SNOWMAN NETWORK

Knowledge for sustainable soils

Project No. SN-02/11

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

Final Report of the SNOWMAN-MCA project carried out as part of the SNOWMAN Network coordinated call II

Start date of project: 15-1-2010
End date of project: 30-12-2013
Date of report: 2014:6

Project coordinator:
Magnus Bergknut
Name of coordinator organisation:
Umeå University, Sweden

NATUR VÅRDS VERKET

SWEDISH ENVIRONMENTAL PROTECTION AGENCY

KOMMUNAL KREDIT PUBLIC CONSULTING

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

Final Report of the SNOWMAN-MCA project carried out as part of the SNOWMAN Network coordinated call II

YEVHENIYA VOLCHKO[1], LARS ROSÉN[1], JENNY NORRMAN[1], MAGNUS BERGKNUT[2], GERNOT DÖBERL[3], ROBERT ANDERSON[1], MATS TYSKLIND[2], DIETMAR MÜLLER-GRABHERR[3]

[1] Chalmers University Of Technology, Göteborg, Sweden, [2] Umeå University, Umeå, Sweden, [3] Environment Agency Austria, Vienna, Austria

ABSTRACT

This final report summarises major activities, results and conclusions derived within the SNOWMAN-MCA project. The main objective of the SNOWMAN-MCA project (2009-2013) was to demonstrate the use of multi-criteria analysis (MCA) in evaluating land management and soil remediation alternatives to access their overall impact on sustainability, with focus on soil functions and soil services. Soil functions are critical for ecosystem survival and for ecosystems' provision of services to humans, and maintained soil function is a key parameter in sustainable development. The SNOWMAN-MCA project was based on studies of three representative polluted sites in Sweden and Austria, and included a range of conventional and innovative remediation scenarios. Key results of the SNOWMAN-MCA project include:

- A suggested hierarchy between soil functions, soil processes, soil services and ecosystem services, resulting in a set of soil function related ecological, socio-cultural and economic criteria and sub-criteria to be used in MCA.
- A suggested minimum data set (MDS) of soil quality indicators for soil function evaluation, and a software tool (SF Box) for calculating changes in soil quality based on the proposed MDS.
- A suggested structured and transparent approach for incorporating soil function and soil use aspects into sustainability appraisal of remediation alternatives using MCA.

Using input from research carried out in tandem with the SNOWMAN-MCA project, the impact of remediation in the ecological, socio-cultural and economic domain was further assessed, including suggested criteria for the socio-cultural domain and research on how uncertainty may be addressed in MCA. Based on this research and on previous efforts (Rosén et al., 2009), an MCA software tool (SCORE) was developed, and used for evaluating the sustainability of suggested remedial actions at the studied sites. The results from the SCORE tool are in this report presented together with the results of the SNOWMAN-MCA project, demonstrating a holistic approach to sustainable remediation.

Key words: soil functions, ecosystem services, contaminated sites, remediation, sustainability assessment, multi-criteria decision analysis

Contents

Preface

The SNOWMAN-MCA project was carried out as part of the SNOWMAN Network coordinated call II (http://www.snowmannetwork.org). Financial funders and partners were the Austrian Ministry for Agriculture, Forestry, Environment and Water Management with the funding managed by Kommunalkredit Public Consulting and the Swedish Environmental Protection Agency. We are sincerely grateful for the received support and for the possibility to extend the project to 2013.

We would also like to acknowledge the following organizations for funding research part of this report: The Swedish research council Formas, the Development Fund of the Swedish Construction Industry, the Swedish Construction Sector Innovation Centre, NCC Construction, and the Swedish Geotechnical Institute.

Former and present co-workers at Umeå University, Chalmers University of Technology, and Environment Agency Austria are highly appreciated for their valuable insights and contributions during the project. Special thanks go out to Tommy Norberg (Chalmers) and Tore Söderqvist (Enveco Environmental Economics Consultancy Ltd., Sweden).

Project acronym:
SNOWMAN - MCA

Full Project Title:
Multi-criteria analysis (MCA) of remediation alternatives to access their overall impact and cost/benefit, with focus on soil function (ecosystem services and goods) and sustainability.

Project consortium:
Umeå University
Chalmers University of Technology
Environment Agency Austria

Project coordinator:
Magnus Bergknut

Project coordinator organisation name:
Umeå University

Umeå, 2014
Magnus Bergknut

1 Introduction

1.1 Background

Remediation of contaminated land is in many cases is associated with high costs, both to the problem owner and to society. Soil remediation may also consume natural resources, produce waste material, result in emissions, and include socio-cultural impacts.

In order to manage society's limited resources, as well as limiting the impact of remediation, priority should be given to the alternative that is considered "best". A key term in environmental decision-making is sustainable development, which in line with the principles outlined in the Brundtland report (WCED, 1987) may be assessed by evaluating changes in the economic, environmental and socio-cultural domains. As such, the evaluation of sustainable soil remediation includes handling multiple stakeholder views as well as handling various and sometimes conflicting criteria accounting for soils diversity, multi-functionality and multiple uses.

A common tool for handling complex, multi-objective and conflicting criteria is Multi Criteria Analysis (MCA, also called Multi Criteria Decision Analysis, MCDA). MCA has been extensively used in environmental decision making and for sustainability appraisal (see e.g. Belton and Stewart, 2002; Burgman, 2005; Hajkowitch and Collins, 2007; DCLG, 2009) MCA is a process that leads to reasonable, justifiable, and explainable decisions (Belton and Stewart, 2002; Mendoza and Martins, 2006) and provides a framework for integrating key management elements, for structuring management problems, and for providing focused discussions.

A key part of MCA is the development of criteria to be used during the analysis. In order to align the result of the SNOWMAN-MCA project with future regulatory practices, the soil functions and services included in the proposed EU Soil Framework Directive (COM, 2006) were used as a basis for the soil criteria used within the SNOWMAN-MCA project. There are a number of challenges associated with defining soil criteria, including how to handle scale, how to incorporate the intended end use of the site, how to provide a link between soil quality, soil functions and ecosystem/soil services, and how to assess the impact of soil remediation on soil quality. These challenges were addressed within the SNOWMAN-MCA project and the results are given in this report, together with results using research carried out in tandem with the SNOWMAN-MCA project, including suggested criteria for the socio-cultural domain and research on how uncertainty may be addressed in MCA.

Sustainable remediation may be defined 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). The SNOWMAN-MCA project demonstrates such a process, with focus on soil function and services.

1.2 Aim and scope

The aim of the SNOWMAN-MCA project was to present a framework for how to include soil functions and services into an MCA procedure for assessing the sustainability of soil remediation. This included several important steps:

- Defining a hierarchy between soil functions, soil processes, soil services, and ecosystem services.
- A scheme for connecting soil functions and services with the ecological, the economic, and the socio-cultural domains of sustainability.
- A method for handling issues of scale and constrains due to the end use of the remediated site.
- Assessing the potential negative and positive impact on soil by soil remediation.
- A procedure for how to include soil functions and services into a MCA framework for assessing the sustainability of soil remediation.

The scope of the SNOWMAN-MCA project is limited to contaminated soils and remediation of contaminated soils, and is based on studies of a three representative polluted sites in Sweden and Austria. The sites were chosen to represent often occurring pollutants, different end uses of the sites, and included both urban and remote settings.

2 Soil functions and remediation

The multi-functionality of soils was recognised during the 1970s and it is now well established that soils contribute to essential environmental, economic, and socio-cultural activities (Bone et al, 2010; Lehmann and Stahr, 2010; Blum, 2005). Based on emerging requirements (e.g. Rodrigues et al, 2009; Bone et al, 2010) it is evident that future management of contaminated sites will require a more holistic approach that is capable of integrating emerging practices and perspectives, such as soil as a non-renewable resource, soil as a provider of fundamental functions and services for ecosystem survival and societal well-being, and soil as a key parameter in future sustainable societal developments.

The change in the understanding of soils has resulted in additional drivers for soil protection, and soil as a provider of fundamental functions and services is at the core of these drivers. This has influenced soil policy, as exemplified by the proposal for a Soil Framework Directive (COM, 2006), which proposes several soil functions and services to be considered: (i) biomass production, including agriculture and forestry; (ii) storing, filtering and transforming nutrients, substances and water; (iii) biodiversity pool, such as habitats, species and genes; (iv) physical and cultural environment for humans and human activities; (v) source of raw materials; (vi) acting as carbon pool; (vii) archive of geological and archaeological heritage.

From above it is evident that soil remediation needs to be sustainable in a wide context and needs to include assessments of soil functions and soil services. On the local level, soil functions and services rely on maintained soil quality, which is based on quantifiable physical, biological, and chemical properties. On a higher level, soil functions and services span the entire temporal scale, from current to future uses, and spread out across all levels of spatial scale, from local to global. As such soil functions and soil services are not only within the scientific domain, but also within the political domain where the global community must agree on how soil functions and services should be used at a given time and space, without compromising the ability of future soil use (Bone et al, 2010; Lehmann and Stahr, 2010).

3 Project structure

The SNOWMAN-MCA project was carried out as part of the SNOWMAN Network coordinated call II (http://www.snowmannetwork.org). The SNOWMAN-MCA project consortium consisted of Umeå University (coordinator), Chalmers University of Technology and the Environment Agency Austria. Financial funders and partners were the Austrian Ministry for Agriculture, Forestry, Environment and Water Management with the funding managed by Kommunalkredit Public Consulting and the Swedish Environmental Protection.

The structure of the SNOWMAN-MCA project, as described in the SNOWMAN Network coordinated call II application, is displayed in Figure 1.

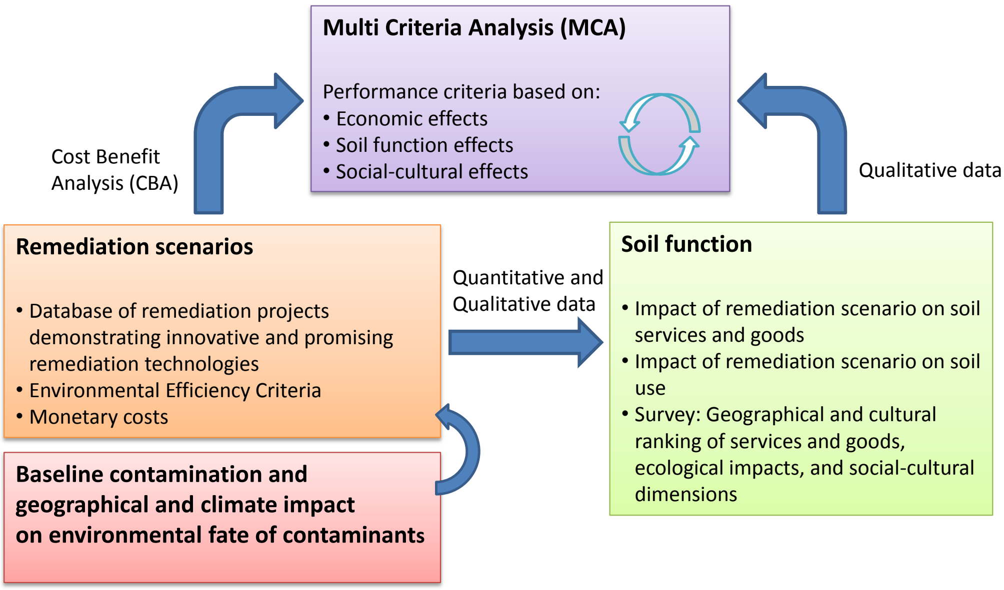


Figure 1: Illustration of the initial SNOWMAN-MCA project structure.

As a result of ongoing research within the SNOWMAN-MCA project, the project structure evolved to accommodate for changes in the envisaged MCA framework and to better suit the actual process when assessing the sustainability of remediation. Some parts of the project were also downscaled due to changes within the consortium and due to practical constraints. One such example was the survey which was cancelled and replaced with criteria accounting for the social-cultural dimension within the MCA. Another such example was the baseline contamination and geographical and climate impact work-package that was not implemented in the final MCA results. The final structure of the SNOWMAN-MCA project, as reflected in the results section of this report, is displayed in Figure 2.

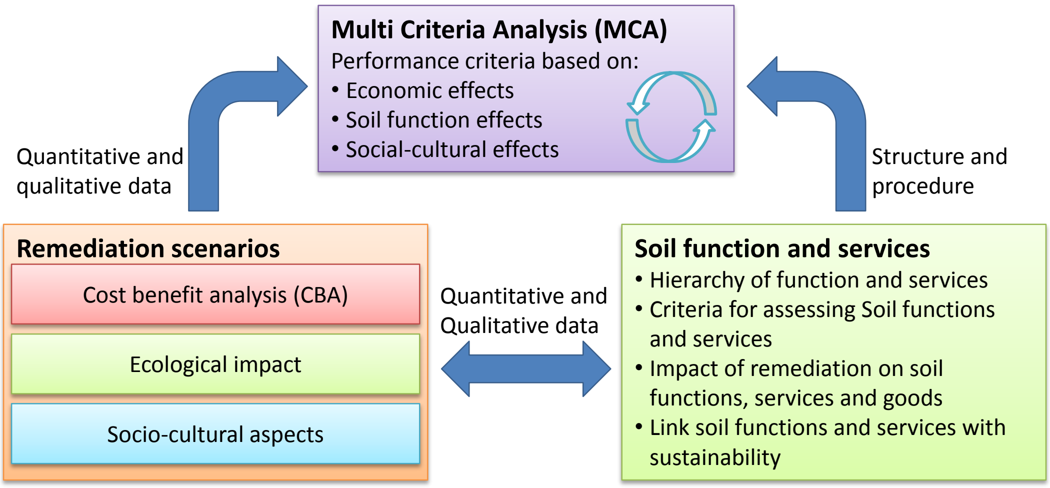


Figure 2: Illustration of the SNOWMAN-MCA project structure.

As illustrated in Figure 2, the sustainability of soil remediation was assessed using a MCA framework receiving site specific data using different remediation scenarios. The data was generated in the economic domain (using cost-benefit analysis) the ecological domain and the socio-cultural domain. The focus of the SNOWMAN-MCA project was to demonstrate how soil functions and services could be included into the MCA framework. Originally envisaged as both giving input to remediation scenarios and the MCA (Figure 1), it later became clear that data connected to soil functions and services had to be funnelled through the economic, ecological and socio-cultural domains in order to maintain a coherent MCA framework. Feedback on structure and procedure was a key part in to incorporating soil functions and services into the MCA framework, having a direct impact on how the framework was developed (Figure 2).

The SNOWMAN-MCA project included the following general milestones and deliverables:

- Establishing a set of performance criteria for the multi criteria analysis
- Selection of representative pilot sites, remediation technologies and scenarios to be used as case studies
- Soil functions and services
    - Hierarchy of function and services
    - Criteria for assessing soil functions and services
    - Impact of remediation on soil functions (Soil Quality Index)
        - SF Box – Excel-based tool
- Environmental and socio-cultural effects of selected management and remediation scenarios
- Monetary cost/benefit of selected management and remediation scenarios
- Cost benefit analysis of selected management and remediation scenarios
- Multi criteria analysis incorporating the soil function concept
        - SCORE – Excel-based tool

In practice most of the project was carried out in an iterative manner, fine tuning different aspect of the MCA framework as new knowledge and new results were made available.

As part of the SNOWMAN-MCA project, three contaminated sites in Sweden and Austria were selected for performing case studies in order to practically demonstrate the application of the MCA framework, the sustainability appraisal using the SCORE tool and the SF Box tool. The selected sites covered different types of contaminants (inorganic and organic) and different settings (remote to urban) allowing for testing a variety of remedial options and representing different levels of strain regarding future land use.

3.1 Cooperation

Besides results from the SNOWMAN-MCA project, this report also includes results generated using funding from the Swedish research council Formas, the Development Fund of the Swedish Construction Industry, the Swedish Construction Sector Innovation Centre, NCC Construction, and the Swedish Geotechnical Institute.

Specific contributions which are fundamental to this report are:

- Research on soil function assessment, identification of socio-cultural criteria and uncertainty assessment in MCA. This was primarily done in cooperation with the project "Multi-Criteria Analysis for Identifying Sustainable Remediation Alternatives", performed 2010-2014 and funded by the Swedish research council Formas and the Swedish Geotechnical Institute.
- Research and development connected to cost-benefit analysis (CBA) and the development of the SCORE method and Excel tool. This was primarily done in cooperation with the projects "Sustainable and Cost-effective Remediation of Contaminated Land in the Built Environment", performed 2010-2014 and funded by the Swedish research council Formas and the Swedish Construction Innovation Center, and "Sustainable Remediation for Construction at Contaminated Sites", performed 2009-2014 and funded by the Development Fund of the Swedish Construction Industry and NCC Construction, and "Decision support for sustainable remediation in urban areas" which is still on-going and funded by the Swedish research council Formas.
- Development of a prototype MCA model for sustainable remediation. This was done in cooperation with the project "MCA for Sustainable Remediation of Contaminated Sites – Method Development and Examples", performed in 2007-2009 and funded by the Swedish Environmental Protection Agency.

The presented SCORE method and Excel-based tool has thus been developed from contributions and work performed in the SNOWMAN-funded project described in this report as well as all of the above mentioned projects and with funding from several sources.

3.2 Dissemination and deliverables

Dissemination was an integral part of the SMOWMAN-MCA project, resulting in a number of activities including conferences, workshops and publications in peer reviewed journals. A complete list of activities is given in Appendix 1.

3.2.1 SCORE tool

Using input from research carried out within and in tandem with the SNOWMAN-MCA project, an Excel-based software tool, the SCORE tool, was developed, and used for evaluating the sustainability of suggested remedial actions at the selected case studies. The SCORE tool and the used MCA framework are described in detail in Chapter 6.

A first demo version of the SCORE tool is planned to be available for download by spring 2015. Please contact lars.rosen@chalmers.se for further information.

3.2.2 SF Box tool

Based on the results of the SNOWMAN-MCA project, an Excel-based software tool, SF Box, was developed for estimating changes in soil quality. The tool includes a suggested minimum set of soil quality indicators (SQIs) for soil function evaluation, as described in detail in Volchko et al (2013b, 2014b).

3.2.3 Peer reviewed scientific articles and reports

The following articles and reports have been published as result of the SNOWMAN-MCA project:

i. Volchko, Y., Norrman, J., Bergknut, M., Rosén, L., Söderqvist, T. (2013a). Incorporating the Soil Function Concept into Sustainability Appraisal of Remediation Alternatives. Journal of Environ. Management129: 367-376.

ii. Volchko, Y., Norrman, J., Rosén, L., Bergknut, M., Söderqvist, T., Norberg, T., Josefsson, S., Wiberg, K. (2014a). Using soil function evaluation in multi criteria decision analysis for sustainability appraisal of remediation alternatives. Science of the Total Environment, 485–486: 785–791.

iii. Volchko, Y., Norrman, J., Rosén, L., Norberg, T. (2014b). A minimum data set for evaluating the ecological soil functions in remediation projects, *Journal of Soils and Sediments*. DOI: 10.1007/s11368-014-0939-8.

iv. Volchko, Y., Norrman, J., Rosén, L., Norberg, T. (2014c). SF Box – a tool for evaluating the effects on soil functions in remediation projects, *Integrated Environmental Assessment and Management*. DOI: 10.1002/ieam.1552.

v. Rosen L., et al,. SCORE: Multi-Criteria Analysis (MCA) for Sustainability Appraisal of Remedial Alternatives. Bioremediation and Sustainable Environmental Technologies - Second International Symposium on Bioremediation and Sustainable Environmental Technologies, Batelle. Jacksonville, Florida, USA, June 10-13, 2013.

vi. Rosén, L., Back, P.-E., Söderqvist, T., Norrman, J., Brinkhoff, P., Norberg, T., Volchko, Y., Norin, M., Bergknut, M., Döberl, G. (2014). SCORE: Multi-Criteria Decision Analysis for Assessing the Sustainability of Remediation at Contaminated Sites, manuscript submitted to *Science of the Total Environment*.

vii. Volchko, Y. SF Box - A tool for evaluating the effects on ecological soil functions in remediation projects (2013b). Report No 2013:1. Chalmers Reproservice, Sweden, 2013.

4 Soil Functions and Services

Soil performs many functions that are essential to humans and the environment, providing clean air and water, crops and forests, wildlife, and landscapes. Soil functions and services encompass all these aspects and include the internal functioning of the soil system as well as the benefits humans gain from soil. A short introduction to soil functions and sustainability is given in the following chapters.

4.1 Background

The confusion about the soil function concept usually stems from unclear definitions of soil functions and soil ecosystem services in the literature. Sometimes the soil function concept is used to describe the internal functioning of the soil system (e.g. Andrews et al., 2004; Singer and Ewing, 2000) and sometimes it relates to the benefits humans gain from ecosystems (e.g. de Groot, 2006). The proposed EU Soil Framework Directive combines both aspects of the soil function concept. The terminology related to the soil function concept and the hierarchy between soil functions and soil ecosystem services are presented in Volchko et al. (2013a).

4.2 Soil functions and sustainability

The terminology presented in Volchko et al. (2013a) suggests a hierarchy between soil functions and soil ecosystem services. The soil functions were defined as the capacity to fulfil the requirements assigned to it by nature. Soil ecosystem services were defined as benefits resulting from utilization of soil functions by humans. Applying this distinction between soil functions and services, soil functions included in the proposed EU Soil Framework Directive are (*a*) *storing, filtering and transforming nutrients, substances and water*; (*b*) *biodiversity pool, such as habitats, species and genes* (COM, 2006). *Biomass production including agriculture and forestry* can be considered both as an ecological soil function (e.g. basis for primary production) and as a soil ecosystem service (e.g. provision of food, fiber and timber). Other soil ecosystem services are (*i*) *physical and cultural environment for humans and human activities*; (*ii*) *source of raw materials*; (*iii*) *acting as carbon pool*; (*iv*) *archive of geological and archeological heritage* (COM, 2006).

Because the aim of a sustainability appraisal of remediation alternatives is to evaluate to what degree a remediation alternative contributes to sustainable development, it was important to link the suggested hierarchy with the ecological, social and economic domains of sustainability. An hourglass model was developed to clearly illustrate the above mentioned linkages and the hierarchy (Figure 3).

In the ecological domain the ecosystem processes are based on the ecosystem structure and interactions between its biotic and abiotic components. These processes result in ecosystem functions. Ecosystem functions turn into ecosystem services once they are utilized by humans and thus passing through the socio-cultural domain. When an ecosystem service has an economic value, this service is transferred to the economic domain.

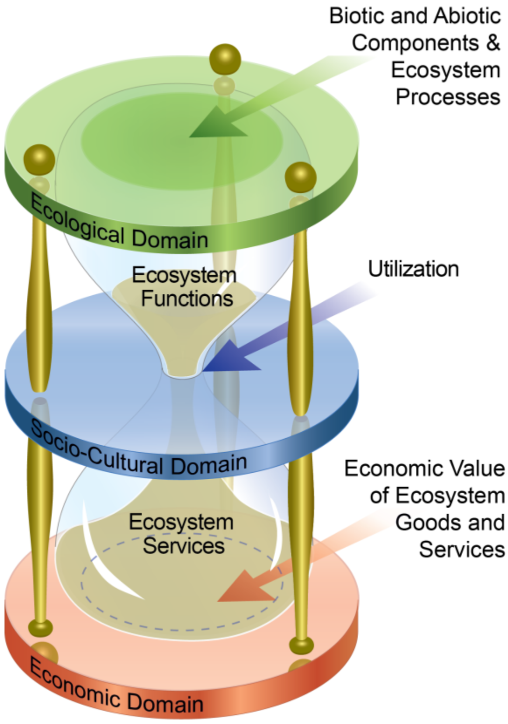


Figure 3: The hourglass of sustainability (Volchko et al., 2013a).

The utilization is a bottleneck in the hourglass of sustainability (Figure 3). Like sand is flowing faster through a wider neck of an hourglass, so are natural resources depleting quickly if overused. Such an overuse can change the potential of supplying ecosystem services critical for human well-being. The usage of natural resources is therefore regulated on the political level, developing and adopting environmental laws, e.g. the proposed EU Soil Framework Directive for sustainable use of soil resources (COM, 2006).

The hourglass of sustainability was also meant to symbolize the importance of investments that aimed at compensating the degradation that human utilization of natural resources might imply. By flipping the hourglass of sustainability and placing the economic domain on top (Figure 3), the benefits gained from ecosystems are returned in form of investments that sustain the functioning of ecosystems.

Incorporation of the soil function concept into sustainability appraisal of remediation alternatives is achieved by allocating soil functions to the ecological domain and soil ecosystem services to the socio-cultural and the economic domains of sustainability. The effects of remediation alternatives on soil functions can be evaluated using soil quality indicators (SQIs), i.e. the measurable physical, chemical and biological properties of soil. SQIs are used to evaluate the degree to which the soil quality matches the soil functions determined by the intended end use of the soil. The effects of remediation alternatives on soil ecosystem services can be evaluated using soil service indicators, i.e. value-related measurements that indicate to which degree a management action contributes to human well-being by preserving, restoring and/or enhancing a soil ecosystem service. These value-related measurements can be expressed in: (1) community-based values, e.g. ethical value, which reflect attitudes, preferences, and intentions associated with a soil ecosystem service; (2) economic values revealed by market data (if any) about a soil service, or the willingness to pay (WTP) for the service provided by the end use of the soil (SAB, 2009). Assigning economic values hinges on the individualistic view that well-being is determined by the degree of preference satisfaction, which typically is monetized through willingness to pay (WTP) (Hausman and McPherson, 1996). For example, if the provision of drinking water is a soil service restored by the remedial action, the WTP for drinking water can be a money-related expression of the environmental change associated with remediation of the contaminated soil. WTP is the economic value people place on the service based on what they think is appropriate for them as individuals rather than what is beneficial for society as a whole since the choice is directly connected to, and constrained by, personal income (SAB, 2009). However, the same individuals taking a community well-being perspective can place another kind of value, e.g. ethical value, on the same service, denoting the degree of its importance for humanity, which is not necessarily reflected in their WTP. Thus, there might be a fundamental difference between their roles as consumers and citizens (Sagoff, 2007).

5 Soil Quality Index – The SF Box Tool

Soil functions are difficult to measure directly, and are usually assessed by measuring soil quality indicators (SQIs). The impact of remediation on soil functions was within the SNOWMAN-MCA project assessed using a soil quality index, which was calculated using a minimum data set (MDS), i.e. a minimum set of SQIs. An introduction to the used method, the selected soil quality indicators, and the proposed Excel-based SF Box tool are given below (for details see Volchko, 2013b and Volchko et al., 2014a, b, c).

5.1 Background

There is no universally accepted definition of soil quality (see a compilation of definitions in Bone et al., 2010). The soil quality is related to both the soil end use and soil functions. The most frequently cited definition is "the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994). However, incorporation of soil functions into a definition of soil quality is a topic of debate in the literature (e.g. Sojka and Upchurch, 1999). In the recent decade, the term soil health was introduced to broaden soil quality and put more emphasis on the soil as a living system (Doran and Zeiss, 2000). Physical, chemical and biological SQIs are usually suggested to describe the capacity of soil to function within managed or natural boundaries. Different sets of SQIs (different MDSs) were developed for assessment of the soil performance to meet agricultural needs (see a detailed review in Kruse, 2007). Several MDSs were suggested for purposes other than maintenance of agricultural productivity of land (e.g. Craul and Craul, 2006; Lehmann et al., 2008; Lehmann and Stahr, 2010; Schindelbeck et al., 2008). Various sets of SQIs were used in soil remediation projects to evaluate the effects of remediation on soil functions (see e.g. Brown et al., 2005; Dawson et al., 2007; Doni et al. 2012, Epelde et al., 2008a; 2008b; 2009; 2010a; 2010b; Jelnsic et al., 2013; Lear et al., 2004; 2007; Li et al., 2009; Makino et al., 2007; Pazos et al., 2012; Plaza et al., 2005; van Herwijen et al., 2007).

Based on literature studies, the MDS was developed for assessment of soil functions associated with primary production, see Table 1. For more details see Volchko et al. (2014b).

Table 1: The developed minimum data set for soil function assessment in remediation projects (Volchko et al., 2014a, b).

Soil Quality Indicators (SQIs)
Soil texture
Content of coarse material
Available water capacity
Organic matter content
Potentially mineralizable nitrogen
pH
Available phosphorus

Evaluation of the effects on ecological soil functions can be done using the scoring approach suggested by Gugino et al. (2009), Idowu et al. (2008), Schindelbeck et al. (2008), and Volchko (2013b). Using scoring curves (Volchko, 2013b; 2014c), each

SQI is transformed into a fractional number in the interval [0; 1], i.e. sub-score. Three types of scoring curves are used in this study: "more is better", "optimum", "less is better" For the "more is better" example, the higher the value of the SQI the higher the sub-score of this indicator. For the "less is better" example, the lower the value of the SQI the higher the sub-score. For the "optimum" example, there is a limited range of values corresponding to a high sub-score, whereas "less" and "more" than this optimum values are scored lower. The sub-scores of [1; 0.71], [0.7; 0.31], [0.3; 0] represent soils of good, medium and poor qualities, respectively (Figure 4).

