Enriching social and economic aspects in sustainability assessments of remediation strategies – Methods and implementation

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Enriching social and economic aspects in sustainability assessments of remediation strategies – Methods and implementation

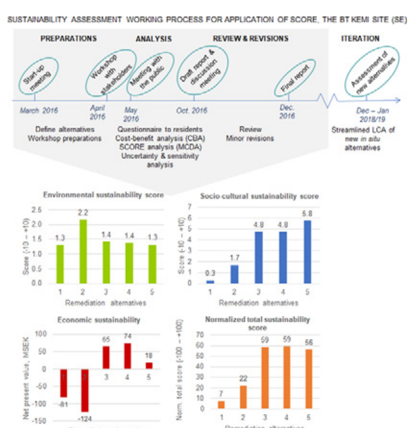
Jenny Norrman [a,*], Tore Söderqvist [b], Yevheniya Volchko [a], Pär-Erik Back [c], David Bohgard [d], Eva Ringshagen [e], Helena Svensson [f], Peter Englöv [g], Lars Rosén [a]

[a] Chalmers University of Technology, Department of Architecture and Civil Engineering, SE-412 96 Göteborg, Sweden
[b] Anthesis Enveco AB, Barnhusgatan 4, SE-111 23 Stockholm, Sweden
[c] Swedish Geotechnical Institute, SE-111 27 Stockholm, Sweden
[d] Tyréns AB, Isbergs gata 15, SE-211 19 Malmö, Sweden
[e] NIRAS Sweden AB, Västra Varvsgatan 19, SE-211 77 Malmö, Sweden
[f] Municipality of Svalöv, SE-268 80 Svalöv, Sweden
[g] Sweco Environment AB, Drottningtorget 14, SE-211 25 Malmö, Sweden

HIGHLIGHTS

- Demonstration of a broad sustainability assessment of remediation alternatives.
- Social and economic data were enriched by a questionnaire study of residents.
- Residents preferred alternatives with a high degree of removal of contaminants.
- The sustainability assessment contributed to the formulation of new alternatives.
- Earlier sustainability considerations in the project would have been beneficial.

GRAPHICAL ABSTRACT



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ABSTRACT

Over the last decade, there has been rapid development in promoting and implementing sustainable remediation. It is now common to include at least some sustainability considerations in remediation projects. Specific challenges that have been highlighted often relate to economic and social aspects not receiving enough attention: broadening the social aspects, community and meaningful stakeholder engagement, understanding stakeholders' risk perception, and a need for better estimates of site-specific economic costs and benefits. This study presents an application of the Sustainable Choice of REmediation (SCORE) framework with special focus on (1) demonstrating the working process for a broad sustainability assessment and (2) sharing the lessons learned from its application. Specific objectives are to describe (a) the types of stakeholders involved in the assessment, (b) the methods for collection of social and economic sustainability data, (c) residents' perception of risks, (d) the use of the sustainability assessment results in the decision-making process, and (5) possibilities for improving the methods and working process. SCORE was applied and evaluated with input from, and together with,

* Corresponding author.
E-mail address: jenny.norrman@chalmers.se (J. Norrman).

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stakeholders at the BT Kemi industrial site in the village of Teckomatorp, south Sweden, a former pesticide production site associated with the most infamous Swedish environmental scandal. A questionnaire ($n = 78$) was used to collect input from residents regarding local acceptance and economic externalities of the remediation alternatives. Alternatives with a high degree of removal of contaminants received a high ranking in the assessment, primarily due to social and economic effects. The working process can be improved, specifically regarding workshop preparation and workshop structure. A broad representation of stakeholders and early establishment of communication channels to residents is key for robust assessment of social aspects. The information from the sustainability assessment was used in the decision-making process, not least for revising remediation options.

1. Introduction

1.1. Background

A few years ago, based on a questionnaire study and a review of theories and empirical evidence, Hou and Al-Tabbaa (2014) concluded that sustainability is a new imperative in land remediation. Since then there has been rapid development of sustainable remediation. In addition to the general trend in society to promote sustainable development, including the development of the Sustainability Development Goals (SDGs) in 2015 by the United Nations (UN, 2019), there are several initiatives actively promoting sustainable remediation. Rizzo et al. (2016) reviewed nine different frameworks created by organizations promoting sustainable remediation and brownfield regeneration, including five national SuRF (Sustainable Remediation Forum) initiatives, the Common Forum, ITRC (Interstate Technology & Regulatory Council), NICOLE (Network for Industrially Co-ordinated Sustainable Land Management in Europe), ASTM International and ISO (International Organization for Standardization). Since then, the ISO standard on sustainable remediation 18504 has been published (ISO, 2017) and today SuRF is active in several countries worldwide, e.g. USA, UK, Canada, The Netherlands, Italy, Brazil, Australia & New Zealand, and Taiwan (SuRF, 2017). In addition, several international conferences on the theme sustainable remediation have been organized (e.g. SustRem in 2009, 2012, 2014, 2016 and 2018). Both in parallel, and as a response to, the increased promotion of sustainability assessment of remediation technologies and brownfield regeneration options, several decision support tools and methods have been developed (see e.g. reviews by Brinkhoff, 2011; Beames et al., 2014; Cappuyns, 2016; Huysegoms and Cappuyns, 2017).

Bardos et al. (2018) concluded that the SuRF-UK guidance material has achieved its aim of encouraging the adoption of a broad set of indicators for sustainable remediation decision-making in the UK, based on several national examples since the adoption of the SuRF-UK framework. To support even wider consistent application of the ISO standard and the SuRF-UK framework, Smith (2019) examined eight common misconceptions regarding sustainable remediation, for example, that sustainable remediation may lead to intolerable residual risks, that sustainability is all about saving money, or that sustainability assessment is the same as conducting a CO_2 footprint analysis or a cost-benefit analysis (CBA). Smith (2019) provided insightful responses to the eight misconceptions, but even though the concept of sustainable remediation is now rather mature and is being applied worldwide (see e.g. Bardos et al., 2018), it is doubtful whether broad sustainability considerations can be described as mainstream for the large number of remediation and brownfield regeneration projects. The benefits of full sustainability assessments compared to more limited assessments such as a green remediation assessment, or a more traditional assessment focusing on health and environmental risks and remediation costs, was demonstrated by Anderson et al. (2018). Today, due to the rapid development over the last few years, it is now common to include at least some sustainability considerations in remediation and regeneration projects.

Examples of specific challenges that have been highlighted in the literature include sustainable management practices in the early stages of projects (Bardos et al., 2016; Harclerode et al., 2016a), community engagement in projects with substantial public investment and broadening the social aspects (Bardos et al., 2018), meaningful stakeholder engagement early in projects (Harclerode et al., 2015; Cappuyns, 2016) and understanding stakeholders' and residents' risk perception (Harclerode et al., 2016b; Prior and Rai, 2017). In particular, the social aspects of sustainable remediation have been critically reviewed (Cappuyns, 2016), with the general conclusion that they do not receive enough attention. Harclerode et al. (2015) also pointed out the need for further research on estimating site-specific economic costs and benefits to be used in a CBA. Although each site is unique, case study applications demonstrating implementation of sustainable remediation in practice are important (Flyvbjerg, 2006) to showcase methods of data collection, demonstrate stakeholder involvement and share the lessons learned (good and bad).

1.2. Aim and objectives of study

The overall aim of this paper is to present an application of the Sustainable Choice of REmediation (SCORE) framework (Rosén et al., 2015) with special focus on (1) demonstrating the working process of a broad sustainability assessment and (2) sharing the lessons learned from its application. Specific objectives are to describe (a) the types of stakeholders involved in the assessment, (b) the methods of collection of social and economic sustainability data, (c) residents' perception of risks, (d) the use of the final sustainability assessment in the decision-making process, and (5) possibilities for improving the methods and working process.

2. Case study: the BT Kemi site

2.1. Site history

BT Kemi is probably one of the most well-known contaminated sites in Sweden, situated in the village of Teckomatorp in the municipality of Svalöv, south Sweden (Fig. 1). The site is divided into a Northern and a Southern Sector by the railway line connecting Teckomatorp and the city of Helsingborg. There follows a summary of the site history, but more detail is available on the municipality's website (Svalöv Municipality, 2017). The description of the contamination status is based on the environmental investigation reports (Sweco Viak, 2004).

The company Bönnelyche & Thuröe AB[1] bought the former sugar beet juice factory at the site in 1964 to move to and expand their pesticide production. Production included various phenoxy acids and chlorophenols from base chemicals, and manufacturing a variety of products from these compounds as well as other active substances. By the mid-70s, the total production was about 4000 t per year of which 2000 t were active substances. Quantitatively, the most common products were the phenoxy acids MCPA, MCPP and 2,4-D. The herbicide Dinoseb (dinitro butylphenol) was manufactured between 1966 and 1971. Sludge and other residual products from the process were stored

[1] AB is the Swedish abbreviation for *aktiebolag*, which translates to *limited company* in English.

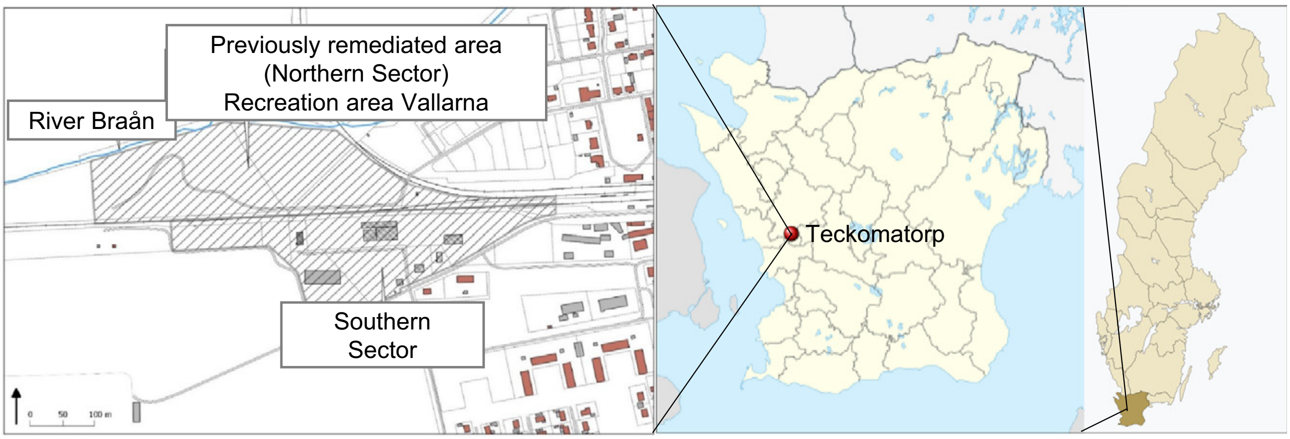

Fig. 1. Location of the BT Kemi site in south Sweden.

in the Northern Sector and dealt with primarily by means of illegal[2] burial of drums containing hazardous waste within that sector. The amount of waste produced at the factory during its production years is unknown. The waste water system was not fully functional and large volumes of process chemicals were released to settling ponds in the Northern Sector, which not only leaked into the nearby River Braån but, at times, were also emptied by pumping waste water directly to the river.

