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DEVELOPMENT OF A RESOURCE CLASSIFICATION FRAMEWORK FOR OLD LANDFILLS IN FLANDERS (PROJECT RECLAF)

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ABSTRACT: Within the project RECLAF (Resource Classification Framework for Old Landfills in Flanders) the resource recovery potential of approximately 2,000 historic landfills in Flanders is prospected. The research project's goal is to systematically provide information for the future management of these former landfill sites, e.g. whether the sites are to be mined or not and under which conditions. Therefore, a consistent and practical classification framework including an evaluation tool is tailored to the specific Flemish situation. Similar to techniques used in the mining industry, this tool is capable to prioritize potential extraction projects by labeling the landfilled materials as either 'reserves' (current economic extraction confirmed) or 'resources' (reasonable prospects for economic extraction in the foreseeable future) or none of both, and to reveal critical factors for the classification of the project. In the presented case study the socioeconomic viability of mining an old landfill close to Antwerp is evaluated. In a first step, relevant material and energy flows are quantified in a Material Flow Analysis. In a second step, a Discounted Cash Flow analysis is performed from a public entity's perspective, considering direct monetary effects (i.e. costs for excavating, transporting, processing materials and the disposal of residues, revenues for selling secondary products and avoided aftercare costs) as well as some selected non-monetary or indirect financial effects. Potential greenhouse gas emission savings of a landfill-mining project compared to a "Do-Nothing" scenario are monetized via a hypothetical CO_2 tax. Further, the prevented pollution of soil, ground and surface water due to landfill mining is included via avoided aftercare costs. In addition, after selling the clean regained land, revenues from annual land tax are incorporated as indirect financial long-term effects for municipalities.

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The evaluation yields a negative net present value of in total -17 mio € (-44 €/t of excavated waste). This implies that the project is currently not economically viable, and can therefore certainly not be classified as 'reserve'. Main drivers of the economic performance on cost side are the sorting costs. Compared to other landfill mining projects, total revenues are lower since the share of metals present in the landfill is a) relatively small and b) not being recovered. Avoided after care costs for 70 years and selling regained land amounts each to approximately 40 % of the total revenues. Gained land tax for a period of 70 years plays a minor role (10%).
Based on required future changes in key modifying factors to make the project economically viable, it could be decided, whether the landfill can be labeled at least as 'resource' or not. The calculated cut-off land price to reach the break-even point is 502 €/ m^2 (instead of currently 150 €/m^2). A combination of increasing land prices up to 350 €/m^2 and parallel decreasing sorting costs to 15 €/t (from currently 35 €/t), can in the authors' opinions realistically be reached. Consequently, the landfill has reasonable prospects for economic extraction in the near future and is classified as 'resource'. Further historic landfill sites in Flanders will be investigated to refine this evaluation tool.

Keywords: Landfill Mining; Urban Mining; Anthropogenic resources; Resource classification

1. INTRODUCTION

Flanders faces a waste heritage of 2.061 landfills, out of which the majority of 2.033 is no longer operational. To evaluate these landfills' contamination risks and their respective resource potential, the Public Waste Agency of Flanders (OVAM) developed the Flaminco-model (Flanders Landfill Mining, Challenges and Opportunities) as a decision support tool. Building on this work, OVAM in cooperation with the Institute for Water Quality, Resource & Waste Management of TU Wien is currently prospecting the resource recovery potential of these historic landfills within the project RECLAF (Resource Classification Framework for Old Landfills in Flanders).

At TU Wien the UNFC-2009 classification framework, originally developed for geogenic resources, has been adapted and successfully applied to two landfill mining projects (cf. Krüse, 2015; Winterstetter et al., 2015). The landfills investigated, i.e. the Hechingen landfill in Germany and the Remo landfill in Flanders, however, differ significantly from the 2,000 historic landfills in Flanders. Those differences, i.e. in size, in waste composition, and also with regard to the level of information available about the deposited waste, affect the evaluation and classification of mining projects. For instance the time required for mining would be only in the range of one year for the smaller sites instead of 30 years for the Remo landfill. Furthermore, materials excavated from small landfills are rather to be treated off-site using existing plants and infrastructure, whereas for large-scale landfill mining projects the installation of new plants might pay off.

