Proceedings of the
4th International Symposium on
Enhanced Landfill Mining

5 - 6 February 2018
Mechelen, Belgium

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

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Introduction

The EU Commission's circular economy strategy pushes for a higher recycling rate and a more long-term waste management practice.[1] Enhanced Landfill Mining (ELFM) can contribute to this agenda as a better landfill management option, by shifting the landfill paradigm from dumping or as end-storage of waste to resource recovery or as temporary storage of resources.[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 having different scopes and objectives. Some cover the entire process value chain while others additionally focused on comparing technological choices for WtE,[5–7] WtM,[8,9] and even ELFM waste valorisation.[10] Furthermore, for the economic assessment, regulation-related costs and benefits as landfill taxes, gate fees and green certificates[5,11,12] are also accounted for. 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 non-sophisticated set-ups, which are not likely to be used for large-scale processing. Hence, more uncertainty is expected from the lack of actual ELFM demonstration projects.

The aim of this study is to analyse the main contributing factors that influence environmental and economic performance of ELFM, considering the landfill owner's

viewpoint. The study is based on a real case of excavation and subsequent separation in an existing stationary facility. Specifically, the influence of the prevailing system conditions is investigated as defined by the current legislation and the market situation.

Method

This study analyses a landfill owned by a large Swedish recycling company, Stena Recycling AB (Stena). The landfill contains about 650,000 tonnes of shredder-waste, mainly from old cars. The main driver for 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 is its market value. In addition, another motivation is metal recovery, which is Stena's long-standing core business. As a step for landfill mining realisation, a feasibility study was performed involving 260 tonnes 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 a relatively sophisticated separation scheme (Figure 1). The sub-unit processes boxed with broken lines are performed more than once.
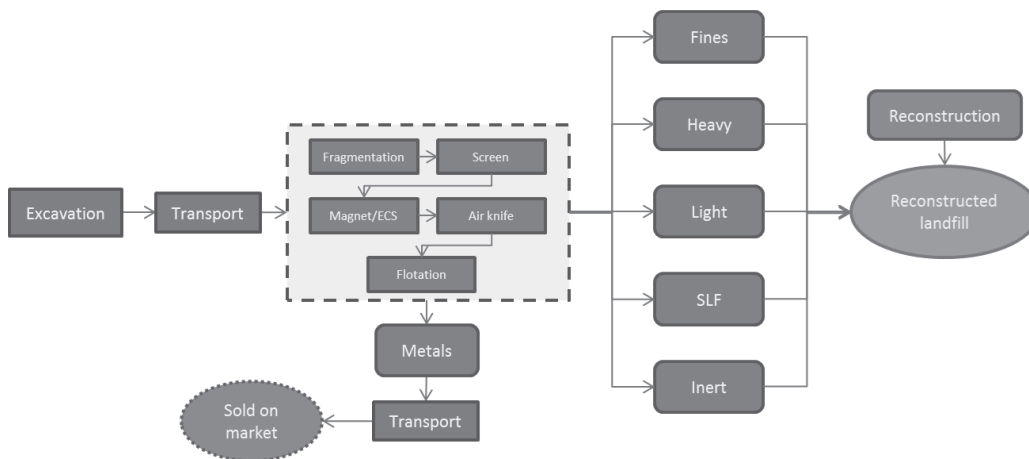

Figure 1: Process flowchart of Stena's landfill mining case as defined by the prevailing system condition wherein all fractions, except for metals, are bound for re-landfilling.

Several fractions were generated from the defined separation technology set-up. Fines (material < 20 mm) are separated by a screener. Metals (ferrous and non-ferrous) are sorted using magnets, eddy current separators (ECS), and flotation processes. Both fines and metals are separated in 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. SLF, heavy, and light fractions have a high calorific value, which is an advantage for incineration. However, they also contain chlorine and heavy metals that exceed the regulatory limits, resulting in these fractions being re-landfilled.

For a full-scale landfill mining project, scenarios were developed by changing the prevailing system conditions 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 another 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 through mixing with other combustibles instead of re-landfilling. In all scenarios, fines and inert fractions are re-landfilled. With the aim of maximising 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 of SLF, heavy and 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 important to account for the uncertainties when extrapolation is performed from the small-scale feasibility project to the actual full-scale processing.

