Assessing the eco-efficiency of contaminated site management

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Abstract: In Finland, the decisions on contaminated site management (CSM) have been strongly driven by urgency and economic resources while other aspects such as the overall environmental impacts have often been ignored or they have only played a minor role. Therefore, being a quick and technically simple method soil excavation combined with landfill treatment has been the prevalent remedial action. However, the eco-efficiency of this method has been questioned particularly due to the long transport distances. The project called “Eco-efficient risk management of contaminated soil and groundwater” (PIRRE) tackled this problem and produced a decision support system (DSS) that consists of information, guidelines and tools to site-specifically assess the eco-efficiency of alternative remedial measures. The DSS also includes a calculation tool "PIRTU" for the site-specific evaluation of the eco-efficiency of alternative risk management (RM) actions. PIRTU comprises four separate modules, namely "Risks", "Environmental impacts", "Costs" and "Other factors" that further include several sub-components. Demonstration of PIRTU using a few model sites proved that it enables efficient communication between different stakeholders and identification of the preferred RM option.

The second phase of the PIRRE project focused on the eco-efficiency of CSM at the regional and country level, and developing the PIRTU-tool more useable. Regional-scale eco-efficiency indicators were developed on the basis of a study on the various methods and tools used for example in life-cycle analysis, cost-benefit analysis and material flow analysis. In addition, the availability of data was considered in the definition of the preliminary indicators that were then tested in three different regions in Finland using the available CSM data from three consecutive years. The final 14 indicators include generic regional factors associated with the remediation activities and population. These are important for the comparisons between different regions and between various years within a certain region. Indicators describing the environmental load and material flows require more specific information about the volume and characteristics of contaminated soil, use of natural resources and emissions. Unfortunately, owing to the lack of data it was not possible to use indicators directly related to environmental and health risks and economic effects. Therefore, defining such indicators and regional systems for gathering the necessary data is an important future development need.

At the regional and national level, the future realization of eco-efficiency in CSM is affected by many factors, the development of environmental policy, legislation and guidelines being the most important of these. Availability and feasibility of remediation techniques are also key determinants. Economic instruments such as trusts are important drivers since eco-efficiency could be included in their criteria for receiving funding. In the future, new recycling options also need to be in hand since the current reuse of slightly contaminated soils in the closure of landfills and in the daily cover of wastes will decline due to several reasons.

INTRODUCTION

In Finland, the number of potentially contaminated sites totals ca. 20 000 while some 300—400 sites are annually remediated (Finnish Environment Institute, 2005). In most cases, the extent of contamination is unknown and therefore, site investigations are required before the need for some risk management (RM) measures is revealed. So far, the most important driver to any actions – including site studies – is the change of land use.

There are various means to manage the risks arising from land contamination, including restrictions to land use and active remediation measures. In Finland, soil excavation combined with off site treatment and replacement with clean soil has to date been by far the most common remediation method. In 2006, soil excavation or the combination of soil excavation and containment were suggested in more than 90 % of the permits and notifications concerning contaminated land remediation (Finnish Environment Institute, unpublished). Groundwater remediation has been much less common than soil reclamation, the most prevailing method being pump and treat using for example absorption into activated carbon.

The majority of excavated contaminated soils have ended up to landfills where they have been either reused as such or after treatment. Alternatively, some soils have been disposed of with other wastes or isolated from them (i.e. encapsulated). The fraction of soils that is actually reused in landfills has so far been unknown. At the same time, the costs of landfill treatment of contaminated soils have been rather low due to the fact that they are exempted from the landfill tax – regardless of whether they are reused or disposed of as wastes. The demand for slightly contaminated soils in particular, has also been high due to the extensive closing operations where they can be used instead of virgin soil. The closure of old landfills is necessary since most of them fails to fulfill the requirements (set by the EC) for the bottom structures. Another driver to reducing the number of landfills is the national waste strategy that emphasizes the reuse of all wastes. The reduction in the number of landfills as well as some restrictions for wastes to be treated in landfills (for example pretreatment demand and limits for organic matter) will inevitably diminish the amount of contaminated soils to be treated in landfills in the future. Therefore, new feasible options to treat and reuse contaminated soils are needed.

