Determination of the potential of Landfill Mining and the need for remediation of landfills in Flanders

Final report – may 2013

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   Flanders has about 2,000 landfill sites. Activities are still being carried out at around ten locations. More than 80% were closed in the mid 1980s. To estimate the potential for landfill mining, the Flaminco model has been developed (Flanders Landfill Mining, Challenges and Opportunities). This model provides a first estimate of the potential of a landfill site for landfill mining based on 7 criteria (landfill type, time of landfilling, volume of dump material, location of the landfill site, other landfill sites in the vicinity, accessibility of the landfill site and need for remediation of the landfill site). In a second phase, the estimate of the potential can be refined based on specific field work. This publication fits into OVAM's broader ELFM research project and describes the method used to make a first estimate of the ELFM potential of a landfill site based on the 7 criteria mentioned above.

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1 Introduction

By order of OVAM the Temporary Partnership Tauw België nv– Witteveen+Bos Belgium is carrying out the study 'Framework Agreement on Technical Support for Landfill Mining'.

The aim of this study is to provide OVAM with technical support for the Landfill Mining (LFM) project at landfill sites in the Flemish Region; it comprises, among other things, the design of a method to determine the potential for Landfill Mining and the need for remediation of landfill sites.

Chapter 1 starts with a history of landfill site management and goes on to explain the broad concepts of 'circular economy' and 'Enhanced Landfill Mining', which are at the basis of this study. After that, OVAM's vision on landfill site management is explained. Finally, an overview is given of the concrete contents of this study.

In the next chapters, first a number of general data from the landfill site database are discussed (Chapter 2) and then the five sub-objectives of this study (Chapters 3 through 9, respectively). Finally, Chapter 10 offers a conclusion and a list of pending actions.

1.1 History: landfill mining

Although landfill mining may seem a new or innovative concept, the large-scale application of which is only to be expected in the coming years, OVAM has been taking important steps in this direction since its creation in 1981. This is because the way in which a landfill site is initially organised and then filled is essential for optimal mining in the future.

Until 1991 OVAM was also the licensing and control authority for waste management (see Waste Decree of 2.7.1981 and its amendment by the Decree on Administrative Policy of 12.12.1990). Within this comprehensive competence framework, among other things, the concept of mono-landfills was introduced. The idea behind this concept can certainly be considered a first step towards Landfill Mining. The aim of this kind of landfills was to fill them with uniform material, which would enable the possibility of mining at a later stage. Typical examples are the large-scale landfill sites with gypsum, fly ash and goethite production waste.

The possibility of mining those mono-landfills is currently being studied, or at least their research potential is being detected. The most famous examples of LFM took place in the 1980s and 1990s, when mining waste from the Limburg coal mining area was valorised. The slag heap of Zwartberg was rewashed by plc Ward and the recovered coal was delivered to power stations. Kempense Steenkoolmijnen and their legal successor NV Mijnen valorised the so-called 'schlamm' (coal-containing sludge stored in separate basins). Both examples occurred in accordance with the rules that applied in the market at the time, but the changing economic circumstances put an end to these activities.

Besides mono-landfills, a subdivision was also made into 3 landfill categories: industrial, household and inert waste. Once again, this approach allows for a clearer mining process. In the early 1990s special conditions were imposed for asbestos; as a result, its presence throughout an entire landfill no longer presents an obstacle for future mining operations.

The application of the concept of LFM within OVAM's remediation projects has only been included in the development of its vision on (E)LFM since 2012. Even so, there have already been remediation operations in the past where the valorisation of the dump material was an important element. The first case dates back to 1993 and comprised the clearance of an acid tar landfill located at Papiermolenstraat in Mariakerke. The acid tar was pre-treated on site and removed to be used as a raw material (and fuel) for the cement industry. This operation was not in accordance with market conditions. The cost was around 12,000 euros per load that was removed (trucks with a load of 30 tonnes).

The largest remediation project that can be classified under LFM took place at the end of the 1990s at the Terra Cotta landfill site in Brecht. OVAM invested around 40 million euros in the excavation and selective separation of this landfill complex. The separation and water purification technology was specifically developed for this project and used on site. In total, almost 160,000 m³ of waste was treated.

The examples above show that until now landfill mining has rarely been aimed at an optimal recovery of materials and/or energy. The determining factor was usually the need for measures from a remediation perspective, and the creation of space for other activities. In the latter cases, raw material recovery was also taken into account and the remediation operation consisted in a concentration of the waste on a smaller surface area (Henneaulaan-Zaventem storm water balancing basin project, 1994) or the (partial) removal to another licensed landfill site (Middelburg landfill project, 1993).

1.2 Broader framework for dealing with landfill sites within the 'material cycle' concept

In Pact 2020 and Flanders in Action, Flanders has expressed the ambition to take important steps towards a '**circular economy**' with the lowest possible use of raw materials, energy, water, resources and space and as little impact as possible on the environment and nature in Flanders and the rest of the world.

The transformation of Flemish waste management by OVAM to Sustainable Materials Management plays a central role in this ambition. Via Sustainable Materials Management OVAM goes beyond the boundaries of traditional waste management to include the management of the entire materials cycle. It does so with the vision that all waste generated today (and in the past) must become the raw materials for a green circular economy.

The projects on Enhanced Landfill Mining (ELFM) can be situated within this innovative policy vision, in which OVAM transforms the traditional policy on final disposal into a raw material for the renewed/renewing economy. Therefore, this project is a nice example of the translation of the ambitions of Flanders in Action into concrete steps forward in practice.

Over the years, large amounts of waste have been landfilled. Taking into account the evolution in recycling and energetic valorisation techniques, and the rise (due to scarcity) in raw material/energy prices, there are opportunities for the valorisation of the waste stored at landfills. Hence, ELFM is a concept that fits into the framework of a sustainable resource policy (from: 'Visienota Enhanced Landfill Mining', OVAM, Luk Umans and Piet De Baere, November 2011).

1.3 Concept of Enhanced Landfill Mining (ELFM) within the research consortium

The term ELFM was first used in Flanders in its current meaning in 2008 within the Flemish ELFM research consortium, which comprises, among others, academic experts, the company Group Machiels, OVAM (the Public Waste Agency of Flanders), and representatives of local residents.

Enhanced Landfill Mining (ELFM) of historical (and future) landfill sites, a concept that sprang from the Closing the Circle project, is an essential solution to close material cycles and evolve towards a circular materials economy. ELFM is defined as the 'safe conditioning, excavation and integrated valorisation of (historical and/or future) landfilled waste streams as both materials and energy, using innovative transformation technologies and respecting the most stringent social and ecological criteria' (source website: http://www.elfm.eu/Default.aspx)

Through Enhanced Landfill Mining the materials and energy potential present at landfill sites is valorised in an efficient way, while at the same time a significant reduction in greenhouse gas emissions is achieved. Waste streams for which valorisation is not yet possible due to technical or economic reasons can be stored separately in a safe way in a 'temporary storage facility' until the most efficient technology is available.

Besides the potential opportunities ELFM offers for people and the environment, there are also uncertainties which should be taken into account when applying ELFM:

— For various components of ELFM the technology is not completely ready and available yet. For this reason, the economic profitability of ELFM cannot be accurately estimated yet;
— Furthermore, economic profitability also depends on e.g. the price evolution of energy, raw materials, space, etc. in the international markets;
— There is no specific legal framework for ELFM yet;
— As the renewed exploitation of a landfill site can cause nuisance in the surrounding area (and hence resistance), it must be studied whether there is support from society, and how this can be created (e.g. by emphasising and developing extra benefits and opportunities for the surrounding area as a result of the ELFM).

In summary, we can say that ELFM certainly offers opportunities for a (start of a) sustainable solution within an integrated whole to a number of current social challenges, such as the reuse of materials or energy production, but that a number of limiting boundary conditions must be taken into account (such as the available technology and the legal framework).

1.4 Global OVAM objectives within the framework of Landfill Mining and landfill site management

1.4.1 Objectives

To OVAM the main reasons for mining and/or managing former and/or existing landfill sites are the following (from: 'Visienota Enhanced Landfill Mining', OVAM, Luk Umans and Piet De Baere, November 2011):

1 **Fighting soil and groundwater contamination**

As a consequence of improper landfilling of waste in the past, soil or groundwater contamination may occur (or have occurred), with the (potential) environmental and health risks connected to this. In such case, from a remediation perspective, one can either take measures to limit the effects on the environment by means of isolation or control techniques, or opt for removing the source of the contamination. In the latter case, there is the possibility of storing the waste elsewhere or re-introducing the material (with or without pre-treatment) into the material chain. This option needs to be studied in more detail taking into account the changing economic situation and the vision on resource management. Until now, most remediation concepts have been based on isolation; this needs to be evaluated.

2 **Infrastructure works or a new use of the land**

Here, the 'value' of the land is the main motivation for mining a landfill site. The presence of waste puts a heavy burden on the future possibilities of a plot of land. The removal of waste at such locations increases the real estate value of the land in question; in such cases, one will also need to decide whether the waste will merely be allocated to another landfill site, or whether it will be re-introduced into the material chain (with or without pre-treatment).

3 **Mining of 'new' raw materials**

Based on the philosophy that there will be a shortage of raw materials in Europe in the (near) future, it is advisable to look into alternative sources of raw materials and resources. LFM can be a limited approach for the mining of certain raw materials (e.g. increased CH4 production). In this context, it must also be emphasised that drinking water is an important but also vulnerable raw material. Here as well, ELFM can contribute to a better protection of our drinking water resources in aquifers.

1.4.2 Periods

OVAM's global objectives regarding landfill site management can be situated within different periods:

For OVAM, in the **short term**, making an inventory of the possibilities offered by the landfill sites in the LFM database[1] is the first step towards global landfill site management. A concept for the future approach to these landfill sites must be developed:

- On the one hand, this should refer to the management of risks caused by contamination at those sites.
- On the other hand, it should refer to the management of reserves for mining in the future. Landfill sites can be regarded as storage rooms for tomorrow. 'What we cannot recover or recycle today, we may be capable of tomorrow.'
- Use of space (Waste to Land): Because of the pressure on the use of space, the recovery of former landfill locations is a valid idea in the short term as well. The economic value of land will already make landfill mining in accordance with market conditions possible in the near future in certain circumstances.
- In **the long term**, OVAM wants to develop a dynamic landfill site management.
- Attention to the possibilities of resource management and temporary storage.
- Attention to reuse and recycling of energy, resources and raw materials.
- Bring all landfills to an 'inert' state (stabilisation and management of risks) with maximum material recycling/valorisation and energy production, rather than focusing on 'isolating and covering up' (IBC).

In Figure 1 the concept of ELFM is presented and situated within the problem of waste management and sustainable materials management. The approach results in the so-called R3P objective: Recycling of Materials, Recovery of Energy, Reclaiming of Land, Preserving Drinking Water Supplies.

1The LFM database, compiled and managed by OVAM (1,692 sites), comprises data on all known historical and currently active landfill sites. These data were taken from the so-called PCS files, which were used to make an inventory for each Flemish province between 1992 and 1995.

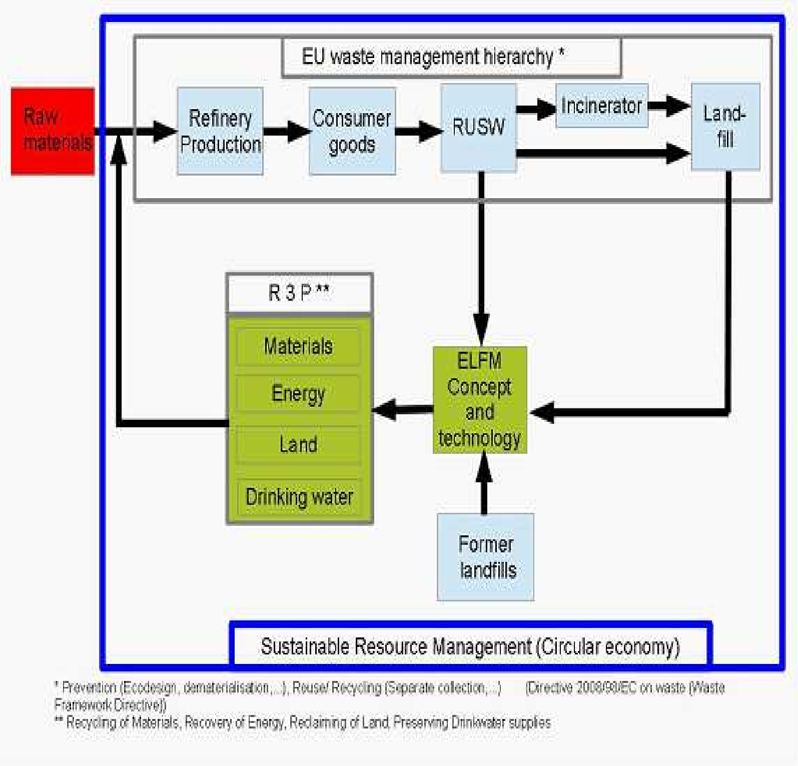


Figure 1: ELFM concept within waste management and sustainable materials management

1.5 Concrete objectives within the study 'Framework Agreement on Landfill Mining'

OVAM wants to start identifying the potential for ELFM at landfill sites in Flanders (see also figure below):

— On the one hand, by developing a **set of criteria** to **determine the potential of ELFM** (sub-task 1 – in diagram 2.2.1) and **testing** these against the database data on landfill sites in Flanders (sub-task 2 – in diagram 2.2.2) to achieve a prioritisation based on potential. If necessary, the **OVAM database** must be completed further and digitalised.

— On the other hand, by designing a method that allows for the determination and prioritisation of the **need for remediation** of the landfill sites which have not been checked (completely) (sub-task 3 – in diagram 2.2.3).

— Furthermore, field work **(field design projects)** will be carried out at some landfill sites 'with potential for ELFM' in order to collect the necessary 'technical' information to calculate the conditions for economic profitability (sub-task 2 – in diagram 2.2.2).

— Based on a literature study, a list of **alternative research techniques** for landfill sites will be drawn up as well (sub-task 4 – in diagram 2.2.4).

— Finally, the **profitability of smaller landfill sites for ELFM** will be determined by testing a number of possible scenarios (sub-task 5 [option]).

Based on the study described in this report OVAM wants to get an idea of the potential of existing landfill sites in Flanders for ELFM and offer a tool for owners of landfill sites to determine this potential.

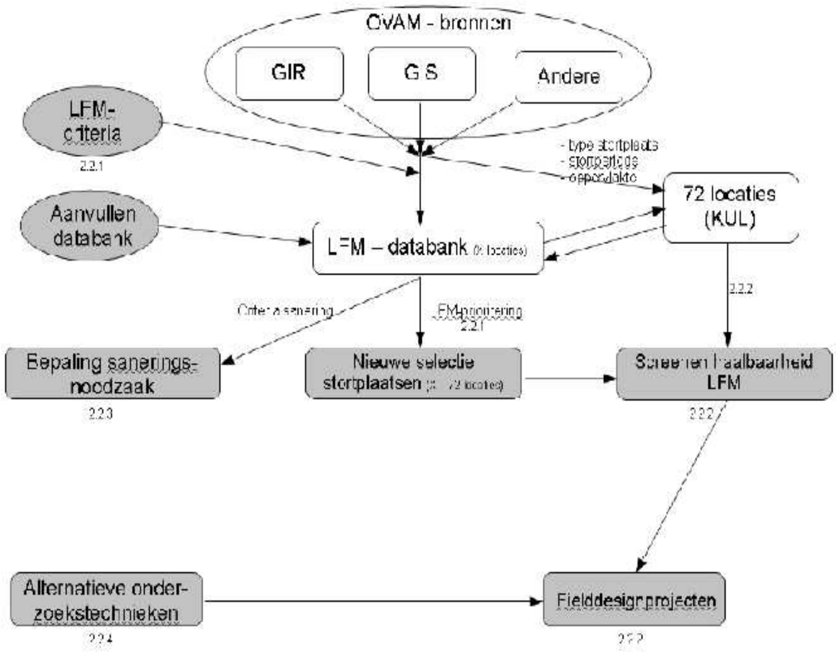


Figure 2: Global diagram for OVAM Framework Agreement on Landfill Mining

In accordance with the task 'Framework Agreement on Technical Support for Landfill Mining', the project is split up into the following sub-tasks:

1 Definition of LFM criteria and environmental prioritisation.
2 Estimation of the potential of the 72 possible sites and of the remaining sites based on documentation and field work.
3 Screening of the need for remediation.
4 Screening of (alternative) research techniques.
5 Other activities which may prove necessary in the course of the project:
   a) completing the database and list of landfill sites;
   b) digitalising data on landfill sites;
   c) carrying out additional field work at landfill sites;
   d) studying the profitability of the landfill sites;
   e) screening of projects that have come to a halt;
   f) other, unforeseen activities, to be determined in consultation with OVAM.

The majority of these sub-tasks are discussed in this report. Some tasks still need to be performed in a second phase of this study.

1.6 Results on two tracks

Given that the determination of the potential for Landfill Mining and the determination of the need for remediation of landfill sites comprise two different objectives, two independent methods are used to reach both objectives during the study.

In other words:

- 1 on the one hand, based on specific criteria, a calculation tool to determine the potential for landfill mining will be designed, based on which prioritisation can take place;
- 2 on the other hand, in a similar way, based on other criteria, a calculation tool will be developed to determine and prioritise the need for remediation of landfill sites.

As sustainable landfill site management ideally takes into account both of the aforementioned objectives (and even tries to combine these, insofar as possible, in the management of landfill sites), based on the results of both methods a matrix is created in which both objectives are combined, so that these can be taken into account when selecting the landfill sites to be dealt with. The interaction matrix is shown in the figure below.

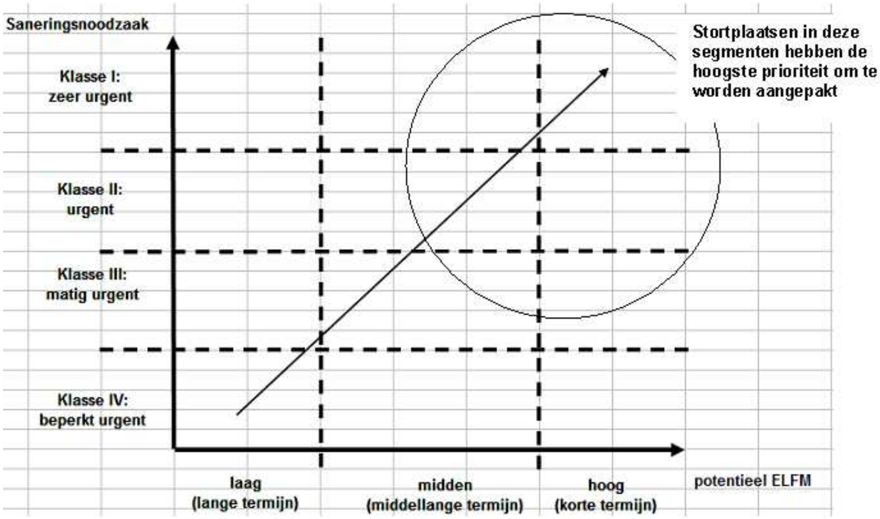


Figure 3: Interaction matrix for determination of LFM potential and need for remediation

1.7 Overview of different ambitions and objectives of landfill site management

Hierarchical overview of objectives
Global Ambition: Ultimately achieve a ‘Cradle to Cradle’ design of production systems (circular economy), in which there is no longer (or hardly) any waste, and there is a strict separation between the ‘technosphere’ (man-made chemicals and materials) and the biosphere (natural products and natural resources)
OVAM objective: Sustainable materials management: (a) the waste streams of the past and present have become raw materials thanks to well-designed actions which have a minimal

impact on people and the environment, and (b) future waste is reduced to the bare minimum and managed in a safe and sustainable way. Re-allocation of land: space used by landfills is valorised in a sustainable way. Fighting soil and groundwater contamination	
Objective of ELFM concept of Consortium: The safe and environmentally friendly conditioning, excavation and integrated valorisation of landfilled waste streams as both materials and energy, while also creating economic benefits as land use values rise *	
Objective of this project (Framework Agreement on Landfill Mining): To determine the potential and first steps towards Field Design for sustainable landfill site management in Flanders	
Track I: Determination of potential and prioritisation for Landfill Mining: Valorisation of materials, energy, space, resource management of landfill sites	**Track II: Determination and prioritisation of the need for remediation of landfill sites:** Minimising the impact of contamination from landfills on people and the environment
Design of methodology for determination of potential and prioritisation	Design of methodology for determination of need for remediation and prioritisation
Testing against LFM database	Testing against LFM database

Table 1: Hierarchical overview of objectives

2 Database of landfill sites in Flanders

The methods developed in sub-tasks 1 and 3 must be applied to the data for landfill sites in Flanders:

— For a first test, the limited database of 72 landfill sites selected from the global LFM database by the Catholic University of Leuven (KUL), hereinafter referred to as the KUL database, will be used (see 2.1);
— For the second test, the methods will be applied to the entire LFM database, which comprises a total of 1,618 landfill sites (see 2.2).

