Multi-Criteria Decision Analysis Application in the Port of Gothenburg

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1. Introduction

1.1 Problem description

Port of Gothenburg is planning to dredge sediments in a small port area in Gothenburg. The port is used for oil loading/unloading/storage and the sediments are contaminated. There is a number of possible sediment handling alternatives, and the scope of the case study was to evaluate the sustainability of these alternatives using Multi-Criteria Decision Analysis (MCDA) and considering economic, social and environmental decision criteria.

From a SMOCS point of view, the challenge was to introduce port owners to MCDA, and to make the MCDA procedure worthwhile. It was important to find an appropriate level of detail for the size and budget of the case study project. Another challenge was to find appropriate sustainability criteria for the scope of the case study project.

1.2 Aim and objectives

One important objective was to develop a comprehensive set of sustainability criteria that cover economy, societal and environmental aspects and that can be measured with a reasonable effort. This list of criteria was to be developed taking into account the port's views, results from a Stakeholder Opinion Analysis (SOA) aimed at port owners, and contaminated sediment MCDA applications described in literature.

1.3 Method

This case study uses the decision support method Multi-Criteria Decision Analysis (MCDA). MCDA offers decision makers a way to reach sustainability goals by identifying the most sustainable handling alternative in a structured and rational way. Fundamental steps in a MCDA are to:

1. Identify possible handling alternatives
2. Identify decision criteria and their indicators
3. Weight decision criteria's relative importance
4. Score the performance of the handling alternatives in relation to each decision criterion
5. Calculate results

Identifying handling alternatives

In this case study, the studied handling alternatives had been identified by Port of Gothenburg prior to case study start. The handling alternatives are briefly described in section 2.1.

Identifying decision criteria and indicators

Prior to the case study, sustainability criteria were investigated through a Stakeholder Opinion Assessment (SOA) among ports and various stakeholder organisations. Criteria were also compared to current practice within sediment MCDA applications.

With the results of the SOA and the studied MCDA literature as a starting point, criteria and indicators for each criterion were selected through an iterative process and discussions with Port of Gothenburg and experts from different areas covered by the criteria, seeking to fit the port's existing data and planning processes. See section 2.3 for further information.

Weighting decision criteria's relative importance

Naturally, all decision criteria are not considered equally important. The port was asked to weight the decision criteria in order to mirror their decision making priorities, meaning that the weights were assessed subjectively. The weight describes how important the criterion is compared to the other criteria. There are many methods for weighting. This case study employed the Simple Multi-Attribute Rating Technique (SMART) as described below:

- Level 1: decision criteria (economic, social and environmental) were weighted in relation to each other:
    - 10 points were given to the least important criterion.
    - The other two criteria were given points (>10) in relation to the least important criterion.
    - Example: Social aspects are by the port considered least important: 10 points. Environmental aspects are considered twice as important as social aspects: 20 points. Economy is considered three times as important as social aspects: 30 points.
- Level 2: environmental criteria were weighted in relation to each other:
    - 10 points were given to the least important criterion.
    - The other criteria were given points (>10) in relation to the least important criterion.
- Level 2: social criteria were weighted in relation to each other:
    - 10 points were given to the least important criterion.
    - The other criteria were given points (>10) in relation to the least important criterion.
- Level 2: economic criteria were weighted in relation to each other:
    - 10 points were given to the least important criterion.
    - The other criteria were given points (>10) in relation to the least important criterion.

Scoring the performance of handling alternatives in relation to each decision criterion

There are a few different scoring and ranking techniques in MCDA. This case study uses a combined approach of Multiple Attribute Value Theory (MAVT) and Analytical Hierarchy Process (AHP). Where possible, decision criteria were measured quantitatively and scored with MAVT. The MAVT approach involves additive value functions and preference modelling. When the handling alternatives are scored for one criterion, the scores are normalised.

Analytical Hierarchy Process (AHP) was used for decision criteria where no quantitative measure could be obtained. This was the case for the criteria "Public acceptance" and "Local/regional economy". AHP enables the user to assign relative values to qualitative attributes by making pairwise comparisons. These can then be included in the quantitative scoring of handling alternatives. In this case study, the question asked was: "How strongly preferred is handling alternative A over alternative B considering decision criterion X?" The scale used for AHP comparisons is shown in Table 1. This is exemplified in Figure 3, where Land disposal is slightly preferred (three times stronger preference) over Confined aquatic disposal considering Public acceptance.

The scores on criteria measured with AHP were assessed by SGI based on facts provided by Port of Gothenburg, in order to produce an objective assessment.

Table 1 Qualitative measures and corresponding scores used in the AHP pairwise comparisons of handling alternatives.

Qualitative comparison	1 - 9 scale
Equally preferred	1
Slightly preferred	3
Strongly preferred	5
Very strongly preferred	7
Extremely preferred	9

Calculations

Calculations were performed using an online-version of MCDA software, Web-HIPRE (http://www.hipre.hut.fi/) that allows mixing AHP and value function based scores. More information on MCDA software is available in (Lundberg et al, 2012).

2. Collected data

2.1 Sediment handling alternatives

Port of Gothenburg has the following alternatives when handling contaminated sediments:

Alternative 1 - Confined aquatic disposal at Lundbyhamnen, Gothenburg

Lundbyhamnen is Port of Gothenburg's operating site for confined aquatic disposal of contaminated sediments. Total capacity of the site is 160 000 m^3, and the site covers a basin of 67 000 m^2 surrounded by a disused quay area. The disposal site is completely submerged in the sea. A wall of blasted rock with a sand filter separates the disposal site from the fairway. When completed, the contaminated sediments will be covered by a layer of clean sand. No geotextile or other membrane is used. Total material used is approximately 110 000 m^3 of sand and 12 000 m^3 of blasted rock. Distance between dredging site and disposal site is approximately 6 km. Sea transport is possible. Investment and life cycle costs are estimated to 435 SEK/m^3 including construction and cover of the disposal site.

Alternative 2 - Rock chamber disposal at Syrhåla, Gothenburg

The rock chamber is not in use at present. There is an alternative use of the rock chamber as an oil storage facility, which would generate an income for the port. This lost income should be considered within the economic decision criteria. The rock chamber's storage capacity is 1.6 million m^3. Distance between dredging site and disposal site is approximately 7 km. Sea transport followed by pumping is possible. It is assumed that a hydraulic cone is maintained outside the rock chamber in the same manner as for oil storage rock chambers. The hydraulic cone is assumed to be maintained the coming 50 years but not in a long term perspective, meaning that some leaching to groundwater and surrounding areas is likely to occur. Investment and life cycle costs are estimated to 400 SEK/m^3 undrained sediment.

