Evaluating sustainable remediation methods for brownfields redevelopment projects (BRPs)

Dr.-Ing. Uwe Hiester & Dr.-Ing. Volker Schrenk

reconsite - TTI GmbH | Auberlenstrasse 13 | D-70736 Fellbach
Tel: +49-(0)711 - 410 190-11 | e-mail: info@reconsite.com | http://www.reconsite.com

Abstract
The advantage of excavation and disposal of contaminated soil ("dig and dump" (DaD)) is to clean up a wide variety of contaminant mixtures (e.g. VOC, BTEX, fuel contaminants, PAH, heavy metals) within only one step with conventional earth working equipment. Moreover, DaD can be used directly for the dismantling of former facilities, such as subsurface tanks. Even these synergetic effects usually do not occur with all other remediation methods. On the downside, life cycle assessment balances (LCA) for DaD show a high consumption of natural resources, increasing rapidly with the distance between remediation-site and deposit. Furthermore, the contaminated soil is not remediated but encapsulated and might cause future risks in case of failure of the deposit sealing.

In the future, more sustainable remediation methods, characterised e.g. by less CO_2-immissions or global warming effects should be used more generally at BRPs. Therefore the LCA-method is an important tool for the assessment of remediation techniques.

Based on more than 30 LCA case-studies of realized remediation projects in Germany and the remediation alternatives considered for the sites a new simplified method for the evaluation of remediation projects was developed. The results demonstrate, that in most circumstances the main environmental impacts of the projects stem from transportation by trucks and not, as generally assumed, from the remediation technique. Compared with DaD, alternatives such as in-situ-remediation methods (ISRM) or encapsulation reveal very often better LCA balances. But in Germany alternatives to DaD very often have to meet the following conditions:

- Alternative methods have to be cost-efficient, i.e. they have to be at least equal to the standard technologies, or preferably more favourable with respect to costs and efficiency.
- Using alternative remediation technologies, remediation goals should be reliably obtainable in a certain period of time. The required operation time should be well assessable in order to make the integration of the remediation process into construction plans possible. For BRPs, remediation times in the order of weeks to a few months will be required.
- The interfaces between remediation technologies and other construction processes at BRPs should be manageable in an almost similar way as with standard techniques.

A new and not often considered argument could be the LCA of different remediation techniques and DaD. With a simplified LCA and the concentration on the main producers of ecological impacts, it is possible to perform a quick and easy comparison of the different remediation options for a site and it is possible to find the best option for a site under ecological criteria. For example the "dig and dump" procedure affects the environment through transportation of the contaminated soil, as opposed to off-site techniques in which the impacts are produced by the remediation methods (thermal treatment, soil washing) and transportation. With on-site techniques, the construction processes, the transportation on-site, and the remediation techniques used are important. In-situ techniques create their impacts in the operation of the pumps and the release of lateral channel sealers. The amount of activated carbon must also be taken into account.

INTRODUCTION

For the EU founded research project REVIT the reconsite - TTI GmbH examined the use of remediation technologies in brownfields redevelopment projects in close cooperation with the city of Stuttgart. The aim of this research was to answer the questions, which technologies will be used and what are the most common techniques of remediation in the special case of brownfields redevelopment projects.

The data collection for this research was carried out by analyzing publications in scientific journals, conference proceedings and by an online inquiry conducted by the city of Stuttgart. The collection of 35 projects that originated from that inquiry has been analyzed by the reconsite - TTI GmbH in collaboration with the city of Stuttgart. During the investigation, further information about other projects emerged. Those projects were also incorporated into the investigation. In total, information from 50 projects has been reviewed (SCHRENK ET AL. 2007).

Additionally, during a former research project life cycle assessments (LCA) of different soil and groundwater remediation projects were calculated (SCHRENK 2005). For that purpose, invitations of tenders, reports, final accounts and records of proper waste management etc., of 15 remediation projects were investigated and analysed in cooperation with consultants and municipalities. All common remediation techniques were investigated by examining real cases. Based on the examples, alternative remediation scenarios were developed. As a result more than 30 data sets of LCA were calculated. The data were transferred to the computer tool “Environmental balancing of soil remediation measures” (LFU 1999) which calculated the LCA for each project. The software-tool runs on an ACCESS-data base and is structured modularly. Based on the input-data for one remediation method or scenario (transportation-distances, mass of contaminated soil, running time of a soil vapour extraction, etc.), the consumption-data (water, fuel, etc.), the life cycle inventory assessment and the life cycle impact assessment are calculated by the software. The inventory analysis contains more than 100 different categories. The interpretation of the results is based on the results of the impact assessment, covering 19 different impact categories, none of which are comparable to each other. Examples for the impact categories are the cumulative energy demand, fossil resource consumption, waste, summer-smog, global warming, acidification and human toxicity. In principle, a comparison of two different remediation options for one site is only possible within the same impact categories.

