Poster Session (PoS) C: Remediation Technologies and Concepts

ENVIRONMENTAL BALANCING OF ‘COLD’ SVE AND THERMALLY ENHANCED SOIL VAPOUR EXTRACTION – PRACTICAL SUPPORT FOR DECISION MAKERS

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1. MOTIVATION

Whilst finding the most suitable technology for the remediation of a contaminated site, environmental sustainability of the chosen technology is becoming more and more important beside the financial and legal aspects. Remediation improves the ecological conditions at the site but also causes different impacts on the environment: energy consumption, the use of materials, emissions, etc. The consideration of these ‘secondary environmental impacts’ has received increasing attention.

VEGAS, the Research Facility for Subsurface Remediation at the University of Stuttgart, Germany carries out research and development projects for new in-situ remediation technologies and brownfield redevelopment. One of these technologies, the steam and steam-air-injection in the unsaturated zone [Fig. 1] was successfully developed by laboratory experiments [Betz 1998, Färber 1997, Schmidt 2001] and has been used efficiently at field sites [Koschitzky et al. 2000, Theurer & Koschitzky 2001]. In comparison with the cold soil vapour extraction (SVE), thermally enhanced soil vapour extraction (TSVE) increases the vapour pressure of all fluids present in the subsurface due to higher temperatures and thus allows higher extraction rate and a significant shortage of remediation time.

Sites can be cleaned much faster and prepared for reuse by new investors. Nevertheless, TSVE is often unfounded criticised for its energy consumption needed for heating the subsurface and thus is said to cause greater negative impacts on the environment in comparison to the cold SVE.

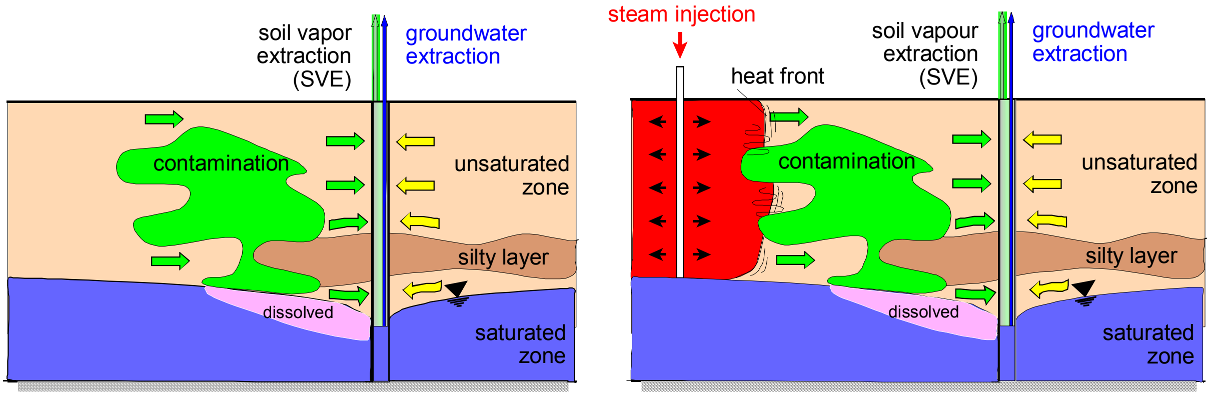


***Fig. 1*: Scheme of ‘cold’ soil vapour extraction (SVE) and thermally enhanced SVE by steam injection**

The aim of this research is in regard to life cycle assessment (LCA) of different field sites, where thermally enhanced soil vapour extraction and cold SVE were compared with each other to estimate the secondary environmental impacts of such techniques.

Examination of the environmental impacts of site remediation techniques is one of the demands of the German Federal Soil Protection Act [BBodSchG] and the German Soil Protection and Contaminated Sites Ordinance [BBodSchV]. In particular the effects of the measures on the environment have to be considered in the decision for a remediation plan.

LCA is a technique used to examine the environmental aspects and potential impacts associated with a product [ISO 14040]. During the last years the LCA-method has been transferred into the field of remediation to do an environmental assessment of these techniques. As a result of a remediation, there is a reduction or elimination of a danger for the environment (‘primary environmental impacts’), on the other side the ‘secondary environmental impacts’ are caused due to the operation of pumps, excavators etc. for remediation.

In the field of remediation techniques there are only a few examinations published. During the last years, investigations of the impacts of subsurface remediation on the environment were done e.g. in Denmark and Canada [ScanRail et al. 2000, Diamond et al. 1999]. A software tool for environmental balancing of soil remediation measures was developed [LfU 1999, Volkwein et al. 1999]. With this tool, secondary impacts on the environment can be determined. The LCA of this research project is calculated with this LfU-software tool ‘Environmental balancing of soil remediation measures’.

2. DESCRIPTION OF METHODS

This investigation is based on data from technical scale experiments investigated at *VEGAS* and field remediations supervised by *VEGAS*.

Based on experiments at the *VEGAS* facility, a field-site remediation of a BTEX contamination (Site A) was conducted [Schmidt 2001]. The design of this remediation plant was very close to the setup of the preceding technical scale experiment. This gave the opportunity to compare technical scale investigations with field remediation data under ‘artificial laboratory conditions’. Comparisons between field remediations and technical scale investigations are made in terms of transferability and appraisal for the environmental impacts. For the remediation of the subsurface below a former waste dump (Site B), the TSVE-technology was adapted to the highly complex hydrogeological conditions [Theurer & Koschitzky 2001]. Here, the TSVE-plant was applied for the treatment of a trichloroethylene (TCE) contamination of the unsaturated zone. At both sites, conventional SVE-plants have been used prior or parallel to the TSVE field experiments. This allowed the determination and comparison of the environmental impacts of these two techniques. This research could be based on the information that had been gained during these field experiments.

