

Exploring the socio-economics of Enhanced Landfill Mining

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Abstract

This paper explores the socio-economics of Enhanced Landfill Mining (ELFM). A conceptual framework including performance drivers is presented. Technology (Waste-to-Energy (WtE) and Waste-to-Material (WtM) technologies), regulation (subsidies, taxes, allowances...) and markets (energy, material prices and input costs) determine the economic performance of ELFM. Using a case study, an investment model is developed to identify the impact of a broad range of parameters on the profitability of ELFM. Especially variations in WtE efficiency, electricity and CO₂ price, investment and operational WtE-costs and ELFM support explain the variation in performance. Furthermore, the carbon footprint of the project was mapped to partly assess the environmental performance. Integrating the avoided greenhouse gas emissions into a broader social cost-benefit model and scaling up to the regional level, we show that developing ELFM projects can lead to substantial socio-economic benefits for Flanders. However, the complex trade-off issues between economic, social and environmental issues of ELFM call for the further refinement of the conceptual framework and the development of integrated decision tools supporting private and public actors.

Introduction

Major improvements in the full set of low carbon energy technologies are needed to achieve global energy security with lower pressure on our environment. Some of the necessary changes are starting to occur but sustaining and accelerating the transition will require government intervention together with eco-innovations and market

diffusions.¹ A transition to a low carbon economy is needed and although clear challenges and costs to our economy have to be faced, it also presents opportunities. Markets for low-carbon and high efficiency goods are set for a prolonged period of rapid growth.² Not only energy resources but in fact all kind of material resources should be managed in a sustainable way. Human use of materials is one of the major drivers of global environmental change.³ Environmental problems occur during (i) the extraction of resources, (ii) the processing of raw materials, and (iii) when emissions and wastes are returned to the natural environment after the materials have been use. In 2000, the global level of resource extraction was 48,5 billion tons with 36% biomass, 33% construction materials, 21% fossil fuels and 10% ores/industrial minerals.³ At global scale, material use is growing at a rapid pace, driven by newly industrialising countries. Current projections expect a substantial increase in material extraction and consumption such as the rise of domestic extraction from currently 60 billion tons to 115 billion tons in 2030.⁴

Enhanced Waste Management can contribute to a more sustainable use of our resources. Such an approach with temporary storage can improve recycling, increase reuse rates and optimise energy valorisation.⁵ Furthermore, an important aspect of Enhanced Waste Management is Enhanced Landfill Mining (ELFM), which includes the valorisation of historic waste streams of both materials and energy resources.⁵

This paper presents a first conceptual framework to assess the socio-economic aspects of Enhanced Landfill Mining. Using the 'Closing the Circle' case study of Group Machiels (Houthalen-Helchteren, Belgium, see also Tielemans and Laevers in this volume) the main drivers of the economic performance are identified and the carbon footprint is estimated. In the last part, the case study results are used to scale up and estimate the socio-economic potential of ELFM in Flanders. A preliminary Cost Benefit Analysis, accounting not only for private costs and benefits, but also for social benefits, such as avoided greenhouse gas emissions, was made. Finally, suggestions are made to refine the conceptual framework and to broaden the framework to a sustainability assessment framework of Enhanced Landfill Mining.

Conceptual framework to explore the socio-economics of ELFM

As discussed in several of the other papers in this volume, most developed countries have adopted a hierarchical approach to waste management: (i) prevention and reduction of waste, (ii) recycle or reuse waste, (iii) incineration with energy recovery and if nothing else works (iv) landfilling.^{5,6} A review to evaluate the impact of different waste strategies (recycling, incineration, landfilling) shows that in general recycling has the lowest impact in total energy use and global warming potential.⁷ Independently

of the methodology used (Life Cycle Assessment or Environmental Impact Assessment), significant environmental savings are achieved from undertaking any recycling.⁸ More generally, reduced landfilling in favour of increased recycling of energy and materials leads to lower environmental impact, lower consumption of energy resources, and lower economic costs.⁹ However, the price uncertainty of recycled materials is a major obstacle for recycling.¹⁰ Taking into account the social costs (including private costs) of incineration and landfilling, landfilling can be seen as the social cost minimising option even in densely populated countries.⁶ Nevertheless, not all authors come to similar conclusions, Emery *et al.*¹¹ showed in their Life Cycle Analysis that incineration can be preferred to landfilling and recycling. In fact, these complex trade-off issues between economic, social and environmental issues, demonstrates the need for new balanced waste management concepts and new technologies for waste valorisation. Waste valorisation is the treatment of waste for beneficial use as raw material or as an energy carrier, with the emphasis on processes and practices that reduce emissions and related environmental impacts.¹²

