Is Enhanced Landfill Mining Profitable?

John Laurence Esguerra, Linköping University and University of Antwerp
Joakim Krook, Linköping University
Niclas Svensson, Linköping University
Steven Van Passel, University of Antwerp and Hasselt University

CONTACT

Name: John Laurence Esguerra
Organization: Department of Management and Engineering, Linköping University, Sweden and Faculty of Applied Economics, University of Antwerp, Belgium
Postal address: IEI Campus Valla, 581 83, Linköping, Sweden
Telephone: +46 13 28 4719
Facsimile: +46 13 14 9403
Email: john.esguerra@liu.se

EXECUTIVE SUMMARY

Landfills are increasingly considered as technospheric stocks of resources that could potentially be recovered within the concept of enhanced landfill mining (ELFM). At present, most ELFM projects are in laboratory- or pilot-scale, remaining as proofs of concept. Economic feasibility is one of the primary considerations that must be satisfied prior to its full-scale realization. Several economic assessments were conducted recently, but there is no systematic synthesis of these studies. The aim of this review is to compile empirical findings of ELFM in different settings in terms of main economic results and critical economic performance drivers, and analyze them with respect to the employed methods, highlighting points for improvement for future economic assessments. With pre-defined exclusion criteria, 15 studies were selected. Empirical findings showed that more than half of the studies are not profitable. Despite the differences in case study specifications, the identified main economic drivers for costs are separation and sorting, thermal treatment and transportation, while for benefits are material sales, recovered land and energy sales. There are few potentially profitable cases, which depend on varying system conditions by increasing market prices and implementing favorable new regulations. Analysis of methods revealed that costs and benefits are accounted at different levels of aggregation, scope and scale—from process to sub-process level, from private to societal economics, and from laboratory to pilot-scale, respectively. As most studies are based on pilot-scale, if not purely conceptual, data estimation mainly depends on extrapolation to full-scale projects or on direct adoption of secondary data from adjacent knowledge fields. In spite of such procedures exhibiting large uncertainties on the model, scenario and parameter levels, less than half of the studies employed sensitivity and uncertainty analyses. Therefore, their results can be considered to have a weak reliability for actual project implementation. In essence, the methods review displays a need for developing systematic frameworks for such early-stage assessment, capturing both stochastic and epistemic uncertainties. Process and system upscaling with exploratory scenario development, and participatory data collection in uncertainty ranges are some of the recommended approaches to generate transparent results with certain level of confidence. In this way, future economic assessments of emerging concepts such as ELFM can veer away from deterministic and highly uncertain profitability statements. Instead, it is recommended to be used as a learning tool, providing results that are more reliable for decision-support and facilitating identification of promising paths of development and key areas for further research.

INTRODUCTION

In the broader scope of circular economy, landfills are considered as technospheric stocks of resources and its subsequent recovery is known as landfill mining (LFM) (Burlakovs et al., 2017; Johansson et al., 2012; Jones et al., 2013; Krook & Baas, 2013). From traditional LFM to the current concept of enhanced landfill mining (ELFM), it aims to utilize innovative concepts and technologies to recover both materials (waste-to-materials, WtM) and energy (waste-to-energy, WtE) in an integrated manner (Jones et al., 2013). Such technologies are expected to maximize resource recovery by improving and extending the process chain including site exploration, excavation, separation and sorting, thermal treatment, and other valorization processes. Furthermore, ELFM project motivation has been suggested to extended towards revitalization of ecosystem services considering a wider sustainability perspective (Burlakovs et al., 2017).

At present, ELFM remains in laboratory-scale to pilot-scale level (Johansson et al., 2012). To bring ELFM to a full-scale level, several challenges have to be addressed that are typical for innovative concepts and technologies in general. One of these challenges is to provide sound economic feasibility and viability to attract stakeholder support (Johansson et al., 2012; Van Der Zee et al., 2004). Several studies on economic assessments of ELFM were done in recent years with varying goals, scopes, and case study specifications. But there is no systematic synthesis of this body of knowledge yet. Moreover, there is also a lack of standard economic assessment methods for anthropogenic resource recovery at present. ELFM, remaining as a proof of concept, lacks practical and real-life implementation. Hence, it is also of interest to analyze the employed methods in these studies dealing with innovative concepts and technologies that have inherently large uncertainties.