At that time, there was regularly a strong smell over the village of Teckomatorp, and several of the residents experienced breathing problems. The situation was complex: residents in Teckomatorp either saw the industry as an asset providing employment opportunities, or as an environmental hazard. Eventually, a civil action group formed, led by Ms. Monica Nilsson (in 2002 she received the environmental prize of Svalöv Municipality), which produced a petition in 1975 requesting cessation of production. The management of BT Kemi had previously dismissed all allegations about improper handling of chemicals but eventually, the controlling authority identified toxic contents in the buried drums. Consequently, in 1977, the authorities banned all activities at the site because of the severe contamination which was found. BT Kemi was declared bankrupt by the parent company Kemisk Værk i Køge A/S[3] by the end of 1977, but the contamination was left at the site. The County Administration led the subsequent environmental investigations and the first remediation work. When the remediation was finished in the late 1970s, the property was transferred to the municipality which sold the land to private businesses. The monitoring programme in the Northern Sector revealed, however, that there was no decline in contamination levels in the drainage water from the site.

2.2. Recent management of the site

The responsibility for the final remediation of the site was taken on by the municipality in 2002 and a dedicated BT Kemi project group was created. Funding was received from the Swedish Environmental Protection Agency (SEPA). The main study for the environmental risk assessment was finalized in 2004 and concluded that the Northern Sector was the major problem in terms of contamination and, during the period 2005–2006, preparations for the remediation of the Northern Sector were carried out. By the end of 2009, the Northern Sector was fully remediated and about 80,000 t of soil were excavated and thermally treated in Germany, using high temperature thermal desorption. At the site, the excavations were backfilled and covered with clean soil, creating a landscape with small hills and a pond, as a recreation area called Vallarna. Leachate from the Northern Sector was continuously pumped to a water treatment plant in the city of Landskrona.

The Southern Sector had previously been remediated, but during work in the Northern Sector, suspicions arose that there was contamination left in the ground. New investigations in the Southern Sector revealed that this indeed was the case and that the remediation would be more complicated than for the Northern Sector due to the presence of old concrete foundations and several active businesses. After some discussions with the SEPA, the work was divided into three phases: 1) reacquisition of properties, relocation of the companies, demolishing all buildings and a detailed assessment of the risks posed by contaminants to the River Braån; 2) preparation, procurement and application for new funding from SEPA; and 3) the remediation and redevelopment of the area. Due to the long-established bad reputation of the site, overarching goals of the remediation project were to find a once and for all solution to the contamination: a solution that is both sustainable and has the potential to change the general attitude towards the village and to allow for long-term positive socio-economic development in the area. The following general project goals were defined for the Southern Sector (Svalöv Municipality, 2016):

- The area shall be remediated in such way that it does not pose any risk to the surroundings and is fit for purpose.
- The area shall, after completed remediation, be used primarily as a public recreation area.
- The ongoing pumping of leachate water collected at the site to the waste water treatment plant in the City of Landskrona shall stop after remediation is completed.
- The remediation shall provide an excellent example for future projects.
- One important goal in the project is that the image of and the attitudes towards the village of Teckomatorp shall change in such way that the village is no longer burdened by its association with BT Kemi.

Early in the project, on the municipality website,[4] historic information was made available; to this, new information is regularly added about the project progress. In addition, to support communication with the community, a specific location was selected, where historic information material is exhibited and where regular meetings are held to inform and to answer any questions from the local community. In order to investigate the sustainability of the remediation strategies that were

[2] The burial was illegal, but the responsible persons could never be charged due the limitation-time of that type of crime being only 2 years at that time. The buried drums were found after 4 years.

[3] A/S is the Danish abbreviation for *aktieselskab*, which translates to *limited company* in English.

[4] http://www.svalov.se/ovrigt/ga-direkt/bt-kemi-efterbehandling.html (Accessed 11/07/2019).

Table 1
Overview of remediation alternatives analysed in the SCORE assessment for the BT Kemi Southern Sector.

Alternative	Description
Reference alternative	No remediation is carried out; the ongoing pumping of leachate water to the municipal waste water treatment plant is stopped. Project goals are not fulfilled regarding risks to humans and the environment, nor regarding the long-term image of the site.
Alternative 1: Pump and cover	Continue pumping of leachate waste water to the treatment plant in Landskrona; release of treated leachate into the sea which is the current temporary solution for the site; 1 m clean soil cover for establishment of vegetation; 2 m clean soil cover in source area as opposed to the current fencing of this area. Risks to human health, the soil ecosystem, and the River Braån will be reduced to tolerable levels, but all project goals are not reached. Contaminants are left in the ground to such an extent that there will be future land use restrictions in the land use plan.
Alternative 2: *On site* containment	A physical barrier around the source area to stop the spread of contaminants, consisting of non-permeable vertical walls and horizontal cover; 1 m clean soil cover for establishment of vegetation; long-term monitoring programme. Risks to human health, the soil ecosystem, and the River Braån are reduced to tolerable levels. Contaminants are left in the ground to such an extent that there will be future land use restrictions.
Alternative 3: Limited excavation and *off site* high temperature thermal desorption	Excavation, transport of contaminated soil for high temperature thermal desorption at a mobile treatment plant established within 50 km of the site; backfilling at the site with treated clean soil; 1 m clean soil cover for establishment of vegetation. Risks to human health, the soil ecosystem, and the River Braån are reduced to tolerable risk levels. Some contaminants (~36%) are left in the soil, resulting in some future land use restrictions. Underground constructions affected by the contamination are excavated and disposed of, pipes and cables are secured.
Alternative 4: Limited excavation and *off site* disposal	Same as Alt. 3, except that the soil is transported to a waste disposal facility situated 460 km north of Teckomatorp. Virgin material will be used to backfill the excavations at the site.
Alternative 5: Full excavation and *off site* high temperature thermal desorption	The same as Alt. 3, but the excavation is more extensive and only 21% of the contaminants are left at the site. This implies some future land use restrictions in the land use plan and involves backfilling of the site with larger amounts of the treated clean soil.
Maximum alternative	Same as Alt. 4 but entails complete excavation of all contaminated material. The maximum alternative is outlined in order to create a global scale against which the other alternatives are scored regarding secondary effects of the remediation in the environmental dimension (i.e. key criteria Air, Natural resources, and Waste).

being proposed by the technical consultant, it was decided to carry out a sustainability assessment using the SCORE method (Rosén et al., 2015), with the aim of supporting the decision-making process.

2.3. Remediation alternatives for the Southern Sector

Five remediation alternatives (including the reference alternative) were developed by Svalöv Municipality (2016), based on earlier consultancy reports and slightly modified for the purpose of the SCORE assessment (Volchko et al., 2016), see Table 1. The five alternatives were later extended to include in situ thermal treatment options, but this was not part of the original SCORE assessment (see also Section 3.2).

3. Method

3.1. Sustainable Choice Of REmediation – SCORE

SCORE was developed to support sustainability assessment of remediation alternatives by means of multi-criteria decision analysis (MCDA) with the opportunity to account for uncertainties in the assessment. For more details on the different parts of SCORE, the reader is

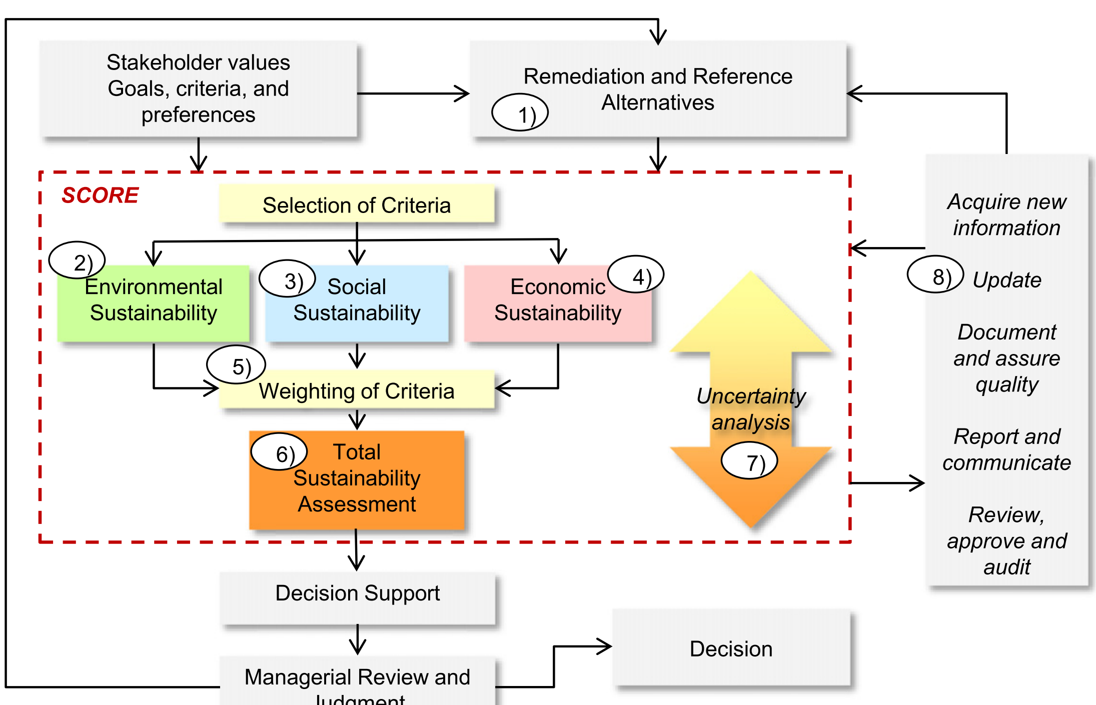

Fig. 2. The SCORE decision support framework (from Rosén et al., 2015). Numbers are explained in Table 3.