In a new concept of Enhanced Waste Management proposed by Geysen *et al.*⁵ prevention, reuse and recycling become even more important while the idea of landfills as a final solution is discarded. In fact, landfills become future mines for materials, which could not be recycled with existing technologies or show a clear potential to be recycled in a more effective way in the near future.¹³ Traditionally, landfill mining or landfill reclamation is described as a process of excavating a landfill using conventional surface mining technology to recover for example metals, glass, plastics, soils and the land resource itself. Also the use of landfill gas to produce energy is well known as a present landfill mining practice.¹⁴ To valorise waste opportunities of new and closed landfills in a sustainable and integrated way, an Enhanced Landfill Mining (ELFM) practice is defined.⁵ ELFM includes the valorisation of the historic waste streams as both materials (Waste-to-Material) and energy (Waste-to-Energy), with the ratio being dependent on the type of waste streams and the state-of-the-art technology for material recuperation and energy production.⁵ More information about the concepts of Enhanced Waste Management and Enhanced Landfill Mining can be found in Jones *et al.*¹⁵

Figure 1 shows a conceptual framework of the performance drivers of ELFM. Important aspects (described as performance drivers) are technology, regulation and markets (both input and output markets). Waste-to-Material or waste-to-product technologies with regard to Enhanced Landfill Mining are described in Van Gerven *et al.*¹⁶ and Quaghebeur *et al.*¹⁷. Waste-to-Energy technologies with regard to Enhanced Landfill Mining are described in Helsen and Bosmans¹⁸ and Chapman.¹⁹ Besides technology also regulation determines the economic and environmental performance.

Note that the initiative for mining comes in many cases from a regional authority and addresses a specific landfill.¹³ In fact, different subsidy schemes (e.g. sustainable energy production support), taxes, allowances (e.g. EU emission trading system), permits, directives (Waste Framework Directive, Landfill Directive) can create important stimuli and barriers for Enhanced Landfill Mining. Furthermore, there is a clear spatial approach of regulation with policies on supranational, national, regional, local and site specific scale.²⁰ Besides technology development (technology push) and government contributions and measures (regulatory push), there is a clear market demand (market pull) for materials and energy. As shown in Figure 1, the economic and environmental performance of Enhanced Landfill Mining will be determined by a combination of technological aspects, markets (especially energy and material prices) and regulation. Note that landfills are quite diverse with respect to location, size and contents, resulting in different costs and benefits of their mining.¹³ However, it can be expected that the main drivers for economic and environmental performance are similar. To make the conceptual framework operational, empirical applications (economic and environmental performance) are needed.

Assessing the economic potential of an ELFM project

In this section the general conceptual framework is applied on a specific case study (for a European perspective see Hogland *et al.* in this volume). In this way the impact of the performance drivers (technology, markets and regulation) can be identified.

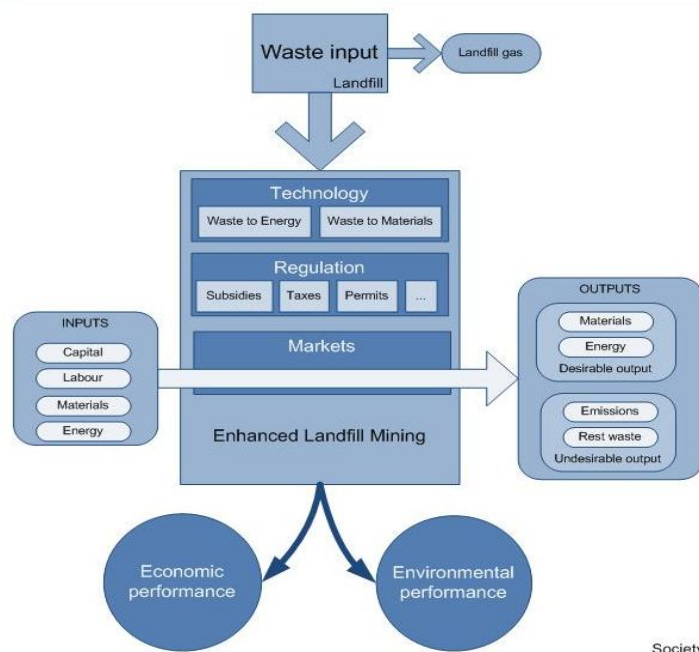


Figure 1: Conceptual framework of the performance drivers of ELFM

Case study: Closing the Circle

The Remo landfill site in Houthalen-Helchteren, in the east of Flanders, has been operational since the beginning of the 1970s. At present it contains more than 16 million tons of waste; approximately half of this material is household waste, while the other half comprises industrial wastes such as shredder material, slags and sludge. It has been estimated that around 45% of the waste can be recycled as materials (Waste-to-Material), either directly or after a controlled treatment process. The remaining fractions have a sufficiently high calorific value allowing them to be energetically valorised after a pre-treatment (Waste-to-Energy). More information about the case can be found in Tielemans and Laevers.²¹