This research differs from most previous LCA research, as complete projects were retrospectively examined and balanced, and all the steps of the remediation projects were considered in the LCA (construction processes, transportation and remediation). In previous studies, the focus was often only on the LCA of the remediation techniques and not on the whole remediation process, including transportation and construction work.

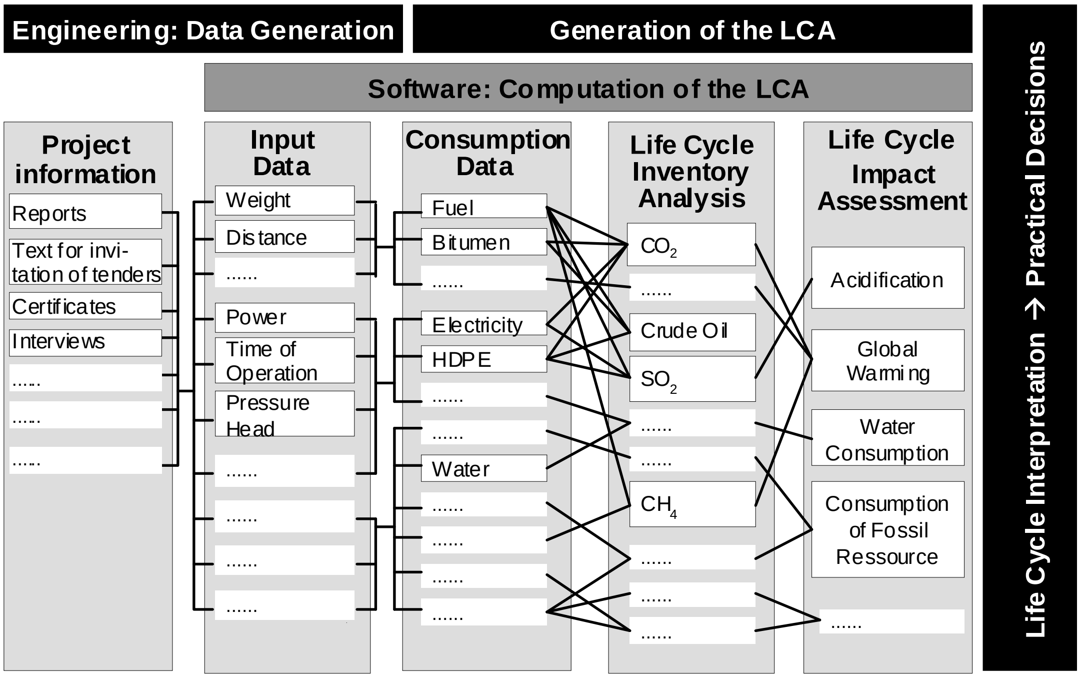

FIGURE 1: Overview on the process of the data generation and the calculation of the LCA with the software "Environmental Balancing" (LFU 1999)

For all projects the contributions of the individual activities (material transportation, drilling, digging, etc.) on the total environmental impact were calculated. In this way, it became clear which remediation steps are environmentally most significant. Based on these results a simplified LCA method was developed and recommendations for an eco-efficient remediation were made. An overview on the process is provided in FIGURE 1.

This paper summarizes the results of research projects (SCHRENK 2005, SCHRENK ET AL. 2007), calculations of comparative sustainability analyses (HIESTER ET AL. 2003) and the application of different decision making tools in conceptual design studies for brownfield redevelopment projects. The paper focuses on the selection sustainable remediation techniques for brownfields redevelopment projects mainly by evaluating proposed environmental impacts of different remediation scenarios and strategies.

RESULTS

The results show that only a few remediation methods are applied more widely for brownfields remediation. The standard procedure in the unsaturated zone is in most cases dig & dump. In the saturated zone it is *pump & treat*. In some rare cases, alternative remediation technologies were used. Table 1 gives an overview of the applied techniques. It is important to know, that in many of the analyzed brownfields redevelopment projects, several different remediation technologies were used at the same site due to the heterogeneity of the contaminants found. For this reason, the number of remediation applications given is higher than the total number of projects.