OVAM's LFM database was created using the data taken from the PCS files. These files were made by the provinces, e.g. by the PIH (Provincial Institute for Hygiene), for PCS (potentially contaminated sites) between 1992 and 1995.

2.1 List of 72 landfill sites - selection by KUL

For a first test of the methods of sub-tasks 1 and 3 a limited database of 72 landfill sites – the KUL database – was used.

The 72 landfill sites were selected by the Catholic University of Leuven (KUL) in the framework of the determination of the potential for ELFM (Van Passel et al., 2012). The following selection criteria were used in the framework of this study:

— Landfill type: only landfills with municipal household waste were selected;
— Period of operation: landfills used between 1950 and 1985 were selected;
— Volume of dump material: the minimum volume of dump material is 100,000 m^3.

In the database for this list of 72 landfill sites information was missing to allow for the testing of the methods developed in the framework of sub-tasks 1 and 3, so it was necessary to complete this database first.

The list (and data connected to it) comprises 72 landfill sites which are geographically spread out across the Flemish Region. The geographical distribution is shown in the map below.

As is clear from Figure 4, most landfill sites are located in the provinces of Antwerp, Flemish Brabant and Limburg. A smaller number of landfill sites can be found in the western half of Flanders.

This is presumably due to the fact that the quality of the PCS files, from which the data for the database were taken, is less good in this region, with missing data, which is why those landfill sites were not selected.

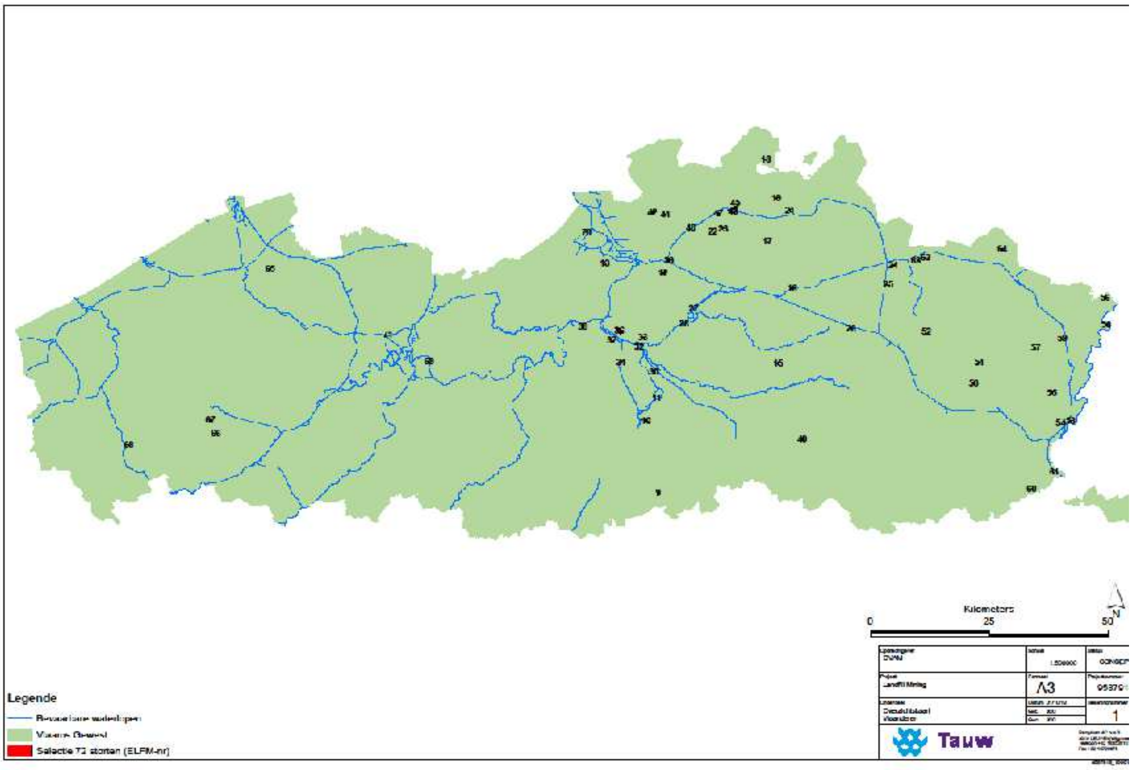


Figure 4: Geographical distribution of the 72 landfill sites selected by the Catholic University of Leuven

2.1.1 Surface area of the landfill sites

The **surface area** of the 72 landfill sites varies between 0.16 and 300 hectares.
The surface area is based on the dimensions of the corresponding plot(s) as recorded in the land register, which may differ from the real surface area of the actual landfill area.
The distribution by surface area is shown in the graph below (Figure 5).

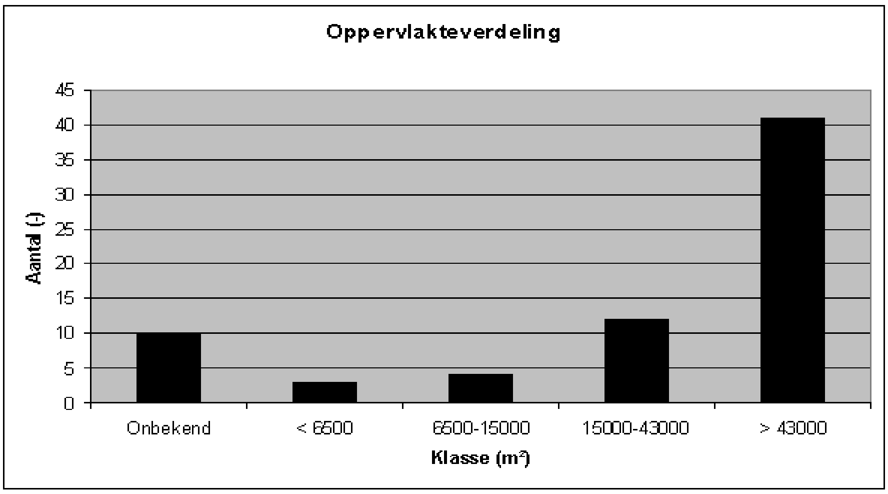


Figure 5: Distribution of landfill sites by surface area

2.1.2 Type and content of landfill sites

Most landfill sites contain household (92%) and inert waste (44%), given that this was one of the selection criteria.

Another observation is that many are mixed landfills. As a result, the sum of the percentages is higher than 100%.

The category 'Other' contains landfills for which the type of dump material is unknown, or where the type of dump material cannot be classified into the 'standard' categories.

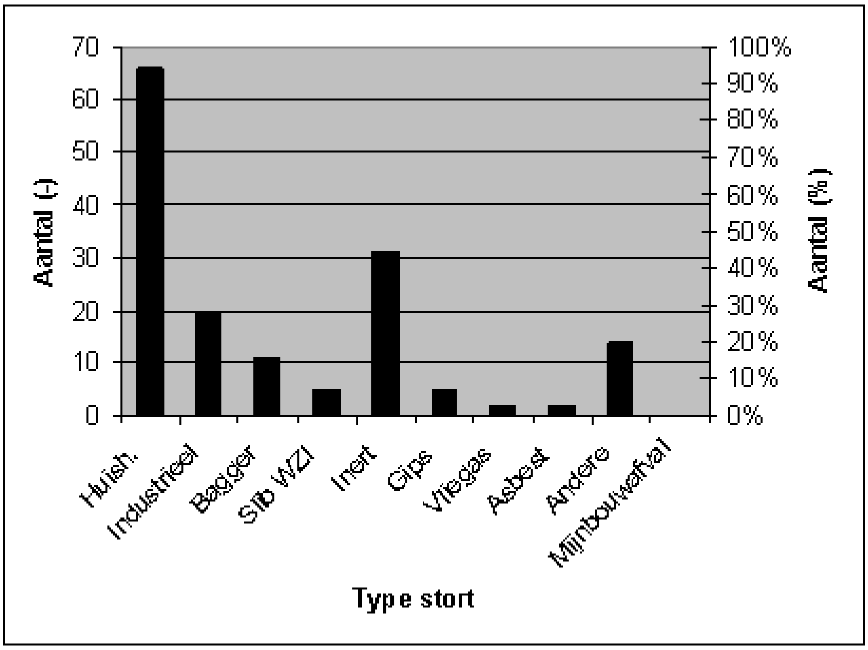


Figure 6: Distribution of number of landfill sites by type

2.1.3 Age of the landfill site

The third selection criterion for the list of 72 landfill sites by KUL is the **period of operation** of the landfill site.

For this criterion it can be said that most landfill sites date from the period between 1950 and 1985. This is the period in which, due to the changing industrial activities and the changing consumption patterns in society, the largest amount of unselected household waste was landfilled, and which is hence the most interesting for landfill mining (Van Passel et al., 2012):

— Before 1950 landfill sites usually contained little waste with economic value (combustion ash, etc.);
— After 1985, as a result of the introduction of Vlarem (the Flemish Regulation for Environmental Licences) and the increased selective collection of waste, waste treatment at landfill sites thoroughly changed (e.g. conditions for operation of landfill sites).

Approximately 65% of the landfills in the database were covered up after the landfilling activities were stopped. This was usually done with soil covered by vegetation, as a result of which now only fallow land or meadowland can be seen.

Fourteen sites from the list are still active.

2.2 List of 1,690 landfill sites in the LFM database

A map showing the geographical location of the 1,690 landfill sites is provided in Appendix 6.

To make the extensive LFM database of landfill sites, data were taken from various **sources**:

— Data about the landfill itself, such as type, size, cover and age, were taken from **PCS files** provided by OVAM. These files contain the data collected during preliminary studies and/or site visits carried out by OVAM. For some (historical) landfill sites no PCS files are available;

— Other data relating to the characteristics of the area around the landfill site were gathered via **GIS data layers** in a GIS system. Examples are the positioning within the regional land use plan, groundwater vulnerability, distance to the road, waterway or railway;

— For eight landfills that are still in use, existing **soil surveys** were requested and inspected in order to collect the necessary information.

— In total, 1,690 current or former landfills were included in the database. 1,175 of these landfills contain household waste, 170 industrial waste and 603 inert waste, such as construction waste. For the remaining types of landfills there were only a few tens of cases.

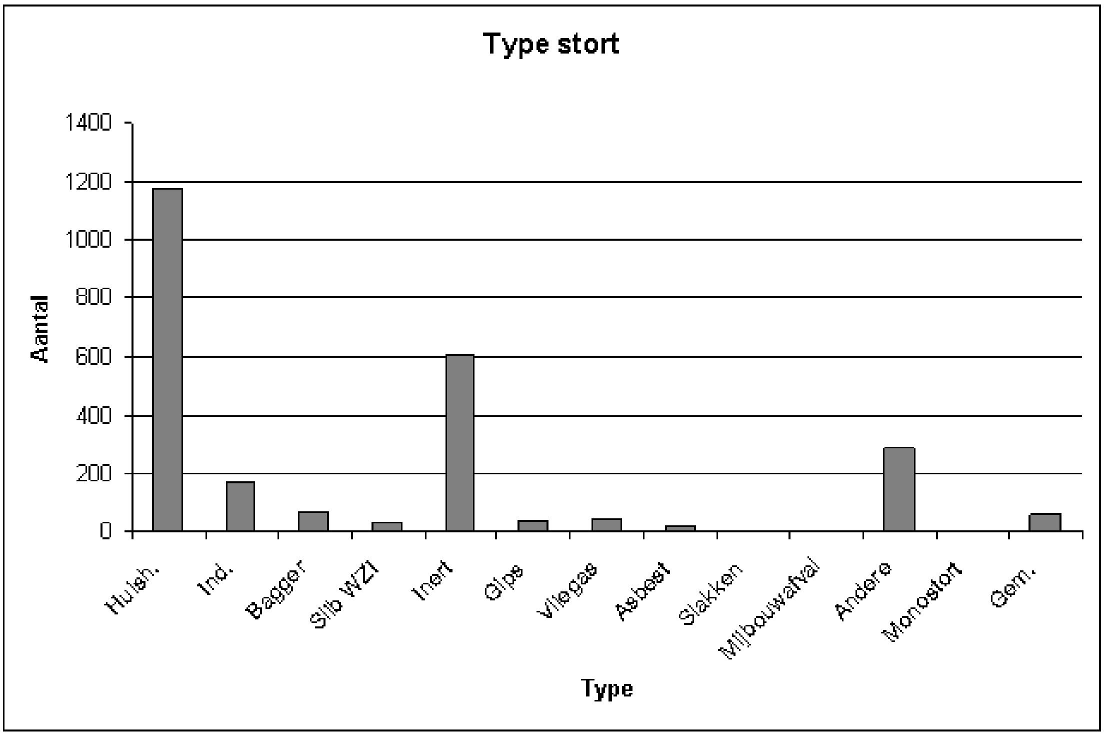


Figure 7: Distribution of number of landfills per type shows number of landfills per type

According to the regional land use plan, most landfill sites are located in agricultural areas. To a lesser extent, landfill sites are found in residential, industrial or nature areas. A small number of landfill sites are located in recreational areas. The distribution of the remaining landfill sites is shown in
Table 2.

Land use type	Number
Residential area	281
Recreational area	47
Agricultural area	775
Industrial area	128
Nature area	314

Table 2: Positioning of landfill sites according to the regional land use plan

Where **accessibility** is concerned, most landfills are located very closely to a public road. The average distance is 32 metres, which means high accessibility. The average distance to the nearest railway or navigable waterway is, respectively, 3.3 kilometres and 3.8 kilometres.

It was also studied what **receptors** are present near the landfill sites. For instance, it was checked how many landfill sites are located near a Natura 2000 area, a watercourse included in the Flemish Hydrological Atlas (VHA) or a groundwater abstraction facility.

The location of the landfill site with respect to a certain receptor is shown in the figure below for three distances: 100 m, 200 m and 500 m.

Nearly 1,000 landfill sites are located less than 100 metres from a stream/river. More than 1,600 landfill sites (98%) are located within a distance of 500 metres from a stream/river. A large number of landfill sites (1,000) are also located within a distance of 500 metres from a groundwater abstraction facility. Natura 2000 areas have also been included in Figure 8 below, but their number is much lower near landfill sites.

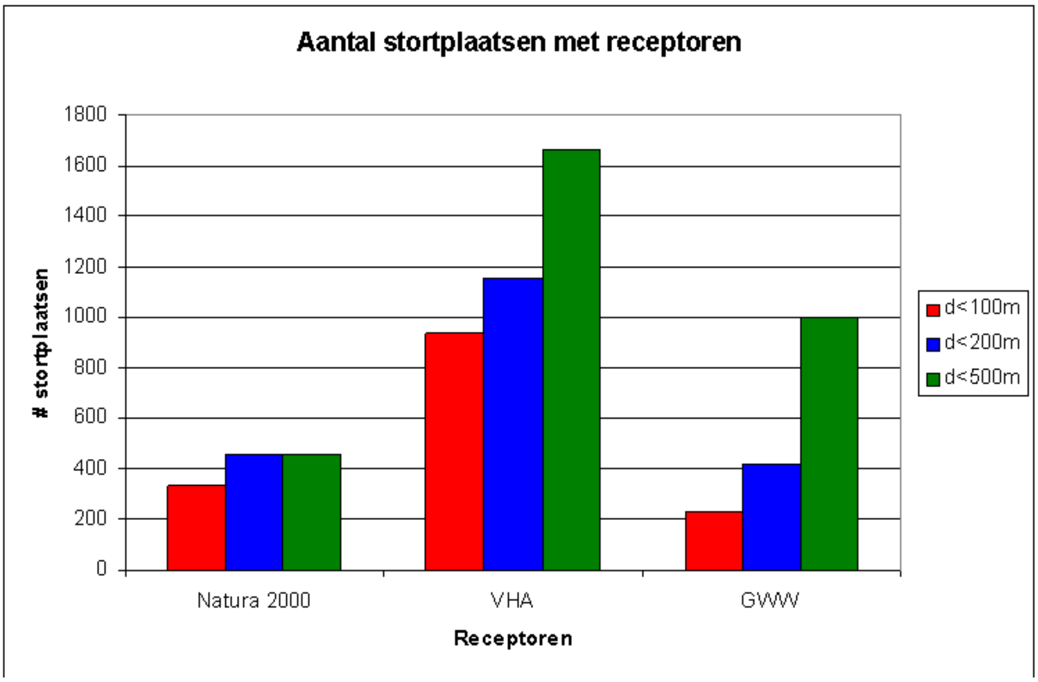


Figure 8: Number of landfill sites located within a certain distance (100 m, 200 m and 500 m) from receptors

The database is not complete yet and needs to be completed for various aspects. For 61 landfill sites no PCS file and hence little information was available. Furthermore, 20 landfill sites (12

PCS files and 8 existing landfill sites) were not included in the GIS data layers, so no calculations could be made for these either. For a number of landfill sites which are currently still in use some data are missing as well (e.g. XY data).

3 Sub-task 1: Definition of LFM criteria and environmental prioritisation

Sub-task 1 mainly consists in a theoretical exercise with the following objectives:

— overview of criteria which can be used to select landfill sites in Flanders that are eligible for Landfill Mining (**objective 1**);
— development of a methodology to determine the environmental priority of landfill sites (**objective 2**).

3.1 Introduction

This chapter describes the basis for the calculation tool which has been developed to determine the environmental priority for Landfill Mining (LFM). This calculation tool is attached in Appendix 1. Based on the defined set of **criteria**, a methodology has been developed to determine the environmental priority of a landfill site to carry out LFM. This set of criteria is linked to the various **objectives (4 in total)**, which enables us to determine the potential of a landfill site.

3.1.1 Objectives

To determine the potential of LFM, the following four objectives are taken into account:

— Objective 1: Waste to Energy (**WtE**);
— Objective 2: Waste to Materials - Materials management (**WtM**);
— Objective 3: Waste to Land - Space (**WtL**);
— Objective 4: Resource Management (**RM**) - Temporary Storage.

Even though LFM is a new concept, various studies have been carried out for objectives 1 and 2 (WtE and WtM). These studies are mainly based on the concepts of LCA, C2C and Lansink's Ladder. Unlike for objectives 1 and 2 (WtE and WtM), until now little attention has been given to objectives 3 and 4 (WtL and RM) from an LFM perspective.

The following definitions have been established for the various objectives:

Waste to Energy (WtE): the production of energy in the form of electricity or heat from landfill gas resulting from the decomposition of organic material or from the dump material, where the waste is converted into fuel through heating.
Waste to Land (WtL): the creation of space at the location of the landfill site and the assigning of a new land use to the landfill site.
Waste to Material (WtM): the valorisation of the waste streams that are released from a landfill and the reuse of the waste streams as materials.
Resource Management (RM): the temporary storage of waste with a view to a later valorisation and use of this waste.

3.1.2 Overview of criteria

To determine the potential of LFM a total of six criteria are used:

— Criterion 1: type;

— Criterion 2: age;
— Criterion 3: volume;
— Criterion 4: use;
— Criterion 5: accessibility;
— Criterion 6: surroundings.

In Chapter 3.1.3 'Matrix of objectives - criteria' the criteria are briefly described, providing a general overview, the interpretation of the criterion and the sources for the input of the data.

3.1.3 Matrix of objectives - criteria

By linking the different criteria to the objectives, an environmental prioritisation of landfill sites for LFM is obtained for each objective.
In Table 3 an overview is given of the criteria that are used to determine the environmental priority for each objective. This matrix has been made based on expert judgement, experience in practice and consultation with OVAM. This matrix shows that the landfill type (criterion 1) is the most decisive criterion for the different objectives. In Chapters 3.2.1 through 3.2.6 these objectives are elaborated on further, starting with a definition and a detailed description of the criteria for each objective.

	type	**age**	**volume**	**use**	**accessibility**	**surroundings**
WtE – energy	X	X	X	X	X	X
WtM – materials	X	X	X	X	X	X
WtLand – space	X	–	X	X	–	X
Resource Management – temporary storage	X	–	–	–	X	X
x: criterion is used to determine the potential of a landfill site for the objective concerned –: criterion is not used to determine the potential of a landfill site for the objective concerned						

Table 3: Matrix of relevance of criteria linked to objectives

3.1.4 Result

By means of the calculation tool the environmental priority is determined for each assessed landfill site for each objective. This results in a prioritisation of all assessed landfill sites for each objective.