Methodology

To assess the economic performance an economic cost benefit model was built. Van der Zee *et al.*¹³ identify Cost Benefit Analysis (CBA) as an interesting tool at designing a quick scan for the selection of promising landfills. In this contribution, CBA is used in a more detailed way to investigate the impact of the performance drivers on the economically feasibility. Frequently, the Payback Time, the Internal Rate of Return and the Net Present Value (NPV) are applied to verify whether or not investing in a project is worthwhile financially. The Payback Time is determined as the time needed to pay back the initial investment with the incoming cash flows. Although this method has the advantage of being generally known and easy to apply, it doesn't take the time value of money into account. Moreover, when applying the payback time, no information is obtained about the profit generated from the investment during the further lifetime of the project, *i.e.* after the investment has been paid back. The NPV is calculated by subtracting the investment cost from the sum of the discounted cash flows and can be considered as the expected profit of the investment. Unlike the payback time, it takes the time value of money and all the relevant cash flows over a predefined period into account. The Internal Rate of Return (IRR), the discount rate at which the NPV is zero, gives an idea about the relative return of the investment but doesn't take the scale of the project into account: while the IRR of two projects can be the same, the NPV of one project can be larger than the NPV of the other. On the other hand, using the IRR does not require assumptions about the discount rate. Because our main objective is to analyse the impact of the performance drivers of ELFM and not to compare different projects, we prefer to use the IRR as economic indicator.

$$NPV(x|\alpha) = \sum_{t=1}^T \frac{CF_t(\alpha)}{(1+x)^{t-1}} = 0 \Rightarrow x^*(\alpha) = IRR$$

with CF_t the cash flow in year t , T indicates the time horizon, x the IRR or the unknown discount rate, α the vector of economic and technical exogenous parameters. A sensitivity analysis is used to analyse the variation of x^* as a function of the exogenous

parameters. To examine how the IRR varies when the value of uncertain assumptions is modified, a Monte Carlo sensitivity analysis is performed. When performing a Monte Carlo sensitivity analysis, probability distributions are specified for uncertain values of model input parameters. Then multiple trials are executed, taking each time a random draw from the distribution for each parameter. Moreover, the results of the model not only incorporate the uncertainties of the input parameters, they also give us their importance.

Results

Table 1 gives an overview of the costs and benefits of landfill mining of the case study. All costs and benefits except the costs and benefits between brackets were considered in the cost benefit model. Note that certain costs and benefits are indicative and assumed using average values and prices. In fact, the cost benefit model is generic and can be fine-tuned if certain choices (*e.g.* Waste-to-Energy technology) are made. In this case, the cost benefit model is built to identify the impact of certain aspects (markets, regulation and technology) on the economic performance of Enhanced Landfill Mining. It is not an optimisation model but rather an interesting tool to tackle uncertainty.

The cost benefit model to analyse the impact of the different performance drivers is formulated in such a way that the IRR becomes 15% (before taxes). In general, projects with an IRR of 15% (before taxes) can be seen as profitable and feasible projects. The model is built determining and assuming several key variables (*e.g.* see Table 2) and calculating an ELFM subsidy (in this case €/MWh) to reach an IRR of 15%. In this base scenario, the ELFM support is similar as the current green power certificate value of incineration (110 €/MWh). Note that we opt for an ELFM subsidy expressed in € per MWh but other schemes (investment support, material recuperation remuneration, waste processing subsidy...) or combinations of support schemes are possible.

Using the cost benefit model, the impact of a wide range of parameters on the internal rate of return (IRR) was investigated by calculating the elasticities ($[\text{IRR}_2/\text{IRR}_1] \cdot [\alpha_1/\alpha_2]$). The considered parameters (α) were (i) the amount of different (> 10) waste types; (ii) the energy content of different (> 10) waste types; (iii) the landfill mining costs of the different waste types; (iv) the investment costs of the WtE en WtM installations; (v) the operational costs of energy production; (vi) the WtE efficiency; (vii) the revenues of different waste types (or materials); (viii) the revenues of electricity production; (ix) the revenue of support (*e.g.* subsidies, certificates...) and (x) the CO₂ cost or revenue.