Further, Belgium is a highly densely populated country (2016: 375 persons / km^2) with population expected to increase from currently 11.3 million to 12.5 million inhabitants in 2050 (+10%) according to World Population Review (2016). Rising land prices and the need for new clean land is therefore one of the key drivers of landfill mining in Flanders, where both current population density and growth rates are even higher than in Belgium as a whole. But also factors like the status / existence of landfill barriers, environmental hazards, the type of waste landfilled, proximity to other waste treatment/disposal facilities, the utilization of the fine and inert fractions in the vicinity of the old landfill are most relevant from a resource classification point of view.

2. OBJECTIVES

The research project's overall goal is to systematically provide information for the future management of former landfill sites in Flanders, e.g. whether the sites are to be mined or not and under which conditions. Potential mining projects should be prioritized, by labelling the landfilled materials as either 'reserves' (current economic extraction confirmed) or 'resources' (reasonable prospects for economic extraction in the foreseeable future) or none of both, and by revealing critical factors for the project's classification. Therefore, in a first step, a previously developed resource classification framework including an evaluation tool is adapted to the specific Flemish situation. Based on a first case study the socioeconomic viability of mining an old landfill is evaluated, being an essential component for the final classification under UNFC-2009.

3. MATERIALS AND METHODS

3.1 Background on the landfill-mining case study

The investigated former landfill site is located in Bornem, a municipality in the Belgian province of Antwerp. The nearest residential area is the community of Temse (around 30,000 inhabitants), which is located on the other side of the Schelde river, about 600 m away from the former landfill site. The adjoining areas are largely undeveloped and are used primarily as forest and meadow. The landfill received over 390,000 metric tons of mainly municipal solid waste (MSW) between 1947 and the late 1970s, when it was closed. It is partially covered with a clay cover from the dike reinforcement work carried out in the period 1978-1980. The bottom layer consists of sand and bulk material. Water catchment areas and protection zones are not in the landfill's immediate vicinity. However, according to the vulnerability map of the county Antwerp the surrounding groundwater is classified as "very vulnerable" (Ca1 index). The nearest groundwater well is located at a distance of approximately 400 meters across the Schelde river. Thus, no influence on groundwater extraction is expected. The former operator was under contract with the municipalities Bornem and Puurs. Today it covers an area of 50,000 square meters (Van Vijle and Van Vooren, 2010).

For the evaluation we assume the landfill to be excavated within one year, with operations starting in 2017. The share of metals is almost negligible and therefore not being recovered. (OVAM, 2015). The fine fraction will be sold as construction material after extraction, while plastics and wood will be entirely turned into Solid Recovered Fuel (SRF) and used in a off-site cement kiln in Antwerp. At the end of excavation activities the regained cleaned-up land will be sold as building land (own assumptions).

3.2 Operative procedure for profiling and evaluating a landfill-mining project

According to the operative evaluation procedure, that has been developed to classify anthropogenic resource deposits under UNFC-2009, the stages ‘prospection’, ‘exploration’ and ‘evaluation’ have to be run through, before starting actual mining activities. Details can be found in Winterstetter et al. (2015), Winterstetter et al. (2015a) and Winterstetter et al. (2015b). Within its Enhanced Landfill Mining (ELFM) policy, OVAM developed a similar approach, comprising also three evaluation steps: ‘Mapping’, ‘surveying’ and ‘mining’ (Behets et al., 2013; Wille, 2016). After the screening of existing data bases and the selection of a specific deposit to be mined, basically three key aspects - as used under the resource classification framework UNFC-2009 (UNECE, 2010) - need to be considered (cf. Table 1):

A) Knowledge on composition of the deposit & share of extractable & potentially usable materials

B) Technical feasibility & project status: Under what conditions can materials be extracted & utilized & how far is the project advanced?