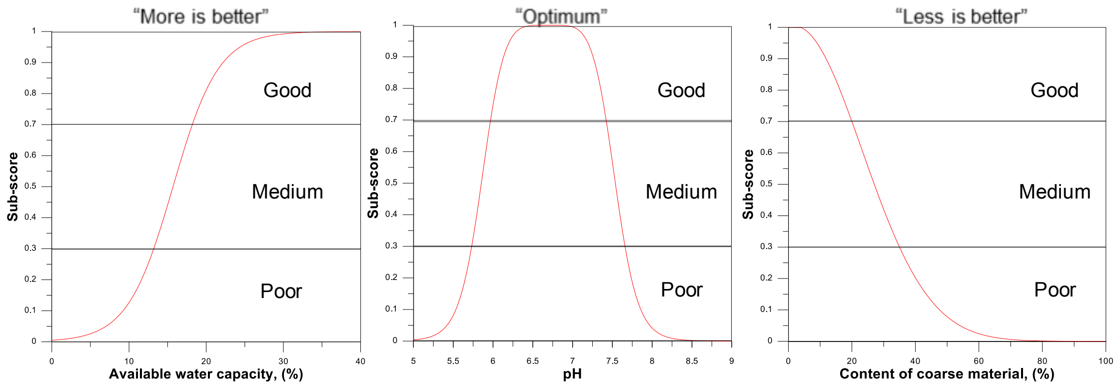


Figure 4: Examples of scoring curves used for interpretation of the measured values of SQIs (Volchko et al, 2014a).

Thereafter, the sub-scores for each SQI are integrated into a soil quality index as arithmetic (or geometric) mean. The soil quality index forms a basis for soil classification into five soil classes: very good, good, medium, poor, and very poor (Table 2).

Table 2: Correspondence between soil classes, soil performances and a soil quality index (Volchko et al., 2014a).

Soil class	Soil performance	Soil quality index
1	Very good	> 0.85
2	Good	0.70 – 0.85
3	Medium	0.55 – 0.69
4	Poor	0.40 – 0.54
5	Very poor	< 0.40

Further, the soil class forms the basis for evaluation of the effects of remediation alternatives on ecological soil functions using a matrix of the effects (Figure 5).

Soil Class of Reference Alternative	Soil Class as a result of Remediation Alternative				
	1*	**2***	**3***	**4***	**5***
1	0	-	--	--	--
2	+	0	-	--	--
3	++	+	0	-	--
4	++	++	+	0	-
5	++	++	++	+	0

Soil Quality Classes:

1	Very good
2	Good
3	Medium
4	Poor
5	Very poor

Effects on Soil Functions:

++	Very positive
+	Positive
0	No effect
-	Negative
--	Very negative

Figure 5: A suggested matrix of the effects on soil functions (modified after Volchko et al., 2014 a).

5.2 SF Box tool

The scoring method (Section 5.1) was realized in the Excel-based tool, called SF Box (see Volchko, 2013b and Volchko et al., 2014c). Using the suggested MDS and the scoring method, the tool computes a soil quality index, a soil class and a soil function performance. Further, the computed soil class and the suggested matrix of effects on soil functions (Figure 5) can be used as input to the MCA.

6 MCA Framework – The SCORE Method

The main objective of the SNOWMAN-MCA project was to demonstrate the use of multi-criteria analysis (MCA) in evaluating land management and soil remediation alternatives to access their overall impact on sustainability, with focus on soil functions and soil services. Using input from research carried out within and in tandem with the SNOWMAN-MCA project, a Excel based software tool, the SCORE-tool, was developed and used for evaluating the sustainability of suggested remedial actions at the pilot sites used as case studies within the SNOWMAN-MCA project. An introduction to the SCORE method is given in this chapter. The following description of the SCORE method is a slightly revised version of the paper by Rosén et al. (2013). Therefore, the information provided in this chapter should be referred accordingly when used elsewhere. A more detailed description of the SCORE model can be found in Anderson et al. (2014) and in Rosén et al. (2014).

6.1 Introduction

The SCORE (Sustainable Choice OF REmediation) method (Rosén et al, 2013) is based on a MCA prototype by Rosèn et al. (2009). Although the MCA prototype has been developed for specific Swedish conditions to meet national environmental policy objectives, it respects an international perspective and approach to sustainability appraisal of remediation alternatives accounting for multiple performance criteria in the ecological, the socio-cultural and the economic domains.

6.2 The SCORE method

6.2.1 Sustainability

It was assumed that the sustainability of a remedial action can be relevantly assessed by evaluating its performances in the *economic*, *environmental* and *socio-cultural* domains, in line with the principles outlined in the Brundtland report *Our common future* from 1987 (WCED, 1987). Each alternative is evaluated relative to a reference alternative by assessing the expected environmental, economic and social effects, using a set of criteria (indicators) in each domain. SCORE thus provides information of whether a specific remediation alternative *leads towards* sustainable development, taking the reference alternative as a point of departure.

SCORE identifies whether there is compensation between sustainability criteria or not and distinguishes between development towards *weak* and *strong* sustainability. Weak sustainability is defined as a non-decreasing total productive base over time, including components such as man-made capital (e.g. machines and infrastructure, natural capital (the environment and natural resources), human capital (health, knowledge, and skills), and social capital (relationships between individuals and institutions) (Arrow et al., 2003; Van den Bergh, 2010; Figge & Hahn, 2004). It builds upon the idea that the different types of capital contributes in a substitutable way to human well-being (Arrow et al., 2003; Bond & Morrison-Saunders, 2011). Weak sustainability might imply that irreversible impacts in the environmental, the social-cultural and the economic domains are neglected (Bond & Morrison-Saunders, 2011).

Strong sustainability on the other hand, requires that each capital type is maintained separately (Van den Bergh, 2010).

6.2.2 Framework and general approach

The SCORE framework (Figure 6) was developed in in line with the view on decision support of e.g. Aven (2003).

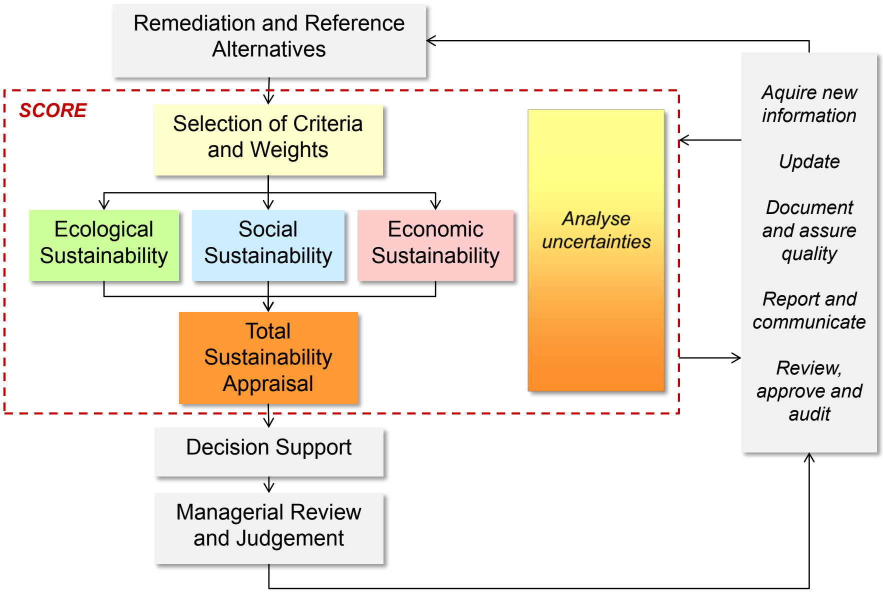


Figure 6: The SCORE framework (Rosén et al., 2013).

SCORE is designed to provide decision support when choosing between a set of remediation alternatives. The expected effects are represented by scorings in the environmental and social domains and quantifications of monetary costs and benefits in the economic domain. A normalized score is calculated for each alternative using a *linear additive approach*, taking into account scorings and quantifications of the criteria and the relative importance (weights) of these criteria. SCORE also uses a *non-compensatory* approach to distinguish between alternatives expected to lead to strong and weak sustainability, respectively (see e.g. Pearce et al., 2006). Uncertainty assessment is performed for each scoring and quantification, facilitating uncertainty and sensitivity analyses of the outcomes.

SCORE assesses whether a specific alternative is expected to *lead towards* sustainable development or not. It is also identifies possibilities on *how to improve* the sustainability of studied remediation alternatives. The method has an iterative approach, allowing for continuous updating as new information becomes available.

6.2.3 Conceptual model

According to Bardos et al. (2011), there are four types of boundaries that must be defined in order to perform a relevant sustainability assessment: (1) System boundaries, (2) Life Cycle Analysis (LCA) boundaries, (3) Temporal boundaries, and (4) Spatial boundaries. The boundaries must be defined with respect to the types of decisions the MCA is supposed to support.

The *system boundary* defines what parts/operations of the remediation project to include in the assessment, e.g. design, mobilisation, construction, production, maintenance, and utilisation. The *LCA boundary* defines how far a particular trail of impacts should be followed and to what level of detail (Bardos et al., 2011). For example, it should be clearly stated if impacts of the manufacturing of components like pipes and equipment should be included in the environmental domain or if they are considered to be outside of the boundary. The *temporal boundary* defines the time perspective applied regarding s e.g. long-term effects, short-term effects, effects during remediation, and/or effects after remediation is completed. The *spatial boundary* defines what locations and areas to include in the assessment, e.g. on-site effects only or also off-site effects.

A conceptual model was developed (Figure 7) to provide a relevant structure for the MCA, with proper consideration of the sustainability concept and providing possibilities for clear definitions of the boundary conditions. The conceptual model was developed according to the *cause-effect chain* concept commonly used in risk assessments. The *cause* of the effects is the remediation taking place at the particular site. The main *stressors* of the remediation is the change in *source contamination*, typically resulting in positive effects in terms of reduced risks to humans and ecosystems and possibilities for new land utilisation, and the *remedial action*, in some cases (not all) resulting in negative effects in terms of use of non-renewable energy, accidental risks, and air emissions. Effects associated with the change in the source contamination and the remedial action can take place at different *locations*, *on-site* and *off-site*. The *receptors* of the effects are humans and ecosystems. The main types of both *long-term and short-term effects* are environmental, economic and sociocultural effects.

The current system boundary of SCORE limits the assessment to a fixed future land-use scenario. The method can thus *not* be used in land-use planning for comparing e.g. the development of an industrial area into a residential area with the development of the same area into a recreational area. The user has to define in detail the system, LCA, temporal and spatial boundaries specific to each particular assessment.

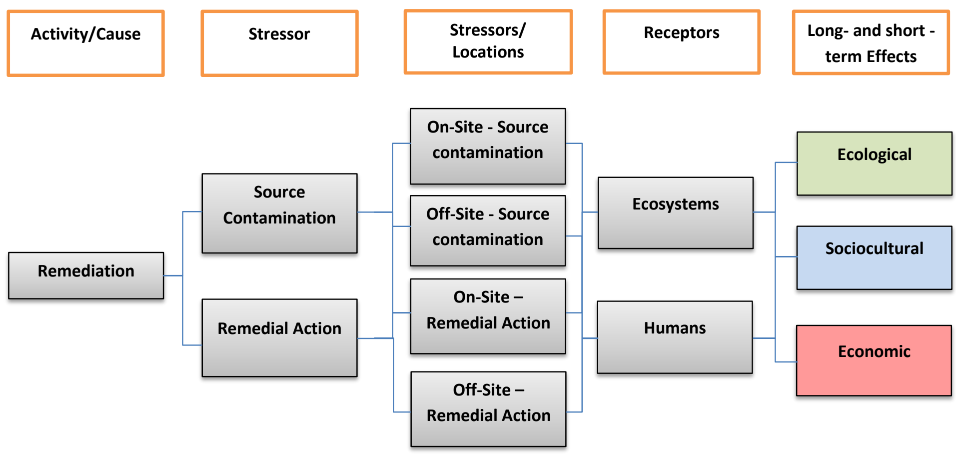


Figure 7: Conceptual Model (Rosén et al., 2013).

6.2.4 Criteria

According to e.g. Van den Bergh (2010) there are some critical aspects in each sustainability domain that cannot be substituted by others. Accepting this view, the purpose should be to select key performance criteria for each sustainability domain of the MCA, given the defined boundary conditions, which are mutually exhaustive and thus capable of collectively representing all critical sustainability aspects.

The selection of the key performance criteria was based on extensive literature review (Brinkhoff, 2011), several focus group meetings in Sweden, and an earlier prototype of the method (Rosen et al., 2009). The identified key performance criteria are listed in Table 3. The key criteria in the environmental and social domains have sub-criteria representing *on-site* and *off-site* effects as well as effects related to the change in *source contamination (SC)* and the *remedial action (RA)*, respectively. The soil criterion has sub-criteria: Soil Functions *RA on-site* and Ecotoxicological Risks *RA* and *SC on-site* (see also Volchko et al., 2014a).

Table 3: Key performance criteria for each sustainability domain in SCORE (Rosén et al., 2013).

Environmental domain	Socio-cultural 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 • Local participation • Local acceptance	• Social profitability

6.2.5 Sustainability assessment

Options evaluated by SCORE must be specified by the user and all effects (impacts) are assessed relative to a reference alternative. It is up to the user to define the reference alternative but it is typically identical to the *no action* alternative, where no action is taken to reduce the risks to humans and the environment. The identified remedial alternatives must satisfy a number of constraints, mainly time, budget, technical feasibility, legal aspects, and public acceptability, see e.g. Bardos et al. (2001). Only remedial alternatives that meet the objectives within the constraints can be considered. The constraints are project specific and they are not part of the MCA.

Scoring of effects (criteria) is performed as follows: 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. The scoring procedure is supported by a guidance matrix for each criterion with examples and key questions to address. The scorings are performed using available data, expert judgment, questionnaires and interviews. The key criterion of the economic domain is social profitability assessed by means of cost-benefit analysis (Rosen et al, 2008). The main cost and benefit items are shown in Table 4. Several cost and benefit sub-items items are used for the CBA. The social profitability is calculated in monetary terms as a net present value (NPV) over the time horizon of the remediation project. In most cases all costs and benefits cannot be monetized and it is therefore important to also provide a qualitative discussion concerning items not quantifiable.

Table 4: Main cost and benefit items of SCORE (Rosén et al., 2013).

Benefits	**Costs**
B1. Increased property value on site	C1. Remediation costs
B2. Improved health	C2. Impaired health due to remedial action
B3. Increased provision of ecosystem services	C3. Decreased provision of ecosystem services due to remedial action
B4. Other positive externalities than B2 and B3	C4. Other negative externalities than C2 and C3

For each remediation alternative *i (i*=1*...N)* a sustainability index *H* is calculated for each domain *D* as the weighted sum of the scorings using a linear additive approach:

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

where w_k *and* w_j are the weights of criterion *k* and its sub-criterion *j* respectively, and *Z* is the score of the sub-criterion *j*. The weighting is performed by the assessment team, taking into consideration judgments and opinions of experts and stakeholders.

In the economic domain, weighting of benefits and costs is carried out through the monetization in the *NPV* calculation.

A normalized sustainability score is calculated for each alternative *i* as:

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

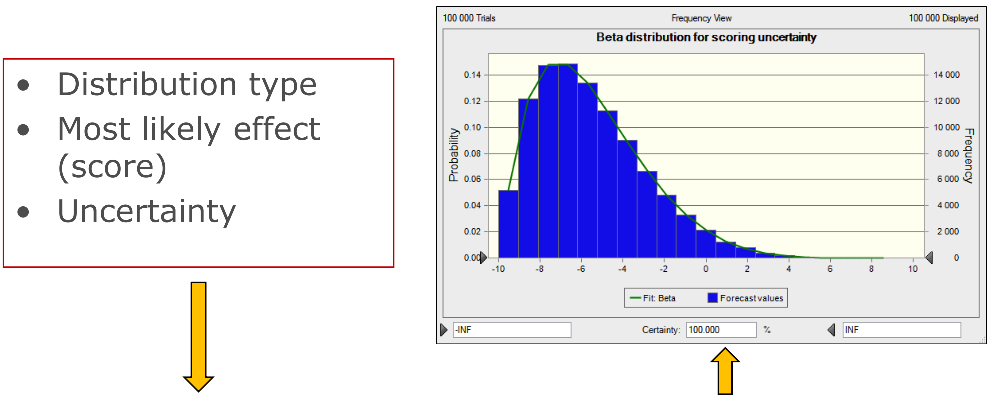
where *E* is the environmental domain, *S* is the sociocultural domain, *NPV* is the net present value, and *W* is the weight of each domain.. The normalized score has a value between -100 and + 100, where a positive score indicates that the alternative leads towards sustainable development, i.e. more positive effects than negative. The normalized score can be used to rank the alternatives.

6.2.6 Uncertainty analysis

Scores and quantifications will always be associated with some uncertainty, i.e. the effects of the remedial alternatives can never be measured exactly. The uncertainty results from lack-of-knowledge (epistemic uncertainty) and natural variability (aleatory uncertainty). The former type of uncertainty can be reduced, at least in principle, but the latter is a result of the inherent randomness in nature. In addition, human subjectivity can result in different persons/groups assigning different scores to the criteria. A certain degree of subjectivity is unavoidable (Harbottle et al., 2008).

SCORE uses statistical distributions to represent the uncertainties in both scores and quantitative metrics. A conceptual description of the uncertainty representations of scorings is shown in Figure 8. The assignment of the uncertainty distribution is performed in three steps: (1) selection of distribution type, i.e. selection of whether all types of effects, only positive, or only negative effects are possible for the specific sub-criterion; (2) estimation of the most likely effect using the scale presented above; and (3) assigning the uncertainty level of the estimation of the most likely effect (Low, Medium, High). The three-step procedure results in a beta probability distribution representing the uncertainty of the scoring of the sub-criterion.

The uncertainties of quantitative metrics of SCORE are represented by continuous statistical distributions. For example, lognormal distributions are used for cost and benefit items in the economic domain.



	Alternative 1			
Key criteria	**Sub-criteria**	**Dist Type**	**Effect**	**Uncertainty**
E1: Soil	Ecotoxicological risk SC On-site A1	No negative scores possible	4	Low
	Ecotoxicological risk RA On-Site A1	No positive scores possible	-2	Medium
	Soil Functions RA On-Site A1	All scores possible	8	Low

Figure 8: Conceptual description of uncertainty representation of scorings (Rosén et al., 2013).

6.3 Comment

SCORE provides: (1) structure, transparency and decision support for identifying sustainable remediation alternatives and for increasing the sustainability of identified alternatives; (2) a means for integrating quantitative and qualitative information into a comprehensive sustainability assessment; (3) cost-benefit analysis of remedial actions, taking into account externalities such as effects on human health and provision of ecosystems services; (4) a means for including effects on soil functions and soil services in accordance with the upcoming EU Soil Framework Directive; (5) an overview of positive and negative effects of remediation on- and off-site due to reduction of the source contamination and the remedial action itself; and (6) uncertainty analysis with e.g. information of the probability of each alternative being the most sustainable and where to focus for achieving a more reliable sustainability appraisal. Finally, despite the substantial amount of results produced by SCORE, its most important contribution may be that it initiates a process where criteria otherwise likely ignored are addressed and openly discussed between stakeholders.

7 Case Studies

In order to practically demonstrate the application of the MCA framework, the sustainability appraisal using the SCORE tool, and the SF Box tool, three contaminated sites in Sweden and Austria were selected as case studies.

7.1 Selection of sites, remediation options and remediation targets

The sites (Table 5) were selected mainly according to following criteria:

- Availability of information and data on contaminants, site characteristics, environmental impacts and planned remedial options.
- Representativeness of contaminants, site characteristics, environmental impacts and remedial options in order to draw general conclusions and recommendations based on the results of the case studies.

The list of sites covers both different types of contaminants (inorganic and organic) and different settings (remote to urban) allowing for testing a variety of remedial options on the one hand and representing different levels of strain regarding future land-use on the other hand.

Depending on the natural characteristics of a site, type and extent of the contamination, the remediation goal and specific environmental targets to be met, in most cases several appropriate remediation techniques are available (remediation options). They mainly differ in their effectiveness to meet goals and targets and in costs. Besides, there may be numerous other differences, e.g. in their technical stability or in their impacts on neighbourhoods, etc.

By performing the case studies the selected sites are virtually remediated by different remedial options. As with the selection of sites, the remedial options have been selected according to the availability of information and data as well as the practical representativeness of the options. For the two Swedish sites the selected remediation options are based on already existing remediation plans or options appraisals. As there are no remediation concepts regarding the Austrian site up to now, three options have been chosen, which seem to be appropriate and may be applicable to the site specific conditions in theory. However, it has to be pointed out that in particular the remedial options chosen for the Austrian site would require site specific evaluation prior to considering their practical application.

In general, cost estimations for the Marieberg and Shooting Range sites have to be considered as very rough, i.e. affected with relatively high uncertainties. The cost and benefit items used as input for the Hexion site are based extensive studies taking uncertainties into consideration (for details see Söderqvist et al., 2014).

A status quo scenario, i.e. no remedial action is performed, served as a reference scenario in all three case studies.

For more information on the selected remedial options see the following chapters with more detailed information on the three sites.

Table 5: List of selected sites and remediation options.

Site	Type	Location	Main contaminants	Affected environmental media	Setting	Remediation options
Hexion	Chemical plant	Mölndal, Sweden	Pb, PAH, aliphatic hydrocarbons, phthalates	Soil, (groundwater)	Urban	0: Status quo 1 to 4: excavation options differing in treatment of fraction to be backfilled / landfilled
Marieberg	Saw mill	Marieberg, Sweden	Dioxins	Soil, groundwater, plants	Remote	0: Status quo 1: Area-wide excavation 2: Hot spot excavation and surface cover 3: Use restrictions
Shooting range		Linz, Austria	Pb, As, Sb, PAH	Soil, plants	Remote (urban outskirts)	0: Status quo 1: Excavation 2: Immobilization 3: Phytostabilization

It is a common procedure in most countries that prior to performing remedial actions a remediation target has to be defined. Mostly this is an authority-driven process taking into account legal frameworks and resulting in target values to be met, which are based on environmental standards. However, legal framing conditions as well as environmental standards significantly differ across Europe. In order to elude this problem in this study, all options chosen are supposed to meet the remediation target; i.e. with the exception of the status quo scenario, the application of all remediation options will result in an environmental status fulfilling national requirements.

7.2 Hexion (Mölndal, Sweden)

7.2.1 General site information

The Hexion site is located in the old centre Mölndal, south of Gothenburg, in the southwestern part of Sweden and covers an area of about 35 000 m² (see Figure 9). The site has a long history of industrial activities which started around 1900. The production of chemicals started in the 1940s, since 1979 binding agents have been produced. Industrial activities ended in 2007 (Landström & Östlund, 2011).

The topography is sloping heavily from north to south with 32 meter difference in ground level. A railroad, "Boråsbanan", marks the northern border of the site, in the west there is a small forest area and street "Kvarnbygatan" lies south of the site. In the east along river Mölndalsån, an area is situated with some old industrial buildings, cafés and museums (see Figure 9). Nowadays the area is planned to be used for apartment blocks, schools, shops and offices, traffic areas and parking lots and green areas with play grounds (Landström & Östlund, 2011).

Figure 9: Arial view of the Hexion site (from Landström & Östlund, 2011; © Lantmäteriet Gävle 2011. Medgivande I 2011/007).

7.2.2 Geology

Hexion is situated in an area with Gothenburg till. This type of till has a complex composition with varying fraction distribution, from sand and gravel to till with lenses of finer grains. The depth of the soil is generally 5 m to 15 m with till closest to the bedrock, followed upwards by sand, gravel and silt (Landström & Östlund, 2011). As a result of the long history of industrial activity there are large amounts of filling materials on top of the natural fractions. The filling material mostly consists of sand, gravel, bricks and asphalt (NCC Teknik, 2010).

The groundwater flows 2 m to 10 m below the surface in southern direction. The groundwater is artesian forming a spring in the steep slope of the Hexion site. The ground water connects to the Mölndalsån river, which runs south-east of the site.

Figure 10 shows a sketch on geology and hydrogeology.

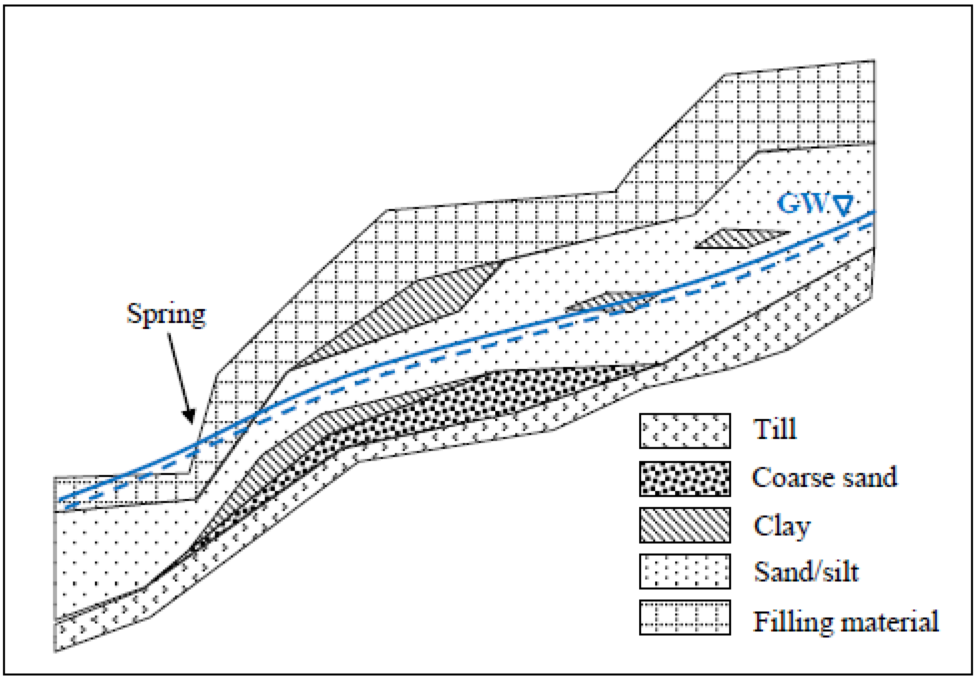


Figure 10: Schematic geological profile (Landström & Östlund, 2011).

7.2.3 Contaminants

There are parts of the area where industrial activities have caused substantial contamination of the soil, primarily by phthalates, lead and solvents. Contaminants primarily have been detected within hot spots in the upper soil layers down to 1 m below surface (see Figure 11). In some areas high concentrations of specific contaminants have been detected at depths down to 4 m below surface or deeper. In particular, the highest concentrations of phthalates (DEHP) have been measured at about 6 m below surface (Landström & Östlund, 2011).

Sampling data show limited effect on groundwater. All samples analyzed for metals showed values lower than the generic guideline values. PAH and BTEX appeared at very low concentrations, except for two samples (Landström & Östlund, 2011).

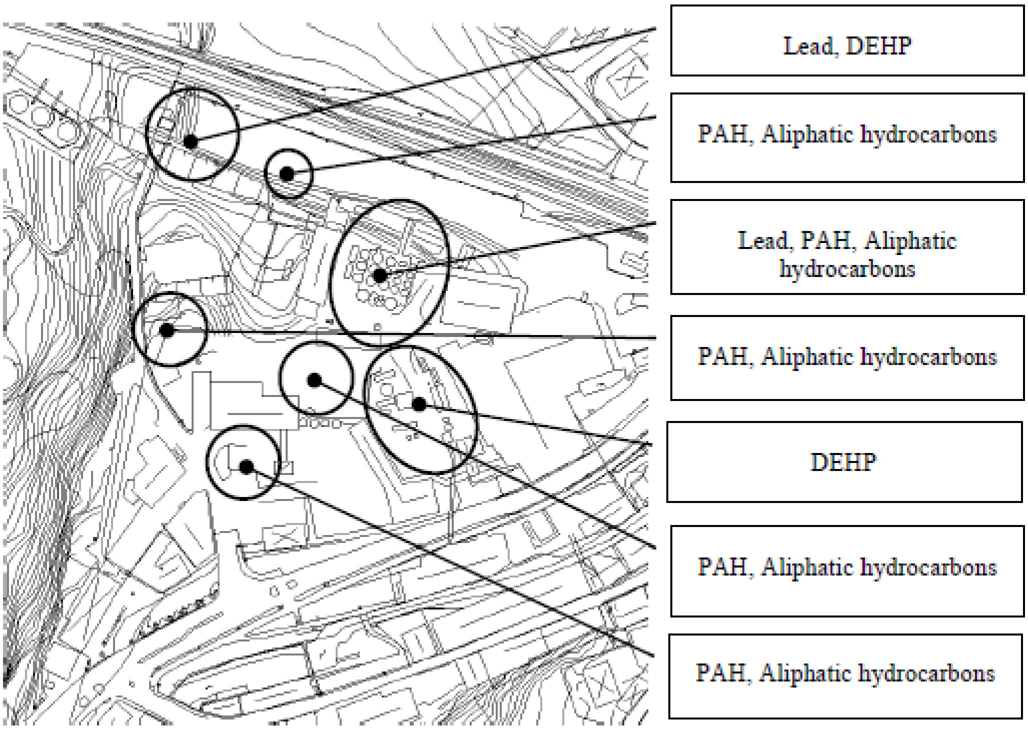


Figure 11: Pollution hot spots at the Hexion site (Landström & Östlund, 2011).

