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Accounting for land-use efficiency and temporal variations between brownfield remediation alternatives in life-cycle assessment

Alistair Beames [a, b, *], Steven Broekx [a], Reinout Heijungs [c], Richard Lookman [a], Katrien Boonen [d], Yannick Van Geert [b], Kris Dendoncker [b], Piet Seuntjens [a, b, e]

[a] *Environmental Modeling Unit, VITO, Boeretang 200, 2400 Mol, Belgium*
[b] *Department of Soil Management, Ghent University, Coupure Links 653, 9000 Ghent, Belgium*
[c] *Department of Econometrics and Operations Research, Faculty of Economics and Business Administration, VU Amsterdam, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands*
[d] *Material Technology Unit, VITO, Boeretang 200, 2400 Mol, Belgium*
[e] *Department of Bioscience Engineering, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerp, Belgium*

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ABSTRACT

The latest life-cycle assessment methods account for land use, due to the production, use and disposal of products and services, in terms of ecosystem damage. The process of brownfield remediation converts otherwise idle urban space into productive space. The value to ecosystems in this context is of course limited since the brownfield site remains urban. When evaluating brownfield remediation technologies, the availability of space on-site is dependent on the duration of time required by the remediation technology to reach the remediation target. Remediation technology alternatives tend to vary largely in terms of duration. Comparative life-cycle assessments of remediation technologies, to date, present the large variations between alternatives in terms of remediation duration but do not translate this into an impact or parameter. The restored subsurface zone is often defined as a functional unit, when in fact the surface area is the resource restored by the remediation service. The economic benefits of making land resources available are particularly important considerations in the context of brownfield remediation. The research proposes an innovative impact assessment approach that allows land to be considered as a finite resource. The method is applied in a comparative life-cycle assessment of two potential remediation scenarios for an idle brownfield in the Brussels region of Belgium. The results show that there is a trade-off between greenhouse gas emissions and land availability and that both are largely dependent on the efficiency of the contaminant extraction mechanism. The results also raise the question as to whether the economic valuation of land, like precious metals and fossil fuels, provides an accurate reflection of the true value of the resource. Considering land as a resource at the midpoint level is also relevant in other urban contexts where competition exists between different land-uses, where urban sprawl is detrimental to undeveloped areas and where urban intensification is a policy objective.

1. Introduction

The rapid conversion of rural areas to peri-urban land cover globally is increasing the demand for space near urban centers (Piorr et al., 2011). At the same time, brownfield sites, unutilized due to the risks associated with local soil and groundwater contamination, take up a considerable amount of space in urban centers, particularly in Europe. The estimated total areas of brownfield space in Belgium, Germany and the Netherlands, for example, are 145 square kilometers (km^2), 1280 km^2 and 110 km^2, respectively (Oliver et al., 2005). Remediating these areas and adding them to the urban supply of land would contribute to more compact urban centers and would reduce the consumption of undeveloped green areas at the periphery, at least to a certain extent. Doing so, however, would require considerable financial and energy investments. The question then arises as to whether such resource investments deliver acceptable financial and environmental returns. The Life-cycle Assessment (LCA) approach can be used to evaluate the potential environmental merit of alternative

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* Corresponding author. Environmental Modeling Unit, VITO, Boeretang 200, 2400 Mol, Belgium. Tel.: +32 14 33 6796.
E-mail address: alistair.beames@vito.be (A. Beames).

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remediation scenarios but the standard LCA methods do not consider land as a finite and increasingly scarce resource. Instead, land-use is accounted for in terms of ecosystem damage and biodiversity loss. The research presented here shows that just as the acquisition and consumption of fossil fuels, precious metals and drinking water bring about both environmental destruction and resource depletion, so too does land transformation and occupation. The occupied area in the life-cycle of a product and service has both an impact on ecosystems and on the availability of the resource.