C) Socioeconomic viability of extraction & utilization

Table 1: General operative procedure for evaluating a landfill-mining project (based on Winterstetter et al., 2015b). MFA = Material Flow Analysis, DCF = Discounted Cash Flow Analysis

Evaluation steps	**Goal**	**Influencing factors**	**Methods for decision foundation**
***1. Prospection / Mapping* (screening)**	**Selection of a deposit to be mined**	**System Variables* a) Availability status b) Type & Location c) Mining condition d) Volume**	Analysis & evaluation of landfill reports / data bases on former landfill sites
2. Exploration / Surveying of a specific landfill	**A) Knowledge on composition of the deposit & share of extractable & potentially usable materials B) Technical feasibility & Project status: Identify options for technologies & project set-ups**	**e) Composition f) Legal, institutional, organizational & societal structures g) Project status h) Different options for methods, technologies & project set-ups for extraction & processing with specific efficiencies & maturity**	Detailed investigation of the landfill: Data from waste disposal log book & waste sampling & analysis Micro scale MFA with specific recovery efficiencies Technology assessment, policy framework analysis, stakeholder analysis
3. Evaluation	**C) Socioeconomic viability of extraction & utilization**	**Modifying factors**** **i) Prices for secondary products j) Costs k) Avoided costs l) Indirect financial effects & monetized external effects**	DCF analysis & cut-off values for key parameters Net Present Values (NPV) a) NPV > 0: Reserve b) NPV < 0: Resource or not?
4. Classification	**Combination of all criteria & classification under UNFC-2009**		

* Determine the physical amount of potentially extractable materials
** Direct impact on the project's economics, but not within the domain of a single stakeholder

Based on a template showing the influencing factors on the classification (cf. Table 1) a potential mining project is profiled, using the data and information on the Bornem case study, as a foundation for the following evaluation.

3.2.1 Prospection / Mapping

The goal of the mapping / prospection phase is to select a specific mining project by screening existing data bases and reports on former landfills (cf. Table 1). The Flaminco model (Flanders Landfill Mining, Challenges and Opportunities) was created as a decision support tool, in order to prioritize the landfills from the ELFM-database for potential mining, according to a) their contamination risks and b) their respective resource potential. The model is based on a multi-criteria analysis using different criteria and specific weighing factors (Behets et al., 2013; Wille, 2016). For this purpose, information on the landfill's type, its location, its specific mining condition (e.g. whether remediation is necessary), its size, depth and volume is collected during this phase.

3.2.2 Exploration / Surveying

In the exploration / surveying phase the selected landfill site in Bornem is investigated in more detail: For the landfill site in Bornem test excavations, trial sortings and waste characterizations of a batch of 500 metric tons have been performed in order to generate and deepen the knowledge on the landfill body's quantitative and qualitative composition as well as on the best suited sorting option (OVAM, 2015). Based on this information, relevant material and energy flows are quantified using the method of Material Flow Analysis (MFA). MFA is a systematic quantification of the flows and stocks of materials within a defined system (in space and time), connecting the sources, the pathways and the sinks of a material (Brunner and Rechberger, 2004). State-of the art transfer coefficients for all relevant processes define that part of the resource potential, which is under current technological conditions extractable and potentially usable. Using MFA further allows to model different project set-ups as well as different options for extraction methods and sorting and processing technologies with their specific recovery efficiencies.

For this case study we modeled only one scenario using the software STAN (Cencic and Rechberger, 2008), comprising the processes "Excavation", "Stationary sorting plant" and "Advanced treatment of the fine fraction" as described in OVAM (2015) as well as "Preparation of Solid Recovered Fuel (SRF)" and "Landfill".

3.2.3 Evaluation

In the actual evaluation step, the socioeconomic viability of extracting and utilizing the identified extractable raw materials is explored. Within a Discounted Cash Flow (DCF) analysis, the project's Net Present Value (NPV) is computed by subtracting the investment cost from the sum of the discounted cash flows over a certain period of time. This method is also widely used for the evaluation for mining projects of primary resources (Torries, 1998).