Possible contaminant exposure scenarios for humans regarding the future land use (as described above) include oral intake of contaminated soil, direct skin contact with contaminated soil, and inhalation of dust originating from contaminated soil. Exposure to volatile contaminants beneath the new buildings is not regarded to be an issue because the constructions will be sealed preventing volatiles from entering the buildings. The risk assessment showed that there is a need to reduce the human health risks, and possibly also the risks for the environment (the upper soil layers and deep soil layers in limited parts of the area). High flows in the river prevent accumulation of contaminants in the sediments. The risk posed by the contaminants at the sites to the receptors in the Mölndalsån river is considered to be low (Landström & Östlund, 2011).

7.2.4 Remediation options

Following four remedial options have been selected for this case study featuring various excavation options which mainly differ in the treatment of the soil fraction to be backfilled or landfilled:

1. Excavation based on generic values
2. Excavation based on risk assessment
3. Excavation based on risk assessment with reuse of coarse fraction after sieving
4. Excavation based on risk assessment with reuse of coarse and clean fine fraction after sieving and soil washing.

Brief descriptions of the options as well as rough cost estimations are given in Table 6. For estimated impacts on the defined criteria within the SCORE tool see sub-chapters in Appendix II.

Table 6: Selected remediation options for case study "Hexion".

#	Remediation Option	Description
0	Status quo	No remedial actions
1	Excavation based on generic values	- Excavation of 91 114 tons contaminated soil according to generic threshold values - Landfilling of excavated soil (incl. transport to landfill) - Transport of clean soil to the site - Backfilling of clean material - Estimated total costs: SEK 55 780 000 (incl. SEK 52 860 000 for remedial action)
2	Excavation based on risk assessment	- Excavation of 57 160 tons contaminated soil according to risk assessment - Landfilling of excavated soil (incl. transport to landfill) - Transport of clean soil to the site - Backfilling of clean material - Estimated total costs: SEK 38 210 000 (incl. EUR 36 120 000 for remedial action)
3	Excavation based on risk assessment with reuse of coarse fraction	- Excavation of 57 160 tons contaminated soil according to risk assessment - Sieving of excavated soil - Landfilling of fine fraction (incl. transport to landfill) - Backfilling of coarse fraction - Transport of clean soil to the site - Backfilling of clean material - Estimated total costs: SEK 36 990 000 (incl. SEK 35 050 000 for remedial action)
4	Excavation based on risk assessment with reuse of coarse and clean fine fraction	- Excavation of 57 160 tons contaminated soil according to risk assessment - Sieving and washing of excavated soil - Landfilling of fine fraction which is contaminated (incl. transport to landfill) - Backfilling of coarse fraction and clean fine fraction - Transport of clean soil to the site - Backfilling of clean material - Estimated total costs: SEK 42 120 000 (incl. SEK 40 330 000 for remedial action)

7.2.5 Inputs to the MCA

7.2.5.1 Criteria selection and scoring

Some irrelevant criteria were sorted out in the environmental (e.g. surface water and sediments on-site and groundwater off-site) and the socio-cultural domains (e.g. local acceptance on-site). All other criteria defined in Table 3 were scored using investigations (e.g. soil sampling and analysis), expert judgements, and available information in the technical reports. Criteria scorings, motivations, distribution types representing uncertainties in the assigned scores and levels of uncertainties are presented in Appendix II.

7.2.5.1.1 Soil functions – output of SF Box

The contaminated soil of the 'green' area at the Hexion site was randomly sampled to two depths (0-0.2m and 0.2-0.5m) and analyzed on SQIs from MDS. The SF Box tool was used to compute the soil class in the reference alternative (Figure 12). The contaminated soil at the site was of class 3 corresponding to medium soil performance. Uncertainty analysis of the assessment results can be found in Volchko et al. (2014c, d). The certainty of obtaining class 3 was higher than 80%.

Hexion 0-20cm												Bulk density 1,6		Type Neutral		Method St. methods		Method AL P		Method Arithmetic mean	
Label	No	Clay [%]	Silt [%]	Sand [%]	Gravel [%]	Code	Name	CM [%]	CM_Score	OM [%]	OM_Score	AW [%]	AW_Score	pH	pH_Score	NH4-N [mg/kg]	N_Score	P [mg/kg]	P_Score	Index	Performance
1d_0	1	0	4	59	37	SL	Sandy loam	37	0,26	1,4	0,13	22	0,90	6,5	1,00	160	0,01	197	0,10	0,40	Very poor
4d_0	2	0	1	79	20	LS	Loamy sand	20	0,70	0,8	0,07	21	0,87	5,6	0,14	160	0,01	21	0,23	0,34	Very poor
5d_0	3	0	3	89	8	S	Sand	8	0,96	3	0,47	22	0,90	5,9	0,60	180	0,01	89	0,98	0,65	Medium
6d_0	4	0	4	87	9	S	Sand	9	0,95	3,6	0,63	22	0,90	6,6	1,00	200	0,02	99	0,91	0,74	Good
2_0	5	0	0	86	14	S	Sand	14	0,86	1,6	0,16	22	0,90	6,7	1,00	170	0,01	134	0,34	0,54	Medium
4_0	6	0	0	82	18	LS	Loamy sand	18	0,76	0,9	0,08	21	0,87	6,2	0,95	170	0,01	21	0,23	0,48	Poor
5_0	7	0	2	94	4	S	Sand	4	1,00	5,7	0,94	24	0,93	5,6	0,14	220	0,04	77	0,99	0,67	Medium
6_0	8	0	4	88	8	S	Sand	8	0,96	5,1	0,90	24	0,93	5,9	0,60	200	0,02	124	0,38	0,63	Medium
Mean		0	2	83	15	LS	Loamy sand	15	0,84	2,8	0,41	22	0,90	6,1	0,91	183	0,01	95	0,95	0,67	Medium
																				Soil Class	**3**

Hexion 20-50cm												Bulk density 1,6		Type Neutral		Method St. methods		Method AL P		Method Arithmetic mean	
Label	No	Clay [%]	Silt [%]	Sand [%]	Gravel [%]	Code	Name	CM [%]	CM_Score	OM [%]	OM_Score	AW [%]	AW_Score	pH	pH_Score	NH4-N [mg/kg]	N_Score	P [mg/kg]	P_Score	Index	Performance
1d_1	1	0	1	65	34	SL	Sandy loam	34	0,32	1	0,09	21	0,87	6,8	1,00	160	0,01	78	0,99	0,55	Medium
4d_1	2	0	2	79	19	LS	Loamy sand	19	0,73	1	0,09	21	0,87	6,8	1,00	160	0,01	29	0,40	0,52	Poor
5d_1	3	0	3	85	12	S	Sand	12	0,90	3,3	0,55	22	0,90	6,3	0,99	120	0,00	136	0,33	0,61	Medium
6d_1	4	0	3	80	17	LS	Loamy sand	17	0,78	3,6	0,63	22	0,90	6,5	1,00	200	0,02	151	0,26	0,60	Medium
2_1	5	0	3	68	29	SL	Sandy loam	29	0,45	8,9	1,00	25	0,95	6,6	1,00	170	0,01	230	0,08	0,58	Medium
4_1	6	0	1	82	17	LS	Loamy sand	17	0,78	0,9	0,08	21	0,87	6,5	1,00	160	0,01	33	0,50	0,54	Medium
5_1	7	0	2	93	5	S	Sand	5	0,99	3,2	0,52	22	0,90	5,7	0,25	210	0,03	81	0,99	0,61	Medium
6_1	8	0	2	88	10	S	Sand	10	0,93	4,2	0,77	24	0,93	5,9	0,60	200	0,02	106	0,79	0,67	Medium
Mean		0	2	80	18	LS	Loamy sand	18	0,76	3,3	0,54	22	0,90	6,4	1,00	173	0,01	106	0,80	0,67	Medium
																				Soil Class	**3**

Figure 12: Results of soil function assessment for the soil to a depth of 0.2 m (upper) and 0.2-0.5m (lower) at Hexion. CM: content of coarse material. OM: organic matter content. AW: available water capacity. NH4-N: potentially mineralizable nitrogen. AL-P: available phosphorus. CM_Score: sub-score for content of coarse material. OM_Score: sub-score for organic matter content. AW_Score: sub-score for available water capacity. pH_Score: sub-score for pH. N_Score: sub-score for potentially mineralizable nitrogen. P_Score: sub-score for available phosphorus. Green-yellow-light red color identification codes correspond to good-medium-poor soil qualities.

The computed soil class was further used as input to the MCA for scoring of the soil functions sub-criterion. Since special soil quality requirements (guidelines) exist for green urban areas in Sweden (AMA, 2010), it was assumed that a clean material for refilling would be of a good quality (i.e. of a higher class than in the reference alternative) for all four alternatives. In particular, according to the above mentioned guidelines, the top layer should perform well on soil quality indicators rather similar to the MDS in SF Box. Thus, the effects on soil functions associated with primary production were considered to be positive (+4) for the four studied alternatives (see Figure 5). The appropriate distribution type (i.e. all scores possible) was selected to represent uncertainties in the assigned score. See also scoring tables in Appendix II.

7.2.5.2 Criteria weighting

The weights for criteria in the environmental and the socio-cultural domains are presented in Figure 13 and Figure 14 respectively.

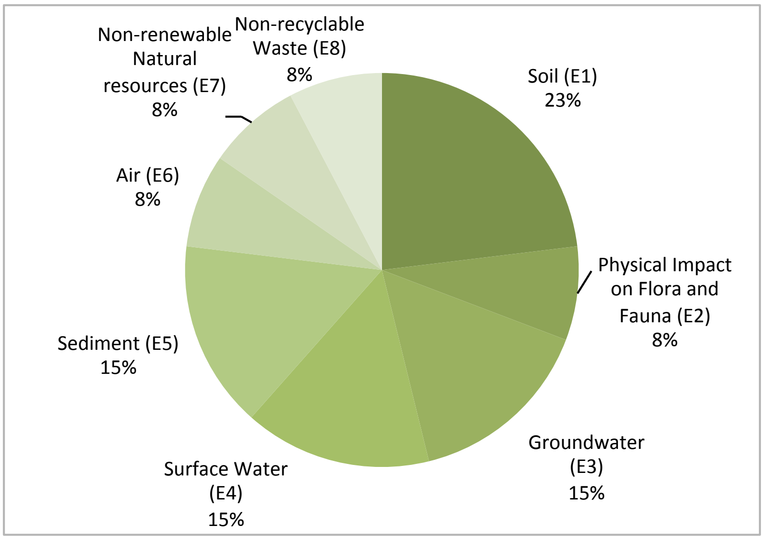


Figure 13: Criteria weighting in the environmental domain of sustainability for the Hexion site.

Because the remedial action should lead to substantial reduction of the risks posed by contaminants in the soil to the environment, the soil criterion was assigned the highest weight. Admittedly, equal weights were assigned to soil sub-criteria (i.e. Ecotoxicological Risks and Soil Functions), because it is essential not only to reduce the risks in the soil to a biota but also to enable the biota to operate in the remediated material. Since groundwater at the site as well as surface water and sediments near the site were vulnerable to the contamination in the soil and might be affected as a result of the remedial action, the associated criteria were given more weights then remaining ones.

In the socio-cultural domain, the Health and Safety criterion was assigned the highest weight, because it is important to reduce the risks posed by contaminants in the soil to human health and ensure workers' health and safety during the remedial action. All the other criteria were weighted almost equally.

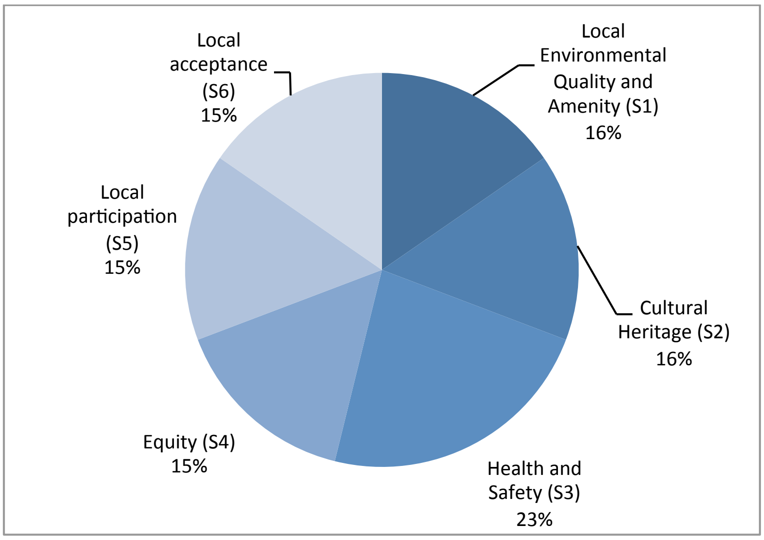


Figure 14: Criteria weighting in the socio-cultural domain of sustainability for the Hexion site.

7.2.5.3 Cost and benefit items

Input values for the CBA of Hexion remediation alternatives see in Appendix II. More detailed description of the costs and benefits for this site can be found in Landström and Östlund (2011) and Söderqvist et al. (2014).

7.2.6 Results of the MCA

Figure 15 shows parts of the SCORE results for Hexion with all domains given equal weight. All alternatives performed well in the social domain. Alternative 1 (associated with extensive excavation and disposal) performed poorly in the environmental domain because of the strong negative secondary effects (i.e. air emissions, waste generation and use of natural resources). This alternative also had a negative social profitability due to high costs for disposal. Alternative 2 (assuming excavation based on site-specific values) performed also poorly in the environmental domain, but better than Alternative 1, due to less negative impacts from air emissions and waste generation. Alternatives with pre-treatment at the site (3 and 4) performed well in all domains. Although for the alternative including both sieving and soil washing (Alternative 4) costs were significantly higher than for Alternative 3 (sieving only), stronger positive effects in the environmental and the social domains made the final sustainability score the highest among the studied alternatives. In total, Alternatives 2, 3 and 4 showed a positive sustainability score. But only, the last two alternatives (3 and 4) had performed well in all three domains and therefore exhibit strong sustainability on the domain level. However, on the criteria and sub-criteria levels all alternatives show compensation between positive and negative effects, i.e. weak sustainability. All alternatives (except Alternative 1) generate as much positive as negative effects, however most negative effects occur off-site, see Figure 16. Alternative 1 generates more negative effects during remediation than other three alternatives (Figure 17).

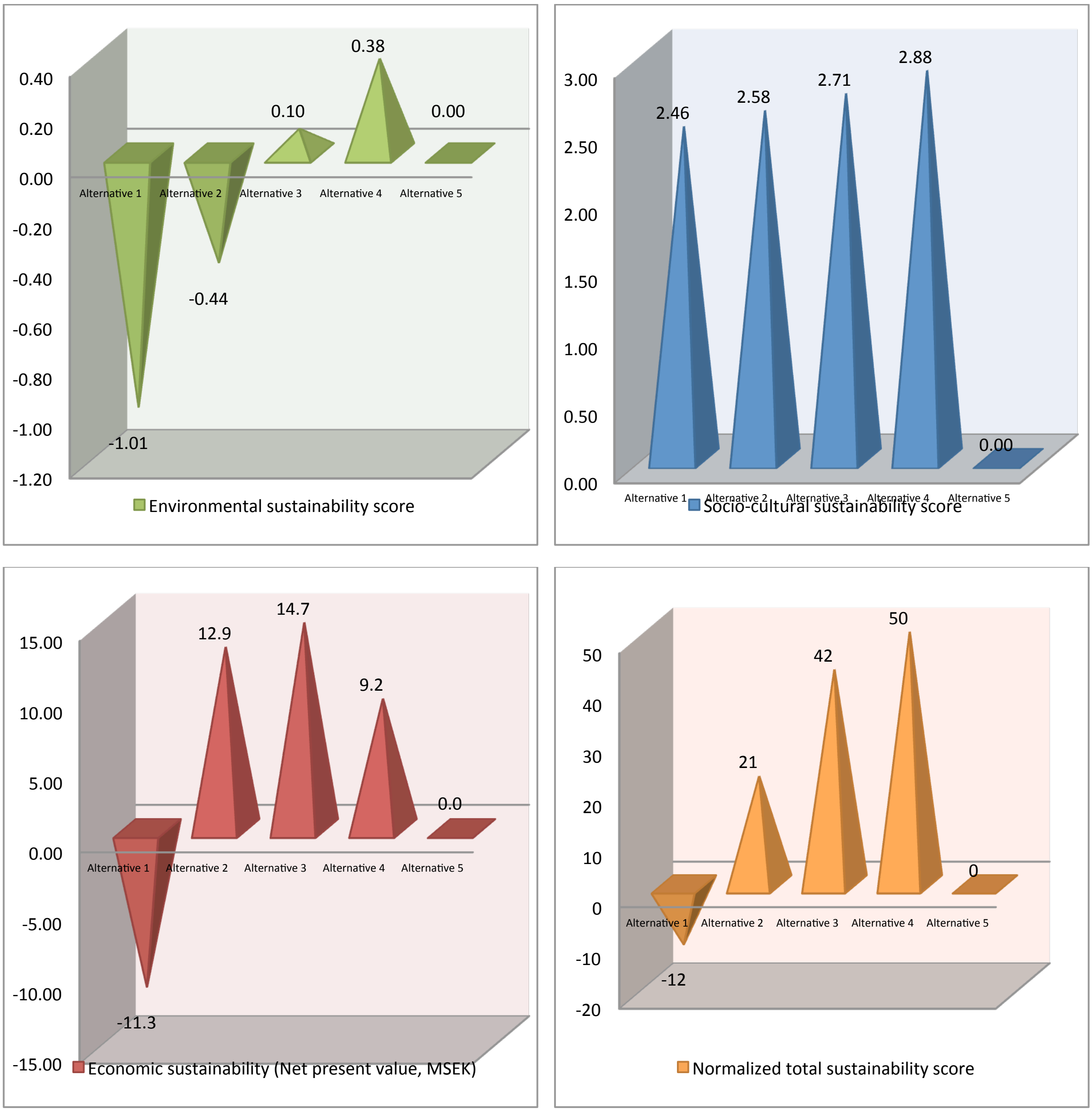
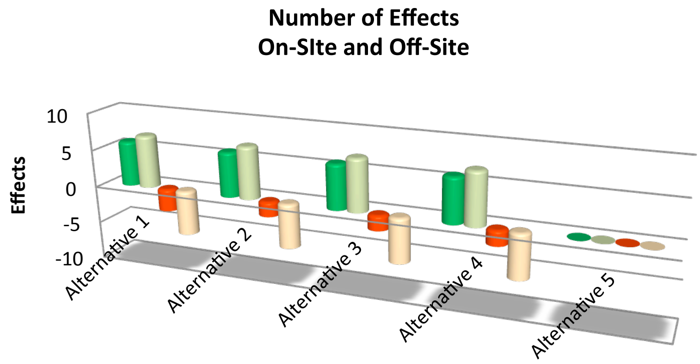
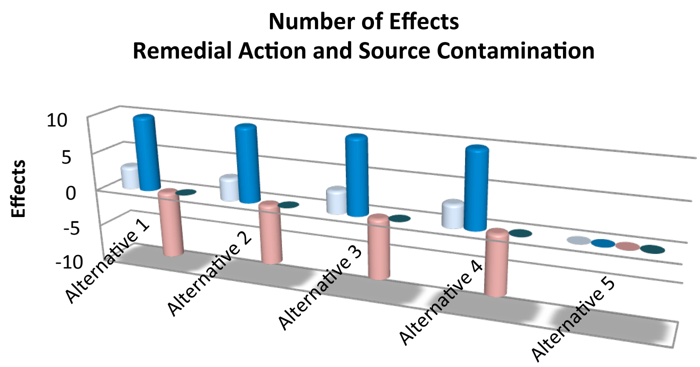


Figure 15: SCORE results for the Hexion site – Environmental sustainability score (upper left), Social sustainability score (upper right), Economic sustainability (lower left), and Normalized total sustainability score (lower right).



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
On-Site Positive	6	6	6	6	0
Off-Site Positive	7	7	7	7	0
On Site Negative	-3	-2	-2	-2	0
Off-Site Negative	-6	-6	-6	-6	0

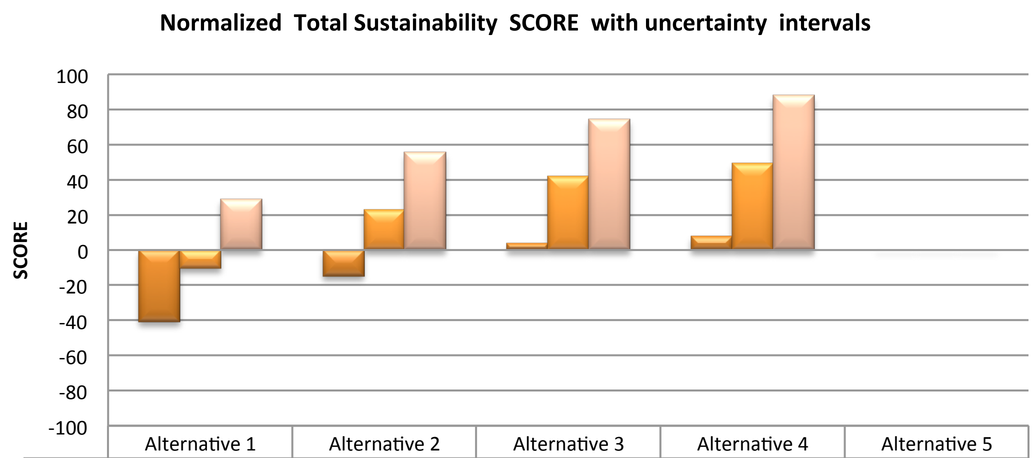
Figure 16: Number of effects - on-site vs. off-site.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Remedial Action Positive	3	3	3	3	0
Source Contamination Positive	10	10	10	10	0
Remedial Action Negative	-9	-8	-8	-8	0
Source Contamination Negative	0	0	0	0	0

Figure 17: Number of effects - remedial action vs. source contamination.

The SCORE assessment of the four remediation alternatives was performed using 10 000 Monte Carlo runs. The results of the uncertainty analysis for the normalized total scores showed that the assessments for all alternatives are associated with substantial uncertainties (Figure 18). Sensitivity analysis for Alternative 4, which had the highest normalized total score, showed that the property value increase and the remediation costs contributed most to the total uncertainty (Figure 19). Alternatives 3 and 4 showed the highest probabilities of being the most sustainable alternative (Figure 20).



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
P05	-41	-15	4	8	0
Mean	-10	23	42	49	0
P95	29	55	74	88	0

Figure 18: Normalized total sustainability scores and uncertainties.

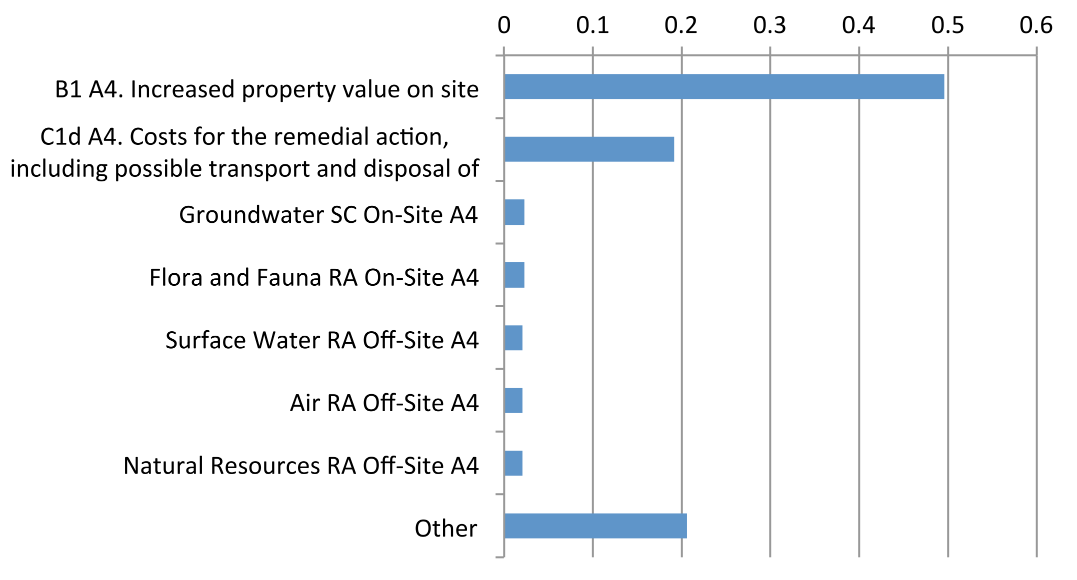


Figure 19: Sensitivity analysis for Alternative 4. Results expressed as the contribution to the variance of the normalized sustainability score for Alternative 4.

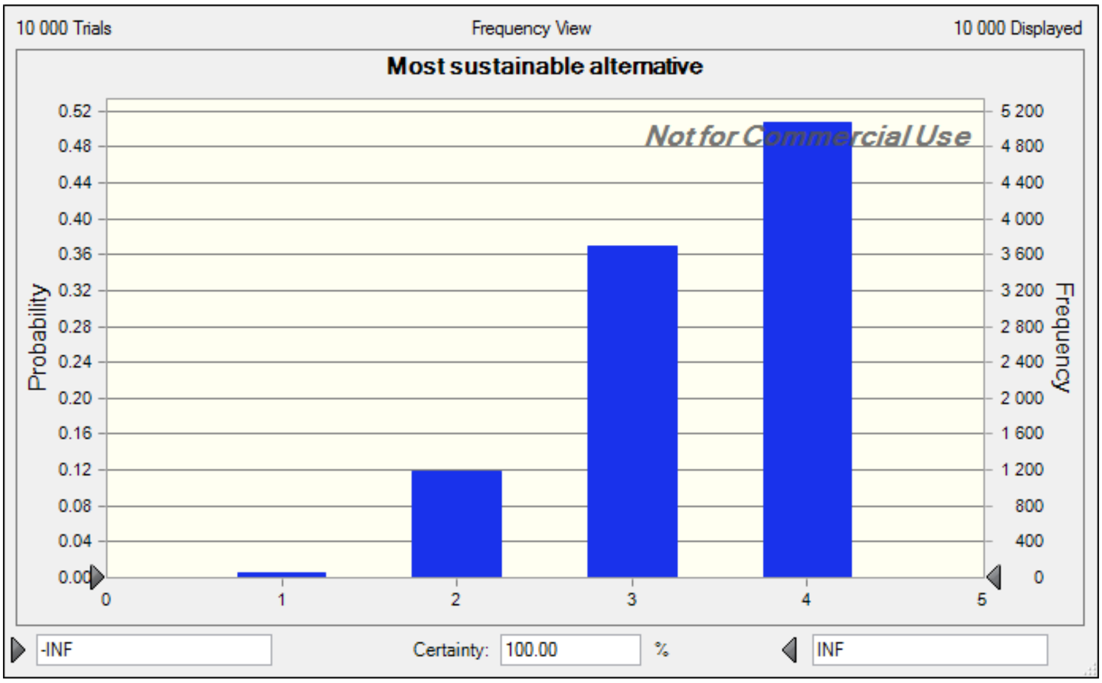


Figure 20: Probabilities of each alternative at the Hexion site being the most sustainable.

7.3 Marieberg saw mill (Sweden)

7.3.1 General site information

The former Marieberg saw mill site is situated in northern Sweden and covers an area of approximately 750 000 m² (1,500 m x 150 m) on the shore of a deep bay (see Figure 21). The saw mill was active during 1862–1970 and used chlorophenol (CP) based wood preservatives from the mid-1940s until closure (Åberg et al., 2010).

In Figure 21 an overview on (former) installations and buildings of the saw mill as well as the recent land-use within the area is given. The site includes areas that were used for sawing, impregnation, indoor storage, indoor drying, and an outdoor timber yard. Inside and just outside the area, there are residential houses, pastures for dairy cows, a farm, a hostel, and a camping area (Åberg et al., 2010).

