Decision support tool for sustainable management of contaminated sediments in coastal areas

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Abstract
The sediments in ports, coastal areas, estuaries etc. are often highly contaminated due to human activities. Land reclamation for new residential areas and development, maintenance and dredging in ports and fairways imply management of these contaminated sediments. The volume to be dredged in the coming years in e.g. the coastal areas in Sweden and Norway is estimated to several million m3 incl. contaminated sediments. The paper has focus on the evaluation of established sustainability indicators using Multi-Criteria Decision tools. Furthermore the quantitative analysis of different scenario using environmental system analysis is described. One key scenario is beneficial use of contaminated sediment e.g. in new harbour areas by applying the emerging technology stabilisation/solidification. All in all the described tool can provide stakeholders with a sound base for using Best Available technology (BAT) for management of contaminated sediments. This method can also prove to be sustainable for handling of contaminated areas on land.

INTRODUCTION

There are many "hot-spots" with highly contaminated sediments in coastal areas, ports, estuaries etc. Human activities, especially during the 19th century, have led to a severe anthropogenic impact on the environment. In Sweden only it is assumed that about 80 000 sites are contaminated. Among those about 700 are related to contamination in lakes and coastal areas. The situation is similar in Norway and internationally. Several million m^3 incl. contaminated sediments will be dredged in coming years in Sweden and Norway, /1/, whilst exploiting harbours.

Dredged sediments are normally deposited on land or at sea. The latter is often not possible for contaminated sediments due to environmental restrictions. To landfill contaminated sediments is very costly, about 150 to 200 Euro/m^3. Recent development in treatment technology makes it possible to consider treatment by stabilisation and solidification to reduce environmental impact and improve technical properties. This method may also prove to be cost-effective and sustainable compared to deposition at land or at sea. The cost is expected to be about 20 to 50 Euros/m^3 and may be even less if the technique is developed further. Using the technique could also enable a beneficial use of the stabilised sediments for land reclamation at exploration for port facilities, industrial activities or other use. In addition the need of natural resources and related transportation could decrease enabling environmental advantages. Several national and international studies have established experience and knowledge. Critical issues have been identified in a report for the Swedish Environmental Protection Agency /2/ e.g. the interaction between sediment, binder, contaminants and surroundings in order to make sure the application is durable. In a manufacturing perspective the binder admixtures could be further developed as well as mixing and construction technologies improved. Those are examples of issues related to the technique itself.

What alternative for handling of the contaminated sediments should be selected? What technique is to be preferred in a broader sense given that a port will dredge. How can reduced global environmental impact be compared to an increased site specific impact for another alternative? How can cost be valued in comparison to lower resource and energy consumption? These questions make it clear that there is a need for a development of a decision support tool to enable a broad and objective comparison to today's accepted solutions. Thus bringing forward a process where an acceptance for the technique is being built in cooperation with authorities and other stake holders. These issues are addressed by the Eureka project STABCON, a joint Norwegian and Swedish project, with partners representing ports, R&D performers and construction industry. The overall objective of the project STABCON is to further develop and implement the stabilisation/solidification technology. This paper puts a focus on WP 4 where the objective is to develop a methodology ”decision support tool” where a sustainability approach is applied in order to enable a broader decision base and support throughout the planning and permit process for a port planning to perform dredging activities. The outcome is expected to be a decision tool where 1) critical issues are brought forward and assessed in a broader sense than currently and 2) improved argumentation in conjunction with environmental permit processes. Furthermore 3) it is important that the tool is based on current knowledge in order to enable an easy implementation into daily practice.

METHOD

The overall approach used is a participatory process based on a so called ”Strategic Choice Approach”, abbreviated SCA /3/. In the first stage indicators were established in an iterative process where legislation & policies, stake holders opinion and knowledge on assessment tools and MCD tools where matched. Based upon the proposed indicators, case studies are being performed in a second stage concerning indicators and decision tools. In the final stage the results will be compiled and a tool will be proposed.