Table 1: Overview of remediation technologies applied in the analyzed projects.

	Technology	Number of applications
Unsaturated Zone	Dig & Dump	29
	Soil washing	1
	Thermal Ex-situ Treatment	2
	Biological on-site treatment	1
	Biological off-site treatment	6
	Soil vapor extraction	1
	Surface sealing	6
	Containment structures	5
	Containment by sealing with buildings	3
	Immobilization	2
Unsatur-ated and Saturated Zone	Vertical barrier	1
	Mixed-in-place vertical barrier	1
	Microbiological in-situ methods	2
	Vacuum vapor extraction	1
Satur-ated Zone	Pump & Treat	7
	Air sparging	1
	Funnel & Gate	2
	Number of applications	***71***
	Number of projects	***40***

In general, techniques for the remediation of the unsaturated zone (soil remediation) and technologies for the remediation of the saturated zone (groundwater remediation) have to be distinguished. Some of the technologies can be used for the remediation of both zones.

For the results of the LCA of different used remediation techniques it is important to consider that the absolute results of the LCA from the projects are not directly comparable with each other. The comparison is impossible because the boundary conditions, e.g. the size of the brownfields, the type and the extent of the contamination, and the duration of the remediation vary from site to site. It is only possible to do a comparison of the related proportions of different activities in every project: the transportation, the construction works and the remediation. This comparison shows that the different procedures of remediation are reflected in the results of most of the impact categories of the LCAs. The procedures can be classified as “dig and dump”, “off-site measures”, “on-site measures” and “in-situ measures”. This is shown in FIGURE 2 for the impact category “Cumulative energy demand” for the different examined real projects A-O. There were too few examples examined for the containment procedure in the research project, so a discussion would not be reasonable for the LCA of such a procedure.

Most of the life cycle impact categories (e. g. cumulative energy demand, green house effect, acidification) were influenced only by some workings of the redevelopment procedure. These are the transportation of material (the so-called mass transport), energy-consuming remediation techniques (thermal treatment plants) and some types of construction works.

In contrast, the transport for installation of the construction-site, drilling work, the transport of construction equipment and some types of construction have only a proportion of a few percentages on many impact categories in most of the projects. These actions do not have to be considered in a simplified LCA. It is enough to consider the main drivers of the environmental impacts of a project in the planning phase for the comparison of different remediation options of one site. With the use of the simplified LCA a quick check of the significance of the secondary environmental impacts is possible.

