RAWFILL project
Theoretical approach on dual DST

May 2018

Disclaimer

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Abstract

The main output of this project is a Decision Support Tool (DST). This tool will help authorities and private companies to choose the best available solution for the landfills they own in terms of enhanced landfill mining and management ($ELFM^2$). $ELFM^2$ is the re-use of matter coming out of old landfills. The re-use can be both as a source of new utensils (Waste-to-materals or WtM) as well as incinerating it and recuperate it to produce steam and/or electricicty (Waste-to-Energy or WtE) (Jones et al., 2012). Especially the latter is of growing importance in Europe as a consequence of various directives (Saner et al., 2011).

In general, creating a decision support system is primarily based on three main components:

- a knowledge base
- the applied model that interconnects with this knowledge base
- the user interface that enables to manipulate the available information

(Power, 2002)

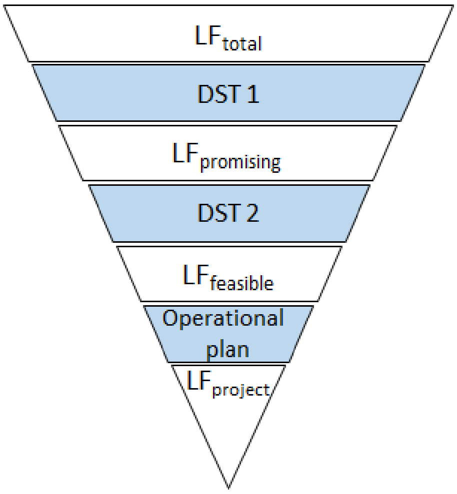
Although the partner regions of RAWFILL and many more already documented the locations of most their old landfill sites, the lack of reliable data on the recovery rate of the landfill sites still is a problem. Additionally there's the absence of a general approach on landfill mining, delaying standardization (Krook, Svensson & Eklund 2011).

The RAWFILL DST will be a dual tool (DST 1 and DST 2). Both DST's are an accomplishment of the cooperation between OVAM, SPAQuE and ATRASOL. The three will construct a table of suitable landfill mining indicators, thereafter define the weight of these indicators and finally design the software tool in which these indicators will be comprised.

The creation of a database on recovery rates is obstructed by the fact current research techniques are very expensive, since they require analysis of multiple excavated waste samples. RAWFILL wants to counter this problem by using geophysical imaging and guided sampling (e.g. Shell, 2014; Maurer & Hauck, 2007) as a primary source of information gathering. These techniques don't need extended and thus costly in situ interventions.

Two locations were chosen to test the mapping method on a landfill system. In first place to discover which materials are present, making it possible to estimate the profitability; and in second place to be able to make an estimation of the costs of the technique within the whole landfill mining project. The locations are a landfill site in Meerhout, Flanders and one managed by SAS Les Champs Jouault in Normandy, France. The mapping will be executed between March 2017 and May 2019.

When mapping is completed, RAWFILL will analyze the collected data via DST 2. Also in later, real life situations, DST 2 will only be usable after the necessary input information is collected. DST 1 will specify exactly what information is needed.



Both DST's will be tested by all project partners managing landfill inventories (OVAM, SPAQuE, BAV and LCJ) on their landfill sites for which good data sets are available. This includes both pilot sites too where data will be gathered through landfill geophysics. Additional validation will be done, creating a methodology with sufficient commitment from these stakeholders. DST support to stakeholders will be given through guidance materials and hands-on workshops & trainings. These activities will continue after the project and through academic and extracurricular training.

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1. Overview of common abbreviations related to this report and RAWFILL in general

BAV	Bergischer Abfallwirtschaftsverband
BEP	Break-even Point
EIF	Enhanced Inventory Framework
ELFM²	Enhanced Landfill Mining and Management
EURELCO	EU Landfill Mining Consortium
CTF	Cleantech Flanders
LCJ	SAS Les Champs Jouault
NERC	Natural Environment Research Council
NPV	Net Present Value
OVAM	Public Waste Agency of Flanders
SPAQuE	Société Publique d'Aide à la Qualité de l' Envionnement
Ulg	Université de Liège

2. RAWFILL and its objectives

2.1. Introduction to RAWFILL

Two years ago, the EU Landfill Mining Consortium (EURELCO) estimated that there are about half a million landfills across the European Union (EURELCO, 2016). The cumulative surface area of these 500.000 sites leads to a significant volume of resources as well as a loss of land due to land-use restrictions and local pollution.

Two remarks can be made when observing these landfills. 1) Materials, energy and land area could be reclaimed via Landfill Mining among other similar ideas (Johansson, 2013) and 2) the risk on pollution could be minimalized if all landfills used the latest techniques on environmental protection systems. Yet these two are the current problem that society has to solve and why RAWFILL was established.

Eight partners originating from four countries (Belgium, France, UK and Germany) will work together on these subjects for the coming three years. The partners include: Société Publique d'Aide à la Qualité de l' Envionnement (SPAQuE), Public Waste Agency of Flanders (OVAM), Bergischer Abfallwirtschaftsverband (BAV), SAS Les Champs Jouault (LCJ), Université de Liège (Ulg), Natural Environment Research Council (NERC), ATRASOL (ATR) and Vzw Cleantech Flanders (CTF) which became part of VITO (Vlaamse Instelling voor Technologisch Onderzoek) in January 2018. Apart from these eight, fifteen other partners will form an advisory board and supply information and/or experience. For this project, the European Union by means of Interreg North-West Europe granted a budget of 2,3 million euro out of the European Regional Development Fund (ERDF).