Basically the work includes identification of what should be described, how that can be described and finally how decisions can be made on the issue of managing contaminated sediments on a project level. This paper describes the work including the first case study. There will be further elaboration as the final studies have been performed.

PROPOSED INDICATORS

The proposed indicators where derived in an iterative and participatory process that are described by Figure 1. The work consisted of a) stake-holder opinion assessment, b) legislation and policies c) assessment tools and d) multi criteria decision tools.

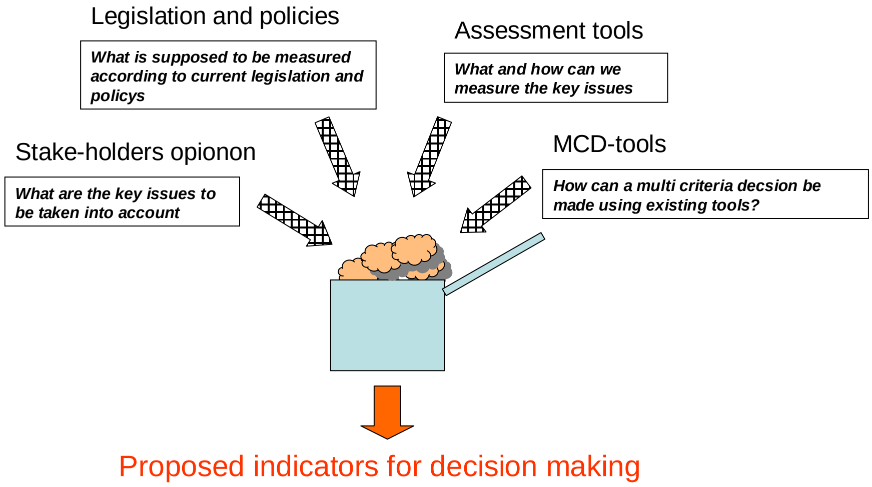

Figure 1: Performed activities in order to establish indicators as a base for decisions.

Stake-holder opinion assessment

Initially a study was performed on finding existing indicators concerning ports and management of sediments. This study showed that there were none directly applicable to the case of STABCON. Therefore a so called stake-holder opinion assessment (SOA) was performed. The methodology is developed at the Royal Institute of Technology, KTH /4/ and can be described as a combination of survey and interviews. In this method key stake-holders are participating in a step by step process to address key issues (later base for indicators). The stake–holders participating included representatives from authorities, business organisations and non-governmental organisations in Sweden. They represented key actors on the local, regional and national level.

The questions and issues addressed in the SOA were grouped according to the basic principles of sustainability and addressed issues of transport but focused on the management of contaminated sediments. A 2/3 reasons level has been used to indentify acceptable and non-acceptable solutions. Concerning ecology it was concluded that the Swedish environmental objectives could serve as base for indicators. On the issue of acceptable allocation of contaminants the stake-holders major opinion was that at higher contaminant levels sediments should be deposited on land. On the issue of risk of contamination the respondents indicated that deposit at sea should be acceptable only if corresponding to insignificant risk on a five grade scale from insignificant to very high. For sediments associated with insignificant to high risk levels stabilisation/solidification could be acceptable whereas at very high levels of risk sediments should be deposited on land.

Legislation and policies

A literature review was compiled in order to 1) describing current legislation (i. e. mainly based upon the environmental code and the building code), 2) compilation of decisions made in the Environmental Court in Sweden and in Nordic countries on the issue of dredging and 3) a description of current practice related to the building process.

Shortly, dredging and management of dredged masses are tested against three chapters in the environmental code. In chapter 9 dredged masses are classified as waste and their use for construction purposes is assessed. Dredging as an activity is handled by chapter 11. This chapter also includes use of dredged masses as construction material in water. Depositing at sea is handled by chapter 15 that includes regulations concerning exceptions from a ban on deposition of waste (dredged masses) at sea. All in all the handling of contaminated sediments will be treated as "significant environmental impact" by the authorities according to the environmental code thus causing a situation where an environmental impact assessment (EIA) will have to address the issue.

