SCORE: Sustainable Choice Of REmediation at Contaminated Sites

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SCORE

• A method
  – Multi-criteria decision analysis (MCDA)

• A computer tool
  – SCORE MCA assessment
  – Cost-benefit analysis (CBA)
  – Project risk analysis (PRA)
  – Soil Function assessment (SF Box)
  – Uncertainty analysis (Monte Carlo)
Why MCDA for sustainability assessment?

- We want support for decisions that lead to sustainable solutions.
- Assessment of sustainability typically involves a wide variety of information of different character.
- MCDA is a decision analysis method for integrating objective measurements with value judgments.

"Development that ensures that the use of resources and the environment today does not restrict their use by future generations."

Brundtland Commission (1987)
SCORE – Sustainable Choice Of Remediation

The Framework

Remediation and Reference Alternatives

Selection of Criteria

Environmental Sustainability

Stakeholder values
Goals, criteria, and preferences

Social Sustainability

Economic Sustainability

Weighting of Criteria

Total Sustainability Assessment

Managerial Review and Judgment

Decision Support

Uncertainty analysis

Aquire new information

Update

Document and assure quality

Report and communicate

Review, approve and audit

Decision
Domains and Criteria (Indicators)

- Soil
- Flora & fauna
- Groundwater
- Surface Water
- Sediments
- Air
- Non-renewable natural resources
- Non-recyclable waste

Effects on...

- Equity
- Health & Safety
- Cultural heritage
- Local Environmental Quality and Amenity
- Local participation
- Local acceptance
- Social Profitability

Literature – focus groups – interviews
Gross list to avoid double-counting!
Environmental key criteria

- **E1** = Soil
- **E2** = Flora & fauna
- **E3** = Groundwater
- **E4** = Surface water
- **E5** = Sediment
- **E6** = Air
- **E7** = Non-renewable natural resources
- **E8** = Non-recyclable waste

**Legend:**
- Dashed line: Groundwater table
- Dashed line with arrows: Groundwater flow direction
- Brown: Sediment

**Diagram Notes:**
- E6 (cloud) indicates air pollution.
- E7 (drill) represents non-renewable natural resources.
- E8 (truck) signifies non-recyclable waste.

**Sections:**
- **On-site**
- **Off-site**
Some Important Properties

- Sustainability assessment made relative to a reference alternative
- Evaluates environmental, economic and social effects on specific receptors on-site and off-site
- Combination of linear additive and non-compensatory MCDA techniques – strong and weak sustainability
- Explicit evaluation of effects on soil functions in accordance with upcoming EU Soil Directive
- Integrates scores and quantitative metrics
- Domains are weighted
- Criteria (indicators) are weighted
- Explicit uncertainty analysis
Case studies

- Hexion, Sweden – former industrial site transformed to residential area
- Marieberg, Sweden – former wood preservation site
- Limhamn, Sweden – former harbor area transformed to residential area
- Linz, Austria – former shooting range
Example – Hexion

- Former paint industry
- More than 100 years of operation
- Complex glacial geology
- Heavy contamination of lead, DEHP (softener), organics
- Exploitation project – site to be transformed to a residential area
## Step 1: Remediation alternatives

<table>
<thead>
<tr>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation and disposal based on generic risk assessment</td>
<td>Excavation and disposal based on site specific risk assessment</td>
<td>Excavation, sieving and disposal based on site specific risk assessment</td>
<td>Excavation, sieving, soil wash and disposal based on site specific risk assessment</td>
</tr>
</tbody>
</table>
## Step 2: Select Criteria