Table 2
Key criteria in SCORE (slightly modified after Rosén et al., 2015).

Environmental dimension	Social dimension	Economic dimension
E1: Soil	S1: Local environmental quality and amenity	Economic profitability as measured by net present value (NPV) in a cost-benefit analysis.
E2: Physical impact on flora and fauna	S2: Cultural heritage	
E3: Groundwater	S3: Health and safety	
E4: Surface water	S4: Equity	
E5: Sediment	S5: Local participation	
E6: Air	S6: Local acceptance	
E7: Natural resources		
E8: Waste		

referred to Rosén et al. (2015), Söderqvist et al. (2015), Volchko et al. (2013, 2014) and Brinkhoff et al. (2015). In short, SCORE builds upon the idea of three dimensions of sustainability: environmental, social and economic. The method combines semi-quantitative scores in the environmental and social dimensions with a qualitative and quantitative cost-benefit analysis (CBA) in the economic dimension and uses a linear additive model to rank alternatives. The SCORE decision support framework is presented in Fig. 2.

There are key criteria (Table 2) in the environmental and social dimensions which have indicators representing on-site and off-site effects as well as effects associated with the change in source contamination (SC) and the impacts of the remedial action (RA), respectively. Each social and environmental indicator is assigned a score between −10 and + 10, representing expected effects relative to the reference alternative. The cost and benefit items are quantified in monetary terms as present values. All indicators and cost-benefit items are assigned statistical distributions representing the uncertainties of the assessments. The economic sustainability is represented by the net present value and social and environmental sustainability are represented by a weighted sum of social and environmental criteria, respectively.

In each dimension, the criteria are weighted according to importance: Not relevant, Not so important, Important, Very important. It is possible to adjust the weights at the dimension level, although the default setting is equal weighting of the three dimensions. A total sustainability index is calculated as a normalized weighted sum of the sustainability values in each domain. The uncertainty of sustainability scores is calculated by means of a Monte Carlo simulation. See Rosén et al. (2015) for a detailed description of the calculations.

3.2. Overview of the sustainability assessment working process

The SuRF-UK framework, summarized by Bardos et al. (2018), outlines a tiered approach to sustainability assessments for remediation projects, which can be carried out either during the Plan/project design (Stage A) or during Remediation implementation (Stage B). The three tiers go from qualitative assessment, via a semi-quantitative to a fully quantitative assessment (if needed), underpinned by suggested Sustainable Management Practices. The SCORE sustainability assessment carried out here corresponds to Stage B in the SuRF-UK framework. The assessment is semi-quantitative to quantitative, including both scoring scales and monetary units. The working process within the SCORE framework is summarized in Table 3. The table also shows which background data were available, the different actors involved and methods and tools that were used. Further details of actors relevant to the sustainability assessment are given in Table 4.

The work was carried out during 2016 with the major part of the data collection during spring, and analysis, report writing, and communication of results during autumn. After two years, the researchers were asked to update the sustainability assessment to add thermal in situ remediation alternatives (Norrman and Rosén, 2019). Although this update is not presented in detail here as it is out of the scope of this paper, the update lead to the final decision for the site. A summary of the timeline is presented in Fig. 3.

3.2.1. Environmental sustainability assessment

In the first round, the criteria in the environmental dimension were evaluated based on the environmental risk assessment and the remedial options appraisal (Svalöv Municipality, 2016) as a desk study. Experts on remediation techniques were contacted to advise on the type of fuel usually used for operating mobile thermal plants in remediation projects. The reasons for the scores were documented to provide a basis for discussion with the BT Kemi project group in the second round of the environmental assessment. Reasons for scoring of criteria that captured secondary effects of remediation alternatives (i.e. E6 – Air, E7 – Natural resources, and E8 – Waste) were based on quantitative assessment of these effects relative to the maximum alternative. In a second round, the scoring of the environmental criteria and their weightings were discussed and agreed upon with the BT Kemi project

Table 3
Overview of the steps in the SCORE framework, summarizing available background data, which actors and stakeholders were involved and the data collection methods and analytical tools that were used in the SCORE application for the Southern Sector. The numbered items are shown in Fig. 2. BTK PG is the BT Kemi project group, STA is the Swedish Transport Administration, and SWEA is the Swedish Work Environment Authority.

	SCORE framework step	Background data	Actors	Methods and tools
1	Generation of alternatives, including defining the reference alternative and the maximum alternative.	Report on suggested remediation alternatives	Researchers, BTK PG	Discussions
2	Selection, assessment and weighting of indicators and key criteria in the environmental dimension	Risk assessment report	Researchers, experts, BTK PG	Desk-study, discussions with experts
3	Selection, assessment and weighting of indicators and key criteria in the social dimension	Earlier questionnaire study carried out by the municipality, site history	Researchers, local and regional stakeholders, residents	Workshop, questionnaire
4	Assessment of economic sustainability	Reports on suggested remediation alternatives, reports from STA (2016) and SWEA (2016).	Researchers, local and regional stakeholders, local experts, residents	Workshop, interviews, desk-study, questionnaire, cost-benefit analysis (CBA)
5	Weighting of sustainability dimensions	–	Researchers, BTK PG	Discussions during workshops, interview with BTK PG
6	Calculation of sustainability index	–	Researchers	Multi-criteria decision analysis (MCDA)
7	Uncertainty analysis	–	Researchers	Monte Carlo simulations (MCS), scenario analysis
8	Review and revisions	–	BTK PG, environmental authority, researchers	Use of streamlined LCA in a later updated sustainability assessment[a]

[a] This method is not presented in this paper but is described in Franceschini (2018).

Table 4
List of actors directly or indirectly involved in the sustainability assessment in the BT Kemi project, either as providing input to the assessment or as important decision-makers. Numbers in brackets indicate which working process step (see Fig. 2 and Table 3) the actor was involved in.

	Supplying information or taking part in the sustainability assessment	Actively informed about the result of the sustainability assessment
	Facilitators	
a	Researchers carrying out the sustainability assessment primarily took on the roles as analysers and facilitators. (1–8)	
	Experts, some of whom are also stakeholders to some extent	
b	The BT Kemi project group (BTK PG), consisting of a project head and a project manager from the municipality and project supporting organization. During the time of the SCORE assessment, this support was an internal expert from the municipality and an external senior advisor with long-term experience in large remediation projects, who supported the project manager. The BT Kemi project group suggested and ordered the sustainability assessment and worked in close co-operation with the researchers to prepare all material. (1–5, 8)	
c	Land manager at the municipality. (4)	
d	External remediation experts. (2, 4)	
	Stakeholders having formal or informal power in BT Kemi project decisions	
e		The municipal council of Svalöv – approves all major decisions regarding the BT Kemi project.
f		The Swedish Environmental Protection Agency (SEPA) which approves the national funding for the BT Kemi project.
g		The steering group of the BT Kemi project group is politically appointed and funded by the municipality. The group approves most of the actions to be taken by the BT Kemi project group.
h	The County Administration which is the regional environmental authority that formally applies for funding from the SEPA, as well as controlling the implementation of the remediation. (3, 4)	
i	Strategic developer from the municipality. (3,4)	
j	Inter-municipal environmental authority (Söderåsens miljöförbund). (3, 4)	
k	Head of the division responsible for culture and leisure (recreation) in the municipality. (3)	
l	The local community/residents in Teckomatorp and the municipality of Svalöv. (3, 4)	

group. Natural gas was assumed to be the fuel that would be used in the thermal treatment plant, but different scenarios were investigated for other types of fuel (natural gas, diesel, ethanol, and natural gas combined with electric vehicles), although not presented in this paper (see Volchko et al., 2016).

3.2.2. Social sustainability assessment

Social sustainability criteria were evaluated and weighted with stakeholders during a 1-day socio-economic workshop in April 2016, facilitated by the participating researchers. Seven representatives with different backgrounds from the municipality, the county administration and from the BT Kemi project group were invited. Not all invited representatives were present due to time constraints, and some were only present during a part of the workshop due to other obligations. The workshop was 5 h long, including a lunch break. Not all participants were familiar with the remediation project in detail beforehand and therefore, along with the invitation, information about the research project and the SCORE method as well as the different remediation alternatives was sent out. The information was presented in a summary format for non-experts. The agenda for the workshop was: short presentation of the research study, presentation of the site and the remediation alternatives and thereafter scoring and weighting of the social criteria S1 – S5 (Table 2). Each social criterion was first presented by the facilitators and thereafter discussed in the group. When the participants were satisfied with the discussion, scores and weights were assigned. The discussions were open and did not follow strict protocols on speaking order, but the facilitators tried to allow all participants an equal amount of time and weight in the discussions. The criterion S6 "Local acceptance" is intended to measure what residents actually think about the different alternatives and, therefore, could not be evaluated by means

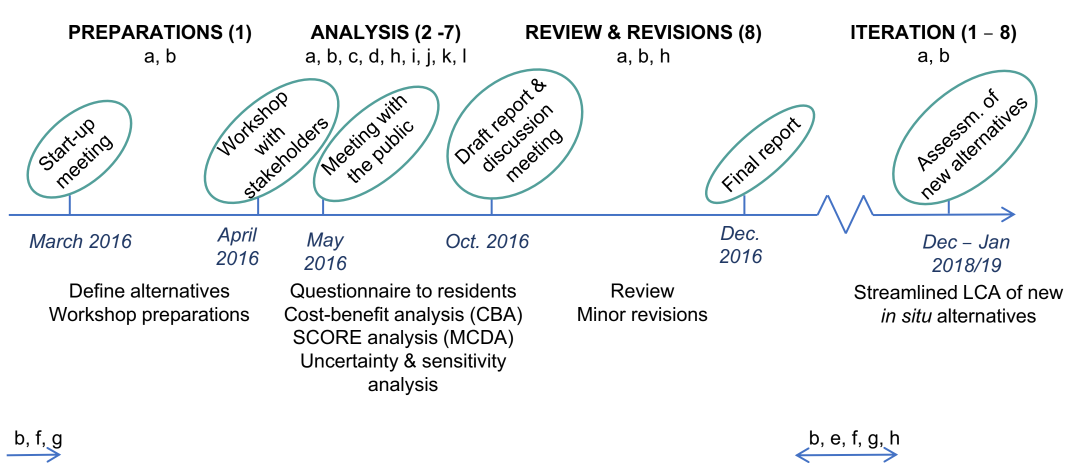

Fig. 3. Overview over the timeline in the BT Kemi sustainability assessment. Numbers refer to stages (see Fig. 2 and Table 3). Letters refer to actors (Table 4). Actors involved in decision-making outside the sustainability assessment are shown at the bottom of the figure. Prior to the assessment, a decision was made to carry out an assessment, and to fund it. After the final report, there was eventually a decision to update the assessment with new in situ alternatives.

of the workshop with representatives. Instead, a questionnaire study was undertaken to collect information about local acceptance; see Section 3.3.