In Finland, the low landfill costs have led to a situation where excavated soils have been transported to distant landfills located even 500 km away from the site under remediation (e.g. Uudenmaan liitto 2002). In fact, in the selection of RM methods, the immediate costs and time needed for RM actions have been the main determinants (Sorvari and Antikainen, 2004). Indirect costs and other consequences, such as environmental impacts caused by remedial measures and other risks, e.g. to structures, human wellbeing and ecosystems, have typically received little attention. Particularly excavation and transportation produce significant adverse environmental impacts, i.e. emissions to air and energy consumption. Excavation also changes the landscape and ecosystems. Therefore, the RM method that is the best from the costs perspective is not always the most eco-efficient option i.e. the best considering the ratio of the input to the gained benefit.

Previously, there were no adequate data, methods and guidelines for a through assessment of the eco-effciency of different CSM alternatives. Therefore, between 2003 and 2006 the Finnish Environment Institute (SYKE) coordinated a project "Eco-efficient risk management of contaminated soil and groundwater" (PIRRE, www.environment.fi/syke/pirre) where an internet-based decision support system (DSS) was developed. The project started with defining what is meant by eco-efficiency in the CSM context (Sorvari et al., 2009). The stakeholder seminar and the Metaplan method used in this seminar for gathering the participants' ideas produced a definition according to which eco-efficiency should be understood as a multidimensional and broad concept, covering environmental factors (health, ecology, quality of the environment in the long term), economic factors as well as socio-economic and -cultural aspects (image, psychological effects, effect on employment etc.). Therefore, in our DSS we included guidelines and recommendations that cover all these components (i.e. risks, costs, environmental impacts and social impacts) and guidelines for organizing risk communication. We also developed a calculation tool known as "PIRTU" that can be used for comparing the eco-efficiency of different RM alternatives in the case of a single contaminated site. We used the Dutch REC tool (Beinat and van Drunen, 1997; van Drunen et al., 2005) as a starting point of PIRTU. The work was continued in 2007 in the PIRRE2 project, the main aim of which was broadening the eco-efficiency studies to regional level. In addition, we wanted to demonstrate the PIRTU-tool in actual remediation projects and further develop it and the whole DSS more useful. This paper focuses on presenting the PIRRE2 project while the main outcomes of the first phase of the PIRRE-project are presented elsewhere (Sorvari et al., 2009; Sorvari and Seppälä, 2009).

MATERIALS AND METHODS

For demonstrating the PIRTU-tool, we studied the feasible RM alternatives for three different contaminated sites located in the City of Helsinki. The sites included 1) an industrial site where the previous operations included a planning works and a garage, 2) a gasoline station and 3) a gas plant (Lundén, 2008). Site data were collected from the previous studies conducted by the City of Helsinki. The main contaminants in the gasoline station comprised petroleum derived hydrocarbons while in the other sites the key contaminants also included metals and cyanides (gas plant). Alternative risk management methods were defined and the values for the different components (i.e. decision criteria) included in the PIRTU-tool (Fig. 1) were determined.

