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Integrating remediation and resource recovery: On the economic conditions of landfill mining

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ABSTRACT

This article analyzes the economic potential of integrating material separation and resource recovery into a landfill remediation project, and discusses the result and the largest impact factors. The analysis is done using a direct costs/revenues approach and the stochastic uncertainties are handled using Monte Carlo simulation.

Two remediation scenarios are applied to a hypothetical landfill. One scenario includes only remediation, while the second scenario adds resource recovery to the remediation project. Moreover, the second scenario is divided into two cases, case A and B. In case A, the landfill tax needs to be paid for re-deposited material and the landfill holder does not own a combined heat and power plant (CHP), which leads to disposal costs in the form of gate fees. In case B, the landfill tax is waived on the re-deposited material and the landfill holder owns its own CHP.

Results show that the remediation project in the first scenario costs about €23/ton. Adding resource recovery as in case A worsens the result to −€36/ton, while for case B the result improves to −€14/ton. This shows the importance of landfill tax and the access to a CHP. Other important factors for the result are the material composition in the landfill, the efficiency of the separation technology used, and the price of the saleable material.

1. Introduction

Large amounts of potentially valuable materials such as metals, combustibles, and earth construction materials are situated in landfills (cf. Cossu et al., 1995; Obermeier et al., 1997; Quaghebeur et al., 2013; Frändegård et al., 2013b). With a number of worldwide changes currently underway, e.g. increasing competition for natural resources and raw material prices, stronger incentives for resource conservation and recovery are created (cf. Kapur, 2006; Halada et al., 2009), which in turn might make the material situated in landfills gradually more interesting to recover.

Landfill mining has recently been defined by Krook et al. (2012) as a process for extracting minerals or other solid natural resources from waste materials that previously have been disposed of by burying them in the ground. This concept can be seen as an alternative method to traditional remediation (i.e., excavate and move the material without including any processes for material extraction) and can have potential advantages if it turns out to be economically justifiable to implement.

Historically, the focus of landfill mining has mostly been on solving local waste management or environmental issues (cf. Cossu et al., 1996), seeing the landfill as mainly a problem and part of what Johansson et al. (2013) calls the "dump regime". This corresponds for example to remediation of a landfill to avoid leaching or other future problems or extending the lifetime of a landfill by gaining additional airspace (e.g. Spencer, 1990; Dickinson, 1995; Cha et al., 1997; EPA, 1997). There are other studies, however, that have a stronger focus on the materials in the landfill and their recovery and use. Examples of this include Obermeier et al. (1997) and Hull et al. (2005), who see landfill mining as a method to secure a high workload of waste fuel for MSW incinerators or cement industries, and Zanetti and Godio (2006), who analyze recovering foundry sands and iron fractions from an industrial landfill from an economic perspective. In spite of this, the emphasis of landfill mining studies so far has mainly been on the material composition of different landfills and on environmental aspects.

In a recent comprehensive landfill mining literature review, Krook et al. (2012) found only two earlier studies that have their main focus on economic issues (Fisher and Findlay, 1995; van der Zee et al., 2004). Since then, a few more studies have shown economic potential in landfill mining. A case study of a Florida landfill focusing on reclaiming landfill airspace shows prospective

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profit (Jain et al., 2013). Moreover, the Flanders-based Enhanced Landfill Mining (ELFM) project has indicated an economic potential, though relying on the development of innovative waste-to-energy technology and significant governmental support in terms of green energy certificates, tax breaks or the like (Bosmans et al., 2013; van Passel et al., 2013).

Landfilling in Sweden has seen a sharp decline in recent years in favor of energy recovery; less than 1% of municipal solid waste is landfilled while about 50% is used as fuel in combined heat and power plants (SWM, 2010). Sweden has more than 4000 municipal landfills (SEPA, 2008); most are old without the appropriate pollution prevention and control techniques, and in extensive need of remediation. Less than 100 of these are currently operational, and the material that is deposited is mainly inorganic material such as waste incineration ashes, concrete, and insulation material.

These landfills contain materials of interest, combined with potential environmental hazards. According to Frändegård et al. (2013b), at least 450 of Sweden's MSW landfills are currently classified as having high or very high environmental risk, when taking aspects such as the level of contamination and hazardousness, the risk of contamination spreading, and the area's sensitivity and conservation value into account. The owners of the contaminated property/area, municipalities in these cases, are responsible for the remediation (SEPA, 2003). Since many municipalities struggle with constrained finances, it is important for them to investigate ways of reducing costs related to remediation.

