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## APPROACHES FOR ASSESSING SUSTAINABLE REMEDIATION

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### Abstract

Sustainable remediation seeks to reduce direct contaminant point source impacts on the environment, while minimizing the indirect cost of remediation to the environment, society and economy. This paper presents an overview of available approaches for assessing the sustainability of alternative remediation strategies for a contaminated site. Most approaches use multi-criteria assessment methods (MCA) to structure a decision support process. Different combinations of environmental, social and economic criteria are employed, and are assessed either in qualitative or quantitative forms with various tools such as life cycle assessment and cost benefit analysis. Stakeholder involvement, which is a key component of sustainable remediation, is conducted in various ways. Some approaches involve stakeholders directly in the evaluation or weighting of criteria, whereas other approaches only indirectly consider stakeholder preferences. MCA methods are very useful when comparing remediation alternatives, since they allow for a joint assessment of many types of indicators; however the available tools and methods differ substantially, for instance in their selection of indicators, approaches to stakeholder involvement and uncertainty analysis.

### Introduction

It has been estimated that there are approximately 2.5 million potentially contaminated sites in Europe. Of these, approximately 340,000 sites are estimated to be contaminated to a degree that may require remediation (Van Liedekerke et al. 2014). Until recently, remediation was considered to be inherently green or sustainable since it removes a contaminant problem. However, it is now broadly recognized that while remediation is intended to address a local environmental threat, it may cause other local, regional and global impacts on the environment, society and economy. Over the last decade, the broader assessment of these criteria is occurring in a movement toward 'sustainable remediation'.

The Brundtland Report by the World Commission on Environment and Development (UN 1987) defined sustainable development as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". Harbottle et al. (2008) presented a framework for assessing sustainability of contaminated land remediation focusing only on the technical and environmental sustainability of the remediation technology. Subsequently a number of different definitions of sustainable remediation have been proposed. A common feature is that they employ a "triple bottom line approach" addressing the three pillars of sustainability: environment, society and economy (SURF 2009, SuRF-UK 2010, Sparrevik et al. 2011, Sparrevik et al. 2012, Søndergaard et al. 2014, Rosén et al. 2015) (Figure 1). Sustainable remediation eliminates or controls contaminant risks while minimizing negative environmental, social and economic impacts. A well balanced decision support processes must therefore address all three aspects.

While the assessment of environmental impacts of remediation systems for contaminated sites using life cycle assessment (LCA) is a well-studied field (Lemming et al. 2010a, 2010b, 2012), the assessment of sustainability is a relatively new discipline in the remediation sector. Methodologies are still in their infancy, there are few documented case studies, and quantitative assessments are especially lacking. An ISO guidance document for the assessment of sustainable remediation is expected to be published in late 2016 with the aim of describing the main concepts and creating common terminology (Nathanail 2016).

In this paper we present and compare the available tools and methods for assessing the sustainability of remedial solutions and discuss some of the key issues and future challenges. The aim of a sustainability assessment is to compare the sustainability of two or more remedial solutions for a contaminated site. A sustainability assessment does not provide an absolute measure of whether remediation of a specific site is sustainable. Instead it provides a relative measure which can be used to select the most sustainable solution from amongst a number of defined remedial scenarios.

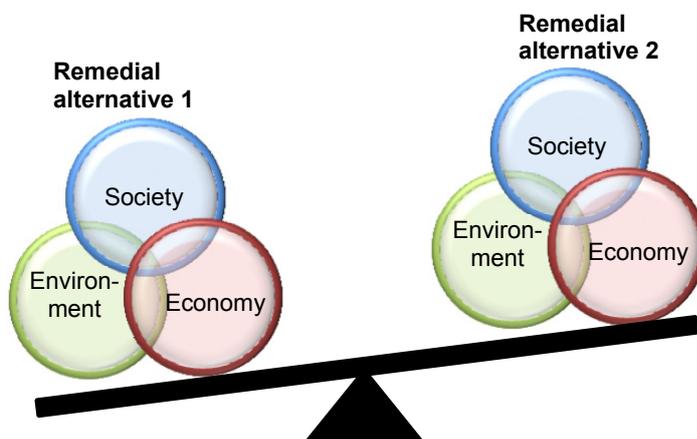


Figure 1. The triple bottom line approach for comparing the sustainability of remediation alternatives

