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The economics of enhanced landfill mining: private and societal performance drivers

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ABSTRACT

This paper addresses the economics of Enhanced Landfill Mining (ELFM) both from a private point of view as well as from a society perspective. The private potential is assessed using a case study for which an investment model is developed to identify the impact of a broad range of parameters on the profitability of ELFM. We found that especially variations in Waste-to-Energy (WtE efficiency, electricity price, CO_2-price, WtE investment and operational costs) and ELFM support explain the variation in economic profitability measured by the Internal Rate of Return. To overcome site-specific parameters we also evaluated the regional ELFM potential for the densely populated and industrial region of Flanders (north of Belgium). The total number of potential ELFM sites was estimated using a 5-step procedure and a simulation tool was developed to trade-off private costs and benefits. The analysis shows that there is a substantial economic potential for ELFM projects on the wider regional level. Furthermore, this paper also reviews the costs and benefits from a broader perspective. The carbon footprint of the case study was mapped in order to assess the project's net impact in terms of greenhouse gas emissions. Also the impacts of nature restoration, soil remediation, resource scarcity and reduced import dependence were valued so that they can be used in future social cost-benefit analysis. Given the complex trade-off between economic, social and environmental issues of ELFM projects, we conclude that further refinement of the methodological framework and the development of the integrated decision tools supporting private and public actors, are necessary.

1. Introduction

During the last decades, environmental concerns, legislation and policy instruments have resulted in lower amounts of waste being sent to landfills. The European Waste directive (EU, 2008a) prescribes a hierarchy for waste management where land filling is only considered as a solution of last resort. Although some authors show that modern sanitary landfills can contribute to the overall efficiency of waste management (Dijkgraaf and Vollebergh, 2004), most academic authors agree that land filling should be phased out (Björklund and Finnveden, 2005; Eriksson et al., 2005; Emery et al., 2007; Mazzanti and Zoboli, 2008; Cherubini et al., 2009).

Historic practices have, however, led to a number of uncontrolled landfills in which no or inadequate measures were taken to avoid long-term emissions to groundwater and air pollution. The consequences of these historic practices continue to have their impact. Large areas of land cannot be used due to the potential health and environmental risks. Recently, concerns about resource and land scarcity have resulted in a renewed interest in these historic landfills. In this context, the new concept of "Enhanced LandFill Mining" (ELFM) proposed by Jones et al. (2013) has originated. In particular, ELFM regards landfills not as a final solution but as temporary storage facilities from which the landfilled waste will eventually be valorized by means of recycling and incineration. This will result in improved recycling, increased re-use rates and optimized energy valorization (Jones et al., 2013; Geysen et al., 2009).

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ELFM includes valorization of the historic waste streams as both Waste-to-Material (WtM) and Waste-to-Energy (WtE). The ratio of WtM to WtE depends on the type of waste streams and the state-of-the-art technology available for material recuperation and energy production. Note that the expected technological progress is of key importance for ELFM and may even reshuffle the hierarchy of waste management options in certain cases. It is for example possible that, although some kind of waste material can be incinerated in a profitable way, it is rational to temporarily landfill this material if one expects significant progress in WtE or WtM technologies.

Fig. 1 shows that technology, regulation and markets are important drivers for ELFM projects. The variety of WtE technologies relevant for Enhanced Landfill Mining, is reviewed by Bosmans et al. (2013), and the characterization of landfilled materials by Quaeghebeur et al. (2013). Besides technology also regulation determines the economic and environmental performance of ELFM. Note that the initiative for landfill mining comes in many cases from a regional authority (van der Zee et al., 2004). In fact, different subsidy schemes (e.g. support for sustainable energy production), 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 (Lavee et al., 2009). Finally, there is also a clear market demand (market pull) for materials and energy.

Clarifying the economic aspects of enhanced landfill mining is an important step in the direction of effective realization of ELFM projects. Moreover, the exploration of the economics of ELFM can support policy makers to design appropriate support schemes. In fact, private entrepreneurs will only initiate projects with a positive return, whereas projects with a negative return will not be picked up. External benefits or costs to society are typically not taken into account, as these are not fully borne by the private investor. Lower environmental pollution, restoration of nature and biodiversity and reduced import dependency are important examples of such beneficial effects for society but they are external to the private investor's decision-making process. Societal costs and benefits are therefore more comprehensive than private interests. In general, the existence of externalities calls for corrective government intervention. Government policy should create financial incentives in such a way that the externalities are internalized in the private return. In other words, policy measures should stimulate projects with external 'benefits' to society and discourage projects with external costs to the society (Callan and Thomas, 2000; Porter, 2002; Tietenberg and Lewis, 2010; Kolstad, 2011).

Fig. 2[1] illustrates the appropriate financial incentives that are needed to obtain the welfare optimizing allocation as a market equilibrium. Without policy support the suboptimal point Q_{Low} will be reached. Only few projects (or none) will be executed and substantial societal benefits are foregone. A sustainable policy framework internalizes the external benefits and pushes the amount of projects up to the optimal amount Q_{Opt}. The support policies create a dynamic environment where innovation thrives and learning effects and economies of scale will push the ELFM potential up to Q_{Future}.

The objective of this paper is to develop and apply a methodological framework to assess the economic performance drivers of ELFM projects both for private entrepreneurs as for society as a whole. More specifically, the following research questions will be addressed: (i) What are the relevant private costs and benefits of a particular ELFM project? (ii) How can one estimate the number of potential ELFM sites, and hence benefits and costs, for an entire region? (iii) What are the external costs and benefits of ELFM to society?