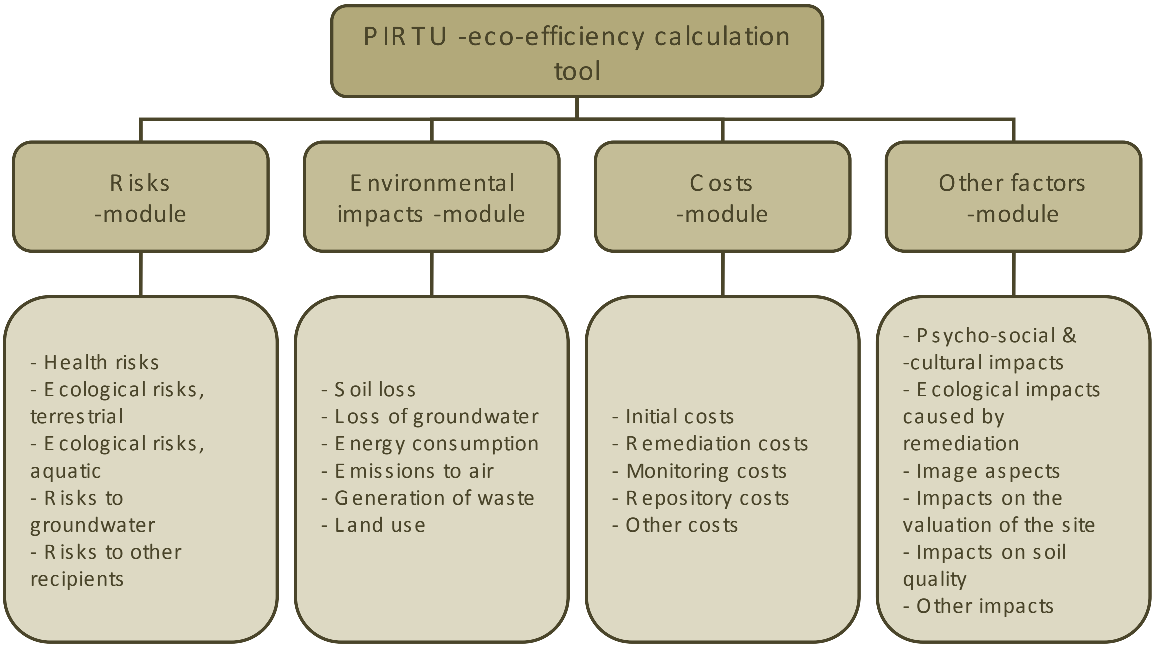

Figure 1. The main components (main decision criteria) and their sub-components included in the PIRTU-tool.

For regional scale eco-efficiency studies it was first necessary to determine proper eco-efficiency indicators. Therefore, a literature research was conducted to find out what kind of methods and indicators have been used to describe the eco-efficiency of CSM. The survey covered literature dealing with inter alia, material flow analysis, life cycle analysis and methods to determine eco-efficiency, eco-efficiency indicators, added (economic) value and cost-benefit relations. The preliminary regional scale indicators of eco-efficiency were demonstrated in three separate regions, namely the City of Helsinki and the areas corresponding the territorial jurisdiction of the Pirkanmaa and the Kainuu regional environment centres, using data collated from the years 2004, 2005 and 2006. Several years were included in the study in order to have a good view on the average number of contaminated sites remediated annually and the yearly volume of contaminated soil and its characteristics. The aim was also to compare the different years from the viewpoint of the fulfillment of eco-efficiency. The number of years included in our study was restricted by data availability and the resources needed for collecting the data.

The eco-efficiency of the current RM practices in Finland was roughly evaluated on the basis of the separate national study that dealt with the volume, characteristics and treatment capacity of excavated contaminated soils during the years 2005 and 2006 (Jaakkonen, 2008). In addition, we gathered and analyzed the relevant data produced in SYKE in different contexts. Part of these data was unpublished. For forecasting the future trend in the realization of eco-efficiency, we first identified the potential factors contributing to the CSM practices. In this identification, we used the project members' expert judgment and the available EU and national documents dealing with the relevant regulatory work. The factors were further discussed with the project steering group members and complemented on the basis of the group work targeted to them and interviews aimed at a couple of CSM experts. The project steering group comprised experts that represent the Ministry of the Environment (1), consulting and/or waste management companies (2), research institutes (2), land owners (1) and regional authorities (2).