The sustainability approach is an overarching approach that is stipulated in the environmental code in the basic paragraphs of chapter 1 and 2. Furthermore analyzing previous permits we learned that the performed risk assessments (RA) as part of EIAs often were limited to the first stage problem definition. And in that context various different limit and threshold values were used originating from practices such as criteria for landfilling, contaminated land and others. Thus giving a situation where assessments will be difficult to compare and the transferability is likely to be limited. Furthermore it was found that resource and energy aspects were treated in qualitative way only. The economical aspects focussed on project costs however usually disregarding a life cycle perspective on costs and furthermore were likely to consider issues of national economy only briefly.

The building process starts with the idea and initial investigation concerning development of the port. The process continues through an application process via detailed design, building and ends with the operations and maintenance phase. The decision situation where the STABCON project support mainly concerns the environmental permit process from initial consultation with authorities etc. to the decision of the appropriate authority.

Assessment tools

A compilation of tools was performed, primarily based upon the works by Svedberg et al /5/, Moberg /6/ and Lindblom /7/ concerning system analysis on both economy and ecology. The sustainability aspect of social aspects was not considered in this part of the work.

There are numerous tools available for environmental assessments. While performing environmental assessments there are numerous questions that have to be addressed and for each question a lot of aspects should be considered. Some of them like EIA are sanctioned by law, the Swedish Environmental Code, others are developed for certain purposes such as chemical risk assessment or a life cycle analysis.

In a site-specific assessment system focus is usually on assessing the risk related to emissions of substances. This is similar to the assessment carried out in chemical risk assessment systems with the difference that the later system tend to focus on chemical composition and occurrence of certain substances as described by Roth /10/ and further by elaborated by Toller /11/. Tools on this system level likely exclude other types of environmental aspects such as use of natural resources and climate.

To assess economical issues there are numerous of different tools that can be used. The most referred and established are project budgeting, life cycle cost assessment and cost benefit analysis. Assessments concerning project cost are considered basic. However the national economic aspects are considered only briefly in current permit processes and mainly concern the port activities and not the dredging and its implications. A port making a decision on the best alternative for management of contaminated sediments is mainly focusing on the so called project level, see Figure 2

Focus for tool \ **Included aspects**	Natural resources	Environmental impact	Natural resources and environmental impact	National economy, natural resources and environmental impact
Policy, Plan, Program		IAM-RAINS	SEI, EIA	PA, CBA
Region	EF TMR		Environmental accounting, IOA	
Company	Em Ex		Environmental accounting	
Project/Object	MIPS	**EIA, RA**	**EIA ESA/LCA**	**CBA**
Product	MIPS	RA	LCA	
Substance		SFA, RA		

Figure 2. The tools can be described related to their actual focus and the corresponding impact. The proposed tools for the case studies corresponding to a project situation are marked in green and in bold, processed from /5/ and /6/.

Multi Criteria Decision Tools

A schematic picture of a decision process, somewhat adjusted to a situation when a port shall extend the port including dredging activities in shown in Figure 3. Kiker et al. (2005) /8/ state that successful decision making in a complex situation regarding environmental aspects to a large extent depends on how much the three key components are integrated in the decision process: human beings, process and tools, see Figure 3