Alternative 3 - Stabilization/Solidification and beneficial use as building material for expanding Port of Gothenburg's terminal area at Arendal, Gothenburg

This alternative is in a planning stage and no details are available on the amount and type of stabilization agent to be used. It is assumed that 175 kg/m^3 stabilizing mixture is needed, consisting of 20% cement, 40% granulated blast furnace slag and 40% fly ash. Approximately 500 m^2 of terminal surface can be produced from the case study site sediments. Distance between dredging site and disposal site is approximately 5 km. Sea transport is possible. No investment and life cycle cost has been calculated for this particular project. Instead, the approximate cost ~220 SEK/m^3 for an on-going stabilisation/solidification project in Port of Gavle is used.

Alternative 4 - Land disposal at Fläskebo, Landvetter

Port of Gothenburg has no land disposal site. It is assumed that the sediments will be classified as hazardous waste and deposited at the existing land disposal site at Fläskebo, Landvetter. The distance between dredging site and Fläskebo is 29 km with no possibility for sea transport. It is assumed that 90 kg/m^3 stabilizing mixture is needed, consisting of 20% cement, 40% granulated blast furnace slag and 40% ash. For this alternative, the disposal cost equals the investment and life-cycle costs. The disposal cost including special dewatering and stabilisation is estimated to be 2000-2500 SEK/m^3.

2.2 Sediment data

Estimated undrained sediment volume is 2700 m^3. Drained sediment volume is estimated to 2300 m^3.

In this case study, sediment samples and analysis results from recent site investigations are used. Sediment samples from two points have been analysed, each with one surface sample and one sample at 35 cm depth. Analyses included: total polychlorinated biphenyls (7 compounds), the ten most relevant organic tin compounds including dibuthyltin and tributhyltin, cadmium, copper, quicksilver, dry weight and loss of ignition.

Tributhyltin was reasonably low compared to other port problem areas. Heavy metals, Polycyclic aromatic hydrocarbons (PAH), Polychlorinated biphenyls (PCB) and total organic carbon should also have been analysed (and oil/oil fractions if indicated or needed).

Where organic tin compounds (OTC), e.g. tributhyltin (TBT) are present, total organic carbon and TBT (and probably also other OTC) are likely to be correlated at neutral pH. At pH lower than 5 or higher than 8, the water solubility of TBT (and probably also for some other OTC) is increased (Pynaert K. and Speleers L., 2003).

2.3 Decision criteria

Prior to this case study, sustainability criteria were investigated through a stakeholder opinion assessment among ports and stakeholder organisations (Lundberg, 2012). In this case study, MCDA criteria was examined in closer detail through comparing the decision criteria presented in five different MCDA applications on contaminated sediment projects; Alvarez-Guerra et al (2010); Kim et al. (2009); Driscoll et al. (1999) as described in Hong et al. (2010); Linkov et al. (2007) and Sparrevik et al. (2011). The criteria used in the published articles were grouped into economic, environmental and social criteria and a number of key decision criteria were identified. The key decision criteria were verified using the results from the SMOCS SOA (Lundberg, 2012). The criteria were also compared (with good compliance) to another set of decision criteria presented in a Swedish guideline for stabilization/solidification (Holm et al., 2011). This resulted in a suggested set of sustainability criteria to be used within contaminated sediment management.

The list of decision criteria and indicators to be used in this case study (Table 2) was then derived through an iterative process involving Port of Gothenburg, environmental experts from SGI and a MCDA practitioner from Norwegian Geotechnical Institute. Notably, the suggested criteria “investment cost” and “life-cycle cost” were merged since the port’s project cost assessments were presented in this manner. “Local / regional economy” was originally proposed to be measured as man-years, but was changed to AHP to reduce the port’s archive search efforts.

Table 2 Decision criteria used in the Port of Gothenburg MCDA case study.

Environmental criteria	Description	Indicator
Environmental risk	Risk to land and water living organisms originating from the alternative (only considering risks after implementation, not during sediment transport etc.).	The sum of relative hazard levels for each complete ecological exposure pathway (source-to-ecological-endpoint): Σ"relative hazard level"$_n$ The relative hazard level is expressed on a scale 1-3, where 1 is low and 3 is high.
Human risk	Risk to humans originating from the alternative. Nr of complete human exposure pathways measured through inhalation, dermal contact or fish consumption pathways.	The sum of relative hazard levels for each complete human health exposure pathway (e.g. inhalation, dermal contact, intake): Σ"relative hazard level"$_n$ The relative hazard level is expressed on a scale 1-3, where 1 is low and 3 is high.
Greenhouse gas (GHG) impact	The amount of greenhouse gases produced when realising the alternative and through its life cycle.	Amount of CO_2-eqivalents produced during project life cycle
Social criteria	**Description**	**Indicator**
Public acceptance	Acceptance of the project by residents (impacts such as stress, worries, noise, odour, accidents etc.)	Relative acceptance to other alternatives, AHP
Local interests	Impacts on the land/seascape view. Use of land or sea areas which means that these areas cannot be used for other purposes (tourism, recreation, outdoor life etc.). Also land use within the port is of importance.	Ratio of impacted area (publicly available land) to facility capacity [m^2/m^3]
Regional or national areas of special interest	Impacts (negative and positive) on areas of special regional or national interest (cultural, natural, wind power, fishing).	Nr of areas impacted negatively (possibly including magnitude of impact)
Economic criteria	**Description**	**Indicator**
Investment and life-cycle costs	Direct cost for initial investment made by the harbour, future maintenance costs and risk for future problems or action needs.	SEK / m^3 sediment
Local/regional economy	Employment, investments, local business opportunities.	Jobs created. Relative to other alternatives, AHP

3. Analysis

3.1 Scoring decision criteria

3.1.1 Human risk & Environmental risk

The criteria Human risk and Environmental risk were analysed in a group discussion with three environmental experts with different backgrounds: environmental geotechnics, technical chemistry and environmental risk assessment. It was emphasized by the expert group that the number of exposure paths and a measure of each path's relative importance for different sediment handling alternatives can only be seen as a vague indication of the actual risk. Nevertheless it may be useful as a means of screening and ranking the available sediment handling alternatives and selecting which alternatives should be studied in closer detail. Before deciding what sediment handling alternative to realize, the decision maker should conduct a more thorough environmental risk assessment.

It was agreed to analyse onsite and offsite risks separately, and to consider three time perspectives: project realization phase, 50 year perspective, and long term perspective. Possible exposure paths were listed for onsite and offsite human risk, and for onsite and offsite environmental risk. The paths were scored from 1 (low importance) to 3 (high importance) or – (not relevant) on each sediment handling alternative and time perspective. For the project realization phase, A (low importance) to C (high importance) was used to avoid direct comparison to the risks in a longer time perspective.

Each sediment handling alternative was summarized for the 50 year perspective and long term perspective (Figure 1 and Figure 2). Each exposure pathway was also summarized across all alternatives and time perspectives in order to identify the most important exposure pathways. Risks during project realisation were considered, but are not included in the summary and final score for the alternatives.

