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Material flow-based economic assessment of landfill mining processes

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ABSTRACT

This paper provides an economic assessment of alternative processes for landfill mining compared to landfill aftercare with the goal of assisting landfill operators with the decision to choose between the two alternatives. A material flow-based assessment approach is developed and applied to a landfill in Germany. In addition to landfill aftercare, six alternative landfill mining processes are considered. These range from simple approaches where most of the material is incinerated or landfilled again to sophisticated technology combinations that allow for recovering highly differentiated products such as metals, plastics, glass, recycling sand, and gravel. For the alternatives, the net present value of all relevant cash flows associated with plant installation and operation, supply, recycling, and disposal of material flows, recovery of land and landfill airspace, as well as landfill closure and aftercare is computed with an extensive sensitivity analyses. The economic performance of landfill mining processes is found to be significantly influenced by the prices of thermal treatment (waste incineration as well as refuse-derived fuels incineration plant) and recovered land or airspace. The results indicate that the simple process alternatives have the highest economic potential, which contradicts the aim of recovering most of the resources.

1. Introduction

The concept of enhanced landfill mining (ELFM) broadens conventional landfill mining (LFM) through a comprehensive processing and valorization of the various waste streams, using innovative technologies to recover as much resources and energy as possible while meeting ecological and social criteria (Jones et al., 2013; Hogland et al., 2010). In contrast to ELFM, conventional LFM concentrates on the excavation of landfilled waste to reduce its space/volume for lifetime extension, recover landfill area, recycle valuable and remove hazardous material fractions, or conduct reorganization and remediation before the waste is landfilled again. Typically, LFM requires a lower processing effort and thus less process complexity (Danthurebandara et al., 2015a; Krook et al., 2012).

In this paper, alternative processes with varying complexity and processing effort are assessed. These processes are referred to as "landfill mining processes", which are defined by combining single technologies for processing landfilled waste. If the focus of applying a certain process is especially on recovering resources and energy from a landfill, the term "ELFM" will be used. Contrary, the term "LFM" will be used if the focus is on the reduction of the amount or volume of landfilled waste.

According to §40, German law on closed cycle management (Kreislaufwirtschaftsgesetz – KrWG), landfill operators in Germany are bound to care for their landfill after the operating phase is terminated. By removing the landfill body partially or fully, (E)LFM can help to eliminate potential pollution by uncontrolled landfill leachate or gas and reduce or avoid costs for long-term landfill aftercare. Further, the recovered airspace can be used for landfilling new waste or the recovered land can be marketed for alternative use.

Moreover, ELFM can be seen as an opportunity for industrial nations to secure raw material access and reduce import dependency by mining their own anthropogenic deposits (Jones et al., 2010, 2013; Münnich et al., 2013). Important waste streams that can be expected in landfills are metals, high calorific fractions such as impure plastics, textiles and wood for the production of refuse-derived fuels (RDF), and fine fractions such as recycling sand or gravel that can be used as construction material. Plastics and glass can also be recovered to substitute primary raw materials (Münnich et al., 2013; Quaghebeur et al., 2013).

In order to explore the full potential of ELFM, three main research areas are currently in the focus of science and practice: (1) the resource potential of landfills and the ecological impact of ELFM (Danthurebandara et al., 2015a; Hermann et al., 2014; Quaghebeur et al., 2013; van Vossen and Prent, 2011), (2) the identification and development of suitable technologies for mining and

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processing, and the estimation of the technical extent to which resources can be recovered from landfills (Bosmans et al., 2013; Breitenstein and Goldmann, 2014; Danthurebandara et al., 2015b,c; Krook et al., 2012; Maul et al., 2014), and (3) the economic feasibility of ELFM projects (Bölte and Geiping, 2011; Frändegård et al., 2015; van der Zee et al., 2004; van Passel et al., 2013). Assessing the economic feasibility of ELFM projects to address questions on the costs and benefits of ELFM as well as the key drivers influencing profitability requires a good understanding of the recoverable resources and suitable technologies, which in turn necessitates a good understanding of the first two research areas discussed earlier.

Among the first researchers who focus mainly on the economics of LFM are van der Zee et al. (2004). They analyze the market opportunities of LFM from a company's perspective that plans to conduct LFM on a large scale. Their approach helps to identify landfills within a particular region or country that are worthy of closer examination for LFM. However, they do not provide a detailed approach for the economic assessment of a particular LFM project. As a first step towards a sophisticated assessment approach they refer to US-EPA (1997), which is a fact sheet from the United States Environmental Protection Agency that provides relevant economic parameters for a cost-benefit analysis of landfill reclamation. Following the same idea, Hermann et al. (2014) give a comprehensive overview of relevant economic, ecological, technical, organizational, political, and mutually influencing factors for ELFM. The factors discussed in their work include, amongst others, costs for planning and approval of the mining action, for preparatory and accompanying measures, for sampling, analysis, and review of all treatment products, revenues from the recovery of secondary raw materials and from the recovery of landfill space, emissions into the air, neighboring structures. Hermann et al. (2014) also discuss the system boundary for an assessment, which determines whether the perspective of the assessment is that of a landfill operator or the society.