Method for the determination and comparison of the environmental impacts

The developed procedure for determining and evaluating of the environmental impacts of alternative remediation techniques is derived from the international standard ISO 14040. This procedure can be split into three major sections [Fig. 2]:

1. The engineering part for the data generation, including selection of the content for investigation along with data preparation. This determines the scope of the investigation and defines the selected contents to be prepared for the execution of the second section.
2. The evaluation of the LCA by using a commercial software ‘Environmental balancing of soil remediation measures’ (LfU 1999). The program computes consumption data, life cycle inventory analysis and life cycle impact assessment.
3. The appraisal of the computed LCA including checking of the plausibility of the results and comparison with LCAs from other remediation scenarios.

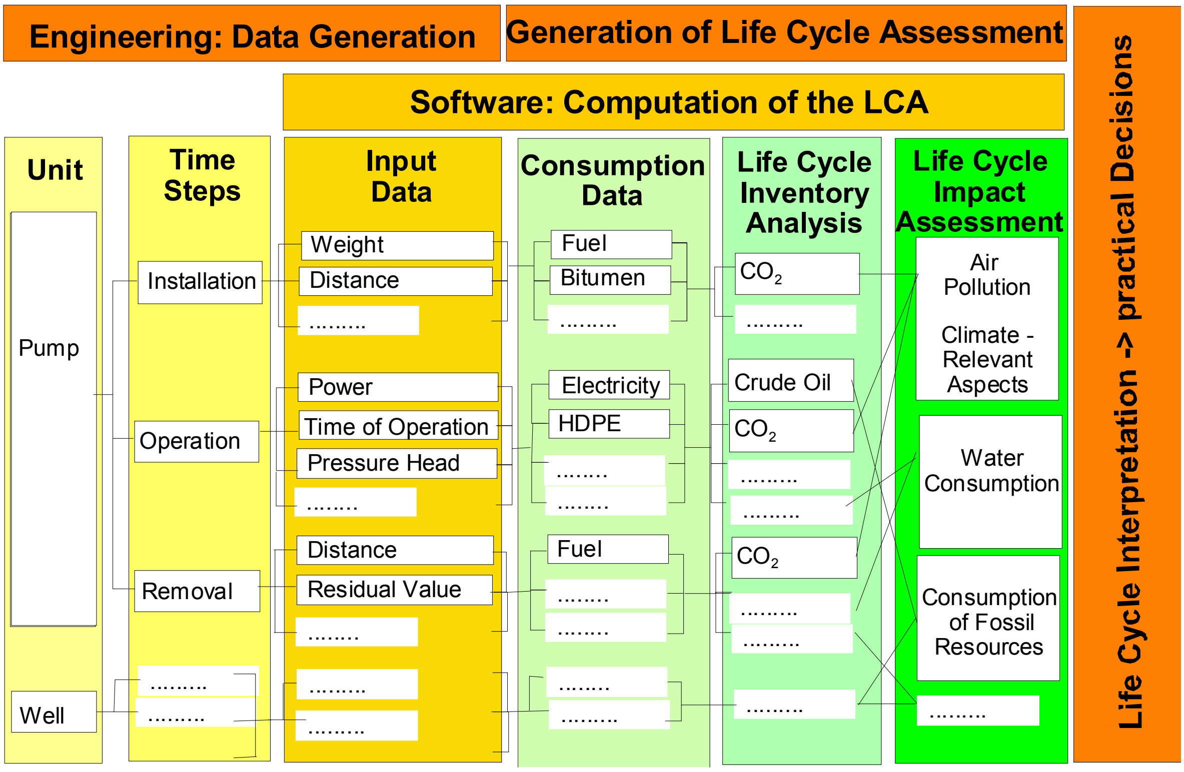


Fig. 2: Modular life cycle assessment (LCA) concept for site specific remediation evaluation

With this PC-tool it is up to the user to define kind and content of an investigation. So the program alone would not have been suitable for comparative investigations. Hence, a site specific procedure must be developed to define the content to be compared, prior to the application of the PC-tool. This developed procedure allows a comparative investigation of arbitrary technical systems [Fig. 2].

Engineering: Input Data Generation for the LCA

To define the range of the investigation, a differentiation between primary and secondary functions has to be introduced. A primary function is an integral part of a technical system that contributes directly to the desired total function of the system. Secondary functions have no direct effect on the total function, but they are needed to install, to run, and to remove a system. Any secondary function must be assigned to a primary function. The product system, which is subject to the investigation, consists of all the primary functions of a technical system and of all the secondary functions assigned to them. For example, an activated carbon filter is a primary function of a SVE-plant, as it contributes directly to the desired total function of extracting, conveying, and treating soil vapour.