LCA is an established method for evaluating environmental impacts associated with different product and service alternatives (Klopffer, 1997). The first scientific LCA study of soil and groundwater remediation alternatives was published in 1999 (Diamond et al., 1999). In a review of scientific literature, 34 life-cycle assessment studies on remediation scenarios could be identified, as well as several literature reviews on the specific topic (Suer et al., 2004; Lemming et al., 2010b; Morais and Delerue-Matos, 2010). Usually, the largest differences between alternatives are their energy requirements and the emissions associated with energy consumption. The duration of different remediation alternatives also varies greatly and usually has an inverse relationship to energy inputs. Duration of treatment is not, however, reflected in any impact category as such, even though it is a decisive factor in making the land available for society and those that will use the site. For example, Lemming et al. (2010c) compare remediation scenarios for a site contaminated with chlorinated hydrocarbons. The more aggressive scenarios that are temporally efficient and require more material inputs, such as *excavation and ex-situ treatment* and *in-situ thermal desorption*, contribute more to global warming, ozone formation, acidification, terrestrial eutrophication, aquatic inorganics and respiratory inorganics than the *'no action'* and *enhanced reductive dechlorination* scenarios. The scenarios range from less than one month to 1200 years in duration. Cadotte et al. (2007) compare remediation alternatives ranging from 8 years, for the most aggressive scenario, through to 302 years for the most passive scenario, for a site contaminated with diesel. Again, the more aggressive alternative, *excavation and ex-situ treatment of soil in biopiles* exceeds the air emissions and energy requirement values of the other alternatives that include *in-situ bioventing* and *monitored natural attenuation*. Suer and Andersson-Skold (2011) compare a scenario of 40 days for an aggressive alternative, to a passive approach of 20 years and a *'no action'* scenario of 20 years. The less aggressive approaches with the least environmental impacts overall, require longer remediation times.

Neither Lemming et al. (2010c) nor Cadotte et al. (2007) use an impact assessment method in which land-use impacts are reflected. Suer and Andersson-Skold (2011) do use an impact assessment method (taken from ReCiPe (Goedkoop et al., 2013)) that includes land-use to compare *excavation and landfilling* to *phyto-extraction coupled with biomass generation*. The land-use results are particularly relevant in understanding the environmental benefit of putting the site to productive use during remediation (Cappuyns, 2013). The results, however, only reflect the land-use benefits in terms of biodiversity preservation for the *'no action'* scenario and not the benefits of being able to utilize the site in the other alternatives. In the context of brownfield remediation, the shorter duration alternatives require more material and energy inputs but yield the benefits of available urban space sooner. The question then is how to account for temporal variations between alternatives.

This article addresses the development of an impact category for land-use with regard to its availability for human (socio-economic) use. Section 2 explains the goal and scope, life-cycle inventory and the land-use impact method used on the case study. The method used is described with reference to the existing approaches and how it differs from those approaches. Section 3 describes the case study and the results generated by the application of the method. Section 4, is a discussion of the implications of considering land as a resource in LCA and the potential concerns that such an approach raises.

2. Methods

This section discusses a number of elements of the LCA framework in relation to the analysis of remediation technologies. The approach adopted in this study is explained with reference to the standard approaches in existing literature.

2.1. Goal and scope definition

Remediation technologies deliver reduced contamination in the soil and groundwater of a given local subsurface space. The contaminant reduction mechanisms vary between technologies and so to do their mass removal efficiency. The rate at which different technologies extract the contaminant mass is also never constant. A linear reference flow would not make different technologies comparable. Different approaches in scientific literature have avoided the use of a reference flow altogether. The first published framework for LCA on remediation technologies defines the functional unit as a volume or mass of soil and groundwater treated (Diamond et al., 1999). This functional unit is intended to be applicable where different remediation alternatives deliver different remediation outcomes that vary in terms of the soil and groundwater quality achieved. Therefore the eventual local soil and groundwater quality delivered by the alternative is considered to be an impact and is measured according to specific soil and groundwater quality metrics. Diamond et al. (1999) suggest including a time horizon up until 25 years after remediation commences to account for long-term impacts brought about by undestroyed contaminants that remain in the subsurface or in stored waste, but this is not a parameter of the functional unit.

In many cases, the remediation target is defined by the regulator. Feasible remediation alternatives must then deliver the regulatory contamination concentration thresholds by removing a certain amount of the contaminant mass. An appropriate functional unit in such circumstances is defined by Lemming et al. (2010c, 2012, 2013), where a certain percentage of contaminant mass is removed in a certain subsurface volume. What varies between alternatives are then resource inputs, and the emissions and duration of treatment. Resource inputs and emissions are captured in the inventory but the duration of treatment is not accounted for.

In this study, a full LCA on the feasible remediation alternatives for the case study site is performed (see case study remediation description in Section 3.1). The scope of the assessment begins with material extraction processes, captured in the relevant background data, and extends through to assembly, use-phase, disassembly and finally the disposal phase, captured in the foreground data. All resources and emissions needed to deliver the functional unit are accounted for. The post-remediation site occupation impacts are beyond the scope of the life-cycle inventory, since the evaluation is concerned with the environmental efficiency of the scenarios in delivering the site. The scope of the assessment does however include the consideration of when in time the remediation process will be completed and therefore when the site will be available for redevelopment and occupation.

The functional unit in this study is the removal of approximately 80% of the estimated 500 metric tons of contaminant mass from a subsurface soil volume of approximately 40,000 cubic meters and can be achieved with the remediation alternatives considered. The