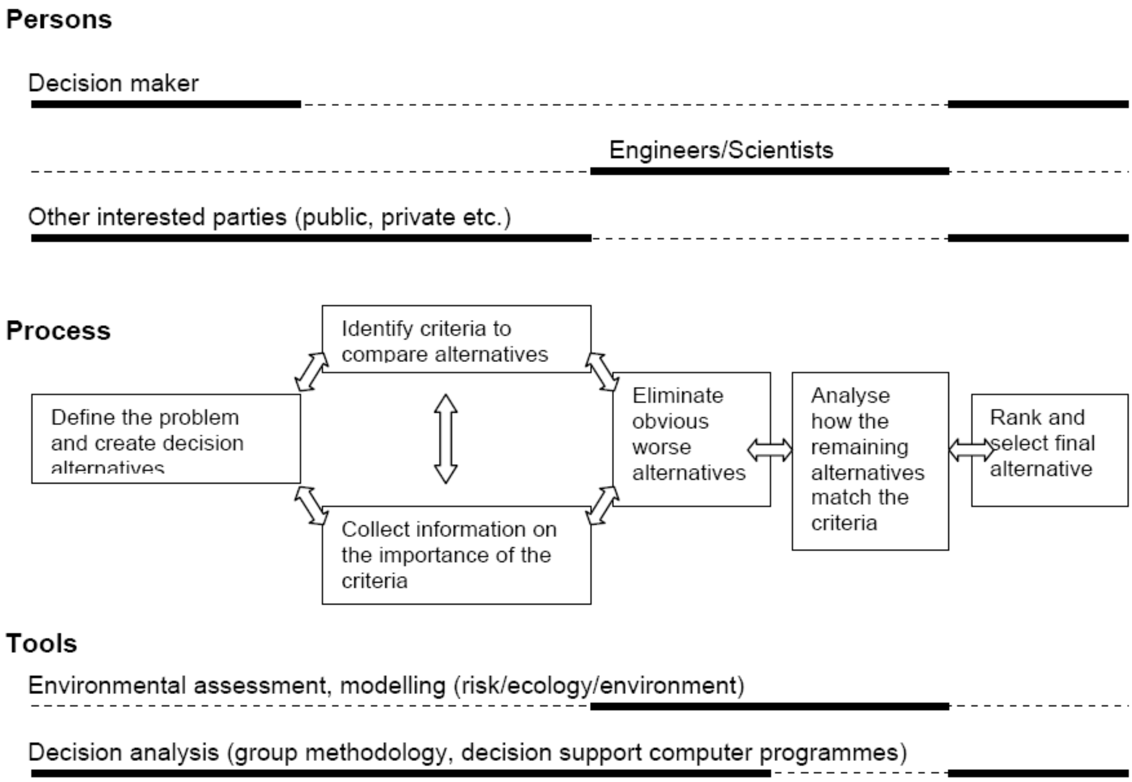

Figure 3.Schematic picture of an integrated decision process comprising person, process and tools.

The process in Figure 3 shows a structural way to evaluate the decision alternatives against each other. In step ”Collect information on the importance of the criteria” the indicators are weighted against each other. Here different interests give different weights depending on background.

MCD tools allow the use of a number of criteria at the same time. It also makes it possible to assess the relative importance of the different criteria. Hence the person deciding has a better control of the basis for the decision. There are three aspects to consider: (1) the evaluation of each indicator, (2) possible weighting between indicators and (3) the fusion of indicators. The structuring of the indicators influences the evaluation.

An example of a MCD tool is Web-HIPRE which is a web-based tools developed at the Helsinki University, Finland (http://www.hipre.hut.fi). The hierarchic decision model is created graphically by defining the overall objective with the decision (e.g. the sustainable solution for handling of contaminated sediments). Then the first criteria related to economy, socio-culture and environment is defined and thereafter the next level of criteria, indicators, and finally the decision alternatives. The results of the final fusion are presented distinctly in graphs. A sensitivity analysis at different levels can be performed in the model.

MCD – Decision based upon proposed indicators

As mentioned above the MCD tool Web-HIPRE is to be used in the STABCON project. This work has just started and will be performed in autumn 2009. Figure 4 shows an example how the results can be presented. For different alternatives, Alt A to Alt D, the contribution of the indicators Economy, Socio-culture and Ecology to the overall result for the alternatives respectively is shown in Figure 4. The higher total value the better.