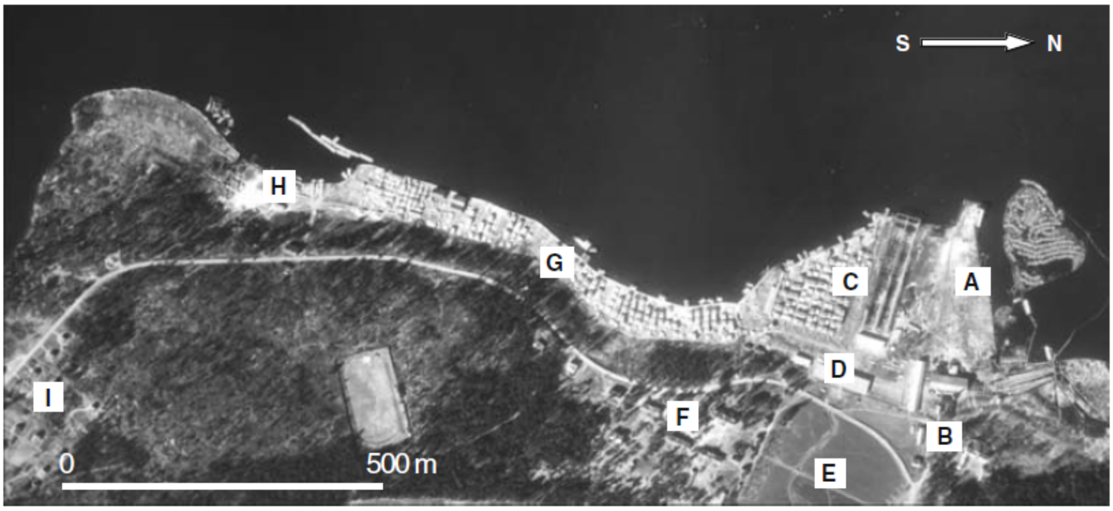


Figure 21: Arial view of the Marieberg site (from Åberg et al., 2010; photo: National Land Survey of Sweden, Gävle, Sweden; ©Lantmäteriet i2012/1099). A–I refer to the following subareas: A former saw mill and impregnation (hot spot), B resident house, C former wood storage, D former drying house, E pastures and farm, F culture area with resident houses and hostel, G former timber yard, H cutter shaving tip and present-day camping, I village.

7.3.2 Geology

Most of the area consists of filling material (0-4 m). Fillings consist mainly of silt, in places mixed with sand, gravel and / or clay, often mixed or layered with bark and sawdust. Wood and brick occurs sporadically in the fillings, as well as concrete and similar waste materials. In most places the waste materials are limited in depth by a rust bed of wood. Underlying the filling material / rust bed follows loose sediment deposits, mostly consisting of sulphide clay with increasing thickness from east to west (towards the river). Glacial till / moraine is found at depths of 10-15 m. Moraine and the rock outcrops are found in the eastern part of the area where the land rises.

The site also has three landfills – a wood chip/sawdust dump and the lower and upper industrial landfills. The lower industrial landfill consists of industrial and municipal waste. A large part of the landfill includes bark and ash but also scrap metal, hardboard, cable and brick. Various filling materials were found in the upper industrial landfill such as sand, silt, clay, bark, wood chips, bricks and elements of scrap.

7.3.3 Contaminants

Since the CP formulations were contaminated with polychlorinated-p-dibenzodioxins and dibenzofurans (PCDD/F), the area is heavily polluted with these substances and is recognized as one of the most PCDD/F polluted sites in Sweden, both in terms of magnitude and spatial extent of the contamination (Åberg et al., 2010).

Table 7 gives ranges of PCDD/F-concentrations in top soil and groundwater from different subareas at the site in accordance with Figure 21.

Table 7: Ranges of measured and interpolated PCDD/F-concentrations in surface soil (0 m to 0.25 m) and groundwater from different subareas within the former sawmill site (from Åberg et al., 2010).

Area	Site description	Surface soil range (median), [ng WHO-TEQ kg^{-1} dw]	Groundwater range (median), [ng WHO-TEQ L^{-1}]
A	Hot spot	0.5-110,000 (130) [c]	<LOD-0.8 (0.1) [d]
B	Resident house	10-1,000 [a]	–
C	Former timber storage	10-4,000 [a]	0.003-0.7 (0.4) [d]
E	Pasture	25 [b]	–
F	Cultural area	17 [b]	–
G	Former timber yard	<LOD-4,900 (78) [c]	–
H	Camping cutter shaving tip	2.2-810 (68) [c]	0.3/1.1 [d]

LOD limit of detection
[a] Interpolated concentration range in surface layers, Kemakta Konsult AB (2007)
[b] Pooled surface soil sample, SWECO VIAK AB (2008)
[c] Kemakta Konsult AB (2007)
[d] SWECO VIAK AB (2005)

In a previous risk assessment study of the site (Åberg et al. 2010), human exposure to PCDD/F through a broad spectrum of exposure pathways was assessed. Soil, air, groundwater, raspberries, carrots, potatoes, grass, milk, and eggs were analyzed for the content of PCDD/F, and the results showed that most exposure media were clearly elevated as compared to national reference samples. The calculated exposure levels showed that a number of site-specific exposure routes can be of importance for people residing in this area. Thus, despite low mobility of PCDD/F, these contaminants can be transferred from the polluted soil to other environmental media and into humans.

7.3.4 Remediation options

Following three remedial options have been selected for this case study ranging from an area-wide excavation to use restrictions:

1. Area-wide excavation
2. Hot spot excavation and surface cover
3. Conservation as "Environmental Risk Area" (use restrictions).

Brief descriptions of the options as well as rough cost estimations are given in Table 8. For estimated impacts on the defined criteria within the SCORE tool see sub-chapters in Appendix II.

Table 8: Selected remediation options for case study “Marieberg saw mill”.

#	Remediation Option	Description
0	Status quo	No remedial actions
1	Area-wide excavation	- Excavation of 40 600 m³ contaminated soil - Landfilling of excavated soil (incl. transport to landfill) - Transport of clean soil to the site - Backfilling of clean material - Re-cultivation of site - Estimated total costs: EUR 13 500 000 (incl. EUR 300 000 € of the total is for demolishing a contaminated building)
2	Hot spot excavation, surface cover with clean soil and measures to reduce groundwater transport to recipient	- Excavation of hot spots - Transport of clean soil to the site - Clean soil cover (28 250 m³) - Ditching/draining and ground water filters - Re-cultivation of site - Further groundwater monitoring - Estimated total costs: EUR 2 500 000 (incl. engineering and groundwater monitoring)
3	Conservation as “Environmental Risk Area” (use restrictions) combined with relocation and compensation measures	- Fencing of area - No further remedial actions - Relocation and compensation to camp ground - Estimated total costs: EUR 1 050 000 (incl. monitoring and monetary compensation to camp ground).

7.3.5 Inputs to the MCA

7.3.5.1 Criteria selection and scoring

Some irrelevant criteria were sorted out, e.g. groundwater off site, because the downstream flow is in the form of surface water. In the socio-cultural domain, the local participation and local acceptance criteria were sorted out, because these criteria were not yet included into the MCA when interviews with stakeholders were performed. Further motivations for sorting out the criteria are presented in Appendix II. Criteria scorings, motivations for scores, distribution types representing uncertainties in the assigned scores and levels of uncertainties can also be find in Appendix II.

7.3.5.1.1 Soil functions – output of SF Box

The contaminated soil at Marieberg was randomly sampled to a depth of 0.5m covering the entire saw mill area. Further, the soil samples were analyzed on SQIs from the MDS (Table 1). The SF Box tool was used to compute the soil class in the reference alternative (Figure 22). The contaminated soil at the site was of class 3 corresponding to medium soil performance. Uncertainty analysis of the assessment results can be found in Volchko et al. (2014a, d). The certainty of obtaining class 3 was higher than 80%. Admittedly, contaminant concentration and bioavailability of contaminants were studied for the same soil samples (for details see Josefsson et al., 2014). The results of bioavailability tests were considered to score the Ecotoxicological Risks sub-criterion in the environmental domain of SCORE (see Appendix II). No correlations were observed between bioavailability test results and soil quality indices competed with help of SF Box.

The computed soil class was further used as input to the MCA for scoring of the soil function sub-criterion. Since there was little known about the quality of the refilling and capping material, the assigned scores to this sub-criterion were associated with a high level of uncertainty. An optimistic assumption was made that the top layer of the soil will be of medium/good quality fulfilling not only requirements with regard to contaminant concentrations but also other important quality aspects, e.g. suggested for consideration in SF Box. The appropriate distribution type (i.e. all scores possible) was selected to represent uncertainties in the assigned score. A score of +2 was assigned to Alternatives 1 and 2, and a score of 0 (no effects) was assigned for Alternatives 3 which assumed no remedial action. See also scoring tables in Appendix II.

												Bulk density 1,6				Method St. methods		Method AL P		Method Arithmetic mean	
Label	No	Clay [%]	Silt [%]	Sand [%]	Gravel [%]	Code	Name	CM [%]	CM_Score	OM [%]	OM_Score	AW [%]	AW_Score	pH	pH_Score	NH4-N [mg/kg]	N_Score	P [mg/kg]	P_Score	Index	Performance
PG1-7	1	0	2	81	17	LS	Loamy sand	17	0,78	0,8	0,07	21	0,87	8	0,04	180	0,01	44	0,76	0,42	Poor
PG1-14	2	0	2	89	9	S	Sand	9	0,96	0,7	0,07	21	0,87	7,1	0,99	180	0,01	28	0,38	0,55	Medium
PG2-2	3	0	1	93	6	S	Sand	6	0,99	1,6	0,16	22	0,90	6,5	1,00	180	0,01	34	0,53	0,60	Medium
PG2-5	4	0	1	79	20	LS	Loamy sand	20	0,70	7	0,99	24	0,93	8,2	0,01	230	0,06	20	0,21	0,48	Poor
PG2-9	5	0	2	79	19	LS	Loamy sand	19	0,73	3,2	0,52	22	0,90	6,3	0,99	220	0,04	29	0,40	0,60	Medium
PR3-1	6	0	2	88	10	S	Sand	10	0,93	3,7	0,66	22	0,90	6,4	1,00	170	0,01	43	0,74	0,71	Good
PR3-2	7	11	14	73	2	SL	Sandy loam	2	1,00	5,8	0,95	25	0,95	6,5	1,00	210	0,03	38	0,63	0,76	Good
PR3-3	8	0	3	82	15	LS	Loamy sand	15	0,83	0,6	0,06	21	0,87	6,7	1,00	170	0,01	30	0,42	0,53	Poor
PR3-4	9	0	1	84	15	LS	Loamy sand	15	0,83	1,5	0,15	22	0,90	6,1	0,89	170	0,01	24	0,28	0,51	Poor
PR3-5	10	0	2	80	18	LS	Loamy sand	18	0,76	0,8	0,07	21	0,87	6,4	1,00	170	0,01	32	0,48	0,53	Poor
PR3-6	11	11	16	70	3	SL	Sandy loam	3	1,00	6	0,96	25	0,95	5,6	0,14	210	0,03	36	0,58	0,61	Medium
PB4-2	12	0	2	77	21	LS	Loamy sand	21	0,68	5,4	0,92	24	0,93	6,5	1,00	210	0,03	25	0,31	0,65	Medium
PB4-3	13	0	2	82	16	LS	Loamy sand	16	0,81	1,5	0,15	22	0,90	6,3	0,99	180	0,01	21	0,23	0,51	Poor
PB4-5	14	0	3	80	17	LS	Loamy sand	17	0,78	3,4	0,58	22	0,90	6,2	0,95	140	0,00	32	0,48	0,62	Medium
PB4-6	15	0	5	78	16	LS	Loamy sand	16	0,80	0,9	0,08	21	0,87	5,8	0,41	180	0,01	59	0,94	0,52	Poor
PB4-7	16	3	10	83	4	LS	Loamy sand	4	1,00	4,4	0,80	25	0,95	5,9	0,60	230	0,06	37	0,60	0,67	Medium
PB4-10	17	0	1	80	19	LS	Loamy sand	19	0,73	1,2	0,11	22	0,90	6	0,77	160	0,01	27	0,35	0,48	Poor
PB4-11	18	0	5	91	4	S	Sand	4	1,00	1	0,09	21	0,87	7,5	0,60	170	0,01	39	0,65	0,54	Poor
Mean		1,4	4,1	81,6	12,8	LS	Loamy sand	12,8	0,88	2,8	0,40	22,4	0,91	6,6	1,00	186,7	0,02	33,2	0,51	0,62	Medium
																				Soil Class	**3**

Figure 22: Results of soil function evaluation for the Marieberg site. CM: content of coarse material. OM: organic matter content. AW: available water capacity. NH4-N: potentially mineralizable nitrogen. Total P: total phosphorus. CM_Score: sub-score for content of coarse material. OM_Score: sub-score for organic matter content. AW_Score: sub-score for available water capacity. pH_Score: sub-score for pH. N_Score: sub-score for potentially mineralizable nitrogen. P_Score: sub-score for available phosphorus. Green-yellow-light red color identification codes correspond to good-medium-poor soil qualities.

7.3.5.2 Criteria weighting

In the environmental domain higher weights were given to the criteria representing vulnerable environmental media (soil, groundwater, surface water and sediment) which may be improved in result of contamination levels' reduction (Figure 23). The secondary effects associated with remediation (air emission, use of natural resources and waste generation) were weighted as somewhat important. In the socio-cultural domain the selected criteria were weighted as equally important (Figure 24).

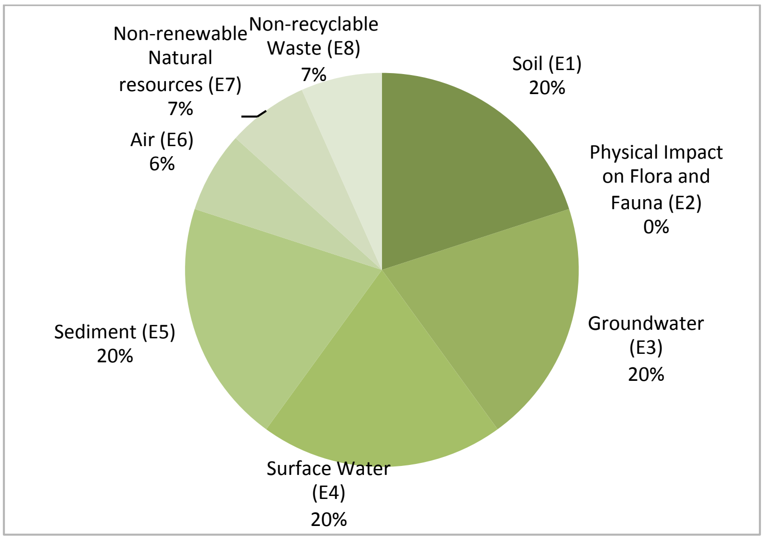


Figure 23: Criteria weighting in the environmental domain of sustainability for the Marieberg site.

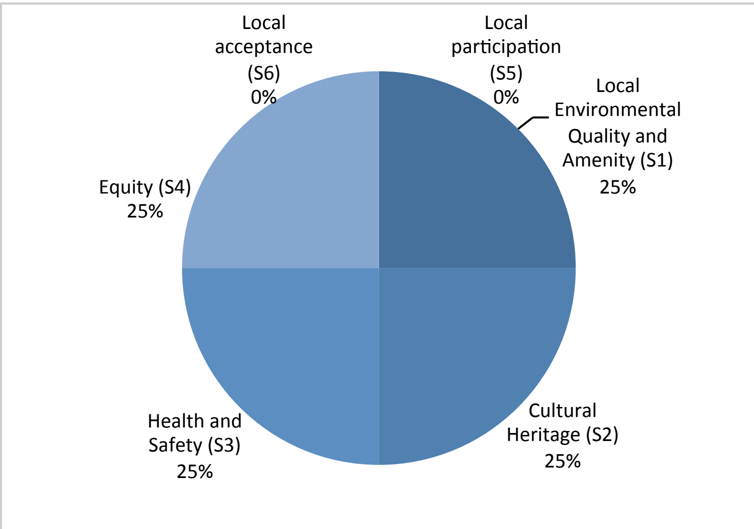


Figure 24: Criteria weighting in the socio-cultural domain of sustainability for the Mariberg site.

7.3.5.3 Cost and benefit items

Input values for the CBA for the Marieberg site see in Appendix II.

7.3.6 Results of the MCA

Figure 25 shows parts of the SCORE results for Marieberg with all domains given equal weight.

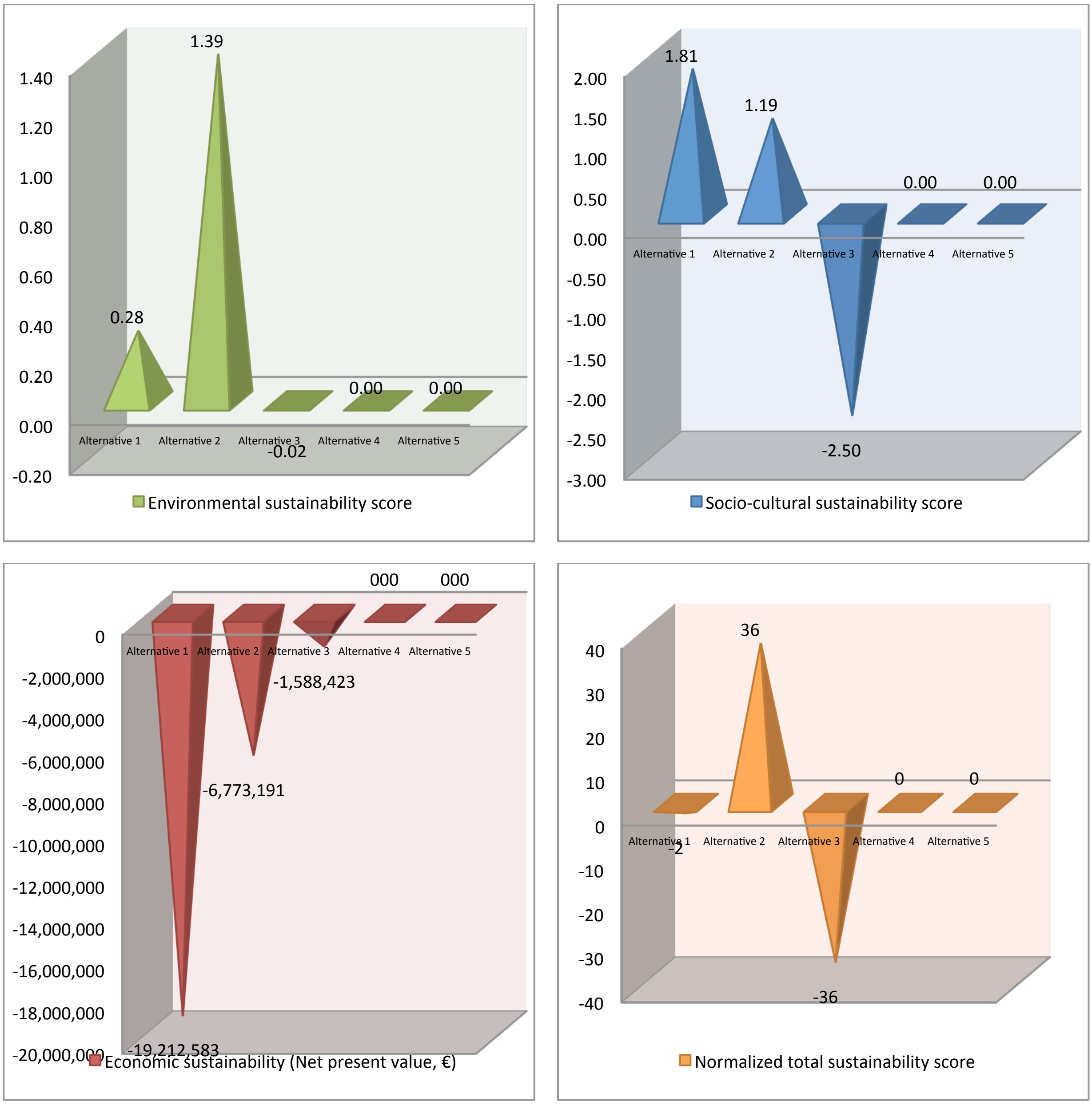
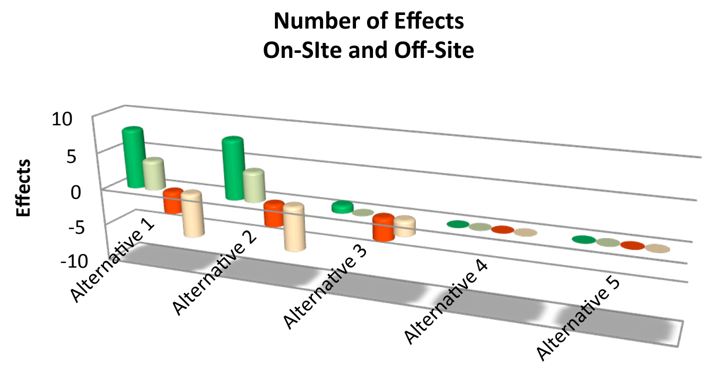


Figure 25: SCORE results for the Marieberg site – Environmental sustainability score (upper left), Social sustainability score (upper right), Economic sustainability (lower left), and Normalized total sustainability score (lower right).

Alternative 2 (assuming surface cover) performed well in the environmental domain due to the much stronger positive effects on soil, surface water and groundwater than negative effects associated with transportation of the clean material to the site. Alternative 1 (associated with extensive excavation and disposal) had a slightly positive environmental sustainability score because very strong positive effects on the affected environmental media in result of remediation were compensated by negative effects caused by the remedial action itself (e.g. possible release of contaminants to groundwater, extensive air emissions, waste generation and use of natural resources).

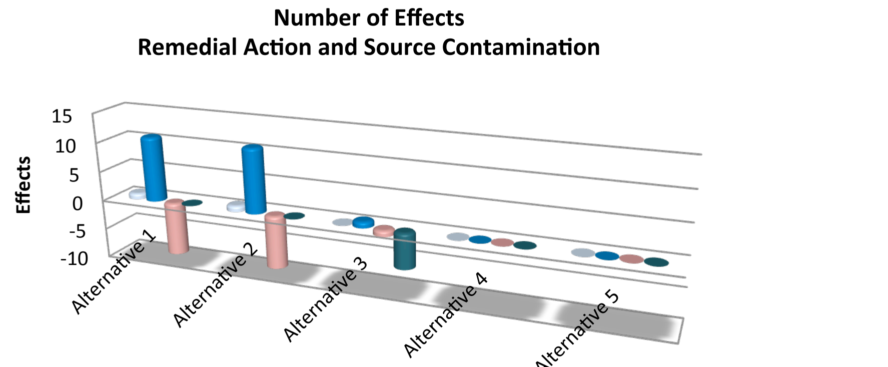
In contrast, Alternative 3 assuming area fencing and no remedial action had no effect on the environment relative to the reference alternative. In the socio-cultural domain, Alternatives 1 and 2 generated positive scores in contrast to Alternative 3 that performed poorly due to strong negative effects on local environmental quality and amenity, and equity (i.e. campers need to be relocated permanently, the environmental problem is left to future generations). Preventing the access of individuals to the site and thus exposure, the latter alternative generated only one positive effect due to improved health and safety on site (Figure 26 and Figure 27).

All alternatives had a negative social profitability due to high costs for waste disposal in Alternative 1, surface capping in Alternative 2 and compensation and relocation of camping in Alternative 3. In total, Alternative 1 assuming excavation generated a slightly negative total sustainability score, because the positive effects in the environmental and socio-cultural domains were compensated by the negative effects in the economic domain (Figure 25). Alternative 2 assuming surface cover showed a positive sustainability score in contrast to Alternative 3 implying area fencing and no remedial activities. The latter alternative performed the worst generating the least number of positive effects (Figure 26) and the strongest negative effects associated with source contamination (Figure 27). Being the best, Alternative 2, however, exhibits weak sustainability on the domain, criteria and sub-criteria levels, where negative effects are compensated by positive ones.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
On-Site Positive	8	8	1	0	0
Off-Site Positive	4	4	0	0	0
On Site Negative	-3	-3	-3	0	0
Off-Site Negative	-6	-6	-2	0	0

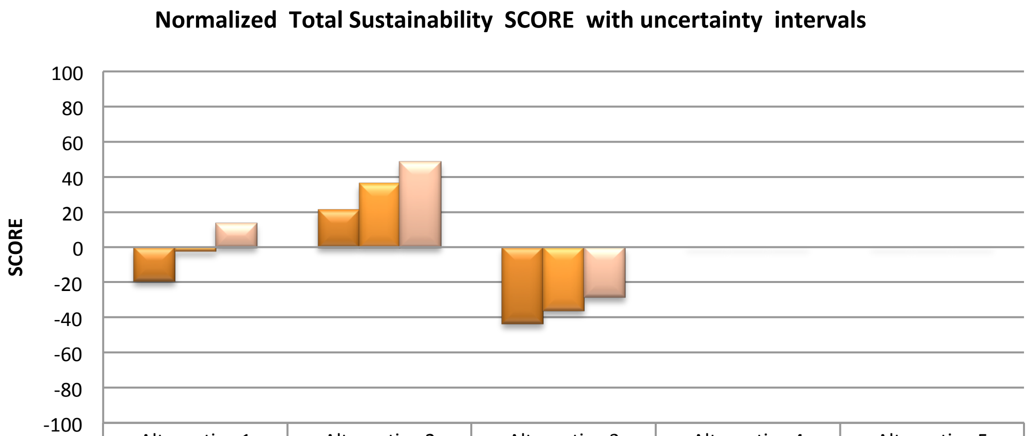
Figure 26: Number of effects - on-site vs. off-site.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Remedial Action Positive	1	1	0	0	0
Source Contamination Positive	11	11	1	0	0
Remedial Action Negative	-9	-9	-1	0	0
Source Contamination Negative	0	0	-6	0	0

Figure 27: Number of effects - remedial action vs. source contamination.

The SCORE assessment of the three remediation alternatives was performed using 10 000 Monte Carlo runs. The uncertainties of the normalized total scores shown in Figure 28 indicate that the assessments for all alternatives are associated with substantial uncertainties.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
P05	-19	21	-43	0	0
Mean	-2	36	-36	0	0
P95	14	49	-29	0	0

Figure 28: Normalized total sustainability scores and uncertainties.

Sensitivity analysis for Alternative 2 (which had the highest normalized total score) showed that the cultural heritage and the costs associated with project risks and the remedial action contributed most to the total uncertainty (Figure 29). This alternative showed the highest probability of being the most sustainable (Figure 30).

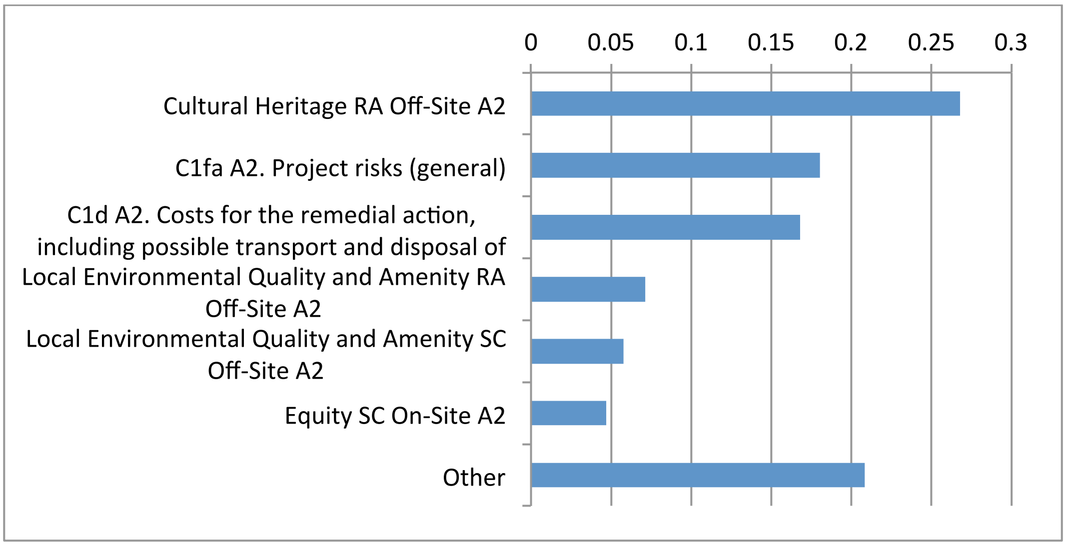


Figure 29: Sensitivity analysis for Alternative 2. Results expressed as the contribution to the variance of the normalized sustainability score for Alternative 2.