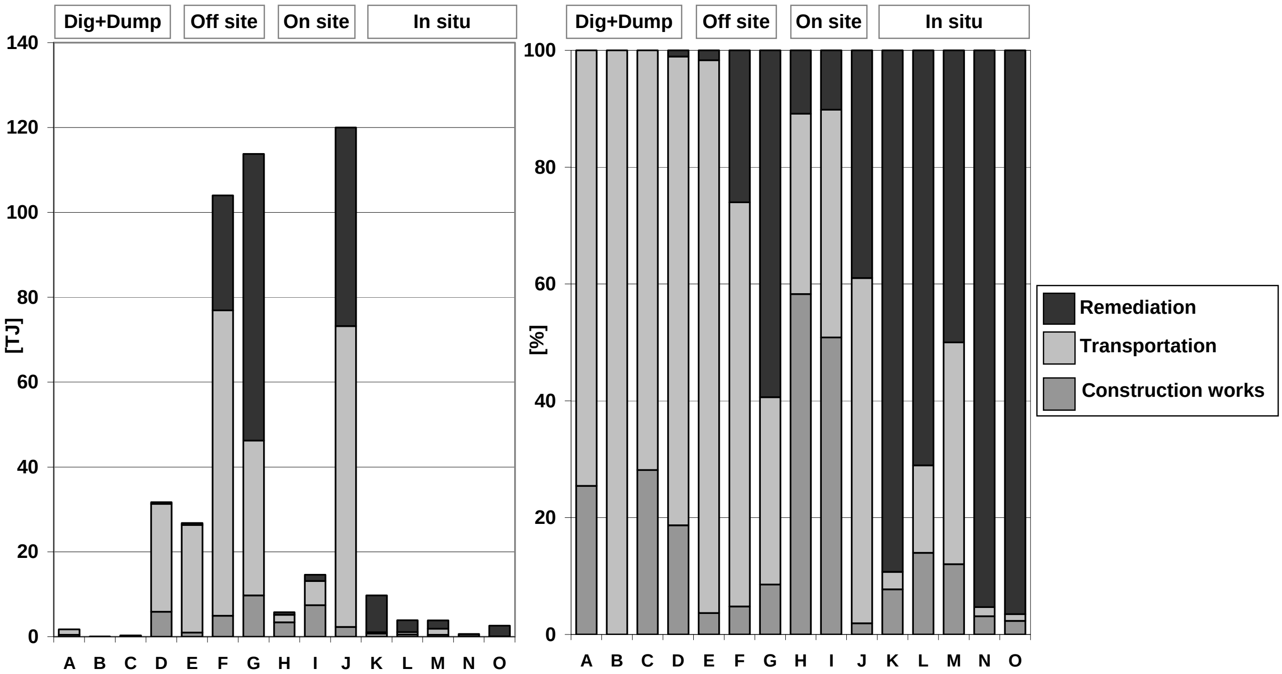

FIGURE 2: The absolute and relative values of the remediation, transportation and construction in different projects A – O in the impact assessment category "Cumulative Energy Demand"

Unsaturated Zone (Soil Remediation)

In many projects, the remediation of the unsaturated zone was carried out by excavation of the contaminated soil. Different ways were used in handling the excavated contaminated material. Different options were on-site containment of the material (containment technology), disposal ("dump") or on-site/off-site treatment and subsequent disposal. Excavation and disposal was used for 29 of the 40 projects (about 70 %) (SCHRENK ET AL. 2007).

In this context, the term (waste) disposal encompasses the reuse and the destruction of wastes (§ 3 KrW-/AbfG Abs. 7). The material was "reused" e. g. on landfill sites for surface modelling and landfill road construction. In the analyzed projects, manifold reasons were given for choosing the option excavation and disposal:

- For many projects, the demanding deadlines didn't allow for long-term remediation measures, due to the fact that the marketing of real property already had started,
- the low costs for the disposal of contaminated soil,

- need for a definitely clean site, as the site will be used as residential area in future, resulting in correspondingly high demands concerning environmental standards,
- the excavation area was used for the foundation of buildings and for underground structures, or an excavation was required anyway due to dismantling of buildings on the site,
- clearly defined point sources of contamination or e.g. filled up bomb craters.

However, cost-effective disposal (e.g. landfill costs) should be regarded critically, as disposal costs only constitute a part of the total remediation costs. The depth of the contaminant source and the resulting additional expenditure for the excavation (e.g. large volumes needed for slopes, sheeting, special excavation methods (e.g. large hole boring)), the accessibility (e.g. open space or below a building), the surroundings (e.g. industrial area, city center area) and last but not least occupational health and safety issues on the building site and the periphery (e.g. pollutants escaping into air, building noise, truck transports, black/white plant) can be of decisive importance for the total remediation costs of a particular project.

The other important topic is the life cycle assessment of such a procedure. In “dig and dump” cases, the environmental impacts result primarily from the emissions generated during transportation. Calculations with the LCA-software (LFU 1999) showed that at transportation distances of greater than 10 km most of the impact categories are dominated by truck transportation. In many cases transport distances of 200 km are standard in Germany. Only in some rare cases transport by railway or barge is used.