<table>
<thead>
<tr>
<th>Key Criteria</th>
<th>Relevant?</th>
<th>Sub-criteria</th>
<th>Relevant?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil (E1)</td>
<td>YES</td>
<td>Ecotoxicological risk SC On-site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ecotoxicological risk RA On-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soil Functions RA On-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Physical Impact on Flora and Fauna</td>
<td>YES</td>
<td>No sub-criteria - relates only to Flora and fauna RA On-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>(E2)</td>
<td>NO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater (E3)</td>
<td>YES</td>
<td>Groundwater RA On-Site</td>
<td>NO</td>
<td>Not relevant, no transport outside site possible</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Groundwater RA Off-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Groundwater SC On-Site</td>
<td>NO</td>
<td>Not relevant, no transport outside site possible</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Groundwater SC Off-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Surface Water (E4)</td>
<td>YES</td>
<td>Surface Water RA On-Site</td>
<td>NO</td>
<td>No surface water on-site</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Surface Water RA Off-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Surface Water SC On-Site</td>
<td>NO</td>
<td>No surface water on-site</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Surface Water SC Off-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Sediment (E5)</td>
<td>YES</td>
<td>Sediment RA On-Site</td>
<td>NO</td>
<td>No surface water on-site</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Sediment RA Off-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Sediment SC On-Site</td>
<td>NO</td>
<td>No surface water on-site</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>Sediment SC Off-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Air (E6)</td>
<td>YES</td>
<td>No sub-criteria - relates only to Air RA Off-Site</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Steps 3 and 4: Assign scores to performance criteria in environmental and social domains

### 1. Scoring guide

<table>
<thead>
<tr>
<th>Very negative effect: -6 to -10</th>
<th>Negative effect: -1 to -5</th>
<th>No effect: 0</th>
<th>Positive effect: +1 to +5</th>
<th>Very positive effect: +6 to +10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive degradation of groundwater quality or groundwater conditions with strong negative impact on ecosystem functions.</td>
<td>Degradation of groundwater quality or groundwater conditions with negative impact on ecosystem functions.</td>
<td>No or negligible effects on groundwater quality or groundwater conditions.</td>
<td>Improvement of groundwater quality or groundwater conditions with positive impact on ecosystem functions.</td>
<td>Extensive improvement of groundwater quality or groundwater conditions with strong positive impact on ecosystem functions.</td>
</tr>
<tr>
<td>Example, Remedial action: Extensive degradation of groundwater quality on-site due to increased leakage of contaminants from stockpiles of contaminated soil. Example, Source contamination: Extensive degradation of groundwater quality off-site due to uncontrollable flow of contaminated groundwater when a clay barrier is installed in the groundwater zone.</td>
<td>Example, Remedial action: Degradation of groundwater quality on-site due to increased leakage of contaminants from stockpiles of contaminated soil. Example, Source contamination: Degradation of groundwater quality off-site due to uncontrollable flow of contaminated groundwater when a clay barrier is installed in the groundwater zone.</td>
<td>Example, Remedial action: The remediation will have a small but insignificant effect on contaminant concentration in groundwater.</td>
<td>Example, Remedial action: Reduced leakage of contaminants due to reduced infiltration during the remediation (the site is partly covered). Example, Source contamination: Reduced contaminant concentration in groundwater after installation of a reactive transport barrier in the groundwater zone.</td>
<td>Example, Remedial action: Leakage of contaminants to the groundwater is largely eliminated remedial action (the site is completely covered). Example, Source contamination: Strongly reduced contaminant concentrations and contaminant mass in groundwater after pump-and-treat remediation.</td>
</tr>
</tbody>
</table>

-6 to -10 Very negative effect
-1 to -5 Negative effect
0 No effect
+1 to +5 Positive effect
+6 to +10 Very positive effect

### Supporting information:
- **Scoring guide**
- **Where to look for information**
- **Key questions**
- **Examples**
Scorings – Example Social Domain

<table>
<thead>
<tr>
<th></th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Environmental Quality and Amenity (S1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SC</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Cultural Heritage (S2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>SC</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>Not relevant</td>
<td>Not relevant</td>
</tr>
<tr>
<td>Health and Safety (S3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA</td>
<td>-4</td>
<td>-3</td>
<td>-4</td>
<td>-4</td>
</tr>
<tr>
<td>SC</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Equity (S4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SC</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Local participation (S5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SC</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Local Acceptance (S6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RA</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SC</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

At Hexion based on interviews
Uncertainties of scores

- Range of possible scores
- Most likely effect (score)
- Uncertainty

<table>
<thead>
<tr>
<th>Key criteria</th>
<th>Sub-criteria</th>
<th>Range</th>
<th>Score</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1: Soil</td>
<td>Ecotoxicological risk RA On-site A1</td>
<td>No positive scores possible</td>
<td>-7</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Ecotoxicological risk SC On-Site A1</td>
<td>No negative scores possible</td>
<td>4</td>
<td>Medium</td>
</tr>
<tr>
<td>SF Box</td>
<td>Soil Functions RA On-Site A1</td>
<td>All scores possible</td>
<td>4</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Step 5: Costs and benefits