Table 1: Costs and benefits of landfill mining

Costs	Benefits
Investment costs	Revenues from materials
Storing costs	Metals
Waste-to-Energy plant	Shredder
Rolling stock	Construction materials
Waste-to-Material plant (metal recuperation)	
Crush and sieve installation	
Operational costs	Revenue from energy production
Energy production (incineration costs)	Electricity
Landfill mining (digging costs, presorting costs, crush and sieve costs, recuperation costs, storing costs)	(Landfill gas)
Emission costs ^a	(Heat)
(Taxation costs)	
(Post-closure care and monitoring)	Support schemes
	Energy subsidies (e.g. green power certificates)
	Investment support
Other possible costs	Other possible benefits
(expenses incurred in project planning)	Carbon capture benefits ^a
(research costs)	(Avoided post-closure care and monitoring)
	(Land value)
...	...

^aThe emission costs/carbon capture benefits are modelled by defining and incorporating a CO₂-price

A first exploration of the elasticities showed that the following parameters have an important impact on the economic performance (IRR and NPV): (i) WtE efficiency; (ii) electricity price; (iii) CO₂ price; (iv) investment costs of the WtE installation; (v) operational costs of energy production and (vi) ELFM support. Using a Monte Carlo sensitivity analysis, the importance of the different parameters can be investigated based on well defined ranges, assuming triangular distributions. The WtE efficiency includes heat recuperation to dry waste input. The electricity price is assumed to increase (small upward bias) and the ELFM support is assumed to decrease (small downward bias). After the distributions are established, 10.000 trials, taking each time a random draw from the distribution for each assumption are executed in order to produce a large number of IRRs and their distribution.

Table 2: Performance drivers of ELFM

Parameter	Relationship
WtE efficiency (%)	36.0 (+)
Electricity price (€/MWh)	10.9 (+)
CO ₂ price (€/ton CO ₂)	26.9 (-)
Investment WtE (€/ton)	6.1 (-)
Operational costs WtE (€/ton)	4.2 (-)
ELFM support (€/MWh)	15.9 (+)

Table 2 shows the share in explanation of variation in IRR and the relationship (+ or -) with IRR. The variation in the IRR can be explained for 36% by the variation in the Waste-to-Energy (WtE) efficiency. Logically, a higher WtE efficiency results in a higher IRR. Furthermore, the variation in the IRR can be explained by the variation in electricity price (for 11%) and by the variation of ELFM support (16%). The impact of investment and operational costs is less apparent. Hence, technology (WtE efficiency), markets (electricity price) and regulation (ELFM support) determine the economic performance. Note that the range definitions of the different parameters highly influence the impact of the different parameters. Nevertheless, the results show several interesting insights. The efficiency of the Waste-to-Energy technology has a significant impact on the IRR. Developing and applying WtE technologies with higher efficiencies is worth the effort. A guaranteed electric efficiency is an important issue when negotiating with technology providers. A guaranteed minimum support value for ELFM seems indispensable in order to make ELFM feasible.