This review of previous economic assessments of ELFM aims to compile insights about empirical results with respect to the employed methods. By acknowledging that ELFM is an emerging concept, key empirical and method challenges for early assessments could be highlighted and reflected upon for better knowledge support and for further process development in this field. This review serves as a basis for judging the usefulness of the results for a more practical industrial use, as in a full-scale ELFM project implementation. In addition, it emphasizes the important aspects for developing a refined method for economic assessments of ELFM.

METHOD

The method is divided into two sections such as literature search and selection procedure, and subsequent review approach for the selected literature. The scientific databases used were Scopus (1960-present) and Web of Science (1975-present) with no restriction on the date of publication. With pre-defined exclusion, such as (i) conference or journal articles, (ii) written in English, (iii) accounting full ELFM value chain, and (iv) quantitative assessment, 15 studies were selected (Damigos et al., 2016; Danthurebandara et al., 2015a, 2015b; Frändegård et al., 2015; Hermann et al., 2016; Kieckhäfer et al., 2017; Rosendal, 2015; Van Passel et al., 2013; Van Vossen & Prent, 2011; Wagner & Raymond, 2015; Winterstetter et al., 2015; Wolfsberger et al., 2015; Zanetti & Godio, 2006; Zhou et al., 2015). The subsequent review approach is retrospective, which starts from the analysis of empirical aspects that includes the synthesis of previous case studies and results, followed by the analysis of employed methods. In this way, it highlighted the validity and usefulness of the former with respect to the latter. Recommendations for an improved economic assessment of ELFM based on the discussions are then enumerated.

RESULTS AND DISCUSSION

Empirical Findings

Only few of the selected studies have concluded that ELFM is profitable (n=3) and most are not profitable (n=7). Converting the results per ton of excavated waste, profit ranges from +3 to +49 € while deficit ranges from -3 to -91 €. A significant number of studies (n=5) concluded potentially profitable results, which ranges from a deficit of -91 € to a profit of +33 €. In some studies (n=2), actual values were not stated explicitly which may be due to company disclosure agreement. At the least, net profitability that is either (+) profitable or (-) not profitable could be inferred.

It should be emphasized that the compiled results are case study-specific, which corresponds to differences in site-specific conditions and project specifications. However, irrespective of these differences, several stated cost and benefit/revenue items are frequently reoccurring which are regarded as the main economic performance drivers. To show the significance of these cost and benefit/revenue items, its frequency of reoccurrence was quantified as shown in **Figure 1**. For the main cost items, separation and sorting process is the most frequently mentioned (n=10), followed by thermal treatment (n=8) and transportation (n=8), secondary waste disposal (n=7), and excavation (including exploration) (n=6). To exemplify the differences in case studies, not all of the selected studies included thermal treatment (n=4) that accounts as the major cost item for several of those studies in which it is included (n=11). For the main benefit/revenue items, material sales is the most frequently mentioned (n=12) followed by energy sales (n=7), value of recovered land (n=7), value of landfill voidspace (n=4), ELFM support (investment subsidies, carbon emission trading, etc., n=3), and avoided aftercare (n=1). It is notable that the direct benefits are the main drivers compared to the indirect ones (avoided aftercare). For the former, apart from the typical project motivation that is the recovery of resources such as materials and energy, the value of the land appeared to be as important.