This paper is organized in the following way. The second section describes the methodologies used to evaluate the three research questions. In a third section, the methodology for the assessment of private costs and benefits is applied to the "Closing the Circle" case study of Group Machiels (Houthalen–Helchteren, Belgium, see also Tielemans and Laevers (2010)). In section four, the case study is scaled up to the regional level starting from an estimate of the total number of potential ELFM sites in Flanders (north of Belgium). The fifth section broadens the scope of the analysis and evaluates the potential of ELFM projects from the point of view of society. First, the carbon footprint of the "Closing the circle" project is calculated. Second, this carbon footprint is combined with literature data on other external effects to society in order to review the impact of a comprehensive ELFM strategy in the region of Flanders. Finally, suggestions are made to refine the proposed methodologies and to broaden the framework to a sustainability assessment framework of Enhanced Landfill Mining.

2. Methodologies to explore the economics of ELFM

This section reviews the methodologies used to assess the three research questions: private costs and benefits (section 2.1), selection of interesting ELFM sites (section 2.2), and costs and benefits to society (section 2.3).

2.1. Methodology to assess the private economic potential of an ELFM project

To assess private economic potential, we review methodologies to assess profitability such as Payback time, Internal Rate of Return (IRR) and Net Present Value (NPV) as well as a methodology to assess financial risk (Monte Carlo simulations).

Frequently, the Payback Time, the IRR and NPV are applied to verify whether or not investing in a project is worthwhile financially, see Brealey et al. (2010) for details. The Payback Time is determined as the time needed to cover 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 flow elements over a pre-defined 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 analyze the impact of the performance drivers of ELFM and not to compare the different projects, we prefer to use the IRR as an indicator of private economic profitability. Formally, the IRR is defined as the critical interest rate that makes the NPV zero:

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

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[1] Own representation based on theory reviewed by Callan and Thomas (2000), Porter (2002) and Tietenberg and Lewis (2010), Kolstad (2011).

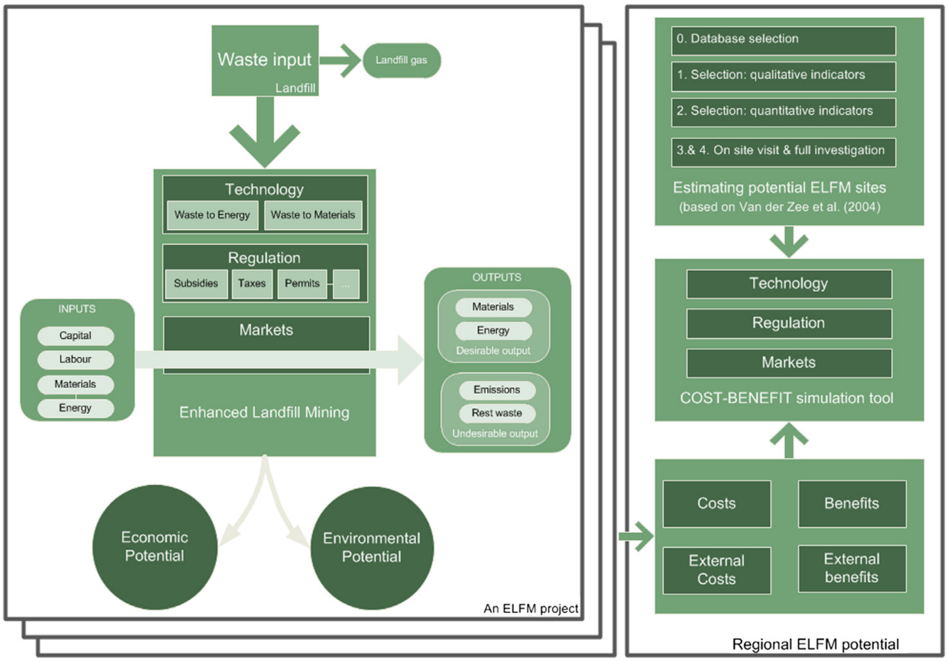

Fig. 1. Methodological steps to assess the economics of ELFM.

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.

The private investment model starts from parameter values for key exogenous variables like technical efficiencies and costs provided by the case study investor and cross-checked by literature research. For this set of exogenous parameter values, the investment model seeks the minimal ELFM support level necessary to reach an IRR of 15% (before taxes). In general, projects with an IRR of 15% are considered to be profitable by private investors.

A sensitivity analysis is used to evaluate 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 simulation approach has been chosen. When performing a Monte Carlo sensitivity analysis, probability distributions are specified for uncertain values of exogenous model input parameters. After the distributions are established, a large number (for instance 100,000) trials – taking each time a random draw from the distribution for each uncertain parameter – are executed in order to produce a large number of IRRs and their empirical joint distribution. The results of the model not only incorporate the uncertainties of the input parameters, they also provide an idea about their importance. The investment 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 optimization model but rather a tool to assess input parameter uncertainty.

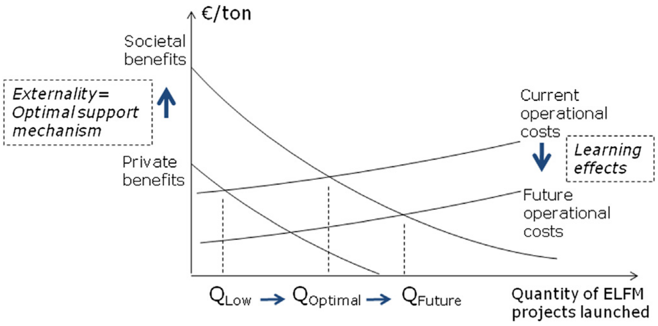

Fig. 2. Economic framework for ELFM.

The methodology to assess private profitability is applied as an illustration to the case study 'Closing the circle' (ELFM project in Flanders, see Tielemans and Laevers, 2010). The project concerns a landfill containing a mix of household and industrial waste. Material recovery and energy production are maximized by a sequence of screens, sifters, cyclones and drying before WtE using Gasplasma™ technology. The input values of the profitability analysis can be found in Appendix A.

2.2. Methodology to assess the regional potential of ELFM

Note that landfills are quite diverse with respect to the location, size and contents, resulting in different costs and benefits of their mining (van der Zee et al., 2004). Also landfill operations such as leachate recirculation, presence or absence of a liner, use of soil cover can differ. Furthermore, there is a clear spatial approach of regulation with policies on supranational, national, regional, local and site-specific scale (Deutz et al., 2010). Therefore, a regional assessment of the ELFM potential can overcome the site-specific challenges and give support to the regional policy making.