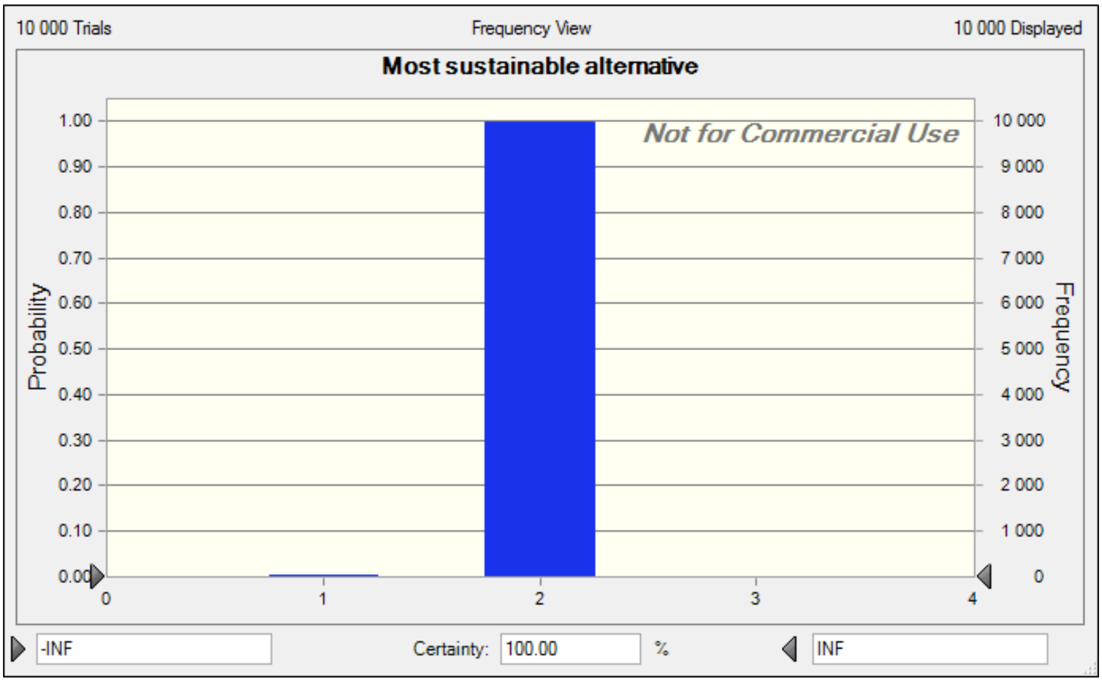


Figure 30: Probabilities of each alternative at the Marieberg site being the most sustainable.

7.4 Shooting Range (Linz, Austria)

7.4.1 General site information

The shooting range is located on the northeastern outskirts of Linz (Figure 31), a city with about 200 000 inhabitants. It is a clay-pigeon shooting range of about 8 hectares in size that is situated on a hill in a military training area. The terrain, a meadow, steeply drops to the north and is bordered by a birch forest to the east and a mixed forest to the north and west (Environment Agency Austria, 2007).

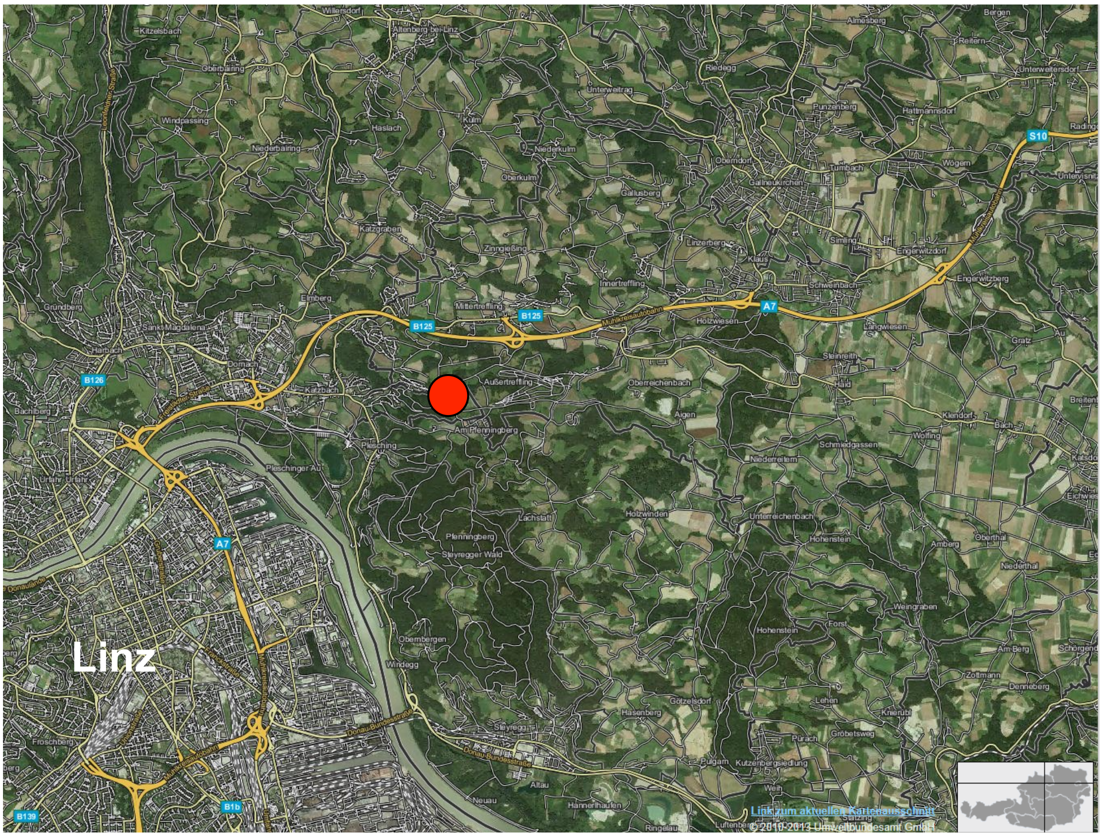


Figure 31: Location of the site (Environment Agency Austria, 2007).

The shooting range exists since 1962. It is a skeet range that is used intensively with about 100 000 shots per year. The main shooting direction is to the north, however according to the eight directions of throw the direction of shots can vary by 150 degrees. Lead shot is used as ammunition. Since the existence of the shooting range about 4 million shots have been fired. Clay-pigeons were used over several decades. Apart from the main constituent rock meal (up to 70%) as binding material they contained up to 30% anthracite coal tar pitch or petroleum tar pitch (Environment Agency Austria, 2007).

In addition to its use as a clay-pigeon shooting range the site, the existing meadow and the bordering forest are presently used as a military training area.

At the edge of the forest about 100 m northwest of the firing point rises a temporarily water bearing chute that is discharged into a small stream (Esternbach). Located in the area of this ditch is a single well. The shooting range is located at the eastern edge of a groundwater protection zone. The nearest inhabited buildings are located in more than 500 m distance.

7.4.2 Geology

The site is located at the southern end of the Bohemian Massif. Crystalline rocks (gneiss, granite) are present at shallow depth and pose a relatively low yielding (fissure) aquifer. There is no continuous groundwater horizon. The groundwater flow direction can vary locally and depends on the dominant fissures in lower rock formations as well as the relief and thickness of the weathered zone close to the surface. Pseudogley (stagnosol) is the predominant soil in the area. To the west brown earth is to be found and to the east gleyic brown earth. Generally there are lime free moderate to very acid soils (partly with a pH of < 4.6) with a high content of organic matter. Normally the pseudogley shows a horizon of low (water) permeability in about 0.5 m depth. Due to the military activities the natural soil structure was partly changed considerably. In many areas the topsoil was relocated and mixed due to the movement of tanks. As in many areas defilades of up to 1.5 m depth were dug and backfilled, the natural horizon of low permeability of the pseudogley is not continuous (Environment Agency Austria, 2007).

Figure 32 gives an overview of the soil types and the land use of the site.

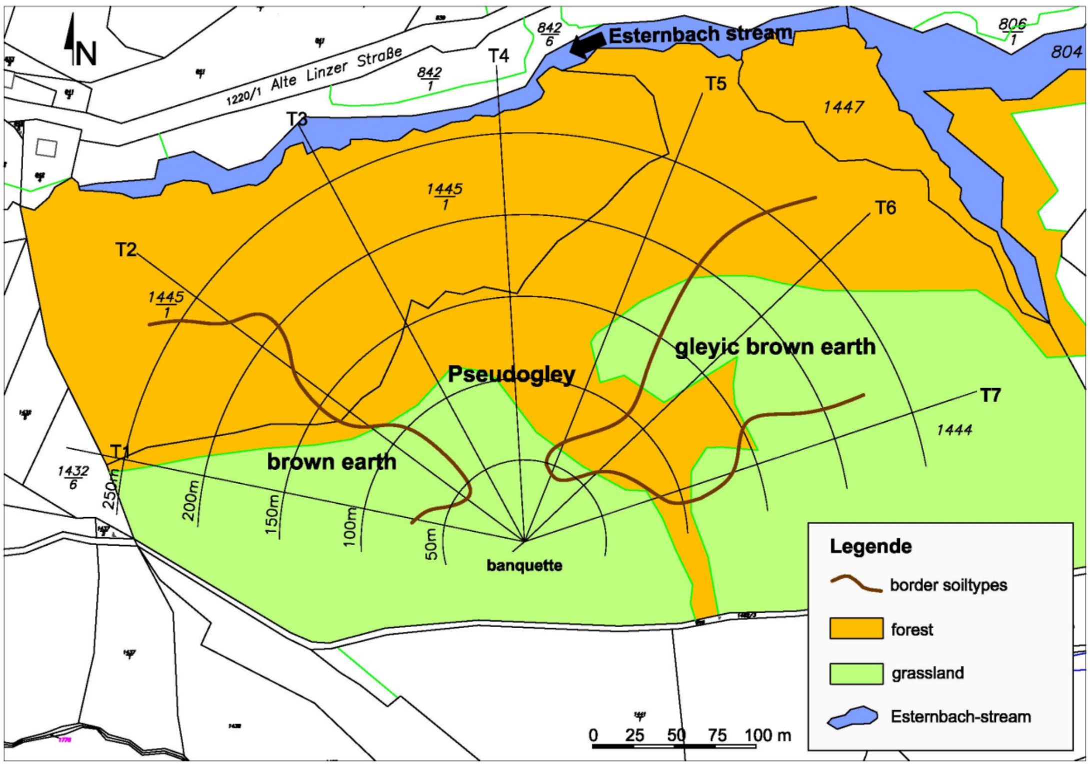


Figure 32: Distribution of soil types and types of land use (Environment Agency Austria, 2007).

7.4.3 Contaminants

Lead, arsenic, antimony and polycyclic aromatic hydrocarbons (PAH) from clay pigeons turned out as the main contaminants in top soil samples. Figure 33 shows the spatial distribution pattern of lead, whereas Figure 34 shows a characteristic depth-profile of metal contents indicating a rapid decrease of concentrations versus depth.

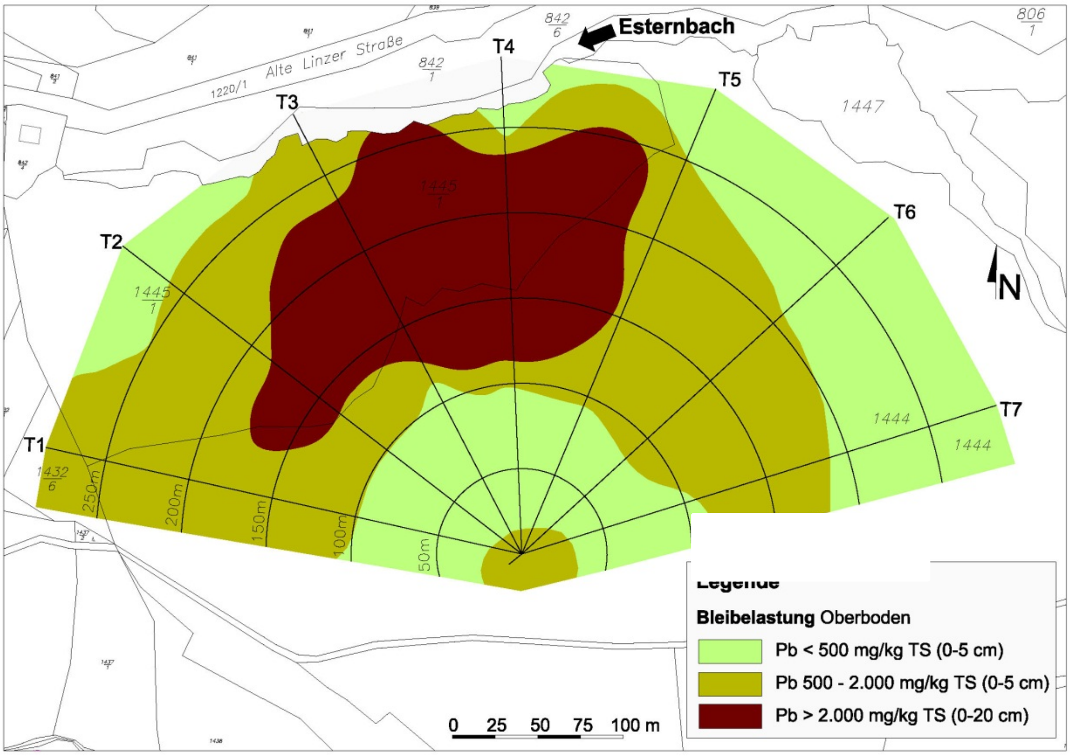


Figure 33: Distribution of lead concentrations in topsoil (Environment Agency Austria, 2007).

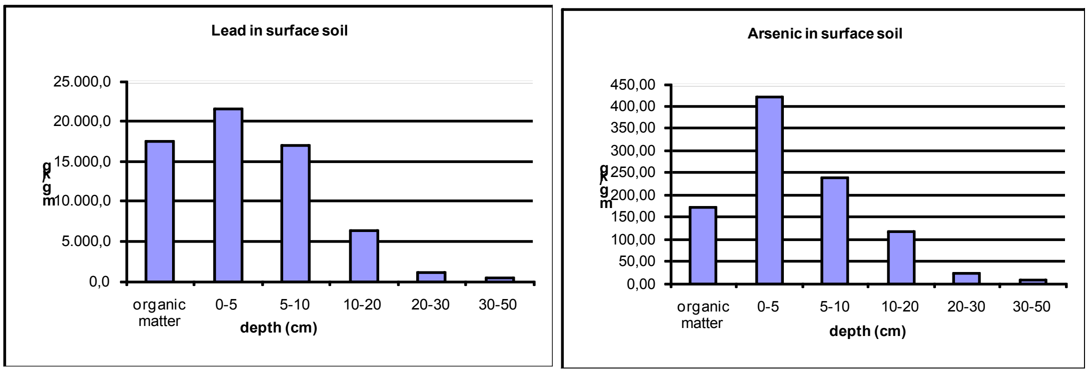


Figure 34: Depth-related distribution of metal concentrations in soil (main shooting direction, distance about 165 m from firing point) (Environment Agency Austria, 2007).

The highest PAH concentration of topsoil (0 cm to 5 cm) in the area of the shooting range was measured at 2,200 mg/kg.

Leachate sampled with suction cups was predominantly acidic and indicated a distinct lead mobility, particularly in top soil layers.

Groundwater and surface water analyses showed no significant influence (lead max. 7 µg/l, antimony < 3µg/l) whereas stream sediment samples alongside the Esternbach and some erosion ditches showed markedly elevated lead (up to 390 mg/kg) and antimony (up to 20 mg/kg) concentrations.

Ammonium-nitrate-extracts from the highly contaminated area were significantly elevated. Concentrations of up to 640 mg/kg lead indicated remarkable plant availability. However, the results from plant samples (grass) taken from the site did not show significant difference to those of reference samples from outside the site.

7.4.4 Remediation options

Following three remedial options have been selected for this case study ranging from excavation of hot spots to rather gentle remediation options applying chemicals and/or plants:

1. Excavation and backfilling
2. Immobilization by chemical means
3. Immobilization by phytostabilization.

Brief descriptions of the options as well as rough cost estimations are given in Table 9. For estimated impacts on the defined criteria within the SCORE tool see Appendix II.

Table 9: Selected Remediation options for case study "Shooting range".

#	Remediation Option	Description
0	Status quo	No remedial actions
1	Excavation	- Excavation of 7 500 m³ heavily contaminated soil (2,5 hectares x 0,3 m) - Landfilling of excavated soil (incl. transport to landfill) - Transport of clean soil to the site - Backfilling of clean material - Re-cultivation of site - Estimated total costs: EUR 2 000 000 (incl. EUR 200 000 for engineering)
2	Immobilization by chemical means	- Excavation of 7 500 m³ heavily contaminated soil (2,5 hectares x 0,3 m) - On-site mixing with immobilization agent (e.g. lime) - Backfilling of homogenized material - Further groundwater monitoring - Estimated total costs: EUR 800 000 (incl. EUR 80 000 for engineering and EUR 60 000 for further monitoring)
3	Immobilization by phytostabilization	- Mixed-in-place application of immobilization agent (e.g. iron-oxide) in heavily contaminated areas (2,5 hectares) - Cultivation of area with metal resistant plants (e.g. *Lolium perenne*) - Further groundwater monitoring - Estimated total costs: EUR 500 000 (incl. EUR 50 000 for engineering and EUR 80 000 for further monitoring)

7.4.5 Inputs to the MCA

7.4.5.1 Criteria selection and scoring

Some irrelevant criteria were sorted out in the environmental (i.e. sediments and physical impact on flora and fauna) and the socio-cultural domains (i.e. cultural heritage). All other criteria defined in Table 3 were scored using investigations, expert judgements, and available information in the technical reports.

7.4.5.2 Criteria weighting

In the environmental domain, higher weights were assigned to soil and groundwater, because these environmental media were considered the most vulnerable to the risks with regard to source contamination (Figure 35). In the socio-cultural domain, local environmental quality and amenity, health and safety, and local participation were assigned slightly higher weights in comparison to other two criteria.

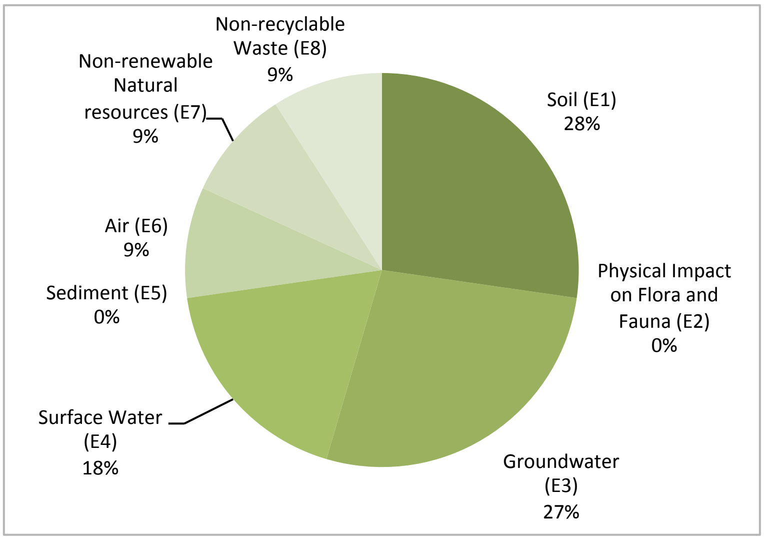


Figure 35: Criteria weighting in the environmental domain of sustainability for the Shooting Range site.

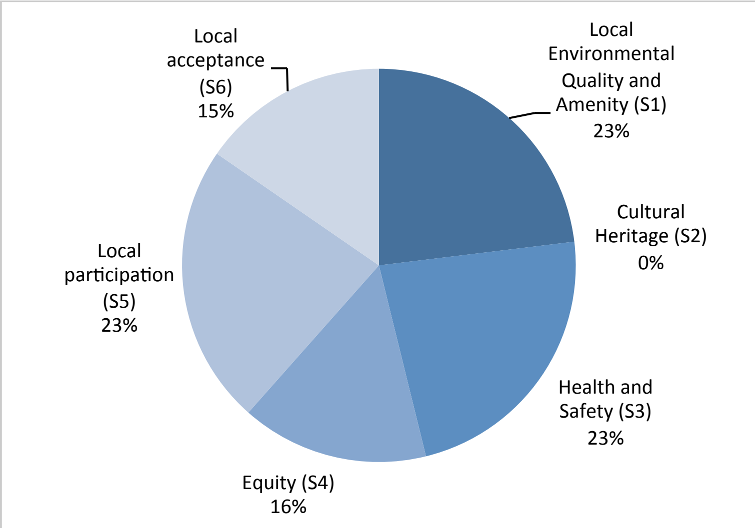


Figure 36: Criteria weighting in the socio-cultural domain of sustainability for the Shooting Range site.

7.4.5.3 Cost and benefit items

Input values for the CBA for the Shooting Range site see in Appendix II. Due to the remote location of the site, no increase in property value was assumed. There was no data available on external costs for this case study. Thus, only private costs, i.e. costs for remediation including engineering and monitoring were considered in the assessment. It has to be noted that the cost estimations reported in Appendix II are very rough and should not be used for any other than demonstration purposes.

7.4.6 Results of the MCA

Figure 37 shows parts of the SCORE results for Shooting Range with all domains given equal weight. Only Alternative 3 (assuming phytostabilization) performed well in the environmental domain, because it was associated with positive effects on the affected environmental media and the least negative effects due to remedial action in comparison to other two alternatives. Alternative 1 (excavation and disposal) generated slightly negative environmental sustainability score because strong positive effects on the soil and groundwater were compensated by negative effects associated with substantial air emissions due to transportation, use of natural resources and waste generation. The same compensation was observed for Alternative 2 (immobilization by chemical means). All alternatives poorly performed in the socio-cultural domain of SCORE. For Alternatives 1 and 2, the positive effects on local environmental quality and health with regard to change in source contamination were compensated with the stronger negative effects due to remedial action. Alternative 3 had the least number of negative effects on and off site generated by remedial action (Figure 38 and Figure 39).

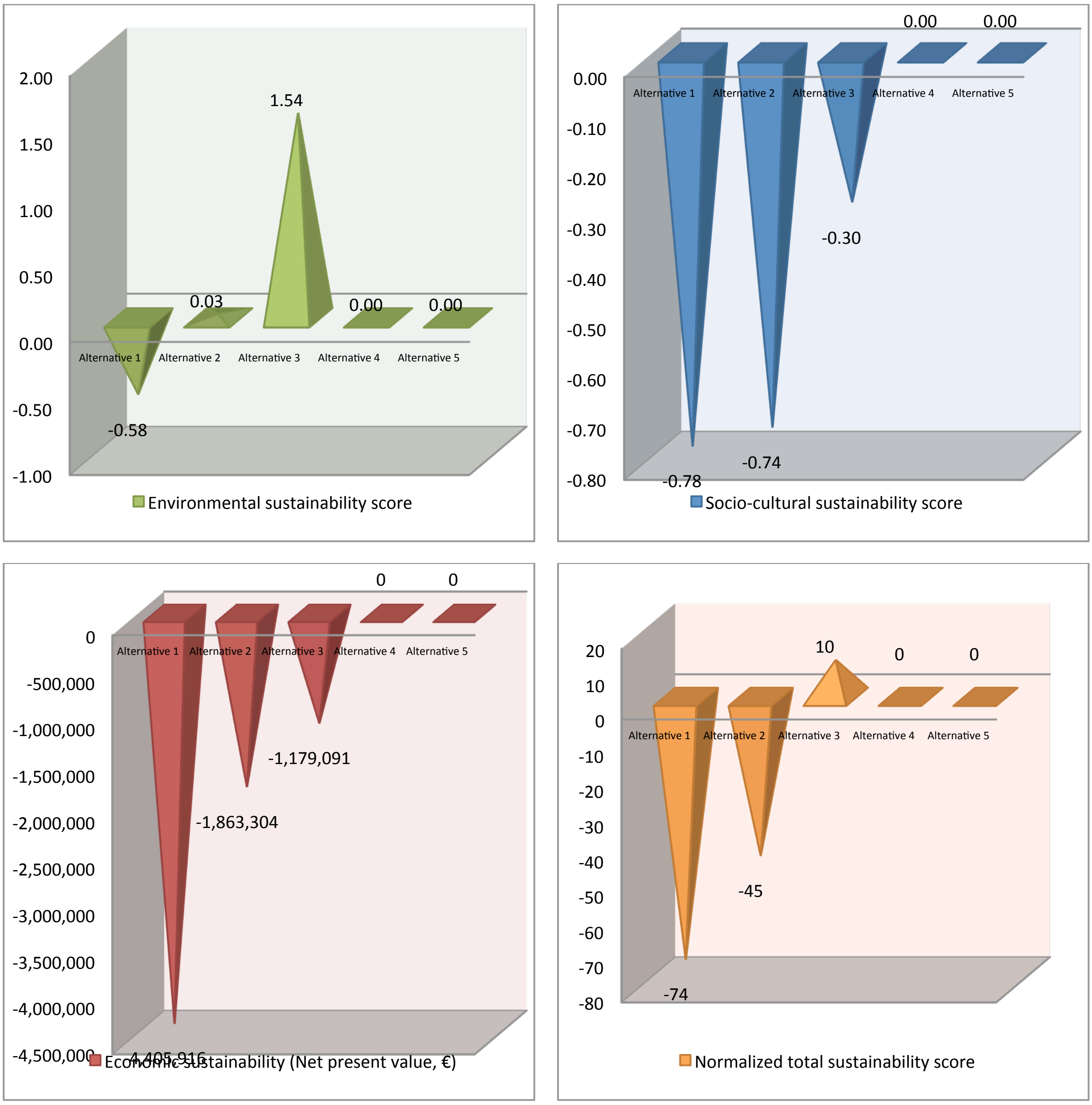
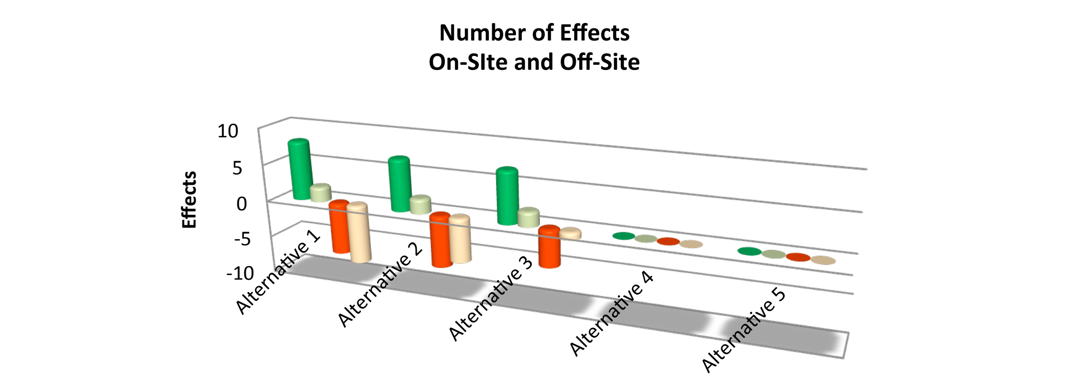


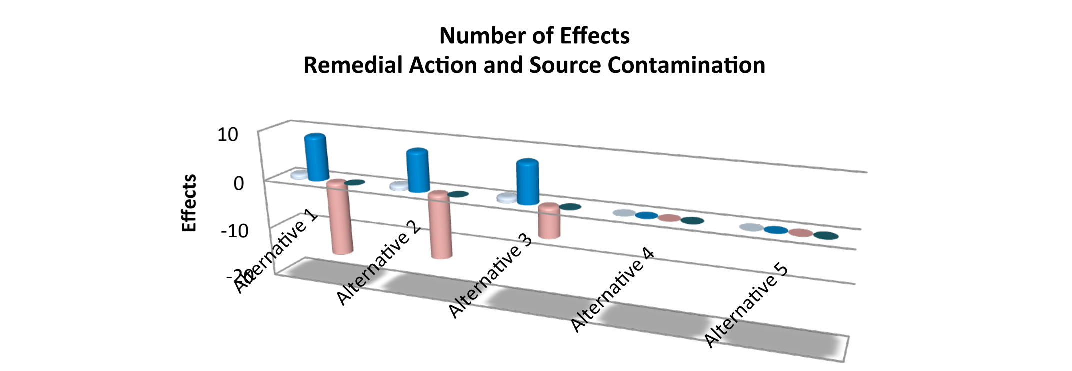
Figure 37: SCORE results for the Shooting Range site – Environmental sustainability score (upper left), Social sustainability score (upper right), Economic sustainability (lower left), and Normalized total sustainability score (lower right).