It must be noted that this prioritisation is not an absolute judgement about the potential of a landfill site, but only a **relative** one, in which landfill sites are compared between them.

3.1.5 Document structure

After a brief explanation of the different criteria and the weighting factors used to determine the environmental priority for Landfill Mining, in the next chapters the various objectives will be described at length, including the concrete interpretation and the basis of these criteria. In Chapter 3.8 a technical explanation of the calculation tool is provided. Finally, in Appendix 3 an overview is given of the sources and references that have been used for this study.

3.2 General overview of criteria and weighting factors

In this Chapter a brief explanation and basis is provided for the criteria and weighting factors used to determine the potential for LFM based on the aforementioned objectives. This Chapter includes a link to the calculation tool as included in Appendix 4 of this report. In Chapter 3.8 a brief explanation of the calculation tool is provided, using these criteria and weighting factors. The calculation tool itself contains instructions for use with notes for each sheet and step.

3.2.1 Criterion 1: Landfill type

3.2.1.1 General

The landfill sites are subdivided into the following landfill types:

- Household waste;
- Industrial waste;
- Mono-landfills:
  - dredging spoil;
  - water purification sludge;
  - inert waste;
  - gypsum;
  - fly ash;
  - asbestos;
  - metal slag;
  - mining (high-grade metals);
- Mixed landfills;
- Other (undefined landfill sites).

3.2.1.2 Input sources

The subdivision into landfill types is based on the structure of the OVAM database of old landfill sites 'elfm oude stortplaatsen_OVAM'. In the current 'elfm oude stortplaatsen OVAM' database no data are included about mono-landfills for mining waste and metal slag. As these mono-landfills certainly have potential for LFM, it is proposed to include these types into the database. The 'elfm oude stortplaatsen_ovam' database also contains landfill sites which fall into several categories, e.g. ‘household waste’ and ‘industrial waste’. For these sites a separate ‘mixed’ category is included (see also the ‘Matrix database’ sheet in the calculation tool).

Based on the OVAM database different landfill sites are classified into different types (e.g. landfill site X is classified under household, industrial and inert waste). For the prioritisation it is assumed that each waste type present at a certain landfill site is present in the same proportion (e.g. for landfill site X: 1/3 household, 1/3 industrial and 1/3 inert) (see also the ‘Calculations 1’ sheet in the calculation tool). This proportion can be changed after a site-specific investigation. There is a possibility to adjust it in the calculation tool.

Finally, it must be remarked that radioactive waste has not been included, because due to its properties radioactive waste does not have any potential for LFM (either now or in the future).

3.2.1.3 Uncertainty factors

The criterion ‘type’ must be linked to the uncertainty factors ‘**uniformity/heterogeneity’** and ‘**layering’**. However, the layered nature of a landfill site is related to its uniformity. Therefore, only the uncertainty factor ‘uniformity’ is used. In the OVAM database and the PCS files currently no location-specific data are available about the uniformity of the landfill sites. Hence, in the

determination of the environmental priority the uncertainty factor 'uniformity' is taken into account **for each landfill type** as included in Table 4. The uniformity of a landfill site is primarily deduced based on the reliability of the historical data and its greatest impact is on the landfill types household waste, industrial waste, mixed waste and other types. Mono-landfills can be heterogeneous, but for simplicity's sake these landfills are considered to have a homogeneous composition.
If more information about a landfill site is known, location-specific data can be entered afterwards in the location-specific database (see ‘Additional input’ sheet in the calculation tool). If a value for uniformity is entered into this location-specific database, this value will be used in the calculation instead of the values shown in Table 4. In the ‘Input’ sheet it can be checked what data are used for the calculations.

Landfill type	**Uniformity (%)**	**Basis for uniformity factor**
Household waste	50	Composition unknown, field work required
Industrial waste	50	Composition unknown, field work required
Dredging spoil	100	Supposed to be homogeneous
Water purification sludge	100	Supposed to be homogeneous
Inert waste	100	Supposed to be homogeneous
Gypsum	100	Supposed to be homogeneous
Fly ash	100	Supposed to be homogeneous
Asbestos	100	Supposed to be homogeneous
Metal slag	100	Supposed to be homogeneous
Mining (high-grade metals)	100	Supposed to be homogeneous
Mixed	25	Composition unknown, field work required
Other	25	Composition unknown, field work required

Table 4: Overview of uniformity by landfill type

The uniformity of mono-landfills is estimated to be high, but this percentage can be refined in the location-specific database after further analysis of each case. Especially with a view to an effective mining operation the inclusion of detailed data is necessary. The factors 'production process' and 'filling method' will play a crucial role. Any changes to the production process will lead to possible variations in concentrations, changed mineralogical or physico-chemical properties and finally different waste streams. Heterogeneity is possible as well in case of hydraulic supply depending on the position of the outlet sluices.

Finally, the uniformity of a landfill site is determined by its age. It can be expected that more recent landfill sites are subdivided into 'uniform' landfill sections. Older landfills, on the other hand, will be very heterogeneous. Nevertheless, for the calculation tool and the determination of environmental priority no link is established between age and landfill type. Based on the available data (e.g. this is not included in the PCS files) this cannot be calculated, as a result of which the uncertainty factor is too high.

3.2.2 Criterion 2: Age of the landfill site

3.2.2.1 General

When the 'age' criterion is taken into account in the determination of the potential, this criterion will depend on the landfill type (criterion 1). The impact of this criterion on the environmental priority will also differ according to the landfill type. For instance, information about the age will be more decisive for environmental prioritisation for a household waste landfill than for a specific mono-landfill.

Generally speaking, the following principles were used for the 'age' criterion:

— first of all, for each landfill type based on the 'elfm oude stortplaatsen OVAM' database the oldest landfill site was chosen as a lower limit;
— former landfill sites where landfilling was not subject to the VLAREM licence (before 1985);
— landfill sites where landfilling is subject to the VLAREM licence (after 1985).

3.2.2.2 Input sources

The OVAM database 'elfm oude stortplaatsen_OVAM' shows the age of the landfill site. However, for many sites in this database the age is missing or unknown (indicated by ‘?’). The information taken from the PCS files gives a clearer view on the age of the sites (see also ‘Matrix database’ sheet in the calculation tool).

When using the calculation tool and making the calculations with a view to environmental prioritisation for LFM, the oldest age available is taken into account.

3.2.3 Criterion 3: Volume of the landfill site

3.2.3.1 General

The determination of the potential for LFM in relation to the volume strongly depends on the total amount of investment necessary to set up an LFM project. In case of small investments the volume will not be very important. As a general rule, it can be said that the larger the volume, the more interesting LFM becomes. Therefore, it is better for the initial investments to be spread out with a lower unit rate per m^3 of waste.

Furthermore, for all four objectives the volume will depend on the landfill type (see criterion 1) and the economic value of the different waste streams at the moment LFM is carried out. For instance, a small volume (e.g. $< 100,000$ m^3) of high-grade metal slag may have a higher potential for LFM (Objective 2: Waste to Material) than a larger volume (e.g. > 1 million m^3) of dredging spoil. Based on the available data for Flanders, volumes varying between the order of 100,000 (small) and the order of 1 million m^3 and more (large) have been chosen. A volume larger than

100,000 m^3 and smaller than 1 million m^3 is considered to be medium (see also the ‘LFMinst’ sheet in the calculation tool).

3.2.3.2 Input sources

In the PCS files the **surface areas** of the landfill sites are mentioned. These data are further supported by means of GIS data. In this process, it is assumed that the surface area equals the total surface area of the plot (or several plots) on which the landfill site is located. This results in uncertainty, and in some cases an overestimation of the surface area.

In order to calculate the final volumes, these surface areas are linked to the **height**. For information about the height, the PCS files are used. These mention the height for some landfill sites. Where the height is not mentioned, ‘0’ is entered into the cells concerned and the following assumptions are made (see also ‘Matrix database’ sheet in the calculation tool):

— for clay pits and quarries: arbitrary height of 7 m;
— for the remaining landfill sites (natural relief): arbitrary height of 3 m.

These assumptions have been made based on expert judgement and experience in practice.

3.2.4 Use of the landfill site

3.2.4.1 General

The 'use' criterion is determined by various characteristics of the landfill site which influence the environmental prioritisation for LFM. The following characteristics are taken into account:

— current use in accordance with the regional land use plan, land use implementation plans ('RUP's and 'GRUP's);
— presence of buildings.

Use

For the use the same general code has been used as in the regional land use plan (codes 0100 to 1700). Given the importance of reserve areas or potential development areas (code xx80) for LFM, these areas have also been included separately in the environmental prioritisation (see also ‘Matrix database’ sheet in the calculation tool).

The intermediate use and the future use are also taken into account. If no data are known yet, these are assumed to be the same as the current use.

Finally, for a certain regional land use plan the corresponding land use type I, II, III, IV or V from the VLAREBO legislation is also mentioned.

Presence of buildings

Another aspect of land use is whether the location has already been developed or not, either for residential or for industrial use.

The presence of existing buildings at a landfill site is not favourable for redevelopment, but this does not mean that this is a limiting factor. If we assume that the development took place soon after the creation of the landfill site, this development may need to be modernised. The redevelopment of these landfill sites to high-quality public spaces or buildings is perfectly possible.

It must be noted that the possibility that an entire residential neighbourhood will be renovated at the same time is fairly small. On the other hand, an old industrial site for which a project developer has plans is interesting.

3.2.4.2 Input sources

Use

For the current use the regional land use plan is used, with the corresponding code. These data were already included in the OVAM database 'elfm oude stortplaatsen_OVAM'. For the intermediary and future use completing this information is more complicated. To do so, the land use plans will need to be requested from the municipal or city authorities, or a request will need to be sent to these authorities to enter these data into the location-specific database.

Presence of buildings

The presence of buildings is not mentioned in the OVAM database 'elfm oude stortplaatsen_OVAM'. However, input can be obtained from the PCS files, Google Earth and the OVAM GIS layer where buildings are shown. It must be noted that this is a variable factor, especially when looking at the future, e.g. the year 2100.

3.2.5 Criterion 5: Accessibility of the landfill site

3.2.5.1 General

The accessibility of a landfill site is determined by the following three characteristics:

- accessibility via a public road;
- accessibility via the railway;
- accessibility via waterways.

Public road

In order for a landfill site to be accessible via a public road, this public road must be passable. The available data (GIS) show that some landfill sites are not or hardly accessible, while others are easily accessible. If a landfill site is not accessible (e.g. in a forest area or a remote nature area) it may be interesting to invest in the construction of a new road. The latter was not taken into account in the environmental prioritisation.

The GIS data show that the accessibility by public road ranges from 0 m (landfill site is located on a public road) to a few hundred metres. The relationship between the distance from a landfill site to a passable public road and the weighting factor assigned to this in the determination of the environmental priority can be shown by means of a natural logarithmic function (see also ‘LFMinst’ sheet in the calculation tool).

Rail

To determine the accessibility of a landfill site by rail, for simplicity's sake it was decided to calculate the distance to a railway line via GIS, i.e. not specifically to a station for passenger transport or a station for freight transport. It is currently being studied whether the distance to stations can be deduced based on SNCB information.

The GIS data show that the accessibility by rail ranges from less than 50 m (landfill site located near a railway line) to more than 20 km. The relationship between the distance from a landfill site to the nearest railway line and the weighting factor assigned to this in the determination of the environmental priority can be shown by means of various functions (see also ‘LFMinst’ sheet in the calculation tool).

Waterways

To determine the accessibility of a landfill site via a waterway, it was decided to use GIS to calculate the distance to a navigable waterway, which was defined as a waterway open to river traffic.

The GIS data show that the accessibility via a waterway ranges from 0 m (landfill site is located on a waterway) to a few hundred metres. The relationship between the distance from a landfill site to the nearest navigable waterway and the weighting factor assigned to this in the determination of the environmental priority can be shown by means of various functions (see also ‘LFMinst’ sheet in the calculation tool).

3.2.5.2 Input sources

All input data for accessibility via public roads, railway lines and waterways are obtained through the available GIS files. These GIS data are reflected in the ‘Matrix database’ sheet in the calculation tool.

3.2.6 Criterion 6: Surroundings of the landfill site

3.2.6.1 General

For the 'surroundings' criterion the main factor that is checked is whether there is another landfill site near the landfill site under assessment, with the aim to cluster landfill sites. To this end, it has been decided to link **the same types** of landfill sites to each other. This way, resource management is possible.

To determine the presence of landfill sites near a specific landfill site the distance is calculated via GIS. Currently this GIS data layer is being prepared by OVAM. The GIS data received until now show that the distance ranges from less than 50 m (landfill site is located near another landfill site of the same type) to more than 10 km.

3.2.6.2 Input sources

To link a specific landfill site to landfill sites located nearby, the input data are obtained via the GIS files that are already available. These GIS data are reflected in the ‘Matrix database’ sheet in the calculation tool. Currently OVAM is preparing a GIS data layer with the location of all landfill sites.

3.3 weighting factors

Based on the aforementioned criteria and objectives, two types of weights are used to determine the potential for LFM and carry out the environmental prioritisation of the landfill sites:

- weight per criterion for the determination of the potential;
- weight based on the characteristics of the landfill site under assessment.

The calculation tool was designed in such a way that the weighting factors can be adjusted at any time so that they are always up to date. Therefore, it is important to be able to adjust the weighting factors in case of changes in the economic situation, developments in available technologies, etc.

3.3.1 Weight per criterion for the determination of the potential

As included in Table 3-1, various criteria determine the intended objective. However, certain criteria will be more decisive for the intended objective than others. For instance, for the WtE objective the ‘landfill type’ criterion will be more important (factor 3) than the age of the landfill site (factor 2).

For the **current situation** an overview of these weights is given in Table 5. The maximum value of the weight is equated to the number of criteria used for that specific objective. The weights in the calculation tool were chosen based on the information described in Chapters 3.4 through 3.7, expert judgement and consultation with OVAM.

For a detailed description of the weights we refer to the ‘LFMinst’ sheet in the calculation tool.

	type	age	volume	use	accessibility	surroundings
WtE – energy	3	3	2	1	1	1
WtM – materials	4	2	3	1	1	2
WtLand – space	3	–	3	3	–	1
Resource Management – temporary storage	3	–	–	–	1	3
1, 2, 3, 4: criterion is used, with a certain weight assigned to it, to determine the potential of a landfill site for the objective concerned –: criterion is not used to determine the potential of a landfill site for the objective concerned						

Table 5: Matrix of relevance of criteria linked to objectives

3.3.2 Weights based on the characteristics of the landfill site under assessment

For the environmental prioritisation of a certain landfill site, a weight in percentages is assigned for each characteristic of the landfill site. The weights in the calculation tool were chosen based on the information described in Chapters 3.4 through 3.7.

For the following criteria weights are linked based on the characteristics of the landfill site under assessment:

— landfill type;
— age;
— volume;
— use;
— accessibility;
— surroundings.

3.3.2.1 The weight of the landfill type depends on the objective

Depending on the intended objective, a different weight is assigned to the landfill type. For instance, a gypsum landfill will score low for a WtE objective, whereas the same gypsum landfill does have potential for material reuse (WtM objective). In Table 6 an overview is given of the weights used for a landfill type for each intended objective.

Landfill type	WtE	WtM	WtLand	RM
Household waste	100%	100%	100%	100%
Industrial waste	100%	100%	100%	100%
Mining (high-grade metals)	25%	100%	100%	100%
Water purification sludge	25%	100%	100%	100%
Metal slag	0%	100%	100%	100%
Gypsum	0%	100%	100%	100%
Fly ash	25%	100%	100%	100%
Dredging spoil	25%	100%	100%	100%

Inert waste	100%	100%	100%	100%
Asbestos	0%	25%	25%	25%
Mixed	100%	100%	100%	100%
Other	50%	50%	100%	100%

Table 6: Overview of the weight of the landfill type for each objective

3.3.2.2 Weight of age for each landfill type

The age criterion strongly depends on the type of landfill.

- Only few household, industrial, mixed and other landfill sites created **before 1950** are selected for LFM due to the relatively low economic value for LFM and the low expected energy recovery for old landfills. Therefore, a weight of 25% is assigned to these. To determine the lower limit, the oldest landfill site included in the PCS files was identified for each landfill type;
- Generally speaking, landfills created **before 1985** have a relatively high economic value for LFM, which is why all landfill types are assigned a weight of 100% for this age.
- Landfills created **after 1985** are selected for LFM to a lesser degree (weight of 75%). Only for dredging disposal sites and landfills containing inert waste is the potential for LFM of a landfill site created after 1985 equal to the potential of a landfill site created before 1985 (both 100%). This is because in 1985 the waste regulations came into effect in Flanders, falling under the competence of OVAM.

It should be noted that the chosen weights are not absolute weights, but relative weights to compare landfill types to each other.

In Table 7 the different weights and lower and upper limits for each landfill type are shown.

Landfill type	**Age**		**Weight**
	lower limit (1)	**upper limit**	
Household waste	1930	1950	25%
	1950	1985	100%
	1985	2100	75%
Industrial waste	1910	1950	25%
	1950	1985	100%
	1985	2100	75%
Mining (high-grade metals)	1930	1985	100%
	1985	2100	75%
Water purification sludge	1950	1985	100%
	1985	2100	75%
Metal slag	1930	1985	100%
	1985	2100	75%
Gypsum	1950	1985	100%
	1985	2100	75%

Fly ash	1950	1985	100%
	1985	2100	75%
Dredging disposal	1940	1985	100%
	1985	2100	100%
Inert waste	1950	1985	100%
	1985	2100	100%
Asbestos	1930	1985	100%
	1985	2100	75%
Mixed	1930	1950	25%
	1950	1985	100%
	1985	2100	75%
Other	1900	1950	25%
	1950	1985	100%
	1985	2100	75%

Table 7: Overview of age and weight assigned for each landfill type

1 To determine the lower limit, the oldest landfill site included in the PCS files and the OVAM database was identified for each landfill type.

3.3.2.3 Weight for each landfill type

As a general rule, one can say that the larger the volume of dump material of a certain landfill type, the more interesting this landfill site will be for LFM. A weight of 100% is assigned to household, industrial, mixed and other landfill sites with a volume greater than 500,000 m³. A weight of 75% or 25% is assigned, respectively, to volumes lower than 500,000 m³ and lower than 100,000 m³ for these landfill types. Despite containing a low volume of dump material, these landfill types are still interesting (to a limited extent) when it comes to applying LFM.

The potential for LFM of a landfill site with metal slag will increase linearly with the volume of dump material from less than 100,000 m³ (0%) to more than 1,000,000 m³ (100%), as shown in Table 3-6. The remaining landfill types are assigned a weight of 100% if the volume of dump material is greater than 100,000 m³, and are not taken into account in the calculation to determine the potential (weight of 0%) if the volume of dump material is smaller than 100,000 m³. For volumes of dump material smaller than 100,000 m³ the investments required for the application of LFM will not be profitable enough for these landfill types.

The volumes were chosen based on the article 'Exploring the socio-economics of Enhanced Landfill Mining' (Van Passel et al., 2010) and the volume range present in the OVAM database. It should be noted that the chosen weights are not absolute weights, but relative weights to compare landfill types to each other.

Landfill type	**Volume limit (m²)**		**Weight**
	lower limit (1)	**upper limit**	
Household waste	–	100,000	25%
	100,000	500,000	75%
	500,000	–	100%
Industrial waste	–	100,000	25%

	100,000	500,000	75%
	500,000	–	100%
Mining (high-grade metals)	–	100,000	0%
	100,000	–	100%
Water purification sludge	–	100,000	0%
	100,000	–	100%
Metal slag	0	100,000	0%
	100,000	200,000	10%
	200,000	300,000	20%
	300,000	400,000	30%
	400,000	500,000	40%
	500,000	600,000	50%
	600,000	700,000	60%
	700,000	800,000	70%
	800,000	900,000	80%
	900,000	1,000,000	90%
	1,000,000	–	100%
Gypsum	–	100,000	0%
	100,000	–	100%
Fly ash	–	100,000	0%
	100,000	–	100%
Asbestos	–	100,000	0%
	100,000	–	100%
Mixed	–	100,000	25%
	100,000	500,000	75%
	500,000	–	100%
Other	–	100,000	25%
	100,000	500,000	75%
	500,000	–	100%

Table 8: Overview of volume and weight assigned for each landfill type

3.3.2.4 Weight of use

The presence of buildings at a landfill site is not favourable for the application of LFM, but it is not a limiting factor. Therefore, a weight of 50% is assigned if buildings are present at the landfill site. If the landfill site has not been developed, a weight of 100% is assigned.