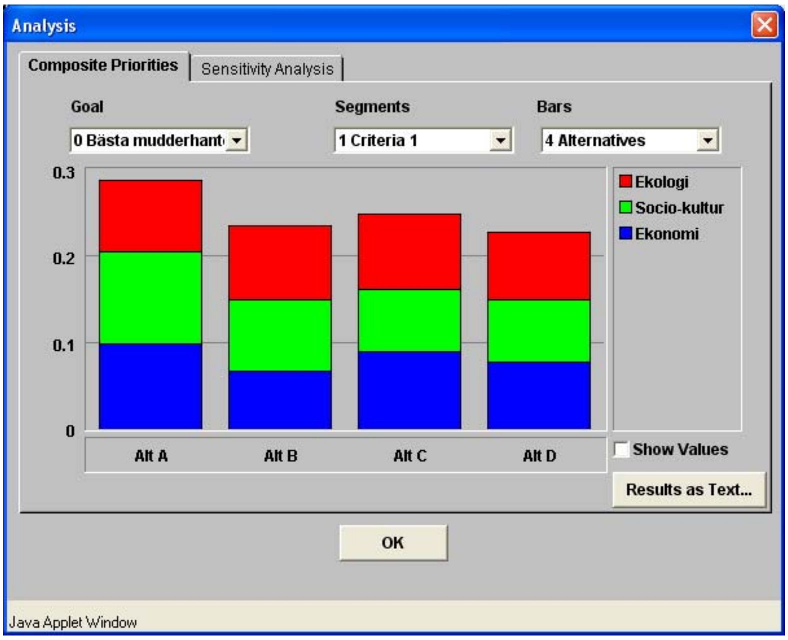

Figure 4. Results of a MCD analysis by WEB-hipre. OBS, only the principle, not actual results.

Conclusions of stage 1: Indicators

A number of indicators were proposed during the work reported above. These were discussed in a workshop with participating experts and based upon a situation where dredging was to be performed in order to extend an existing harbour. The resulting indicators are shown in Table 3 below.

Table 3: Elaborated indicators in the project STABCON for a situation where dredging will be performed to further develop an existing harbour.

Level 1	Level 2	Level 3	Commentary
Economiy aspects	Investment cost including project risk		The cost related to the developer/project owner
	National economy		Economy in a broader context
Socio-cultural aspects	Local protection areas		Impact on nearby environment, including acceptance/worry concering recreation, noise, accidents etc.
	Regional and national protection areas		Impact on national interests such as culture, power supply, fishing etc, for ex Natura 2000
Environment aspects	Enviromental impact on a site specific scale	Risk for contamination of nearby land	Toxic impact on water and land areas
		Risk for toxic effect on organisms	Toxic impact on vegetation and organisms
		Risk for health effects	Toxic impact on humans
	Environmental impact on a global scale	Use of finite resources	Use of materials and fossil fuels
		Use of land and water areas	Enabling or limiting use of areas on land or in water
		Emissions to air and water	Emissions from transport and material manufacturing (for ex green house gases, and acid substances)

Socio-cultural aspects – Indicators on participative process
The proposed indicators for social aspects are impact on local areas for protection, such as Natura 2000, and impact on regional and national protection areas, like national parks etc. It is expected to be difficult to perform a quantitative assessment on the importance of a protected area; this is likely to be in the eyes of the beholder. Nevertheless it is important that the issue is highlighted and brought forward in the decision. The process according to the environmental code chapter 6 puts a clear focus on the applicant to actively include stake holders in a participative process. In the performed SOA it was also clarified that it is of utmost importance to include the public, preferably local, in order to gain acceptance and reduce fear that often arise from lack of communication. This aspect on socio culture was not considered as an indicator as it should be considered whatever alternative is considered.