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 refer to metal sales such as iron, copper, aluminium, and stainless steel. Metals are the highest value material recovered. As expected in this study, significantly higher metal contents were recovered when comparing to performing ELFM to a municipal solid waste (MSW) landfill, which agrees with other studies on metal-rich industrial landfills.[14,15] On the other hand, several studies noted WtE as typical main costs contributor while WtM is second.[5,7–9,12]
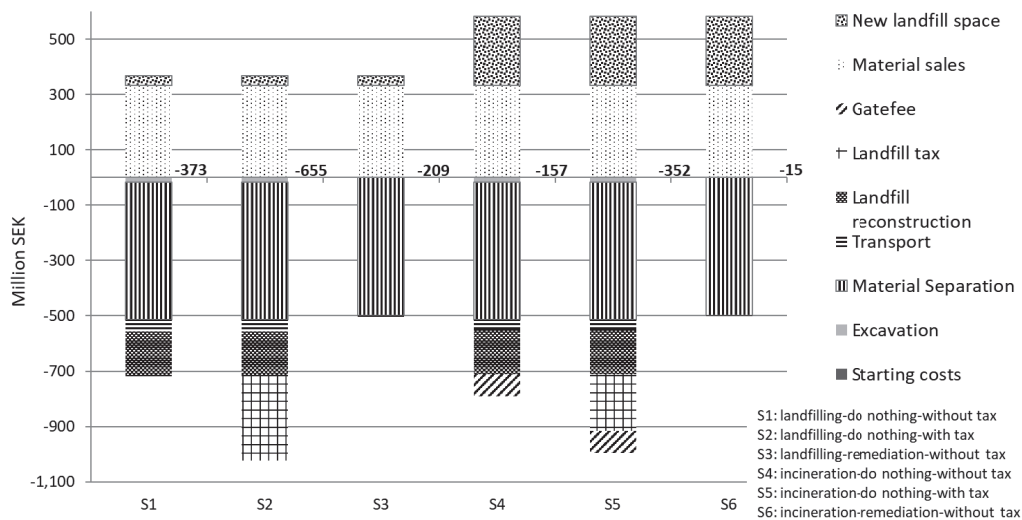

Figure 2: Process-specific costs and revenues (million SEK) for all scenarios (S1-S6), given as positive and negative values, respectively. The net results are presented in bold.

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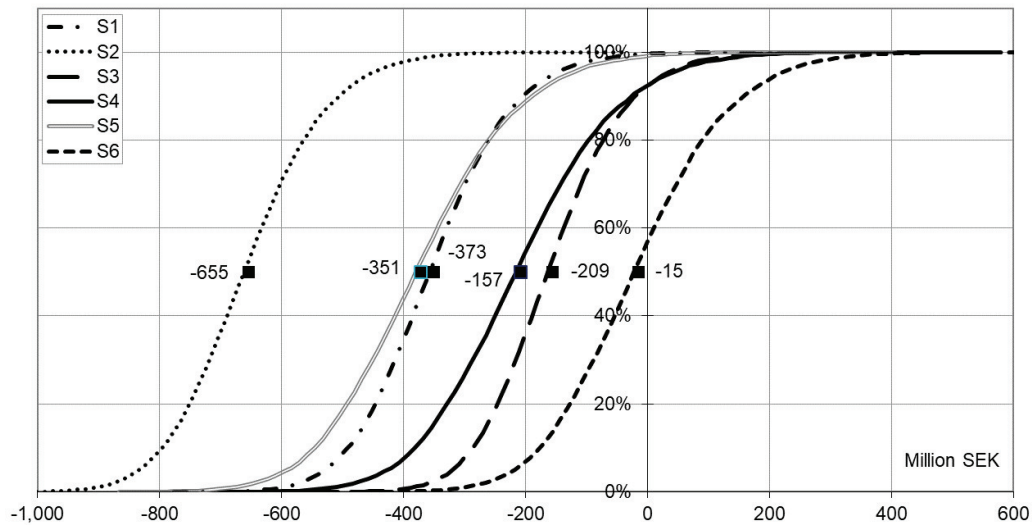
Figure 3: Cumulative probability distribution plot of the net economic results (million SEK) for all scenarios (S1-S6), generated through Monte Carlo simulation with 30,000 runs