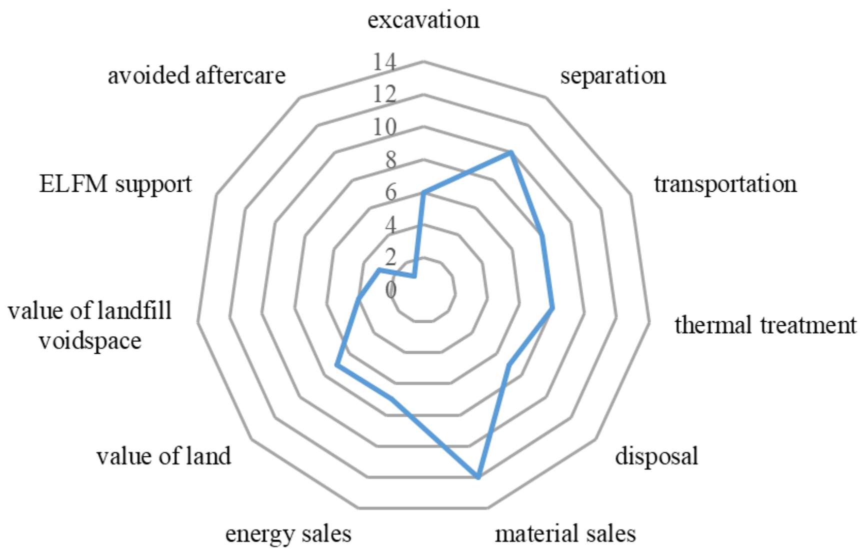

Figure 1. The economic performance drivers of enhanced landfill mining in terms of main costs and benefits/revenues as frequently mentioned in selected studies (n=15).

Further analysis of the not profitable studies showed that additional costs do not guarantee compensation by the expected revenues. For example, an increase in costs by using sophisticated separation and sorting processes results to an increase in quantity and quality of recovered materials. However, based on the current market for materials, only non-ferrous and ferrous metals are highly valued fractions while RDF, glass, aggregates are of far lower value, or the market does not exist at all. These fractions could even entail costs for disposal including gate fees, re-landfilling tax, and transport. The same is true for the thermal treatment costs, although generating electricity but the sales is not enough to compensate the costs. As in potentially profitable cases, the net profitability of an ELFM project could mainly be driven by system-related variations such as accounting of longer aftercare period and different forms of ELFM support such as exemption for re-landfilling tax, investment subsidies, and inclusion of environmental (i.e. carbon emission trading scheme) and societal benefits (i.e. direct employment, minimization of contamination, etc.).

Methods Analysis

The lack of standard method for economic assessment of anthropogenic sources such as landfills, leads to significant variations of employed methods in the selected studies. In this paper, the methods are analyzed based on modeling, scenario and parameter aspects in which uncertainties and variability of assessment could be highlighted (Clavreul et al., 2012; Huijbregts et al., 2003).

In the modeling aspect, the economic scope varied in terms of the applied perspective, whether private or societal hence accounting different cost and benefit/revenue items (**Figure 2**). A broader sustainability consideration corresponds to the extension from private to societal perspective, which also implies consequent complexity of valuation (Burlakovs et al., 2017). Most of the studies were assessed based on private perspective (n=11) while the rest (n=4) are based on societal perspective. It signifies that most of the studies were performed considering the view of landfill owner and/or prospective landfill mining investor. Furthermore, in the modeling aspect, the cost and benefit/revenue items varied in terms of parameter aggregation. It can be as specific as in parameter-level like thermal treatment efficiency alone, or as general as in process-level like the entire thermal treatment process, which includes aggregated thermal efficiency, investment costs and operation costs, among others. Although it is acknowledged that it depends on disclosure agreement, at least transparency on mass and energy flows, in which economic flows are dependent, must be stated at an allowable level of aggregation to avoid "black boxing" of process data.