Even though recovery of deposited materials and energy resources alone seldom seem to economically justify landfill mining on municipal landfills, previous studies indicate that such a material-focused landfill mining project has the potential to lower the costs of remediation (e.g. Rettenberger, 1995; Prechtai et al., 2008). Given the upcoming need for landfill remediation in Sweden and elsewhere, it is therefore interesting to analyze landfill mining in another context, namely from an integrated approach, where resource recovery (defined as separation and utilization of deposited materials in this study) is added to an already planned remediation project.

The aim of this study is to assess the economic potential of landfill mining for facilitating remediation of municipal landfills and contribute to closing material loops. In doing so, we analyze and compare two remediation scenarios from an economic perspective, one scenario without material separation, and one scenario where material separation is included.

2. Method

To realize the aim we have chosen to construct a hypothetical municipal solid waste landfill, based on the current conditions in Sweden.

Two scenarios are applied to this landfill, firstly a traditional remediation scenario with no material separation, and secondly an integrated remediation and resource recovery scenario including material separation. The reason for including resource recovery in the second scenario is to analyze the potential of how this will alter the project costs and revenues.

In the second scenario, the integrated approach, we set up two cases, A and B, to analyze how different conditions affect the result. Since the hypothetical landfill should be the same in each case, the changed conditions should not be site specific. From a range of possible aspects, such as metal prices, separation technology, or transportation costs, we chose to analyze two previously identified scenario uncertainties related to how the landfill tax is applied and the ownership and capacity of local waste incineration plants (cf. Frändegård et al., 2013b). Both of these factors are interesting to analyze since there are many indications that these will undergo change in the near future. Swedish waste incineration operators are experiencing an increase in overcapacity, which will probably lead to a larger dependence on import and a possible lack of waste supply, and the Swedish landfill tax is currently being revised to be more beneficial to landfill mining projects with regards to remediation (see Section 2.2.1). Case A is based on the current conditions, while case B is based on future potential.

2.1. The landfill and scenarios

The remediation is taking place in Sweden, on a municipal solid waste (MSW) landfill. According to Hogland et al. (2010), 26% of Sweden's landfills have a volume larger than 100,000 m^3 and about 15–20% are considered to be in immediate need of remediation. From a resource recovery point of view, a large and old landfill is believed to have better potential than a smaller, younger one, due to more prospective recyclables, and a larger land area to reclaim (cf. van der Zee et al., 2004). The hypothetical landfill is therefore set at 100,000 m^3. It is common for landfills that previously were situated outside a city core to eventually become part of the main urban areas, due to urban expansion (Johansson et al., 2012). The landfill in this study is located in an expansive area in a medium-sized city (100,000 people) and is owned by a municipality.

The landfill has an average depth of 10 meters and using a density of 1 ton per m^3 (e.g. Hull et al., 2005) gives a landfill area of 10,000 m^2 to be remediated. The landfill closed down 30 years ago and is no longer in use, however, in its current condition it is deemed a potential environmental hazard due to lack of appropriate cover and lining systems. The only nearby open landfill is a waste incineration ash landfill, which does not have the capacity to handle this amount of material and does not want to blend its homogenous ash residue with the heterogeneous residues that the remediation project will produce. Since no appropriate landfill site can handle this amount of material, the material in the closed down landfill needs to be excavated and re-deposited while the landfill site is rebuilt according to Swedish standards.

The material composition of the hypothetical landfill is set to a typical composition for municipal solid waste landfills, based on a literature review of previous landfill mining pilot studies from the industrialized part of the world, Table 1 (Frändegård et al., 2013a). This typical composition is divided in ten deposited material types: *soil-type material*; *paper*; *plastic*; *wood*; *textiles*; *inert materials*;

Table 1
Shows estimated material composition (in weight%) of a typical MSW landfill, presented as mean values and absolute standard deviations.

Material type	Mean (%)	St. dev. (%)
Soil-type material	56.3	14.2[a]
Paper	7.9	6.1[a]
Plastic	8.1	5.4[a]
Wood	7.4	4.3[a]
Textiles	3.3	1.3[a]
Inert materials	9.7	10.8[a]
Organic waste	2.7	2.0[a]
Ferrous metals	3.6	4.1[a,b]
Non-ferrous metals	0.8	0.7[a,b]
Hazardous	0.5	0.1[a]

[a] Based on the following landfill mining studies: Cossu et al. (1995), Hogland et al. (1995, 2004), Hull et al. (2005), Krogmann and Qu (1997), Rettenberger (1995), Richard et al. (1996), Stessel and Murphy (1991) and Sormunen et al. (2008).

[b] For ferrous and non-ferrous metals, a special case had to be made, since only a few of the landfill mining cases made a distinction between these two material types; a majority of the cases had just one aggregated material type called "metals." The mean values for ferrous and non-ferrous metals are therefore based on the fact that the accumulated consumption of metals in Sweden over time is around 80% ferrous and 20% non-ferrous, so the mean values for these two material types were calculated proportionally (SEPA, 1996).