CASE STUDIES

Based upon the results from the first stage tools for assessment were chosen to describe the indicators both qualitatively and quantitatively. Thereafter the findings will be used as input for case studies with representatives of ports concerning decision tools. Preliminary results for the first case study and the indicators environment and national economy are presented below.

The port of Oxelösund was chosen for the case study, since as a member of the STABCON project the data collection was easy. The port is planning to expand to enable RoRo-traffic and container- and feeder traffic. Thus dredging will be needed to build new quays and enable deep draught ships. About 175 000 m^3 of sediments will be dredged of whom ca 50 000 m^3 are contaminated by non-organic pollutants and PAH and PCBs. In order to perform assessments system boundaries were set according to Figure 5. The overall activity is the development of the port including dredging activities and construction of quays, areas for storage and transportation. The main alternatives for handling the sediments are proposed to be stabilisation/solidification (Scenario 1), landfilling (Scenario 2), Deposit at sea (Scenario 3) and confined disposal at seaside (Scenario 4). Activities that are identical in the different scenario are excluded in the study. Thus dredging and its impacts are not considered, and neither is the construction of the superstructure. No geographical delimitation concerning included activities and environmental impacts are made. The time span studied is 100 years for all civil works such as quays, landfill, site at sea and for the confined disposal at sea. The expected technical life span for the quay was set to 100 years.

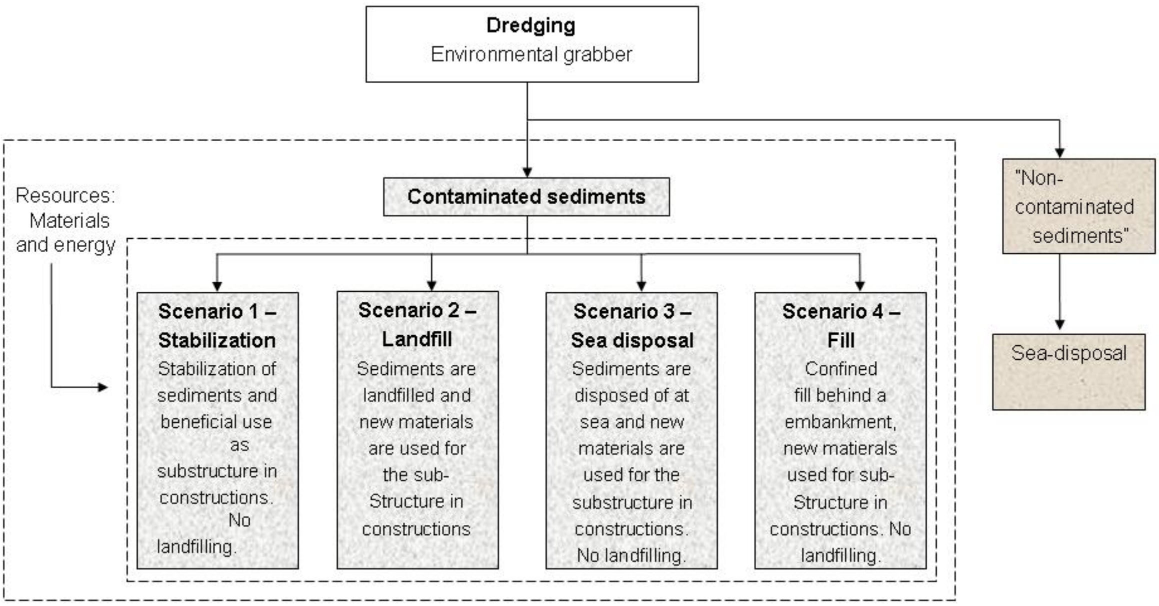

Figure 5: System boundaries of the performed assessments for the handling alternatives. Dredging as well as handling of non-polluted sediments is excluded from the system.