All alternatives had a negative social profitability due to high costs for remedial action in Alternative 1 and 2, and design and implementation in Alternative 3. In total, alternatives assuming extensive excavation (Alternative 1) and immobilization by chemical means (Alternative 2) generated a negative sustainability score (Figure 37). Alternative 3 assuming phytostabilization showed a positive sustainability score. However, on the domain, criteria and sub-criteria levels this alternative showed compensation between positive and negative effects, i.e. weak sustainability.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
On-Site Positive	8	7	7	0	0
Off-Site Positive	2	2	2	0	0
On Site Negative	-7	-7	-5	0	0
Off-Site Negative	-8	-6	-1	0	0

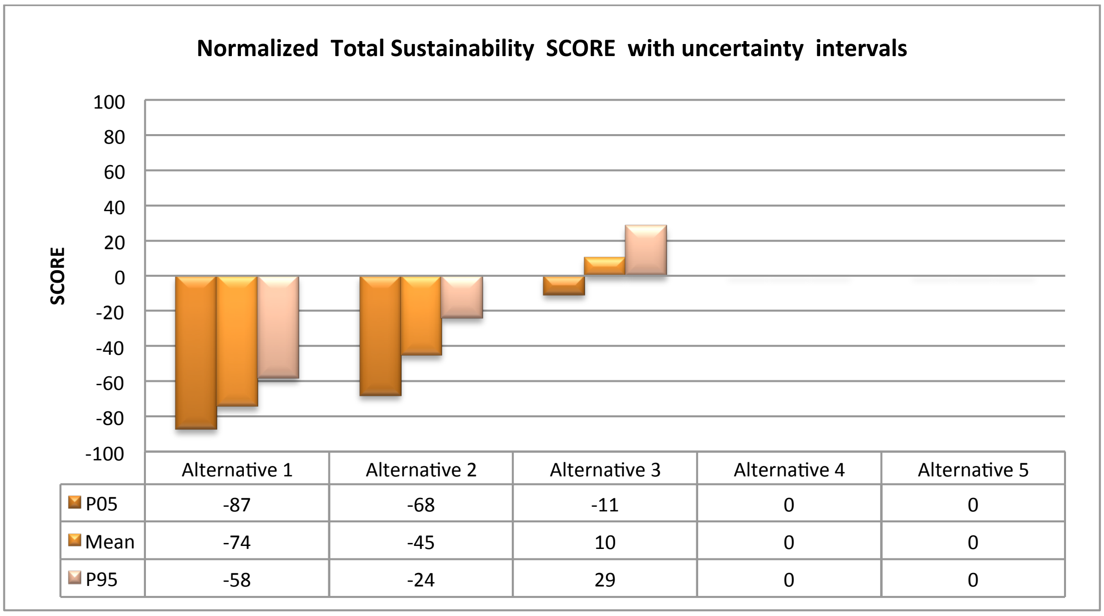
Figure 38: Number of effects - on-site vs. off-site.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Remedial Action Positive	1	1	1	0	0
Source Contamination Positive	9	8	8	0	0
Remedial Action Negative	-15	-13	-6	0	0
Source Contamination Negative	0	0	0	0	0

Figure 39: Number of effects - remedial action vs. source contamination.

The SCORE assessment of the three remediation alternatives was performed using 10 000 Monte Carlo runs. The uncertainties of the normalized total scores are shown in Figure 40 showing that the assessments for all alternatives are associated with substantial uncertainties.



	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
P05	-87	-68	-11	0	0
Mean	-74	-45	10	0	0
P95	-58	-24	29	0	0

Figure 40: *Normalized total sustainability scores and uncertainties.*

Sensitivity analysis for Alternative 3, which had the highest normalized total score, showed that the costs for the remedial action, local environmental quality and amenity and local participation contributed most to the total uncertainty, see Figure 41. Alternatives 3 showed the highest probability of being the most sustainable alternative, see Figure 42.

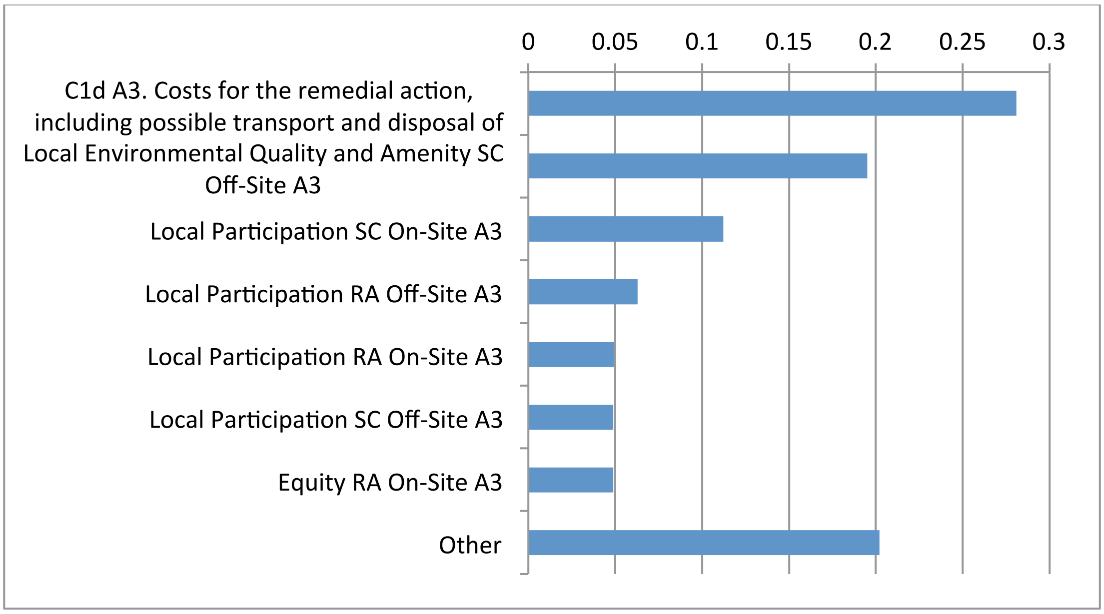


Figure 41: *Sensitivity analysis for Alternative 3. Results expressed as the contribution to the variance of the normalized sustainability score for Alternative 3.*

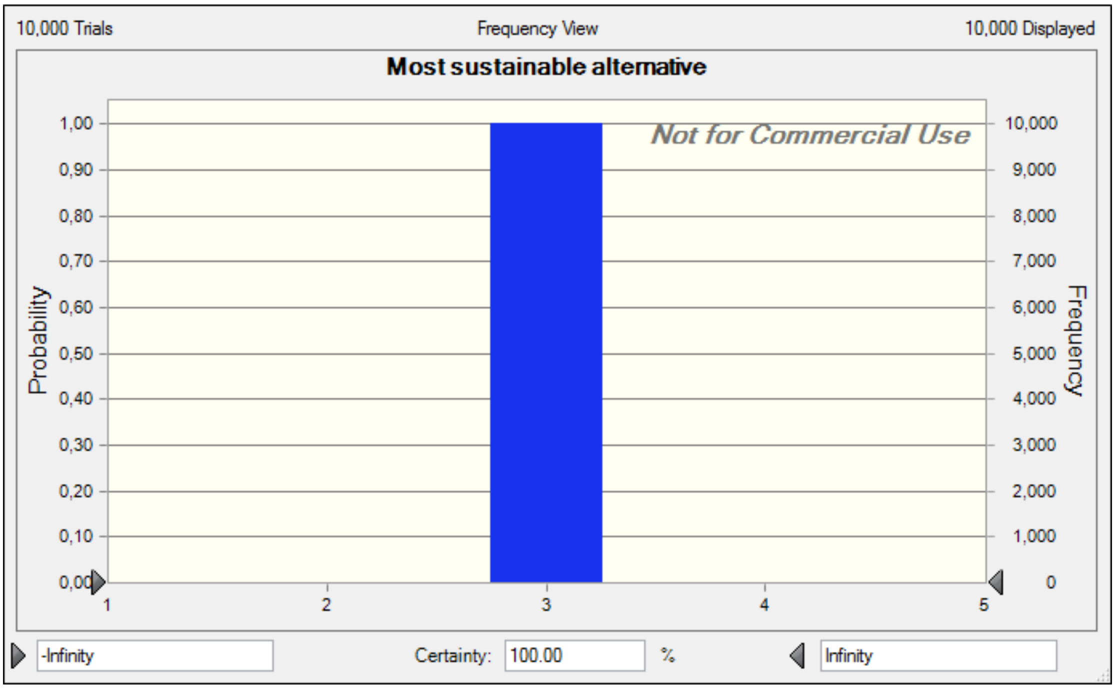


Figure 42: *Probabilities of each alternative at the Shooting Range site being the most sustainable.*

8 Practical aspects of the developed methodology

The presented approach and results connected to soil functions and services (Chapter 4), soil quality index (Chapter 5), and the MCA framework (Chapter 6) are key aspects of the SNOWMAN-MCA project and, when put together, forms the core of the sustainability appraisal at the selected case studies.

In practice, the sustainability appraisal includes additional steps which also needs pointing out. The work connected to the selected case studies followed a general workflow of:

1. Defining remediation options, including reference alternative.
2. Selecting relevant criteria and assigning weights to each ecological and social criterion and sub-criterion.
3. Assign expected effect (positive or negative), possible range of values (all scores possible, no positive scores possible, no negative scores possible) and uncertainties for each sub-criterion (Low, Medium or High uncertainty) in the environmental domain.
    a. The effect on soil functions was assessed using the SF Box tool when applicable (i.e. data was readily available). This was done for the Hexion and Marieberg case studies.
    b. When the SF Box tool was not applicable (i.e. data was not available, the matrix of the effects on soil functions (Figure 5) was used as basis for expert judgment on scoring by the assessors. This was done for the Shooting Range case study.
4. Assigning expected effect (positive or negative), possible range of values (all scores possible, no positive scores possible, no negative scores possible) and uncertainties for each sub-criterion (Low, Medium, or High uncertainty) in the socio-cultural domain.
    a. In the presence of focus group meetings, each sub-criterion was set according to results from meetings as described in chapter 6.2.5. This was done for the Hexion and Marieberg case studies.
    b. In the absence of focus group meetings, the sub-criteria: Health and safety; Equity; Local environmental quality and amenity were estimated according to expert judgment within the project group. This was done for the Shooting Range case study.
5. Assigning net present values for each cost and benefit item, including uncertainties for each item (Low, Medium, High uncertainty).
6. Assigning for each cost item the main payer and for each benefit item the main beneficiary (DEV=Developer; EMP=Employees; PUB=Public, including neighbors; Other).
7. Calculations and decision support using the SCORE tool.

The above listed steps where performed for each case study site and documented using the SCORE tool.

9 Discussion

Key results of the SNOWMAN-MCA project are:

• *A suggested hierarchy between soil functions, soil processes, soil services and ecosystem services, resulting in a set of soil function related ecological, socio-cultural and economic criteria and sub-criteria to be used in MCA.*

The suggested hierarchy between soil functions and soil ecosystem services formed a basis for incorporating the soil function concept into sustainability assessment of remediation alternatives. Soil functions are assessed in the environmental domain of sustainability using soil quality indicators, e.g. organic matter content and pH. Soil ecosystem services are suggested to be assessed in the socio-cultural and the economic domains of sustainability using value-related indicators, e.g. opinions, attitudes, WTP, and prices for ecosystem goods. Soil ecosystem service as source of raw materials is suggested to be taken into account in the social profitability criterion of the economic domain of SCORE. It is suggested to account for cultural soil ecosystem services, such as geological and archaeological archive, in the cultural heritage criterion of the socio-cultural domain of SCORE.

• *A suggested minimum data set (MDS) of soil quality indicators for soil function evaluation, and a software tool (SF Box) for calculating changes in soil quality based on the proposed MDS.*

There is no general consensus on an MDS for soil function assessment in the literature. In this study the MDS for soil function assessment was derived using a screening method searching for the most frequently suggested SQIs in remediation projects and for non-agricultural purposes. The suggested MDS is relevant to soil functions associated with primary production and consists of soil texture, content of coarse material, available water capacity, organic matter content, potentially mineralizable N, pH and available phosphorus. It is generally recognized that an MDS should fulfil the following criteria: 1) sensitivity to variations in soil management; 2) good correlation with beneficial soil functions; 3) helpfulness in revealing ecosystem processes; 4) comprehensibility and utility for land managers; and 5) inexpensive and easy to measure (Doran and Zeiss 2000; Kruse 2007). The majority of the suggested MDS indicators (*i*) correlate well with soil functions associated with primary production (as shown by statistical analysis results in Gugino et al., 2009); (*ii*) reveal soil processes, e.g. N mineralization; (*iii*) are comprehensible for land managers (interpretation in terms of soil functions is available in the literature); and (*iv*) relatively inexpensive and easy to measure.

• *A suggested structured and transparent approach for incorporating soil function and soil use aspects into sustainability appraisal of remediation alternatives using MCA.*

Being critical for ecosystem survival and human well-being, soil functions form an important aspect of sustainability assessment of remediation alternatives, especially when the goal of remediation is to protect the soil environment. The developed soil function assessment method is operationalized with help of SF Box and integrated into SCORE for sustainability assessment in remediation projects. The information from SQIs provides a land manager with input on the soil functions sub-criterion in

SCORE and allows for an assessment of the impact of remediation alternatives on selected ecological soil functions. A soil quality index generated with help of SF Box provides information on the soil's ability to carry out its functions associated with primary production, whereas contaminant concentration is related to the risks posed to the soil organisms. It is therefore suggested to treat ecotoxicological risks and soil functions in different sub-criterions of the soil criterion in SCORE.

The presented results clearly demonstrate the importance of the quality of the refilling material when using excavation as the primary remediation strategy. The effects of remediation alternatives on soil functions strongly depended on the refilling material. While reducing the risks posed by contaminants to a soil biota, the remedial action itself can cause negative effects on other important soil quality aspects (not necessarily related to the risks), e.g. availability of water and nutrients for the soil biota. In this respect the SQIs may also be used as basic information by practitioners for developing remediation strategies. For example, if the soil has potentially favorable conditions for providing ecological soil functions, alternative remediation strategies can be considered, e.g. reducing risks by immobilization of contaminants with soil amendment and also enriching the soil with nutrients, improving soil moisture retention, and stimulating biological activity in the soil.

10 Conclusion

The SCORE tool and the conceptualized hierarchy between soil functions and services used within the SNOWMAN-MCA project can be applied in various land management projects, as demonstrated using three different sites in Sweden and Austria.

The developed SF Box tool allows the practitioner to assess soil functions associated with primary production and to account for those aspects of soil quality which could otherwise be ignored. There is a potential for using SF Box for soil function assessment not only in remediation projects but also for other types of land management projects focused on soil function.

The effect of remediation on soil functions (i.e. natural capabilities of the soil ecosystem) is suggested to be assessed using physical, chemical and biological soil quality indicators. Soil ecosystem services (i.e. utilized soil functions to yield human well-being) are more related to socio-economic effects of remediation and should therefore be assessed using value-related indicators.

Lessons learned during the practical work surrounding the three included sites where:

- Defining site-specific criteria, assigning weights and estimating missing data (e.g. using a group of experts, stakeholders, focus groups, etc.) may be time-consuming process and should be initiated early on in the project.
- Generating data and support documents from previous investigations at the sites is a relatively straightforward process requiring a couple of days of one or more persons. This is the standard scenario for most sites being considered for remediation.
- Assigning values in the SCORE tool does generally not require more than a few hours to perform. However, as already mentioned in connection to the SCORE tool, this last step benefits from being done in a group allowing for an iterative process where each criterion and scoring is openly discussed.

11 References

AMA, (2010). *Råd och anvisningar till AMA anläggning 10*, Västerår: Edita Västra Aros AB.

Anderson 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, ISSN 1652-9162. Chalmers Reproservice, Gothenburg.

Andrews, S.S., Karlen, D.L., Cambardella, C.A. (2004). The soil management assessment framework: a quantitative soil quality evaluation method, *Soil Science Society of America Journal*, 68, 1945-1962.

Arrow, K. J., Dasgupta, P., Mäler, K.-G. (2003). Evaluating projects and assessing sustainable development in imperfect economies, *Environmental and Resource Economics,* 26, 647–685.

Aven, T. (2003). *Foundations of risk analysis - A knowledge and decision-oriented perspective*. Wiley.

Bardos, R.P., Bakker, L.M.M., Slenders, H.L.-A., Nathanail, C.P., (2011). Sustainability and remediation, In *Dealing with contaminated sites*, Swartjes, F.A. (Eds), Springer, pp. 889-948.

Bardos, R.P., Mariotti, C., Marot, F., Sullivan, T. (2001). Framework for Decision Support Used in Contaminated Land Management in Europe and North America, *Land Contamination and Reclamation,* 9 (1), 149-163.

Belton, V., Stewart, T. J., (2002). *Multiple Criteria Decision Analysis: An integrated Approach*. Kluwer Academic Publishers.

Bond, A., Morrison-Saunders, A. (2011). Re-evaluating sustainability assessment: aligning the vision and the practice, *Environmental Impact Assessment Review*, 31 (1). pp. 1-7.

Bone, J., Head, M., Barraclough, D., Archer, M., Scheib, C., Flight, D., Voulvoulis, N., (2010a). Soil quality assessment under emerging regulatory requirements, *Environment International*, 36, 609–622.

Bone, J., Head, M., Jones, D.T., Barraclough, D., Archer, M., Scheib, C., Eggleton, P., Voulvoulis, N., (2010 b). From Chemical Risk Assessment to Environmental Quality Management: The Challenge for Soil Protection, *Environmental science and technology*, 45(1), 104-110.

Brinkhoff, P. (2011). *Multi-Criteria Analysis for Assessing Sustainability of Remedial Actions - Applications in Contaminated Land Development*. A literature Review. Publ B2011:14. Chalmers University of Technology, Göteborg, Sweden.

Brown, S., Sprenger, M., Maxemchuk, A., Compton, H. (2005). Ecosystem Function in Alluvial Tailings after Biosolids and Lime Addition, *Journal of Environmental Quality*, 34, 139-148.

Burgman, M.A. (2005). *Risks and decisions for conservation and environmental management*. Cambridge University Press.

COM, (2006). *Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC*. Brussels, Belgium.

Craul, T.A., Craul, P.J. (2006). *Soil Design Protocols for Landscape Architects and Contractors*. Hoboken, Wiley, New Jersey.

Cundy, A.B., Bardos, R.P., Church, A., Puschenreiter, M., Friesl-Hanl, W., Müller, I. (2013). Developing principles of sustainability and stakeholder engagement for “gentle” remediation approaches: The Europen context, *Journal of Environmental Management*, 129, 283-291.

Dawson, J.J.C., Godsiffea, E.J., Thompson, I.P., Ralebitso-Senior, T.K., Killhama, K.S., Paton, G.I. (2007). Application of biological indicators to assess recovery of hydrocarbon impacted soils, *Soil Biol Biochem*, 39, 164–177.

DCLG (Department for Communities and Local Government), (2009). *Multi-criteria analysis: a manual. UK Treasury*. [online] Available at: https://www.gov.uk/government/uploads/system/uploads/ attachment_data/file/7612/1132618.pdf. [Accessed: March 27, 2013]

Doni, S., Macci, C., Peruzzi, E., Arenella, M., Ceccanti, B., Masciandaro, G. (2012). In situ phytoremediation of a soil historically contaminated by metals, hydrocarbons and polychlorobiphenyls, *Journal of Environmental Monitoring*, 14, 1383-1390.

Doran, J.W., Parkin, T.B. (1994). Defining and assessing soil quality, In *Defining soil quality for a sustainable environment*, Doran, J.W., Coleman, D.C., Bezdicek, D.F. (Eds.), pp. 3-21, Soil Science Society of America.

Doran, J.W., Zeiss, M.R. (2000). Soil health and sustainability: Managing the biotic component of soil quality, *Applied Soil Ecology*, 15, 3-11.

Environment Agency Austria (2007). *Shooting Range Linz. Risk Assessment and Prioritization according to the Act on the Remediation of Contaminated Sites*. Vienna, Austria.

Epelde, L., Becerril, J.M., Barrutia, O., Gonza lez-Oreja, J.A., Garbisu, C. (2010b). Interactions between plant and rhizosphere microbial communities in a metalliferous soil, *Environmental Pollution*, 158, 1576-1583.

Epelde, L., Becerril, J. M., Hernάndez-Allica, J., Barrutia, O., Garbisu, C. (2008b). Functional diversity as indicator of the recovery of soil health derived from Thlaspi caerulescens growth and metal phytoextraction, *Applied Soil Ecology*, 39(3), 299-310.

Epelde, L., Becerril, J.M., Kowalchuk, G.A., Deng, Y., Zhiu, J., Garbisu, C. (2010a). Impact of Metal Pollution and Thlaspi caerulescens Growth on Soil Microbial Communities, *Applied and Environmental Microbiology*, 76 (23), 7843–7853.

Epelde, L., Becerril, J.M., Mijangos, I., Garbisu, C. (2009). Evaluation of the efficiency of a phytostabilization process with biological indicators of soil health, *Journal of Environmental Quality*, 38(5), 2041-2049.

Epelde, L., Hernάndez-Allica, J., Becerril, J.M., Blanco, F., Garbisu, C. (2008a). Effects of chelates on plants and soil microbial community: Comparison of EDTA and EDDS for lead phytoextraction, *Science of The Total Environment*, 401(1-3), 21-28.

Figge, F., Hahn, T. (2004). Value-oriented impact assessment: the economics of a new approach to impact assessment, *Journal of Environmental Planning and Management*, 47(6), 921-941.

Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., van Es, H.M., Wolf,e D.W., Moebius-Clune, B.N., Thies, J.E., Abawi, G.S. (2009). *Cornell Soil Health Assessment Training Manual*, 2nd ed., Cornell Digital Print Services, Ithaca.

Hajkowicz, S., Collins, K. (2007). A Review of Multiple Criteria Analysis for Water Resource Planning and Management, *Water Resources Management*, 21 (9), pp.1553-1566.

Harbottle, M. J., Al-Tabbaa, A., Evans, C. W., (2008). Sustainability of land remediation. Part 1: overall analysis. *Geotechnical Engineering,* 161 (April 2008 Issue GE2), 75–92.

Hausman, D.M., McPherson, M.S. (1996). *Economic Analysis and Moral Philosophy*. Cambridge University Press, Cambridge, UK.

Idowu, O.J., van Es, H.M., Abawi, G.S., Wolfe, D.W., Ball, J.I., Gugino, B.K., Moebius, B.N., Schindelbeck, R.R., Bilgili, A.V. (2008). Farmer-oriented assessment of soil quality using field, laboratory, and VNIR spectroscopy methods, *Plant Soil*, 307, 243-253.

Jelusic, M., Grcman, H., Vodnik, D., Suhadolc, M., Lestan, D. (2013). Functioning of metal contaminated garden soil after remediation, *Environ Pollut*, 174, 63-70.

Josefsson et al., (2014). *In vivo* and *in vitro* tests of the bioavailability of dioxins and polycyclic aromatic compounds in field-contaminated soil, manuscript for submission to *Environmental Science & Technology*.

Kruse, J.S. (2007). Framework for Sustainable soil Management: Literature Review and Synthesis, *Soil and Water Conservation Society*, Ankeny.

Landström, Å., Östlund, A-S. (2011). *Choosing sustainable remediation alternatives at contaminated sites Application and Evaluation of a Multi-Criteria Analysis method*. Dept. of Civil and Environmental Engineering, Chalmers University of Technology, Göteborg, Sweden. Master's thesis no 2011:110.

Lear, G., Harbottle, M.J., Sills, G., Knowles, C.J., Semple, K.T., Thompson, I.P. (2007). Impact of electrokinetic remediation on microbial communities within PCP contaminated soil, *Environmental Pollution*, 146(1), 139-146.

Lear, G., Harbottle, M.J., van der Gast, C.J., Jackman, S.A., Knowles, C.J., Sills, G., Thompson, I.P. (2004). The effect of electrokinetics on soil microbial communities, *Soil Biology and Biochemistry*, 36(11), 1751-1760.

Lehmann, A., David, S., Stahr, K. (2008). *TUSEC—A manual for the evaluation of Natural Soils and AnthropogenicUrban Soils*. Bilingual edition. Hohenheimer Bodenkundliche Hefte, Stuttgart.

Lehmann, A., Stahr, K. (2010). The potential of soil functions and planner-oriented soil evaluation to achieve sustainable land use, *Journal of Soils Sediments*, 10, 1092–1102.

Li, H., Shi, W.-y., Shao, H.-b., Shao, M.-a., 2009. The remediation of the lead-polluted garden soil by natural zeolite, *Journal of Hazardous Materials,* 169, 1106–1111.

Linkov, I., Moberg, E. (2011). *Multi-Criteria Decision Analysis Environmental Applications and Case Studies*. CRC Press.

Makino, T., Kamiya, T., Takano, H., Itou, T., Sekiya, N., Sasaki, K., Maejima, Y., Sugahara, K. (2007). Remediation of cadmium-contaminated paddy soils by washing with calcium chloride: Verification of on-site washing, *Environmental Pollution,* 147(1), 112-119.

Mendoza, G.A., Martins, H. (2006). Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms, *Forest Ecology and Management,* 230, 1-22.

NCC Teknik, (2010). *Saneringsanmälan för Trädgården 1:124*. NCC Teknik. December 2010.

Pazos, M., Plaza, A., Martin, M., Lobo, M.C. (2012). The impact of electrokinetic treatment on a loamy-sand soil properties, *Chem Eng J*, 183, 231-237.

Pearce, D., Atkinson, G., Mourato, S. (2006). *Cost-Benefit Analysis and the Environment: Recent Development*. OECD, Paris.

Plaza, G., Nałęcz-Jawecki, G., Ulfig, K., Brigmon, R.L. (2005). The application of bioassays as indicators of petroleum-contaminated soil remediation, *Chemosphere,* 59, 289–296.

Rodrigues, S.M., Pereira, M.E., Ferreira da Silva, E., Hursthouse, A.S., Duarte, A.C., (2009). A review of regulatory decisions for environmental protection: Part II- the case-study of contaminated land management in Portugal, *Environment International*, 35 (1), 214-225.

Rosén, L., Back, P.-E., Söderqvist, T., Norrman, J., Brinkhoff, P., Norberg, T., Volchko, Y., Norin, M., Bergknut, M., Döberl, G. (2014). SCORE: Multi-Criteria Decision Analysis for Assessing the Sustainability of Remediation at Contaminated Sites, manuscript submitted to *Science of the Total Environment*.

Rosén, L., Back, P-E., Norrman, J., Söderqvist, T., Norberg, T., Volchko, Y., Brinkhoff, P., Norin, M., Bergknut, M., Döberl, G. (2013). SCORE: Multi-Criteria Analysis (MCA) for Sustainability Appraisal of Remedial Alternatives. *Proceedings of the Second International Symposium on Bioremediation and Sustainable Environmental Technologies*. Batelle. Jacksonville, Florida, USA, June 10-13, 2013.

Rosén, L., Söderqvist, T., Back, P.E., Soutukorva, Å., Brodd, P., Grahn, L. (2008). *Cost-benefit analysis (CBA) as a tool for prioritization of remedial actions at contaminated sites. Method development and examples*. Report 5836. Swedish Environmental Protection Agency, Stockholm.

Rosén, L., Söderqvist, T., Back, P.E., Soutukorva, Å., Brodd, P., Grahn, L. (2009). *Multi-criteria analysis (MCA) for sustainable remediation at contaminated sites. Method development and examples*. Report 5891. Swedish Environmental Protection Agency, Stockholm.

SAB, (2009). *Valuing the Protection of Ecological Systems and Services: A report of the EPA Science Advisory Board*. Washington. EPA-SAB-09-012, May 2009.

Sagoff, M., 2007. *The Economy of the Earth: Philosophy, Law and the Environment*. Second Edition. Cambridge University Press, Cambridge UK, 280 p.

Schindelbeck, R., van Es, H.M., Abawi, G.S., Wolfe, D.W., Whitlow, T.L., Gugino, B.K., Idowu, O.J., Moebius-Clune, B.N. (2008). Comprehensive assessment of soil quality for landscape and urban management, *Landscape Urban Plan*, 88, 73-80.

Sojka, R.E., Upchurch, D.R. (1999). Reservations regarding the soil quality concept, *Soil Science Society of America Journal*, 63, 1039-1054.

SuRF-UK (2010). *A Framework for Assessing the Sustainability of Soil and Groundwater Remediation. Contaminated Land: Applications In Real Environments* (CLAIRE).

SuRF-UK (2011). *Annex 1: The SuRF-UK indicator set for sustainable remediation assessment*, Final November 2011, Contaminated Land: Applications In Real Environments. (CLAIRE).

Swartjes, F.A., Breure, A. M., Beaulieu, M. (2012a). Introduction to ecological risk assessment, In *Dealing with contaminated sites*, Swartjes (Eds.), pp. 573-624, Springer.

Swartjes, F.A., Rutgers, M., Lijzen, J.P.A., Janssen, P.J.C.M., Otte, P.F., Wintersen, A., Brand, E., Posthuma, L. (2012b). State of the art of contaminated site management in The Netherlands: Policy framework and risk assessment tools, *Science of the Total Environment*, 427-428, 1-10.

Swedish EPA (2009). *Evaluation of the Knowledge Programme Sustainable Decontamination*. Report 5998.

Söderqvist, T., Brinkhoff, P., Norberg, T., Rosén, L., Back, P-E., Norrman, J. (2014). Cost-benefit analysis as part of a sustainability assessment of remediation alternatives for contaminated land, manuscript for submission to *Journal of Environmental Management*.

USEPA, (2012). *Methodology for Understanding and Reducing a Project's Environmental Footprint*. USEPA Office of Solid Waste and Emergency Response. Office of Superfund Remediation and Technology Innovation. EPA 542-R-12-002

van den Bergh, J.C.J.M. (2010). Externality or sustainability economics? *Environmental Economics,* 69 (11), 2047–2052.

van Herwijnen, R., Al-Tabbaa, A., Hutchings, T.R., Moffat, A.J., Ouki, S.K., Johns, M.L. (2007). The Impact of Waste Compost-Based Soil Amendments on the Leaching Behavior of a Heavy Metal Contaminated Soil, *Environ Eng Sci*, 24 (7), 897-904.

WCED, (1987). *Our Common Future*, Report of the World Commission on Environment and Development, United Nations, A/42/427.