Benefits include additional positive effects due to the remediation:
B1. Increased property value on site
B2. Improved health
B3. Increased provision of ecosystem services
B4. Other positive externalities than B2 and B3

Costs restricted to the specific remediation measures:
C1. Remediation costs
C2. Impaired health due to remedial action
C3. Decreased provision of ecosystem services due to remedial action
C4. Other negative externalities than C2 and C3.

B1 and C1 – Internal project effects
B2, B3, B4, C2, C3, C4 – Externalities
A total of 31 cost-benefit items
## Uncertainties of economic items

<table>
<thead>
<tr>
<th>Cost/Benefit Item</th>
<th>Likeliest value, (MSEK)</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>B1. Increased property values</strong></td>
<td>CBA Tool DEV 48.81</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>B2. Improved health</strong></td>
<td>CBA Tool EMP 0.0003</td>
<td>Medium</td>
</tr>
<tr>
<td>B2a. Reduced acute health risks</td>
<td>No P/B</td>
<td>Medium</td>
</tr>
<tr>
<td>B2b. Reduced non-acute health risks</td>
<td>CBA Tool</td>
<td>Medium</td>
</tr>
<tr>
<td>B2c. Other types of improved health, e.g. reduced anxiety</td>
<td>CBA Tool PUB 0.07</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Step 6: Weights

Domains

Environmental

Social
Step 7: Weighted scores

Environment

Social

Economy
Step 7: Normalized Sustainability Score

Between -100 and +100

\[
H_i = 100 \left[ W_z \frac{H_{z,i}}{\text{Max}(\text{Max}(H_{z,1:N}), \text{Min}(H_{z,1:N}))} + W_{\text{ec}} \frac{\text{Max}(H_z)}{\text{Max}(\text{Max}(H_{z,1:N}), \text{Min}(H_{z,1:N}))} \right] + W_{\text{NPV}} \frac{\text{Max}(\text{NPV}_i)}{\text{Max}(\text{Max}(\text{NPV}_{1:N}), \text{Min}(\text{NPV}_{1:N}))}
\]
Uncertainties Total Score

Normalized Total Sustainability SCORE with uncertainty intervals

<table>
<thead>
<tr>
<th>Alternative</th>
<th>P05</th>
<th>Mean</th>
<th>P95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>-17</td>
<td>26</td>
<td>73</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>0</td>
<td>43</td>
<td>83</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>10</td>
<td>53</td>
<td>93</td>
</tr>
<tr>
<td>Alternative 4</td>
<td>21</td>
<td>62</td>
<td>100</td>
</tr>
<tr>
<td>Alternative 5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
How convinced are we that we select the most sustainable alternative?
Where to look to perform a more reliable assessment?

- What criteria provide most uncertainty to the end result?
- Guidance for where to collect information to achieve a more reliable assessment
Effects

Number of Effects
On-Site and Off-Site

<table>
<thead>
<tr>
<th>Effects</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
<th>Alternative 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-Site Positive</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Off-Site Positive</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>On Site Negative</td>
<td>-3</td>
<td>-2</td>
<td>-2</td>
<td>-2</td>
<td>0</td>
</tr>
<tr>
<td>Off-Site Negative</td>
<td>-6</td>
<td>-6</td>
<td>-6</td>
<td>-6</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusions

- Provides structure, transparency and decision support
- Helps us to identify most sustainable alternative
- Helps us integrate various types of data
- Identifies potential for sustainability improvements
- Shows degree of compensation - strong and weak sustainability
- Are effects mainly positive or negative?
  - On-Site?
  - Off-Site?
  - Source Contamination?
  - Remedial action?
- Explicit uncertainty analysis
  - How convinced are we that we select the most sustainable alternative?
  - Where to focus for achieving a more reliable sustainability assessment?

The most important feature is the process!
Publications - examples


Thanks for your attention!

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