In contrast, Bölte and Geiping (2011), van Vossen and Prent (2011), Jain et al. (2013), van Passel et al. (2013), Danthurebandara et al. (2015a), Winterstetter et al. (2015) and Zhou et al. (2015) introduce specific approaches for the economic assessment of particular ELFM projects. The studies in the literature differ in the method and the perspective used for the assessment, their focus concerning the technological options investigated, and finally in their results, which will be discussed in the following.

With regards to the method for the economic assessment, most of the studies use capital budgeting evaluation techniques and use either the net present value (NPV) or the internal rate of return (IRR) as an indicator for profitability. Often, uncertainties are considered with the help of sensitivity or risk analyses, e.g. by using Monte Carlo simulations. Both approaches are reasonable, considering the long-term nature of ELFM and its characteristics as an investment project with uncertain and dynamic cash flows. With regards to stakeholders, the perspective of the landfill operator, a central decision maker operating or coordinating all necessary processes, or the society perspective are adopted. The landfill operator's perspective is particularly important for economic feasibility studies, since they are the one who typically decide whether to realize an ELFM project or not (van der Zee et al., 2004; van Passel et al., 2013; Winterstetter et al., 2015).

The most sophisticated economic assessment approaches from a landfill operator's perspective are provided by van Passel et al. (2013), Danthurebandara et al. (2015a), Winterstetter et al. (2015) and Zhou et al. (2015), even though the majority do not concentrate on the economics of ELFM alone. Zhou et al. (2015) are the only ones focusing primarily on the economic assessment in their case study for a Chinese landfill. They make use of eight cost indicators (e.g., rental or purchase of excavation and hauling equipment, waste processing cost) and nine benefit indicators (e.g., producing residue derived fuels, generating heat or electricity) from which different LFM scenarios are derived for a cost-benefit analysis. In this analysis, amongst others, two alternative options of land use after reclamation are compared, which are to regain land or to recover airspaces for further landfilling. On the other hand, Van Passel et al. (2013) and Danthurebandara et al. (2015a) integrate economic, environmental, and social aspects in their assessment of an ELFM project in Flanders, Belgium. The strength of their approach lies in the comprehensive analysis of a wide range of parameters to identify the performance drivers of profitability. These drivers are comprised of Waste to Energy (WtE) efficiency, electricity price, CO_2 certificates price, investment expenditures for the WtE installation, operational costs of energy production, and ELFM support (e.g. subsidies, certificates). Winterstetter et al. (2015) also assess the ELFM project in Flanders, Belgium. They classify landfills as resource or reserve according to the natural resource classification framework UNFC-2009.

Most studies are centered around locations in Europe, Belgium and consider the use of advanced mining and processing technologies such as ballistic and eddy current separators and air classifiers that have high degree of automation for landfill mining. The landfill mining project introduced by Zhou et al. (2015) takes place in China, where manual sorting is applied since the Chinese requirements on product quality (fine grained fraction as fertilizer) and wages are comparatively low.

In order to integrate landfill aftercare in the assessment, Winterstetter et al. (2015) and Zhou et al. (2015) consider avoidance of landfill aftercare as a benefit at the end of the ELFM project. Danthurebandara et al. (2015a) compare ELFM with a "do nothing scenario", which is landfill closure and aftercare.

Regarding the economic feasibility of LFM projects, Zhou et al. (2015) show that the Chinese project is profitable if certificates for avoided emissions can be obtained according to the clean development mechanism (CDM). Van Passel et al. (2013) conclude that ELFM is interesting for private investors when adequate public support is given, leading to favorable societal outcomes such as greenhouse gas emission reduction and land reclamation. Danthurebandara et al. (2015a) emphasize the ecological benefits of ELFM. While a clear statement on the profitability of ELFM projects is missing, the thermal treatment processes (waste incineration as well as refuse-derived fuels incineration plant) are identified as the one with the highest impact on economics and ecology. Winterstetter et al. (2015) argue that ELFM is not profitable at the moment with realistic chances for profitability in the future.

Landfill operators can choose between landfill closure and aftercare and LFM or ELFM by choosing a specific process alternative from the several alternatives presented and discussed extensively in the literature. While studies have made valuable contributions in defining various elements of economic assessment of (E)LFM projects, they do not capture the varying complexity and processing effort of the technological alternatives. There is thus a lack of knowledge on the design of economically feasible landfill mining processes and its consequences for the exploitation of the resource and energy potential considering the technological complexities involved in the decision-making.

The objective of this paper is to analyze the economic feasibility of alternative landfill mining processes from a landfill operator's perspective. Specifically, the following questions will be examined: (1) Which landfill mining processes are economically advantageous and how do they contribute to the aim of maximizing the utilization of a landfill's resource and energy potential? (2) Under which conditions are specific landfill mining processes economically beneficial compared to landfill closure and aftercare? (3) What are the main drivers of profitability?