RESULTS AND DISCUSSION

Site-specific studies using the PIRTU-tool

The results from the eco-efficiency studies on the three sites using the PIRTU-tool showed that soil excavation is the least cost-effective method but the best option from the viewpoint of risk reduction and social impacts. In addition, the zero alternative, i.e. the alternative where no remediation measures are carried out, proved to be eco-efficient in some situations, that is, when the risk level associated with the contamination is low. Soil stabilization using asphalt and incineration showed high energy consumption that leads to poor eco-efficiency. These results were rather expected and in line with those of the previous studies conducted in PIRRE1 (Sorvari et al., 2005). In practice, in some situations it can be difficult to identify the most eco-efficient RM option by only studying the separate factors (decision criteria) involved in a particular case. Therefore, to facilitate the identification, different decision criteria and their sub-components can be combined using multi-criteria decision aid methods (e.g. Sorvari and Seppälä, 2009).

Some development needs related to the reporting, input data and visual appearance of the PIRTU-tool were identified during its demonstration. Therefore, the tool was modified accordingly. In addition, it was found useful to link PIRTU with a simple risk assessment tool. The latter work is still ongoing in SYKE.

Regional scale eco-efficiency indicators

On the basis of the literature study (Nerg, 2008) and the data available on the three study regions we ended up to suggest 14 indicators that would imply the realization of eco-efficiency in CSM at the regional level (Table 1). These indicators comprise so-called background factors (indicators 1-6) and factors that directly or indirectly depict the risks or risk reduction, environmental impacts and material flows.

Table 1. Suggested indicators to assess the eco-efficiency of CSM at the regional level.

	Indicator	**Unit/indent**
1	Total land area	km^2
2	Population	Number of inhabitants, dimensionless
3	Population density	Number of inhabitants/km^2
4	Number of remediated sites	Number/year
5	Remediation methods, share	% or qualitative description
6	Remediation in situ (including groundwater)	Number/year
7	Amount of transported contaminated soil	t/yr or t/inhabitant
8	Contaminants in transported contaminated soil	Amount of contaminated soil per contaminant type (t)
9	Contaminant levels of transported contaminated soils	t, classed for example as per the soil benchmark or guideline values (VNA 214/2007)
10	Branch causing contamination	Landfill, shooting range etc.
11	Amount of clean soil needed	t/year or kg/inhabitant
12	Average transportation distance,	km classed as per contaminant levels
13	Carbon footprint	t CO_2/year (from excavation and transportation)
14	Water consumption	m^3

The so-called background factors (indicators 1-6) that describe the characteristics of the regions facilitate the comparisons between different regions and various years within a particular region. Transportation distance, contaminants in the transported soil and their concentration levels, branch data, water consumption and carbon footprint describe the environmental load and material flows. It was not possible to define an unambiguous indicator that would directly show the magnitude of risks or risk reduction attainable by different RM actions on a regional scale. The reason for this is the site-specificity of risks i.e. their dependence on the land use, area, environmental characteristics and characteristics of the contamination (extent, type of contaminants) at a certain contaminated site. Therefore, an indicator implying the risks or the risk reduction would require rather detailed information from each single contaminated site that could be combined at the regional level. Such data are unavailable in most cases due to the fact that both the data on the residual contaminant levels at remediated sites and the contamination level at sites that have not yet been properly investigated (i.e. sites that are registered as "potentially contaminated") are inadequate. Therefore, we have to describe the risks (or risk reduction) using indirect indicators such as the amount and quality (contamination level) of transported excavated soils. Consequently, the residual contaminant levels and contamination at sites that have not been remediated are ignored. In addition, due to the lack of data it was not possible to include an indicator that denotes the costs. The unavailability of cost data is partly caused by the site-specificity of costs that is, their dependency on several factors such as soil type, the array of contaminants and their concentrations, remediation method and schedule, amount of soil excavated and/or treated, location of the site and finally, the pricing of the remediation companies and treatment plants. It was also impossible to include social impacts in the indicators since separating the impacts associated with RM activities from the overall social impacts within a particular region is difficult and the data needed for such analysis are not available. Moreover, the lack of feasible methods aggravates the assessment of social impacts.

