Life cycle assessment of soil and groundwater remediation technologies: literature review

Background, aim, and scope
Life cycle assessment (LCA) is becoming an increasingly widespread tool in support systems for environmental decision-making regarding the cleanup of contaminated sites. In this study, the use of LCA to compare the environmental impacts of different remediation technologies was reviewed. Remediation of a contaminated site reduces a local environmental problem, but at the same time, the remediation activities may cause negative environmental impacts on the local, regional, and global scale. LCA can be used to evaluate the inherent trade-off and to compare remediation scenarios in terms of their associated environmental burden. Main features An overview of the assessed remediation technologies and contaminant types covered in the literature is presented. The LCA methodologies of the 12 reviewed studies were compared and discussed with special focus on their goal and scope definition and the applied impact assessment. The studies differ in their basic approach since some are prospective with focus on decision support while others are retrospective aiming at a more detailed assessment of a completed remediation project.

Literature review
The literature review showed that only few life cycle assessments have been conducted for in situ remediation technologies aimed at groundwater-threatening contaminants and that the majority of the existing literature focuses on ex situ remediation of contaminated soil. The functional unit applied in the studies is generally based on the volume of contaminated soil (or groundwater) to be treated; this is in four of the studies combined with a cleanup target for the remediation. While earlier studies often used more simplified impact assessment models, the more recent studies based their impact assessment on established methodologies covering the conventional set of impact categories. Ecotoxicity and human toxicity are the impact categories varying the most between these methodologies. Many of the reviewed studies address the importance of evaluating both primary and secondary impacts of site remediation. Primary impacts cover the local impacts related to residual contamination left in the subsurface during and after remediation and will vary between different remediation technologies due to different cleanup efficiencies and cleanup times. Secondary impacts are resource use and emissions arising in other stages of the life cycle of the remediation project. Discussion Among the reviewed literature, different approaches for modeling the long-term primary impacts of site contamination have been used. These include steady state models as well as dynamic models. Primary impacts are not solely a soil contamination or surface water issue, since many frequently occurring contaminants, such as chlorinated solvents, have the potential to migrate to the groundwater as well as evaporate to ambient air causing indoor climate problems. Impacts in the groundwater compartment are not included in established impact assessment methodologies; thus, the potential groundwater contamination impacts from residual contamination are difficult to address in LCA of site remediation. Due to the strong dependence on local conditions (sensitivity of groundwater aquifer, use for drinking water supply, etc.) a more site-specific impact assessment approach than what is normally applied in LCA is of relevance. Conclusions, recommendations, and perspectives The inclusion of groundwater impacts from soil contaminants requires the definition of an impact category covering human toxicity via groundwater or the inclusion of these impacts in the human toxicity impact category and the associated characterization models and normalization procedures. When evaluating groundwater impacts, attention should also be paid to potentially degradable contaminants forming metabolites of higher human toxic concern than the parent compound.

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