3.2.3. Economic sustainability assessment

The CBA is structured around a number of cost and benefit items; see Söderqvist et al. (2015) for details. Cost items are costs of carrying out the remediation as well as negative externalities due to the remedial action, i.e. costs not incurred by the party responsible for the remediation such as emissions from transportation to and from the site. Benefits are potential increases in property value of the remediated site, but there are also positive externalities such as reduced health and environmental risks in the surroundings, i.e. consequences not accounted for by the increased property value of the remediated site.

The data collection for these costs and benefits was initiated at the 1-day socio-economic workshop. Participants were asked to make a qualitative assessment of the different cost and benefit items as either “very important”, “somewhat important” or “not relevant or not important”, as an indication of what items should be subject to monetization efforts. This was followed up through individual e-mail contact with the participants. The workshop indicated that a substantial increase in the value of properties in Teckomatorp is a likely effect of a successful remediation. This is because of the stigma associated with the BT Kemi scandal, with the general public still linking the village with contamination. An attitudinal survey carried out in 2009, i.e. 30 years after completion of the initial remediation of the site, indicated that 78% of residents in the County of Skåne associated Teckomatorp with BT Kemi (GfK, 2009). A questionnaire survey of local residents was therefore undertaken to obtain an indication of the perceived likely extent of property value increases; see Section 3.3. If the potential impact of remediation on property values can be isolated and estimated, this impact would serve as a measure of positive externalities due to the remediation. This is based on the hedonic approach to property values, suggesting that property values are determined by a range of characteristics of the property and its surroundings, including perceived environmental and health conditions (Freeman III et al., 2014). Relying on perceived property value increases implies a setting similar to stated preferences valuation studies. While they are numerously applied (Carson, 2011), their reliance on hypothetical scenarios might introduce biases (Johnston et al., 2017). On the other hand, a survey approach implies insights about potential market actors' attitudes, which has repeatedly been employed as a data source for hedonic studies (Phaneuf et al., 2013), and housing research often relies on self-assessed property values (Benítez-Silva et al., 2015). Besides the input from stakeholders during the workshop and the questionnaire study, additional interviews, collection of generic data, and a desk study of site-specific data sources relating to remediation costs and negative externalities associated with remedial action were carried out to complete the CBA. Experts were contacted for advice on the working environment in remediation projects to monetize impaired health due to remedial action.

3.3. Questionnaire study design

To collect data on the expected effects on property values and on local acceptance of the different remediation alternatives, a 7-page questionnaire was sent out to residents of the village of Teckomatorp. The first two pages of the questionnaire contained information about the research project and the remediation project. They were formulated in consultation with the BT Kemi project group. The questionnaire was based on a comparison of today's situation and two different types of remediation technologies: excavation and containment. It should be noted that the reference alternative in the SCORE assessment is not equivalent to the current situation, and that the SCORE assessment analyses five alternatives, not just two. However, this was a compromise in order to prevent the questionnaire being too complex and to avoid introducing residents to scenarios which would not be realistic. The content of the questionnaire is presented below, and the full questionnaire can be found in the Appendix.

- Background data (Q1 – Q3).
- What is important to consider in the remediation based on factors relating to either the end result or the implementation of the remediation (Q4)?
- Comparison between remediation technologies based on factors relating to the end result (SC) as well as the implementation of the remediation (RA) (Q5).
- Effects on property values (Q6 – Q15).
- Overall attitude towards remediation technologies (Q16 – Q17).
- Final comments.

The questionnaire was distributed in various ways:

- At a public information meeting in Teckomatorp organized by the BT Kemi project group: nine replies were handed over directly to the researchers. This served as a pilot study of the questionnaire, resulting in only limited changes.
- At the premises of local organizations in Teckomatorp: nine replies were sent to the researchers in prepaid envelopes handed out together with the questionnaires.
- By mail to 100 randomly selected residents in Teckomatorp, aged 18–80 years: 34 replies were obtained.
- By mail specifically to 91 randomly selected residents in Teckomatorp who own their house or condominium (people already included in the previous group were screened out): 26 replies were obtained. Note that “property” is used below as an abbreviation of “house or condominium”, if not otherwise stated.

In total, there were 78 respondents to the questionnaire, which is a sample of 4.3% of the 1808 residents aged 18–80 years in Teckomatorp. Some respondents did not reply to all questions in the questionnaire, thus the number of respondents (n) in the results do not always add up to 78.

3.4. Uncertainty and sensitivity analysis

Uncertainty analysis was performed with the Oracle Crystal Ball add-in software. The uncertainties in the resulting sustainability index were handled by assigning probability distributions to each variable in SCORE (i.e. the scores of criteria and the cost and benefit items) and running a Monte Carlo simulation (MCS), here 50,000 runs. MCS is a technique that randomly and repeatedly picks values from the probability distributions for each uncertain variable in the model to provide estimates of the likelihood of different outcomes (Bedford and Cooke, 2009). The method for assigning probability distributions to the variables of SCORE is described in Rosén et al. (2015) and Söderqvist et al. (2015).

Sensitivity analysis was performed with Oracle Crystal Ball to determine which input variables contribute most to the uncertainties in the sustainability assessment results. The sensitivity was determined by computing the correlation coefficients between each variable of SCORE and the resulting sustainability index during the MCS. Scenario analysis was performed to evaluate the contribution of data from the questionnaire studies.

4. Results

4.1. Stakeholder workshop: social assessment and economic aspects

In general, consensus was reached among the participants about the scoring and weighting of the social indicators and key criteria. The

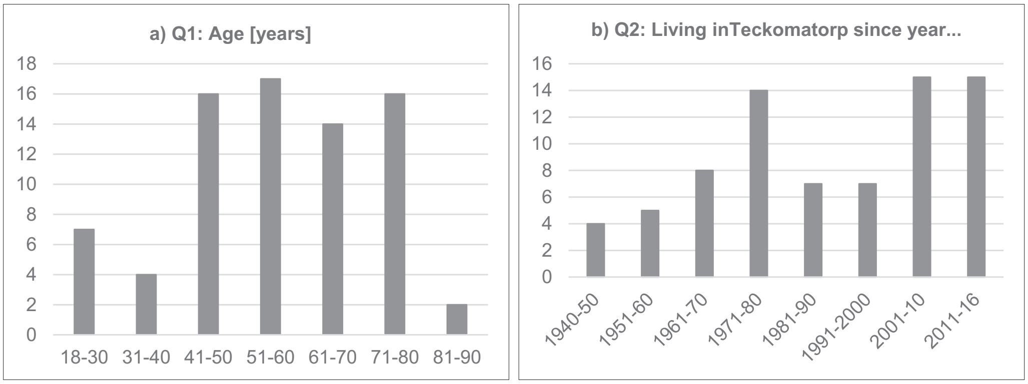

Fig. 4. Background data relating to the respondents. Graph a) shows a histogram of the ages of the respondents ($n = 76$, mean = 56 years, median = 55.5, min – max = 18–83, Stdev = 16.1) and graph b) shows the decade that the respondent started living in the village of Teckomatorp ($n = 75$, mean = 1988, median = 1990, min – max = 1940–2014, Stdev = 21.1).

overall goal of the project, to get rid of the stigma associated with Teckomatorp, was very apparent in the discussion of several of the criteria. A summary of the discussion and the detailed scores are presented in the Supplementary material.

The qualitative assessment of cost and benefit items that were initiated at the workshop indicated that it is not likely that the site itself will be subject to any major property value increase because of the remediation. This is because recreation is the designated land use of the site after remediation. There was an expectation of major positive externalities because of the remediation, especially in the case of Alts. 3–5, and all participants except one predicted that these externalities would be reflected in property value increases in Teckomatorp. The public acceptance of Alts. 1–2 was expected to be much lower and these alternatives would therefore probably not help to mitigate the stigma associated with Teckomatorp. As to cost items, remediation costs and negative externalities due to increased health and environmental risks because of emissions associated with the remedial action, were emphasized.

4.2. Questionnaire study results

The results relate to all respondents unless otherwise stated.

4.2.1. Background data

The age distribution and how long the respondents have lived in the village of Teckomatorp is shown in Fig. 4 (Questions Q1 and Q2). The mean of the respondents' ages is somewhat higher than the mean in the entire municipality (Svalöv Municipality, mean age 2016 = 40.4 years, Statistics Sweden, 2019). Fig. 5 shows the result of Q3 (How often do you visit Vallarna?).

4.2.2. Important factor to consider in remediation projects

Figs. 6 and 7 show the result of Q4 (What do you think is important or not important to consider when selecting a remediation alternative?), for the end result and for implementation of the remediation, respectively. Apart from accidents due to transportation, the respondents are in general more concerned about the end result of the remediation than its implementation. Fig. 6 shows that the respondents consider risks to human health, soil and surface water ecosystems and groundwater to be more important to consider for the end result than to be able to use the area for other purposes than recreation in the future. Interestingly, a slightly higher number of respondents consider "minimizing future effects on groundwater" to be Very important (70) than the number of respondents considering "achieving tolerable health risks" to be Very important (63). The questionnaire is not constructed to ask respondents to rate if one aspect is more important than another: such construction would likely have produced a different outcome. However, although the concerns for health effects were in focus for the public during the 1970s, the open and continuous communication in the current remediation project is likely to have affected the public's perception about current risks (human health risks are in fact rather low at present). Another factor which may influence the responses is that there are still households in the village of Teckomatorp with private drinking water wells.

In Q4, the respondents were also given the opportunity to reply to an open question about what they think is very important to consider with respect to the end result or the implementation. Below are some quotes from the replies.

> "That we finally get rid of the BT Kemi problem for ever."

> "To remove as much of the toxic material as possible so that Teckomatorp can be associated with something other than the toxin scandal, which still lives on."

> "That everyone can benefit from the area or from new construction."

> "It's more important that it's done well rather than being done quickly and conveniently with a less satisfactory outcome."