2.2.1. Selection of potential sites

To estimate the number of potential ELFM sites in Flanders, we follow the funnel methodology proposed by van der Zee et al. (2004). As visualized in Fig. 1, the methodology follows a 5-step procedure: the first three steps concern desk research, the last two steps involve site visits and analysis.

The ***first*** step is the ***database selection***. Most data sources available in Flanders are limited to landfills that applied for a permit after 1981, the foundation of OVAM (the Flemish Soil and Waste

Agency). This would restrict the amount of sites to only 297 as older landfills and landfills operated by municipalities would be out of scope. However, in 1994 Flanders was preparing its soil remediation legislation. All municipalities were asked to use local knowledge to list all sites that were potentially contaminated. A predefined survey format was used to collect this information. The municipalities listed a total number of 1618 landfills irrespective of the permit status with exploitation dates going back to 1900. This survey will serve as a starting database for our analysis.

The ***second*** step ranks the historic sites based on ***qualitative indicators***. The type of waste to be mined is a key parameter in the economic performance of an ELFM project. A first selection criterion is therefore the type of landfill. The database distinguishes between household waste landfills, inert waste landfills and several mono-waste landfills. Inert landfills are filled with glass, inert building materials and 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. Mono-waste landfills are filled with homogeneous materials such as dredging residues, fly ash, or other industrial wastes. Environmental impact and potential mining profitability is diverse and assessment is strictly site-specific. We have therefore restricted our assessment to landfills with municipal solid waste.

A second qualitative selection criterion is period of exploitation. Waste is a reflection of the lifestyle of society. As consumption patterns and waste management have changed dramatically over time, also the composition of landfills has changed. 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 for instance horse manure. Recycling of glass, textiles and metals was a common practice. Plastics were still to be invented. 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. 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. Lightweight packaging alternatives were introduced and therefore the aluminum and plastics fractions in waste increased (Strasser, 1999; Walsh, 2002; EPA, 2009; Senternovem, 2009). In the late 1970s, public attitude towards waste started to change. Sorting schemes were launched for easily recyclable materials and residual waste was increasingly incinerated. In terms of valuable materials content, waste streams going to landfills became gradually less interesting for ELFM projects. Taking into account the historic evolution in consumption patterns and landfill composition, the inventory is restricted to the household waste landfills that were operational between 1950 and 1985.

The ***third*** step is the selection of sites based on ***crude, quantitative indicators***. An on-site ELFM project needs significant capital investments for both WtM and WtE installations. Given the magnitude of the fixed costs involved, there are important economies of scale. Therefore, only sites containing a sufficient amount of waste material are of interest for ELFM. As precise information on the volume of waste stored in historic landfills is missing, we have to use area of the terrain as a proxy indicator for the waste volume stored. Further assessment is restricted to medium and large sized sites with an area of more than 100,000 m^2. Adding the economic potential of the selected historic landfills to the potential of the existing landfills gives an upper bound to the long-term ELFM potential in Flanders.

The ***final two steps*** in the research methodology concern on-site research and full investigation. This includes contact with owners, research at the community archives, verification of potential ground remediation files, soil sampling and laboratory testing. As this type of research is time consuming and costly, we were not able for this study to conduct these steps. We will discuss the results of this site screening exercise in section 4.

2.2.2. Simulation tool for private costs and benefits

As more insight is gained about the number of potential ELFM sites, both private entrepreneurs and policy makers need a simulation tool to assess the economic opportunities from ELFM projects. In order to evaluate private profitability and the impact of support policies, we set up a generic simulation tool that incorporates the major economic drivers. Different technologies compete to maximize efficiency and resources going to WtM and WtE. The rollout of an ELFM project will also require many choices and fine-tuning in operational matters. The optimal technological and operational choices are site-specific and can only be made by private entrepreneurs. To avoid fixation on operational issues and site-specific characteristics, we use a generic approach with indicative reference data based on an extensive literature review and business feedback.

Although our generic approach allows analysis without selection of specific technologies, we do assume a set-up where waste is excavated and extensively pre-treated with the aim to maximize material streams going to WtM and WtE. Using a sequence of separation techniques based on size, density and magnetic properties six main material streams are produced: top soil, granulates, fines, ferro-metals, non-ferro metals and the feedstock for WtE. Most landfill excavations reported in the literature, produced high fractions of fines up to 75 mm because production of cheap landfill cover was a principle objective (EPA, 1997; Renosam, 2009). Within the scope of ELFM and taking into account technological progress in separation techniques, inferior applications as landfill cover should be minimized. The fines are therefore sieved to sizes of about 5 mm (Hayes, 2003; Hogland et al., 2004; Hull et al., 2005; VITO, 2005; Meinel, 2010; Jones et al., 2013). WtE conversion is performed on site with connection to the grid and the support mechanism for WtE from household waste in Flanders is taken into account. Residual heat of WtE is used to dry the waste fraction destined for WtE. WtE can also be used in a cogeneration framework to produce heat for local clients. This option has not been modeled. Hazardous waste management requires a site-specific approach. Because most concerns can be dealt with proper safety management (e.g. safety plans, training of personnel, gas measurement, over-pressurized excavator cabins, personnel protective equipment), no specific cost is included to deal with hazardous waste (IWC, 2009). If, however, landfills have site-specific risks of hazardous waste, the financial impact has to be taken into account. To deal with site-specific conditions, uncertainty on waste characteristics, operational performance and market conditions, a contingency provision is included. Recommended average values are proposed for excavation data (density, moisture content, waste composition), project costs (excavation, sorting, treatment,…) and project returns (material returns, electricity price, Flemish support schemes and land prices). The detailed input data can be found in Appendix B. As an illustration this simulation tool is applied to the sites selected in the analysis of the regional potential. The results of this exercise are reported in section 4.