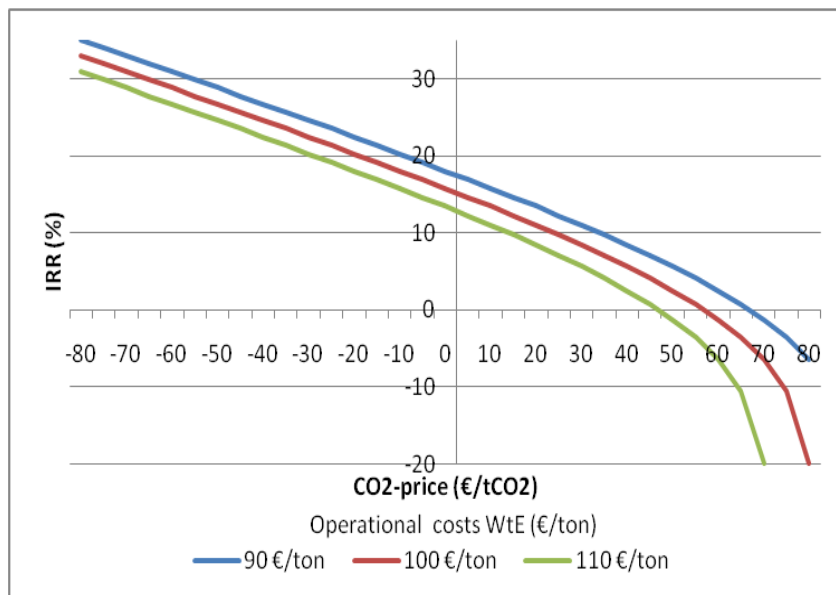


Figure 2: The impact of CO₂-price variations on IRR

Also the CO₂-price can have a significant impact on the economic performance of ELFM. We assumed a CO₂-emission coefficient of unity (one ton waste incineration results in one ton CO₂-emission) and we assumed no free emission allowances. The impact of a broad CO₂-price range is investigated: -80 till + 80 € per ton. Negative prices can be interpreted as the impact of support for reducing emissions. Figure 2 illustrates the impact in more detail.

Assessing the environmental potential of an ELFM project

Every ELFM project is characterised by a wide set of potential environmental effects, both positive and negative ones. For instance, after the landfill site has been mined, possible problems of leaching and ground water contamination are permanently solved. In this section, we focus on one particular environmental dimension of ELFM projects, in particular its impact on greenhouse gas emissions. To assess the environmental performance, the carbon footprint was calculated (see also Tielemans and Laevers²¹ in this volume). In this carbon footprint, only greenhouse gases are considered which are covered by international agreements, such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O).

For this study, we used the Bilan CarboneTM methodology²², developed by ADEME, the French government agency for the environment. In the overall carbon balance, all incoming and outgoing materials streams are accounted for, as in financial bookkeeping.

The scope of the carbon footprint takes into account the widest possible range of factors related to company emissions (indicated as scope 3²²). The way to estimate these emissions is to derive them from activity data: the number of trucks driven and distance travelled, tonnes of steel purchased, *etc.* An inventory of six categories of activity data is considered: (i) emissions from energy production, (ii) emissions from freight, (iii) emissions from transport of people, (iv) emissions from incoming and outgoing materials and services, (v) emissions from direct waste and waste water and (vi) emissions from capital assets. For each category the obtained observable data obtained are transformed into greenhouse gas emission estimates by using a database of emission factors.

For this study, we performed the carbon footprint analysis for two scenarios assuming a time frame of 20 years. In this way, we investigate which scenario is most beneficial in terms of climate change mitigation. The Remo landfill site is an existing landfill containing historical waste with energy recovery from methane. The energy recovery from methane would last for about 15 years, using a combined heat and power cycle. This will generate an amount of usable electricity and an amount of usable heat.

Keeping the situation unchanged ‘forever’ is called the ‘do nothing’ (DN) scenario. No incoming materials, no outgoing materials. In a second scenario, Closing the circle (CtC), most of the historical waste from the Remo landfill site would be recovered as energy and materials. As in the DN scenario, energy recovered from methane would last for about 15 years. In the closing the circle scenario, a waste to energy (WtE) plant and a sorting and recycling plant (WtM) need to be built on the Remo landfill site. All operational emissions of the six categories mentioned are taken into account.

The DN scenario is only producing a small amount of energy (from methane recovery), and not producing any materials. Therefore, the difference in materials and energy will be purchased on the market in the case of the DN scenario. Greenhouse gas emissions of conventional market production methods will be accounted in the DN carbon footprint. Comparing the footprints of both scenarios gives us an idea which scenario is more beneficial towards greenhouse gas mitigation (see Figure 3). Detailed Sankey Flow diagrams of both scenarios (DN and CtC) are available (not included).

For the same amount of energy and materials, the CtC scenario leads to 5,3 Mton CO₂e greenhouse gas emissions compared to 6,3 Mton CO₂e in the DN scenario. This corresponds to 15 percent less greenhouse gas emissions (See Figure 3).