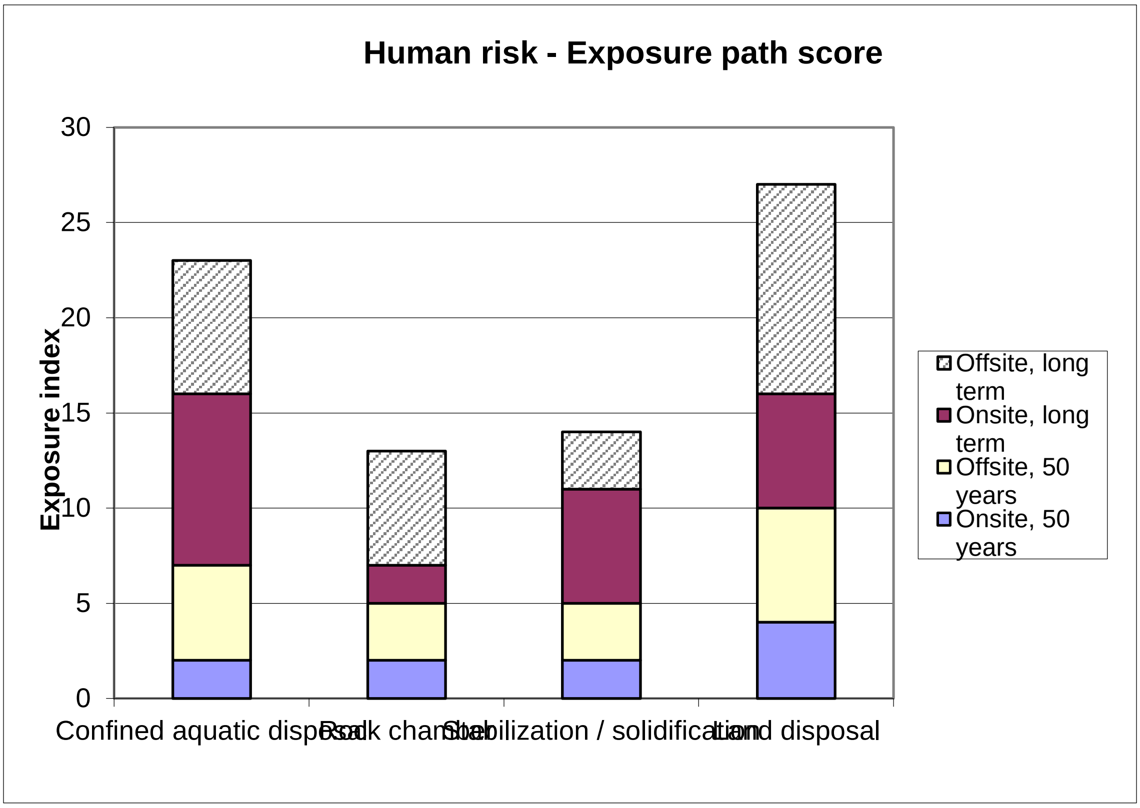

Figure 1 Human risk exposure path scores for the considered sediment handling alternatives.

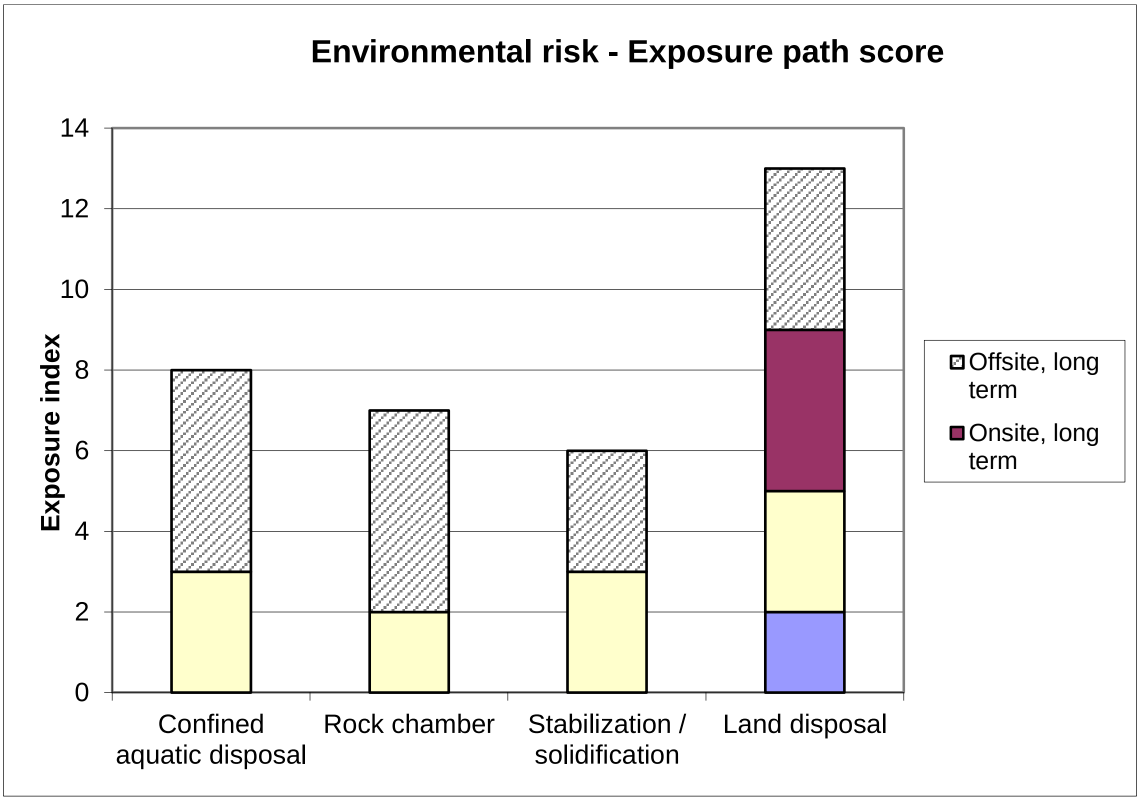

Figure 2 Environmental risk exposure path scores for the considered sediment handling alternatives.

Conclusions for human risk onsite: Direct intake and skin contact are the most important exposure paths in all three time perspectives, followed by dust inhalation, plant/fish intake and swimming. Vapour inhalation and drinking water intake were considered irrelevant in all time perspectives for the studied sediment handling alternatives.

Conclusions for human risk offsite: Fish intake and swimming were considered the most important exposure paths in the 50 year and long term perspective, followed by dust inhalation, drinking water intake, irrigation and uptake through plants. During project realization, dust inhalation was considered the most important exposure path, followed by fish intake and swimming. The other exposure paths were considered irrelevant for the studied sediment handling alternatives. For the 50 year and long term perspective, the exposure paths were considered more relevant for offsite effects than for onsite effects. The importance of each exposure path was generally considered higher in the long time perspective than in the 50 year perspective.

Conclusions for environmental risk onsite: Exposure to mammals and birds as well as to terrestrial organisms and plants were considered equally important in the 50 year and long term perspective. Exposure to aquatic organisms and plants was considered irrelevant. Risk for exposure during project realization was considered irrelevant.