Volchko, Y. (2013b). *SF Box – A tool for evaluating ecological soil functions in remediation projects*. Report 2013:1, ISSN 1652-9162. Chalmers Reproservice, Gothenburg.

Volchko, Y. (2014d). *Assessing Soil Functions for Sustainable Remediation of Contaminated Sites*. Doctoral thesis. Chalmers Reproservice, Gothenburg.

Volchko, Y., Norrman, J., Bergknut, M., Rosén, L., Söderqvist, T. (2013a). Incorporating the Soil Function Concept into Sustainability Appraisal of Remediation Alternatives, *Journal of Environ. Management,* 129, 367-376.

Volchko, Y., Norrman, J., Rosén, L., Bergknut, M., Söderqvist, T., Norberg, T., Josefsson, S., Wiberg, K. (2014 a). Using soil function evaluation in multi criteria decision analysis for sustainability appraisal of remediation alternatives, *Science of the Total Environment*, 485–486, 785–791.

Volchko, Y., Norrman, J., Rosén, L., Norberg, T. (2014 b). A minimum data set for evaluating the ecological soil functions in remediation projects, *Journal of Soils and Sediments*. DOI: 10.1007/s11368-014-0939-8.

Volchko, Y., Norrman, J., Rosén, L., Norberg, T. (2014 c). SF Box – a tool for evaluating the effects on soil functions in remediation projects, *Integrated Environmental Assessment and Management*. DOI: 10.1002/ieam.1552.

Åberg, A., Tysklind, M., Nilsson, T., Mac Leod, M., Hanberg, A., Andersson, R. (2010). Exposure assessment at a PCDD/F contaminated site in Sweden - field measurements of exposure media and blood serum analysis, *Environmental Science and Pollution Research*, 17 (1), 26-39.

Appendix I: List of dissemination activities

Table 1a. SNOWMAN-MCA national and international dissemination activities.

Date	Country	Setting	Presentation /Activity
September 2010	Denmark	NORDROCS 2010 3rd Joint Nordic Meeting on Remediation of Contaminated Sites International conference	Poster: Incorporating soil services in multi-criteria analysis of remediation alternatives
September 2010	Sweden	Northern Sweden remediation centre (MCN) g	Presentation: SNOWMAN – MCA
December 2010	France	Joint meeting SOLENV project	Presentation: SNOWMAN – MCA
January 2011	Sweden	FRIST competence centre (Forum for Risk Investigation and Soil Treatment): Sustainable management of contaminated sites, a workshop on future methods	Presentation: Soil function in the assessment of sustainability
February 2011	Sweden	Clean Soil Network - Workshop: Research on soil processes with potential application for contaminated soils	Presentation: Soil Functions and Services
May 2011	Stockholm, Sweden	The SNOWMAN-MCA International workshop on sustainable remediation and soil functions and services	Workshop organised by the SNOWMAN-MCA project
June 1-3, 2011	Amherst, MA, USA	EPA/TEI International Sustainable Remediation Conference 2011	Presentation: Integrating the soil function concept and multi-criteria analysis for sustainable remediation of contaminated land. Authors: Volchko, Y., Bergknut, M., Rosén, L., Norrman, J.
May 2012	Copenhagen, Denmark	The 16th Nordic Geotechnical Meeting	Presentation and paper in the proceedings: Development of a tool for evaluating the sustainability of remediation alternatives. Authors: Norrman, J., Volchko, Y., Rosén, L., Brinkhoff, P., Norin, M., Söderqvist, T., Kinell, G., Norberg, T.
September 18-21, 2012	Oslo, Norway	The 4th Joint Nordic Meting on Remediation of Contaminated Sites	Presentation and short paper in the proceedings: Accounting for soil functions and services in sustainability appraisal of remediation alternatives. Authors: Volchko, Y., Bergknut, M., Rosén, L., Norrman, J., Söderqvist, T., Norberg, T.
March 28-29, 2013	Gothenburg, Sweden	Clean Soil Network (RenareMark) Spring Meeting	Presentation: Markfunktioner – Hur kan vi bedöma effekter på markens funktioner av en sanering? (*In English*: Soil Functions – How can we evaluate the effects of remediation on soil functions?). Authors: Volchko, Y., Norrman, J., Bergknut, M., Rosén, L., Söderqvist, T.
April 16-19, 2013	Barcelona, Spain	The 12th International UFZ-Deltares Conference on Groundwater-Soil-Systems and Water Resource Management	Poster and paper in the proceedings: Using soil function evaluation in multi criteria decision analysis for sustainability appraisal of remediation alternatives. Authors: Volchko, Y., Norrman, J., Rosén, L., Bergknut, M., Söderqvist, T., Norberg, T., Josefsson, S.
June 10-13, 2013	Jacksonville, Florida, USA		Presentation and paper in the proceedings: SCORE: Multi-Criteria Analysis (MCA) for Sustainability Appraisal of Remedial Alternatives, oral presentation. Authors: Rosén, L., Back, P-E., Norrman, J., Söderqvist, T., Norberg, T., Volchko, Y., Brinkhoff, P., Norin, M., Bergknut, M., Döberl, G.

The results from the SNOWMAN-MCA International workshop on sustainable remediation and soil functions and services (19th of May 2011) are available on the SNOWMAN Network webpage.

Appendix II: MCA Inputs and Motivation

Hexion (Mölndal, Sweden)

Table 2a. *Input values for the Hexion site in the environmental domain. NR = Not relevant; NP = No positive scores possible; NN = No negative score possible; AS = All scores possible; Mode = most likely score; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Key criteria	Sub-criteria	Alternative 1			Alternative 2			Alternative 3			Alternative 4		
		Range	Mode	Unc	Range	Mode	Unc	Range	Mode	Unc	Range	Mode	Unc
E1: Soil	Ecotoxicological risk RA On-site	NP	-2	L	NP	0	H	NP	0	H	NP	0	M
	Ecotoxicological risk SC On-Site	NN	4	M	NN	4	M	NN	4	M	NN	4	M
	Soil Functions RA On-Site	AS	4	M	AS	4	M	AS	4	M	AS	4	M
E2: Physical Impact on Flora and fauna	Flora and fauna RA On-Site A1	AS	0	M	AS	0	M	AS	0	M	AS	0	M
E3: Groundwater	Groundwater RA On-Site A1	AS	0	M	AS	0	M	AS	0	M	AS	0	M
	Groundwater RA Off-Site A1		NR			NR			NR			NR	
	Groundwater SC On-Site A1	AS	8	M	AS	4	M	AS	4	M	AS	4	M
	Groundwater SC Off-Site A1		NR			NR			NR			NR	
E4: Surface Water	Surface Water RA On-Site A1		NR			NR			NR			NR	
	Surface Water RA Off-Site A1	NP	0	M	NP	0	M	NP	0	M	NP	0	M
	Surface Water SC On-Site A1		NR			NR			NR			NR	
	Surface Water SC Off-Site A1	NN	0	L	NN	0	L	NN	0	L	NN	0	M
E5: Sediment	Sediment RA On-Site A1		NR			NR			NR			NR	
	Sediment RA Off-Site A1	NP	0	M	NP	0	M	NP	0	M	NP	0	M
	Sediment SC On-Site A1		NR			NR			NR			NR	
	Sediment SC Off-Site A1	NN	0	L	NN	0	L	NN	0	L	NN	0	L
E6: Air	Air RA Off-Site A1	NP	-9	L	NP	-6	M	NP	-5	M	NP	-5	M
E7: Non-renewable Natural	Natural Resources RA Off-	NP	-9	L	NP	-5	L	NP	-2	M	NP	-1	M
E8: Non-recyclable Waste Generation	Waste RA Off-Site A1	AS	-9	M	AS	-5	M	AS	-2	M	AS	-1	M

***Table 2b**. Scoring motivation for the Hexion site in the environmental domain.*

Key criteria	Sub-criteria	Motivation			
		Alt. 1	Alt. 2	Alt. 3	Alt. 4
E1: Soil	Ecotoxicological risk RA On-site	**Score: (-2) -** Toxic soil or waste will be stored in an uncontaminated portion of the site without protection causing substantially increased risks for the soil ecosystem.	**Score: (0)** - No effect is expected, however, the level of uncertainy is high.	**Score: (0)** - See alt.2	**Score: (0)** - See alt.2
	Ecotoxicological risk SC On-Site	**Score: (+4)** - Reduced contaminant concentrations and contaminat mass in soil will lead to risk reduction.	**Score: (+4)** - See alt.1	**Score: (+4)** - See alt.1	**Score: (+4)** - See alt.1
	Soil Functions RA On-Site	**Score: (+4)** - The contaminated soil of medium quality will be substituted with a soil of good quality in accordance with the Swedish guide for installations in urban areas (MarkAMA).	**Score: (+4)** - See alt.1	**Score: (+4)** - See alt.1	**Score: (+4)** - See alt.1
E2: Physical Impact on Flora and fauna	Flora and fauna RA On-Site	**Score: (0)** - No physical disturbance of any species with protection value.	**Score: (0)** - No physical disturbance of any species with protection value.	**Score: (0) -** No physical disturbance of any species with protection value.	**Score: (0) -** No physical disturbance of any species with protection value.
E3: Groundwater	Groundwater RA On-Site	**Score: (0)** - The remediation will have a small but insignificant effect on contaminant concentration in groundwater.	**Score: (0)** - See alt.1	**Score: (0)** - See alt.1	**Score: (0)** - See alt.1
	Groundwater RA Off-Site	Not relevant	Not relevant	Not relevant	Not relevant
	Groundwater SC On-Site	**Score: (+8)** - Substantial amounts of the contaminated soil will be removed reducing the risk for releases of contaminants to the groundwater.	**Score: (+4)** - The contaminated soil will be removed reducing the risk for releases of contaminants to the groundwater.	**Score: (+4)** - See alt.2	**Score: (+4)** - See alt.2
	Groundwater SC Off-Site	Not relevant	Not relevant	Not relevant	Not relevant
E4: Surface Water	Surface Water RA On-Site	No surface water on-site	No surface water on-site	No surface water on-site	No surface water on-site
	Surface Water RA Off-Site	**Score: (0)** - Water from the site reaches recipient Mölndalsån, which has a high protective value. During excavation, contaminants may be released and travel with ground- or surface water to the recipient. However, the intent is to collect and treat this water.	**Score: (0)** - Water from the site reaches recipient Mölndalsån, which has a high protective value. During excavation, contaminants may be released and travel with ground- or surface water to the recipient. However, the intent is to collect and treat this water.	**Score: (0)** - Water from the site reaches recipient Mölndalsån, which has a high protective value. During excavation, contaminants may be released and travel with ground- or surface water to the recipient. However, the intent is to collect and treat this water.	**Score: (0)** - Water from the site reaches recipient Mölndalsån, which has a high protective value. During excavation, contaminants may be released and travel with ground- or surface water to the recipient. However, the intent is to collect and treat this water.
	Surface Water SC On-Site	No surface water on-site	No surface water on-site	No surface water on-site	No surface water on-site
	Surface Water SC Off-Site	**Score: (0)** - Remediation will have a negligable effect on surface water since no contaminants were detected in Mölndalsån before remediation.	**Score: (0)** - Remediation will have a negligable effect on surface water since no contaminants were detected in Mölndalsån before remediation.	**Score: (0)** - Remediation will have a negligable effect on surface water since no contaminants were detected in Mölndalsån before remediation.	**Score: (0)** - Remediation will have a negligable effect on surface water since no contaminants were detected in Mölndalsån before remediation.
E5: Sediment	Sediment RA On-Site	No surface water on-site	No surface water on-site	No surface water on-site	No surface water on-site
	Sediment RA Off-Site	**Score: (0)** - If the contaminants will reach Mölndalsån as a result of the remedial action, the high flow velocity will prevent sedimentation.	**Score: (0)** - If the contaminants will reach Mölndalsån as a result of the remedial action, the high flow velocity will prevent sedimentation.	**Score: (0)** - If the contaminants will reach Mölndalsån as a result of the remedial action, the high flow velocity will prevent sedimentation.	**Score: (0)** - If the contaminants will reach Mölndalsån as a result of the remedial action, the high flow velocity will prevent sedimentation.
	Sediment SC On-Site	No surface water on-site	No surface water on-site	No surface water on-site	No surface water on-site
	Sediment SC Off-Site	**Score: (0)** - The remediation will have a neglible effect on the sediments.	**Score: (0)** - The remediation will have a neglible effect on the sediments.	**Score: (0)** - The remediation will have a neglible effect on the sediments.	**Score: (0)** - The remediation will have a neglible effect on the sediments.
E6: Air	Air RA Off-Site	**Score: (-9)** - Extensive increase in green house gas (GHG) emissions due to extensive transportation of excavated soil to a landfill.	**Score: (-6)** - Increase in green house gas (GHG) emissions due to transportation of excavated soil to a landfill. The CO2 emissions are 64% of the maximum alternative (complete excavation of all contaminated soil).	**Score: (-5)** - Increase in green house gas (GHG) emissions due to transportation of excavated soil to a landfill. The CO2 emissions are 60% of the maximum alternative (complete excavation of all contaminated soil).	**Score: (-5)** - Increase in green house gas (GHG) emissions due to transportation of excavated soil to a landfill. The CO2 emissions are 60% of the maximum alternative (complete excavation of all contaminated soil).
E7: Non-renewable Natural resources	Natural Resources RA Off-Site	**Score: (-9)** - Large amounts of gravel will be used as backfilling material. Extensive transportation of excavated and refilling material from and to the site respectively will lead to substantial consumption of oil.	**Score: (-5)** - Large amounts of gravel will be used as backfilling material. Transportation of excavated and refilling material from and to the site respectively will lead to consumption of oil.	**Score: (-2)** - Gravel will be used as backfilling material. Transportation of excavated and refilling material from and to the site respectively will lead to consumption of oil.	**Score: (-1)** - Gravel will be used as backfilling material. Transportation of excavated and refilling material from and to the site respectively will lead to consumption of oil.
E8: Non-recyclable Waste Generation	Waste RA Off-Site	**Score: (-9)** - Substantial amounts of the waste will be generated.	**Score: (-5)** - See alt.1	**Score: (-2)** - Some excavated material will be reused on site after sieving.	**Score: (-1)** - Very little waste is produced. The sieved and washed materialls are reused on-site.

Table 2c. *Input values for the Hexion site in the social domain. NR = Not relevant; NP = No positive scores possible; NN = No negative score possible; AS = All scores possible; Mode = most likely score; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Key criteria	Sub-criteria	Alternative 1			Alternative 2			Alternative 3			Alternative 4		
		Range	Mode	Unc	Range	Mode	Unc	Range	Mode	Unc	Range	Mode	Unc
S1: Local Environmental Quality and Amenity	LEQ RA On-Site	NR			NR			NR			NR		
	LEQ RA Off-Site	AS	-5	M	AS	-4	M	AS	-3	M	AS	-2	M
	LEQ SC On-Site	AS	8	L	AS	8	L	AS	8	L	AS	8	L
	LEQ SC Off-Site	AS	4	M	AS	4	M	AS	4	M	AS	4	M
S2: Cultural Heritage	Cultural Heritage RA On-Site	NP	-1	L	NP	-1	L	NP	-1	L	NP	-1	L
	Cultural Heritage RA Off-Site	AS	0	L	AS	0	L	AS	0	L	AS	0	L
S3: Health and Safety	Health and Safety RA On-Site	AS	-4	M	AS	-3	M	AS	-4	M	AS	-4	M
	Health and Safety RA Off-Site	AS	-4	M	AS	-3	M	AS	-2	M	AS	-1	M
	Health and Safety SC On-Site	AS	0	L	AS	0	L	AS	0	L	AS	0	L
	Health and Safety SC Off-Site	AS	8	M	AS	8	M	AS	8	M	AS	8	M
S4: Equity	Equity RA On-Site	NR			NR			NR			NR		
	Equity RA Off-Site	AS	-2	M	AS	-2	M	AS	-2	M	AS	-2	M
	Equity SC On-Site	NN	8	M	NN	6	M	NN	6	M	NN	6	M
	Equity SC Off-Site	NN	8	M	NN	6	M	NN	6	M	NN	6	M
S5: Local Participation	Local Participation RA On-Site	AS	0	M	AS	0	M	AS	0	M	NN	0	M
	Local Participation RA Off-Site	NN	4	M	NN	4	M	NN	4	M	NN	4	M
	Local Participation SC On-Site	NN	8	M	NN	8	M	NN	8	M	NN	8	M
	Local Participation SC On-Site	NN	4	M	NN	4	M	NN	4	M	NN	4	M
S6: Local Acceptance	Local Acceptance RA On-Site	NR			NR			NR			NR		
	Local Acceptance RA Off-Site	NN	4	M	NN	6	M	NN	7	M	NN	8	M
	Local Acceptance SC On-Site	NR			NR			NR			NR		
	Local Acceptance SC On-Site	NN	8	M	NN	8	M	NN	8	M	NN	8	M

Table 2d. *Scoring motivation for the Hexion site in the social domain.*

Key criteria	Sub-criteria	Motivation			
		Alt. 1	Alt. 2	Alt. 3	Alt. 4
S1: Local Environmental Quality and Amenity	LEQ RA On-Site				
	LEQ RA Off-Site	**Score: (-5)** - There are some negative effects off-site due to heavy transports.	**Score: (-4)** - There are some negative effects off-site due to heavy transports but less transport than alt 1.	**Score: (-3)** - There are some negative effects off-site due to heavy transports but less transport than alt 2.	**Score: (-2)** - There are some negative effects off-site due to heavy transports but less transport than alt 3.
	LEQ SC On-Site	**Score: (+8)** - There is a great positive effect on the local env quality and amenities on the site.	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1
	LEQ SC Off-Site	**Score: (+4)** - There are some positive effects, for the sourrounding as well.	**Score: (+4)** - see alt 1	**Score: (+4)** - see alt 1	**Score: (+4)** - see alt 1
S2: Cultural Heritage	Cultural Heritage RA On-Site	**Score: (-1)** - The old SOAB buildning and some old walls will be teared down by the remedial action.	**Score: (-1)** - see alt 1	**Score: (-1)** - see alt 1	**Score: (-1)** - see alt 1
	Cultural Heritage RA Off-Site	**Score: (0)** - The remedial action does not affect any cultural heritage off-site.	**Score: (0)** - see alt 1	**Score: (0)** - see alt 1	**Score: (0)** - see alt 1
S3: Health and Safety	Health and Safety RA On-Site	**Score: (-4)** - The workers on-site are exposed to contaminated material.	**Score: (-3)** - The workers on-site are exposed to contaminated material	**Score: (-4)** - The workers on-site are exposed to contaminated material, but since they are working with the sieving etc, they are also more aware of the working env guidelines.	**Score: (-4)** - The workers on-site are exposed to contaminated material, but since they are working with the sieving etc, they are also more aware of the working env.
	Health and Safety RA Off-Site	**Score: (-4)** - The heavy traffic will be a safety risk for neigbours. There will also be some dusting.	**Score: (-3)** - The heavy traffic will be a safety risk for neigbours. There will also be som and dusting.	**Score: (-2)** - There is some traffic. Dust will be prevented at the sieve.	**Score: (-1)** - There is even less traffic. Dust will be prevented at the sieve.
	Health and Safety SC On-Site	**Score: (0)** - Since the reference alternative is considering a closed factory, i.e. no workers, there is no effect on-site as a result of the remediation alternative.	**Score: (0)** - see alt 1	**Score: (0)** - see alt 1	**Score: (0)** - see alt 1
	Health and Safety SC Off-Site	**Score: (+8)** - Neigbours will be less exposed to contamination spreading from the site.	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1
S4: Equity	Equity RA On-Site	Not relevant, no population on-site.	Not relevant, no population on-site.	Not relevant, no population on-site.	Not relevant, no population on-site.
	Equity RA Off-Site	**Score: (-2)** - Neighbours are affected somewhat negatively by the remedial action but are able to influence the decision to some extent, e.g. when transports will take place etc.	**Score: (-2)** - see alt 1	**Score: (-2)** - see alt 1	**Score: (-2)** - see alt 1
	Equity SC On-Site	**Score: (+8)** - The future environmental cost is reduced to a very large extent/eliminated.	**Score: (+6)** - The future environmental cost is reduced to a large extent.	**Score: (+6)** - see alt 2	**Score: (+6)** - see alt 2
	Equity SC Off-Site	**Score: (+8)** - The future environmental cost is reduced to a very large extent/eliminated.	**Score: (+6)** - The future environmental cost is reduced to a large extent.	**Score: (+6)** - see alt 2	**Score: (+6)** - see alt 2
S5: Local Participation	Local Participation RA On-Site	**Score: (0)** - The remedial action does not affect job opportunities etc on site.	**Score: (0)** - see alt 1	**Score: (0)** - see alt 1	**Score: (0)** - see alt 1
	Local Participation RA Off-Site	**Score: (+4)** - Due to the remedial action there are some positive effects off-site, such as an increased use of services.	**Score: (+4)** - see alt 1	**Score: (+4)** - see alt 1	**Score: (+4)** - see alt 1
	Local Participation SC On-Site	**Score: (+8)** - The change in landuse will affect local job opportunities positively. There will also be school at the site.	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1
	Local Participation SC Off-Site	**Score: (+4)** - The change in landuse will affect local job opportunities and probably services for the surroundning positively.	**Score: (+4)** - see alt 1	**Score: (+4)** - see alt 1	**Score: (+4)** - see alt 1
S6: Local Acceptance	Local Acceptance RA On-Site	Not relevant, no population on-site.	Not relevant, no population on-site.	Not relevant, no population on-site.	Not relevant, no population on-site.
	Local Acceptance RA Off-Site	**Score: (+4)** - Neighbours are worried about heavy transports through the area but want something to be done.	**Score: (+6)** - Neighbours are worried about heavy transports through the area, this alt gives less transport.	**Score: (+7)** - This alternative results in small amounts of transport and is viewwed as very positive by neighbours.	**Score: (+8)** - This alternative results in even smaller amounts of transport and is viewed as very positive by neighbours.
	Local Acceptance SC On-Site	Not relevant, no population on-site.	Not relevant, no population on-site.	Not relevant, no population on-site.	Not relevant, no population on-site.
	Local Acceptance SC Off-Site	**Score: (+8)** - Neighbours are very positive to the reduction of source contamination since there for long has been a strong loval opinion against the SOAB factory.	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1	**Score: (+8)** - see alt 1

Table 2e. *Input values for the CBA of Hexion remediation alternatives. All monetary values in million Swedish kronor (MSEK). P = Payer; B = Beneficiary; DEV = Developer; EMP = Employees; PUB = Public, including neighbours; NR = Not relevant; (X) = Non-monetized item judged to be somewhat important; X = Non-monetized item judged to be very important; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Main items	Sub-items	Alternative 1			Alternative 2			Alternative 3			Alternative 4		
		B/P	Mode	Unc	B/P	Mode	Unc	B/P	Mode	Unc	B/P	Mode	Unc
B1. Increased property values	B1. Increased property value on site	DEV	48.81	M	DEV	48.81	M	DEV	48.81	M	DEV	48.81	M
B2. Improved Health	B2a. Reduced acute health risks	NR			NR			NR			NR		
	B2b. Reduced non-acute health risks	EMP	0.0003	M	EMP	0.0003	M	EMP	0.0003	M	EMP	0.0003	M
	B2c. Other types of improved health, e.g. reduced anxiety	PUB	0.07	M	PUB	0.07	M	PUB	0.07	M	PUB	0.07	M
B3. Increased provision of ecosystem services	B3a. Increased recreational opportunities on site	No P/B	X	M	No P/B	X	M	No P/B	X	M	No P/B	X	M
	B3b. Increased recreational opportunities in the surroundings	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M
	B3c. Increased provision of other ecosystem services	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M
B4. Other positive externalities	B4. Other positive externalities	NR			NR			NR			NR		
C1. Remediation costs	C1a. Costs for investigations and design of remedial actions	NR			NR			NR			NR		
	C1b. Costs for contracting	NR			NR			NR			NR		
	C1c. Capital costs due to allocation of funds to the remedial action	DEV	1.15	M	DEV	0.72	M	DEV	0.71	M	DEV	0.87	M
	C1d. Costs for the remedial action, including possible transport and disposal of contaminated soil minus possible revenues of reuse of contaminants and/or soil	DEV	38.14	M	DEV	23.95	M	DEV	23.61	M	DEV	28.77	M
	C1e. Costs for design and implementation of monitoring programs including sampling, analysis and data processing	DEV	9.03	M	DEV	9.03	M	DEV	9.03	M	DEV	9.03	M
	C1f. Project risks	DEV	4.56	L	DEV	2.41	L	DEV	1.71	L	DEV	1.66	L
C2. Impaired health due to the remedial action	C2a. Increased health risks due to the remedial action on site	DEV	0.835	M	DEV	0.835	M	DEV	0.835	M	DEV	0.835	M
	C2b. Increased health risks due to transports to and from the remediation site	DEV	1.52	M	DEV	0.9	M	DEV	0.77	M	DEV	0.64	M
	C2c. Increased health risks at disposal sites	NR			NR			NR			NR		
	C2d. Other types of impaired health due to the remedial action, e.g. increased anxiety	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M
C3. Decreased provision of ecosystem services on site	C3a. Decreased provision of ecosystem services on site due to the remedial action	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M
	C3b. Decreased provision of ecosystem services off site due to the remedial action	PUB	0.56	M	PUB	0.35	M	PUB	0.33	M	PUB	0.31	M
	C3c. Decreased provision of ecosystem services due to environmental effects at the disposal site	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M	No P/B	(X)	M
C4. Other negative externalities	C4. Other negative externalities	NR			NR			NR			NR		

Marieberg saw mill (Sweden)

Table 2f. *Input values for the Marieberg site in the environmental domain. NR = Not relevant; NP = No positive scores possible; NN = No negative score possible; AS = All scores possible; Mode = most likely score; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

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

Table 2g. *Scoring motivation for the Marieberg site in the environmental domain.*