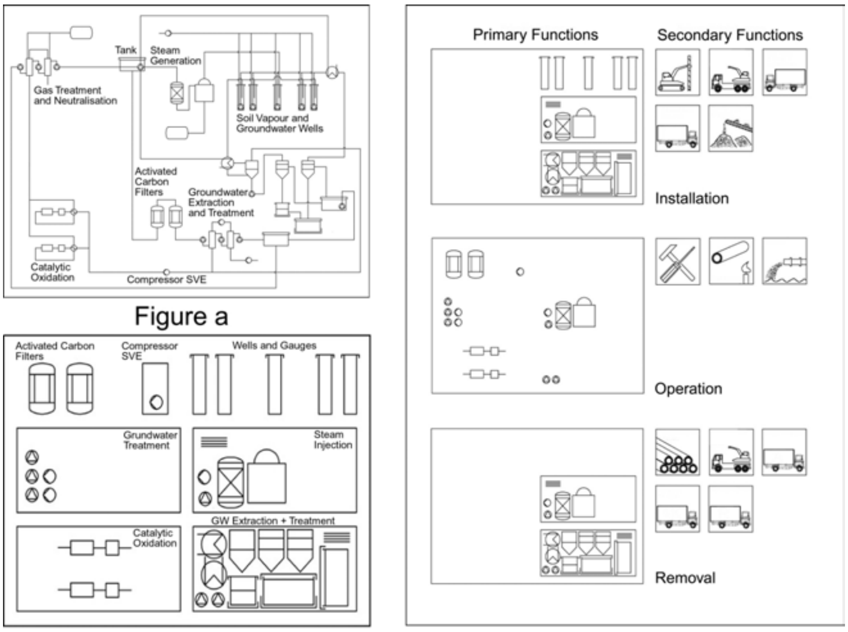


Figure a

Figure b

Figure c

Fig. 3: Analytical separation of the remediation plant from site B: a) flowchart of TSVE plant, b) separation in functional units, c) temporal discretisation of the input data

Secondary functions are caused by transportation to and from the site, installation and removal works.

All these actions do not directly contribute to the plant's desired total function. However, they are essential in achieving the plant's total function. The aim of the procedure's first step is to identify all the primary functions of a plant, and to create a flow chart for it or for a component of a larger plant, which shall then be subsequently examined.

With this step of the procedure the structuring of the investigation's content begins. For this reason the complete plant shown in a flowchart [Fig. 3a] is separated into technical units, e.g. groundwater extraction, steam injection etc. [Fig. 3b] and hardware components, e.g. pumps, wells, steam generator etc. In order to complete this step an inventory of all primary functions has been achieved. Furthermore, each part can be assigned to a unit of the plant. This action helps to assure that no important parts of a plant have been omitted and that none other than the necessary parts belong to the subsequently regarded product system.

In this second step of the procedure, all units can be categorised with a temporal description, e.g. site installation, plant operation, and facility removal [Fig. 2, Fig. 3c]. This extends the examination and includes secondary functions in its consideration. All action that is necessary to prepare a plant for operation belongs to the installation process. This temporal phase consists of the transportation of all plant parts and all action for their installation as well as the delivery of all that necessitates consumables for example, fuel. The operation phase summarises all action of the desired regular operation of a plant over a certain period of time. The removal phase consists of all action to dismantle and remove the facility. After this step a product system has been defined which is separable from its environment, and is structured by content as well as by temporal phases [Fig. 3c].

This structure is used for the computation of environmental impacts to identify the dominating plant components per environmental impact category. Therefore, this product system must be transferred into modules of a PC-software [LFU 1999]. Modules with respect to ISO 14040 are the smallest fractions of product systems. They form the elementary entities of the investigation for the description of which input data has to be collected.

It is one of the procedures advantages that the first two steps require only little detail information about the examined system (e.g. electricity consumptions). This third step is the dominating time consuming one because a lot of detailed information must be collected. These data are necessary to describe the product system by modules in the PC-software. For these data, e.g. power consumption of pumps, operation times etc. must be inquired [Fig. 2]. Thus data collection and preparation can be executed focused. Data collection starts in the third step when the necessary parameters are selected.

Generation of Life Cycle Assessment

The PC-tool 'Environmental balancing of soil remediation measures' [LfU 1999] consists of 54 modules which represent each a single operation, e.g. the transportation of masses or the drilling of wells. By combining several modules, all the actions can be simulated which have to be taken during a real remediation measure. Each module demands for the input of characteristic parameters, which describe the operation represented by the respective module.

Out of this information, each module quantifies the amount of raw material, fuel or energy, which would have been necessary for the individual operation's action. From the summation of consumption data of all the modules, the program calculates the total amount of consumed values.

Life cycle inventory analysis is generated from the consumption data by multiplication with generic data. Generic data is the result of independent life cycle inventory analysis, which has been performed prior to the compilation of the database for the program. Each set of generic data gives the life cycle inventory of an unit amount of a consumed good, e.g. of 1 kg diesel. Fractional inventory analysis can be generated through the multiplication of the total amount of any consumed good with the correspondent set of generic data. Hence, this results in a set of fractional life cycle inventories. As all sets of generic data consist of the same categories, these fractional inventories can be summarised by addition, and through this, the life cycle inventory of the whole remediation can be generated.

The determination of the life cycle inventory is followed by the life cycle impact assessment [Fig. 2]. This is an evaluation of life cycle inventory with reference to potential environmental impacts. For this evaluation, all of the 160 positions of the life cycle inventory have to be evaluated with respect to their potential effect on any of the 19 impact categories in the PC-tool (e.g. global warming, land use, etc.). Some of these 19 impact categories are an adaptation of the impact categories that have been proposed by the Society of Environmental Toxicology and Chemistry (SETAC).

Comparability of different remediation systems – definition of the functional unit

This investigation intends not only to determine, but also to compare the environmental impact of different plants. Thus a functional unit has to be defined. The functional unit for this examination is based on the amounts of extracted contaminant.