The evaluation is performed from a public entity's macro perspective, considering direct monetary effects (i.e. costs for excavating, transporting, processing materials and the disposal of residues, revenues for selling secondary products and avoided aftercare costs) as well as some selected non-monetary (avoided GHG emissions) or indirect financial effects (newly gained land tax).

The fine fraction is sold as construction material after extraction, while plastics and wood fractions are entirely turned into Solid Recovered Fuel (SRF) and used in a off-site cement kiln in Antwerp (cost 50 €/t). A certain amount of excavated materials has to be re-landfilled off-site (cost 65 €/t). At the end of excavation activities the regained cleaned-up land will be sold at a price of 150 €/m^2.

Potential greenhouse gas emission (GHG) savings of a landfill mining project compared to a “Do-Nothing” scenario are included via a hypothetical CO_2 tax at 10 €/t CO_2 eq. This corresponds to the average price of carbon emission futures between 2010 – 2015 (Investing.com, 2016). Additionally, the prevented pollution of soil, ground and surface water due to landfill mining is counted in by avoided aftercare costs. Moreover, after selling the cleaned-up regained land, revenues from annual land tax are incorporated as indirect financial long-term effects for municipalities. In addition, a rather low discount rate of 3 % is applied and aftercare obligations in the “Do-Nothing” scenario are assumed to be 70 years (minimum requirement under the landfill directive is 30 years), which implies that both avoided emissions and avoided aftercare costs are higher due to landfill mining and can be considered as revenues (Winterstetter et al., 2015).

All costs and revenues are discounted over 1 year. The sensitivity of the evaluation results with respect to input parameter variation is analyzed to identify the main drivers of economic performance. A positive NPV implies that a project is economically viable. Consequently, the evaluated materials can be classified as ‘reserve’. If the NPV turns out to be negative, however, one has to judge, whether there are reasonable prospects for economic extraction in the foreseeable future. Whether the deposit can be labeled a ‘resource’ or not, can be decided by anticipating realistic changes of key parameters, by calculating the so-called “cut-off values”, i.e. required changes in prices or costs to reach the break-even point (NPV = 0) (cf. Winterstetter et al., 2015).

4. RESULTS

Following the previously described operative evaluation procedure (cf. Table 1) we profiled a potential mining project at the former landfill site in Bornem, as a basis for the following evaluation (cf. Table 2).

Table 2: Profile of a potential mining project at the former landfill site in Bornem

Profile: Landfill Mining Project Bornem	
Main Goal: Determine the socioeconomic viability from a public entity's perspective	
System variables	
a) *Availability status*	• Obsolete stock
b) *Type & location*	• MSW landfill (some IW) in Flanders
Period of landfilling	• ca. 1947 - 1977
Distance from LF to stationary sorting plant (km)	25
Distance from stationary sorting plant to cement kiln (km)	25
Distance from stationary sorting plant to disposal (km)	50
Proximity to other landfills (km)	25
Land use: Location in relation to actual /potential residential, industrial, agricultural, recreational & ecological valuable area	• Nearest residential area: Community of Temse, located across the Schelde river, about 600 m away from the site. • Adjoining areas largely undeveloped, used primarily as forest and meadow (Nature /recreational area)
Vulnerability of the soil & groundwater	• Landfill is partially covered with a clay cover from the dike reinforcement work. • The bottom layer consists of sand and bulk material, but there is no bottom liner and leachate infiltrates into the subsurface. • Water catchment areas and protection zones are not in the landfill's immediate vicinity. • According to the vulnerability map of the county Antwerp the surrounding groundwater is classified as "very vulnerable" (Ca1 index).
Location in relation to surface water, water wells & flooding area	• The nearest groundwater well is located at a distance of approximately 400 m across the Schelde river. No influence on groundwater extraction is expected.
c) *Specific mining condition*	• No urgent need for remediation, mainly mined for land / resource recovery (pull situation)
d) *Volume*	
Wet / dry weight (t)	390,000 / 273,000
Height (m)	6
Area (m^2)	50,000