In order to provide a broader base for decisions and to described the proposed indicators in a quantitative way the work of STABCON focused on enhancing the statutory EIA and improve the assessments made concerning energy and resource aspects as well as site specific assessment using tools as ESA/LCA and RA. The latter, RA, is ongoing and focusing on how risk should be characterized in order to enable comparison between the different alternatives or fates of the dredged masses. Furthermore a study concerning national economy was performed using an environmental economics approach.

Ecology – Indicators on site specific and global scale

The developed indicators for ecology where grouped into a site-specific and global/regional scale. In order to address these system levels two tools were brought forward, LCA and RA as they are established and widely used. The LCA will address the global and regional issues and RA to address the site specific level. The focus has been on identifying methods or practice in order to characterize risk so that the main handling alternatives can be compared. LCA was proposed as tool in order to bring forward quantitative data concerning energy and resource aspects.

Furthermore a system for describing site specific pollution risk had to be elaborated. This study is at the moment in progress. One of the approaches to describe site specific impact, s.c. exotoxpotential, is shown here. All in all on the site specific level it is proposed that future assessments be carried out further in order to enable better comparisons between different handling alternatives. In Figure 6 key results concerning energy consumption and potential for global warming are presented. Part of the work has been based on adjoining works by /9/.

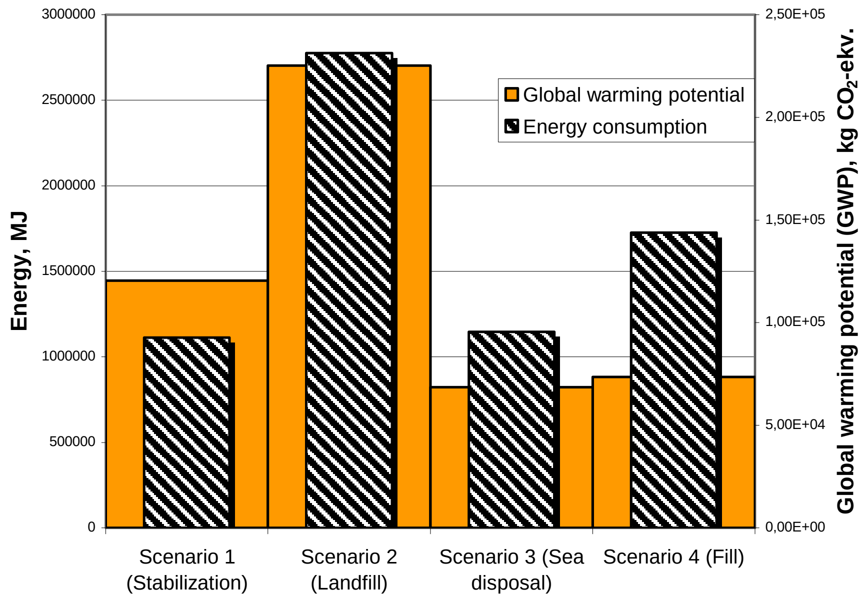

Figure 6. Energy consumption and global warming potential for the different alternatives. Let it be noted that this is a relative assessment.

Economy – Indicators on project cost and national economy

A Cost Benefit Analysis (CBA) was performed in order to address the issue on national economy concerning the fate contaminants including PCBs and PAHs, see /7/. Some of the key results from /7/ are presented below. The tested tool (CBA) for assessing the national economy is in brief adding costs to the performed LCA. In Figure 7 it is shown that Scenario 2 is the alternative that is most costly in a national economy perspective. The assessed cost is relative and case specific and therefore only useful for the actual case to enable comparisons. Scenario 3 is, relatively, causing the lowest cost. The performed assessment furthermore concludes that emissions to water are related to far lower costs than emissions to air. The emissions to water are however slightly higher for Scenario 3 than 1 and 2. This is due to the fact that no action is taken to immobilize the contaminants of the sea deposited sediments whilst placing them on the sea bottom.