## Approaches and indicators for assessing sustainable remediation

An overview of approaches for assessing the sustainability of remedial alternatives is provided in Table 1. The overview mainly includes approaches that consider all three dimensions of sustainability. For completeness, however, earlier methodologies such as the REC tool (Beinat et al. 1997) and the Harbottle et al. (2008) framework are included even though they lack one or more dimensions. The REC tool was intended to be a decision support system for comparing remediation methods and is not a sustainability assessment tool. The Harbottle et al. (2008) framework is a multi-criteria assessment (MCA) approach for assessing the technical and environmental sustainability of a remediation system with less consideration of social and economic impacts. The MCA approach has subsequently been used in a number of sustainability assessment tools because of its ability to address many criteria at different scales and integrate qualitative and quantitative assessments.

Multi-criteria assessment approaches range from simple qualitative matrix-based scoring systems to semi-quantitative and fully quantitative methods. All of the studies shown in Table 1 (except Sparrevik et al. 2012) use the *linear additive model* which is a type of MCA method based on multi-attribute value theory (MAVT) or multi-attribute utility theory (MAUT). In MAVT/MAUT criteria scores are transformed into normalized values (e.g. on a scale from 0 to 1) and the overall value,  $v$ , of an alternative  $\mathbf{x}$ , is calculated based on the weighted sum of the normalized criteria values as shown in Equation 1:

$$v(\mathbf{x}) = \sum_{i=1}^n w_i v_i(x_i) \quad \text{Equation 1}$$

where  $v_i(x_i)$  is the normalized value of criteria  $i$ ,  $n$  is the total number of criteria and the weights  $w_i$  reflect the relative importance of the criteria, with the sum of the weights being one. The method is *compensatory*, meaning that criteria with high scores can compensate for other criteria with low scores. Sparrevik et al. (2012) employs *outranking*, a different type of multi-criteria assessment method where a comparative assessment of alternatives is conducted using the PROMETHEE II algorithm which ranks the alternatives without normalization of criteria values. Two of the studies in

Table 1 (Sparrevik et al. 2012 and Rosén et al. 2015) address uncertainty of the assessment using Monte Carlo simulations.

Table 1. Comparison of approaches for assessing sustainable remediation. LCA: Life cycle assessment. <sup>a</sup>Using a linear additive model is a possibility, but not a requirement. <sup>b</sup>Only for the remediation cost

| Reference                    | MCA type                             | No. of indicators | Assessment type   |                   |   | Other main criteria                        | Weighting      | Stochastic/uncertainty |
|------------------------------|--------------------------------------|-------------------|---|-------------------|---|--|----------------|------------------------|
|                              |                                      |                   | Environmental   | Social            | Economic  |  |                |                        |
| REC (Beinat et al. 1997)     | Linear additive <sup>a</sup>         | 12                | Quantitative (life cycle thinking)                        | -                 | Quantitative (costs)  | Risk reduction                             | x <sup>a</sup> | (-) <sup>b</sup>       |
| Harbottle et al. (2008)      | Linear additive                      | 17                | Semi-quantitative; quantitative (LCA)                     | Semi-quantitative | -   | -  | x              | -                      |
| Sparrevik et al. (2011)      | Linear additive                      | 9                 | Quantitative (LCA)  | Semi-quantitative | Quantitative (costs)  | -  | x              | -                      |
| Sparrevik et al. (2012)      | Outranking                           | 4                 | Quantitative (LCA)  | Quantitative      | Quantitative (socio-economic benefit)                         | -  | x              | x                      |
| SuRF-UK (2013a) Case study 2 | Linear additive                      | 16                | Semi-quantitative; quantitative (CO <sub>2</sub> )        | Semi-quantitative | Semi-quantitative; quantitative (costs)                       | Effectiveness and practical implementation | -              | -                      |
| SuRF-UK (2013b) Case study 3 | Linear additive                      | 8                 | Qualitative   | Qualitative       | Semi-quantitative; quantitative (costs and selected benefits) | -  | x              | -                      |
| Søndergaard et al. (2014)    | Linear additive                      | 15                | Quantitative (LCA); semi-quantitative (local soil impact) | Semi-quantitative | Quantitative (costs)  | Effectiveness and time                     | x              | -                      |
| Rosén et al. (2015)          | Linear additive and non-compensatory | 22                | Semi-quantitative   | Semi-quantitative | Quantitative (CBA)  | -  | x              | x                      |

