THE ECONOMIC AND ENVIRONMENTAL PERFORMANCE OF A LANDFILL MINING PROJECT FROM THE VIEWPOINT OF AN INDUSTRIAL LANDFILL OWNER

John Laurence ESGUERRA[1,2], Niclas SVENSSON[1], Joakim KROOK[1], Steven VAN PASSEL[2,3], Karel VAN ACKER[4]

[1]Department of Management and Engineering, Environmental Technology and Management, Linköping University, SE-581 83 Linköping, Sweden
[2]Department of Engineering Management, Faculty of Applied Economics, University of Antwerp, BE-2000 Antwerp, Belgium
[3]Center for Environmental Sciences, Hasselt University, BE-3500 Hasselt, Belgium
[4]Department of Materials Engineering, KU Leuven, BE-3001 Leuven, Belgium

john.esguerra@liu.se, niclas.svensson@liu.se, joakim.krook@liu.se, steven.vanpassel@uantwerpen.be, karel.vanacker@kuleuven.be

Introduction

There is an increasing attention in the EU towards transitioning to a circular economy as stimulated by the adoption of circular economy package, which includes revised legislative proposals on waste management and recycling[1]. From dumping to resource recovery regime, enhanced landfill mining (ELFM) is sought to be a better approach to landfill management[2–4]. Through ELFM, landfills becomes a secondary source of both material (Waste-to-Material, WtM) and energy (Waste-to-Energy, WtE) with the use of innovative technologies[3,4].

Several studies explored the environmental and/or economic aspects of ELFM at different scopes and objectives. Some covers the entire process value chain while others additionally focused on comparing technological choices for WtE [5–7], WtM[8,9], and even secondary waste valorisation[10]. Furthermore, for the economic assessment, regulation-related costs and benefits like landfill tax, gate fee, and green certificates[5,11,12] are also accounted. Regarding the identification of economic hotspots, many of these studies concluded similar processes to be important. However, most of these studies were based on either hypothetical cases, or real cases but with small-scale excavation and separation using less sophisticated set-up, which may less likely be used for large-scale processing. Hence, more uncertainty is expected from upscaling that is typically done in feasibility studies.

The aim of this study is to analyse the main contributing processes and factors that influence environmental and economic performance of landfill mining, which is based on a real case of excavation and subsequent separation in an existing stationary facility, considering the landfill owners' viewpoint. Specifically, the influence of the prevailing system condition is investigated as defined by the current legislation and the market situation.

Method

This study analyse a shredder landfill owned by a large Swedish recycling company, Stena Recycling AB (Stena). The landfill contains about 650 000 tons of shredder-waste, mainly from old cars. The main driver of Stena to do landfill mining is to regain landfill space considering that it has only 10-year capacity remaining. Moreover, with restrictions of constructing new landfill sites, the demand for landfill space is expected to be higher and so with its value. In addition, another motivation is metal recovery, which is Stena's long-standing core business. As a step for landfill mining realization, a feasibility study was performed involving 260 tons of landfill waste. This case is interesting compared to most of the previous studies as it includes actual feeding of excavated waste in an existing stationary plant with relatively sophisticated separation scheme (**Figure 1**). The sub-unit processes boxed with broken lines are performed more than once.

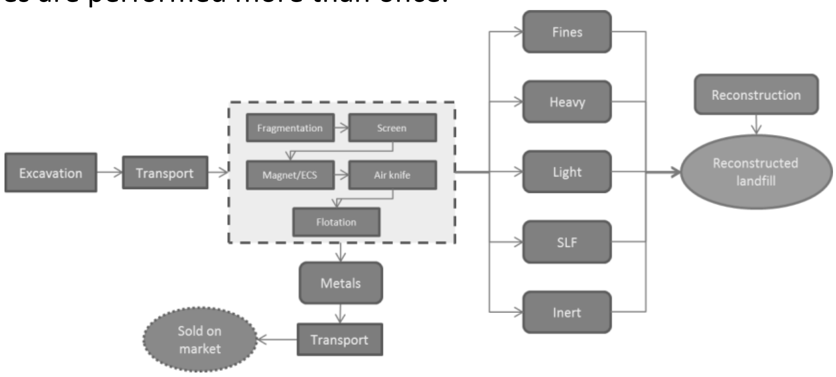

Figure 1. Process flowchart of Stena's landfill mining case as defined by the prevailing system condition wherein all fractions, except for metals, are bound for re-landfilling.

Several fractions were generated from the defined separation technology set-up. Fines is composed of material <20 mm and is separated by screener. Metals (ferrous and non-ferrous) are sorted using magnets, eddy current separator (ECS), and flotation processes. Both fines and metal are separated on several points in the process. Shredder light fraction (SLF) contains lightweight materials separated by suction of the air classifier. Heavy and light fractions consist a mix of residual materials separated by flotation, mostly containing rubber and plastic. Finally, inert materials consist mainly of stones and glass. With the prevailing system condition, all fractions, except for metals, go to re-landfilling on the same site for this feasibility study. This is acknowledging the high calorific content of SLF, heavy, and light fractions but also containing chlorine and heavy metal that exceeds the regulatory limit for incineration.