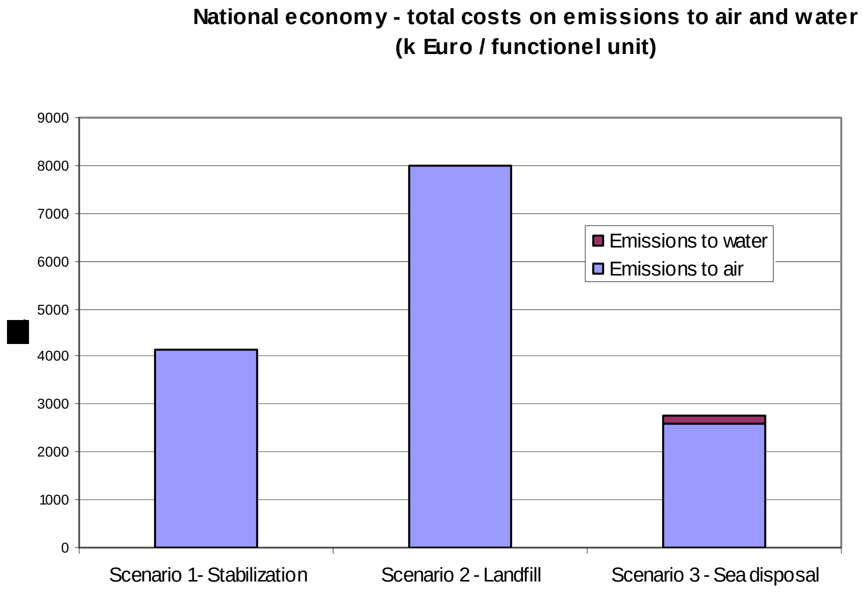

Figure 7. National economy cost per scenario, k Euro/f.u. /7/

CONCLUSIONS

In the STABCON project the methodology for decision support has been examined and a system for decision making regarding handling of dredged contaminated sediments has been developed. .

Key issues on **assessment tools/current use**: 1) Current assessments can be improved with existing tools for assessment. LCA is not used frequently as support in EIA assessments in the application process, but a use of LCA would give a quantitative approach to key sustainability issues such as energy and resource aspects. 2) Risk assessments (site specific) mostly only include the first stages of a RA. The risk characterisation should be improved in order to enable comparisons and 3) The proposed CBA gives a good perspective and base for decisions but is however complicated and lacking data, especially concerning certain substances and their corresponding costs.

Key issues **on indicators**: 1) the indicators are developed for a project specific case and should be used in that context. For a broader context, for example planning on a national base a new set of indicators should be elaborated, 2) In the pre-tests that have been made it is clear that the indicators provide a broader decision base and give the application permit process a improved argumentation as well as a sustainability approach and 3) Relative and absolute, the statutory EIA is likely to be improved using existing tools already on the "market".

Key issues on **decision support tool**: 1) The decision tool will have to handle both qualitative as well as quantitative data/information, 2) The tool has to be very basic in order to be taken into account whilst working with a permit, 3) The Best Available Technology (BAT)-

approach could very well be used for other comparisons of technical systems, for example treatment options on land, use of technology for soil reinforcement etc. Thus enabling a situation where the function of a construction as a whole is assessed and not limited to assessments on a material level. In this case ports are the problem owners, but of course it could be applied for other BAT-situations like brownfield regeneration.

STABCON PROJECT (www.stabcon.com)

The Eureka project STABCON has addressed a number of issues related to stabilisation/solidification of contaminated sediments and will provide guidance on management of contaminated sediments with respect to handling alternatives for sediments incl. beneficial use of treated contaminated sediments for e.g. new areas in harbours. Also a tool-box of treatment technologies and tools for assessment of sustainability and decision support tool to be used in planning and application processes. Additionally field tests are performed to validate, demonstrate and communicate the application of the stabilisation/solidification method. For more information, see the project website www.stabcon.com.

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