Density (t/m³)	1.3
e) *Composition*	• Data from old reports, sample excavations & trial sorting (combustible fraction, fines, plastics & organics, wood, others)
f) *Legal, institutional, organizational & societal structures*	• No legal LFM framework existing, but established institutional structure with a number of committed partners, positive public perception
g) *Project Status*	• Project is still in the pre-feasibility stage with mainly design & planning activities, operations only on a pilot scale
h) *Project set-up for*	
Planned project period	• 1 year (start 2017)
Considered after care period	• 70 years*
Interest rate (real)	• 3 %
Sorting Options	• Stationary off-site
Thermal treatment	• Off-site co-combustion of the combustible waste fraction in a cement kiln
Options fine treatment	• Advanced (to obtain soil-like quality)
Re-landfilling	• Off-site
Modifying factors	
i) *Prices for secondary products*	• Regained cleaned-up land, soil / construction material
j) *Costs*	• Costs for excavation & pre-treatment • Costs for sorting & separation • Costs for fine treatment • Costs for disposal of SRF at cement kiln • Costs for disposal of residues • Transportation costs
k) *Avoided costs*	• Avoided costs for aftercare, considered for 70 years
l) *Indirect financial effects & monetized external effects*	• Expected newly gained land tax, considered for 70 years • Avoided GHG emissions via hypothetical CO_2 –tax, considered for 70 years

Table 2 (continued)

*In practice the landfill is not managed, hence no aftercare measures are taken. However, in order to evaluate the "environmental damage" caused by the landfill, a hypothetical aftercare period of 70 years (including the collection and treatment of leachate and landfill gas) has been assumed.

To evaluate the project's socioeconomic viability, the NPV is calculated based on the MFA results, i.e. the potentially recoverable and salable quantities of secondary products (cf. Table 3).

Table 3: Total potentially recoverable and usable quantities from the Bornem landfill

	Unit	
Regained salable land	[m²]	50,000
SRF	[t]	129,200
Soil / construction material		207,400
Amount of materials to be re-landfilled (sorting residues)		34,600

Total discounted cost amount to -28 million € (-73 €/ton). The overall evaluation yields a negative NPV of in total -17 million €, which equals to -44 € per ton of excavated waste. This implies that the project is currently not economically viable, and can therefore certainly not be classified as 'reserve' (cf. Table 4).

Table 4: Total discounted cost and NPV (total and per 1 ton of excavated waste). Cash flows are discounted over 1 year with a discount rate of 3 %.

Total discounted cost (mio €)	- 28
Total NPV (mio €)	- 17
NPV in € /t of total excavated waste	- 44

Main drivers of the economic performance on cost side are clearly the relatively high sorting costs, owing to the complex sorting procedure selected (OVAM, 2015). Compared to other landfill mining projects, total revenues are lower since the share of metals present in the landfill is a) relatively small and b) not being recovered. Avoided after care costs for 70 years and selling regained land amounts each to approximately 40 % of the total revenues. The land tax gained by the municipality for a period of 70 years plays a minor role (10%). The greenhouse gas emission saving potential compared to a "Do-Nothing" scenario turned out to be negative and therefore appears on the cost side.

Based on required future changes in key modifying factors to make the project economically viable, it could be decided, whether the landfill can be labeled at least as 'resource' or not. The calculated cut-off land price to reach the break-even point is 502 €/m^2 (instead of currently 150 €/ m^2) (Figure1).