Conclusions for environmental risk offsite: Exposure to aquatic organisms and plants were considered the most important exposure path for all three time perspectives, followed by mammals and birds, then terrestrial organisms and plants. In general, the exposure paths were considered much more relevant for offsite effects than for onsite effects. The importance of exposure paths were generally considered higher in the long time perspective than in the 50 year perspective.

Comparison of exposure pathway scores for human risk: Land disposal scored highest (highest indication of risk), closely followed by Confined aquatic disposal. Rock chamber and Stabilization/Solidification scored significantly lower. The scores on offsite long term effects differed the most, followed by onsite long-term effects.

Comparison of exposure pathway scores for environmental risk: Confined aquatic disposal, Stabilization/Solidification and Rock chamber scored similarly. Land disposal scored well above the other alternatives. The difference in score is explained by the fact that only Land disposal scored on onsite effects, both long term and 50 year perspective.

Assumptions: The rock chamber has a hydraulic cone that is maintained in a 50 year perspective, but discontinued in a long term perspective. This means that operating costs for pumping and water treatment will occur. It is assumed that the waste will be classified as hazardous. It is assumed that Confined aquatic disposal and Landfill are fenced throughout the 50 year perspective, but not in the long term perspective.

The scores for environmental and human risk that were used in the MCDA are presented in Table 3.

Table 3 Overall exposure pathway score (summary of onsite and offsite 50 year and long-term scores) that were used in the multi-criteria analysis.

	1 - Confined aquatic disposal	2 - Rock chamber disposal	3 - Stabilization / Solidification	4 - Land disposal
Human risk	23	13	14	27
Environmental risk	8	7	6	13

3.1.2 Greenhouse gas impact

Greenhouse gas impact was estimated through a simplified LCA for each alternative, including transports and raw material production. The LCA output is the global warming potential (GWP-100) for each alternative, and is expressed in relative terms to the worst alternative (Table 4). Assumptions and calculations are presented in Appendix 1.

Table 4: Relative greenhouse gas impact.

	1 - Confined aquatic disposal	2 - Rock chamber disposal	3 - Stabilization / Solidification	4 - Land disposal
Relative GWP-100	31%	0,20%	100%	62%

3.1.3 Public acceptance

Public acceptance was scored using AHP in the MCDA software based on the text below. Results are shown in Figure 3.

Confined aquatic disposal

Sediments would be transported by barge to the site in Lundbyhamnen. The disposal site is located next to a busy road with a residential area on the other side. Approximately 2000 residents live within 400m of the site. Residents are screened from the road and the disposal site by a noise reduction fence. The disposal site is fenced in. Confined aquatic disposal might be considered an unsatisfactory solution for some people since it is not widely used in Sweden. However it is less likely to cause public protests than the criticized deep confined aquatic disposal in the Oslo fiord since this site is shallow, close to land and in an industrial area operated by the port. Some environmentalists may be worried. Noise, odour and accident risks are considered to have high public acceptance. All in all, confined aquatic disposal is likely to have medium to high public acceptance.

Rock chamber disposal

Sediments are transported by barge most of the way, then pumped to the rock chamber. Syrhåla is an industrial site with no residents in the vicinity. Neither odour, risk for accidents, noise, stress or worries should be a problem, hence public acceptance is expected to be high.

Stabilization/Solidification

The exact location of port expansion is not known, but a hotel and some industries might be affected. Depending on what mixing and placing methods are used, noise may occur. However the noise level of s/s is unlikely to exceed that of regular quay construction. Port of Gavle has, with success, conducted a pilot study with high demands on noise reduction. The principle of containing contaminated sediments in a construction in direct contact with water might worry the public. The risk for accidents affecting the public is minimal since all work takes place in an industrial area. Running the s/s process simultaneously to placing the mixture minimises potential odour problems. All in all, stabilisation/solidification is likely to have medium public acceptance.

Land disposal

Dewatering would take place on-site in an industrial area in Göteborg, the closest residents living across the river ~500m from the site. All studied factors indicate a high public acceptance for the on-site activities. A truck capacity of 25 ton loads would result in ~90 truckloads and as many empty truck transports. Transports to the site would pass through Göteborg on main roads primarily through industrial areas, followed by route 27. At Fläskebo the fenced road passes within 100m of 15 residential homes. The land disposal site Fläskebo has no residential neighbours within 400m. Assuming that the site is fenced, accidents are considered unlikely. Noise might be a problem for few people during transport and disposal site preparation. Odour might be a concern for ~15 residential homes. The technical solution is well established. All in all, land disposal is likely to have high public acceptance.