> "That the forward planning is effective enough to avoid a further round of remediation."

> "Not to create a whole load of damned hills. Everyone should be able to access the area."

> "To use local companies and natural resources as far as possible."

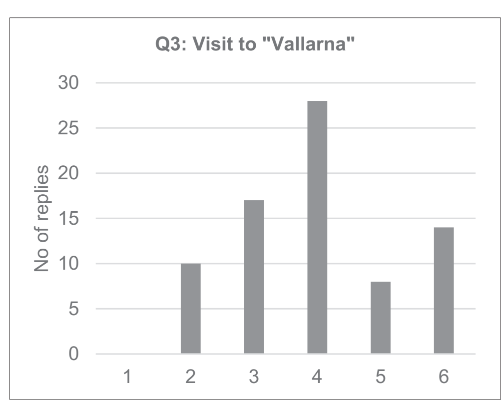

Fig. 5. The frequency of respondents' ($n = 77$) visits to the Vallarna recreational area. Category explanation: 1) every day; 2) one or a few times per week; 3) one or a few times per month; 4) one or a few times per year; 5) more rarely; 6) never.

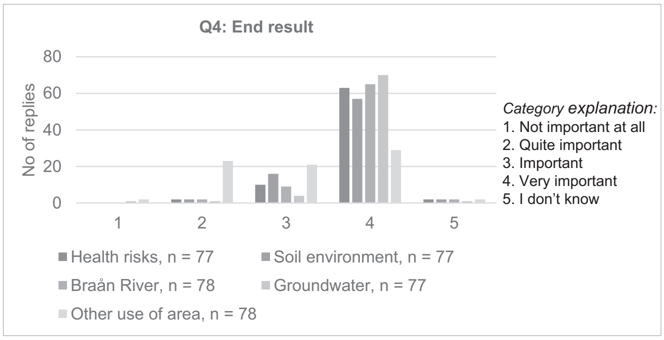

Fig. 6. Result of Q4 regarding the end result of the remediation: What do you think is important or not important to consider when selecting a remediation alternative? Q4a: To achieve tolerable health risks. Q4b: To achieve tolerable risks for the soil ecosystem in the Southern Sector. Q4c: To minimize future effects on the River Braån. Q4d: To minimize future effects on the groundwater. Q4e: That the area could be used for other purposes than recreation in the future.

4.2.3. Comparison of technologies

Q5 was about whether the respondent disagreed or agreed with statements about the two principally different remediation technologies: (i) excavation and (ii) containment. The replies are illustrated in Fig. 8. With respect to inconvenience during the remediation (Q5a and Q5b), there is little difference between the two approaches. However, although the end result of both containment and excavation are satisfactory from a technical as well as human health and ecological risk point of view, the respondents' perceptions about the end result of those alternatives differ quite much. Fig. 8 show that the attitudes towards excavation reaching satisfactory end results are more positive than towards containment (Q5c, Q5d, and Q5e).

4.2.4. Effects on property values

The answers to Q5d indicate that the majority of respondents predicted increasing property values after remediation through excavation, whereas the corresponding attitudes associated with containment are more mixed. Questions 6–15 in the questionnaire are less general in the sense that they are about potential value changes in the respondents' own property.

Of the respondents, 76% were property owners (Fig. 9a). Those respondents were asked, in Q7 – Q9, to state the sizes of plot and living space and their assessment of the present market value of their property, i.e. the pre-remediation price. This made it possible to calculate the present mean market price as SEK 11693 per m^2 of living space (median: 11538, min – max: 3279–20,000, Stdev = 4808). This mean value is very close to the mean price for residential properties sold in the municipality of Svalöv in the period September 2015 – August 2016: SEK 11337 per m^2 of living space (Svensk Mäklarstatistik, 2016). Annual price statistics for residential properties sold in Teckomatorp during the last ten years are based on scarce data, but almost all these prices are in the range SEK 5000–15,000 per m^2 of living space (Johansson, 2016) and thus indicate a somewhat lower mean price than in the municipality as a whole. While the respondents' self-assessed market values do not suggest such a price differential, this could be explained by the fact that homeowners tend to overestimate the value of their properties; Kiel and Zabel (1999) and Benítez-Silva et al. (2015) found for surveys in the US an average overvaluation of 5 and 8%, respectively. On the other hand, one has to keep in mind that residential location might be endogenous with respect to risk preferences (Schneider and Zweifel, 2013). If there are enough housing demanders having relatively small aversion towards potential risks from contaminants, this might, all else equal, tend to reduce price differentials across different locations in the municipality, in particular because the County Administrative Board (2015) reported no excess supply at the local property market. However, a potential zero price differential would not preclude a price increase in case of a remediation because this could turn also more risk averse individuals to potential buyers.

In Q10, the respondents were asked to assume that the remediation is completed and implemented by means of excavation. Thereafter they were asked to assess the direction of any change in the market price of their property as a result of the remediation. Fifty-eight percent of the respondents answered that the price would be somewhat or much higher. None of the respondents answered that the price would be somewhat or much lower. Question 13 was a corresponding question for the case of containment. In this case, 23% of the respondents answered that the price would be somewhat or much higher, and 12% that the price would be somewhat or much lower. The results are displayed in Fig. 9b.

Questions 11–12 and Q14–15 were follow-up questions to Q10 and Q13, respectively. The respondents were asked to state an interval for the market price in SEK that they predict for their property after remediation. The midpoint of these intervals was subsequently used in the analysis as a point estimate of the post-remediation property value. A percentage change in property value because of the remediation was obtained by comparing this point estimate to the respondents' assessments of present market value. Those respondents who in Q10 and Q13 stated that there would be no price change were asked in an open-ended question to state their reasons for this statement. The most common reasons were that other factors than the remediation are more influential for property prices and that the respondent's property is situated on the outskirts of the village.

Taking zero price changes into account, the resulting mean percentage change in property value because of remediation was +14% (median: 8, min – max: 0–108, Stdev: 19) in the case of excavation and + 1% (median: 0, min – max: (−25) – 46, Stdev: 11) in the case of containment. These results are consistent with the answers to Q5d, i.e. that remediation by excavation will probably result in increased property values in Teckomatorp, but remediation by containment is not likely to have this effect. A 14% property value increase might not be an unrealistic estimate. It is consistent with the predominant expectation among the stakeholder workshop participants. Also, a recent analysis of the impact of brownfield remediation in the US on nearby property values indicated average increases between 5 and 15%, which was found to be within a 3%–36% interval suggested by earlier literature (Haninger et al., 2017)."Nearby" was defined as being within 2.07 km from the remediated site, which is consistent with the situation in the village of Teckomatorp.

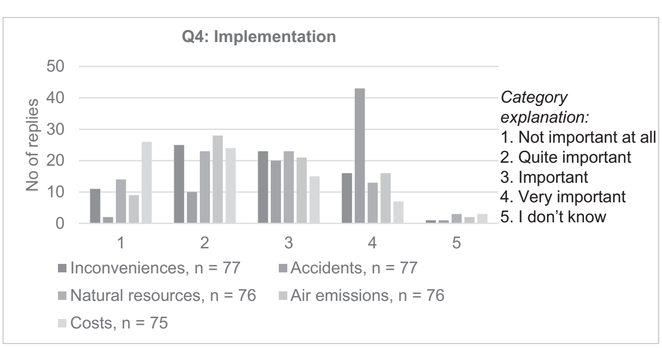

Fig. 7. Results of Q4, continued, regarding the implementation of the remediation: What do you think is important or not important to consider when selecting a remediation alternative? Q4f: That disturbance (transport, smells, dust, noise) are minimized. Q4g: That transportation hazards are minimized. Q4h: To minimize the consumption of natural resources, e.g. soil and gravel, petrol/ diesel. Q4i: To minimize air emissions, e.g. of greenhouse gases such as carbon dioxide. Q4j: That remediation costs are kept down.

4.2.5. Acceptance

Questions 16–17 were about the respondents' overall attitude towards the two remediation technologies; see Fig. 10. The respondents were, in general, more positive towards excavation.