Eco-efficiency studies in the selected regions

The study based on the set of indicators showed no clear eco-efficiency trend in the three regions (City of Helsinki, Pirkanmaa, Kainuu) (Fig. 2).

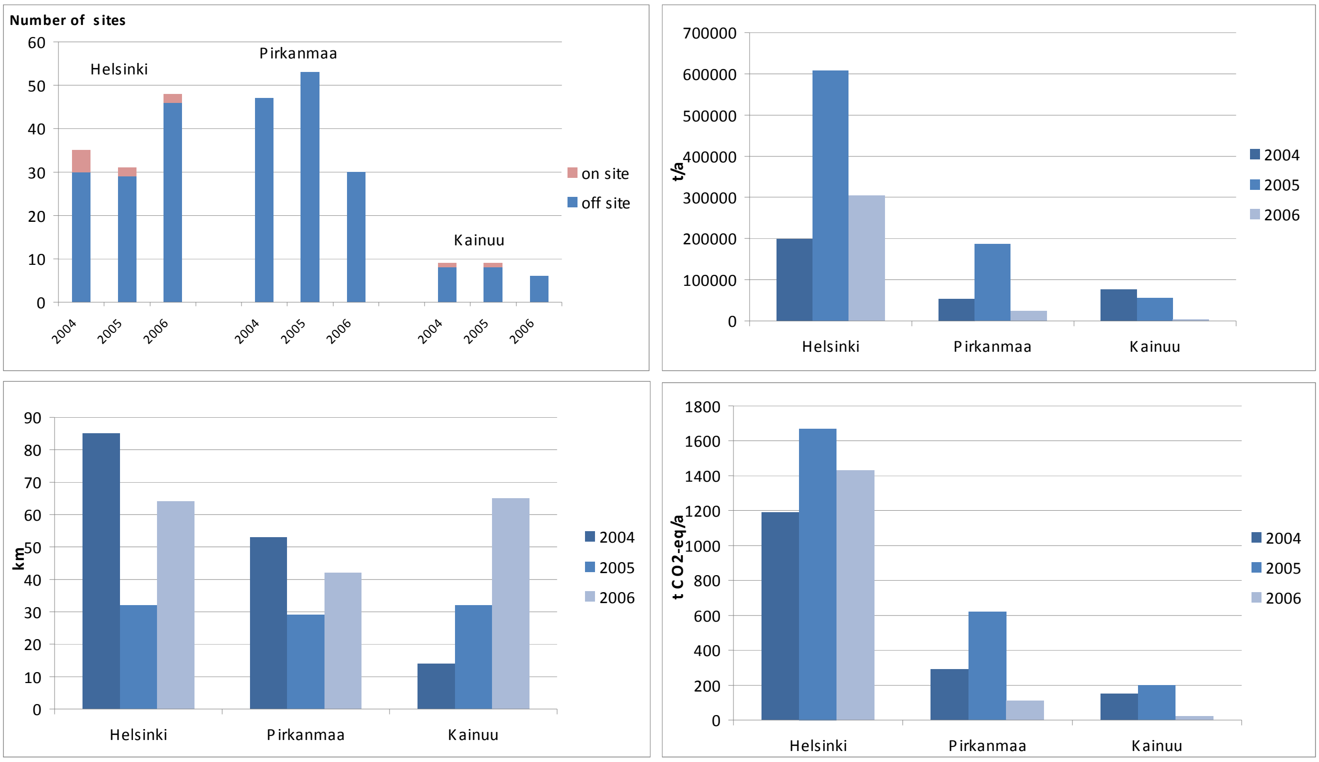

Figure 2. The comparison of the eco-efficiency of contaminated site management in the three regions (Helsinki, Pirkanmaa, Kainuu): the values of the indicators ""Number of remediated sites" (classed as per on site and off site remediations), "Amount of transported contaminated soil", "Transportation distance" and "Carbon footprint" in 2004—2006.