For guidance purposes, SuRF-UK (2011) has developed a set of 15 environmental, economic and social indicator categories (see Table 2). Specific tools for assessing the impacts have not been specified by SuRF-UK. The total number of indicators employed in each of the 9 approaches in Table 1 varies between 4 and 22. Many of the approaches use LCA as a tool to assess impacts in the environmental domain, however SuRF-UK (2013a) uses only a simplified carbon footprint calculation. SuRF-UK (2013b) and Rosén et al. (2015) do not apply LCA. Environmental and economic impacts are often quantitatively assessed, but because of their nature, social impacts are most often assessed semi-quantitatively or qualitatively.

Table 2. Indicator categories defined by SuRF-UK (2011)

| Environmental                   | Economic                               | Social                                  |
|---------------------------------|--|---|
| - Air emissions                 | - Direct economic costs and benefits   | - Human health and safety               |
| - Soil and ground conditions    | - Indirect economic costs and benefits | - Ethical end equity                    |
| - Groundwater and surface water | - Employment and employment capital    | - Neighborhoods and locality            |
| - Ecology                       | - Induced economic costs and benefits  | - Communities and community involvement |
| - Natural resources and wastes  | - Project lifespan and flexibility     | - Uncertainty and evidence              |

## Discussion

A multi-criteria approach has been widely used to assess the sustainability of remediation systems because it can integrate different types of qualitative and quantitative data. Furthermore its structured approach facilitates a broader assessment of indicators and provides a more balanced and transparent decision support than traditional approaches which focus mostly on risk reduction and cost. A MCA also has the advantage of not requiring all criteria to be monetized. Rosén et al. (2015) suggests that a fully quantitative CBA be conducted for the economic domain and Sparrevik et al. (2012) used a willingness to pay study to assess the socio-economic benefit of the remediation. The other approaches only quantify direct costs and other costs and benefits are then covered by qualitative assessments. The use of extensive CBAs for the economic domain requires

considerable resources and may be hampered by the difficulty of treating externalities consistently since their evaluation is often based on different primary sources and assumptions.

In the environmental domain, some sustainability assessment methods focus only on air emissions of selected substances such as CO<sub>2</sub>. Assessments do not always take a life cycle view of environmental impacts meaning that only emissions related directly to the remediation are considered and not upstream and downstream processes (raw material extraction and production of goods, waste treatment). Sometimes only life cycle impacts of remediation technologies are considered while local impacts such as those on soil quality are ignored. Such simplifications may bias the assessment.

One difficulty of fully quantitative MCA is that it requires expensive data collection and careful data processing. Therefore, Bardos et al (2016), SuRF-UK 2013b and others advocate a tiered approach to ensure that sustainability assessments are not unnecessarily complex, and that there is a balance between the cost of the evaluation and the benefit of the remediation project.

When selecting sustainable solutions for contaminated site remediation, the involvement of stakeholders is critical in order to ensure solutions are well accepted by the community and have a lasting impact. Stakeholder involvement is tackled in various ways in the approaches presented in Table 1. Sparrevik et al. (2011) and Søndergaard et al. (2014) employ a stakeholder panel to derive the criteria weights applied in the linear additive model (Equation 1). Harbottle et al. (2008) and Rosén et al. (2015) included “stakeholder acceptability” or “local acceptance” as a criterion in the social domain. Sparrevik et al. (2012) used three sets of predefined criteria weights representing different decision profiles (cost effectiveness, cost benefit and value plural profiles). Stakeholders were not directly involved in the case studies provided by SuRF-UK (SuRF-UK 2013a,b).

## Conclusion

This study has reviewed available methods for assessing and comparing the sustainability of contaminated site remediation alternatives. Recently a variety of methods have been developed which address all three pillars of sustainability: environment, economy and society. The methods all employ multi-criteria analysis because it allows the combined assessment of criteria which may be either quantitatively or qualitatively assessed. To date very few documented assessments of sustainable remediation have been published. Further work is needed to test the assessment approaches for real case studies so they can be refined and further developed, for example to improve methods for involvement of stakeholders and to address the uncertainty of results.

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