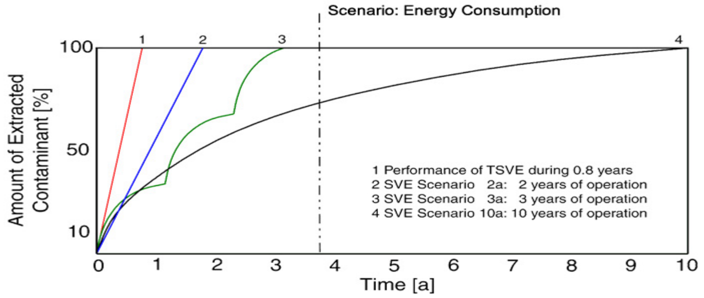


Fig. 4: TSVE field data and assumed remediation times for the SVE, based on similar amount of extracted contaminants for site B

The success of an in-situ-extraction of volatile substances from the subsurface does not only depend on the applied technique. Other influencing factors include geological and hydrogeological conditions at the site. Therefore, the comparison of 2 plants which are operated at different sites could only be roughly performed, if it all. Thus, only site specific SVE and TSVE plants can be compared. In this way it could be assumed that the influences of the subsurface properties have similar effects on the remediation efficiencies.

Data from a former SVE- as well as from a TSVE-plant are available for field sites. To compare both treatments with each other, comparability in remediation success that means same mass of removed contaminants is postulated. Therefore, the mass extraction of the TSVE operation is taken as 100 % mass extraction [Fig. 4, curve 1]. The comparable SVE scenario has to extract the same amount. Uncertainties exist concerning the expected efficiency of the SVE. Therefore, three scenarios were examined, one with an overestimating linear mass extraction [Fig. 4-2], the second using an optimistic intermitting mass extraction [Fig. 4-3], and the final example a realistic mass extraction [Fig. 4-4] (from extrapolating the former field data for the SVE [Theurer & Koschitzky 2001]).

3. RESULTS

The results of this investigation can be resolved by content and by temporal steps [Fig. 5]. They show independently for both remediation technologies that environmental impacts are mainly caused by the plant operation. Impacts from site installation and plant removal are negligible, except the impact category ‘Total Waste’ due to the drilling of wells during the site installation phase.

But the reasons for the dominance of the plant operation time are different. For the conventional SVE the operational impacts depend significantly on time. The energy demand due to operation, in scenario ‘2 years’, reaches 80 % of the total energy demand. With increasing duration of operation, the energy demand contributes to the total energy demand with 95 %, as shown in scenario ‘10 years’ [Fig. 5, diagram 2, 4]. Similar results show the impact categories ‘Fossil Resources’, ‘Land Use’ and ‘Global Warming’.