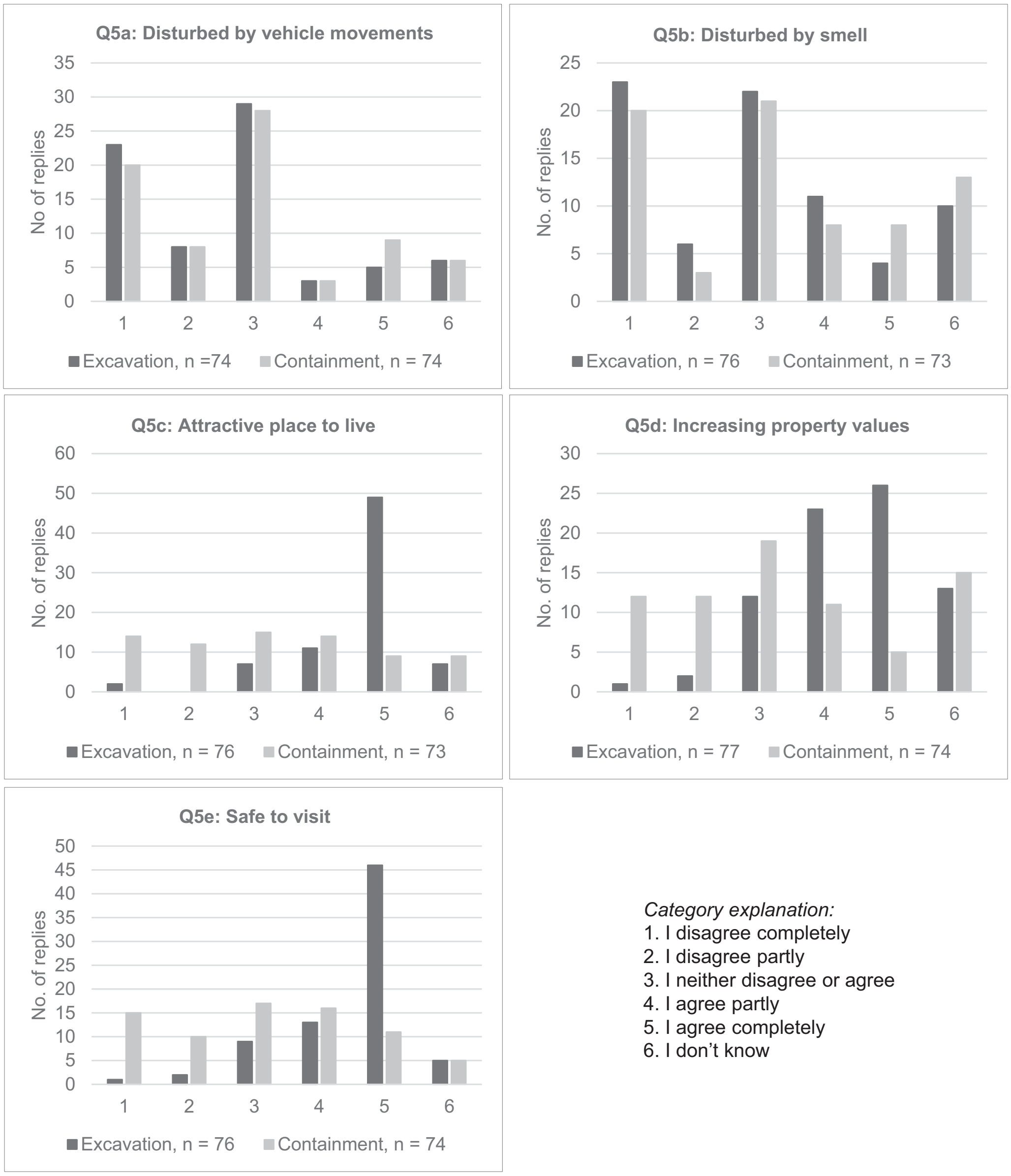

Fig. 8. Q5a: I would be disturbed by vehicle movements during the work. Q5b: I would be disturbed by smell during the work. Q5c: Teckomatorp will be a more attractive place to live in when the remediation of the Southern Sector is completed. Q5d: The price of properties in Teckomatorp will rise when the remediation of the Southern Sector is completed. Q5e: When the remediation is completed, I will feel completely safe to visit the Southern Sector.

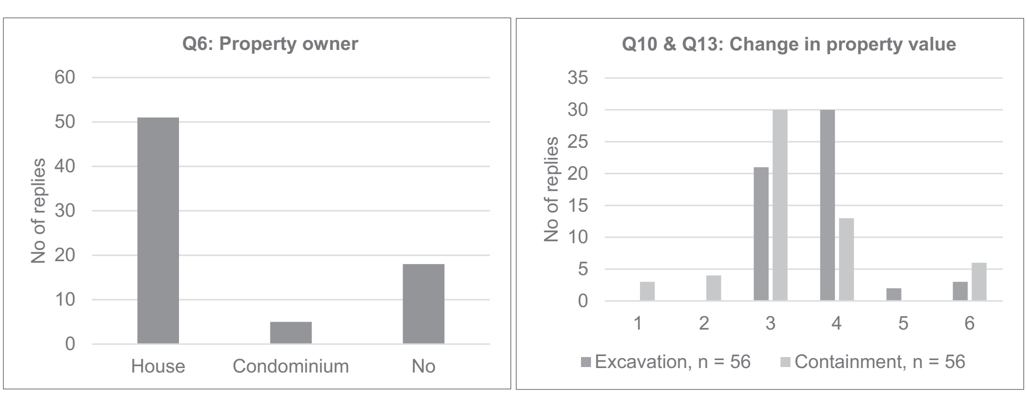

Fig. 9. a) Property owners ($n = 74$); b) Change of property values compared to current market price in the case of excavation and containment respectively. Category explanation: 1) much lower, 2) somewhat lower, 3) no change, 4) somewhat higher, 5) much higher, 6) I don't know.

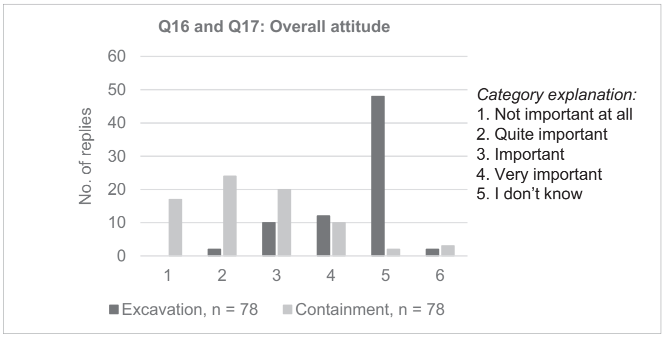

Fig. 10. The respondents' overall attitude to excavation and containment.

4.2.6. Final comments

The final Q18 was open-ended and gave the respondents the opportunity to describe, in their own words, their thoughts about what the remediation of the Southern Sector would result in for Teckomatorp as a village. The majority of the respondents ($n = 46$) provided a comment, some of which are quoted below.

> "For those of us who live here, a very sad story will finally be brought to a close, which is reassuring. For those moving into the area, the toxin scandal will still be part of the history of the village but it will have been remedied in a way that is right and fitting. The future residents of Teckomatorp, and their children who will eventually grow up here, will not feel part of this episode in history. I've grown up in Teckomatorp and lived here for most of my life. There was a time when I avoided telling people that I lived in Teckomatorp because the name had such strong negative connotations. That happened when I met anyone new. Remediation allows us to regain control of the contaminated land and the local residents can feel safe and secure and be in a position to respond well to any negative opinions. This applies equally to new people moving into Teckomatorp who are not involved in the scandal."

> "BT Kemi will be associated with the village for at least another generation. Remediation will not change this to any great extent. The questionnaire is very leading. Most residents in the village are unable to relate to abstract, future environmental consequences, and it is very likely that they will only respond from a transport and noise perspective. There was considerable resistance in the village prior to remediation, the reason being 'now it will start smelling again'. Think about the questions you pose and to whom before you draw any conclusions from the responses. This applies in particular to the market value of properties. Property prices in Teckomatorp, in the Municipality of Svalöv, and in the area in general, are very low, due largely to the way the area has been managed. In the case of Teckomatorp, far more is needed than remediation of the Southern Sector to enhance the attractiveness. Drive along the main street through the village and observe a level of misery that goes way beyond the norm."

> "The BT Kemi scandal is still very much alive in people's minds, particularly among those who do not live in Teckomatorp. Remediation would go some way towards ridding the village of its bad reputation. This would later lead to people moving here and the village would gradually grow and develop. If the Southern Sector were to be developed into a green space where people could spend time, perhaps with an outdoor gym, barbecue facilities, ponds and so on, it would speed up the process."

4.3. Translation of questionnaire results to SCORE input

When translating the results from the questionnaire to the SCORE assessment, there are two important things to bear in mind:

- The reference alternative in the SCORE assessment is a worse situation than today's situation.
- In the SCORE analysis, there are five alternatives (Table 1), whereas only two principally different strategies are investigated in the questionnaire. Four of the alternatives (Alts. 2–5) correspond to these principally different strategies, whereas Alt. 1 is more or less equal to today's situation but with the addition of soil cover to avoid direct contact with the contaminated soil.

4.3.1. Property values

It was noted above that the present mean self-assessed market price of properties in Teckomatorp is about SEK 11700 per m^2 of living space. Answers to Q8 in the questionnaire indicate that the mean living space is 154 m^2, which suggests a market price of an average property amounting to MSEK 1.8. There are about 800 properties in Teckomatorp, which implies a total market value of these properties amounting to $800 \times 1.8 =$ MSEK 1440.

Applying the point estimates above to the average price increase after remediation implies a post-remediation total market value of $1440 \times 1.14 =$ MSEK 1642, i.e. an increase of about MSEK 200, in the case of excavation. However, as noted in Section 4.2.4, it is an open question to what extent the self-assessed value is an overestimate. If the actual mean market price would be about SEK 10000 per m^2 of living space instead, i.e. about 14% lower, the total present market value of the properties would be MSEK 1232, and a 14% increase from this level corresponds to MSEK 172.The MSEK 200 increase was included in the CBA part of the SCORE assessment, used as the monetized positive externalities associated with excavation alternatives 3–5, but a lower estimate of MSEK 172 should be kept in mind below when interpreting the results.

The corresponding calculation for the case of containment is $1440 \times 1.01 =$ MSEK 1454, i.e. an increase of about MSEK 14, which is applied to the containment alternative (alt 2). The fact that the questionnaire study was based on a more beneficial reference alternative than used in the SCORE assessment implies that these increases might underestimate the positive externalities when used in the SCORE assessment, all else equal. As for Alt. 1, the questionnaire gives no information about the positive externalities. They are therefore assumed to be zero in the SCORE assessment, which might also be an underestimate. Medium uncertainty was assigned to all benefit estimates.

4.3.2. Local acceptance

Alt. 1 represents today's situation, but the source of contamination is currently fenced rather than being covered with a 2 m clean soil layer. Furthermore, in contrast to Alt. 1, the rest of the area is currently associated with risks to the soil ecosystem. The effect on the local acceptance for this alternative compared to the reference alternative defined in this study is translated to be positive but very low, +1, with a high uncertainty and the possibility of being either positive or negative. It is based on the respondents' replies regarding the end result of the remediation, where they state that it is very important to reach tolerable health risks and to protect the River Braån.

Alternative 2 is equivalent to the containment strategy in the questionnaire. In general, the respondents are negative about containment as a strategy compared to today's situation. Compared to the reference alternative in the SCORE assessment, the effect on the local acceptance of containment is interpreted to be positive, +4, with medium uncertainty and the possibility of being either positive or negative.

Alternatives 3, 4 and 5 all consider excavation to different extents, and with different treatment of the excavated masses. The difference between Alts. 3 and 4 is interpreted to be small or negligible, unless the difference in air emissions and use of natural resources is very large. The analysis, however, revealed that the difference in air emissions is not so large between these two treatment options (see Section 4.4), and the alternatives are scored +8 each. Alt. 5 is allocated a score of +10 due to the almost complete excavation. The uncertainty is set to low and the effect is assumed to take on only positive values based on the replies in the questionnaire study. The local acceptance is here a parameter which considers both the expected end result as well as effects during implementation. The residents in Teckomatorp have already experienced a rather large excavation remediation of the Northern Sector and the replies in the questionnaire study strongly indicate that their acceptance for excavation as remediation method in the Southern Sector is positive despite disturbances during the implementation.

4.4. Environmental assessment results

The assessment of environmental effects of remediation alternatives was based on a desk study of data presented in Svalöv Municipality (2016), personal communication with remediation consultants, a quantitative assessment of secondary effects using the TrExTool (Fridell et al., 2009), and discussions with the BT Kemi project group. A summary of the assessment and the detailed scores are presented in the Supplementary material.