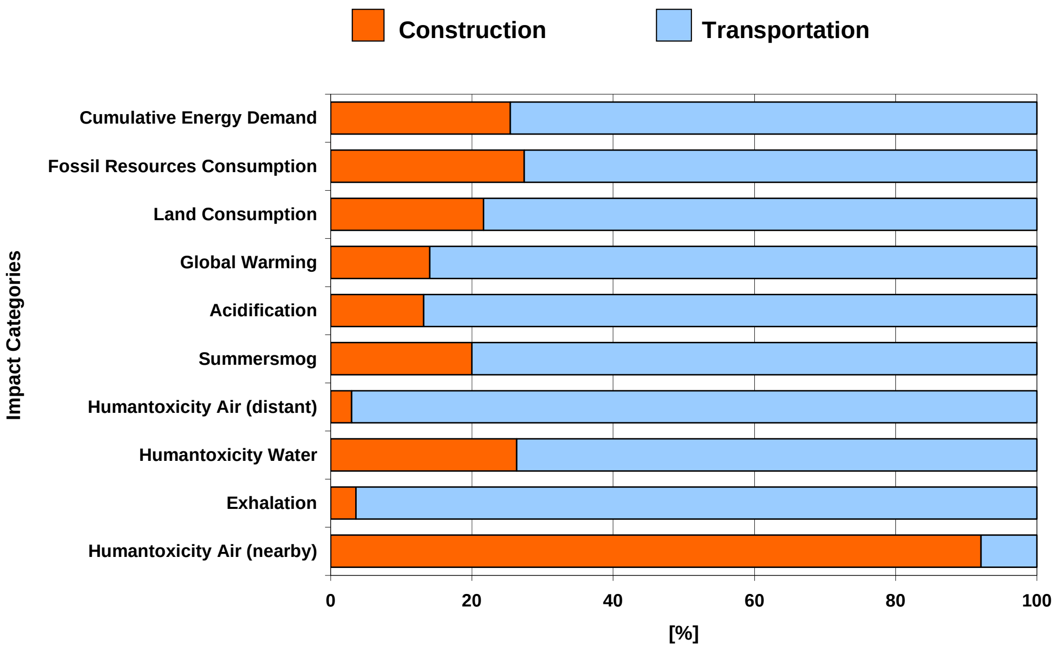

FIGURE 3: Proportion of the construction and transportation at different impact categories in a project example for the procedure “dig and dump”

Thus, for a simplified LCA only consided transport distances and transported mass of the excavated material are needed for to calculate of most impact environmental impact categories.

Besides the disposal of excavated, contaminated soil on landfills at some of the analyzed brownfields sites, an off-site soil treatment of the contaminated excavation material was carried out and the material was subsequently disposed of. Soil treatment influences the disposal route (e.g. disposal with or without prior processing); however, the application of technologies on the site itself is usually not affected. Soil washing (ex-situ), thermal treatment (ex-situ) and biological treatment (ex-situ) were employed in the analyzed projects as well.

In this procedure, the environmental impacts are caused mainly through transportation and soil treatment. In many cases the majority of life cycle impact categories were dominated by more than 50 % by transportation accounts (SCHRENK 2005). The biological treatment of soil often has small impact on the environment; however in some cases it was impossible to reach the remediation target. For thermal soil treatment methods, usually the energy consumption dominates environmental impact categories. In some cases, contaminated soil was only cleaned to enable landfill disposal. Here, additional transport effects need to be considered in the LCA. Transportation and remediation have to be considered to get a simplified estimation of the environmental impacts of a planned project. For off-site biological treatment with long transport distances, again the impacts from transportation dominate the LCA results. The following example shows the LCA-result of the transportation of 12,000 t of contaminated material to a biological treatment facility 400 km away from the site (FIGURE 4):