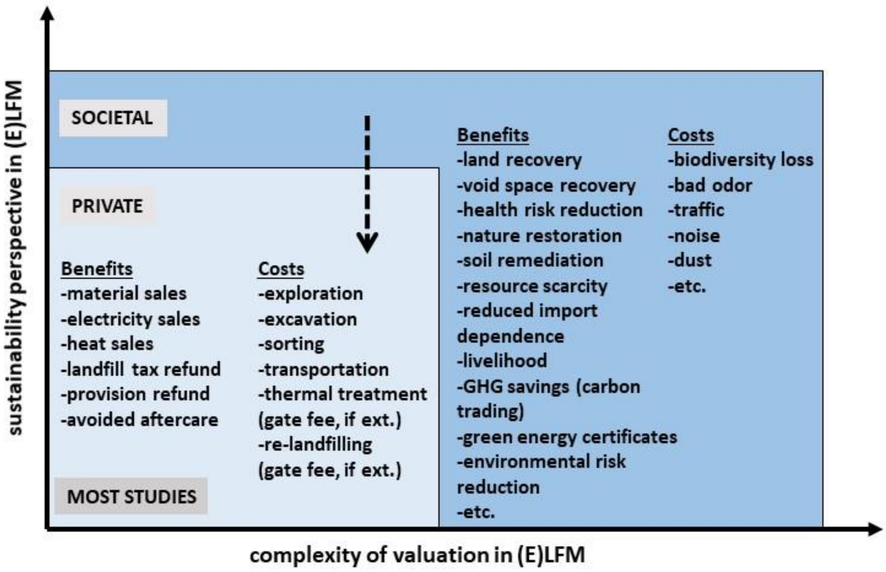

Figure 2. The economic perspectives applied in selected ELFM assessment illustrating direct relationship of wider sustainability paradigm and complexity of valuation of the corresponding costs and benefits/revenues (derived from Burlakovs et al. 2017).

In the scenario aspect, different goal and scope of the selected studies were reflected with variation in terms of project specification including different technological alternatives (for WtE (n=3), WtM (n=2), and even for secondary waste valorisation (n=1)) and organizational structure (whether internal or external WtE (n=3), WtM (n=3) and disposal of aggregates (n=2)). Moreover, system-related variations were also explored with inclusion/exclusion of landfill tax, gate fee, and green certificates (n=3). For a clearer context regarding the avoided costs, a proper reference scenario should be stated. However, only less than half of the studies explicitly mentioned such choices including do nothing (n=6), aftercare alone (n=7), and both closure and aftercare (n=1). As most of the studies depend on

case studies, variation of site-specific conditions were seldom explored including waste composition and landfill height and depth, among others. This limits the applicability of results of the selected studies when dealing with completely different landfill sites.
In the parameter aspect, acknowledging that ELFM is still in early stage of development, the collected data is based on laboratory-scale to pilot-scale level, if not hypothetical. Hence, most of the studies are ex-ante or based on forecast rather than actual results (n=13), and only few (n=2) are ex-post. Ex-ante assessments face challenges in parameter-level including lack of primary data, setting of best estimates, and upscaling (Caduff et al., 2011; Hellweg & Milà i Canals, 2014). As a result, data estimation were performed by extrapolating to full-scale projects or by directly adopting secondary data from adjacent knowledge fields or related studies. This approach is inevitable for ex-ante assessment, however transparent communication of assumptions and data harmonization is seldom stated. With expected large uncertainties not just in parameter aspect, but also in model and scenario aspects, less than half of the studies employed sensitivity and uncertainty analyses. Therefore, their results can be considered to have a weak reliability.

Recommendations

Several practical recommendations for improved economic assessment of ELFM could be emphasized based on this review. Transparent description of the economic and technological scope technological should be provided as well as the corresponding material and energy flows, even at different level of aggregation to resolve disclosure reasoning. Also, the type of economic assessment approach such as ex-ante or ex-post should be explicitly stated. In the case of ex-ante assessment, process and system upscaling should be performed and clearly stated, to harmonize the scale of each of the value chain processes. As an emerging concept, exploratory scenario development should be done, allowing participatory data collection and realistic modelling with various stakeholders, as there is no single ELFM expert. Lastly, the inherent uncertainties in the aspect of model, scenario, and parameter have to be systematically identified and the methodology of doing so should be explained.

CONCLUSION

ELFM remains as an emerging concept with lack of real-life, full-scale project implementation. At this stage, economic assessments were performed in recent studies which majority concluded that it is not profitable. However, analysis of the employed methods reveal weak reliability of most results based on unclear and unsystematic manner of assessment, especially for the case of ex-ante assessment. Several approaches to generate transparent results with certain level of confidence were recommended to veer away from typical deterministic and highly uncertain profitability statements for emerging concepts such as ELFM. Future economic assessment should rather serve as a learning tool, providing results that are more reliable for decision-support and facilitating identification of promising paths of development and key areas for further research.

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