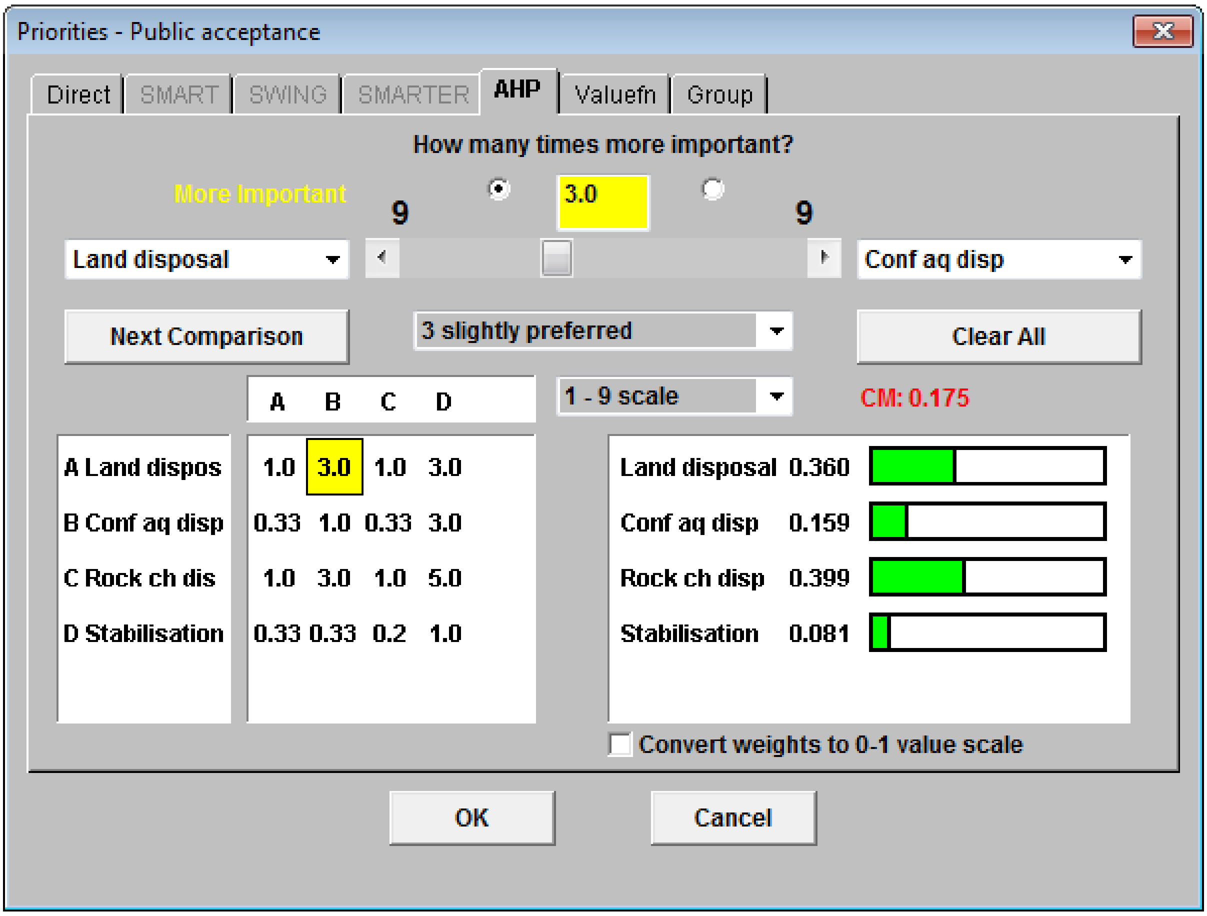

Figure 3 Public acceptance for the investigated sediment handling alternatives.

3.1.4 Local interests

A ratio of impacted area (publicly available land or port available land) to facility capacity [m^2/m^3] was calculated for each alternative. For land disposal it is assumed that the sediment will be placed in an existing site with a mean sediment thickness of 10 m.

Table 5 Ratio of impacted area to facility capacity. A positive values means that usable land area is created.

Alternative	Capacity	Used / produced area	Ratio (impacted area/capacity)
Confined aquatic disposal	160000	-67000	-0,42
Rock chamber disposal	1600000	0	0
Stabilization/Solidification	2700	500[1]	0,19
Land disposal	2500	-250	-0,10

3.1.5 Regional or national areas of special interest

The location of each sediment handling alternative was inventoried for the following regional/national interests: nature reserves, national parks, cultural reserves, cultural and nature national interests, bathing places, water intakes, Natura 2000 habitat and bird protection areas, wind power stations and flora/fauna protection areas.

The bay Torslandaviken next to Syrhåla and the rock chamber disposal site is a bird protection area (Natura2000). Depending on the season and the sea transport route, birds may be negatively affected during transport only. The area also features some wind power stations which will not be affected.

The water west of the stabilization/solidification site in the Arendal port area is a bird protection area (Natura2000). However the distance is more than one kilometre from the planned site, and no negative effects on bird life are expected. The islands Aspholmarna to the southeast of the port area is a cultural area of national interest partly due to an old fort. In the planned s/s site, the westernmost island will be transformed into a quay area.

No regional or national interests are conflicted on the planned sites for land disposal and confined aquatic disposal.

3.1.6 Investment and life cycle costs

Costs for confined aquatic disposal (435 SEK/m^3) and rock chamber disposal (400 SEK/m^3) were calculated by Port of Gothenburg. The cost for stabilisation/solidification (~150 SEK/m^3) was approximated by Port of Gavle based on an ongoing stabilisation/solidification project. The cost for land disposal (2000-2500 SEK/m^3) was approximated by SGI and LTU.

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[1] Assuming a construction depth of 4 m results in approximately 500 m^2 produced quay area.

3.1.7 Local/regional economy

Effects on local and regional economy were assessed through number of jobs created. This criterion was measured relatively using AHP, as shown in Figure 4.

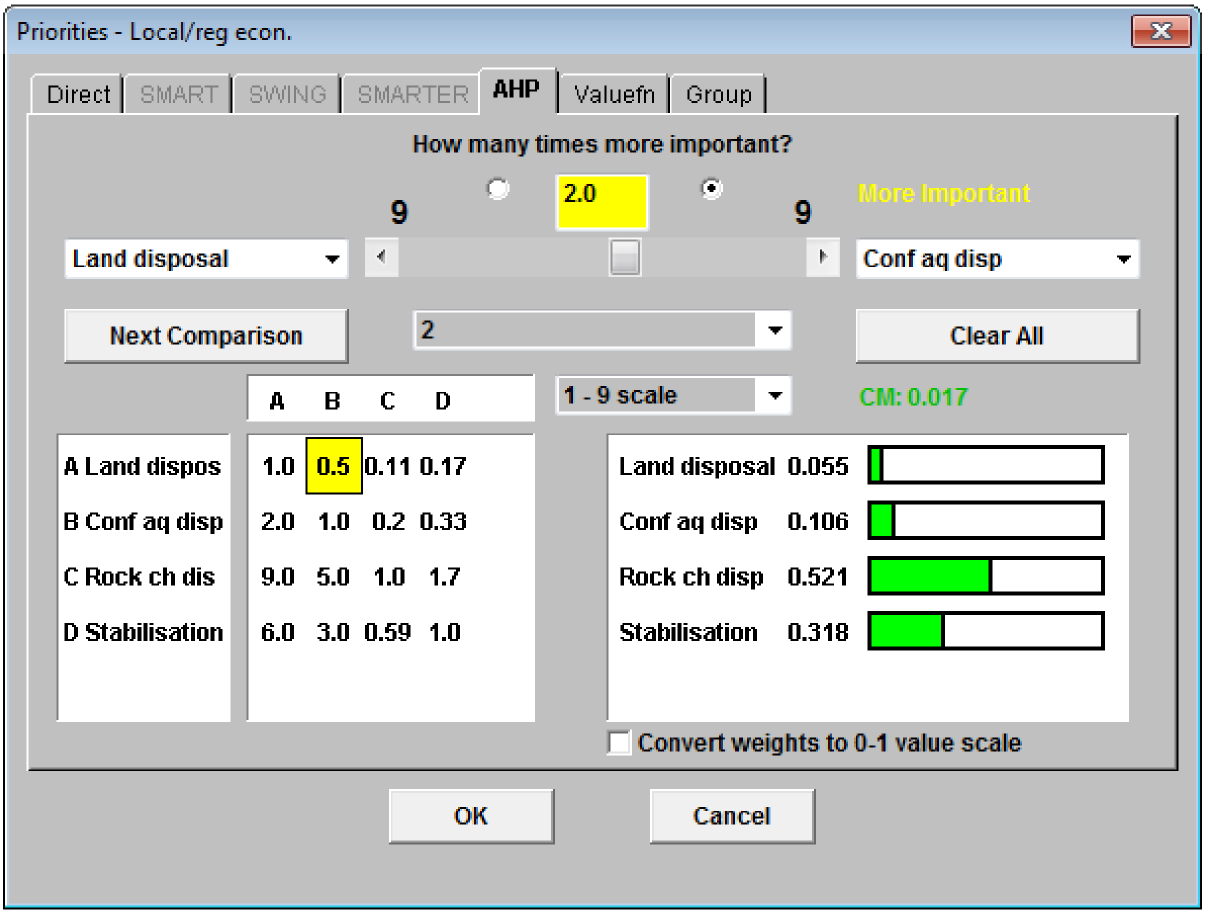

Figure 4 Effects on local/regional economy.