There are some shortcomings in the final indicators. First of all, they do not cover economic impacts. So far in Finland, the costs of CSM have not been systematically monitored at the regional level. Consequently, monitoring of costs was identified as an important development need. If the cost data are systematically collected in the future it is possible to use, for example the indicator "Costs/remediated soil" that has been presented in the European EURODEMO project (EURODEMO, 2005). Another clear development need is to define an indicator that directly describes the risks and their reduction. Like in the case of costs, the use of such indicator would require collecting more detailed data on a regional scale. Only the data needed for the indicators classed as "Background factors" are currently readily available and simple. However, the usefulness of these indicators is diminished by the fact that they can hardly be used as instruments to attain better eco-efficiency in CSM.

Evaluating the eco-efficiency of current risk management methods

The primary assumption in our study was the low eco-efficiency of the current RM practices. This assumption was based on the information that most contaminated sites are remediated by replacing the contaminated soil with clean soil and treating the former in landfills. However, the separate study, which was linked to the PIRRE2-project and finalized in 2008, showed that most i.e. more than 80% of the excavated contaminated soils ending up in landfills are actually reused as such or treated in daily cover or different landfill structures (Jaakkonen, 2008). In many cases, this can be seen as an eco-efficient practice since clean soil would otherwise be needed. In addition, the emissions from landfills are controlled and hence, the risks from contaminated sites are effectively managed. Therefore, reuse in landfills is besides material-efficient also efficient from the viewpoint of risk reduction. However, on the basis of our site-specific and regional studies it is evident that the eco-efficiency of such landfill treatment is highly dependent on the location of the landfill in relation to the contaminated site. Long transportation distances markedly reduce the energy efficiency of this RM option and increase the adverse environmental impacts and hence, diminish the eco-efficiency.

Future perspectives of eco-efficiency

There are several factors that determine the RM practices in the future. These factors include the following:

- environmental policy, regulations and guidelines (international agreements, national strategies, regulations, policy programmes, guidelines and permit practices);
- market situation (price of energy and raw materials, availability of remediation methods, availability of virgin soil, number of remediation projects and demand for contaminated soils due to construction projects);
- environmental factors (climate change, change of background concentrations);
- available data (e.g. on background concentrations – this can reflect to remediation need and the definition on the remediation targets; suitability of remediation methods; the actual observed adverse impacts associated with contaminated sites; new contaminants);
- social factors (sosio-economic factors such as employment, attractiveness of the area, economic situation; socio-cultural factors such as preservation of cultural heritage; socio-psychological factors such as subjective risk perceptions);
- image aspects (these can become important along with the increased competition);
- population movement (effect on the development of regions and consequently, on construction activities);
- remediation methods and sites to be remediated (availability of feasible remediation methods, type of contaminated sites, characteristics of soils);
- assessment methods (associated with e.g. BAT principles, eco-efficiency of RM methods, risk assessment, reporting, use of registers, monitoring the realization of remediation) and practices in land use planning;
- availability of funding.

In the category of environmental policy, regulations and guidance, the IED (Directive on Industrial Emissions) that will replace the present IPPC[1]-directive; Soil Directive; Groundwater Directive; the new Waste Directive that includes the End of Waste –principles[2]; and the existing landfill regulations that include requirements for bottom structures and solubility limits of contaminants for wastes to be disposed of in landfills, are the main determinants of future CSM practices. The most important national regulation is the Government Decree on the assessment of soil contamination level and remediation need that

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[1] Integrated Pollution Prevention and Control

[2] Principles according to which waste ceases to be waste (http://susproc.jrc.ec.europa.eu/activities/waste/documents/ Endofwastecriteriafinal.pdf)

came into force 1 June 2007 (VNA 214/2007). The decree includes soil benchmark values and guideline values that act as policy instruments for the selection of RM actions and methods. The BAT[3] criteria for remediation methods and the criteria for reuse of excavated contaminated soils, that are both in preparation, are also important future factors contributing to the realization of eco-efficiency.