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/tonne) than re-landfilling (landfill tax 500 SEK/tonne 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 contribution of processes 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 the same results (S1-S2 and S4-S5) due to having only economic differences (with or without landfill tax). All scenarios resulted in net avoided emissions across all the impact categories. This 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.
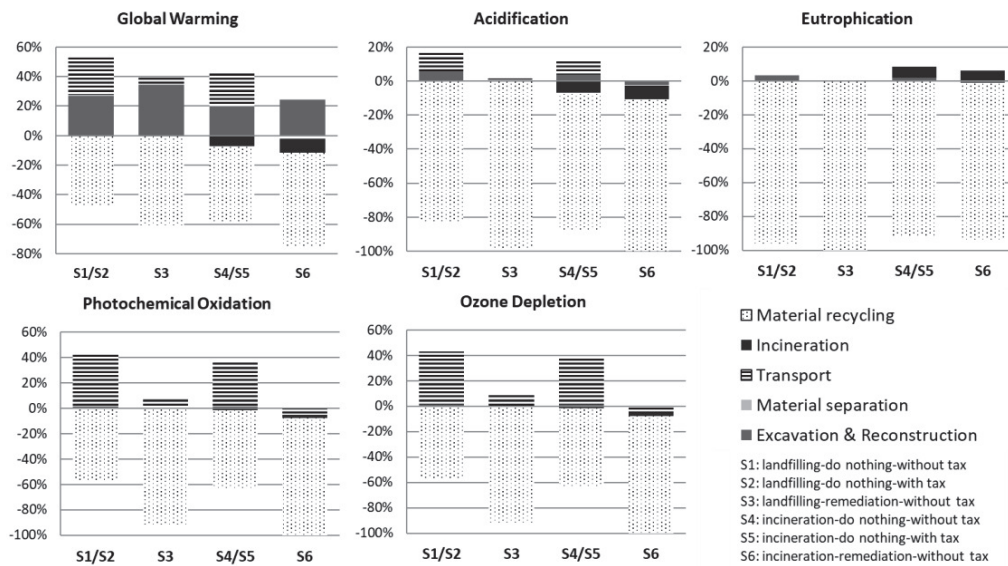
Figure 4: Process contributions (%) in five environmental impact categories for all scenarios (S1-S6). Avoided and added emissions are shown as negative and positive values, respectively.

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 has a better environmental performance than the substituted waste incineration in this case study.

Conclusion

This study highlighted the significance of system conditions on the profitability of ELFM. Defined by current legislation and the resulting market situation (landfill tax, default reference scenario, and waste quality limit), this study recognises and supports the necessary policy-making decisions. For further research, an integrated approach can be developed to weigh the economic benefit and environmental burden of incineration. In addition, it is interesting to perform a multi-factor sensitivity analysis acknowledging that in reality, adjustments of multiple parameters can contribute to a better understanding and further realisation of ELFM.

Acknowledgement

References

1. European Commission, *Circular Economy Strategy - Environment - European Commission*, 2017. Available at: http://ec.europa.eu/environment/circular-economy/index_en.htm. (Accessed: 1st November 2017)
2. N. Johansson, J. Krook and M. Eklund, "Transforming dumps into gold mines. Experiences from Swedish case studies", *Environ Innov Soc Transitions,* **5** 33-48 (2012).
3. J. Krook, N. Svensson and M. Eklund, "Landfill mining: A critical review of two decades of research", *Waste Manage,* **32** 513-520 (2012).
4. P. T. Jones, D. Geysen, Y. Tielemans, S. Van Passel, Y. Pontikes, B. Blanpain, M. Quaghebeur and N. Hoekstra, "Enhanced Landfill Mining in view of multiple resource recovery: a critical review", *J Clean Prod,* **55** 45-55 (2013).
5. S. Van Passel, M. Dubois, J. Eyckmans, S. Gheldere, F. Ang, P. T. Jones and K. Van Acker, "The economics of enhanced landfill mining: Private and societal performance drivers", *J Clean Prod,* **55** 92-102 (2013).
6. M. Danthurebandara, S. Van Passel, I. Vanderreydt and K. Van Acker, "Environmental and economic performance of plasma gasification in Enhanced Landfill Mining", *Waste Manage,* **45** 458-467 (2015).
7. A. Winterstetter, D. Laner, H. Rechberger and J. Fellner, "Framework for the evaluation of anthropogenic resources: A landfill mining case study - Resource or reserve?", *Resour Conserv Recy,* **96** 19-30 (2015).
8. P. Frändegård, J. Krook and N. Svensson, "Integrating remediation and resource recovery: On the economic conditions of landfill mining", *Waste Manage*, **42** 137-147 (2015).
9. K. Kieckhäfer, A. Breitenstein and T. S. Spengler, "Material flow-based economic assessment of landfill mining processes", *Waste Manage,* **60** 748-764 (2017).
10. M. Danthurebandara, S. Van Passel, L. Machiels and K. Van Acker, "Valorization of thermal treatment residues in Enhanced Landfill Mining: Environmental and economic evaluation", *J Clean Prod,* **99** 275-285 (2015).
11. P. Frändegård, J. Krook, N. Svensson and M. Eklund, "A novel approach for environmental evaluation of landfill mining", *J Clean Prod,* **55** 24-34 (2013).
12. M. Danthurebandara, S. Van Passel, I. Vanderreydt and K. Van Acker, "Assessment of environmental and economic feasibility of Enhanced Landfill Mining", *Waste Manage,* **45** 434-447 (2015).
13. SEPA (Swedish Environmental Protection Agency), *Översyn av deponiskatten [Revision of the landfill tax]*, 2013.
14. M. Zanetti and A. Godio, "Recovery of foundry sands and iron fractions from an industrial waste landfill", *Conserv Recycling,* **48** 396-411 (2006).
15. T. P. Wagner and T. Raymond, "Landfill mining: Case study of a successful metals recovery project", *Waste Manage,* **45** 448-457 (2015).