3.1.8 Summary of decision criteria scores

Results of decision criteria scores are summarized in Table 6.

Table 6 Decision criteria scores

Criteria	1 - Confined aquatic disposal	2 - Rock chamber disposal	3 - Stabilization / Solidification	4. Land disposal	Indicator
Environmental risk	23	13	14	27	The sum of relative hazard levels for each complete ecological exposure pathway (source-to-ecological-endpoint): Σ"relative hazard level"$_n$ The relative hazard level is expressed on a scale 1-3, where 1 is low and 3 is high.
Human risk	8	7	6	13	The sum of relative hazard levels for each complete human health exposure pathway (e.g. inhalation, dermal contact, intake): Σ"relative hazard level"$_n$ The relative hazard level is expressed on a scale 1-3, where 1 is low and 3 is high.
Greenhouse gas (GHG) impact	31 %	0,2 %	100 %	62 %	Relative GWP-100 (%)
Social criteria					**Indicator**
Public acceptance	-	-	-	-	Relative acceptance to other alternatives, AHP
Local interests	-0,42	0	0,19	-0,10	Ratio of impacted area (publicly available land) to facility capacity [m^2/m^3]
Regional or national areas of special interest	0	1	1	0	Nr of areas impacted negatively (possibly including magnitude of impact)
Economic criteria					**Indicator**
Investment and life cycle costs	435	400	220	2000-2500	SEK / desired volume of sediment
Local/regional economy	-	-	-	-	Jobs created. Relative to other alternatives, AHP

3.2 Weighting decision criteria

Weighting is subjective and was carried out by Port of Gothenburg using the SMART methodology (Simple Multiple Attribute Rating Technique). The goal with weighting is to reflect the decision maker's priorities among the aspects considered in the multi-criteria analysis.

On each level, the least important criterion was given 10 points. Then the other criteria were given points (>10) to reflect their relative importance to the least important criterion. In this case study weighting was carried out separately by two project managers at Port of Gothenburg. Then the weights were discussed and averaged. Decision criteria and weights are shown in Table 7.

Table 7 Decision criteria weights were assigned by Port of Gothenburg, and are summarized below.

Group	**Criterion**	**Weight points**
Level 1	Environmental	15
	Social	10
	Economic	20
Level 2 - Environmental	Environmental risk	50
	Human risk	100
	Greenhouse gas (GHG) impact	10
Level 2 – Social	Public acceptance	10
	Local interests	11
	Regional or national areas of special interest	11
Level 2 – Economic	Investment and life cycle costs	100
	Local / regional economy	10

4. Results

Results with bars divided in environmental, social and economic criteria are shown in Figure 5. The contribution of each criterion towards the result is shown in Figure 6. A higher score should be interpreted as a better overall result, meaning that Rock chamber disposal and Solidification/stabilization are the most favourable methods.

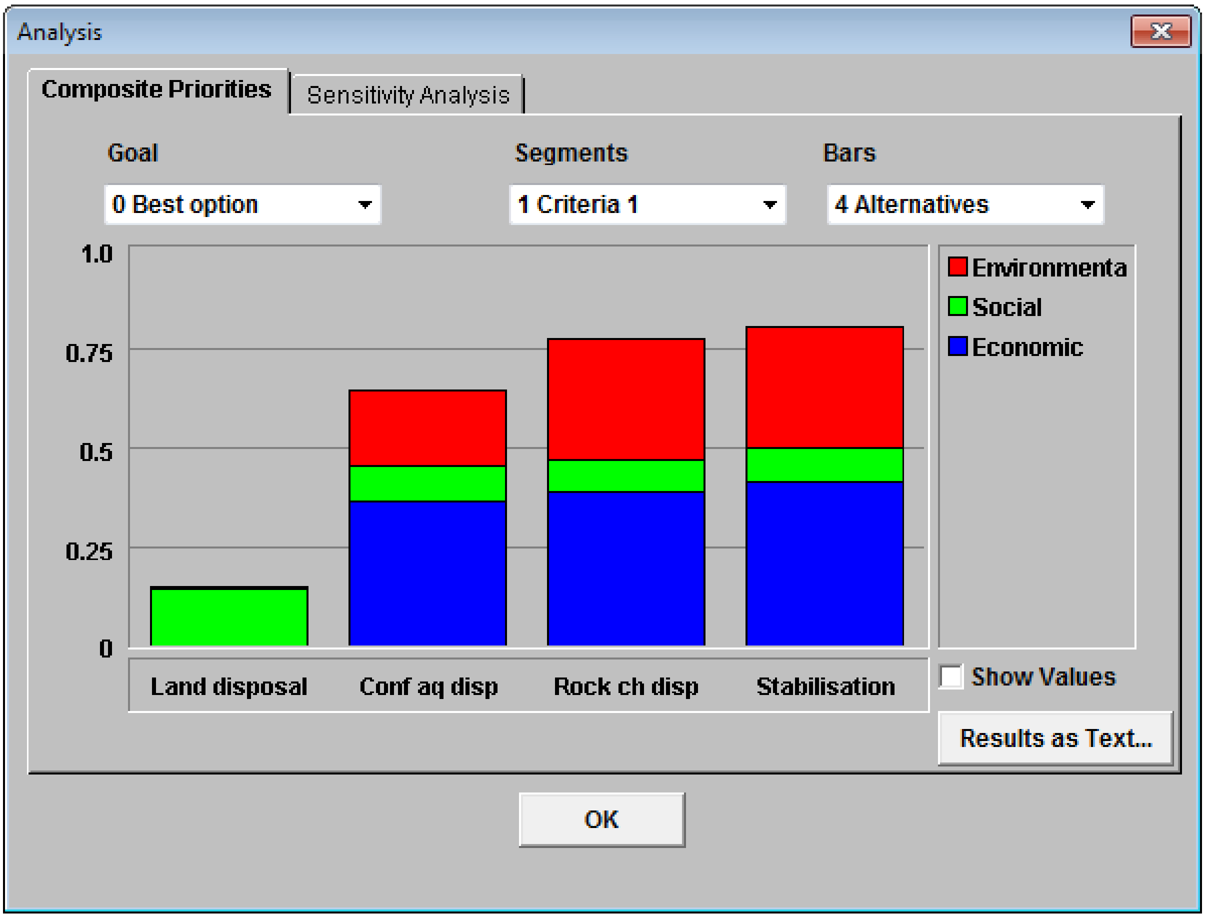

Figure 5 The MCDA results show the performance of each handling alternative. A higher score means better overall performance. A handling alternative scoring best on all decision criteria would result in the overall performance score 1.0. The bar colours show the contributions of environmental, social and economic criteria to the overall performance of each sediment handling alternative. The impact of the port's weighting can be seen clearly: economic and environmental criteria are given 2 and 1.5 times the weight of social criteria, and hence these contribute more to the overall performance.