From the viewpoint of the availability of funding, the different funding mechanisms are important. The most important national mechanisms include the SOILI- program that finances the remediation of former gasoline stations and state funding system. Increasing the public funding and funding through (statutory) reserves could enhance the fulfillment of eco-efficiency in the future. This can be accomplished by specifying the eco-efficiency criterion as the prerequisite for receiving any funding.

In the long term, the number of contaminated sites that are remediated will depend on several factors such as the economic situation, population distribution, the importance of social and image aspects and legislation. Particularly the Soil Directive would – if implemented in its current form – increase the investigations and presumably also the RM actions at potentially contaminated sites in the future. It is also expected that the remediation activities will focus on slightly different sites than before. For instance, most of the closed landfill sites have been remediated in the near future. Whereas, the number of shooting ranges to be remediated can escalate due to the increased knowledge on the risks at abandoned shooting ranges and the new RM requirements issued in the environmental permits for operating ranges. In the beginning, the change in the contamination type of sites to be remediated can diminish the eco-efficiency of CSM since feasible and material and energy efficient RM methods are missing in some cases.

The regulations and guidelines that are under preparation as well as the increased information, for instance on the soil background concentrations and actual threats related to soil contamination, the development and implementation of new assessment methods, and land use planning practices that consider contamination as a starting points, are all expected to enhance the attainment of eco-efficiency in CSM in the future. All the above scenarios are however, uncertain and hence it is difficult to conclude what is the overall effect of different factors on eco-efficiency.

CONCLUSIONS

In the PIRRE project we developed a decision support system for assessing the eco-efficiency of contaminated site management. Eco-efficiency is to be considered only as a relative concept and therefore, can merely be used for comparing the pre-eminence of different CSM strategies or RM methods. On the basis of the stakeholders' feedback, in our project we adopted a broad definition for eco-efficiency and included the social aspects in it.

In the first phase of the PIRRE project we developed a calculation tool for determining the eco-efficiency of different RM options. This PIRTU-tool comprises four modules that make the eco-efficiency (i.e. risks, costs, environmental impacts and other factors e.g. social

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[3] Best Available Technology

aspects). While the eco-efficiency criteria depicted by these four components are suitable for site-specific evaluation, they are not straightforwardly applicable for the eco-efficiency assessment on a regional scale mainly due to the different level of elaborateness. Therefore, in the second phase of the PIRRE-project we determined indicators that could be used to assess and monitor the eco-efficiency at the regional level. Unfortunately, in practice the availability of quantitative data restricts the factors to be included in the regional indicators. For example, the data on costs, emissions, and energy efficiency of different remediation methods are provided by consultants and other service providers and hence, the information is hardly exhaustive or adequately verified. Therefore, establishing a public, independent database that includes data on the life cycle extending environmental impacts of different remediation methods would be very useful.

In the assessment of eco-efficiency at the regional level, the determination of risks is particularly difficult since this should be done site-specifically. Hence, adding a risk component in the regional studies is a major development need. Here, the existing risk prioritization systems used in some regions could prove as a useful starting point. While the consideration of socio-cultural aspects would in the first place require developing feasible methods. Overall, the planning of RM strategies to enhance eco-efficiency in CSM on a regional scale is challenging and requires adequate monitoring and reporting, for example related to the costs and residual contaminant levels in remediated sites The attainment of eco-efficiency also assumes changes in CSM practices, such as implementation of new assessment methods and including eco-efficiency as a prerequisite in the permits and decisions based on notifications. These goals could be reached for instance by specifying the national regulations or issuing new national guidelines.