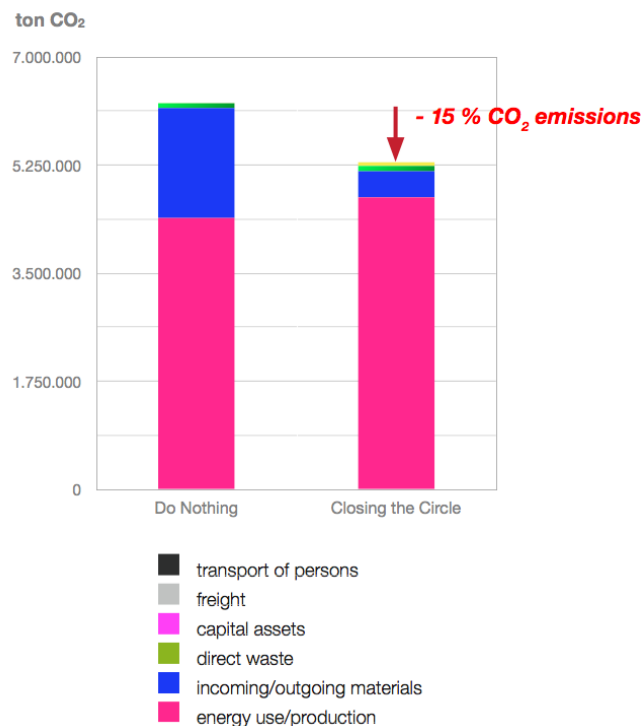


Figure 3: Carbon footprint of DN and CtC scenario

It should be noted that the margin of error on both carbon footprints is about 20%. This is in line with the national greenhouse gas inventory as described by ADEME in the Bilan Carbone method.²² Also, this result has been obtained without taking into account any carbon capture and storage (CCS).

To understand the robustness of the conclusion, a sensitivity analysis was performed to evaluate the effect of changing several parameters: (i) the electricity mix, (ii) the carbon content, (iii) the biogene fraction of waste, (iv) the calorific value of the waste, (v) the electrical efficiency WtE and (vi) the material recuperation of the installations (WtM). The conclusion remains true upon varying most of the examined parameters. In addition to the greenhouse gas mitigation, Enhanced Landfill Mining potentially offers other benefits such as curbing of fossil and material resources, and fully restoring the landfill site to its original site. Some of these aspects will be discussed in the following section.

Estimating the socio-economic potential of ELFM in Flanders

Methodology

It was shown by means of a private investment analysis of an ELFM case study that Enhanced Landfill Mining projects can have a clear economic potential when legal barriers are removed and adequate regulation and support policies are in place. It was also shown that the ELFM case study has a positive impact on greenhouse gas emissions. In a next step, we explore the overall potential for ELFM projects in a densely populated and economically advanced region. In order to answer this question, we will scale up the case study results from the local to the regional scale (Flanders, densely populated northern part of Belgium, six million inhabitants). We will also broaden the scope of the analysis towards a Social Cost Benefit Analysis by explicitly accounting for opportunity costs and environmental externalities. As Flanders is a front-runner in sustainable waste management with the ambition to maximise materials recycling, the region is well suited as a test case for ELFM. We will first discuss the methodology to identify the most promising landfill sites in Flanders before turning to a first estimate of the societal costs and benefits.

Estimating the total number of potential ELFM sites in Flanders

Van der Zee *et al.* describe a 5-step procedure for investigating the profitability of landfill mining projects. The first three steps concern desk research, the last two steps involve site visits and analysis.

Step 0: Database selection. As a starting point the data sources that provide basic information on landfills have to be identified. In Flanders, OVAM (the Flemish soil and

waste administration), collects and manages extensive databases on active and historic landfilling activities. A thorough screening of the OVAM archives resulted in the identification of several data sources for the evaluation of the ELFM potential: the landfill permit archive, the database on landfills in exploitation, the archives of historic landfill taxes, yearly reports of landfills, landfill sites with running soil remediation procedures and, finally, the land information register.

OVAM was founded in 1980 and, therefore, most data sources mentioned above, contain little information on activities before 1980. Most data sources are also limited to landfills that operate (or operated) with a permit. These limitations imply that from the specific databases on landfilling activities, only 297 sites could be retrieved. From contacts with OVAM it became clear that this was too restrictive as a data source.

That's why also other information sources to make an inventory of Flemish landfills will be used, in particular information on soil contamination and brown fields. In 1994 Flanders was preparing its soil remediation legislation. All municipalities were asked to use local knowledge to list sites that were potentially contaminated. A pre-defined structured survey format was used to collect the information. The municipalities listed landfills with or without permits, and with exploitation dates that go back to 1900. This data later has been imported in OVAM's 'land information register' in a structured way and can be used after a data clean-up. From this data source, 1618 landfill sites could be identified. This is the starting database for our analysis.

Step 1: Selection based on qualitative indicators. A first selection criterion is the type of landfill. The database distinguishes between (i) solid household waste landfills, (ii) inert waste landfills and (iii) several mono-waste landfills such as dredging , fly ash, asbestos, gypsum, sewage sludge and other industrial waste.

From a private business perspective, landfills that contain high value materials either for WtE or WtM are most interesting to mine. Inert landfills are filled with glass, inert building materials, bound asbestos. This is a heterogeneous stream of non-leaching and, currently relatively low-value, materials. Inert landfills are therefore not very interesting for an ELFM project and have been filtered out.