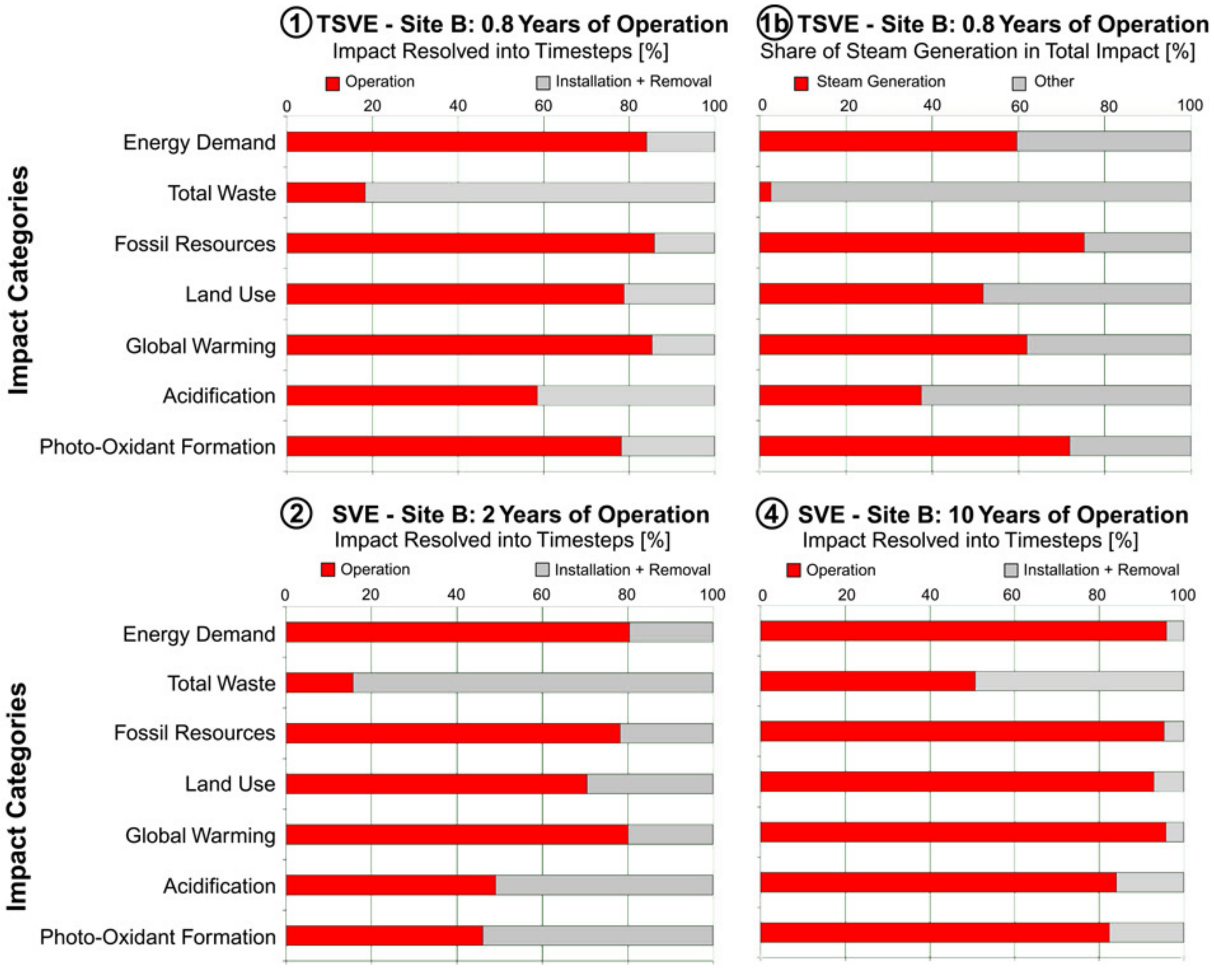


Fig. 5: Portion of the operation time and installation/removal at Site B at the different impact categories and share of steam generation in the operation phase of the site B

For the TSVE plant, the operational impacts depend mainly on the steam generation as the significant energy consumer. This can be seen from retracing the results from the life cycle impact assessment to the consumption and input data [Fig. 2]. The steam generation creates 75 % of the total impact in the category ‘Fossil Resources’ and well beyond 50 % of the impact of the categories ‘Energy Demand’, ‘Land Use’, ‘Global Warming’ and ‘Photo-Oxidant Formation’ [Fig. 5, diag. 1b].

TSVE steam and steam-air-injections are used to heat up a certain soil volume. Thus the required steam volume depends mainly on the size of this volume and not on the duration of operation.

To generalise these site specific results from the LCA of SVE and TSVE, some transformations have to be done. Therefore, the remediation scenarios ‘cold’ SVE with the longest remediation time per site is defined as 100% operation time and 100% of the category specific environmental impact (EI) (e.g. energy demand, acidification etc.). All other scenarios are related to this baseline scenario.

Regarding the total environmental impacts [Fig. 6a] in the different impact categories of the SVE over the operation time of a plant, large variations of the different balancing parameters can be seen.

This is caused by the time dependent genesis of the EIs; waste is produced mainly during the installation of a plant, e.g. from well drilling. The energy consumption for the drilling process has got a low impact of the LCA due to the dominating energy consumption of the treatment during operation. All in all, only individual EI parameter equations (e.g. 'Total Waste') can be given [Fig. 6, a].

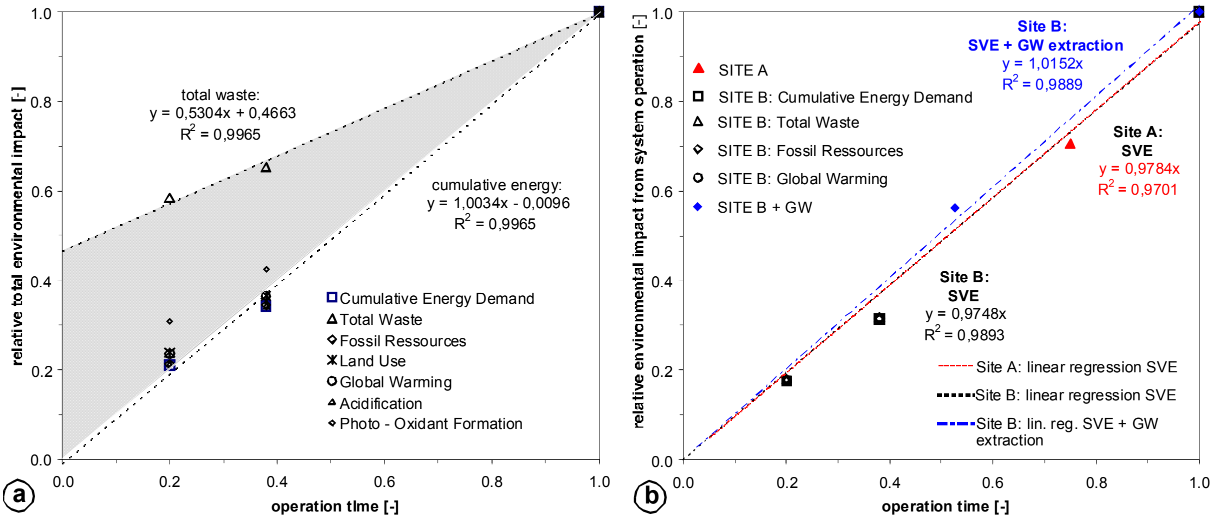


Fig. 6: Total environmental impacts of site B (a) and environmental impacts from plant operation from site A and B (b) related on the maximum operation time for several impact categories

In order to generalize the evaluation of the EI, the effects must be standardized based on the operation time of a plant. Therefore, a differentiation for the genesis of the total environmental impact I_{tot} in site installation I_{inst}, plant operation I_{op} and facility removal I_{rem} per life cycle impact category x for the treatment i is necessary.

$$I_{tot\,x,i} = I_{inst\,x,i} + I_{op\,x,i} + I_{rem\,x,i} \qquad [1]$$

The impacts caused only by operation I_{op} can be described now by linear equations for different sites and different remediation scenarios (SVE with (= SVE + GW), and without groundwater extraction) [Fig. 6b]. By definition, EIs for operation of a remediation are caused, when the plant is switched 'on'; therefore the linear function must cross zero at the y-axis.