Finally, we can conclude that the RM practices of contaminated sites are determined by various factors, such as policy instruments, market situation, and available funding systems, RM methods and assessment methods as well as social aspects and environmental factors. Changes in any of these factors can drive the RM practices towards eco-efficiency or away from it. The effect of different factors can also be contradictory making the prediction of future eco-efficiency a difficult task.

REFERENCES

Beinat E, van Drunen MA, editors. The REC decision support system for comparing soil remediation options. A methodology based on Risk reduction, Environmental merit and Costs, REC report version 2.0. CUR/NOBIS, Deventer, 1997, 93 pp.

EuroDemo. Interim results for the ‘Framework for Sustainable Land Remediation and Management’. Deliverable reference number: D 5–1. European Platform for Demonstration of Efficient Soil and Groundwater Remediation (EuroDemo), 2005. [http://www.eurodemo.info/results/]. Accessed September 2009.

Finnish Environment Institute. Remediation of contaminated sites. Finnish Environment Institute, 2005. [http://www.environment.fi > Environmental protection > Soil protection > Remediation of contaminated sites]. Accessed October 2009.

Jaakkonen S. Treatment of contaminated soil in Finland, Reports of the Finnish Environment Institute 36/2008. Finnish Environment Institute, Helsinki, 2008, 45 pp. ISBN 978-952-11-3334-3 (PDF). In Finnish with an English abstract. [http://www.ymparisto.fi/download.asp?contentid=97280&lan=fi]. Accessed October 2009.

Lunden P. Eco-efficiency in the risk management of contaminated soil in the city of Helsinki. – An industrial area site in Tapaninkylä, a gas station site in Leppäsuo and a gas plant site in Suvilahti, Reports of the Finnish Environment Institute 30/2008, Finnish Environment Institute, Helsinki, 2008, 66 pp. ISBN 978-952-11-3261-2 (PDF). In Finnish with an English abstract. [http://www.ymparisto.fi/syke/pirre]. Accessed October 2009.

Nerg N. Eco-efficiency indicators in regional contaminated soil management. Reports of Finnish Environment Institute 29/2008, Finnish Environment Institute, Helsinki, 2008, 79 pp. ISBN 978-952-11-3258-8 (PDF). In Finnish with an English abstract. [http://www.ymparisto.fi/syke/pirre]. Accessed October 2009.

Sorvari J, Antikainen R, editors. Risk management on contaminated sites – a review on current practices. Suomen ympäristökeskuksen moniste 316, Finnish Environment Institute, Helsinki, 2004, 82 pp. ISBN 952-11-1909-8. In Finnish with an English abstract. [http://www.ymparisto.fi/syke/pirre]. Accessed October 2009.

Sorvari J, Antikainen R, Utriainen E. Estimating eco-efficiency in soil remediation - studies on four model sites. Proceedings of the 9th International FZK/TNO Conference on Soil-Water Systems, ConSoil 2005, Bordeaux, France 3-7 Oct. 2005. FZK, Karlsruhe, Germany, 2005. pp. 2480-2486. ISBN 3-923704-50-X.

Sorvari J, Antikainen R, Kosola M-L, Hokkanen P, Haavisto T. Eco-efficiency in Contaminated Land Management in Finland – Barriers and Development Needs. J Environ Manage 2009; 90: 1715-1727.

Sorvari J, Seppälä J. A decision support tool to prioritize remediation technologies for contaminated sites. Sci Tot Environ 2009. Submitted.

Uudenmaan liitto. Pilaantuneiden maiden, voimalaitosjätteiden, ylijäämämassojen sekä rakennusjätteiden rejektien käsittely- ja loppusijoituspaikkaselvitys. Uudenmaan liiton julkaisuja E75-2002. Uudenmaan liitto, Helsinki, 2002.

Van Drunen MA, Beinat E, Nijboer M, Okx J. Multiobjective Decision Making for Soil Remediation Problems. Land Contam Recl 2005; 13: 349-359.