2.3. Methodology to analyze the costs and benefits of an ELFM project from a societal perspective

In addition to private costs and benefits, every ELFM project is characterized by a wide set of potential effects to society, both positive and negative ones. For instance, after the landfill site has been mined, possible problems of leaching and groundwater contamination are permanently resolved. At the same time, energy input and investments are needed to perform such an excavation. To have an overall view on the value to society of ELFM projects, a detailed analysis should be made of every impact. However, weighting the positive and negative impacts against each other contains the risk of subjective influences. Indeed, comparing carbon emissions with remediation of groundwater pollution or resource scarcity is not straightforward. Moreover, besides environmental impact, economic feasibility is crucial. The integration of investment data and environmental gains requires an additional weighting step. The environmental economics literature recommends the use of Cost Benefit Analysis (CBA) to deal with this weighting step (Pearce et al., 2006; Brent, 2009; de Rus, 2010). Empirical research has established monetary values for many categories of costs and benefits. Using these values, the inventory of unweighted impacts can be transformed to a single monetary index. After this monetary transformation of benefits to society, the investment costs can be easily integrated to obtain a full-blown CBA. CBA allows to obtain a fully integrated view on the impact to society of ELFM projects, including external benefits and costs.

To obtain information for societal CBA, we focus in a first step on a particularly important environmental dimension of ELFM projects: its impact on greenhouse gas emissions. To calculate the carbon footprint, the Bilan Carbone™ (2007) methodology, developed by ADEME, the French government agency for the environment, will be used (see also Jones et al., 2013). In this carbon footprint, only greenhouse gases are considered which are covered by international agreements, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O). In the overall carbon balance, all incoming and outgoing materials streams are accounted for, as in financial book keeping.

The scope of the carbon footprint takes into account the widest possible range of factors related to company emissions (indicated as scope 3 – Bilan Carbone™, 2007). The way to estimate these emissions is to derive them from activity data: the number of trucks driven and distance traveled, tons 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 data, are transformed into greenhouse gas emission estimates by using a database of emission factors. To integrate the carbon footprint in the CBA, a monetary value has to be assigned to emissions of greenhouse gases. Different reference values circulate in the literature. Examples are the estimates by Tol (2005, 2007) of the social cost of carbon emissions or the expected future price of carbon in the current EU Emission Trading Scheme EU ETS (European Commission, 2008b).

In a second step, other effects for society than the carbon footprint are reviewed. After successful implementation of ELFM projects, large land areas are restored which can be used for housing, economic activities, recreation and nature reserves. The projects also eliminate the threat of future groundwater pollution. In addition, ELFM projects contribute to programs that tackle resource scarcity and import dependence. All of these impacts can in principle be assigned a monetary value based on literature data so that they can be used in CBA. Preferences of policy makers and society are however heterogeneous in a global world and therefore, monetary values of these preferences can vary widely. To remain coherent with the focus of our paper, we use monetary values that are applicable to a densely populated and industrially advanced region such as Flanders (northern part of Belgium, six million inhabitants).

3. Private costs and benefits of the ELFM case study project "closing the circle"

In this section the methodology to assess private profitability – as described in section 2.1 and illustrated in (the left part of) Fig. 1 – is applied to a specific ELFM case. The case study is an existing landfill situated in Flanders. 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 waste such as shredder material, metallurgical slags and dried sludge. The amount, the type and the location of the various waste streams landfilled in the past, have been documented in log books. It has been estimated that around 33% of the waste can be recycled as materials (WtM), either directly or after a controlled treatment process. The remaining fractions have a sufficiently high caloric value allowing them to be energetically valorized (WtE) after a pre-treatment. More information about the case can be found in Jones et al. (2013) and Tielemans and Laevers (2010).

An investment model was built according to the methodology described in section 2.1 in order to identify the impact of the performance drivers (technology, regulations and markets). The input values of the model can be found in Appendix A. The investment model determines the minimal ELFM support necessary to reach an IRR of 15%. In the base scenario, an ELFM support is approximately equal to the current market value of green power certificates (i.e. 108€/MWh in Flanders in 2010) is required to attain the target IRR. Note that we opt for an ELFM subsidy expressed in Euro per MWh but other schemes (investment support, tax breaks, incentives for material recuperation, land restoration) or combinations of support schemes are possible.

Using the investment model, the impact of a wide range of parameters on the IRR was investigated. The considered parameters (α) were (i) the amount of different (>10) waste types; (ii) the energy content of different 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 CO_2 cost or revenue.

Monte Carlo simulations show that the following parameters have an important impact on the economic performance (IRR and NPV): (i) WtE efficiency; (ii) electricity price; (iii) CO_2-price; (iv) investment costs of the WtE installation; (vi) operational costs of energy production and (v) ELFM support.

Table 1 shows the contribution of the different parameters in explaining the variation in IRR and their direction of influence (+ or –). First, the total variation in the IRR can be explained for 34% by the variation in WtE efficiency. Logically, a higher WtE efficiency results in a higher IRR. This shows that WtE efficiency is of key importance for the economic feasibility of ELFM projects. ELFM project developers could, for instance, try to negotiate contractually guaranteed electric efficiency rates with technology suppliers in order to limit their investment risk. The left panel in Fig. 3 illustrates the impact of WtE efficiency on the project's IRR in more detail. The different lines trace out the combinations of IRR WtE efficiency and resulting IRR for different investment cost levels. Roughly speaking, an increase of the WtE efficiency by one percent, leads to a gain in IRR of one percent. This relation is approximately linear on the interval of WtE efficiency values considered and does not change much with the investment cost level. It should be noted that the range definitions of the different parameters highly

Table 1
Performance drivers of ELFM.