Aside from buildings, the current and future use of the landfill sites must also be taken into account in the calculation to determine the potential for LFM. The redevelopment of landfill sites into buffer zones, green areas, forest areas, agricultural areas, mining areas, landfills, rural areas and development areas has a high priority and is therefore assigned a weight factor of 100%. Recreational areas and park areas have a moderate potential for LFM and are assigned a weight of 50-60%. The remaining land use types are not included in the calculation to determine the potential and are hence assigned a weight of 0%. The weights that have been assigned to the various current, intermediate and future land use types according to the regional land use plan are shown in Table 9. It must be noted that the chosen weights are not absolute weights, but relative weights to compare the landfill types to each other.

Where old industrial areas are concerned, brownfields are interesting and have a higher possibility of redevelopment. At the time of writing of this report, OVAM is working to map the brownfields in Flanders. As soon as these data are available, they can be integrated into the calculation tool. Space has been made available for this.

Landfill type	**Volume limit (m²)**			**Explanation**
	Current	**Intermediate**	**Future**	
0100 – Residential areas	0%	0%	0%	no to low potential for ELFM
0200 – Community facilities	0%	0%	0%	no to low potential for ELFM
0300 – Services areas	0%	0%	0%	no to low potential for ELFM
0400 – Recreational areas	50%	50%	50%	low to moderate potential for ELFM
0500 – Park areas	50%	60%	60%	low to moderate potential for ELFM
0600 – Buffer zones	100%	100%	100%	high potential for ELFM
0700 – Green areas	100%	100%	100%	high potential for ELFM
0800 – Forest areas	100%	100%	100%	high potential for ELFM
0900 – Agricultural areas	100%	100%	100%	high potential for ELFM
1000 – Industrial areas	0%	0%	0%	no to low potential for ELFM
1100 – Industrial areas (brownfields)	100%	100%	100%	high potential for ELFM
1100 – Industrial areas	0%	0%	0%	no to low potential for ELFM
1100 – Industrial areas (brownfields)	100%	100%	100%	high potential for ELFM
1200 – Mining areas	100%	100%	100%	high potential for ELFM
1300 – Landfill	100%	100%	100%	high potential for ELFM
1400 – Military areas	0%	0%	0%	no to low potential for ELFM
1500 – Infrastructure	0%	0%	0%	no to low potential for ELFM
1600 – Other	0%	0%	0%	no to low potential for ELFM
1700 – Rural areas	100%	100%	100%	high potential for ELFM
Xx80 – Development areas	100%	100%	100%	high potential for ELFM

Table 9: Overview of weights per land use type

3.3.2.5 Weight of accessibility

As a general rule, it can be said that the further a landfill site is located from a passable public road, a railway or a navigable waterway, the less interesting that landfill site will be for the application of LFM.

The total accessibility is determined in the calculation tool by adding up all three options (public road, railway or navigable waterway), with the possibility to assign a weight for each distance. Currently a weight of 60% is assigned in the calculation tool for a public road and 20% each for a railway and for a waterway (total 100%). These weights can be adjusted.

The relationship between the distance from a landfill site to a passable public road and the weighting factor assigned to this can be shown by means of a natural logarithmic function.

$$y = -0.1086\ln(x)+1$$

where x is the distance between the landfill site and the public road, and y the corresponding weighting factor. In the figure below this relationship is shown graphically.

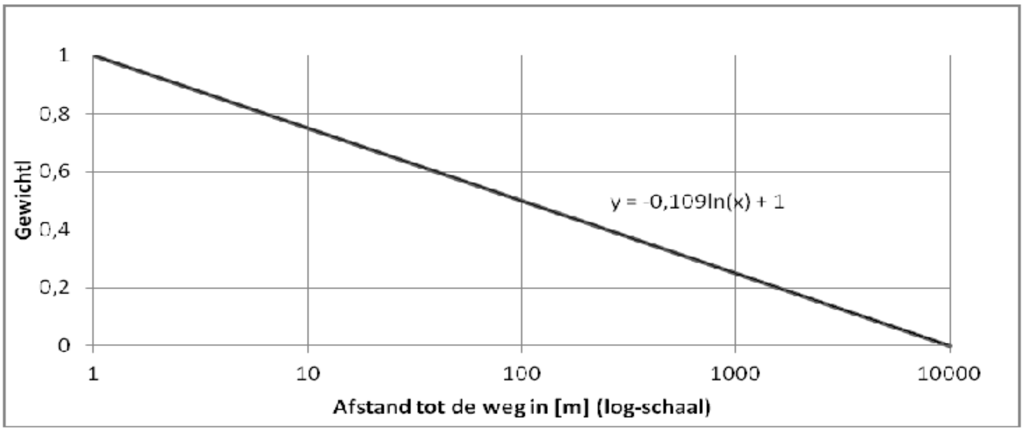


Figure 9: Relationship between the distance from a landfill site to a public road and weighting factors

Both the relationship between the distance from a landfill site to the nearest railway and the weighting factor assigned to this, and the relationship between the distance from a landfill site to the nearest navigable waterway and the weighting factor assigned to this, can be shown by means of the following functions:

$y = 1$

if $x < 50$ m;

$y = -0.0017x + 1.0833$

if $50 \text{ m} < x < 500$ m;

$y = -6e^{-0.5x} + 0.2778$
if $500 \text{ m} < x$;

where x is the distance between the landfill site and the nearest railway or navigable waterway, and y is the corresponding weighting factor. In Figure 10 below this relationship is shown graphically.

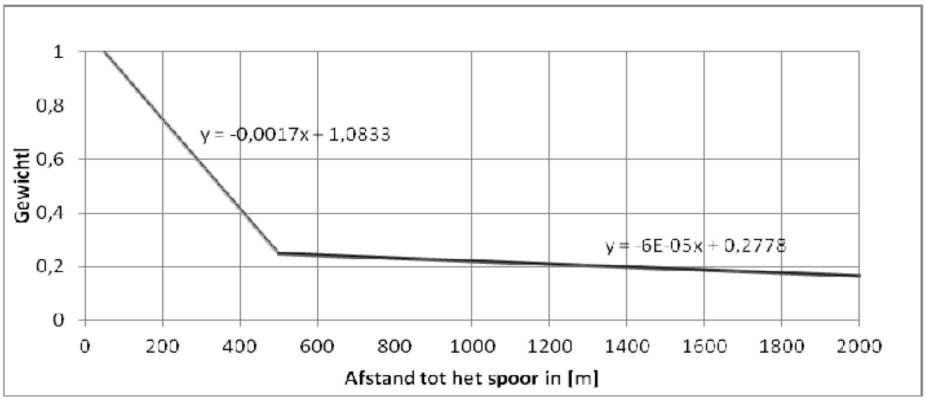


Figure 10: Relationship between the distance from a landfill site to a railway or navigable waterway and weighting factors

3.3.2.6 Weight of the surroundings

Another landfill site of the same type in the vicinity can offer interesting possibilities for LFM because a greater volume is generated if LFM is applied at both landfill sites simultaneously, or because one landfill site could be used to deposit waste from the other landfill site. The relationship between the distance from a landfill site to another landfill site and the weighting factor assigned to this can be shown by means of the following functions:

$y = 1$

if $x < 50$ m;

$y = -0.0006x + 1.0278$

if $50 \text{ m} < x < 500$ m;

$y = -0.0013x + 1.4$

if $500 \text{ m} < x < 1{,}000$ m;

$y = -1e^{-0.5x} + 0.1111$

if $1{,}000 \text{ m} < x < 10{,}000$ m;

$y = 0$

if x > 10,000 m

where x is the distance between the landfill site and another landfill site, and y the corresponding weighting factor. In Figure 11 below this relationship is shown graphically (on a logarithmic scale).

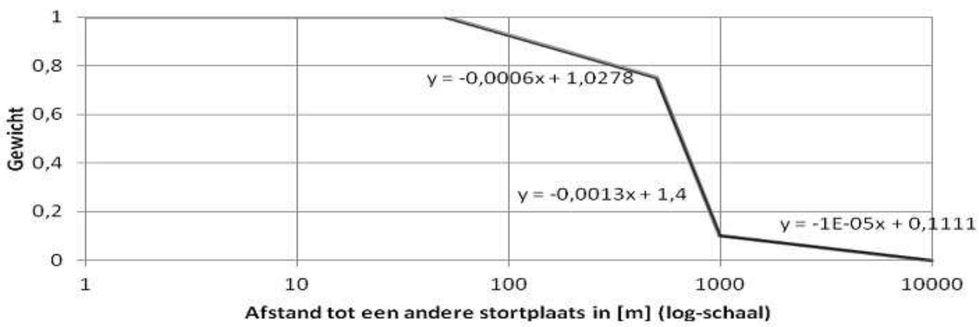


Figure 11: Relationship between the distance from a landfill site to other landfill sites and weighting factors

3.4 Objective 1: Waste to Energy (WtE);

3.4.1 Introduction

Waste to Energy (WtE) is a form of energy recovery. This is a process in which energy in the form of electricity or heat is produced from:

- **landfill gas**: at landfills where biodegradable waste is landfilled, landfill gas is generated as a result of the degradation of organic matter in the waste. Afterwards, this landfill gas can be transformed into energy;
- **waste**: the waste of the landfill site can be heated in such a way that it is converted into fuel. This way, new energy is produced with a high yield (depending on the quality of the waste).

In relation to the determination of the potential for Landfill Mining, only the process by which energy can be recovered from an already existing landfill site is referred to. Concretely, this means that the combustion of waste which would otherwise be landfilled is not taken into account.

Most WtE applications produce electricity via combustion processes, or produce combustible (raw) materials, such as methane, methanol, ethanol or synthetic fuels.

If there is a choice between using the landfill site for energy (WtE) or for the reuse of materials (WtM) it must be studied for which objective the material is most suitable in order to guarantee an optimal use of the material.

3.4.2 Criterion 1 – Type

3.4.2.1 Household waste

Landfill gas

Landfill gas is generated by the natural degradation of biodegradable waste by anaerobic micro-organisms (without oxygen). Once the gas has been produced, it can be collected by means of a collection system, which typically consists of a series of boreholes in the landfilled waste, connected by a plastic pipe system (see Figure 12). The first step in the treatment of the gas is the separation of water, followed by filtering. After that, a radial pump ensures correct suction strength and pressure, and the landfill gas is cleaned and dried. The landfill gas is used by the CHP plants, which deliver their power to the crushers or the electricity grid; the heat from the CHP plants is delivered to the greenhouses. If necessary, the heat that is not used immediately is stored in a buffer tank. The landfill gas that cannot be used is stored, to a certain extent, in a flexible gas storage container. The unused landfill gas is flared.

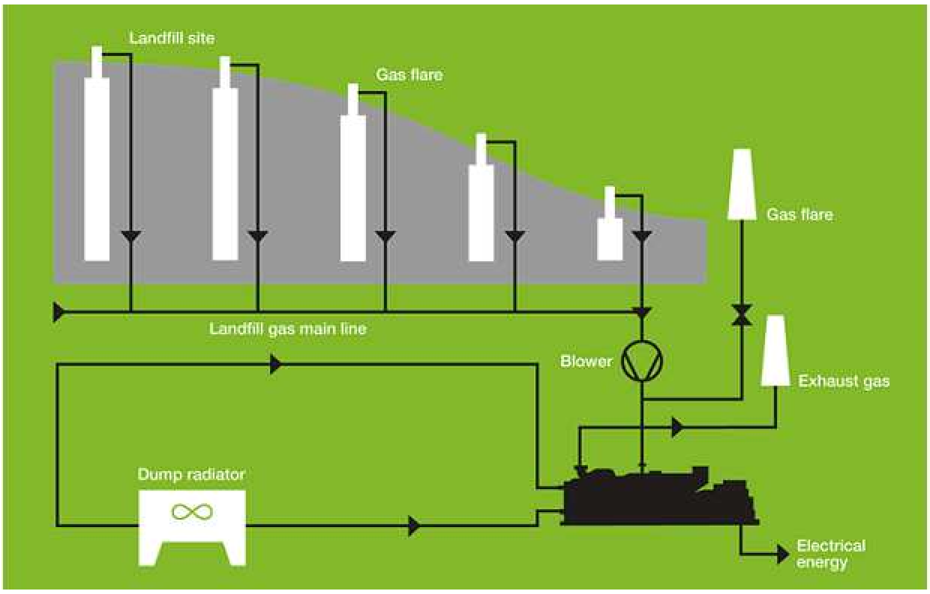


Figure 12: Schematic diagram of the principle of transformation of landfill gas into electricity (source: http://www.clarke-energy.com/gas-type/landfill-gas/

The gas that is collected is saturated with water. This water must be removed prior to any further treatment. The typical composition of the gas is 50-60% methane, 40% carbon dioxide and other components (N_2, H_2, O_2).

Since 1995 it has been obligatory in Flanders for landfill sites where biodegradable waste is dumped for the produced landfill gas to be valorised as an energy source (electricity or heat), or, when this is not feasible, incinerated in a gas flare (source VMM, MIRA report, 2010). Thanks to this obligation, diffuse methane emissions (CH_4) have decreased considerably at the landfill sites concerned (see Figure 13). Since 2004 the electricity produced with the collected landfill gas has been eligible for green energy certificates, and since 2005 all collected gas has been used for energetic valorisation. In 2010, 65 GWh of electricity was produced with landfill gas; this is 2% of the total green energy production.

At old landfills, completed before 1995, the landfill gas does not have to be collected. These old landfills completed before 1995 accounted for 92% of methane emissions from landfills in 2010 (source: http://www.milieurapport.be/nl/feitencijfers/MIRA-T/milieuthemas/afval/verwerking-van-afval/milieudruk-van-stortplaatsen/). However, methane emissions from these old landfills are gradually decreasing.
The potential in Flanders is estimated at 46 million m^3 (source: Flemish authorities). This brings the amount of landfill gas that can be obtained (in optimal circumstances, with an extraction yield of 80%) to approximately 37 million m^3, with a total energy potential of 662 TJ (50% methane). The valorisation of the total amount of landfill gas that can be obtained via CHP results in an electrical potential of 64 GWhe (35% electrical yield) (the supply for 18,000 households) and a possible heat recovery of 331 TJ.

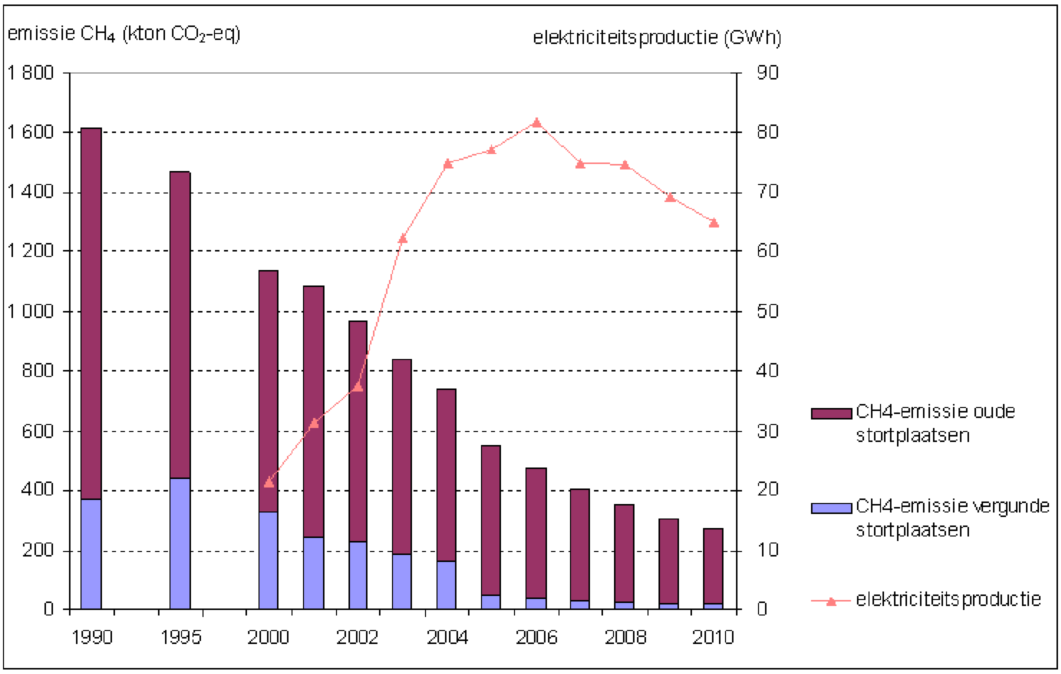


Figure 13: Methane emissions in relation to electricity production (source VMM, MIRA report, 2010)

From a technical and economic point of view, electricity generation by means of a gas motor is the most feasible option for use for landfill operators. Even so, investments in the valorisation of landfill gas often entail high financial and industrial risks:

— the total investment cost for landfill gas extraction, and possibly gas transport and a CHP plant, is high;

— the valorisation of electricity is only feasible if a continuous biogas supply can be guaranteed for at least 10 years, and certainly at peak moments, and/or if a natural gas pipeline is available as a back-up. Often it is not possible to valorise the heat produced.

The price of the supplied (electrical) energy is decisive for the profitability of concrete investment projects. Only with additional subsidies is the recovery time for landfill gas valorisation projects acceptable. Taking into account the rapidly decreasing global landfill gas potential in Flanders, the valorisation of landfill gas should be able to start as soon as possible.

Energy from waste

There are various methods to generate energy from waste. The most common method is **electricity generation through the incineration of (household) waste at waste plants**. In the waste incinerator the heat that is released is used to heat water to steam. This steam is then transported under pressure to produce electricity or to be used as a source of heat (see Figure 14 below). During the incineration CO_2 is released, but this CO_2 emission is many times lower than the emission of greenhouse gases (mainly methane) from the waste deposited at a landfill site. As a result of the incineration, fly ash and bottom ash are released as waste streams as well.

Even so, energy generation through the incineration of waste is considered to be a good alternative when it comes to energy generation. In 2011, 2.57 million tonnes of waste was incinerated in Belgium; with this waste, more than 1.22 million MWh of electricity was produced – a sufficient amount for the internal consumption of the waste plant (20%) and to supply more than 275,000 households with electricity (source: http://www.bw2e.be/nl).

The yield of energy generation through the incineration of waste does not only depend on the fraction of organic matter, but also on the moisture content, homogeneity and calorific value of the waste.

Aside from (direct) incineration there are a number of (emerging) techniques with which **energy or other (bio)fuels can be produced from waste**. By using these techniques, in principle, more energy can be generated per tonne of waste than through (direct) incineration. As corrosive materials (ash) are separated from the fuel, the waste can be incinerated at a higher temperature. Some examples of thermal techniques are gassing and pyrolysis. Furthermore, there are also non-thermal techniques with which **biofuels** can be produced, such as anaerobic digestion and fermentation.

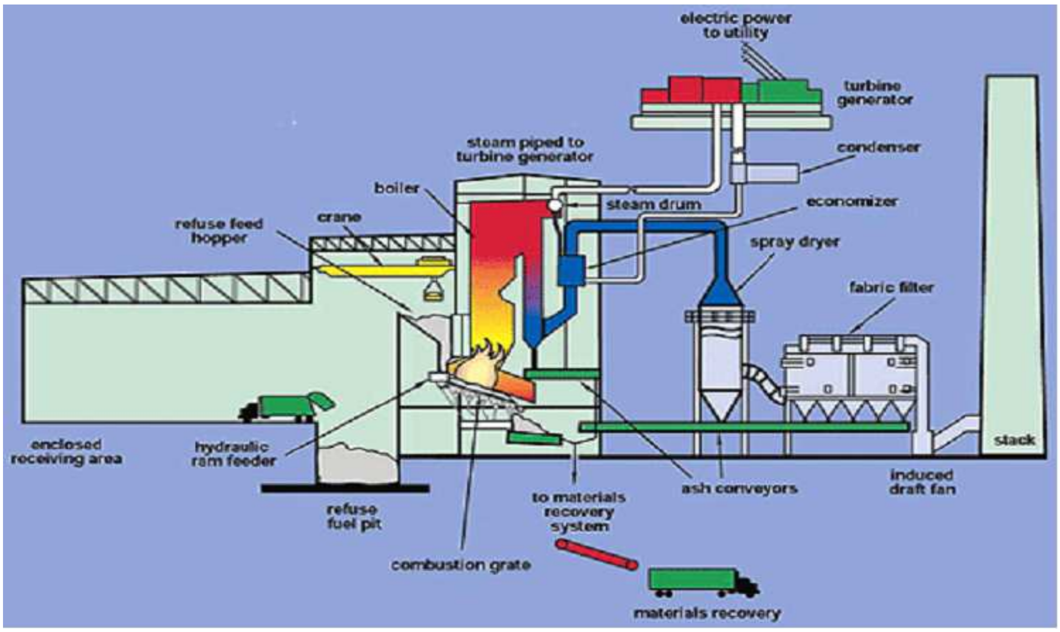


Figure 14: Schematic representation of energy from waste (source://www.pinellascounty.org/utilities/wte-diagrams.htm)

3.4.2.2 Industrial waste

Landfill gas

Organic-biological industrial waste is waste of plant or animal origin that is generated by industrial or traditional production or scientific activities (residual products from production processes, cancelled products and recall products). These are waste streams with a dry matter content > 5% from the food and stimulants industry, the distribution sector, the hotel and catering sector, port activities, the tobacco industry, the paper industry and the textile industry.