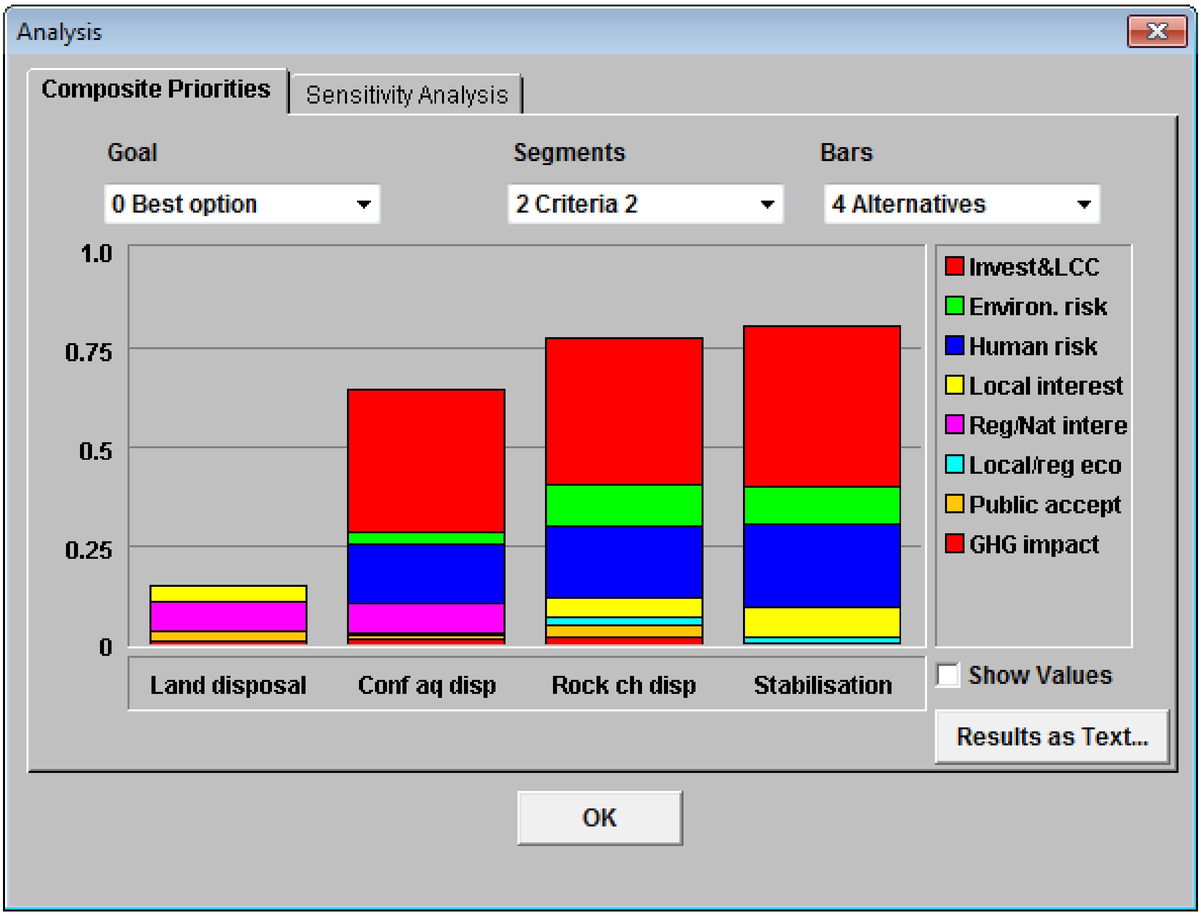

Figure 6 The MCDA results show the performance of each handling alternative, where a higher score means better overall performance. In this graph the MCDA results are broken down into the considered decision criteria. Investment and life cycle costs and Human risk make major contributions to the overall performance of the three best handling alternatives.

5. Discussion

Case specific discussion

Results from a Multi-Criteria Decision Analysis are not the simple truth but can be useful as an indication on what sediment handling alternatives should be studied further. The results indicate that Rock chamber disposal and Stabilization/solidification are equally preferred, closely followed by Confined aquatic disposal. Land disposal scores low mostly because of poor scores on environmental and human risks and the exceptionally high investment cost. The differences are amplified by the weights of these criteria.

Method discussion

MCDA provides a structured way of thinking through the whole range of decision criteria that should be taken into consideration when planning for handling contaminated sediments. MCDA can provide the transparency and documentation necessary for creating consensus between port owners and governmental organizations. This requires that a common opinion on decision criteria and weights can be established. It also requires that permit authorities embrace the concept of evaluating social, economic and environmental decision criteria together.

The Delphi method is one way of reaching stakeholder consensus on what weights to use in the MCDA. Stakeholders are then asked to provide individual weighting and motivate their choices. The answers are summarized anonymously along with motivations. This procedure is repeated until a pre-defined stop criterion is reached (e.g. number of rounds, achievement of consensus).

Port of Gothenburg's case study experiences

Once a MDCA model has been constructed to suit the port's needs, MCDA can be a pedagogic way to present dredging projects and explain and motivate the selected sediment handling alternative in discussions with governmental organizations as well as the public.

In general there are not many alternatives available for handling contaminated sediments. Small ports have scarce experience and resources and may not even know what alternatives there are.

LCA is considered too cumbersome for small maintenance dredging operations such as the case study (~2300 m^3). The port's experience is that governmental organizations consider social aspects more important than air emissions.

It is desirable to have two different MCDA models. One detailed model for large maintenance dredging projects and a simplified model for small projects.

A possibility to assess the decision criteria Environmental risk and Human risk without involving external experts is desirable.

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Appendix 1 – Simplified LCA for assessing greenhouse gas impact

General information

- 2 300m^3 dredged masses.
- Calculations per m^3 dredged masses.
- Sediment density is assumed to be 1,25t per m^3 dredged masses.
- Transport distances for raw materials are assumed to be 50 km.
- Results are shown in Figure 7.