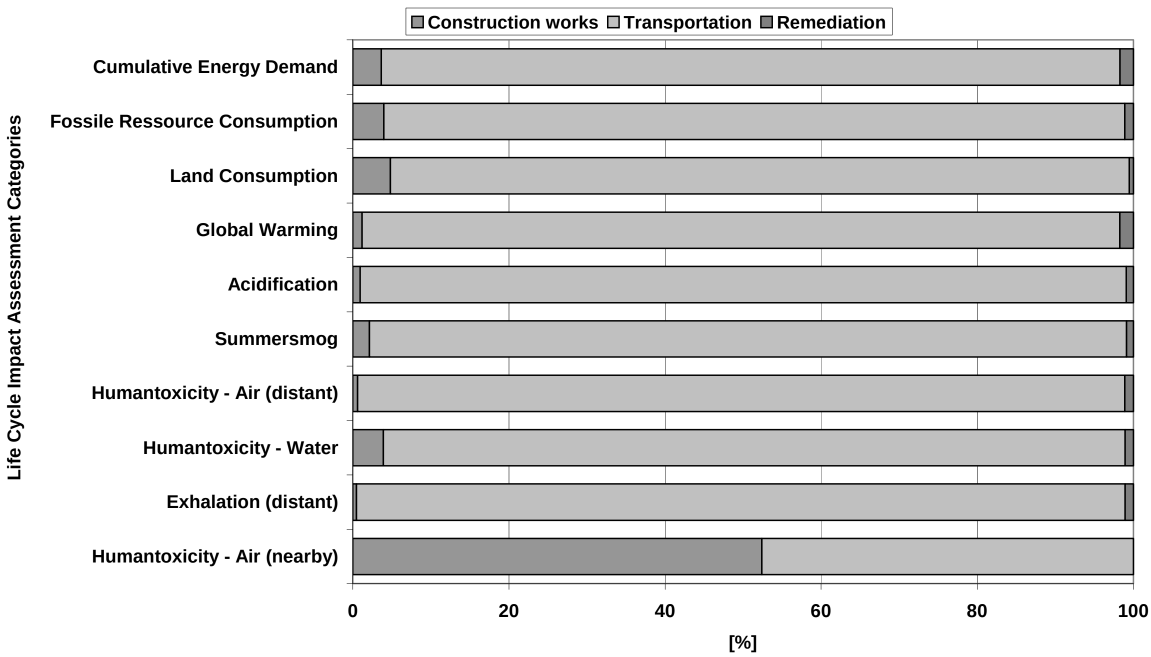

FIGURE 4: LCA of an off-site biological treatment of contaminated material

In the case studies of the LCA, on-site measures were only used on large sites with big masses of contaminated material. The application of on-site measures also depends on the available time for the remediation, the planned re-use of the site and the space available for the installation of the remediation plant.

The magnitude of environmental impacts is influenced by the construction of the treatment facility, transportation and the remediation process according to the on-site remediation procedure selected. One important question is whether the cleaned soil will remain on the property or whether it will be used at another site. In the second case the transportation of the cleaned material has to be considered. On-site measures have advantages if transportation can be avoided.

For a simplified LCA of on-site measures it is important to consider the transportation processes on the site, the construction works and the treatment method.

Containment measures were employed at some of the analyzed brownfields projects (SCHRENK ET AL. 2007). They were applied for the containment of contaminated areas on-site or for landfills constructed on-site and pits. The containment of contaminants leads to a disruption of the exposure pathways. On abandoned sites, surface sealing was carried out for instance through sealing by construction. Examples for this are the construction of a parking lot over contaminated zones or the construction of new buildings. Surface sealing methods can limit the future use of the site. On one of the examined sites, only buildings without a basement but with a surface foundation are permitted, such as industrial buildings.

Due to the high construction and running costs (maintenance of reverse flow gradient), containment techniques constitute an economical alternative only for complex pollution cases and large areas or volumes. Typically, maintenance has to be considered for all containment measures. This often includes a continuous treatment of the groundwater or the water from the insulated zones. Apart from surface sealing and incapsulation methods, methods for the immobilization of contaminants are of special importance. Immobilization methods are employed predominantly in the case of contamination with heavy metals (LUA NRW 2005). At applied immobilizations, treated soil was reintroduced on-site, in parts below roads and noise protection banks. These sites are going to be used as residential area in the future, which argues favourably for the acceptance of these methods.

There were too few examples examined for the containment procedure in the research project, so a discussion would not be reasonable. Some rough estimates show that the LCA of containments are influenced by the used material (e.g. bentonite) and the construction works. The production of bentonite is very energy intensive. This circumstance is reflected e. g. in the corresponding impact categories like cumulative energy demand and green house effect. For the calculation of the LCA it is important to consider the transportation processes of the delivery of construction materials and the disposal of contaminated (excavated) materials, due to the construction of a hydraulic barrier.

Additionally, it should be considered that the running of a hydraulic protection system is necessary for a long period of time. As a consequence the environmental impacts and the energy consumptions can be added to very high amounts.

Saturated Zone (Groundwater Remediation)

All remediation technologies in the saturated zone share the characteristic that they have to be operated over a longer period of time. During the operation time, the remediation facilities or installations (e.g. wells, funnel & gate) usually have to be accessible. For brownfields redevelopment these characteristics result in the problem that remediation times for hydraulic measures in the saturated zone are difficult to estimate and the site owner is left with financial insecurities.

In the saturated soil zone, the following technologies were employed at the analyzed project sites (SCHRENK ET AL. 2007):

- Pump & treat (P&T): The time needed for remediation with P&T technology is normally several years to decades. For this reason, P&T is often employed for protection instead of remediation of the site. An application with fixed remediation times and goals is only feasible in special cases. P&T can be identified as a standard technique.
- Air sparging technology was employed at a former gas station area during the brownfield remediation of a military site due to geological boundary conditions (depth of contamination in hard sandstone, low yield of groundwater wells).
- Groundwater circulation wells (GCW)/Vacuum vaporized wells (UVB): A vacuum vaporized well was employed for the pollutant source remediation of a gas station at another military site. Advantages for the application of this technology at that particular site were the low costs in comparison to an excavation of the pollutant source and the improved treatment of the capillary fringe compared to a hydraulic technology (P&T). At the site, the remediation area could not be used for other purposes during the remediation process of seven years.
- Microbiological remediation methods in the saturated zone were applied in two projects.
- Funnel & gate systems were used at two sites. At one site the criteria for the choice of method were among others the prevention of contaminant transport into a second aquifer.