Energy from waste

If industrial waste contains an organic fraction, energy can be generated from industrial waste as well. Whether this is feasible and profitable depends on the composition of the industrial waste.

3.4.2.3 Water purification sludge

In Flanders a considerable amount of water purification sludge is produced each year, which needs to be processed and disposed of. There is a rising trend towards the energetic valorisation of this waste stream. In this context the use of anaerobic digestion is considered to be very positive. During the digestion of the sludge an energy-rich biogas is produced (55-75% methane) which can be fed to gas motors for the production of heat and electricity. However, due to the presence of rigid structures that are hard to decompose, the digestion of sludge is a slow process and hence a long time in the digestor is necessary (typically between 15 and 20 days). Even with such long processing times, the total degree of conversion is limited. Only around 50% of the total organic dry matter is converted into gas.

Pre-treatment methods, which cause a partial disintegration of the sludge, offer ample potential to considerably increase the digestion speed and yield.

3.4.2.4 Other types of landfills

Like household and industrial landfill sites, mixed landfills offer a great potential for energy recovery. For 'other' landfills this potential is estimated to be lower, depending on the composition of the non-defined landfill site. Given that landfills where dredging spoil is stored contain a limited amount of organic material, dredging disposal sites are also interesting for energy generation, although to a lesser extent.

Mining waste (e.g. slag heaps with incomplete separation between coal and schists) can still contain a certain energy potential.

The remaining landfill types (metal slag, gypsum, fly ash, inert waste and asbestos) do not contain organic material and therefore do not generate landfill gas. As a result, they are not interesting for energy generation from methane gas.

3.4.3 Criterion 2 – Volume

The amount of landfill gas present at a landfill site and the energy obtained from waste is proportional to the volume of the landfill site, and specifically to the amount of organic matter. The higher the carbon content, the more landfill gas will be released over time.

To calculate the amount of landfill gas, the following formula is used in relation to the volume (source CE Delft, Afvalverwerking en CO_2, March 2006, p. 24) .

$$V_t = \xi \cdot M \cdot C_0 \cdot k \cdot e^{-kt}$$

V_t = volume stortgas

ξ = fractie van de organische koolstof die daadwerkelijk wordt omgezet

M = hoeveelheid gestort materiaal

C_0 = gehalte aan organisch afbreekbaar materiaal

k = factor ter bepaling van de halfwaardetijd

3.4.4 Criterion 3 – Age

The potential for energy generation from waste depends on the organic content in the waste. In principle, it can be stated that the older the landfill, the more organic material will have been decomposed, and the lower the potential for energy generation.

The biochemical processes that are at the basis of the formation of landfill gas are slow. As a result, the release of landfill gas is a delayed process: at first, a relatively large amount is released; in later years, this amount gradually decreases. For this process a half-life period is used. For landfill gas this results in a formation and extraction curve as shown in Figure 3-7 with the following general characteristics: in the exploitation phase the amount of landfill gas that is generated increases fairly quickly as a result of the increasing amount of waste at the landfill site, and decreases over the next years (depending on the half-life period).

After that, the extraction yield is estimated. For an optimal extraction yield, it is advisable to follow the formation curve as accurately as possible when extracting landfill gas. The closer the extraction curve is to the formation curve, the higher the extraction yield will be. As illustrated by the graph, the extraction yield is generally lower in the exploitation phase. This is because it is harder to extract and collect gas during exploitation. When the landfill site has a compartment structure, sometimes an indentation is obtained because the extraction is started compartment after compartment. As soon as a landfill site has been finally closed, an extraction yield of 95-100% is generally assumed.

To determine the potential of LFM for WtE, the end of the exploitation phase is set at 1995, because from then onwards the extraction of landfill gas has been obligatory (Vlarem - Flemish Regulation for Environmental Licences).

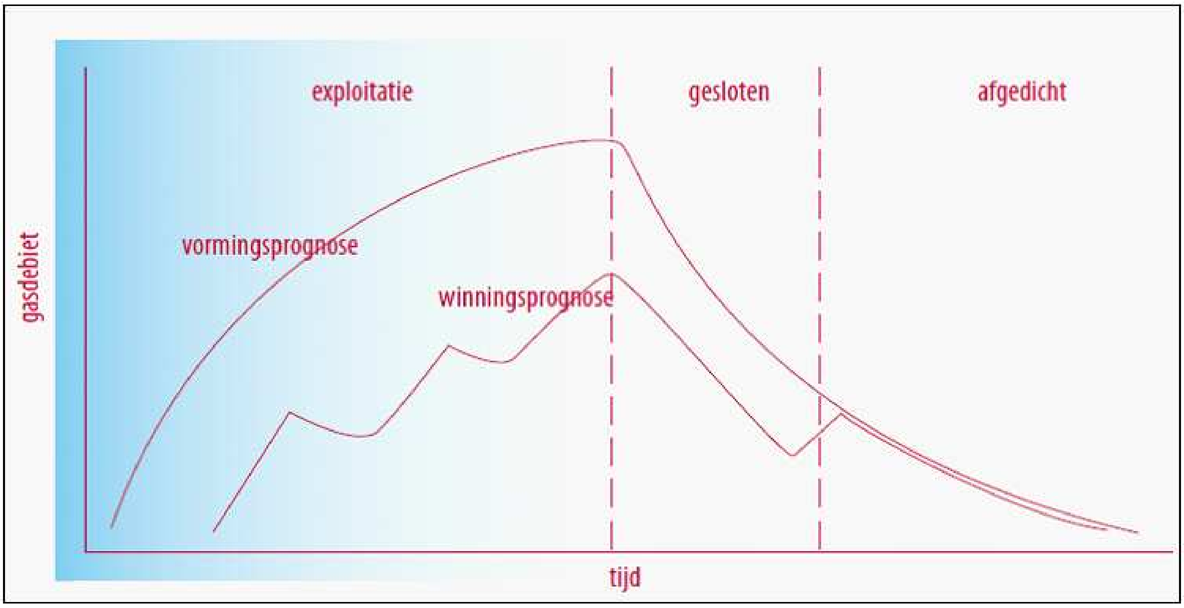


Figure 15: Graph illustrating the principle of the formation and extraction curve for landfill gas (source Senternovem, Handreiking methaanreductie stortplaatsen, 2010)

3.4.5 Criterion 4 – Use

3.4.5.1 Use

The use can affect the WtE objective. For instance, former landfills in agricultural areas, nature areas or conurbation areas are often interesting as they are often large (several hectares) and have a real possibility of landfill gas formation (objective 1 - WtE).

3.4.5.2 Development

The presence of existing structures at a landfill site is not favourable for the use of the material for energy generation.

3.4.5.3 Criterion 5 – Accessibility

Good accessibility via public roads, navigable waterways or railway lines increases the potential of a landfill site for WtE.

3.4.5.4 Criterion 6 – Surroundings

The location of a landfill site in relation to other landfill sites is also a decisive factor for WtE. The ideal situation would be for landfill sites of the same type to be located near each other to allow clustering.

3.5 Objective 2: Waste to Materials (WtM) - materials management

3.5.1 Introduction

Objective 2 - Waste to Materials (WtM) consists in the valorisation of the various waste streams that are released from a certain landfill, and the reuse of these waste streams as materials.

In Figure 16 an overview is provided of the different waste streams which can be released from the various landfill types, treatment techniques and end products.

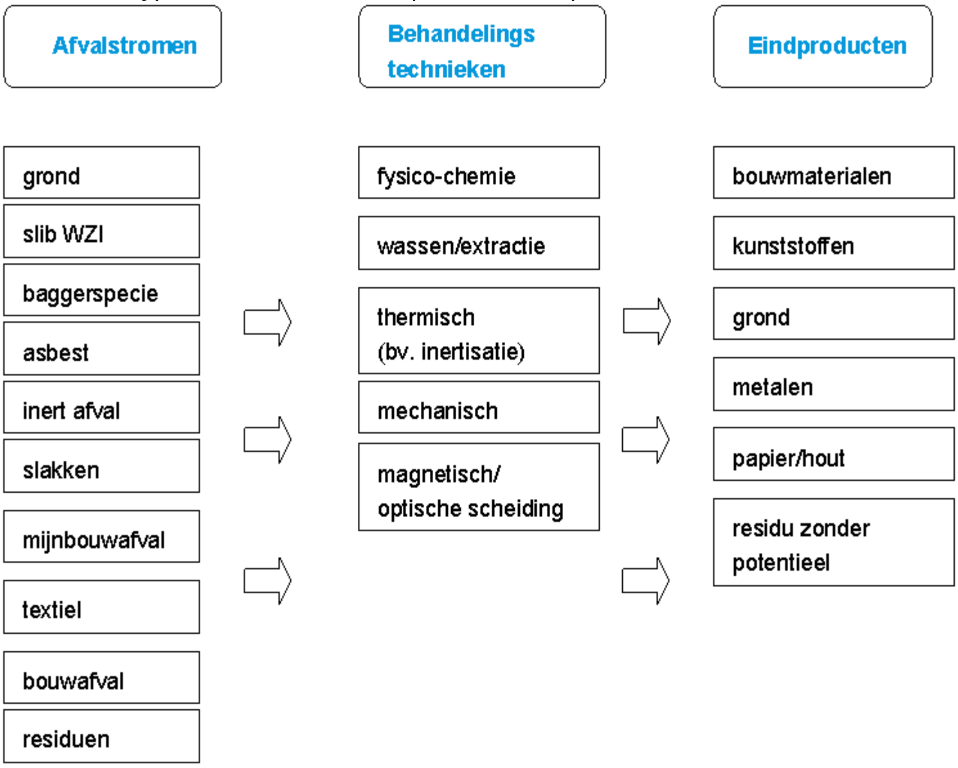


Figure 16: General overview of waste streams and end products (WtM)

3.5.2 Criterion 1 – Type

3.5.2.1 Household waste

Household waste contains various material and waste streams. A considerable share of these materials can be recovered by excavating and separating the waste into different fractions (soil, metals, plastic, mineral components, etc). The percentage that can be recovered and the purity of the different fractions depend on the physical and chemical composition of the waste and the separation methods. Based on LFM projects carried out in the past, 85-95% of the soil, 70-90% of (ferrous) metals and 50-75% of the plastic can be recovered. The purity of these fractions varies between 70% and 95%. (Source: Technical Brief from the World Resource Foundation).

Depending on the composition, purity and environmental hygiene quality, the fractions of debris, soil, metals, plastic, wood and paper can be reused. For instance, concrete and brick debris can be reused as a raw material for the construction of roads and houses.

3.5.2.2 Industrial waste

Like household waste, the common industrial waste consists of a mixture of stone, wood, metals, plastic, textile and paper/cardboard. To recover these materials, as described under household waste, this waste will need to be separated and possibly subjected to additional treatment.

Organic-biological industrial waste is mostly reused in agriculture and horticulture as animal feed, fertiliser or soil improver (after stabilisation, composting or digestion). Its use in animal feeds (with or without pre-treatment) is a high-quality form of recovery. Landfilling and mere incineration are also still (too) common. The digestion technology is generally applied and encouraged for the processing of organic-biological waste streams from the industry. This has a very positive impact especially for water purification sludge when these waste streams are discharged into the surface water.

3.5.2.3 Mining waste

In the mining industry two types of waste are distinguished: 'overburden' material and 'tailings'.

'**Overburden**' is the material that is removed to obtain economically interesting deposits/ores. Overburden material can contain fractions of metals or coal for which extraction was not economically profitable during the mining operation.

The second waste stream is the residual waste stream generated after the extraction of e.g. metals. A well-known waste stream is '**tailings**', a slurry that is generated after the fine crushing of rock and treatment with water, among other things.

Another waste product is e.g. '**zinc ash**', which is released during the extraction of zinc from ore.

Depending on the type of mineral and the extraction technique, there is always a possibility that exploitable mineral/metal fractions are present in mining waste, because as for overburden material, the extent of metal extraction depends on the extraction technique and the metal prices at a given moment.

Over the years, as a result of technological innovations in the mining process and/or an increase in metal prices, the **re-mining** of overburden material, tailings or zinc ash may become economically interesting. Regular re-mining operations of e.g. old tailings are common in the mining industry.

In **re-mining** operations, besides the common techniques for metal extraction, such as high-temperature ('**pyrometallurgical**') or electrochemical processes, less intensive techniques, such as biomining, are applied as well. Biomining is a general term that is used to describe the commercial use of micro-organisms for metal extraction from iron or sulphide ores. It comprises both leaching (**bioleaching**) and **bio-oxidatation processes**. Bioleaching was originally developed to achieve the extraction of copper from low-quality ores, but is now also used for other low-quality metal ores (gold, kobalt, nickel, zinc and uranium). The advantage of biomining is that large amounts of material (dumps) can be treated on site.

The economic feasibility of the re-mining of mining waste depends on the type of mineral, the extraction method used, the physical and chemical properties and homogeneity of the mining waste, and metal prices. The economic feasibility will need to be studied for each case. As a general rule, it can be said that 'the older the mining waste, the greater the possibility that exploitable metal and/or coal fractions are present'.

3.5.2.4 Metal slag

Metal slag is the by-product of extractive metallurgy and mainly consists of solidified oxides. Furnace slag is a specific by-product of the reaction between coal and a furnace. Furnace slag mainly consists of silicon oxide, calcium oxide, magnesium oxide and aluminium oxide. Furnace slag also always contains a limited amount of iron oxide.

Slag can be reused as a concrete aggregate. Its usability depends on its mechanical properties, such as strength, and the environmental conditions, such as composition and leachability of heavy metals. Furnace slag can be reused in the cement industry as a substitute for limestone. Due to its high calcium, iron and phosphorus content, slag is also used as fertiliser (Thomas slag). Another application under consideration is the extraction of CO_2 from processes that use fossil fuels (CO_2 collection and storage) by calcinating CaO-rich slag.

3.5.2.5 Dredging disposal sites

Flanders has large amounts of spoil from dredging, clearance and infrastructure operations. Hence, at first sight, spoil offers a possible alternative to surface minerals. However, most of this spoil is deposited under water again and unavailable for reuse. Up to now, it is not clear either which possibilities of use are most desirable for society, and what policy initiatives are necessary to make the conversion of spoil possible in practice.

Possibilities of selling dredging and clearance spoil

The current possibilities of selling dredging and clearance spoil are very limited. Sandy dredging and clearance spoil (which complies with the requirements for reuse as soil) can be sold in the same market as excavated soil. However, given the technical characteristics of the material, it can hardly compete with that soil material. For less sandy spoil, the market is smaller and focused on specific applications, such as embankments, noise barriers or screens, and landfill covers. The sand fraction of clearance spoil (and ditch spoil), in particular, can be sold to concrete plants.

An analysis of the environmental hygiene and construction quality of the spoil as well as the current supply and demand of primary minerals and alternatives results in the following situation when it comes to possible markets for spoil:

- filler sand: from a construction and environmental hygiene perspective, the largest amount of spoil is eligible for this market;
- however, the market for filler sand is dominated by large amounts of excavated soil that is made available at very low or even negative prices;
- construction sand: due to the grain distribution of spoil, the potential spoil supply for this use is limited. As a lot of primary construction sand is still being extracted or imported, alternative secondary material would be interesting;
- clay/loam: a relatively large amount of spoil, especially dredging and clearance spoil, is eligible for this market. As a lot of primary mineral is still being extracted or imported; alternative secondary material would be interesting. However, the economic feasibility of the use of spoil has not yet been demonstrated. This spoil can be used as a construction material (e.g. bricks, roof tiles, etc.).

Obstacles relating to the sale and processing

The greatest obstacles to the reuse of spoil are:

- from an environmental hygiene and construction perspective, especially dredging and clearance spoil are often not satisfactory alternatives to primary raw materials;

— due to surpluses of other secondary raw materials, concretely soil from earth-moving operations, dredging spoil will need to be disposed of at high negative prices in order to make it economically interesting to the user;
— at this moment, the cost-saving that can be achieved by using dredging spoil instead of landfilling it is limited or even non-existent.

Selling recycled materials is also often much more difficult than selling primary materials. There are often barriers that complicate the sale of secondary (recycled) materials. These barriers for recycled (and secondary) materials can be summarised as follows (Nielsen, 2007):
— primary products are sold in many places; one generally knows where and at what price. For buyers and sellers of secondary materials it is much more difficult to find each other. Moreover, the materials/products are often unique, so one is not always sure about what one is buying or selling. This also makes it difficult to agree on a price;
— lack of information about the material/product. The buyer and seller have different information about the material/product. The seller is often not the producer of the material/product and does not have a clear idea about what he/she is selling, and the buyer is often unsure about what he/she is buying;
— unlike for primary materials, the buyer cannot fall back on experience of other buyers of the material/product (or this is difficult). As often little experience with recycled materials/products is available, the buyer takes a risk when buying (and using) these materials;
— the scale on which the recycled material/product is offered and the density of outlets often put it at a disadvantage compared to primary materials. There is insufficient knowledge about all the characteristics and properties of the recycled materials/products.

These obstacles can be eliminated by (Nielsen, 2007):
— boosting market mechanisms by discouraging monopolies;
— establishing quality guarantees for the materials through certification, providing support (subsidies) for test equipment, defining liabilities in case of an incorrect presentation of the recycled products, working on solutions in case of disputes between buyers and sellers;
— demonstration projects to demonstrate the quality of the recycled material; use of product standards based on the performance of the material, dissemination of information on the properties of the recycled material;
— transaction and search costs: dissemination of information to potential market parties, drawing up of standard contracts to reduce negotiation and transaction costs;
— technological characteristics: extend producer responsibility.

3.5.2.6 Inert waste

According to the Flemish Regulation for Environmental Licences (VLAREM), inert waste is waste which does not undergo any significant physical, chemical or biological changes. Inert waste does not dissolve, burn or undergo any other physical or chemical reaction, it is not biologically degraded and does not have any harmful effects on other substances with which it enters into contact which may cause environmental contamination or damage to human health.

Examples of inert waste are:
— glass (packaging);
— construction materials: bricks, concrete;
— tiles and ceramics;
— mixtures of concrete, bricks, tiles and ceramics;
— glass wool, cell glass.

This material can be revalorised for the production of cementitious materials or as a substitute for primary construction materials. However, before reusing cementitious materials, one must check for possible leaching components.

3.5.2.7 Gypsum

Gypsum can be valorised and reused as a material in the following applications:

— approx. 90% clean gypsum powder can be produced from gypsum waste. This powder is used by gypsum plants for the production of new gypsum slabs;

— soil improver.

It must be remarked that for reuse of the gypsum the quality requirements have to be complied with. For instance, it has to be ensured that no radon gas (radioactive) is released.

3.5.2.8 Fly ash

The composition of fly ash, and hence also its valorisation, strongly depends on the fuel (coal, biomass) and the incineration process. Fly ash from coal (and to a limited extent biomass) can be reused and processed into cement, concrete, paving bricks and asphalt. It condenses the structure of the concrete, increasing its protection against outside influences. Fly ash from the incineration of waste in a waste incineration plant is currently not being used yet.

Various scientific studies have shown that fly ash can be valorised to construction materials that can replace cement. By adding high alkaline solutions[2], an amorphous aluminosilicate with a similar structure is formed, such as a zeolite precursor (A. Palomoa, M.W. Grutzeckb,*, M.T. Blancoa, 1998). The temperature and the proportion of solution/fly ash have an influence on the mechanical properties (e.g. strength) of the end product.