Alternative 1 - Confined aquatic disposal

Production

Sand	110 000/160 000 = 0,687 m^3 2,2t*0,687m3 = 1,5t
Rock	12 000/160 000 = 0,075 m^3 2,2t/m^3 gives 2,2t*0,075m^3 = 0,165t

Processes used in SimaPro:
Sand, at mine/CH U
Gravel, crushed, at mine/CH U

Transportation

Sand 50 km (by lorry) ASSUMED
Rock 50 km (by lorry) ASSUMED
Dredged masses 6 km (by ship)

Processes used in SimaPro:
Transport, lorry >28t, fleet average/CH U
Transport, ocean freighter, average fuel mix/US

Alternative 2 - Rock chamber disposal

Transportation

Dredged masses 7 km (by ship)

Processes used in SimaPro:
Transport, ocean freighter, average fuel mix/US

Alternative 3 - Stabilization/Solidification

Production

Cement (20%) (0,2*175kg = 35 kg) 0,035t
Merit (40%) (0,4*175kg = 70 kg) 0,070t
Ash (40%) (0,4*175kg = 70 kg) 0,070t(No production, is waste)
Asphalt 500m2/2 300m3 = 0,21 m^2
0,2 m deep asphalt layer with density 2,2t/m^3:
0,2*2,2 = 0,44t per m^2
0,21m^2*0,44t = 0,092t asphalt

Processes used in SimaPro:
Cement, unspecified, at plant/CH U
Merit 5000 – ramber (include only Swedish electricity mix)
Mastic asphalt, at plant/CH U

Transportation

Cement 50 km (by lorry) ASSUMED
Merit 50 km (by lorry) ASSUMED
Ash 50 km (by lorry) ASSUMED
Asphalt 50 km (by lorry) ASSUMED
Dredged masses 5 km (by ship)

Processes used in SimaPro:
Transport, lorry >28t, fleet average/CH U
Transport, ocean freighter, average fuel mix/US

Alternative 4 - Land disposal

Production

Cement (17,5 kg) 0,0175t Merit (35 kg) 0,035t
Ash (35 kg) 0,035t
Gravel 0,66t
Sand 0,074t
Soil 0,168t
Geotextile 0,0008t
Bentonite 0,0023t

Calculated amounts, example:

From previous project 200m^2 area with 1000m^3 sediment.
200m^2/1000m^3 = 0,2m^2 per m^3 sediment
168t soil was used.
168t/200m^2 = 0,84t per m^2.
0,84t * 0,2m^2 = 0,168t per m^3 sediment

Processes used in SimaPro:
Cement, unspecified, at plant/CH U
Merit 5000 – ramber (include only Swedish electricity mix)
Gravel, crushed, at mine/CH U
Sand, at mine/CH U
Clay, at mine/CH U (soil)
Bentonite, at mine/DE U
Polypropylene, granulate, at plant/RER U (geotextile)

Transportation

Cement	50 km (by lorry)	ASSUMED
Merit	50 km (by lorry)	ASSUMED
Ash	50 km (by lorry)	ASSUMED
Gravel	50 km (by lorry)	ASSUMED
Sand	50 km (by lorry)	ASSUMED
Soil	50 km (by lorry)	ASSUMED
Geotextile	50 km (by lorry)	ASSUMED
Bentonite	50 km (by lorry)	ASSUMED
Dredged masses	29 km (by lorry)	

<u>Processes used in SimaPro:</u>

Transport, lorry >28t, fleet average/CH U

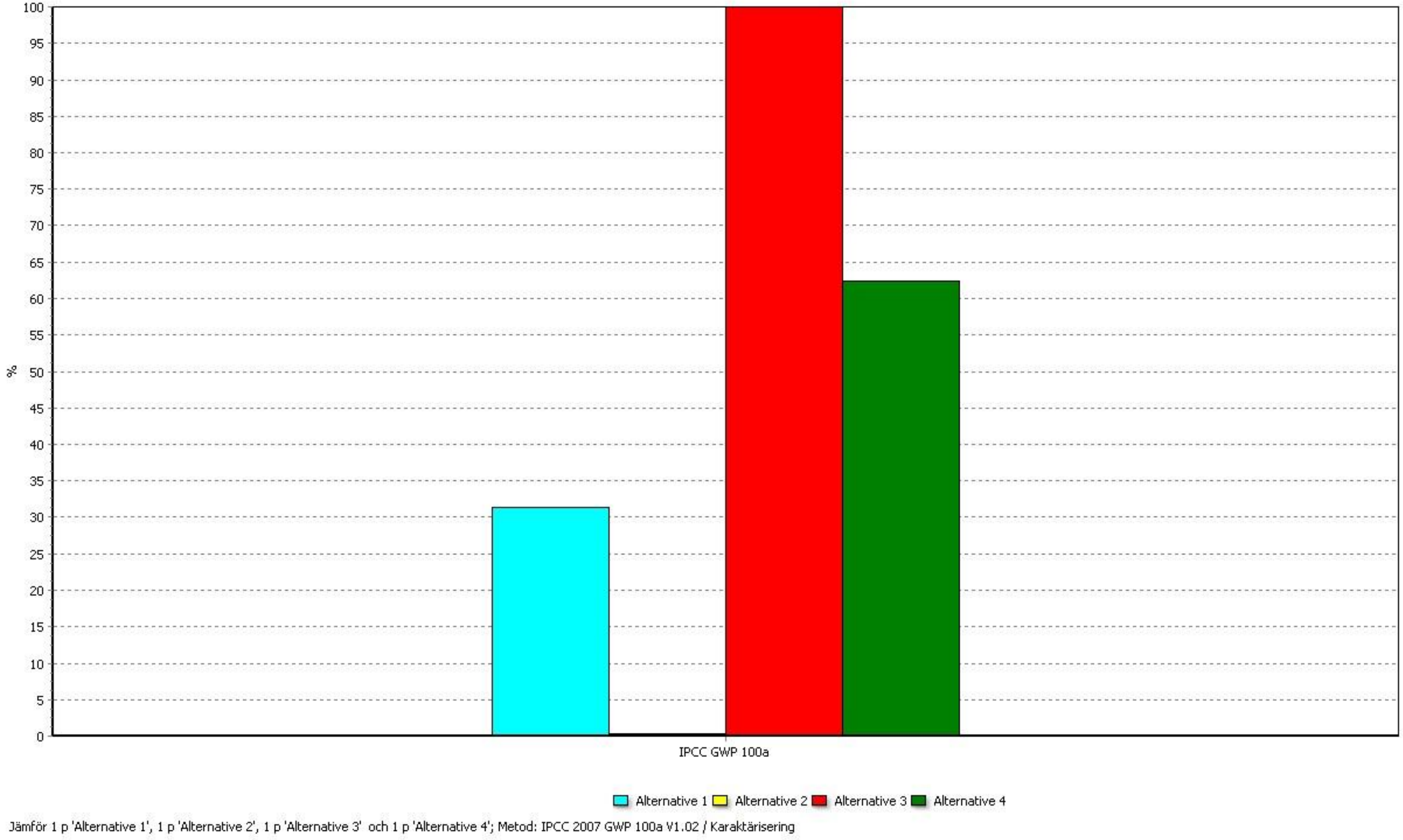

Figure 7 Relative global warming potential (GWP-100) for alternative 1 - Confined aquatic disposal, alternative 2 - Rock chamber disposal, alternative 3 - Stabilization/Solidification and alternative 4 - Land disposal. The alternative with the highest GWP-100 is shown as 100 %, and the other alternatives are shown as percentages of the highest GWP-100.