Parameter	Minimum value	Maximum value	Relationship IRR
WtE efficiency (%)	21	29	33.6 (+)
Electricity price (€/MWh)	60	80	9.0 (+)
CO_2-price (€/ton CO_2)	−20	+20	29.2 (−)
Investment WtE (€/ton)	450	550	4.2 (−)
Operational costs WtE (€/ton)	40	70	16.2 (−)
ELFM support (€/MWh)[a]	85	125	+7.8 (+)

[a] The ELFM support is calculated as support per MWh electricity production (price green certificates) for a fixed share renewable energy (in Flanders: 47.75%).

influence the final impact of the different parameters on the project's IRR.

Secondly, the cost of CO_2-emission explains about 29% of the variation in IRR. We assumed a CO_2-emission coefficient of unity (one ton of waste incinerated results in one ton of CO_2-emission (NSCA, 2002)) and we assumed that the incineration would not receive free emission allowances. As there is significant uncertainty regarding the future regulatory treatment of CO_2-emissions of WtE installations in ELFM projects, and as future CO_2-prices in the EU ETS are highly unpredictable, we have chosen to consider the impact on the ELFM project IRR of a broad CO_2-price range: −80–+80 € per ton of CO_2. Negative prices can be interpreted in this setting as the impact of support for reducing CO_2-emissions. The results are plotted in the right panel of Fig. 3. Compared to a scenario in which CO_2-emissions of the WtE installation would not be priced, inclusion of the activity in the EU ETS scheme at a price of about 40 €/ton of CO_2 would lower the ELFM projects IRR by 5%.

Thirdly, the variation in the IRR is also explained by the variation in electricity price (for 9%) and by the variation of ELFM support (8%). The other parameters, like for instance prices of recovered materials, have less of an impact on the variation in IRR. Summarizing we can say that technology (WtE efficiency), markets (electricity price) and regulation (ELFM support) determine to a large extent the economic performance of ELFM projects. In particular the efficiency of the Waste-to-Energy technology and the price of its CO_2-emission have a key impact on the IRR. Also a guaranteed minimum support value for ELFM seems indispensable in order to make ELFM feasible.

4. Economic potential for ELFM projects in Flanders

In a next step, we scale up our analysis towards a regional point of view. We analyze the ELFM potential using the methodology as described by van der Zee et al. (2004) and build a cost-benefit simulation tool for the densely populated and industrial region of Flanders as explained in section 2.2.

Table 2 represents the selection of potential ELFM sites in Flanders. Our assessment according to the funnel approach by van der Zee et al. (2004) has narrowed down the initial number of 1618 historic landfills to 58 medium sized sites. Six of these landfills have a surface exceeding 500,000 m^2. Adding the ELFM potential of these historic landfills with the potential of landfills currently in exploitation gives an upper bound to the potential of ELFM in Flanders. The long-term ELFM potential in Flanders expressed in total site surface is more than 20 km^2. Note that once ELFM technology has matured, it might become interesting to also include smaller sites. Possibly recycling of machinery, mobile installations or clustering of different small sites might make smaller ELFM projects financially profitable in the future.

As we argued in section 2.2, entrepreneurs and policy makers require a benchmark to assess the economic opportunities of potential sites. Based on literature data, we therefore built a simulation tool that contains the major drivers of an ELFM project. Literature data serve as a starting point for economic analysis that can be fine-tuned along the project stages while more site-specific data become available. To illustrate the use of the cost-benefit simulation tool, we have analyzed the total Flemish economic potential for ELFM projects. An overview of the input data and references can be found in Appendix B. The summarized output data in Table 3 show that, under current conditions, WtE constitutes the most important cost (about 60% of all costs) as well as the most important benefit (more than 70% of all benefits). It should be noted that government incentives for renewable energy make up a substantial part of these benefits. Land reclamation constitutes a relatively low benefit in our calculations but that can of course be very different depending on local conditions and needs.

Summarizing, our calculations show that ELFM projects have a substantial positive economic potential for Flanders. The main driver of this positive result is the WtE activity in the ELFM projects. We recognize that this result is preliminary in the sense that it does not include all possible sources of economic benefits of ELFM projects because local site-specific conditions can have important positive impacts on the potential for WtM and WtE technologies. For instance, glass and building materials constitute a significant

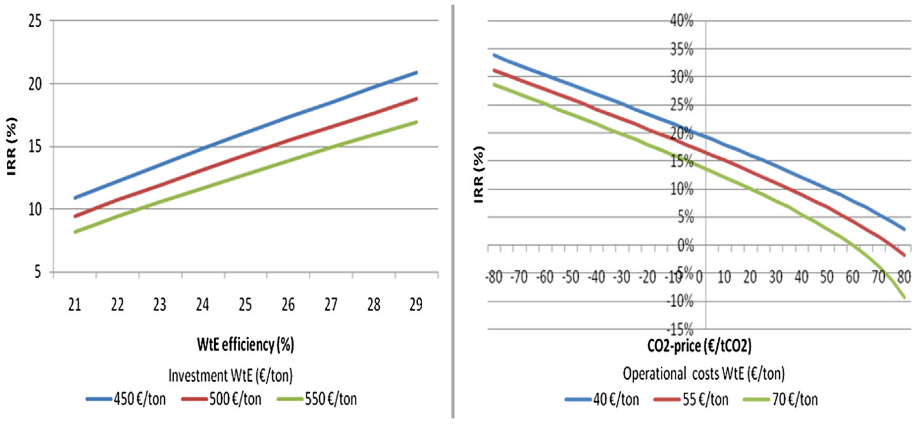

Fig. 3. The impact of WtE efficiency and CO_2-price variations on IRR.

Table 2
Selection of potential ELFM sites in Flanders.