3.5.2.9 Asbestos

By applying the vitrification process with a plasma torch (high temperatures of 1,600 °C) the fibre structure of asbestos is destroyed. This results in an inert vitrified product called Cofalit. This is a vitreous, chemically stable matrix. Various scientific studies have shown that this vitrified product is harmless and non-toxic (source: Europlasma/Inertam), so, in principle, it could be classified as an end-product. However, at the time of writing approval by the legislative framework is pending. The product has been approved by the French authorities for use in road construction. Its appearance is that of black glass or basalt stone. It is currently sold as an aggregate for bottom layers in road works, but it can also be used for other, 'nobler' applications, such as the manufacture of concrete products or other construction materials (paving bricks, …).

3.5.2.10 Water purification sludge

After the dewatering of water purification sludge, the so-called sludge cake can be processed further, for instance by digestion for the production of bio-gas or by incineration. The ash from sludge incineration can be used to generate new raw materials, such as phosphate for the production of artificial fertiliser, or the incineration ash can be used in asphalt for road construction.

3.5.2.11 Mixed landfills and other landfills

Like household and industrial landfill sites, mixed landfills offer a great potential for material recovery. For ‘other’ landfills this potential is estimated to be lower, depending on the composition of the non-defined landfill site.

2 These solutions, made with NaOH, KOH, etc., have the general property of containing high OH concentrations.

3.5.3 Criterion 2 – Volume

To recover materials from waste, the general rule is that a plant must be built where the waste can be separated and/or treated. The volume of the waste is important when it comes to the investment costs. The rule is that the larger the volume of waste, the greater the possibility of recovering investment costs.

3.5.4 Criterion 3 – Age

For household and industrial waste, there is a relation between age and the composition of the landfill site. For mining waste and metal slag, the general rule applies that the older the waste, the higher the possibility that exploitable metal and/or coal fractions are present.

3.5.5 Criterion 4 – Use

The use (agricultural area, industrial area, residential area, recreational area or nature area) can have an influence on the WtM objective. The presence of existing structures at a landfill site is not favourable either for the reuse of the material (WtM).

3.5.6 Criterion 5 – Accessibility

Good accessibility via public roads, navigable waterways or railway lines increases the potential of a landfill site for WtM.

3.5.7 Criterion 6 – Surroundings

The location of a landfill site with respect to surrounding landfill sites is also assessed to determine the potential for WtM. The ideal situation would be for landfill sites of the same type to be located near each other.

3.6 Objective 3: Waste to Land (WtL) - space

3.6.1 Introduction

Once they are full and waste is no longer deposited, former landfills are often no longer used, or barely so, and are left fallow. However, the location of many former landfills often invites an intensive use. From the 1950s up to 1985 the waste was landfilled on the edge of the village or city. In each town or city there were several locations where the municipal authorities and companies could deposit their waste. As a result of the expansion of villages and cities, many landfill sites are surrounded by built-up areas. In Flanders this is the case for a total of approx. 55 km² (approx. 0.45% of the total surface area), with a theoretical volume of approx. 400 Mtonnes.

As a result of the increased pressure on space, landfill sites are also looked at from the perspective of an efficient use of space as possible sites for the development of housing and industrial estates and recreational, agricultural and nature areas. By assigning a new use to this space, which would otherwise remain unused, space is freed up elsewhere for agriculture and nature.

Besides building on a landfill site, space can also be created for new uses (companies, living, nature) by excavating a landfill, recycling usable materials (WtM) and depositing the remaining part at a nearby landfill site.

3.6.2 Criterion 1 – Landfill type

For objective 3 'Waste to Land', all landfill types are eligible on condition that the location of the landfill site offers added value for the redevelopment of the area. In practice, however, and according to the available OVAM database, these are mainly former landfills for **household waste** and **industrial waste (demolition and business waste)**.

3.6.3 Criterion 3 – Volume

Especially the surface area occupied by the landfill site is important for objective 3. Larger surface areas generate a lower unit rate per m³ of waste.

3.6.4 Criterion 4 – Use

3.6.4.1 Use

Based on the spatial context for (re)development possibilities former landfills can be subdivided into three characteristic types:

1 Rural area (agriculture/nature).

2 Conurbation area.

3 Inner city and industry.

Former landfills in **agricultural or nature areas** have a strong visual presence in the landscape. In many cases, they were in use until the 1980s and consist of filled deep sand and clay pits. As demolition and industrial waste was dumped at many of these landfill sites, asbestos may be present. These landfill sites often cover a large surface area (various hectares) and the formation of landfill gas is a real possibility (objective 1 - WtE). An example of such landfill sites can be found in the clay pits of Terhagen in the Rupel area.

Former landfills in **conurbation areas** are often less recognisable as those in rural areas. A common use is temporary storage. These landfill sites were used for the landfilling of household waste, small industrial waste and demolition waste until the 1970s. Due to their location in a conurbation area, spatial pressure on the surroundings often increases. There are often good possibilities for the development of public facilities, such as sports fields, playgrounds, cultural venues or event centres. Special attention needs to be paid to the sensitivity of the dump material to subsidence and to the generation of landfill gases. These landfill sites are medium-sized (1-5 ha). As an example, the former landfill sites near the city of Lier can be mentioned.

Landfill sites in **urban and industrial areas** are often not recognisable as such. These landfill sites consist of filled old city ditches or sand pits. The dump material mainly consists of household waste. The developments at these locations date back to the 1950s and need modernisation. The redevelopment of these landfill sites to high-quality public spaces or buildings is perfectly possible.

3.6.4.2 Development

The presence of existing buildings at a landfill site is not favourable for redevelopment, but this does not mean that this is a limiting factor. If we assume that the development took place soon after the creation of the landfill site, this development may need to be modernised. The redevelopment of these landfill sites to high-quality public spaces or buildings is perfectly possible.

3.6.4.3 Cost per m²

A high cost of a certain plot can be an extra stimulus to perform LFM, because this results in a lower unit rate per m³ of waste (see also development - redevelopment to high-quality spaces or buildings).

3.6.4.4 Criterion 6 – Surroundings

By clustering landfill sites, space can be created for new uses as well. For the clustering of landfill sites it is important that other landfill sites are located near the landfill site under assessment. The rule is that the further the waste needs to be transported, the less profitable moving a landfill site will be.

3.7 Objective 4: Resource Management (RM) - Temporary Storage.

3.7.1 Introduction

Temporary storage - resource management

In practice, it happens that new waste is either landfilled or incinerated. The reason for this is that currently no suitable techniques are available yet to valorise this waste. Hence, this can lead to a sub-optimal use of this waste. Objective 4 refers to the temporary storage of waste and resource management. De terminologie in het Engels is “Temporary Storage” of “Resource Management”. The waste is not landfilled, but is stored temporarily with a view to its future valorisation when suitable techniques are available. In short, a landfill site becomes a mine for tomorrow's raw materials.

The traditional incineration of new waste often leads to sub-optimal choices for certain waste streams. Temporary storage with a view to valorisation prevents expensive, energy-intensive separation processes for waste streams which can be exploited again as raw materials in the future.

In Figure 17 the concept of temporary storage is illustrated schematically (source Prof. P. Jones - KU Leuven).

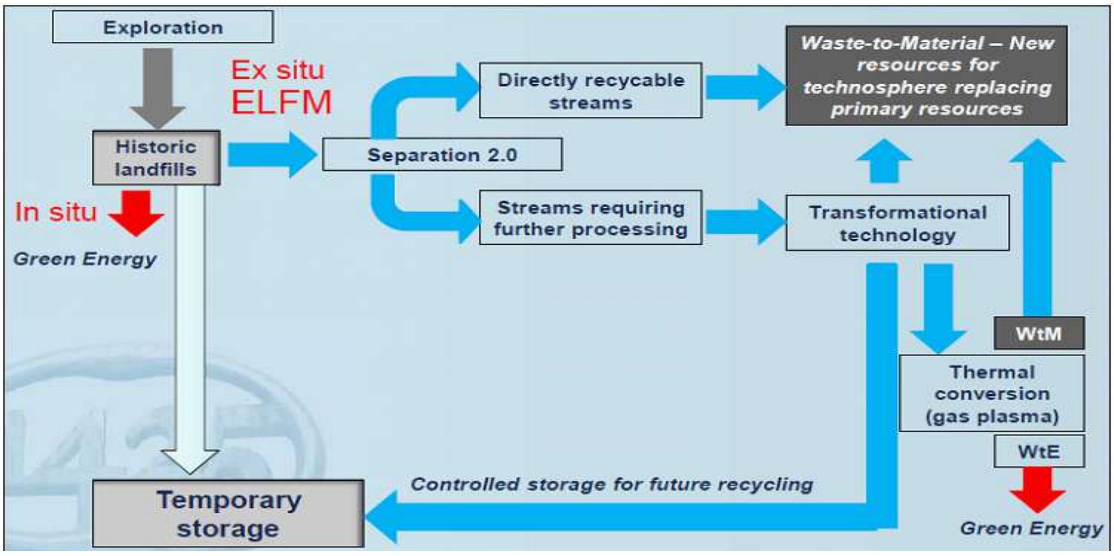


Figure 17: Concept of Temporary Storage (Source: Prof. P. Jones - KU Leuven)

Temporary storage can take place in two different ways. Firstly, the waste can be distributed into different compartments based on the type of waste stream **at a specific landfill site**. This landfill site is built in accordance with the current regulations (foil, leachate collection, drainage layers, etc.) and can receive other waste streams from outside. Another principle involves the creation of mono-landfills with one type of waste stream (cf. current metal business) (Temporary Storage) (see figure above). This principle simplifies the valorisation process of this specific waste stream).

Current status

For the actual implementation of temporary storage, the current legislative framework needs to be adapted and specific stimuli need to be provided by the authorities. Furthermore, further research by private market players is required into the prevention of the dispersion of contaminated substances and the limitation of losses of valuable raw materials.

3.7.2 Criterion 1 – Type

The landfill type is the first factor that determines the way in which resource management can be implemented:

- household waste, industrial waste and mixed waste:
  - one can opt for separating the different waste streams on site and distributing them into different compartments;
  - one can opt for depositing one specific waste stream (e.g. the principal component) and moving the other waste streams to other landfill sites that implement resource management;
- mono-landfill: in theory, this consists of one main component, which can be used for resource management.

3.7.3 Criterion 5 – Accessibility

Good accessibility via public roads, navigable waterways or railway lines lower the unit rate per m³ of waste, which increases the potential of a landfill site.

3.7.4 Criterion 6 – Surroundings

The location of a landfill site in relation to other landfill sites is also a decisive factor for the implementation of resource management. The ideal situation would be for landfill sites of the same type to be located near each other. As we have already mentioned, it must be further assessed based on market developments and the legislative framework which landfill sites and waste streams are eligible for resource management.

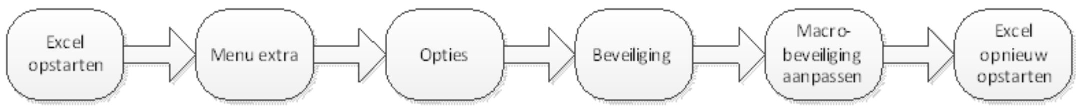
3.8 Technical development of a calculation tool for environmental prioritisation for LFM[3]: the FLAMINCO model

3.8.1 Introduction

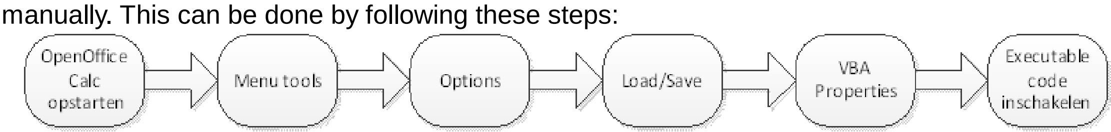
Based on the previous chapters, this chapter contains a brief explanation of the principle of the calculation tool for environmental prioritisation for LFM. The calculation tool is attached in Appendix 1.

— ‘Matrix database’ sheet: basic data;
— ‘Working database’ sheet: this database contains the same data as the matrix database. However, in the working database the data from the matrix database can be modified and new information can be added;
— ‘Input’ sheet: input data for the calculations, based on the ‘Additional input’ data sheet and the ‘Matrix database' data sheet;
— ‘LFMinst’ sheet: overview of weight factors assigned for the calculations
— ‘Summary by objective’ sheet: results of the calculations for all landfill sites
— ‘Summary by landfill site’ sheet: displays the potential of each landfill site
— ‘Final graph’ sheet

The calculation tool was made using macros. These need to be activated before the calculation tool can be used. When macro security in Excel has been set to ‘Low’, all macros are executed without any prior notification. When macro security has been set to ‘Medium’, a dialogue box is displayed asking whether the macros may be activated. When macro security in Excel has been set to ‘High’, only macros which have been digitally signed or stored in a trusted location, such as the Excel startup folder, are executed. Macro security can be adjusted by following these steps:



The use of Microsoft Office macros in OpenOffice is usually possible, but needs to be activated manually. This can be done by following these steps:



3The calculation tool that has been developed for this study and is able to calculate the order of priority based on the potential for LFM and the potential need for remediation in an integrated way has been named the **FLAMINCO model.**

3.8.2 'Guidance' sheet

This worksheet contains the general explanation of the various sheets in the calculation tool. It also contains a reference to each worksheet.

3.8.3 'Matrix database' sheet

This worksheet contains the basic data on each landfill site for environmental prioritisation. As a first input for the determination of environmental priority, we have opted for a list of 72 landfill sites. After linking the calculation tool for environmental prioritisation to the calculation tool for the need for remediation, the input data are extended with data on the approximately 1,700 landfill sites of the LFM database. The matrix database has been compiled based on data found in OVAM's PCS files, complemented with data from available GIS data layers. Besides identification and address information, the input data are subdivided by criterion (type, age, volume, use, accessibility and surroundings).
This sheet is protected and no changes are allowed (see Figure 18: Protection of 'Matrix database' sheet). Changes must be carried out in the 'working database' sheet. It is recommended to perform regular (e.g. annual) updates based on the changes carried out.

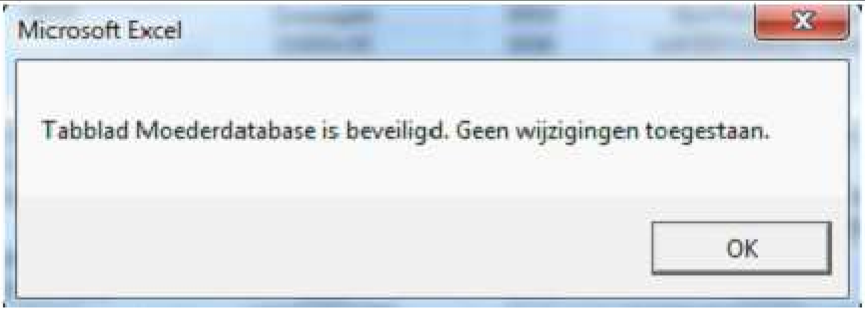


Figure 18: Protection of 'Matrix database' sheet

3.8.4 'Working database' sheet

3.8.5 'Input' sheet

This sheet contains the data used for calculations. The user can choose between using the data as included in the matrix database or in the working database. Via the 'process' button the data from the matrix database or the working database are imported through a single action. When data are modified in the working database compared to the matrix database, these cells are marked in red.

3.8.6 'LF Minst' sheet

In Figure 19 the 'LFMinst' sheet is shown. Via the 'load' button the input data needed for the calculations in the 'LFMinst' sheet are loaded. Via two selection boxes a landfill type (household waste, industrial waste, dredging spoil, water purification sludge, inert waste, gypsum, fly ash, asbestos, metal slag, mining waste, mixed waste and other) and an objective (Waste to Energy (WtE), Waste to Materials (WtM), Waste to Land (WtL) and Waste to Resource Management (RM)) can be selected, after which the different weights assigned for each criterion are displayed.

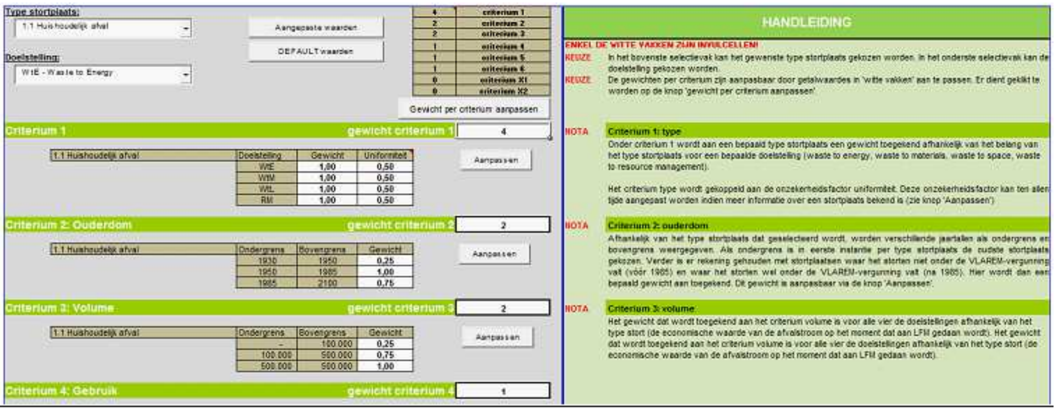


Figure 19: 'LFMinst' sheet

By means of the weight factors an order of environmental priority of the different landfill sites can be obtained based on the specific characteristics (see 'input' sheet) of each landfill site. These weight factors can be adjusted at any time. For a justification of the weight factors assigned we refer to Chapter 3.3 of this report.

3.8.7 'Summary by objective' sheet

The 'load' button in the 'Summary by objective' sheet loads the data from the 'input' sheet for the different landfill sites. Via the weighting factors determined in the 'LFMinst' sheet a potential value is calculated for each landfill site for each of the four objectives. The landfill sites are put in order vertically by objective in decreasing order of potential for the objective in question. It must be remarked here that the landfill sites are always compared to a hypothetical landfill site, which is assigned the maximum score for a specific objective. This way, a **relative order** is obtained to allow for comparison of the landfill sites between them. A landfill site which seems to have a high potential for LFM within a certain set of landfill sites may have a low potential in comparison with another set of landfill sites. The output data obtained must always be looked at critically. For each objective the 10 landfill sites with the highest potential for that specific objective are shown in a graph. Finally, in a fifth graph the ten landfill sites with the highest potential for LFM are displayed (see Figure 20: Example graph of 10 landfill sites with the highest potential for LFM).

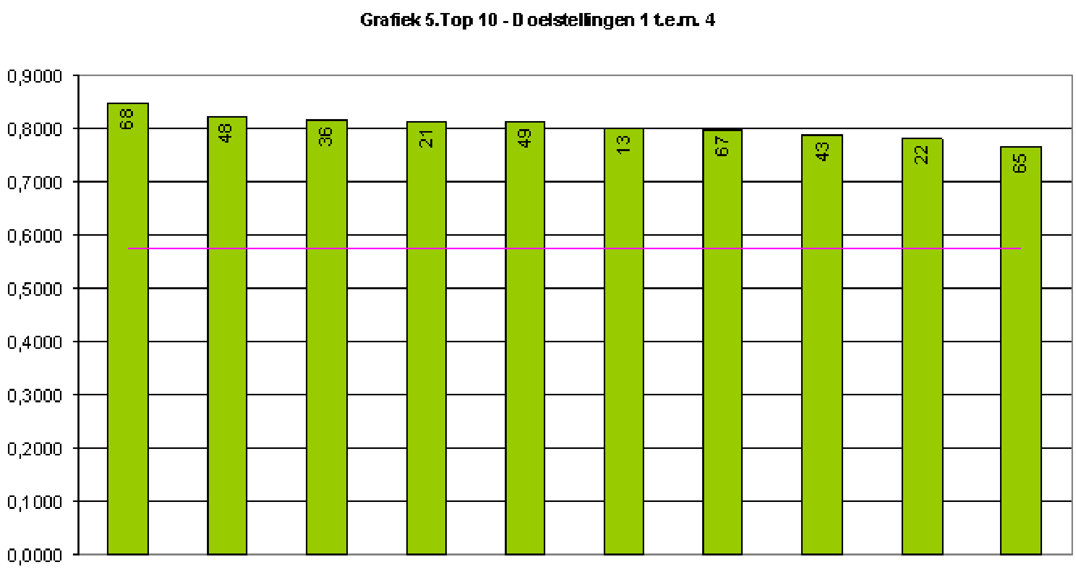


Figure 20: Example graph of 10 landfill sites with the highest potential for LFM

3.8.8 'Summary by landfill site' sheet

The ‘load landfill sites’ button in the 'Summary by landfill site' sheet loads the different landfill sites. In the selection box the desired landfill site can be selected (see Figure 21).