4.5. Economic assessment: cost-benefit analysis

The results of the CBA are summarized in Table 5 below; more details can be found in the Supplementary material. The property value on site is not expected to increase. This conclusion is based on the fact that the post-remediation land use at the site is expected to be the same as for the already remediated Northern Sector (Vallarna), i.e. a recreation area owned by the municipality and accessible free of charge to the public. Such land is typically assumed to have a zero market value (Johansson, 2016). The positive externalities in the table are based on the questionnaire study as explained above. The results regarding remediation costs and negative externalities due to remedial action are based on a desk study of data for Svalöv Municipality (2016) and personal communication with remediation consultants. The negative externalities because of remedial action are primarily due to emissions of CO_2 and other air emissions (NOX, SOX), and safety risk increases due to transportation, which primarily are present in the case of excavation alternatives 3–5. Those externalities were monetized by applying default values established for CBA by the Swedish Transport Administration (STA, 2016). The result, as described by the net present values in Table 5, suggests that Alts. 3–5 would give a positive social economic profitability, whereas Alts. 1–2 are associated with an economic loss. However, the relatively small positive net present value of Alt. 5 suggests that other assumptions about the self-assessed market values could imply an economic loss; the positive sign of the net present value of Alts. 3 and 4 is likely to be a more robust finding.

4.6. SCORE analysis result

The results of the SCORE analysis with all three sustainability dimensions weighted equally is presented in Fig. 11. Detailed scores, costs and benefits, and weights can be found in the Supplementary material. In the social dimension, Alts. 3–5 which include excavation, are associated with more positive effects than Alts. 1 and 2, whereas in the environmental dimension Alt. 2 gets the highest rank. This is due to the combination of reaching tolerable risks and low secondary impacts of the containment option. The CBA results addressing the economic profitability criterion in the economic dimension of SCORE show that only the alternatives assuming excavation are associated with positive net present values, because of much higher expectations among residents in Teckomatorp regarding the increase in property values after this type of remediation. However, Alt. 5 results in a less positive net present value than Alts. 3–4 because its extensive excavation is associated with relatively high remediation costs. The combined result shows a higher sustainability index for the three alternatives associated with removing the contamination by excavation, but very small differences between those.

Table 5
Summary of CBA results at 2014 prices. Present values were computed based on the probable time of completion of each remediation alternative, and a social discount rate of 3.5%, as recommended for CBA by the Swedish Transport Administration (STA, 2016).

Present values of benefits and costs (MSEK)	Remediation alternatives				
	1	2	3	4	5
Increased property value on site	0	0	0	0	0
Positive externalities	0	14	200	200	190
Remediation costs	−62	−110	−140	−130	−170
Negative externalities	−0.43	−0.58	−5.8	−6.1	−7.9
Net present value	−62	−97	54	64	12

4.7. Uncertainty and sensitivity results

As stated in the description of SCORE, the assessment includes an uncertainty analysis. The results of the uncertainty analysis show that there is a slight overlap of uncertainty intervals between Alt. 2 and Alts. 3–5 (Fig. 12) but the probability plot (Fig. 13, black bars) shows that the probability that Alt. 2 comes out as having a higher rank than any of Alts. 3–5 is negligible.

The Monte Carlo simulations also provide the opportunity for parameter sensitivity analysis. The sensitivity analysis shows that the parameters contributing most to the uncertainty in the normalized sustainability index are associated with the remediation costs and the positive externalities, as reflected by the residents' expectations regarding the increase in property values after remediation (see Supplementary material).

In this study, we focus on enriching the social and economic aspects in a sustainability assessment and it is therefore of interest to investigate the impact of these data on the full analysis. Excluding local acceptance from the sustainability assessment of the remediation alternatives does not affect the ranking of alternatives in the social dimension of SCORE, although Alt. 3 has a somewhat higher probability of being ranked highest (Fig. 13, dark grey bars).

If the estimated increase in surrounding property values is not included in the economic analysis of SCORE, all the remediation alternatives generate negative net present values. However, as the sustainability dimensions are normalized using local scales and weighted equally, even though there is a large difference in economic sustainability, there is no large difference in the mean sustainability indices for Alts. 2–5 compared to the full SCORE analysis. This is also the result for the uncertainty intervals. However, the probability of being ranked highest gets more similar for Alts. 2–5 (see Fig. 13, grey bars) if the residents' expectations about the increase in property values regarding the two principally different remediation technologies (excavation vs containment of contaminants) are not included. Similarly, if both local acceptance and the estimated increase in property values are excluded from the sustainability assessment, the ranking of alternatives remains the same, but the probability of Alt. 2 of being highest ranked increases (see Fig. 13, white bars).

5. Discussion

In the SCORE assessment of the remediation alternatives considered for the Southern Sector of the BT Kemi site, alternatives 1 and 2 never come out as being ranked highest, but there are only small differences between alternatives 3, 4 and 5 (Figs. 12 and 13). All alternatives receive a positive normalized sustainability index relative to the formulated reference alternative. The questionnaire study provided input to the sustainability assessment in terms of local acceptance and economic benefits of the different remediation technologies. Although the input from the questionnaire study did not have much impact on the ranking of alternatives (Fig. 13), it did reveal greater support for the more

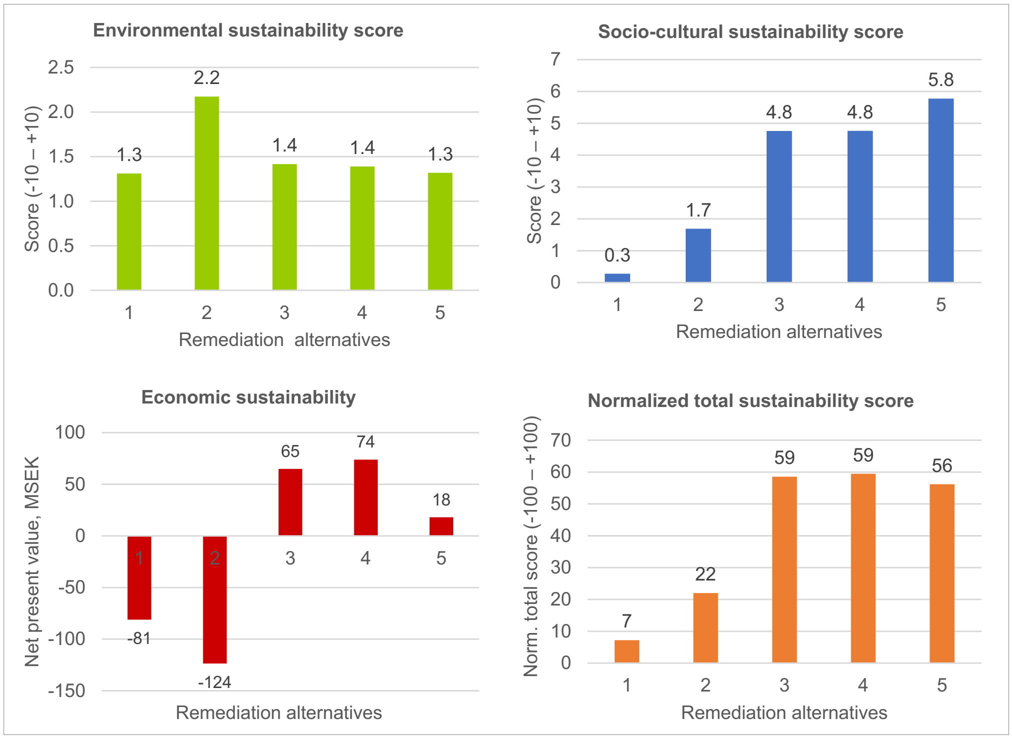

Fig. 11. The result of the SCORE analysis in the environmental, socio-cultural and economic dimensions, as well as the normalized sustainability index for Alts. 1–5 at BT Kemi Southern Sector.

extensive alternatives, and it did provide the BT Kemi project group with additional information about the residents' risk perception. Not least, including the positive externalities of the remediation project, here as increase in property values in the surroundings, indicates that the relatively high costs of full remediation of the site can be justified from an economic point of view. From a distributional point of view, it should be noted that it is the present property owners that would benefit financially from the remediation, in particular because the public funding through SEPA implies no other responsibility for paying for the remediation costs other than being ordinary taxpayers. Another funding system implying that remediation costs would be incurred by the local residents might have implied less strong preferences for relatively expensive remediation options, but an investigation of such an alternative funding setting was not carried out within the scope of the present study. It should be noted that potential post-remediation property value increases at the contaminated site itself is another issue; such increases are normally taken into account by the legal framework for publicly funded remediations in Sweden. Regarding environmental and social effects, there are distributional effects also in these sustainability dimensions, but since these effects are normally measured in various metrics or scores, a distributional analysis is trickier. The idea of both green and sustainable remediation is indeed to balance (often positive) local environmental effects against (often negative) regional and global effects of remediations, to avoid simply shifting environmental problems on a local scale to a global scale and instead reach a net environmental gain. In the social dimension in SCORE, local short-term, potentially negative effects (e.g. disturbances and risks during the remediation, potentially relocating on-going activities) are balanced against long-term positive effects (e.g. no environmental debt for future generations, possibilities for new land uses). There is however no unified view (nor legislation) on how such effects should be weighed or balanced against each other: typically, it is recommended that stakeholders perform such weighting (e.g. ISO, 2017). The view on how this balance should be achieved may thus be significantly different in different remediation projects and is likely to vary over time as priorities shift.

The reference alternative was chosen together with the project group but was not formulated as equivalent to today's situation. Instead it involved the site being left as it is, i.e. without the current pumping and subsequent water treatment. This formulation made it possible to assess the sustainability of remediation alternative 1, representing a

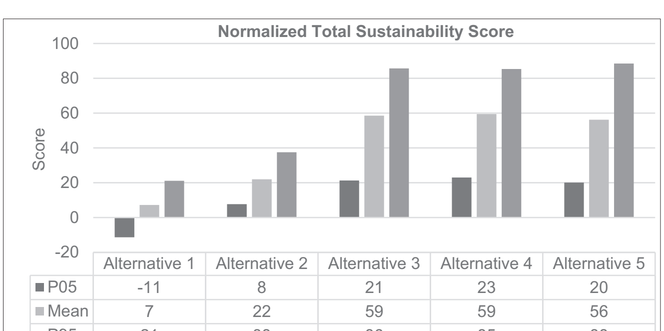

Fig. 12. The uncertainty interval for the normalized sustainability index.