For a full-scale landfill mining project, scenarios were developed by changing the prevailing system condition to determine opportunities for outlet of these fractions while considering the environmental and economic performance (**Table 1**). Reference scenarios include do nothing (no processes) and remediation (relocation to other landfill). Landfill tax refers to the regulation-based payment required for re-landfilling of waste. Classification of landfill mining as a remediation process (lifting of re-landfilling tax), is currently under review in Sweden[13]. Lastly, secondary waste management refers to redirection of SLF, heavy, and light fractions to incineration instead of re-landfilling through mixing with other combustibles. In all scenarios, fines and inert fractions remain to be re-landfilled. With the aim of maximizing the landfill space to be regained, an external landfill site is considered for re-landfilling.

Table 1. Exploratory scenarios generated by varying the system conditions.

Scenario	Secondary Waste Management for SLF, heavy, light fractions		Reference Scenario		Re-landfill Tax	
	Re-landfilling	Incineration	Do Nothing	Remediation	With	Without
1	✓	-	✓	-	-	✓
2	✓	-	✓	-	✓	-
3	✓	-	-	✓	-	✓
4	-	✓	✓	-	-	✓
5	-	✓	✓	-	✓	-
6	-	✓	-	✓	-	✓

Both the environmental and economic assessments were based on a life cycle perspective. Stena provided the data on material flows and the corresponding economic details. The environmental inventory and subsequent impact assessment was done using Ecoinvent 3.0 and ReCiPe 2016, respectively. Parametric uncertainty analysis was also performed through Monte Carlo simulation with 30 000 runs. This is deemed important to account the uncertainties for extrapolation of the feasibility project to full-scale.

Results and Discussion

Economic Assessment

In **Figure 2**, the costs and revenues of all scenarios (S1-S6) are shown detailing process-specific contributions. Generally, the major revenue comes from material sales ranging from 57 to 91% of the total revenues, while the major cost comes from material separation ranging from 49 to 94% of the total costs. Specifically, material sales refers to metal sales such as iron, copper, aluminium, and stainless steel. Metals are the highest valued secondary recovered material. In this study, significantly higher metals content were recovered as expected for a shredder landfill, which agrees with other studies on metal-rich industrial landfills[14,15]. On the other hand, several studies noted WtE technology as typical main costs contributor while WtM comes second[5,7–9,12]. But in this study, WtE is external to the system boundary considering Stena's viewpoint. WtE is accounted as a gate fee instead of the capital and operational costs of owning a WtE plant.

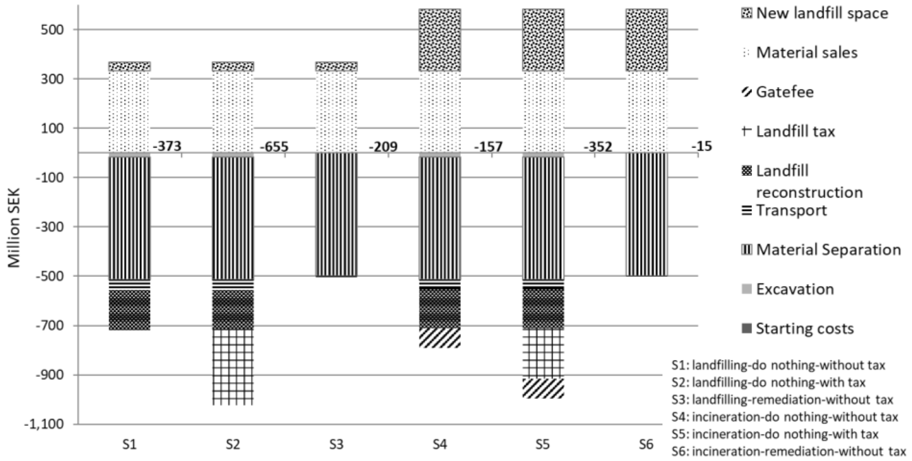

Figure 2. Process-specific costs and revenues (million SEK) for all scenarios (S1-S6), given as positive and negative values , respectively. The net results are presented in bold.

In **Figure 3**, the net economic results for S1-S6 are shown as cumulative probability distribution through Monte Carlo simulation. All scenarios are net negative with mean values ranging from -655 to -15 MSEK with only 0 to 10% of probability distribution values as net positive. S6 is approaching net profitability with about 50% of its probability distribution values as net positive.