Mono-waste landfills are filled with homogeneous materials that often have environmentally impacting features because of leaching to ground water or fugitive emissions to the air. Unfortunately, current technology does not allow for a financially viable ELFM project. This may change in the future as technological breakthroughs may change the costs and benefits of the projects. Given the current state of technology, we have therefore selected 1104 landfills with municipal solid waste.

It is well documented that waste is a reflection of the lifestyle in the society. As these lifestyles and consumption patterns have changed dramatically over time, also the composition of the municipal solid waste landfills has changed. As the composition of the waste mined will critically determine the economics of an ELFM project, a historic perspective is necessary to understand the composition of waste in landfills.

In the early 20th century, 80% of all municipal household waste consisted of ashes from residential heating. The remaining part was composed of easily degradable material like horse manure. Recycling of glass, textiles and metals was common practice. Plastics and composite materials were still to be invented. Old paper and cardboard were used to heat the houses. Therefore, these old landfills contain very little materials of high economic value. It was only in the 1950s and 1960s, when mass production and consumption changed lifestyle, that composition of municipal solid waste changed drastically. The throwaway style of life came into fashion^{a1} and landfills were popping up everywhere. Soft drinks in non-returnable steel and glass bottles became popular. Refrigerators and chemical preservatives limited food spoilage but also increased the amount of plastic and paper packaging. Light-weight packaging alternatives got a boost and therefore the aluminium and plastics fractions in waste increased.²³⁻²⁷

As landfills generated more and more negative environmental externalities and occupied a considerable amount of valuable space, public attitude towards waste started to change in the late 1970s. In 1980, OVAM was founded in Flanders and a waste management hierarchy principle was integrated in Flemish legislation. From then onwards, easily recyclable materials were sorted out before solid household waste going to final disposal (mainly incineration). Therefore, in terms of valuable materials content, waste streams going to landfills after 1980 became less and less interesting for ELFM projects.

As the composition of the waste stream is crucial to the profitability of an ELFM project, and as the age of the waste stream is a reasonable proxy for its composition, we decided to focus only on landfills that were active between 1950 and 1985. This reduced the number of eligible sites to 850.

Step 2: Selection based on crude, quantitative indicators. An on-site ELFM project needs significant capital investments for both the WtM and WtE installations.

^{a1} The August 1 1955 issue of Life magazine illustrates this change in lifestyle: the article offers a two-page article on “Throwaway Living” with a photo of a family cheerfully tossing dozens of disposables into the air. It celebrated these products’ ability to “cut down on household chores”.

Given the magnitude of the fixed costs involved, there are important economies of scale in this type of projects. Therefore, sites containing sufficient waste material are of interest for ELFM. As the OVAM files do not contain precise information on the volume of waste stored, we have to use area of the terrain as a proxy indicator of the waste volume stored. Six old landfill sites that contain solid household waste have a surface area exceeding 500.000 m². If we add also landfills actually in exploitation of category I^{a2} and II, we arrive at 14 sites that are interesting for site-specific research. Once ELFM technology has matured, it might become interesting to include also smaller sites. Possibly recycling of machinery or (semi-) mobile installations might make it financially feasible. In total 58 extra old sites have a surface larger than 100.000 m². This brings the long-term ELFM potential expressed in surface at more than 20 km².

Step 3 & step 4: On site visit and full investigation. Further research should consist of a site visit, update of the data, contact with owners, contact with neighbours, research at the community archives, verification of potential ground remediation files. If all indications are positive a full scan with soil sampling should be done. As this is very time consuming and costly, we were not able for this study to conduct these steps.

Estimating societal costs and benefits of ELFM projects for Flanders

In order to inform decision making, we have set up a preliminary social cost benefit model. It is a flexible simulation tool that allows a quick scan of an ELFM project. On the basis of extensive literature research and business feedback, recommended average values are proposed for excavation data (density, moisture content, waste composition) project costs (excavation, sorting, treatment, etc.) and project returns (material returns, electricity price, Flemish support schemes and land prices).²⁸

To illustrate the use of the simulation tool, we have analysed the Flemish potential for ELFM projects. Table 3 shows that, under current conditions, WtE is the most important benefit. It should be noted that government incentives for renewable energy make up a substantial part of these benefits. Although subsidies should not be counted as benefits in standard social Cost Benefit Analysis, we have included them in our analysis as they can be interpreted as a compensation for the social value of the contribution of ELFM projects to the attainment of, among others, the renewable energy target imposed by EU legislation on Flanders (13% of final energy demand for Belgium).