	Selection criteria	Selection	Landfills
Step 0: database selection	Data on historic landfills irrespective of validity permit	Land Information Register	1618
Step1: selection based on qualitative indicators	Type of waste landfilled Exploitation period	Household waste 1950–1985	850
Step 2: selection based on crude, quantitative indicators	Size	Surface >100,000 m^2	58
		Surface >500,000 m^2	6
Step 3 & 4: on-site visit and full investigation	Further research required		

fraction of the recycled material but, as they have a relatively low economic value, transport costs limit substantially the profitability of recovering these materials from old landfills. Integrating landfill mining with infrastructure, industry or real estate development can create significant synergies for recycled building materials. Also low-heat energy recovery could create important synergies for local activities that require heat input like for instance glasshouse agriculture. In addition to these local synergies, the development of ELFM projects in Flanders might also lead to a new and competitive export industry capable of developing similar ELFM projects internationally. This type of new export industry aspects and synergies has not been integrated in our analysis but it might have an important positive impact on the economic potential of ELFM for Flanders.

5. Costs and benefits to society

Both the private investment analysis of the case study ('Closing the Circle') project and the regional upscaling to Flanders show that ELFM projects have a clear private economic potential when adequate regulation and support policies are in place. This is important because it shows that there is scope for private entrepreneurs to invest profitably in ELFM projects. In this section we broaden the scope of analysis by including also some of the most significant external effects of ELFM projects for the society. In particular, we want to explore the environmental impact of ELFM projects. In a first step we focus on the carbon footprint of the "Closing the Circle" case study. The footprint will be assessed and later monetized. In a second step the analysis of impacts for society is extended to the valuation of other benefits to society.

Table 3
Cost-benefit simulation tool: illustration for ELFM in Flanders.

General data	
Surface (m^2)	20,000,000
Excavated volume (m^3)	160,000,000
Weight cover soil (ton)	26,000,000
Weight waste (ton)	182,000,000
Treatment data	
WtM fraction: cover soil, granulates, metals (ton)	62,400,000
WtE fraction before drying (ton)	100,100,000
WtE electricity production (MWh)	97,493,229
Fines (ton)	45,500,000
Present value Costs	
Excavation (€)	177,894,199
Sorting & pre-treatment (€)	2,698,062 017
Incineration (€)	6,304,862 647
Contingency (€)	918,081,886
Present value Revenues	
WtM (€)	2,637,355 621
WtE (€)	8,785,195 215
Land reclamation (€)	800,000,000
Total (€)	2,123,650 088

5.1. Assessing the carbon footprint and its economic value

For the case study, we performed the carbon footprint analysis for the two scenarios assuming a time frame of 20 years. In this way, we investigate which scenario is the most beneficial in terms of climate change mitigation. The Remo 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 (CHP) cycle. This will generate an amount of electricity and an amount of recoverable heat. Keeping the situation unchanged 'forever' is called the Business as usual (BAU) scenario. No incoming materials, no outgoing materials. In a second scenario (ELFM) most of the historical waste from the Remo site would be recovered as energy and materials. As in the BAU scenario, energy recovered from methane would last for about 15 years. In the ELFM scenario, however, a WtE plant and a sorting and recycling plant (WtM) need to be built on the Remo site. All operational emissions of the six categories mentioned are taken into account (see Fig. 4). We assume that biogenic emissions do not generate any net addition to global warming.

The BAU scenario would only produce 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 BAU scenario. Greenhouse gas emissions of conventional market production methods will be

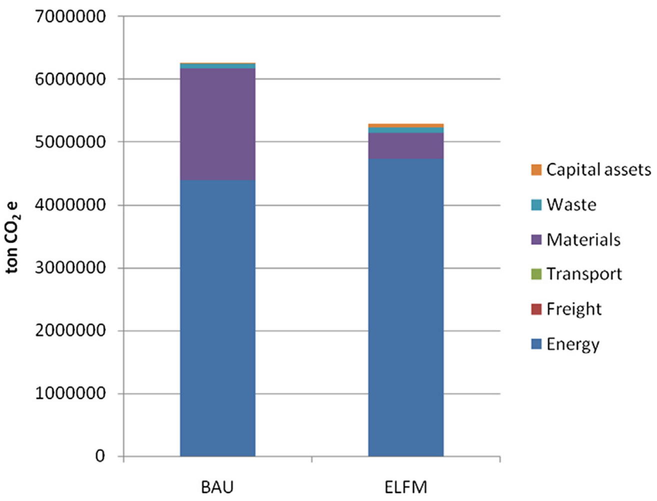

Fig. 4. Carbon footprint of BAU and ELFM scenario.

accounted for in the BAU carbon footprint. Comparing the footprints of both scenarios gives us an idea of which scenario is more beneficial towards greenhouse gas mitigation.

For the same amount of energy and materials, the ELFM scenario leads to 5.3 Mton CO_2e greenhouse gas emissions compared to 6.3 Mton CO_2e in the BAU scenario. This corresponds to 15% less greenhouse gas emissions (see Fig. 4). Most of this reduction in greenhouse gas emissions is accounted for by the emissions savings resulting from material recovery. Although emissions from WtE are higher in the ELFM scenario than in the BAU scenario, this is compensated by the decrease in greenhouse gas emissions in the WtM activities. In particular, the ELFM scenario makes it possible to replace extraction of greenhouse gas intensive virgin materials by less emission intensive locally recycled materials.

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 (Bilan Carbone™, 2007). 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 caloric 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. This will be discussed in the following section.

5.2. Valuation of external effects

The carbon footprint analysis shows that the ‘Closing the Circle’ project reduces emissions with one million tons of CO_2 equivalents. The monetary value of CO_2-emissions is estimated between € 20 per ton (Tol, 2007) and € 40 per ton (EU, 2008b). In addition to greenhouse gas emissions, the impact of ELFM projects on other air emissions should be evaluated in a full cost benefit analysis. To evaluate the impact of the different air pollutant emissions, a comprehensive air emission footprint can in principle be done and the changes in air pollution can be valued using the external cost estimates of the ExternE project for instance. This would require a very detailed analysis – not only of ELFM techniques but also of the full life cycle for the recovered materials – that takes into account current and future emission standards set by the regulatory environmental authorities. Such an analysis falls beyond the scope of our contribution.