Figure 21: ‘Summary by objective’ sheet

For the selected landfill site the share of each criterion in the calculation to determine the potential is displayed in a graph. In a second graph the potential of the selected landfill site for the four different objectives is displayed graphically.

3.8.8.1 Result of the calculation tool

As an example, in this paragraph the potential for LFM of a randomly selected landfill site will be looked at in more detail using the calculation tool. For this illustration the landfill site with ELFM number 32 has been selected.

'Input' sheet

In the ‘input’ sheet we can read that this landfill site is located on Rupeldijk in Willebroek and that it comprises 13 plots according to the land register and has a total surface area of 175,421 m². The landfill site is a mixed landfill site which was in use from 1942 to 1977. The landfill site was used in the past for the disposal of household waste, dredging spoil and inert waste. The landfill site is located above ground level, but the landfill height was not specified in the PCS files. Therefore, a random height of 3 m above ground level is assumed in order to be able to make an estimate of the volume of dump material. This results in a volume of dump material of 526,263 m³. This landfill site is supposed to have been covered and be partly covered with forest and partly left fallow. Based on the data in the PCS files there is no development at this landfill site. According to the GIS data layers the land use codes 1504, 0901, 0800, 0701 and 0402 of the regional land use plan apply to this landfill site. The landfill site is located on a passable road, Rupeldijk, and a navigable waterway, the Rupel. The nearest railway line is 2,410 m away, and the nearest landfill site in the surroundings is the landfill site with AMB file number 4138, located at a distance of 276 m.

'LF Minst' sheet

The calculated weighting factors in this sheet for the different criteria and the different LFM objectives are used further in the calculations to determine the environmental priority of the landfill site.

‘Summary by objective’ sheet

In this sheet the relative order for all landfill sites combined is displayed. Out of 72 landfill sites, landfill site 32 occupies the 2nd place for the Waste to Resource Management objective, the 9th place for the Waste to Land objective, the 15th place for the Waste to Material objective, and the 43rd place for the Waste to Energy objective. Globally speaking, for all objectives combined, landfill site 32 occupies the 13th place in this relative ranking. The high ranking for the Waste to Resource Management objective can be explained by the excellent accessibility of the landfill site and its surroundings. The landfill site is located on a navigable waterway, the Rupel, and on a passable road, Rupeldijk. Moreover, another landfill site of the same type is located in the surroundings of landfill site 32, at a distance of only 276 m.

'Summary by landfill site' sheet

In graph 6 (see Figure 22) the share for each of the six criteria in the calculation to determine the environmental priority of landfill site 32 is displayed, subdividing criterion 1 (type) for the four different objectives.

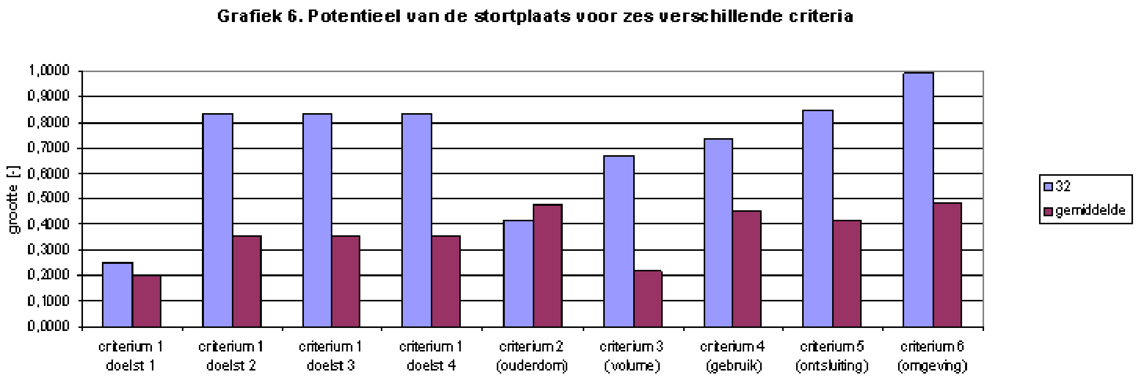


Figure 22: Potential of landfill site 32 for the different criteria

As it concerns a mixed landfill site of household waste, dredging spoil and inert waste, with a volume greater than 500,000 m³, which has not been developed and is located in a recreational area, near a passable road and a navigable waterway, and a landfill of the same type is located relatively close by, landfill site 32 scores better for all criteria than the average of all landfill sites, except for the age criterion. Given that the operation of the landfill site started in 1947 (before 1950) and that, among others, household waste was dumped there, the landfill site is less suitable for LFM based on age due to the relatively low economic value for LFM.

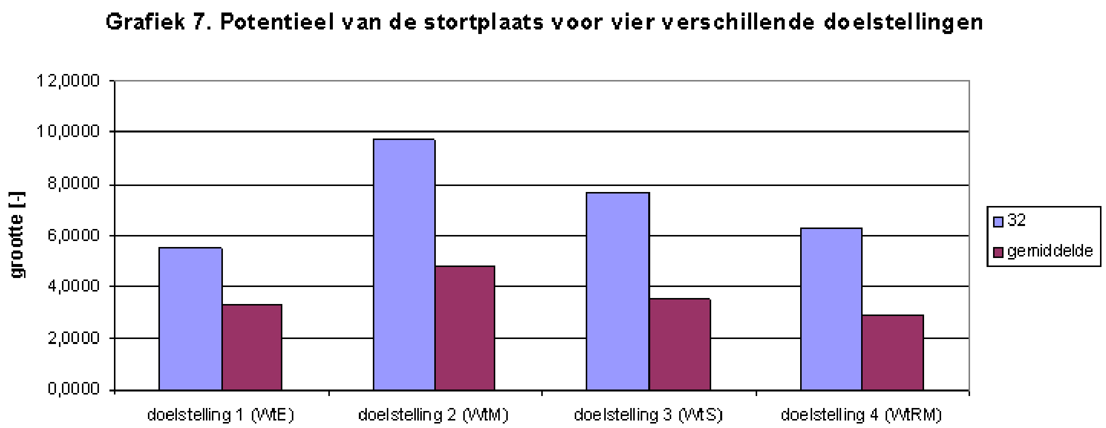


Figure 23: Potential of landfill site 32 for the different objectives

In graph 7 (see Figure 23) the potential of landfill site 32 for the different objectives is compared to the average potential of all landfill sites combined.

As landfill site 32 is an old landfill site, compared to the average for all landfill sites combined, this landfill site scores relatively lower for the Waste to Energy criterion due to the low expected energy recovery at old landfill sites. For the other objectives landfill site 32 scores relatively well for LFM potential due to the favourable characteristics of this landfill site for LFM.

4 Sub-task 2: Field Design projects

This chapter is only available in the Dutch version.

5 Sub-task 3: Screening of the need for remediation

Part of the landfill sites in Flanders have not yet been studied in the framework of the Soil Decree. At a number of landfill sites, the investigations stopped after the exploratory soil survey or during the descriptive soil survey. For both cases a method has been developed to determine the need for remediation in view of the contamination present. The screening of the need for remediation is done **step by step and in a cost-efficient way** to enable **prioritisation based on the need for remediation** afterwards.

The method studies the need for remediation of landfill sites in a **simple and unambiguous manner** , based on **information which is easy to obtain and can be interpreted** in an unambiguous way.

5.1 Conceptual site model of the landfill site

To develop the method, the Conceptual Site Model of a standard landfill site is used as a basis.

For historical contamination the reason for remediation is risk-based. The following general Conceptual Site Model for a landfill site is proposed:
To determine the need for remediation based on the Conceptual Site Model of a landfill site, a **multi-stage method** is proposed:

Source	**PATH: transport route(*)**	**PATH: exposure**	**Receptor**
Dump material	Evaporation from dump material and via gas formation	Inhalation of outside air	Employees (operation) Surrounding residents/employees/recreational users
	Distribution by wind drift	Direct contact (ingestion, inhalation, dermal contact) of soil and/or dust	Surrounding residents/employees/recreational users
		Consumption of crops, dairy, meat	Surrounding residents/agriculture
		Adverse effects on ecosystems	Ecosystems in the surroundings
	Leaching and distribution from and via the groundwater		Surrounding residents/agriculture
			Surface water
			Groundwater abstraction: users of contaminated well water
			Drinking water abstraction and protection zones in the

			vicinity
			Groundwater-related ecosystems in the surroundings

Table 11: 1 Conceptual Site Model for average landfill site

(*) direct contact of the dump material itself with the receptor 'people' is not considered relevant as it is assumed that there will be at least a topsoil layer. Obviously, if such a scenario does occur, this must be taken into account.

Concretely, a system must be developed to do the following in a cost-efficient way:

— Estimate the potential need for remediation based on global criteria (step 1).
— Link a priority within the list of landfill sites to this determination of potential (step 1).
— Define a further detailed assessment of the need for remediation and the need to carry out soil remediation works (steps 2 and 3).

5.2 Step 1: Prioritisation of the need for remediation based on general characteristics of the landfill site and the surroundings

In a first step the possible risks connected to a landfill site are estimated on a global level based on a number of basic criteria which are easy to look up and provide both a qualitative and a quantitative estimation of

— the possible impact of the **source;**
— the impact on the **receptors**.

Criteria for the global assessment of the potential need for remediation.

As the need for remediation is determined by:

— both the possible impact of the **source** (i.e. the landfill site);
— and the presence and vulnerability of the surrounding **receptors**;
— criteria must be defined for both the source and the receptors to describe this possible impact.

First of all, a list is made of possible criteria that characterise the source or receptor (see 5.2.1); after that, a selection is made from these criteria (see 5.2.2).

In the risk assessment for contamination caused by the presence of a landfill site, the **source** needs to be characterised using the following parameters:

— Type, volume and age of the dump material (can also be checked on (historical) aerial photographs);
— (Possible) licence of the landfill site;
— History of the landfill site (e.g. evolution or changes in dump material, …);
— Location of dump material compared to the natural groundwater table;
— Presence of capillary water;
— Completion (or planned completion) of the landfill site: presence of bottom and lateral sealing, clay layers, top sealing, presence and thickness of a (foil) cover layer, collection of leachate, collection of landfill gas,…;
— Availability of monitoring data: surrounding groundwater, leachate, landfill gas,…;
— Availability of other data from (soil) surveys on the site or in the surroundings (e.g. based on the OVAM database) concerning the soil, dump material, groundwater, …
— …

- Furthermore, the possible impact on the following **receptors** must be assessed:
- People: depending on the (current and future) land use type and the actual use of the plot and the surrounding area: residential area, recreational area, agricultural area (food);
- Ecosystems: depending on the (current and future) land use type and the location of the plot and its surroundings within certain 'vulnerable' nature areas (NATURA2000, Habitat, VEN/IVON,…);
- Groundwater: surrounding and underlying aquifers: geology and hydrogeology
- Surface water in the vicinity;
- Groundwater abstraction (+ depth, + use) in the vicinity;
- Protected drinking water abstraction zones in the vicinity;
- Location with respect to flood zones;
- …

From the above list of parameters the **most relevant criteria must be selected** to determine the global potential need for remediation of the landfill site in step 1. Based on these selected criteria the different types of potential risks of a landfill site must be described.

5.2.1 Selected criteria for prioritisation

For the selection of the criteria the following boundary conditions were taken into account: they had to be simple and workable based on relatively easily obtainable information, but also complete to the extent that all possible risks should be taken into account.

Based on these criteria a calculation tool (see 5.2.3) with a score system was designed to enable us to establish a prioritisation of the landfill sites when it comes to the need for remediation.
The selected criteria are shown in the table below[4], as well as the information based on which the criterion was translated into the calculation tool:

1 Characterisation/inventory of the possible source of contamination:

Parameter	Description	Translation for calculation tool information (database)
1. Type of dump material	What material does the landfill site contain?	From the PCS file for the landfill site in question
2. Age of the landfill	During what period was the landfill site operated?	From the PCS file for the landfill site in question
3. Size of the landfill	What is the size of the plot on which the landfill site is located according to the land register?	From land register data in GIS
Completion of the landfill site	Location in a clay pit / in accordance with Vlarem and completed / in accordance with Vlarem and in operation / partly in accordance with Vlarem / no completion / unknown	Must be taken to the second phase
Location of the dump material with respect to the	Dump material above groundwater / Dump material	Must be taken to the second phase

4The criteria in grey were initially taken into consideration as well, but were then moved to the second step of the determination of the need for remediation due to the excessive complexity for the determination of potential in the first step.

groundwater table / capillary water with respect to dump material	below groundwater / Leachate collection – No information	
Availability of soil data (analyses of soil and groundwater) for the landfill site.	Data on dump material – landfill gas – leachate	Must be taken to the second phase
Availability of soil data (analyses of soil and groundwater) for the surroundings.	Data on soil and groundwater in the surroundings	Must be taken to the second phase

2 Characterisation/inventory of the possible receptors

Parameter	Description	Translation for calculation tool information (database)
1a. Location with respect to residential area: current + potential	Distance to current and potential residential area (possible human exposure)	From GIS data in regional land use plan
1b. Location with respect to recreational area: current + potential	Distance to current and potential recreational area (possible human exposure)	From GIS data in regional land use plan
1c. Location with respect to agricultural area: current + potential	Distance to current and potential agricultural area (possible human exposure)	From GIS data in regional land use plan
1d. Location with respect to industrial area: current + potential	Distance to current and potential industrial area (possible human exposure)	From GIS data in regional land use plan
2. Location with respect to ecologically valuable areas: current + potential	Distance to current and potential ecologically valuable areas (possible damage to ecosystem)	From NATURA 2000 Nature areas (VEN/IVON)
3. Groundwater vulnerability	Groundwater body as a receptor of contamination in itself	From GIS data in groundwater vulnerability map
(Permeability for aquifer)	Groundwater migration speed	Included in groundwater vulnerability
Presence of a separating clay layer	Protection of underlying aquifers	Included in groundwater vulnerability
4. Location with respect to surface water	Impact on surface water	From GIS data in hydrographic atlas
5. Location with respect to groundwater abstraction (+ depth + use)	Impact on groundwater abstraction	From GIS data from the DOV database
6. Location with respect to	Impact on drinking water	From GIS data on drinking water

groundwater abstraction and protection zones	extraction	areas
7. Location with respect to flood zones	Impact in flood zones	From GIS data on flood zones

5.2.2 Calculation tool for prioritisation of need for remediation

Based on the global criteria mentioned above a **calculation tool** has been developed to (1) calculate the potential need for remediation for each landfill site in the database. The second objective of this calculation tool is to (2) make a global ranking for the list of landfill sites, calculating a ranking order of '**potential need for remediation**', which then needs to be refined in a number of subsequent steps based on more detailed information:

- In this calculation tool **for each criterion** for the determination of the impact of the source or receptor different possible **interpretations of the criterion** based on the need for remediation are described (columns 1-2-3);
- In addition, each of these possible interpretations has been given a score based on the estimated relevance when it comes to the potential need for remediation (column 4);
- Finally, for each criterion an **weighting factor** is assigned based on the '**relative' relevance or impact**[5] of the criterion itself in the assessment of the potential need for remediation (column 5). The weighting factor varies between moderately important (1) – important (2) – very important (3) – extremely important (4);
- In the last column the **maximum assessment score per criterion** is displayed (column 6);
- Finally, the resulting final score for each landfill site is divided by (the maximum score*100) to obtain a score as a percentage.

It is emphasised that the magnitude of the scores and the weighting factors, as used in the calculation tool provided in step 1, represent a **relative** quantification – '**in comparison with'** or '**with respect to'** the other interpretations of criteria and/or criteria – aimed at establishing a ranking order for potential need for remediation, not an absolute quantification. The absolute or detailed quantification of the need for remediation will be dealt with in more detail in steps 2 and 3.

This calculation tool has been integrated in the calculation tool for the determination of the potential for LFM (see description in 3.8 ff.).

1 Criteria related to the estimation of the potential need for remediation based on the source (landfill site)

weighting factor 3 (very important) has been assigned to the **type of dump material** . The class to which the dump material is assigned is mostly deduced from the information that is available based on the PCS files. Based on expertise an estimate of the impact was made, and a corresponding score for potential need for remediation was estimated. Industrial waste (possible presence of drums of chemicals, …) and a lack of data were assigned the highest priority. The presence of inert waste was assigned the lowest priority.

Where the **age** of the landfill site is concerned, an estimate was made of the impact on the potential need for remediation based on the industrial processes and social consumption patterns that are considered important in this period. The period 1950-1985 is assigned the highest score, as in this period a wide range of (new) chemicals were used and dumped and landfill sites were not yet completed properly. After 1985 landfilling took place in a more controlled manner, and landfill sites

5By '**relative' relevance/impact** we mean: the relevance of the criterion compared to the relevance of the Other criteria when it comes to the need for remediation, not 'absolute' relevance. For instance, if a criterion is assigned weighting factor 1 'moderately important', this does not mean that it is 'unimportant', only that the relevance is estimated to be lower in comparison with other criteria which are assigned a higher weighting factor.

were completed in a more adequate way. weighting factor 2 (important) has been assigned to the age criterion.

The last criterion that characterises the source in step 1 concerns the **size** of the landfill: here, it is clear that a larger size of a landfill site results in a higher possibility of contamination and hence potential risks. The relevance of the criterion is estimated to be moderately important (weighting factor 1).
In the table below the criteria for the determination of the potential of the source, as well as the scores and the weighting factors, are displayed.

Source					
1. Type of dump material	**Classes based on dump material**	**Categories**	**Score**	**weighting factor**	**Partial score**
		Household waste	70	3	
		Industrial waste	100		
		Dredging spoil	40		
		Water purification sludge	50		
		Inert waste	30		
		Gypsum	40		
		Fly ash	40		
		Asbestos	60		
		Other/unknown	100		MAX 300
2. Age landfill	**Classes based on age**				
	Former industrial activities		30	2	
	Gas plants		80		
	Chemical-household waste		100		
	Vlarem legislation		40		
		Unknown	60		MAX 200
3. Size of landfill	**Surface area**	**Various classes based on size**			
	Classification based on statistics	Small (A < 6,500 m²)	30		
	Database	Medium (6,500 m² <A< 15,000 m²)	40		
		Large (15,000 m² <A< 43,000 m²)	70		
		Very large (A >	100		MAX 100

		43,000 m²)			

Table 12: Criteria for determination of potential need for remediation based on the source in step 1

2 Criteria related to the estimation of the potential need for remediation based on the receptors (people and environment)

The first receptor that is assessed is people. To this end, the presence of people at the landfill site and/or in the surroundings is looked at for both the current and the future use. The following different scenarios, with the corresponding weighting factor, will be discussed: people

- 1.a) **in a residential area** (current: current residential areas – potential: including future development areas): with scores according to the distance between the residential area and the landfill site and with weighting factor 3: very important
- 1.b). **in a recreational area** (current: in current recreational areas – potential: including green and 'normal' nature areas): with scores according to the distance between the recreational area and the landfill site and with weighting factor 2: important
- 1.c) **as a consumer of food resulting from agricultural activities**: current and potential agricultural areas: with scores according to the distance between the agricultural area and the landfill site and with weighting factor 1: moderately important
- 1.d) **in an industrial area**: current and potential industrial areas: with scores according to the distance between the industrial area and the landfill site and with weighting factor 1: moderately important

By means of a GIS assessment a score is calculated for each of these four land use types based on the presence of the land use type in relation to the distance to the landfill site. After that, for these four scores the maximum score is taken to continue the calculations in order to avoid overlap between the different land use types.

The second receptor is **ecologically valuable areas**. For the assessment of these areas the Natura 2000 areas (Habitats Directive and Birds Directive) and the VEN and IVON areas are selected based on GIS data and a score is assigned according to the distance between the nature area and the landfill site. The weighting factor for this criterion is 2: important.

A third receptor is the **groundwater in the corresponding aquifer**. Based on the coding on the groundwater vulnerability map a score is assigned according to whether the aquifer in question is assessed as more or less vulnerable. If several groundwater vulnerability codes are present at the location of the landfill site, the most vulnerable (i.e. the highest score) is taken as a worst case scenario to continue the calculations. The weighting factor for this criterion is 2: important.

The next receptor that is assessed is the **surface water** in the surroundings. The score is assigned according to the distance between the waterway and the landfill site, as calculated based on the hydrographic atlas. The weighting factor for this criterion is 2: important.

