than 50% of transportation than in max alternative (the area is excavated partially)
E7: Non-renewable Natural resources	RA Off-Site	Less than 50% of gravel than in max alternative will be used as backfilling material. Transportation of excavated and refilling material from and to the site respectively will lead to consumption of oil.	Less than 50% of gravel than in max alternative will be used as backfilling material. Transportation of excavated and refilling material from and to the site respectively will lead to consumption of oil. (One part is treated with phytoremediation in contrast to alt.1)	Less consumption of oil (no transportation to landfill), less material for cover (around the buildings only)	More than 50% of max alternative (however, the area will be half refilled because some space is reserved for foundations)	Less than 50% of transportation than in max alternative
E8: Non-recyclable Waste Generation	RA Off-Site	Substantial amounts of the waste will be generated (more than 50% of max alternative).	See alt.1, but one part is treated with phytoremediation and less waste will be produced in contrast to alt. 1	Very little waste is produced. Less than 10% of waste than in max alternative.	A large amount of the waste is generated (max alternative).	Less than 50% of waste than in max alternative

Motivation to scoring of social domain, done with researchers from Balance 4P project, is presented in Table A11-3 and Table A11-4.

Table A11-3 Motivation to scoring in the social domain (S1-S3)

Key criteria	**Sub-criteria**	**Motivation / Comments**				
		Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
S1: Local Environmental Quality and Amenity	RA On-Site	Increased physical disturbances due to remedial action (noise, transportation) We included construction phase/ end land use scenario		Least transport due to remediation	The worst case in terms of noise	
	RA Off-Site	One point worse than on-site				
	SC On-Site	There is a very positive effect on the local env quality and amenities on the site.		(Phytoremediation area should possibly be fenced) to reduce the risks	The tram hall is moved to the middle. It is not that good on-site	
	SC Off-Site	There are some positive effects, for the surrounding as well			The tram hall is moved to the middle. It is better for off-site	
S2: Cultural Heritage	RA On-Site	The Fixfabriken building will be turned down, The archael remains will be destroyed. The tram hall will be preserved.	The Fixfabriken building will be turned down. The tram hall and arch. remains will be preserved.	The Fixfabriken will be turned down. The tram hall and arch. remains will be preserved. A bit worse than alt. 2	The tram hall is destroyed. But the archeol. remains will not be preserved.	The tram hall is preserved. The archeol. remains will also be preserved.
	RA Off-Site	No physical disturbance of remains off-site.	see alt 1	see alt 1	see alt 1	see alt 1
S3: Health and Safety	RA On-Site	The workers on-site are exposed to contaminated material	The workers on-site are exposed to contaminated material	The best alternative	We consider only demolishing (not construction phase). The worst remediation alternative with regard to the risks. Demolishing of building and extensive excavation.	The Fixfabriken building is not demolished
	RA Off-Site	The heavy traffic will be a safety risk for neighbours. There will also be some dusting.	The heavy traffic will be a safety risk for neighbours. There will also be dusting.	Demolishing of buildings, transport of waste. But in-situ treatment	Heavy traffic, dust.	
	SC On-Site	The contaminants in the Fixfabriken area poses unacceptable risks in the reference alternative.	We assume that the risks are handled properly. The phytoremediation handles the risks removing the contaminants from the upper layer (that is what humans exposed to).	Not the safest method. High uncertainty. We assume that the risks are handled properly.	All the contaminated soil is removed. The risks are substantially reduced (the best case with regard to risk reduction). The safe method. Low uncertainties.	
	SC Off-Site	No drinking water source nearby. Nothing known if the neighbours are exposed to contamination spreading from the site. The uncertainty is high. All scores are possible.	see alt 1	see alt 1	see alt 1	see alt.1

Table A11-4 Motivation to scoring in the social domain (S4-S5)

Key criteria	**Sub-criteria**	**Motivation / Comments**				
		Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
S4: Equity	RA On-Site	The contaminants are to some extent left on site to future generations. Activities in the buss garage may be affected negatively, but other may benefit of redevelopment. The idea of the municipality is to keep the small businesses. All scores possible.	see alt 1	see alt 1	see alt 1	see alt 1
	RA Off-Site	Neighbours are somewhat/not affected somewhat negatively by the remedial action (buildings for social vulnerable groups will (?) be demolished relocated).	see alt 1	see alt 1	see alt 1	see alt 1
	SC On-Site	See alt. 4	The future environmental cost is reduced (the future generation better off due to remedial action and land use)	Although all the contaminants are not completely removed, the risks are handled/ contamination levels are reduced.	Substantial reduction of the future environmental costs (future generation is a vulnerable group).	See alt 3
	SC Off-Site	We look at the final redevelopment results. Positive effects for future generation (accessibility to the site)	see alt 1	see alt 1	see alt 1	see alt 1
S5: Local participation	RA On-Site	The remedial action does not affect job opportunities etc. on site	see alt 1	see alt 1	see alt 1	see alt 1
	RA Off-Site	Due to the remedial action there are slight positive effects off-site, such as an increased use of services.	see alt 1	see alt 1	see alt 1	
	SC On-Site	The change in land use will affect local job opportunities positively (mixed land use). We cannot really differentiate between alternatives. There will also be schools, day cares and sport facility at the site. Uncertainties are high. All scores are possible (e.g. high rent).	see alt 1	see alt 1	see alt 1	see alt 1

A11 Bibliography

Chalmers University of Technology (2014). Sustainable Choice of Remediation (SCORE) software tool v1.0. Gothenburg: Chalmers University of Technology.