In addition to its effect on air pollutants, an ELFM project may potentially restore large areas with no or limited use to zones with economic activity (industry, housing, recreation,…) or valuable nature reserves. The positive external benefit of nature restoration can potentially be high in densely populated regions and is certainly higher than the market value of the land. LNE (2007) reports different reference values for national parks in Flanders. Analysis based on travel cost pricing shows that the Meerdaal–Heverlee forest (2000 ha[2]) has a yearly recreational value of € 2 million (Moons et al., 2000). The same study uses a contingent valuation method to quantify the one-time willingness to pay at € 26 million to transfer a military domain of 160 ha in forest area. Smaller nature parks close to residential areas are even more valued. Using a combination of hedonic pricing, travel method pricing and contingent valuation, Ecolas (2004) estimates the combined use value of visitors and nearby residents at € 3–37 million for parks from 1 to 163 ha. Taking into account the estimated willingness to pay for recreation and existence values of nature, the value of land reclamation to society may be – depending on local conditions near the ELFM site – considerably higher than market prices. Another methodology to quantify land use is proposed by Dijkgraaf and Vollebergh (2004). They argue that space occupied by a landfill should be valued at the price of the most valuable opportunity forgone. In Flanders that would be residential building space at a price of € 155 per m^2. Most of these approaches lead us to conclude that the benefits to society of the land reclamation after an ELFM project are most likely higher than the prevailing market prices of land that were used in the assessment of private costs and benefits.

Only recently landfills are subject to strict legislation and standards. Old landfills rarely have protective layers to avoid soil and groundwater pollution. Contamination strongly depends on local conditions. Some landfills are situated in abandoned sand mines or unused lowlands with high groundwater mobility. Health and environmental impacts will be high. Other landfills have a natural clay protection layer and will only have limited dispersion of the leachate. Thewys et al. (2000) report two hedonic studies in Flanders that value the external costs for the neighborhood of two important areas with soil pollution at € 1–22 million. The exact degree of risk seems to be less important than the knowledge that a contamination is present. By mining the landfill, ELFM projects eliminate further risk of soil contamination. This is an important benefit to society of ELFM projects that is typically not, or only partially, reflected in private costs and benefits born by ELFM project developers.

Industrial economies are strongly dependent on the import of fossil fuel resources. The dependence on imported resources creates a vulnerability to sudden price shocks. Leiby (2007) shows that fossil fuel energy prices do not fully incorporate this macroeconomic risk. He estimates the external benefit of reducing import dependence at 5–15% of the market value of energy. WtE uses locally available resources that reduce import dependence. This is valid for the energy produced from the organic (renewable) fraction as well as for the energy originating from the residual (non-renewable) combustible fraction. As municipal solid waste contains a high fraction of renewable organic waste, WtE also limits the dependence of the energy mix on non-renewable resources. Although the reduced import dependence is hard to quantify in monetary terms, it does constitute a significant benefit to society.

The Belgian and Flemish governments have ratified European and international treaties that define targets for carbon emissions, renewable energy, import dependence, nature reserves and forest conservation. The cost of the support mechanisms that are in place to meet these obligations is significant. Certificates for green energy are exchanged at € 108 per MWh. Combined heat and power certificates are exchanged at € 39 per MWh energy savings. Subsidies exist for forest plantations and maintenance. As ELFM projects help to reach these targets, governments have a clear benefit by stimulating ELFM projects. In the private investment analysis, subsidies in the form of green power certificates were already taken into account. Under the assumption that the current market price of these certificates reflects the shadow cost of the targets on greenhouse gas emissions and renewable energy use, these external environmental benefits are already taken into account in our analysis so far.

The examples above of different external benefits lead us to the conclusion that there are substantial extra benefits to society from the reduction in air emissions, land reclamation and lower import

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[2] 1 ha = 10.000 m^2.

dependence for energy and materials, than the numbers we used so far in the private investment analysis. This reinforces the case for developing ELFM projects and justifies public support mechanisms like subsidies to internalize these positive externalities.

6. Conclusions

In this paper, methodologies to assess the economic potential of EFLM is proposed and applied. Based on an ELFM case study, we found that technology, regulation and markets have a clear impact on the economic potential of landfill mining. The development of innovative technologies (and especially Waste-to-Energy technologies) 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, leveling out the importance of material prices. Besides technology and markets, also regulation plays an important role determining the private economic potential 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. Moreover, as local conditions can have a significant impact on the benefits to society of an ELFM project, a flexible support framework is needed.

In fact, with regard to landfill mining the complex trade-off between economic, social and environmental issues, demonstrates the need for (i) a more detailed information of economic, social and environmental aspects and (ii) a clear, integrated decision tool. We have contributed to this goal by studying an ELFM study in detail and by scaling up the results to the regional level of Flanders. After identifying potential ELFM sites in Flanders, we compared private costs and benefits and concluded that there is a clear incentive for entrepreneurs to initiate such projects if adequate support is provided. Finally, we broadened the scope of the analysis by reviewing in a more qualitative way some important external effects like groundwater contamination, contribution to renewable energy and greenhouse gas reduction objectives, and land reclamation values. An assessment of the carbon footprint of the case study revealed a substantial reduction of greenhouse gas emissions by about 15% compared to a business-as-usual. Also substantial external benefits can be expected from land reclamation in a densely populated region like Flanders. Overall, we concluded that, also from the point of view of society, the development of ELFM projects has a positive pay-off for Flanders.

We recognize that further research is needed to refine and extend the social cost-benefit simulation tool. Aspects for which little data is available or for which detailed local conditions matter should be included. In this way, a sound estimation of the potential of ELFM in Flanders can be made in order to support policy making and to contribute to enhanced waste management policies.

Appendix A. Case study input data (in round figures).