For the receptor **groundwater abstraction** a distinction is made between 'normal' groundwater abstraction and drinking water abstraction and the corresponding protection zones. The calculations for **normal groundwater abstraction** were carried out with the data obtained from the DOV database. These data will need to be updated regularly. The weighting factor for this criterion is 2: important. weighting factor 4 is assigned to **drinking water abstraction and the corresponding protection zones**, as this criterion is considered to be extremely important.

As a last receptor-related criterion, the **location of the landfill site with respect to flood zones** is assessed.

In the table below the criteria for the determination of the potential of the receptors, as well as the scores and the weighting factors, are displayed.

Receptor					
		Categories	**Score**	**weighting factor**	**Partial score**
1. a) Location with respect to a residential area: current + potential					
	Regional land use plan: code up to 1080 and up to 1180	Currently at	100	3	
	Regional land use plan: code 1080, 1180	Potentially at	80		
		Currently < 100 m	80		
		Currently > 100 m	20		
		Potentially < 100 m	60		
		Potentially > 100 m	10		MAX 300
1. b)Location with respect to a recreational area: current + potential					
	Regional land use plan: code up to 0480	Currently at	100	2	
	Regional land use plan: code 0480, 0500, 0700	Potentially at	80		
		Currently < 100 m	80		
		Currently > 100 m	20		
		Potentially < 100 m	60		
		Potentially > 100 m	10		MAX 200
1. c) Location with respect to an agricultural area (food): current + potential					
	Regional land use plan: code 1000	Currently at	100	1	
	Regional land use plan: code 0510	Potentially at	80		
		Currently < 100 m	80		
		Currently > 100 m	20		
		Potentially < 100 m	60		
		Potentially > 100 m	10		MAX 100
1. d) Location with respect to an industrial area: current + potential					
	Regional land use plan: code up to 1080 and up to 1180	Currently at	100	1	
	Regional land use plan: code 1080, 1180	Potentially at	80		
		Currently < 100 m	80		

		Currently > 100 m	20		
		Potentially < 100 m	60		
		Potentially > 100 m	10		MAX 100
2. Location with respect to ecologically valuable areas: current					
	Natura2000 and VEN/IVON	Currently at	100	2	
		Currently < 100 m	80		
		Currently > 100 m	80		MAX 200
3. Groundwater vulnerability					
	Groundwater vulnerability map	Extremely vulnerable	100	2	
		Very vulnerable	70		
		Vulnerable	40		
		Moderately vulnerable	20		
		Not very vulnerable	10		MAX 200
4. Location with respect to surface water					
	Hydrographic atlas	Surface water at less than 100 m from the landfill site	50	2	
		Surface water at less than 200 m from the landfill site	30		
		Surface water at more than 200 m from the landfill site	20		
		no threat	10		
		definite threat	100		MAX 200
5. Location with respect to groundwater abstraction					
	DOV	suspected harmful effect	100	2	
		located at < 100 m from the landfill site	60		
		located at < 200 m from the landfill site	40		
		located at < 500 m from the landfill site	20		MAX 100
6. Location with respect to groundwater abstraction and protection zones					
	Drinking water abstraction areas	Drinking water abstraction - suspected harmful effect	100	4	

		Drinking water abstraction located at < 100 m from the landfill site	60		
		Drinking water abstraction located at < 200 m from the landfill site	40		
		Drinking water abstraction located at < 500 m from the landfill site	20		
		Drinking water abstraction located at > 500 m from the landfill site	10		MAX 300
7. Location with respect to flood zones					
	Flood zones	Location in flood zone: yes	100	2	
		Location in flood zone: no	0		MAX 200

Table 13: Criteria for determination of potential need for remediation based on the receptor in step 1

With the help of the Flaminco calculation tool the potential need for remediation was calculated for the landfill sites in the KUL database and those in the LFM database. After that, the relative scores of the landfill sites were reflected in a ranking (according to decreasing importance of the potential need for remediation).

Based on this global list, general decisions can be taken with respect to the prioritisation of the need for remediation of the landfill sites in question, e.g. for the landfill sites with the greatest potential it can be studied in more detail in steps 2 and 3 what data need to be studied further and completed in order to be able to carry out a full risk assessment and determination of the need for remediation of the landfill site.

In step 2 one can also opt for including a sheet in the calculation tool with the connected database in which this additional information (including the explanation) is stored:

— The **standard sheet** is the tool that is proposed above and that is based on standard data from the global database;
— The **adapted sheet** consists of a tool that has been adapted and completed based on location-specific information which has been added for the specific landfill site in a refined database. The landfill sites for which additional information has been provided can be marked in a special way, e.g. in a specific colour. *This way, the ranking based on the potential need for remediation is refined and adapted with more accurate data.*

The determination of the relative potential need for remediation can also be combined with the list of landfill sites which are prioritised based on their potential for LFM (as determined in sub-tasks 1 and 2). This is described in Chapter 6.

The input, calculation rules and output of the calculation tool for the determination of the need for remediation are attached in Appendix 5. This calculation tool has been included and integrated into the calculation tool for the determination of the potential for LFM; this whole is called the Flaminco model. In the Chapter below, the results based on the Flaminco model for the 'need for remediation' component are discussed.

5.3 STEP 2: Collection of additional information based on field tests and analyses

Based on the **first step**, the **priority landfill sites (with a large potential impact on the surroundings)** – determined according to the ranking with the help of the calculation tool described above – will be selected.

In a second step, all information needed to reach a well-founded judgement on the need for remediation will be carefully screened and any missing information will be listed. In this step, as much detailed **information as possible must be collected** based on licences (municipal and provincial authorities, LNE, ALBON, …), municipal inventory (insofar as available), GIR, GIS-Vlaanderen, DOV, LFM database, aerial photographs, possibly site visits… It must also be checked with OVAM (Soil Management and Waste and Materials Management departments) and possibly other parties involved (e.g. owners, operators, …) whether (historical) data are available on the soil and groundwater quality.

First phase: Collection of information

After the screening of the information that is already available, **any missing information** needed to make a thorough estimate of the need for remediation will be **listed**. This additional information then needs to be obtained, mostly through field work.

As a minimum, the following information must be collected:

— (historical) licences: information about the history of the dump material, volume, completion (presence of bottom and lateral sealing, clay layers, top sealing, presence and thickness of a (foil) cover layer, collection of leachate, collection of landfill gas,…);
— (historical) land register data;
— (historical) aerial photographs and topographic maps;
— photographs of site visits;
— available monitoring data about the landfill site: surrounding groundwater, leachate, landfill gas,…;
— availability of soil survey data for the landfill site and/or the surrounding area (up to a distance of 100 m from the landfill site): these data can be found in the OVAM database.

For an overview of the information that needs to be checked, we refer to the tables in Chapter 2.7 ('Comprehensive sighting study for landfill sites') of OVAM's Standard procedure for conducting an exploratory soil survey, October 2011.

Second phase: Field tests and analyses to map missing information related to potential risks

The field work must be aimed at **describing possible risks** identified during the screening in step 1 as potential risks, both from the point of view of the source and from that of the receptor. In this process, the availability of the necessary information obtained in the first phase of step 2 must be taken into account.

The following information must be collected e.g. through additional field tests and analyses:

— if no information is available on the top layer quality of the landfill site and receptors are present at the landfill site, **samples from the top layer of the landfill site** must be collected and analysed for the relevant contamination parameters. If necessary, any contamination found must be adequately marked out.

- if no information is available about the possible **impact of the dump material on the surrounding groundwater**, observation wells must be installed in the surroundings and samples must be analysed for the relevant contamination parameters. If necessary, any contamination found must be adequately marked out.
- if **certain receptors may be threatened**, e.g. groundwater abstraction or surface water, the necessary research data must be collected in order to identify these risks in detail, e.g. measurements of groundwater, water from groundwater abstraction, surface water, …

This field work should ideally (and if relevant) be combined with field work that is necessary for the detailed determination of the potential for Landfill Mining (see also Field design projects in Chapter 4.1).

For the use of alternative research techniques at landfill sites we refer to the information in Chapter 8.

5.4 STEP 3: Determination of the need for remediation based on detailed risk assessment and prioritisation

Based on the information collected via the field work a full risk assessment must be performed. If risks resulting from the present landfill site cannot be excluded, the urgency must be determined.

Based on the results of this risk assessment and the determination of the urgency, the landfill sites can be classified into different classes according to the priority of the need for remediation, e.g:

- No need for remediation: Class I;
- Low urgency: Class II;
- Moderately urgent: Class III;
- Urgent: Class IV.

The results of the detailed determination of the need for remediation can be entered into the Flaminco model for the determination of the need for remediation as input for the determination of the potential when it comes to the need for remediation in a separate sheet (indicating the sources and reasons). *This adaptation of the model has not yet been carried out and should be included in a second phase of the project*.

6 Link between potential for LFM and need for remediation

In Chapters 18 and 61 the methods for the determination of the potential for Landfill Mining and the determination of the need for remediation of a certain landfill site have been developed.

On the one hand, in Chapter 18, based on specific criteria a calculation tool was developed for the determination of the potential for landfill mining, and, on the other hand, in Chapter 61, based on other criteria, a calculation tool was developed for the determination and prioritisation of the need for remediation of landfill sites. Both these calculation tools were integrated into a single calculation tool in the Flaminco model.

As sustainable landfill site management ideally takes into account both of the aforementioned objectives (and even tries to combine these, insofar as possible, in the management of landfill sites), based on the results of both methods an interaction matrix has been created in which both objectives are combined. This can be taken into account in the selection of the landfill sites to be dealt with.

Based on the interaction matrices we get a visual idea of which landfill sites have a high priority to be dealt with based on the need for remediation and the potential for LFM. These interaction matrices can also be shown as output of the Flaminco model.

In the Flaminco model it is also possible to combine the prioritisation for LFM and the need for remediation into a single list for combined prioritisation. The relative weight assigned to LFM and the need for remediation, respectively, can be determined according to the objective of the prioritisation and the importance attached to both aspects.

Within the combinations of the different LFM objectives and the need for remediation, several landfill sites appear in the TOP25 several times. These are the landfill sites that may be eligible for more detailed study, namely

- a more detailed determination of the potential for landfill mining;
- a more detailed determination of the potential need for remediation.

(See also under selection of landfill sites for field design in Chapter 4.1.)

In a first step, this should be done by **collecting and interpreting more detailed information which is already available.** Based on the interpretation of this detailed information, the determination of the potential can be **refined**:

- If, based on this information, it is found that both the potential for LFM and the potential need for remediation are still high, these landfill sites can be selected to carry out a field design project in the next phase;
- If, based on this information, it is found that the potential for LFM and the potential need for remediation (for both objectives or for one of them) is lower, the ranking in the calculation tool can be adjusted and the necessary conclusions should be drawn from the adjusted ranking;
- If it is found that the necessary information (for both objectives or for one of them) is not available, this landfill site can be selected as a landfill site for which additional data need to be collected.

7 Link between calculation tool and GIS

Via a link to GIS, the results of the calculation tool can quickly be visualised geographically.

The following results of the calculation tool can be generated via GIS:

— For each selected landfill site: summary of the main results (see Figure 28

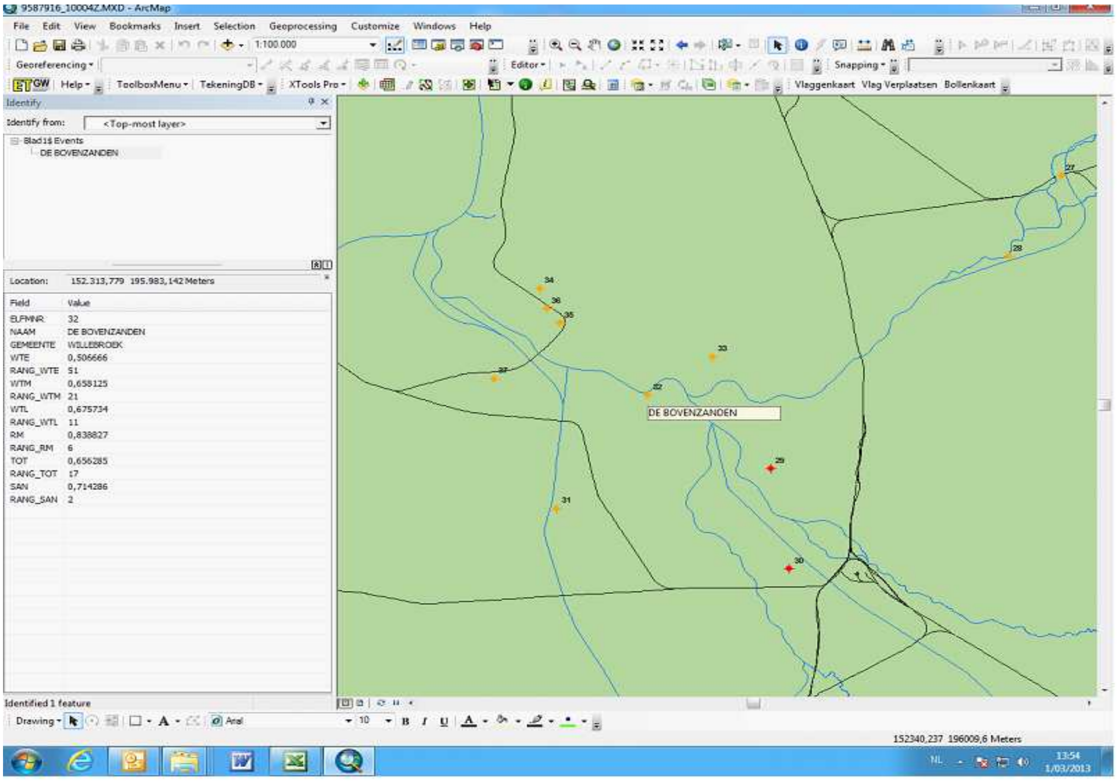


Figure 28: Visual representation of information per selected landfill site in GIS

8 Sub-task 4: Screening of alternative research techniques

This chapter is only available in the Dutch version.

9 Conclusion and pending actions

9.1 Summary of activities performed

By order of OVAM the Temporary Partnership Tauw België nv– Witteveen+Bos Belgium has carried out the first phase of the framework agreement on 'Technical Support for Landfill Mining'. The aim of this study was to provide OVAM with technical support for the Landfill Mining (LFM) project within the framework of global landfill management in Flanders; it comprises, among other things, the design of a method to determine the potential for Landfill Mining and the need for remediation of landfill sites.

For OVAM, in the **short term**, making an **inventory** of the possibilities offered by the landfill sites in the LFM database[6] is the first step towards global landfill site management. A concept for the future approach to these landfill sites must be developed:

— On the one hand, this should refer to the **management of risks** caused by contamination at those sites;
— On the other hand, it should refer to the management of reserves for mining in the future. Landfill sites can be regarded as storage rooms for tomorrow. 'What we cannot recover or recycle today, we may be capable of tomorrow';
— **Use of space (Waste to Land):** Because of the pressure on the use of space, the recovery of former landfill locations is a valid idea in the short term as well. The economic value of land will already make landfill mining in accordance with market conditions possible in the near future in certain circumstances.

In the long term, OVAM wants to develop a dynamic landfill site management:

Attention to the possibilities of **resource management** and temporary storage;

Attention to reuse and recycling of **energy, resources and raw materials;**

Bring all landfills to an **'inert' state (stabilisation and management of risks) with maximum material recycling/valorisation and energy production,** rather than focusing on 'isolating and covering up' (IBC);

Sub-task 1 mainly consists in a theoretical solution with the following objectives:

— overview of criteria which can be used to select landfill sites in Flanders that are eligible for Landfill Mining (**objective 1**);
— development of a methodology to determine the environmental priority of landfill sites (**objective 2**).

To determine the potential of LFM, the following four objectives are taken into account:

— Objective 1: Waste to Energy (**WtE**);
— Objective 2: Waste to Materials - Materials management (**WtM**);
— Objective 3: Waste to Land - Space (**WtL**);
— Objective 4: Resource Management (**RM**) - Temporary Storage.

6The LFM database (1,692 sites), compiled and managed by OVAM, comprises data on all known historical and currently active landfill sites. These data were taken from the so-called PCS files, which were used to make an inventory for each Flemish province between 1992 and 1995.

The following definitions have been established for the various objectives:

Waste to Energy (WtE): the production of energy in the form of electricity or heat from landfill gas resulting from the decomposition of organic material or from the dump material, where the waste is converted into fuel through heating.

Waste to Land (WtL): the creation of space at the location of the landfill site and the assigning of a new land use to the landfill site.

Waste to Material (WtM): the valorisation of the waste streams that are released from a landfill and the reuse of the waste streams as materials.

Resource Management (RM): the temporary storage of waste with a view to a later valorisation and use of this waste.
To design the methodology for the determination of the potential 6 criteria were selected. The table below indicates the criteria for the calculation of a score for the four sub-objectives for LFM.

	type	**age**	**volume**	**use**	**accessibility**	**surroundings**
WtE – energy	X	X	X	X	X	X
WtM – materials	X	X	X	X	X	X
WtLand – space	X	–	X	X	–	X
Resource Management – temporary storage	X	–	–	–	X	X
x: criterion is used to determine the potential of a landfill site for the objective concerned –: criterion is not used to determine the potential of a landfill site for the objective concerned						

Table 16: Criteria for the calculation of a score for the four sub-objectives for LFM

For each of these criteria classes were created to which scores were assigned. A weight was also assigned to each criterion for each sub-objective. This way, a calculation tool was created with which a total score per landfill site could be calculated for each of the four sub-objectives for LFM and a score for a combination of the four sub-objectives (total potential for LFM). This calculation tool was combined with the calculation tool for the need for remediation (see below) into the integrated **Flaminco model**. Based on the Flaminco model, **GIS** maps indicating the geographical location of the landfill sites with potential can also be generated.

In sub-task 2 a method was developed to determine for which landfill sites a need for remediation exists. To determine the need for remediation based on the Conceptual Site Model of a landfill site, a **multi-stage method** is proposed:

- Based on global criteria, estimate the relative potential need for remediation and assign a priority to each landfill site in the list based on the estimated potential (step 1);
- Define a further detailed assessment of the need for remediation and the need to carry out soil remediation works (steps 2 and 3).

In step 1 the possible risks resulting from a landfill site are estimated globally using a number of basic criteria that are easy to look up and express a qualitative and a quantitative estimate of both the possible impact of the **source** and the impact on the **receptors**.

To determine the ranking order when it comes to the relative potential need for remediation in step 1 a calculation tool was developed (based on global criteria – which characterise the source and the receptors – with scores and weights assigned to them), which was afterwards integrated into the **Flaminco model**. For the further, more detailed determination of the need for remediation in steps 2 and 3 instructions were included explaining the actions to be taken in order to determine this need for remediation in detail.

In **sub-task 3** a strategy for the use of traditional and alternative research techniques at landfill sites was described. In addition, a description of the most common alternative research techniques was provided, together with a description of their practical usability, what information is obtained, what the advantages and disadvantages are and what the average cost is.

9.2 Missing information and pending actions

It is remarked that a number of data have not yet been entered into the database (e.g. because PCS files are not available, certain data have not yet been entered, …). Furthermore, a more thorough verification of the correctness of certain data in the database is necessary. It is proposed to first complete these missing data and correct any incorrect data before carrying out an assessment of the criteria with the corresponding scores and weights of the Flaminco model and before calculating a final prioritisation of the landfill sites for the various objectives.

In addition, the results of this first prioritisation must be checked against the available information 'outside' the model (e.g. soil surveys performed, remediations, current need for remediation,…). These checks of the results can be performed in the model based on the deduplicated sheet with database data in which data can be modified manually.

The following pending actions must be followed up and carried out in a next phase of the study:

- Completion and assessment of LFM database data;
- Performance of model calculations based on the entire database;
- Critical evaluation of the criteria with corresponding scores and weights of the Flaminco model;
- Possible adjustment and refinement of criteria, scores and weights and recalculation based on the adjusted Flaminco model;
- Verification of the results of the adjusted Flaminco model with the available information 'outside' the model (e.g. soil surveys performed, remediations, current need for remediation,…) to refine the results;
- Selection of landfill sites for further exploration of the potential for landfill mining and the need for remediation;
- Field design projects and their development;
- Determination of the cause of the suspension of cases when it comes to the screening of the need for remediation;
- Performance of a profitability study of landfill sites when it comes to landfill mining.

Bijlage 1: List of tables

Bijlage 2: List of figures

Bijlage 3: Bibliography

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the appendix showing a few printscreens of this 'FLAMINCO-model' calculation tool .