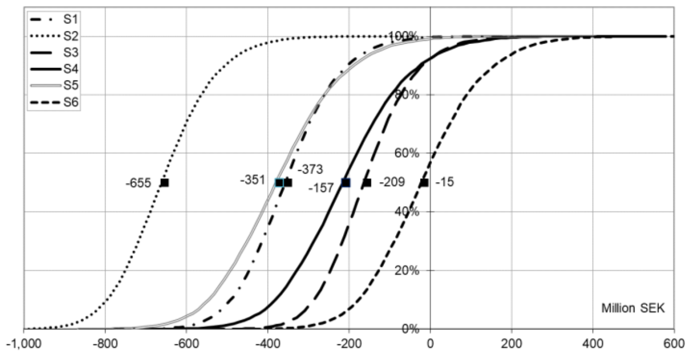

Figure 3. Cumulative probability distribution plot of the net economic results (million SEK) for all scenarios (S1-S6), generated through Monte Carlo simulation with 30 000 runs.

Using S1 as reference, the effect of the system conditions to the net result were derived; decrease by 70% with landfill tax (S2), increase by 54% with remediation (S3), increase by 12% with incineration (S4), decrease by 26% with both landfill tax and incineration (S5), and increase by 66% with both remediation and incineration (S6). Remediation accounts for higher cost than do-nothing as an alternative to landfill mining, while incineration accounts for lower cost (gate fee 400 SEK/ton) than re-landfilling (landfill tax 500 SEK/ton plus handling cost 300 SEK/ton) as secondary waste handling option. Additionally, landfill tax is lifted for remediation while more landfill space is recovered with incineration, which reduces the costs and increases the revenues, respectively.

Environmental Assessment

In **Figure 4**, results are shown for all scenarios, detailing the processes contributions for the five impact categories such as global warming (CO_2 eq.), acidification (SO_2 eq.), eutrophication (P eq.), ozone formation (NO_x eq.), and ozone depletion (CFC-11 eq.). As expected, several scenarios gave same results (S1-S2 and S4-S5) due to non-environmental scenario differences that is landfill tax. All scenarios resulted to net avoided emissions across all the impact categories. It is mainly accounted to the high amount of recovered metals, wherein avoided emission from primary resource substitution is considered. Previous studies have not demonstrated the same result dealing with landfill site for municipal solid waste and/or mixed waste with expected lower metal resource[8,12]. On the other hand, the main added emissions are accounted to transport to external re-landfilling (up to 100 km) and incineration.

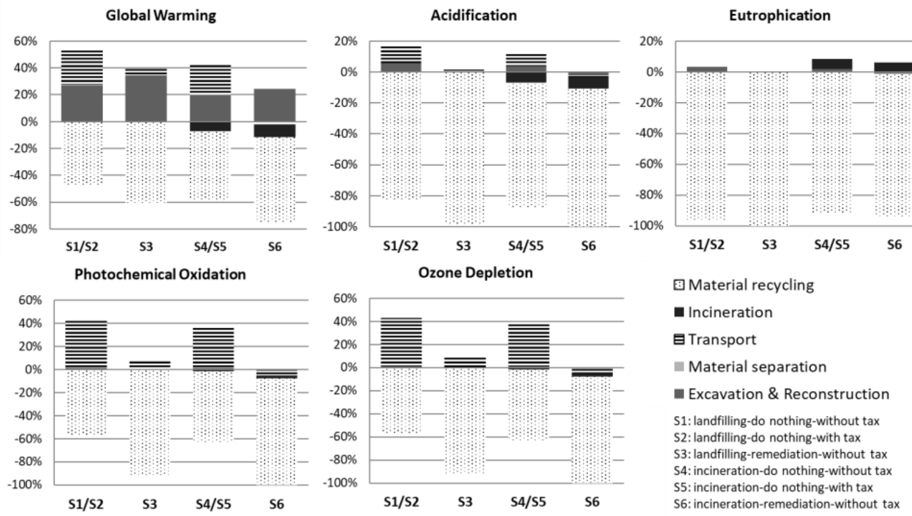

Figure 4. Process contributions (%) in five environmental impact categories for all scenarios (S1-S6). Avoided and added emissions are shown as negative and positive values, respectively.

Using S1/S2 as reference, the effect of the system conditions to the net global warming impact, for exemplification, were derived; decrease by 197% with remediation (S3), increase by 420% with incineration (S4 and S5), and increase by 223% with both remediation and incineration (S6). Despite the avoided emissions accounted to heat and electricity recovery, incineration worsens the net environmental results. The Swedish energy system have better environmental performance than the substituted waste incineration in this case study.

Conclusion

This study highlighted the importance of system condition that is mainly regulation-related, affecting the choice of reference scenario, implementation of landfill tax, and setting of waste quality threshold dictating the marketability of waste fractions. For further research, an integrated approach is necessary to weigh the economic benefit and environmental burden by incineration. In addition, it interesting to account for second-order parametric relations, accounting interdependencies, in identifying the critical economic and environmental performance factors of ELFM.

Acknowledgement

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