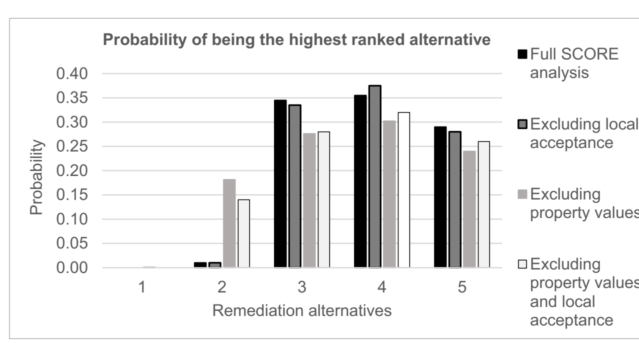

Fig. 13. The probability of each alternative being ranked highest for the full SCORE analysis as well as for scenarios where data from the questionnaire study are not included in the analysis.

slightly modified current solution for the site, i.e. pumping as today, but with an additional cover with clean soil. On the other hand, this formulation made questionnaire responses less straightforward to translate into SCORE inputs. However, had the reference alternative been formulated as being equivalent to the current situation, it is not likely that the ranking order of the alternatives would change, but the results in terms of the sustainability index may have been more positive or more negative. This means that communication of the results must ensure an understanding of the relative nature of the sustainability index (as of any sustainability assessment).

The SCORE sustainability assessment came in rather late in the remediation project, when investigations had already been carried out and a preliminary qualitative analysis of the remediation alternatives in terms of costs and risk reductions already performed. The SuRF-UK guidance suggests early adoption of sustainability management practices in projects (e.g. Bardos et al., 2016) and that sustainability considerations are implemented as early as possible in projects – without necessarily being very refined or quantitative. In the BT Kemi case, there has been a strong drive to finally address this problem, i.e. to eliminate the stigma associated with Teckomatorp due to this site. This wish, combined with the type of contaminants at the site (difficult to degrade and to treat), suggested excavation as the most obvious and most easily communicated solution, although containment was also investigated. However, in the market evaluation which was carried out after the SCORE assessment, to investigate the market conditions for implementing the excavation and thermal treatment/disposal options, it became clear that some of the assumptions used in the sustainability assessment would not be fulfilled (e.g. the possibility of reusing the treated soil, the distance to the mobile thermal treatment plant). Combined with not being able to choose a more green fuel type in the thermal treatment and new findings on in situ thermal treatment technologies, another iteration of the assessment was performed, assessing two different in situ alternatives along with the excavation alternatives instead of alternatives 1 and 2. Thus, although explicit consideration of sustainability metrics was not adopted early in the project, the sustainability assessment that was performed was effectively used to refine the alternatives. Potentially, this refinement could have been achieved sooner if more explicit consideration of sustainability aspects had been implemented earlier in the project.

It has been suggested that stakeholder engagement in sustainable remediation projects ideally consists of a broader representation than in traditional projects, in order to better assess and understand social aspects. From a social sustainability point of view, community involvement and engagement are highlighted as often neglected and of increasing importance (Cappuyns, 2016; Bardos et al., 2018). Huynh et al. (2018) argue that there is a growing recognition that finding solutions to complex environmental challenges requires “plural knowledges”, i.e. acknowledging residents' perceptions of risk in remediation policies. Residents' perception of risks and benefits of different remediation technologies were investigated by Prior and Rai (2017). Their framework to consider and understand residents' perceived risks and benefits suggests that it is dependent on a range of aspects, including the residents' physical context, the residents' engagement with institutions during the remediation process and technological characteristics. In SCORE, the public as a group is taken into consideration in the assessment by investigating Local acceptance (S6), which should be seen as a combined measure of all perceived risks and other aspects associated with the different alternatives. Other specific social aspects, such as local environment amenities, including disturbances, and health and safety issues, are taken into consideration in SCORE on the basis of investigations, consultations with experts, and stakeholder representatives.

In practice, it remains a challenge to identify stakeholders to involve and to find suitable ways to involve them. In the BT Kemi case, a specific difficulty for stakeholder involvement in the SCORE working process was due to that the SCORE assessment was implemented over a relatively short time period (March – December 2016). However, the BT Kemi project is quite unique in terms of public engagement and the long-term history of the site. Open information and transparent communication with residents was a high priority for the BT Kemi project group from the start of the remediation of the Northern Sector. An already established process with regular meetings with residents facilitated the convening of a public meeting and distributing the questionnaire as parts of the SCORE assessment. Besides these ways of reaching the residents, stakeholder involvement was primarily undertaken by means of one workshop, which was followed up by additional interviews. Several of the workshop participants were municipality officials representing different interests of the residents in Teckomatorp and the municipality as a whole. However, a broader representation of stakeholders at the workshop would have been useful for the sustainability assessment. Representatives of physical planning, cultural heritage, local industries, and public health and social welfare were missing: they either unable to attend at the last minute or did not respond to the invitation.

Residents cannot be expected to be a group with homogeneous interests (which is also obvious from the quotes presented), and this is a challenge when investigating their preferences. The random sampling of residents to answer the questionnaire is one way of trying to take into account the preferences of residents who are otherwise reluctant to participate in the processes. However, such residents may still be overrepresented among non-respondents. A less restrictive response requirement with respect to time could have been employed, along with face-to-face interviews and focus groups with randomly invited residents. The questionnaire still resulted in a rich picture of opinions, thanks to the respondents' willingness to answer the open-ended Q18; it also indicated strong support for removal of contaminants from the site.

The main lessons learned from the BT Kemi case study application included the need for better preparations for the workshop on social aspects and the workshop structure. There was limited time to properly identify all relevant stakeholder representatives. For proper representation, those involved need to see the advantage of broad representation, thus encouraging attendance at the workshops. People with roles that are usually not involved in remediation projects may feel that the issues are irrelevant or that they will not be able to contribute. Tight time schedules may also influence the chance of achieving broad representation. On the other hand, a group larger than eight is very difficult to manage and at the same time allow everyone to make their voice heard. Thus, careful identification of representatives is a key issue and should be done jointly by sustainability assessors and project managers. A stakeholder mapping exercise is beneficial for successful involvement (see e.g. Norrman et al., 2016).

Regarding workshop structure, group dynamics is something that must be managed properly. In the workshop for BT Kemi, one member had the tendency to dominate and quickly suggest a score, and thus influence all other members. There are remedies, e.g. the expert elicitation procedures suggested by Oakley and O'Hagan (2016) and O'Hagan et al. (2006): equal and relevant information to everyone (to avoid the availability heuristic), filling in forms with carefully phrased questions individually (to avoid undue influences), and thereafter group discussion allowing the representatives, one after another, to justify their different scores and uncertainty estimates. Overconfidence can be avoided by clearly stating that honest estimates of uncertainty intervals are requested. Based on such an approach, forms were developed and applied in a subsequent project (Norrman et al., 2018). Although such procedures are theoretically more attractive, they will inevitably also be more time-consuming, which implies a need for both having enough time for the working process of the assessment and introducing incentives that encourage participation in workshops, e.g. support from participants' superiors.

The sustainability assessment provided relevant input to the project decision-making process by highlighting factors that contribute positively and negatively to achieving sustainable solutions. The documentation of the SCORE working process and its result also provided transparency to the assessment and the opportunity for tracing back any given assessment and conclusion. A market evaluation made after the SCORE assessment revealed that several of the assumptions relating to the evaluated thermal treatment options could not be delivered. The sustainability assessment could then act as a basis for suggesting new and revised options; indeed, instead in situ thermal treatment at high temperatures using Inductive Thermal Dynamic Stripping Process (IT-DSP) was suggested. The new options were evaluated using an updated SCORE assessment including a streamlined LCA to better assess secondary environmental impacts (Norrman and Rosén, 2019). The results indicated that the in situ options perform better than the more traditional excavation options originally assessed, despite high energy consumption. Using such in situ thermal treatment can avoid long-distance transport and physical disturbance to the surroundings of the site, but at the same time remove the contaminant instead of leaving it in place.

6. Conclusions

The main conclusions regarding the sustainability assessment of remediation alternatives for the BT Kemi Southern Sector site are summarized below.

- All alternatives are associated with positive sustainability indices, but Alts. 3, 4 and 5, which are associated with removal of contaminants from the site, have much higher indices because of high positive scores in the social and economic dimensions, with quite small differences between them.
- The residents in Teckomatorp expect property values to be positively affected to a large degree if contaminants are removed from the site, and to a lesser degree, but still a positive effect, if contaminants are contained.
- The most uncertain input variables in the analysis are the remediation cost and the positive externalities (reflected in the residents' expectations regarding the increase in property values after remediation).
- The questionnaire study made it possible to include all social criteria in SCORE and to monetize positive externalities of the remediation. The questionnaire confirms the general view among the representatives taking part in the workshop for assessment of social criteria, that removal of the contamination instead of containment is viewed, unequivocally, as more positive by the residents in Teckomatorp. The results from the questionnaire further indicate, that for the BT Kemi site, it is important to remove contaminants to eliminate the stigma associated with the village. The results also indicate that people are less concerned about the implementation of the remediation project than with the end result.
- Without the monetization of the positive externalities, all the alternatives would have been allocated negative net present values in the economic analysis. The estimated future increase in property values is uncertain and, as pointed out by several respondents, it is potentially not only due to the remediation of the Southern Sector. On the other hand, the questionnaire's elicitation of respondents' opinions about value changes was contingent on the remediation, and several respondents confirmed the unusually strong stigma associated with the village of Teckomatorp because of the contamination.
- The SCORE working process could be improved, specifically regarding workshop preparation and workshop structure being better aligned with theoretical aspects of group dynamics and expert elicitation. In general, a broad representation of stakeholders for social aspects and early establishment of communication channels is key for proper assessment of social aspects within site remediation projects.
- The information from the SCORE sustainability assessment was used in the decision-making process, specifically with regard to revising remediation options. The final remediation strategy is, however, decided in a procurement process.

On May 29th, 2019, the final decision, following the procurement process, was made by the board of the BT Kemi remediation project to engage the company Geoserve AB to carry out the remediation using in situ thermal treatment by IT-DSP. (Svalöv Municipality, 2019).

Declaration of competing interest

The authors declare that there is no conflict of interest.

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Appendix A. Supplementary data

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