To compare different treatment technologies, setups, configurations with each other, the basic (here: TSVE-plant) and alternative treatment (here: SVE-plant) are differed. For specific EI categories x, the 'alternative treatment 2' must create less EI according to the 'basic design 1' to be favoured. Thus, the critical operation time $t_{crit.\ operat\,x,2}$ of the 'alternative plant 2' can be calculated as

$$t_{crit\,op\,x,2} = \frac{nI_{tot\,x,1} - I_{inst\,x,2} - I_{rem\,x,2}}{I_{calc\,op\,x,2} / t_{calc\,op\,2}} \qquad [2]$$

with:	index x	specific environmental impact categories, e.g. cumulative energy demand
	index i	treatment scenario
	index 1	basic treatment 1
	index 2	alternative treatment 2
	$t_{crit\ op\ x,2}$	category specific operation time of treatment 2 before a significant impact difference can be quantified
	n	element of uncertainty for data generation from research and from PC-tool, to quantify clear impact differences (here n = 2) between the treatments
	$I_{tot\ x,1}$	category specific sum of total environmental impact of the treatment 1
	$I_{inst\ x,2}$	category specific sum of environmental impact from installation of treatment 2
	$I_{rem\ x,2}$	category specific sum of environmental impact from the removal of treatment 2
	$I_{calc\ op\ x,2}$	category specific sum of environmental impact from the balanced operation of treatment 2
	$t_{calc\ op\ 2}$	balanced operation time of treatment 2

The parameter $a_{x,i}$ is now defined as the influence of operational impact on the total impact:

$$a_{x,i} = \frac{I_{op\,x,i}}{I_{tot\,x,i}} = 1 - \frac{I_{inst\,x,i} + I_{rem\,x,i}}{I_{tot\,x,i}} \tag{3}$$

With the postulates, that the impacts from operation are linear to the operation time and impacts from installation and removal can be summarised and replaced by the parameter, the general equation for the critical operation time $t_{crit.\ operat\,x,2}$ is:

$$t_{crit\,op\,x,2} = \frac{n\frac{I_{op\,x,1}}{a_{x,1}} - (1-a_{x,2})\frac{I_{calc.op\,x,2}}{a_{x,2}}}{\frac{I_{calc.op\,x,2}}{t_{calc.op\,2}}} \tag{4}$$

Table 1: Parameter $a_{x,i}$ determined in this research

	Site A			Site B			
Treatment	**TSVE**	*SVE*		**TSVE**	*SVE*		
Duration of Plant Operation	**0.2a**	*3a*	*4a*	**0.8a**	*2a*	*3a*	*10a*
Parameter	$a_{x,1}$	$a_{x,2}$	$a_{x,2}$	$a_{x,1}$	$a_{x,2}$	$a_{x,2}$	$a_{x,2}$
Cumulative Energy Demand	**0.8**	*0.9*	*0.9*	**0.8**	*0.8*	*0.9*	*1.0*
Total Waste	**0.2**	*0.3*	*0.4*	**0.2**	*0.2*	*0.2*	*0.5*
Fossil Resources	**0.8**	*0.8*	*0.9*	**0.9**	*0.8*	*0.9*	*1.0*
Land Use	**0.6**	*0.8*	*0.8*	**0.8**	*0.7*	*0.8*	*0.9*
Global Warming	**0.8**	*0.9*	*0.9*	**0.9**	*0.8*	*0.9*	*1.0*
Acidification	**0.7**	*0.7*	*0.8*	**0.6**	*0.5*	*0.6*	*0.8*
Photo-Oxidant Formation	**0.7**	*0.7*	*0.8*	**0.8**	*0.5*	*0.6*	*0.8*

By transposing these equations, the effective total EI of the ‘treatment 2’ after a chosen operation time $t_{crit\ op\,x,2}$ can be determined for a specific impact category x as:

$$\begin{aligned} I_{crit.total\,x,2} &= I_{install\,2} + i_{calc.operat\,2}\,t_{crit.operat\,2} + I_{remov\,2} \\ &= (1-a_{x,2})\frac{I_{calc.op\,x,2}}{a_{x,2}} + \frac{I_{calc.op\,x,2}}{t_{calc\,op\,2}}\,t_{crit\,op\,x,2} \end{aligned} \tag{5}$$

In order to compare TSVE and SVE treatments with each other, several scenarios for 2, 3 and 10 years of the SVE are balanced and the intersection point for the environmental impacts is detected by the equations above [Fig.7]. Here, only 7 of the 19 impact categories of the PC-program have been chosen for the confrontation of the two techniques because of their special importance. Due to uncertainties, e.g. of the generic data of the PC-program, an alternative scenario would have to produce twice as much environmental impact in a particular category in order to appear significantly worse. This is indicated by the grey area which illustrates the error bounds of the investigation.