General data		Sources
Total amount dry waste (million ton)	12.8	Case study
Time length (years)	20	Case study
Internal rate of return (IRR)(%)	15	Industrial reference
Excavation and storage cost (€/ton)	4	Case study
Waste composition case study	**Share of total**	**Share going to WtE (%)**
Shredder (wt%)	17	85
Plastics (wt%)	16	100
Paper (wt%)	15	100
Slag (wt%)	6	0
Industrial sludge (wt%)	6	50
Construction waste (wt%)	6	0
Wood (wt%)	5	100
Other (metals, glass, textiles, organic,...) (wt%)	29	(Total of all waste categories <5% of total amount of waste)
Waste to materials (WtM)		**Sources**
Share WtM of total amount of waste (wt%)	33	Case study
Weighted average WtM cost[a] (operational + capital costs) (€/ton)	11	Case Study
Weighted average WtM revenues[b] (€/ton)	13	Case study
Waste to energy (WtE)		**Sources**
Share WtE of total amount of waste (wt%)	67	Case study
Capital cost (€/ton capacity)	500	VITO, 2001; TNO, 2006
Exploitation cost (€/ton)	55	VITO, 2001; TNO, 2006; VITO, 2007
Calorific value waste after separation & drying (MJ/kg)	16	Case study
Energy efficiency (%)	25	C-tech, 2003
Price electricity (€/MWh)	70	CREG, 2010 – Energy stock exchange
Fraction renewable energy (%)	47.75	OVAM, 2011; Flemish directive, 5/03/2004
Price green certificates (€/MWh)	108	Support renewable energy, VREG, 2010 – Belpex
Land reclamation		**Sources**
Weighted land price (€/m^2)[c]	0	Case study

wt%: weight percentage.

[a] Crushing, screening, presorting, separation, sales costs.

[b] Revenues from shredder, metals and slag.

[c] Fully restored to nature area wt%.

Appendix B. Cost-benefit simulation tool – input data.

		Sources
General data		
Surface excavated (m^2)	20,000,000	OVAM[a] archives; van der Zee et al., 2004
Depth waste landfill (m)	7	OVAM archives; "Closing the circle" reference
Thickness overlaying soil layer (m)	1	OVAM archives
Time length (years)	15	VITO, 2001; TNO, 2006
Cost contingency (%)	10	Industrial reference
Discount factor[b] (%)	4	Pearce et al. (2003), the standard discounting rate EU (http://ec.europa.eu/governance/impact/)
Pre-treatment		
Cost excavation (€/ton)[c]	1.5	Industrial reference
Wet density (waste + soil) (ton/m^3)	1.3	Hogland et al., 2004; Hull et al., 2005
Separation & drying (€/ton)	20	Savage et al., 1993; Göschl, 1999
Efficiency metal recovery (wt%)	90	Savage et al., 1993; VITO, 2001; Sekito et al., 2003
Composition excavated materials[d]		
Moisture content excavated (wt%)	30	Morelli, 1990; EPA, 1997; Walsh, 2002; Themelis et al., 2002; Hogland et al., 2004; Hull et al., 2005; VITO, 2005; EPA, 1997; Mira, 2007; EPA, 2009; Renosam, 2009; Senternovem, 2009; Compendium, 2010; Meinel, 2010
Fines fraction (<5 mm) (wt%)	25	
Ferro fraction (wt%)	5	
Non-ferro fraction (wt%)	1	
Granulate fraction (wt%)	20	
Moisture content after drying (wt%)	15	VITO, 2001; C-tech, 2003; Industrial feedback MBT
Waste to Materials (WtM)		
Price ferro (€/ton)	230	Fost Plus, 2010; De tijd, 07/04/2011; Eurofer scrap price
Price non-ferro (€/ton)	1000	Fost Plus, 2010; De tijd, 07/04/2011; industrial feedback
Price granulates (>5 mm) (€/ton)	1	VITO, 2001; Fost Plus, 2010
Price fines (<5 mm) (€/ton)	0	Re-use on-site
Waste to Energy (WtE)		
Capital cost (€/ton capacity)	500	VITO, 2001; TNO, 2006
Exploitation cost (€/ton)	55	VITO, 2001; TNO, 2006; VITO, 2007
Calorific value waste after separation & drying (MJ/kg)	16,5	VITO, 2001; ECN, Phyllis database; Industrial reference MBT; C-tech, 2003; IPPC, 2006
Energy efficiency (%)	25	C-tech, 2003
Price electricity (€/MWh)	70	CREG, 2010 - Energy stock exchange
Fraction renewable energy (%)	47.75	OVAM, 2011; Flemish directive, 5/03/2004
Price green certificates (€/MWh)	108	Support renewable energy, VREG, 2010 – Belpex
Land reclamation		
Weighted land price (€/m^2)[e]	40	see weighted analysis below
Reference prices land use Flanders		
Residential area (€/m^2)	155	Statbel.fgov.be, kerncijfers vastgoed, 2011
Industrial area (€/m^2)	80	Reference: Sale industrial zone of 95 ha, 2011
Agricultural land (€/m^2)	10	Estimation geometrical surveyor
Nature (€/m^2)	3	ANB, 2010; Purchase Natuurpunt, 2010
Presence in database		*See section 'Methodology to asses regional potential'*
Residential area (%)	3.4	OVAM archives
Industrial area(%)	39.0	OVAM archives
Agricultural land (%)	20.3	OVAM archives
Nature land (%)	37.3	OVAM archives
Weighted value (€/m^2)	39.62	

[a] OVAM: Flemish Public Administration of Soil and Waste.

[b] A discount factor of 4% applied on a lifespan of 15 years gives a multiplication factor of 74% when comparing annual costs and benefits with investments made at the start of the project.

[c] Inclusive odor control and safety management.

[d] Based on reports of excavated landfills and literature describing historical composition of landfilled municipal waste in Western Europe (average historical composition: Paper and cardboard 25%, Plastics 7%, wood 3%, Rubber & leather 3%, textiles 2%, organics 35%, Glass 11%, Ferro 5%, Non-ferro 1%, inert 8%).

[e] The implicit assumption is made that land occupied with a historic landfill cannot be sold. ELFM upgrades the area so that it is available for normal market transactions. The private investor can internalize the price increase either by ownership or by a financial compensation from the landlord.

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