^{a2} Only recently Cat I landfills were forbidden to accept solid household waste

Table 3: Social Cost Benefit Analysis for ELFM in Flanders

Data	
Site surface (m ²)	20 000 000
Costs	
Total (€)	12 779 680 000
Benefits	
Total WtM (€)	1 534 382 080
Total WtE (€)	9 937 782 556
Landfill reclamation (€)	1 368 000 000
Reduced carbon footprint	256 650 240
Total (€)	317 134 876

We also accounted for the opportunity costs of land occupied currently by landfills. Once the ELFM project completed, the landfill sites can be safely used for building land, industry land, or even new nature reserves and forests. This constitutes a clear social benefit of ELFM projects which we evaluated at a weighted average land price for these different functions. Finally, we used the results of the Bilan Carbone exercise to estimate the monetary value of greenhouse gas savings by ELFM projects in Flanders. We valued CO₂e at a price of 40€/ton, an often used price projection for the third phase of the EU Emission Trading Scheme after 2012.²⁹

Using the value of reclaimed land, greenhouse gas savings and the contribution of ELFM projects to achieving the EU renewable energy objective as sources of socio-economic benefits, the ELFM projects would result in a substantial positive benefit for Flanders. We recognise that this result is very preliminary in the sense that it does not include all possible sources of environmental and socio-economic benefits and costs of ELFM projects. For instance, after the ELFM project, the site constitutes no longer a potential threat to ground water quality. Furthermore, research and planning costs are not included. Also, the development of ELFM projects in Flanders might lead to a new and competitive export industry capable of developing similar ELFM projects internationally. None of these aspects has been integrated in our analysis but they might have an important impact on the socio-economic potential of ELFM.

Finally, for each ELFM project, local site specific conditions have important impacts on the potential for WtM and WtE technologies. For instance, glass and building materials constitute a significant fraction of the recycled material. As they have a relatively low-value, transport costs limit the profitability of these materials. Integrating several projects that combine landfill mining and development of an industrial terrain can create significant synergies for recycled building materials. Such interactions have not been taken into account in our analysis but might lead to a more favourable outcome.

Conclusions

In this paper, a first conceptual model of the socio-economics of ELFM is proposed. In a first section, we focus in detail on the drivers of economic performance based on a case study. In fact, our results can be used to extend step 2 of van der Zee *et al.*¹³, which concerns the use of crude quantitative indicators for selecting landfills. Besides using mining costs and costs of re-dumping or removing, we propose to include technology costs of both Waste-to-Materials and Waste-to-energy. Besides assumed benefits of regained land and recyclables, we propose to include also the revenues of energy production. Moreover, also regulation benefits (subsidies) and costs should be included. In fact, as shown by our conceptual framework, technology, regulation and markets (input and output) have a clear impact on the economic performance of landfill mining.

The development of innovative technologies (and especially Waste-to-Energy technologies) with a high WtE efficiency is an important aspect to improve the feasibility of ELFM practices. Logically, market prices also have an impact on the economic performance of ELFM. We found a significant impact of the electricity price and low impact of material prices on the economic performance. The impact of specific material prices is in our case study less important due to the fact that the waste streams are heterogeneous resulting in different materials as output, levelling out the importance of material prices. Besides technology and markets, also regulation plays an important role determining the economic and environmental performance of ELFM. Tailored policy measures taking into account the economic and environmental benefits and costs of ELFM should be developed to support Enhanced Landfill Mining.

In fact, with regard to landfill mining the complex trade-off issues between economic, social and environmental issues, demonstrates the need for (i) more detailed information of economic, social and environmental aspects and (ii) a clear, integrated decision tool. We have contributed to this goal by assessing the carbon footprint of the case study. A clear reduction of greenhouse gas emissions by about 15% compared to a business-as-usual scenario (DN-scenario) proved to be robust for variations in the main parameters.

Finally, we scaled up the results of the case study to the regional level of Flanders. After identifying potential ELFM sites in Flanders, we calculated costs and benefits including major socio-economic effects like contribution to renewable energy and greenhouse gas reduction objectives, and land reclamation values. Overall, the development of ELFM projects has a positive payoff for Flanders. Further research is needed to refine and extend the social cost and benefit model by including all relevant aspects. In this way, a sound estimation of the potential of ELFM in Flanders can be

made. Such an estimate can support policy making and contribute to Enhanced Waste Management policies.

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