Key criteria	Sub-criteria	Motivation		
		Alt. 1	Alt. 2	Alt. 3
E1: Soil	Ecotoxicological risk RA On-site	**Score: (0) -** The remediation will not affect the ecotoxicological risk on-Site	**Score: (0) -** The remediation will not affect the ecotoxicological risk on-Site	**Score: (0)** - No change in relation to the reference scenario.
	Ecotoxicological risk SC On-Site	**Score: (+8) -** High levels of dioxins and other pollutants present at site in relation to health effects, moderate levels in relation to soil/environmental effects. About 20% of site (judging from maps) affected by levels that may cause severe negative effects on soil/environment. The remediation will result in substantially reduced contaminant concentrations and contaminant mass in soil.	**Score: (+4) -** High levels of dioxins and other pollutants present at site in relation to health effects, moderate levels in relation to soil/environmental effects. About 20% of site (judging from maps) affected by levels that may cause severe negative effects on soil/environment. The remediation will result in barriers between contaminated layers of soil and surficial soil ecosystems as well as water pathways.	**Score: (0) -** No change in relation to the reference scenario.
	Soil Functions RA On-Site	**Score: (+2)** - About 50% of site will reach a higher level of soil status after remediation (i.e. some improvements of soil quality) judging from maps of alternative 4.2. Quality of filling material and top layer material not given in report. The quality of filling material is here assumed to be of medium to poor quality and quality of top layer is assumed to be of medium/good quality, (Medium = same as site, poor = lower quality than material at site).	**Score: (+2) -** About 50% of site will reach a higher level of soil status after remediation but only for the top 0,5 m (i.e. some improvements of soil quality). Quality of top layer material not given in report. The quality of top layer is here assumed to be of medium/good quality, (Medium = same as site). About 20% of site (judging from maps) affected by levels that may cause severe negative effects on soil/environment. The net result is an expected increase of soil quality compared to reference scenario.	**Score: (0) -** No change in relation to the reference scenario.
E2: Physical Impact on Flora and fauna	Flora and fauna RA On-Site A1	**NR** - No physical disturbances on any species with protection value.	**NR** - No physical disturbances on any species with protection value.	**NR** - No physical disturbances on any species with protection value.
E3: Groundwater	Groundwater RA On-Site A1	**Score: (-8)** - The remedial action is expected to have negative impact on the ground water quality on-site. The reason is that the number of polluted soil particles is expected to increase in ground water due to extensive excavation.	**Score: (-4)** - The remedial action is expected to have some negative impact on the ground water quality on-site. The reason for this is the limited amount of excavation.	**Score: (0)** - The ground water quality on-site is negatively affected by pollutants but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
	Groundwater RA Off-Site A1	**NR**- Off-site and downstream flow is in the form of surface water.	**NR** - Off-site and downstream flow is in the form of surface water.	**NR** - Off-site and downstream flow is in the form of surface water
	Groundwater SC On-Site A1	**Score: (+8)** - A long-term positive effect is expected on site when the contaminant concentration in the ground water is reduced. Uncertainty in the positive effects arises from the fact that minor "hot-spots" may be overlooked during excavation (experience based observation).	**Score: (+8)** - The remediation strategy is assumed to reduce the amount of groundwater at the site using barriers and extensive ditching. A long-term positive effect is expected on site when the contaminant concentration in the ground water is reduced.	**Score: (0)** - The ground water quality on-site is negatively affected by pollutants but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
	Groundwater SC Off-Site A1	**NR** - Off-site and downstream flow is in the form of surface water	**NR** - Off-site and downstream flow is in the form of surface water	**NR** - Off-site and downstream flow is in the form of surface water
E4: Surface Water	Surface Water RA On-Site A1	**Score: (-8)** - Excavation is expected to cause an increase of polluted soil particles is surface water. Excavation is also assumed to include handling of polluted soil at the surface of the site. The extensive excavation is expected to have severe negative impact on the surface water quality on-site.	**Score: (-4)** - Excavation is expected to cause an increase of polluted soil particles is surface water. Excavation is also assumed to include handling of polluted soil at the surface of the site. The limited excavation is expected to have some impact on the surface water quality on-site.	**Score: (0)** - The surface water quality on-site is negatively affected by pollutants but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
	Surface Water RA Off-Site A1	**Score: (-8)** - The remedial action is expected to have negative impact on the surface water quality off site (downstream recipients). The reason is that number of polluted soil particles is expected to increase in surface water due to extensive excavation.	**Score: (-4)** - The remedial action is expected to have limited negative impact on the surface water quality off-site (downstream recipients). The reason for this is the limited amount of excavation.	**Score: (0)** - The surface water quality on-site is negatively affected by pollutants but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
	Surface Water SC On-Site A1	**Score: (+8)** - All polluted soil at the surface of the site will be removed, leading to significantly lower levels of contaminants in surface (run off) water.	**Score: (+8)** - All surface soil at the site will be free of contaminants, leading to significantly lower levels of contaminants in surface (run off) water.	**Score: (0)** - The surface water quality on-site is negatively affected by pollutants but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
	Surface Water SC Off-Site A1	**Score: (+8)** - A long-term positive effect is expected for the downstream ecosystems when the contaminant concentration in the surface water is reduced. Remaining polluted sites in the region will still have a negative effect on downstream ecosystems. Uncertainty in the positive effects also arises from the fact that "hot-spots" may be overlooked during excavation.	**Score: (+8)** - A long-term positive effect is expected for the downstream ecosystems when the contaminant concentration in the surface water is reduced. Remaining polluted sites in the region will still have a negative effect on downstream ecosystems. The remediation strategy is assumed to treat all of the effected water at the site.	**Score: (0)** - The surface water quality on-site is negatively affected by pollutants but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
E5: Sediment	Sediment RA On-Site A1	**Score: (0)** - Contaminated sediments are present at the site. The excavation is performed at the contaminant source, on land. The excavation itself is not expected to have any effect on the sediments on-site. Removal of contaminated sediments is not part of the remediation action.	**Score: (0)** - Contaminated sediments are present at the site. The excavation is performed at the contaminant source, on land. The excavation itself is not expected to have any effect on the sediments on-site. Removal of contaminated sediments is not part of the remediation action.	**Score: (0)** - No significant effect is expected in the sediments off-site (the contribution from the site to sediments off-site is assumed to be minimal).
	Sediment RA Off-Site A1	**Score: (0)** - Contaminated sediments are present at the site. The excavation is performed at the contaminant source, on land. The excavation itself is not expected to have any effect on the sediments off-site. Removal of contaminated sediments is not part of the remediation action.	**Score: (0)** - Contaminated sediments are present at the site. The excavation is performed at the contaminant source, on land. The excavation itself is not expected to have any effect on the sediments off-site. Removal of contaminated sediments is not part of the remediation action.	**Score: (0)** - Contaminated sediments are present at the site but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
	Sediment SC On-Site A1	**Score: (+4)** - The contaminant transport to the sediments on-site is expected to decrease when the contaminated soil has been excavated and removed. This is expected to result in a long-term reduction of contaminant concentration in the sediments. Removal of contaminated sediments is not part of the remediation action.	**Score: (+4)** - The contaminant transport to the sediments on-site is expected to decrease when the contaminated soil has been excavated and removed. This is expected to result in a long-term reduction of contaminant concentration in the sediments. Removal of contaminated sediments is not part of the remediation action.	**Score: (0)** - Contaminated sediments are present at the site but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
	Sediment SC Off-Site A1	**Score: (0)** - No significant effect is expected in the sediments off-site (the contribution from the site to sediments off-site is assumed to be minimal).	**Score: (0)** - No significant effect is expected in the sediments off-site (the contribution from the site to sediments off-site is assumed to be minimal).	**Score: (0)** - Contaminated sediments are present at the site but will not change as no remediation is taking place (i.e. no change in relation to the reference scenario).
E6: Air	Air RA Off-Site A1	**Score: (-8)** - Significant increase in green house gas (GHG) emissions due to transportation of excavated soil to a landfill, as well as transportation of filling material. See also C3b.	**Score: (-4)** - Increase in green house gas (GHG) emissions due to transportation of excavated soil to a landfill, as well as transportation of filling material. See also C3b.	**Score: (0)** - No change in relation to the reference scenario.
E7: Non-renewable Natural resources	Natural Resources RA Off-Site A1	**Score: (-8)** - Amount soil needed for refilling 41 000 m3.	**Score: (-4)** - Amount soil needed for refilling 28 250 m3.	**Score: (0)** - No change in relation to the reference scenario.
E8: Non-recyclable Waste Generation	Waste RA Off-Site A1	**Score: (-8)** - Amount of waste soil generated by excavation is 41 000 m3.	**Score: (-4)** - Amount of waste is unknown but is expected to be more compared to the reference alternative.	**Score: (+4)** - No change in relation to the reference scenario.

Table 2h. *Input values for the Marieberg site in the social domain. NR = Not relevant; NS = Not scored; NP = No positive scores possible; NN = No negative score possible; AS = All scores possible; Mode = most likely score; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Key criteria	Sub-criteria	Alternative 1			Alternative 2			Alternative 3		
		Range	Mode	Unc	Range	Mode	Unc	Range	Mode	Unc
S1: Local Environmental Quality and Amenity	LEQ RA On-Site	NR			NR			NR		
	LEQ RA Off-Site	NP	-4	M	NP	-4	M	NP	0	H
	LEQ SC On-Site	NN	4	M	NN	4	H	NP	-8	M
	LEQ SC Off-Site	NN	4	L	NN	4	H	NP	-8	M
S2: Cultural Heritage	Cultural Heritage RA On-Site	NR			NR			NR		
	Cultural Heritage RA Off-Site	AS	0	H	AS	0	L	AS	0	M
S3: Health and Safety	Health and Safety RA On-Site	NR			NR			NR		
	Health and Safety RA Off-Site	NP	-4	M	NP	-4	M	NP	0	L
	Health and Safety SC On-Site	NN	8	L	NN	8	M	NN	4	H
	Health and Safety SC Off-Site	NN	4	L	NN	2	M	AS	0	M
S4: Equity	Equity RA On-Site	AS	-2	M	AS	-2	M	AS	-8	M
	Equity RA Off-Site	AS	0	H	AS	0	M	AS	0	M
	Equity SC On-Site	AS	8	L	AS	4	M	AS	-8	L
	Equity SC Off-Site	AS	8	M	AS	4	M	AS	-8	L
S5: Local Participation	Local Participation RA On-Site	NS			NS			NS		
	Local Participation RA Off-Site	NS			NS			NS		
	Local Participation SC On-Site	NS			NS			NS		
	Local Participation SC On-Site	NS			NS			NS		
S6: Local Acceptance	Local Acceptance RA On-Site	NS			NS			NS		
	Local Acceptance RA Off-Site	NS			NS			NS		
	Local Acceptance SC On-Site	NS			NS			NS		
	Local Acceptance SC On-Site	NS			NS			NS		

Table 2i. *Scoring motivation for the Marieberg site in the social domain. NR = Not relevant; NS = Not scored.*

Key criteria	Sub-criteria	Motivation		
		Alt. 1	Alt. 2	Alt. 3
S1: Local Environmental Quality and Amenity	LEQ RA On-Site	NR	NR	NR
	LEQ RA Off-Site	**Score: (-4)** There will be a lot of disturbances due to the extensive transports required.	**Score: (-4)** Also here, there will be a lot of disturbances due to transports and the site unavailable.	**Score: (0)** A fence is put up, not so much disturbance.
	LEQ SC On-Site	**Score: (+4)** Depends on how the site will look after the remediation, aesthetics will make a difference here.	**Score: (+4)** Depends on how the site will look after the remediation, aesthetics will make a difference here.	**Score: (-8)** The area is not available for recreation any more.
	LEQ SC Off-Site	**Score: (+4)** Depends on how the site will look after the remediation, aesthetics will make a difference here.	**Score: (+4)** Depends on how the site will look after the remediation, aesthetics will make a difference here.	**Score: (-8)** The area is not available for recreation any more.
S2: Cultural Heritage	Cultural Heritage RA On-Site	NR	NR	NR
	Cultural Heritage RA Off-Site	**Score: (0)** No effect (assuming that the building for indoor spraying will be preserved)	**Score: (0)** No effect (assuming that the building for indoor spraying will be preserved). Possibly a negative effect on the landscape due to the raise of the ground level.	**Score: (0)** No effect (assuming that the building for indoor spraying will be preserved)
S3: Health and Safety	Health and Safety RA On-Site	NR	NR	NR
	Health and Safety RA Off-Site	**Score: (-4)** Increase in accidental risks due to transport.	**Score: (-4)** Increase in accidental risks due to transport.	**Score: (0)** No effect
	Health and Safety SC On-Site	**Score: (+8)** A very positive effect as humans no longer are exposed to the contaminants site.	**Score: (+8)** A very positive effect as humans no longer are exposed to the contaminants site	**Score: (+4)** A positive effect as humans no longer are exposed to the contaminants site.
	Health and Safety SC Off-Site	**Score: (+4)** Possibly a positive effect downstream to due removal of contaminants and thus hinedring spreading and transport to the Baltic Sea.	**Score: (+2)** Possibly a positive effect downstream to due removal of contaminants and thus hinedring spreading and transport to the Baltic	**Score: (0)** No effect
S4: Equity	Equity RA On-Site	**Score: (-2)** The people with the summer house area need to (at least) temporarily move, and the site is unavailable for everyone.	**Score: (-2)** The people with the summer house area need to (at least) temporarily move, and the site is unavailable for everyone.	**Score: (-8)** The people with the summer house area need to permanently move, and the site is unavailable for everyone.
	Equity RA Off-Site	**Score: (0)** No effect on vulnerable groups.	**Score: (0)** No effect on vulnerable groups.	**Score: (0)** No effect on vulnerable groups.
	Equity SC On-Site	**Score: (+8)** Nothing left for future generations.	**Score: (+4)** Although risks are reduced, contamination is left in the ground and can possibly leach out in the future.	**Score: (-8)** The site is unavailable for use for future generations.
	Equity SC Off-Site	**Score: (+8)** Nothing left for future generations.	**Score: (+4)** Although risks are reduced, contamination is left in the ground and can possibly leach out in the future.	**Score: (-8)** The site is unavailable for use for future generations.
S5: Local Participation	Local Participation RA On-Site	NS	NS	NS
	Local Participation RA Off-Site	NS	NS	NS
	Local Participation SC On-Site	NS	NS	NS
	Local Participation SC Off-Site	NS	NS	NS
S6: Local Acceptance	Local Acceptance RA On-Site	NS	NS	NS
	Local Acceptance RA Off-Site	NS	NS	NS
	Local Acceptance SC On-Site	NS	NS	NS
	Local Acceptance SC Off-Site	NS	NS	NS

Table 2j. *Input values for the CBA of Marieberg remediation alternatives. All monetary values in euros (€). P = Payer; B = Beneficiary; DEV = Developer; EMP = Employees; PUB = Public, including neighbours; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Main items	Sub-items	Alternative 1			Alternative 2			Alternative 3		
		B/P	Mode	Unc	B/P	Mode	Unc	B/P	Mode	Unc
B1. Increased property values	B1. Increased property value on site									
B2. Improved Health	B2a. Reduced acute health risks	PUB	25855	M	PUB	25855	M	PUB	25855	M
	B2b. Reduced non-acute health risks									
	B2c. Other types of improved health, e.g. reduced anxiety									
B3. Increased provision of ecosystem services	B3a. Increased recreational opportunities on site									
	B3b. Increased recreational opportunities in the surroundings									
	B3c. Increased provision of other ecosystem services									
B4. Other positive externalities	B4. Other positive externalities									
C1. Remediation costs	C1a. Costs for investigations and design of remedial actions	PUB	88889	M	PUB	88889	M	PUB	88889	M
	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	PUB	13333333	M	PUB	2505556	M	PUB	1050000	M
	C1e. Costs for design and implementation of monitoring programs including sampling, analysis and data processing	PUB	30000	M	PUB	100000	M	PUB	100000	M
	C1f. Project risks	PUB	1333333	M	PUB	2505556	M	PUB	0	M
C2. Impaired health due to the remedial action	C2a. Increased health risks due to the remedial action on site									
	C2b. Increased health risks due to transports to and from the remediation site									
	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	C3a. Decreased provision of ecosystem services on site due to the remedial action									
	C3b. Decreased provision of ecosystem services off site due to the remedial action	PUB	37558	M	PUB	13723	M	PUB	0	M
	C3c. Decreased provision of ecosystem services due to environmental effects at the disposal site									
C4. Other negative externalities	C4. Other negative externalities									

Shooting Range (Linz, Austria)

Table 2k. *Input values for the shooting range site in the environmental domain. NR = Not relevant; NP = No positive scores possible; NN = No negative score possible; AS = All scores possible; Mode = most likely score; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Key criteria	Sub-criteria	Alternative 1			Alternative 2			Alternative 3		
		Range	Mode	Unc	Range	Mode	Unc	Range	Mode	Unc
E1: Soil	Ecotoxicological risk RA On-site	NP	-4	L	NP	-4	M	NP	-4	M
	Ecotoxicological risk SC On-Site	NN	8	L	NN	4	M	NN	4	L
	Soil Functions RA On-Site	AS	4	L	AS	4	H	AS	8	H
E2: Physical Impact on Flora and fauna	Flora and fauna RA On-Site A1	NR			NR			NR		
E3: Groundwater	Groundwater RA On-Site A1	AS	-4	L	NP	-4	M	AS	0	M
	Groundwater RA Off-Site A1	AS	-4	H	NP	0	L	AS	0	M
	Groundwater SC On-Site A1	AS	8	L	NN	4	M	NN	4	H
	Groundwater SC Off-Site A1	AS	4	L	NN	4	L	NN	4	L
E4: Surface Water	Surface Water RA On-Site A1	NP	-8	L	AS	-4	M	NP	-4	L
	Surface Water RA Off-Site A1	NP	-4	L	NP	0	M	NP	0	L
	Surface Water SC On-Site A1	NN	8	L	AS	4	M	NN	4	M
	Surface Water SC Off-Site A1	NN	4	L	NN	4	L	NN	4	M
E5: Sediment	Sediment RA On-Site A1	NR			NR			NR		
	Sediment RA Off-Site A1	NR			NR			NR		
	Sediment SC On-Site A1	NR			NR			NR		
	Sediment SC Off-Site A1	NR			NR			NR		
E6: Air	Air RA Off-Site A1	NP	-8	L	NP	-4	L	NP	0	L
E7: Non-renewable Natural	Natural Resources RA Off-Site A1	NP	-8	L	NP	-4	L	NP	0	L
E8: Non-recyclable Waste Generation	Waste RA Off-Site A1	NP	-8	L	NP	-4	L	NP	0	L

Table 2l. *Scoring motivation for the shooting range site in the environmental domain.*

Key criteria	Sub-criteria	Motivation		
		Alt. 1	Alt. 2	Alt. 3
E1: Soil	Ecotoxicological risk RA On-site	**Score: (-4)** - Partly mobilization of pollutants.	**Score: (-4)** - Partly mobilization of pollutants (As)	**Score: (-4)** - Partly mobilization of pollutants.
	Ecotoxicological risk SC On-Site	**Score: (+8)** - High levels of Pb (and other pollutants) present at site in relation to health effects and to soil/environmental effects. Large area affected. The remediation will result in substantially reduced contaminant concentrations and contaminant mass in soil.	**Score: (+4)** - High levels of Pb (and other pollutants) present at site in relation to health effects and to soil/environmental effects. Large area affected. The remediation will result in an immobilization of Pb.	**Score: (+4)** - High levels of Pb (and other pollutants) present at site in relation to health effects and to soil/environmental effects. Large area affected. The remediation will result in an immobilization of Pb.
	Soil Functions RA On-Site	**Score: (+4)** - A large area will reach a higher level of soil status after remediation (i.e. improvements of soil quality). The quality of filling material is assumed to be of good quality.	**Score: (+4)** - A large area will reach a higher level of soil status after remediation. However, at the same time liming may affect some soil functions in a negative way.	**Score: (+8)** - A large area will reach a higher level of soil status after remediation..
E2: Physical Impact on Flora and fauna	Flora and fauna RA On-Site	**NR** - No physical disturbances on any species with protection value.	**NR** - No physical disturbances on any species with protection value.	**NR** - No physical disturbances on any species with protection value.
E3: Groundwater	Groundwater RA On-Site	**Score: (-4)** - The remedial action is expected to have negative impact on the groundwater quality on-site.	**Score: (-4)** - The remedial action is expected to have some negative impact on the ground water quality on-site.	**Score: (0)** - Planting and addition of a small amount of iron oxides will not affect groundwater quality.
	Groundwater RA Off-Site	**Score: (-4)** - The remedial action may also have negative impact on the groundwater quality off-site.	**Score: (0)** - Liming will not affect groundwater quality off-site.	**Score: (0)** - Addition of iron oxides will not affect groundwater quality off-site.
	Groundwater SC On-Site	**Score: (+8)** - A short-term and long-term positive effect is expected on site when the contaminant concentration in the soil is reduced.	**Score: (+4)** - A short-term and long-term positive effect is expected off site when contaminants are immobilized by liming.	**Score: (+4)** - A mid-term and long-term positive effect is expected on site when contaminants are immobilized by phytostabilization.
	Groundwater SC Off-Site	**Score: (+4)** - A long-term positive effect is expected on site when the contaminant concentration in the soil is reduced.	**Score: (+4)** - A long-term positive effect is expected off site when contaminants are immobilized by liming.	**Score: (+4)** - A long-term positive effect is expected on site when contaminants are immobilized by phytostabilization.
E4: Surface Water	Surface Water RA On-Site	**Score: (-8)** - Excavation is expected to cause an increase of polluted soil particles in surface water. Excavation is also assumed to include handling of polluted soil at the surface of the site. The extensive excavation is expected to have severe negative impact on the surface water quality on-site.	**Score: (-4)** - The surface water quality on-site may be affected by chemicals or machinery etc.	**Score: (-4)** - The surface water quality on-site may be affected by machinery etc.
	Surface Water RA Off-Site	**Score: (-4)** - Excavation is expected to cause an increase of polluted soil particles in surface water. Excavation is also assumed to include handling of polluted soil at the surface of the site. The extensive excavation is expected to have negative impact on the surface water quality off-site.	**Score: (0)** - The surface water quality off-site is not affected.	**Score: (0)** - The surface water quality off-site is not affected.
	Surface Water SC On-Site	**Score: (+8)** - All polluted soil at the surface of the site will be removed, leading to significantly lower levels of contaminants in surface (run off) water.	**Score: (+4)** - Contaminants in surface soil at the site will be immobilized, leading to significantly lower levels of contaminants in surface (run off) water.	**Score: (+4)** - Contaminants in surface soil at the site will be immobilized, leading to significantly lower levels of contaminants in surface (run off) water.
	Surface Water SC Off-Site	**Score: (+4)** - All polluted soil at the surface of the site will be removed, leading to significantly lower levels of contaminants in surface (run off) water.	**Score: (+4)** - Contaminants in surface soil at the site will be immobilized, leading to significantly lower levels of contaminants in surface (run off) water.	**Score: (+4)** - Contaminants in surface soil at the site will be immobilized, leading to significantly lower levels of contaminants in surface (run off) water.
E5: Sediment	Sediment RA On-Site	**NR** - Not affected	**NR** - Not affected	**NR** - Not affected
	Sediment RA Off-Site	**NR** - Not affected	**NR** - Not affected	**NR** - Not affected
	Sediment SC On-Site	**NR** - Not affected	**NR** - Not affected	**NR** - Not affected
	Sediment SC Off-Site	**NR** - Not affected	**NR** - Not affected	**NR** - Not affected
E6: Air	Air RA Off-Site	**Score: (-8)** - Significant increase in green house gas (GHG) emissions due to transportation of excavated soil, as well as transportation of filling material. See also C3b in the economic domain.	**Score: (-4)** - Increase in green house gas (GHG) emissions due to transportation of chemicals. See also C3b in the economic domain.	**Score: (0)** - No significant change in relation to the reference scenario.
E7: Non-renewable Natural resources	Natural Resources RA Off-Site	**Score: (-8)** - High amount soil needed for refilling.	**Score: (-4)** - Amount of lime needed for immobilization.	**Score: (0)** - Very small amount of chemicals needed; Growing of renewable resources.
E8: Non-recyclable Waste Generation	Waste RA Off-Site	**Score: (-8)** - Amount of waste generated due to lamndfilling.	**Score: (-4)** - Volume increase due to liming which causes excavation waste.	**Score: (0)** - No significant change in relation to the reference scenario.

Table 2m. *Input values for the shooting range site in the social domain. NR = Not relevant; NP = No positive scores possible; NN = No negative score possible; AS = All scores possible; Mode = most likely score; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Key criteria	Sub-criteria	Alternative 1			Alternative 2			Alternative 3		
		Range	Mode	Unc	Range	Mode	Unc	Range	Mode	Unc
S1: Local Environmental Quality and Amenity	LEQ RA On-Site	NP	-8	M	NP	-4	M	NP	0	M
	LEQ RA Off-Site	NP	-8	M	NP	-4	M	NP	0	M
	LEQ SC On-Site	NN	8	M	NN	4	M	NN	4	H
	LEQ SC Off-Site	NN	0	M	NN	0	M	AS	0	H
S2: Cultural Heritage	Cultural Heritage RA On-Site	NR			NR			NR		
	Cultural Heritage RA Off-Site	NR			NR			NR		
S3: Health and Safety	Health and Safety RA On-Site	NP	-4	M	NP	-4	M	NP	-4	M
	Health and Safety RA Off-Site	NP	-4	M	NP	-4	M	NP	0	M
	Health and Safety SC On-Site	NN	8	L	NN	4	M	NN	4	M
	Health and Safety SC Off-Site	NN	0	L	NN	0	L	NN	0	L
S4: Equity	Equity RA On-Site	NP	-4	M	NP	-4	M	NP	-4	M
	Equity RA Off-Site	NR			NR			NR		
	Equity SC On-Site	NN	4	L	NN	0	L	NN	0	L
	Equity SC Off-Site	NR			NR			NR		
S5: Local Participation	Local Participation RA On-Site	AS	0	L	AS	0	L	AS	0	L
	Local Participation RA Off-Site	AS	0	L	AS	0	L	AS	0	L
	Local Participation SC On-Site	AS	0	L	AS	0	L	AS	0	L
	Local Participation SC On-Site	AS	0	L	AS	0	L	AS	0	L
S6: Local Acceptance	Local Acceptance RA On-Site	NP	-8	L	NP	-4	L	NP	-4	L
	Local Acceptance RA Off-Site	NP	-8	L	NP	-4	L	NP	-4	L
	Local Acceptance SC On-Site	NN	4	L	NN	4	L	NN	4	L
	Local Acceptance SC On-Site	NR			NR			NR		

Table 2n. *Scoring motivation for the shooting range site in the social domain.*

Key criteria	Sub-criteria	Motivation		
		Alt. 1	Alt. 2	Alt. 3
S1: Local Environmental Quality and Amenity	LEQ RA On-Site	**Score: (-8)** - Strongly affected by excavation.	**Score: (-4)** - Affected by lime-mixing etc.	**Score: (0)** - No significant change in relation to the reference scenario.
	LEQ RA Off-Site	**Score: (-8)** - Strongly affected by transport etc.	**Score: (-4)** - Affected by transport etc.	**Score: (0)** - No significant change in relation to the reference scenario.
	LEQ SC On-Site	**Score: (+8)** - Multipurpose use	**Score: (+4)** - Better than before.	**Score: (+4)** - Better than before.
	LEQ SC Off-Site	**Score: (0)** - No significant change to reference scenario.	**Score: (0)** - No significant change to reference scenario.	**Score: (0)** - No significant change to reference scenario.
S2: Cultural Heritage	Cultural Heritage RA On-Site	**NR** - No cultural heritage.	**NR** - No cultural heritage.	**NR** - No cultural heritage.
	Cultural Heritage RA Off-Site	**NR** - No cultural heritage.	**NR** - No cultural heritage.	**NR** - No cultural heritage.
S3: Health and Safety	Health and Safety RA On-Site	**Score: (-4)** - Workers' safety	**Score: (-4)** - Workers' safety	**Score: (-4)** - Workers' safety
	Health and Safety RA Off-Site	**Score: (-4)** - Neighbourhoods affected	**Score: (-4)** - Neighbourhoods affected	**Score: (0)** - Neighbourhoods affected
	Health and Safety SC On-Site	**Score: (+8)** - Strong decrease in risk for exposure.	**Score: (+4)** - Strong decrease in risk for exposure.	**Score: (+4)** - Strong decrease in risk for exposure.
	Health and Safety SC Off-Site	**Score: (0)** - No significant change to reference scenario	**Score: (0)** - No significant change to reference scenario.	**Score: (0)** - No significant change to reference scenario.
S4: Equity	Equity RA On-Site	**Score: (-4)** - Neighbourhoods affected	**Score: (-4)** - Neighbourhoods affected	**Score: (-4)** - Neighbourhoods affected
	Equity RA Off-Site	**NR** - No significant change to reference scenario.	**NR** - No significant change to reference scenario.	**NR** - No significant change to reference scenario.
	Equity SC On-Site	**Score: (+4)** - Multipurpose use	**Score: (0)** - Multipurpose use	**Score: (0)** - Multipurpose use
	Equity SC Off-Site	**NR** - No significant change to reference scenario.	**NR** - No significant change to reference scenario.	**NR** - No significant change to reference scenario.
S5: Local Participation	Local Participation RA On-Site	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.
	Local Participation RA Off-Site	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.
	Local Participation SC On-Site	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.
	Local Participation SC Off-Site	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.	**Score: (0) -** No significant change to reference scenario.
S6: Local Acceptance	Local Acceptance RA On-Site	**Score: (-8)** - Strongly affected by excavation.	**Score: (-4)** - Affected by lime-mixing etc.	**Score: (-4)** - Affected by mixed-in-place .
	Local Acceptance RA Off-Site	**Score: (-8)** - Strongly affected by transport etc.	**Score: (-4)** - Affected by transport etc.	**Score: (-4)** - Affected by transport etc.
	Local Acceptance SC On-Site	**Score: (+4)** - Multipurpose use.	**Score: (+4)** - Better than before.	**Score: (+4)** - Better than before.
	Local Acceptance SC Off-Site	**NR** - No significant change to reference scenario.	**NR** - No significant change to reference scenario.	**NR** - No significant change to reference scenario.

Table 2o. *Input values for the CBA of the shooting range remediation alternatives. All monetary values in euros (€). P = Payer; B = Beneficiary; DEV = Developer; EMP = Employees; PUB = Public, including neighbours; Unc = degree of uncertainty; L = Low uncertainty; M = Medium uncertainty; H = High uncertainty.*

Main items	Sub-items	Alternative 1			Alternative 2			Alternative 3			Alternative 4			Alternative 5		
		B/P	Mode	Unc	B/P	Mode	Unc	B/P	Mode	Unc	B/P	Mode	Unc	B/P	Mode	Unc
B1. Increased property values	B1. Increased property value on site	DEV	0	M	DEV	0	M	DEV	0	M						
B2. Improved Health	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	B3a. Increased recreational opportunities on site															
	B3b. Increased recreational opportunities in the surroundings															
	B3c. Increased provision of other ecosystem services															
B4. Other positive externalities	B4. Other positive externalities															
C1. Remediation costs	C1a. Costs for investigations and design of remedial actions	PUB	200 000	M	PUB	80 000	M	PUB	50 000	M						
	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	PUB	2 000 000	H	PUB	800 000	H	PUB	500 000	H						
	C1e. Costs for design and implementation of monitoring programs including sampling, analysis and data processing	PUB	0	L	PUB	60 000	M	PUB	60 000	M						
	C1f. Project risks															
C2. Impaired health due to the remedial action	C2a. Increased health risks due to the remedial action on site															
	C2b. Increased health risks due to transports to and from the remediation site															
	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	C3a. Decreased provision of ecosystem services on site due to the remedial action															
	C3b. Decreased provision of ecosystem services off site due to the remedial action															
	C3c. Decreased provision of ecosystem services due to environmental effects at the disposal site															
C4. Other negative externalities	C4. Other negative externalities															