The environmental impacts of active hydraulic or pneumatic in-situ measures depend on the operation time of pumps or lateral channel blower (SCHRENK 2005). A longterm operation cumulates a high energy demand and corresponding emissions. Thus, power generation is the main source of environmental impacts for long term active hydraulic or pneumatic in-situ measures. With increasing operation time the proportion of environmental impact caused by material consumption (pipes, filters), transportation to the plant and maintenance steadily decrease and reaches values of less than 10 % in most impact categories.

Another important factor affecting the result of a LCA is the consumption of activated carbon for the treatment of contaminated water or air. The production of activated carbon is a very energy consumptive process, so the consumed activated carbon affects the LCA of in-situ projects.

For a simplified LCA it is necessary to consider the operation time of pumps (= operation time of the remediation) and the amount of consumed activated carbon.

Conclusion of the LCA of the remediation

The projects examined show that the LCA of remediation measures is more complex than the general assessment of cleanup techniques. In most of the projects the remediation technique utilized accounts only for a small portion of the final-result (exception: in-situ measures and very energy intensive techniques). In most of the projects a large proportion of the environmental impact was created during transportation.

A simplification of LCA is possible by neglecting the site investigation, the plant construction and equipment as well as laboratory methods. Depending on the selected remediation procedure the relevant impacts are generated only by transportation and the remediation technique.

RECOMMENDATIONS FOR ENVIRONMENTAL OPTIMISED REMEDIATION ACTIVITIES

On the basis of the results of the projects examined and the calculated scenarios, the following recommendations can be derived for remediation planning according to ecological criteria (SCHRENK 2005). For many projects the calculations of the alternative scenarios show possibilities for reductions in the environmental impacts through the use of alternate forms of transport, reduction in the transport distance or application of another remediation technology:

- **Reducing transport distances and type of the transport**

Transport distances for brownfields redevelopment measures should be minimized. Ship or rail transportation performs much better regarding the environmental impact than truck transportation. One example is shown in FIGURE 5. In this example the contaminated material was transported more than 400 km by truck to a biological soil treatment facility. Two alternatives were remediation near the site in a mobile treatment facility (“On-site Treatment”) or rail transport to a treatment facility (“Transport by Train”). The results in the “Cumulative Energy Demand" impact assessment category for the different options are plotted in FIGURE 5.

- **Preference for on-site remediation techniques**

Compared to off-site treatment, on-site remediation techniques (mobile soil washing plants, biological procedures) have proven favourable under environmental criteria - especially because transportation can be avoided. A prerequisite for the use of such a system is that space be available at the site (for the system itself and the storage of soil). Furthermore, the time factor is of importance, since such measures can only be used for certain concentrations.

Likewise, in order to avoid the transportation of materials from other sites, reintegration and/or on-site re-use of cleaned soil material must be possible. Among on-site techniques, biological remediation methods have proven favourable for soil contaminated with mineral oils.