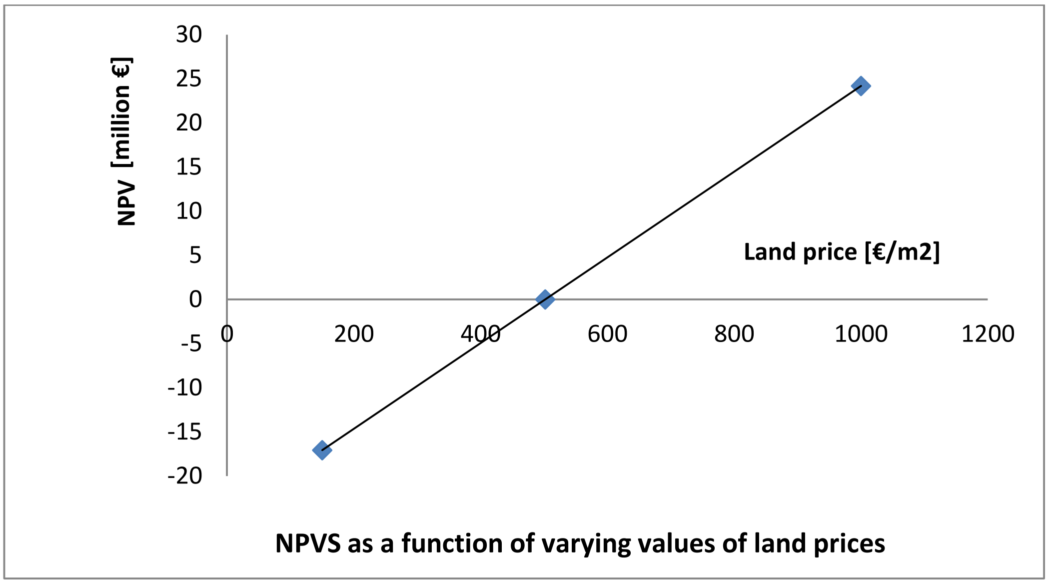

Figure 1: NPVs are shown as a function of varying values of land prices. Cut-off land price are reached at 502 €/ m^2 (instead of currently 150 €/ m^2).

A combination of increasing land prices up to 350 €/m^2 and parallel decreasing sorting costs to 15 €/t (from currently 35 €/t), can in the authors' opinions realistically be reached. Consequently, the landfill has reasonable prospects for economic extraction in the near future and is classified as 'resource'.

5. SUMMARY AND OUTLOOK

The research project's overall goal is to systematically provide information for the future management of former landfill sites in Flanders. In this study, a previously developed resource classification framework including an evaluation tool is adapted to the specific Flemish situation. In the presented case study the socioeconomic viability of mining an old landfill close to Antwerp is evaluated.

In a first step, relevant material and energy flows are quantified in a Material Flow Analysis. In a second step, a Discounted Cash Flow analysis is performed from a public entity's perspective. The evaluation yields a negative net present value of in total -17 million € (- 44 €/t of excavated waste). This implies that the project is currently not economically viable, and can therefore certainly not be classified as 'reserve'. Main drivers of the economic performance on cost side are clearly the relatively high sorting costs. Selling regained cleaned-up land amounts to 40 % of the total revenues. To decide whether the deposit can be labeled as 'currently economically viable for extraction' or whether there are at least 'reasonable prospects for future economic extraction', the concept of "cut-off values" is used. Based on required future changes in key modifying factors to make the project economically viable, it could be decided, whether the landfill can be labeled at least as 'resource' or not. The calculated cut-off land price to reach the break-even point is 502 €/m^2 (instead of currently 150 €/m^2). A combination of increasing land prices up to 350 €/m^2 and parallel decreasing sorting costs to 15 €/t, can in the authors' opinions realistically be reached. Consequently, the landfill has reasonable prospects for economic extraction in the near future and is classified as ‘resource’.

In a next step, all of the aforementioned results will be combined and used as a basis for the classification under UNFC-2009 (cf. Winterstetter et al., 2015; Winterstetter et al., 2015b).

This study provides a transparent base for future evaluations of further landfill sites in Flanders in order to prioritize potential mining projects. In the end the method presented should allow to assess the overall amount of recoverable materials from Flemish landfills in dependency of different modifying factors (e.g. prices for scrap metals, SRF disposal, land, or costs for sorting, incineration and re-landfilling).

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ABBREVIATIONS

DCF: Discounted Cash Flow analysis
LFM: Landfill Mining
MFA: Material Flow Analysis
MSW: Municipal Solid Waste
NPV: Net Present Value
OVAM: Public Waste Agency of Flanders
SRF: Solid Recovered Fuel
UNFC-2009: United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009

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