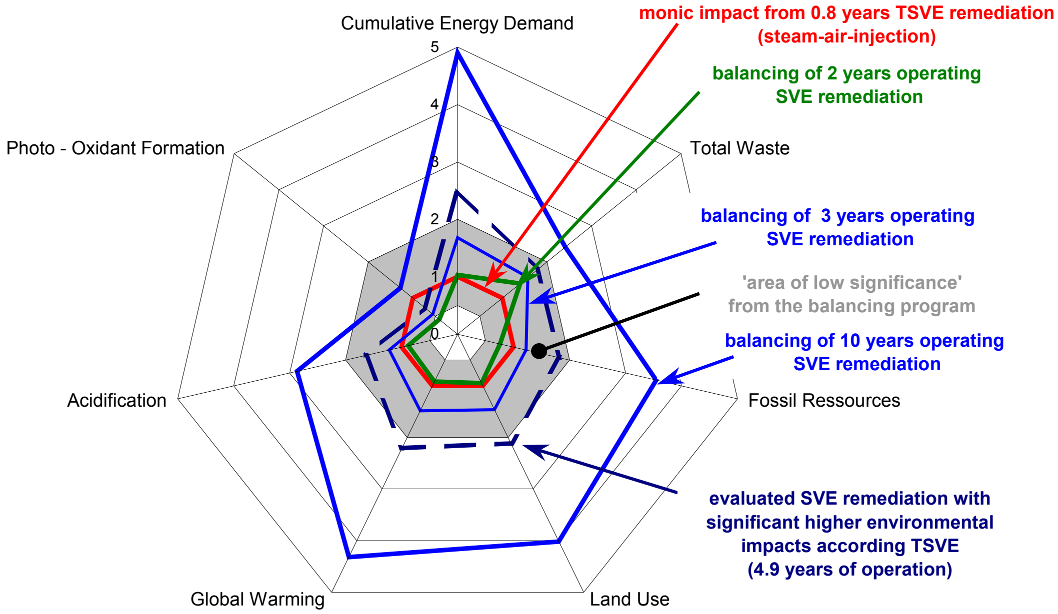
The results of the SVE-scenarios 2, 3 and 10 years of SVE operation are shown in relation to the result of the TSVE plant operation of 0.8 years. The result of the TSVE holds the value 1 on any axis as all results of the environmental impact assessment have been benchmarked to the result of the TSVE-plant. Values higher than 1 show how many times worse an alternative is in comparison to the TSVE plant. All Values below 0.5 indicate a significant (factor 2) advantage of the alternative SVE over the TSVE-plant. Results higher than 2 indicate a significantly advantage of TSVE-plant [Fig. 7].

The environmental impact comparison between TSVE and SVE can be summarised as follows

- even a SVE with an overestimated linear mass extraction of contaminants does not show significantly less environmental impacts in comparison to the TSVE remediation,
- the SVE consumes twice as much energy during 3.8 a of operation according the TSVE-plant during 0.8 years,
- the SVE remediation causes significantly more environmental impacts after less than five years of operation,
- the SVE operation time estimated by using realistic extraction rate is, at minimum, about 12 times longer (10 years) according to the TSVE plant (0.8 years).

The general scheme for a simplified LCA for the comparison of treatment technologies could be:

- select the comparable conditions (e.g. removed mass of contaminant, treated m³ of soil …),
- split a basic treatment in technical units and calculate one scenario for the impacts of plant operation,
- split an alternative treatment as well and calculate also one operating time scenario,
- select the main impact categories of interest, useful chosen for the site specific conditions,
- check the accuracy of your prognoses (e.g. ascertain if the environmental balancing program needs a difference of factor 2 to allow significant quantifiable statements),
- use statistical data or estimate the parameter a (if the impacts of the operation are very dominant, $a \approx 1$),
- calculate the critical operation time of the alternative remediation with the equation [4],
- determine the environmental impacts of the alternative system with equation [5].



monic impact from 0.8 years TSVE remediation (steam-air-injection)

balancing of 2 years operating SVE remediation

balancing of 3 years operating SVE remediation

'area of low significance' from the balancing program

balancing of 10 years operating SVE remediation

evaluated SVE remediation with significant higher environmental impacts according TSVE (4.9 years of operation)

Fig. 7: Environmental impacts from scenarios calculated for site B

4. COST ESTIMATIONS

The LCA method can only be used for the estimation of the ecological consequences of the remediation of a site. Currently, the decision for a remediation technique is often limited by costs. As a result, the economic efficiency is the main criteria, the environmental impacts have only a very small influence in the decision process. The combination of LCA and cost estimation could be one possibility to improve the consideration of the environmental balancing in the decision process.

In the context of the balancing of the TSVE, a cost estimation on the basis of the calculated consumption data was carried out: the used PC-tool [LFU 1999] calculates automatically the consumption data of remediation projects based on information from databases containing averaged data of machines, remediation plants etc. The consumption data (calculated by the tool) were combined with market prices for electricity, gas, fuel, water, disposal of waste, transportation etc. [WEISS 2002]. The results of this estimation give a scale for the costs of the operation of the remediation plant. These results were compared with the real costs of the operation.

It could be shown that the prices, calculated on the basis of the consumption data, and the real data correlate. But there are of course some inaccuracies. The reason for these failings is the use of averaged data for the different modules of the PC-tool. Another uncertainty is the reason, that some parts of the SVE have no environmental impacts during the operation time, so they are not considered in the calculation of the costs. A further problem are shut down periods: during these times there are no environmental impacts, but costs for example for maintenance and engineering overhead. Table 2 shows the estimated costs, based on the calculated consumption data from the software-tool and the real costs of the SVE-installation.

This cost estimation shows the possibility of estimating the costs based on the consumption data of the LCA. With the elimination of the personnel costs, the results of estimation and real costs would be nearly the same dimension. It is obvious that much more research is necessary in this field to enable this tool to accurately calculate the costs.