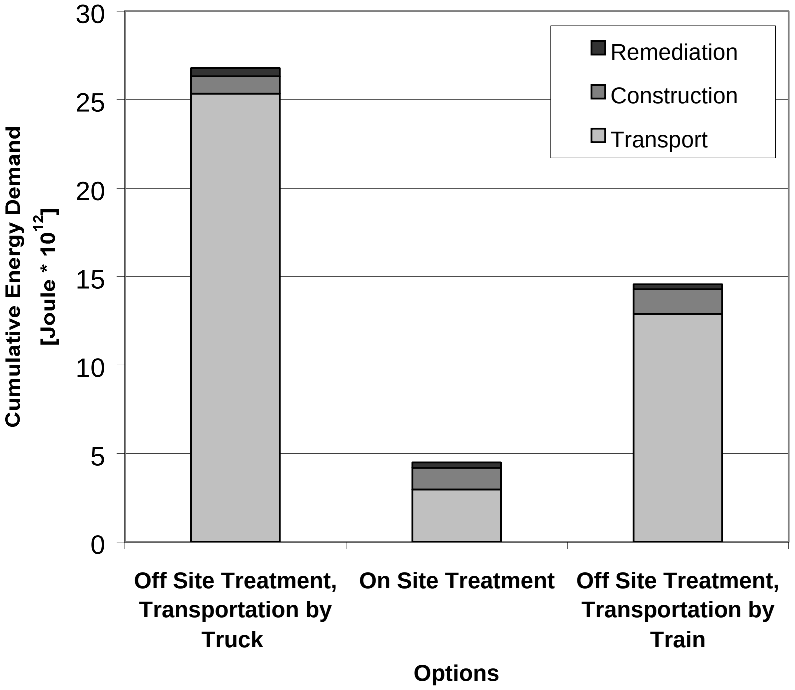

FIGURE 5: The "Cumulative Energy Demand" for a project of biological treatment with different options of transportation

- **Adjustment of the land development**

The adaptation of land development to the treatment conducted is an efficient way to optimise projects according to environmental criteria. Excavation for "dig and dump" methods can be effectively used for the construction of new buildings. Surface sealing of a contaminated area and subsequent use of the surface as a parking lot offers another possibility to secure a contaminated site. Planners can thereby avoid excavation and transportation.

Use-related remediation is also favourable under the aspect of the environmental impacts of the procedures. In Germany, there are regulatory differences depending on whether the site is being prepared for industrial or for residential use. The critical limiting values for heavy metals, for example, are higher for an industrial site.

Coordination of future land development must occur in the planning phase of a project. In order to accomplish this, close co-operation between planners/architects and engineers/geologists is important. The coordination of land development with remediation can make refilling measures unnecessary, reduce transport distances, and eliminate issues regarding the construction of building foundations.

SUMMARY

The results of this investigation demonstrate that in most circumstances the primary environmental impacts of remediation projects are produced by mass-transportation by truck and not, as is generally assumed, by the remediation technique itself. In-situ remediation technologies are an exception. The extent of the impacts in this case depends on the running time of the plants and the amount of activated carbon used, because the production of carbon is an energy consuming process.

LCA may be simplified by estimating the main ecological impact producing steps and accounting for them. For example the “dig and dump” procedure affects the environment through the transportation of contaminated soil, unlike off-site techniques which produce impacts through the remediation methods (thermal treatment, soil washing). For on-site techniques, construction processes, transportation on-site and the remediation techniques applied are important factors. In-situ techniques generate impacts based on how long pumps and lateral channel sealers are in operation and the amount of activated carbon consumed. With an emphasis on the main producers of ecological impacts, it is possible to conduct a quick and easy comparison of various remediation alternatives for a property.

REFERENCES

HIESTER, U., SCHRENK, V. & WEISS, T. (2003): Environmental balancing of ’cold’ SVE and thermally enhanced soil vapour extracion – practical support for decision makers. In: Annokkée G.J., Arendt F. & O. Uhlmann (eds.): 8. International FZK/TNO Conference on Contaminated Soil (ConSoil 2003-Proceedings) (12. - 16. Mai 2003, Gent, Belgium). The Netherlands Organization for Applied Scientific Research (TNO), 2003, 2253-2262. Poster Session.

LFU – LANDESANSTALT FÜR UMWELTSCHUTZ BADEN-WÜRTTEMBERG (1999): Umweltbilanzierung von Altlastensanierungsverfahren. CD-ROM Version 1.0 Rev.16., Karlsruhe.

LUA NRW - Landesumweltamt Nordrhein-Westfalen 2005, (Hrsg.). Leistungsbuch Altlasten und Flächenentwicklung 2004 / 2005. Materialien zur Altlastensanierung und zum Bodenschutz, Band 20, Essen.

SCHRENK, V. (2005): Ökobilanzen zur Bewertung von Altlastensanierungsmaßnahmen. – Mitteilungsheft Nr. 141, (Promotionsschrift) Institut für Wasserbau, Universität Stuttgart, 2005. - ISBN: 3-933761-44-1.

SCHRENK, V., HIESTER, U., KIRCHHOLTES, H. J. & BÄRLIN, M. (2007): The use of innovative remediation technologies in brownfield redevelopment projects. S. 67 - 77. In: BUNDESMINISTERIUM FÜR BILDUNG UND FORSCHUNG (Hrsg.): 2nd International Conference on Managing Urban Land. Towards more effective and sustainable brownfield revitalisation policies. Saxonia, ISBN 978-3-934409-33-4; ISBN 0-9547474-4-5 Freiberg.