Table 2: Cost-estimation based on the results of the software tool and the real costs of the TSVE-installation of site A [SCHMIDT 2001]

Estimated remediation costs from LCA consumption data	**Units**	**Con-sumption data**	**Price per unit [€]**	**Price [€]**
Waste – disposal	kg	18 815	0.20	3 763
Waste – recycling	kg	4 000	0.03	120
Activated carbon	kg	4 192	5.11	21 423
Gravel/sand	kg	14 975	0.04	599
Bentonite	kg	1 563	0.08	125
Electricity	kWh	3 675	0.20	735
Gas	kg	11 470	0.10	1 147
HDPE	kg	525	4.50	2 363
Transportation (truck < 10 t)	km	649	1.00	649
Diesel (machines)	kg	216	1.00	216
Fuel	kg	12	1.00	12
Transportation (truck > 10 t)	tkm	10 088	1.00	10 088
Transportation car	km	3 688	0.25	922
Steel	kg	1 458	5.70	8 313
Water consumption	m³	14 112	3.22	45 441
Amount	**€**			**95 916**

Good and services of the real remediation	**Real costs [€]**	**Real costs for positions comparable to LCA [€]**
Surface sealing	2 556	--
Shift of underground pipes	2 812	--
Drilling of wells	14 418	14 418
Installation / removal of plant	15 339	15 339
Operation of the facility	66 468	66 468
Material consumption	13 294	13 294
Chemical analytics	2 556	--
Manpower / transport-costs	18 407	*18 407*
Amount	**135 850**	**127 926**

5. SCALING FROM TECHNICAL SCALE EXPERIMENTS TO FIELD SITE REMEDIATION

At *VEGAS* technical scale experiments are run to test and optimise the technical feasibility of new remediation methods. For environmental balancing, it is interesting if data from technical scale experiments allow estimation of environmental balancing of field site remediations.

In a first step, site installation and site removal investigations must be neglected, because of the differences between the *VEGAS* experiment and the field site A. The experimental work features the complete implementation of an artificial, similar to natural soil structure, investigation with highly accurate measurement equipment for research, and a prototype design of technical facility in the pilot study.

Therefore, only the operation time is compared between technical scale investigation and field remediation. Furthermore, the technical setup between field remediation and technical scale investigation should be comparable. Representatively, the field remediation site A is compared with the technical scale experiments in *VEGAS*.

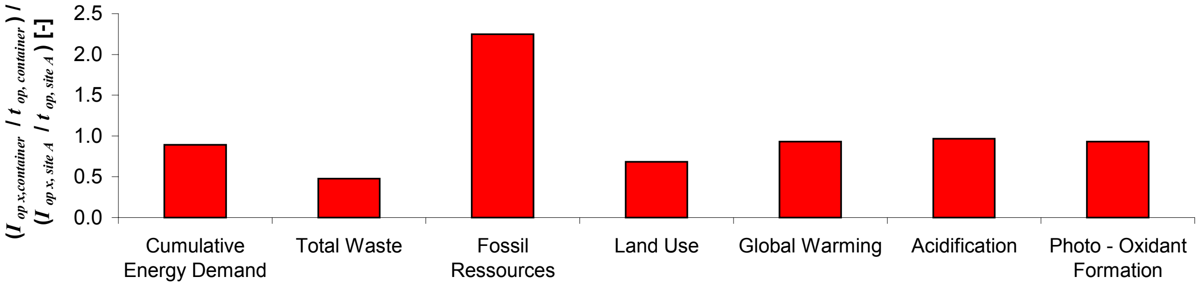


Fig. 8: Transfer parameter for environmental impact factors from technical scale experiments in VEGAS to field site A

Due to differences in spacing, operation time, extracted contaminant mass etc., the data from the environmental balancing are averaged over the operation time. By relating these factors from the technical scale experiment and the field site A it can be seen, that both independent data sets deliver approx. the same factors for all area and soil dependant parameters. This enables a direct scaling from technical scale experiments in *VEGAS* to field site facilities of these parameters. But the parameter ‘Fossil Resources’ shows significant higher relation (factor 2.5). This is caused by the way of steam generation: in the laboratory, an electric powered steam generator was used; at the field site A, a more economical operating gas served generator for higher discharges was under operation.

6. CONCLUSIONS

The method of LCA is a universal tool for comparison of the ecological impacts of different remediation technologies. The suggested methods and equations can be used as both planning and prediction tool for the impact appraisal of treatments.

For steam injection in comparison with the standard ‘cold’ soil vapour extraction, the LCA shows the following preliminary fundamental conclusions:

- The impacts from site installation and facility removal at a site are often negligible. Plant operation generates 80 – 90 % of the category specific environmental impacts.
- To reduce the environmental impact of SVE and TSVE, their efficiency and performance during operation is the key issue. However, the SVE operation impacts are mainly related to the operation time, whereas the TSVE impacts are related to the steam mass to be generated.
- An improvement in performance can be achieved by an intensification of field site investigation.
- The TSVE has got a potential for further optimisation as the major factor for its environmental impacts, the steam generation, directly corresponds to the size of the treated soil volume.
- The transferability from technical scale investigations in *VEGAS* to equivalent field remediation is possible. The reduction of the operation time for these comparisons would be useful.
- First cost estimations for the operation time by an economical evaluation of the consumption data are feasible. Effective costs for a remediation, e.g. including ‘times of no action’ and overhead costs for the personal staff, are not included, but can be considered additionally.

The comparison of the two techniques (SVE and TSVE) by LCA gives a favourable result for the TSVE. Nevertheless, to install LCA as a common method for the design of remediation plans, further results of LCAs of remediation projects are necessary to improve and generalize the data quality.

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