Rawfill builds upon a number of regionally, nationally and EU-funded landfill (mining) related projects such as REMO, MINERVE, METABOLON, NEW-MINE, Sulfanet4EU and SANDFORD FARM. The recent approved project COCOON is very closely related to the activities of Rawfill and has two mutual project partners (OVAM and CTF).

3. Overview of the used knowledge base

3.1. Introduction

In this chapter, the first main component of our decision support system will be explained. Throughout the years, many DST's were developed. The way of using them varied with each tool as well as the amount of output it gave. Nevertheless and somewhat comparable with network theory, one tool can be linked to another via identical criteria that were used in there applied model.
The following subchapters will give an overview of some - but not all – of the researches conducted on the subject of decision supporting within the landfill mining business, shortly explained what the concerned investigators did and more importantly which criteria were important for them to include in their respective models.
We did this to sort out the criteria that emerged often versus criteria that were used only once or a select number of times. We argued that these criteria must be keystones in a good decision support tool and had to be included in our DST 1 but only on the condition the criteria represented readily available information.

3.2. Evolution of DSTs for landfill mining

3.2.1. van der Zee's approach on LFM criteria

The way people live into today's society strongly diverge from for instance the seventies and eighties. The growing awareness for environment and finiteness of materials lead to the production of less waste and more recycling.
This development has a second, less positive side for the waste processing industry. Since they have less waste to landfill, they have reduced earnings which implicates a bankruptcy in a worst case scenario.
van der Zee (2003) pointed out that the waste industry is fully transitioning into a landfill mining business, since a lot of landfills nowadays contain a lot of materials having an economical value compared to the time when they were deposited.
A landfill is like a closed treasury box. You know it's there, but you don't know what's in it until you open it. Some boxes contain valuable gadgets, others are completely empty. The same can be said for landfills. Opening up a landfill is a great financial risk for a company since its yield is very unsure.
This dilemma, according to van der Zee, should be solved by the development of a tool that can help companies in finding the most profitable landfills based on the amount and type of materials it contains. The tool should be fast, cheap and easy to use.
Van der Zee's tool was one of the first of its kind in the landfill mining sector. Its foundations are based upon the five step approach on landfill reclamation of the American Environmental Protection Agency (EPA, 1997). Van der Zee only focused on the materials in a landfill, but the foundations of a complete DST concept where there, ready to be further developed and fine-tuned.

3.2.2. Gaeth and Nispel’s essay on landfill resource potential

Ordered by two State institutions, Professor Gaeth (2012) determined the resource potential of two landfills. One in Hechingen (Baden-Württemberg) and the Dyckerhoffbruch landfill in Wiesbaden (Hessen). The Hechingen landfill contained approximately 2 million tonnes of waste, the Dyckerhoff landfill was much larger with about 15 million tonnes of waste.

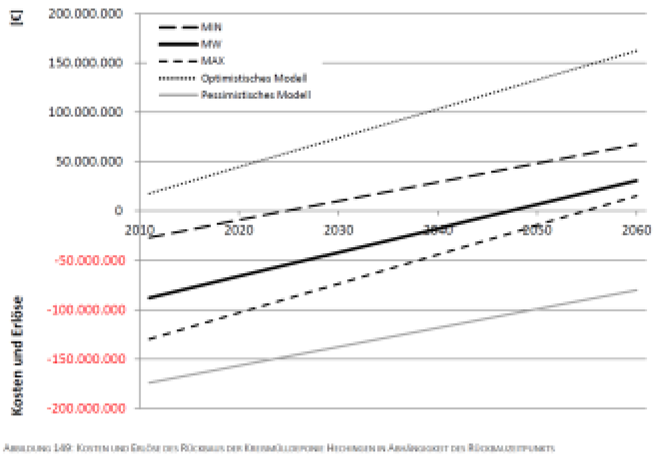


Figure 1: graph taken out of the paper of Gaeth and Nispel, showing a possible forecast of feasibility for the Hechingen landfill.

Gaeth determined the landfill potential after the exploration of the material composition. With these data, he made three possible scenario’s based on the content of the landfill and the evolution of the value of the recovered metals and energy. One scenario is a worst possible case where only a small part of the landfill can be recycled, the second one a best possible case where most of the content can be recycled; and a third and most realistic case. A forecast of the commodity prices was made by using the average price growth of typical landfill metals as iron, copper, aluminum and nickel between 2001 and 2011. The profits from energy recuperation were mainly based on CO_2-certificates.

This approach is very comparable with Van der Zee’s investor-oriented perspective, in which a cost-benefit scheme is the base of the project feasibility. Effects of so called externalities caused by environmental pollution were not considered.

Results of the research revealed a strong effect of the commodity prices of non-ferrous metals on the profitability of the mining. In chapter 2.5.2 the relation between commodity pricing and landfill mining is more thoroughly discussed.

3.2.3. How Van Passel introduced the external factors into the DST story

The investigation of Van Passel et al. (2013) used partially the research of van der zee (2004) as a base for the determination of his methodology. As with our approach, he narrows down the number of potential landfills by applying an increasing number of criteria.

The first four of these criteria are very similar to other ELFM² selection methods: firstly a database is used to get an idea of the total number of landfills in a certain area. Secondly, a screening is done on the materials inside the landfill. Van Passel considers the age of the landfill as a good benchmark for this, since different times mean different kinds of waste and quantities of them. A bigger landfill is easier to create a break-even landfill mining project (Webb, 2010; Rosendahl, 2014). Therefore, the size of the landfills is Van

Passel's third factor. However, the Rawfill project will point out that this criterion should be interpreted in a different way in a decision support model. The fourth and final step consists of the thorough on-site research of the remaining landfill sites after the first three eliminating criteria.
So far, the followed pathways are very typical. However, Van Passel came up with the idea to add external factors to his model. They can potentially influence the outcome in a positive or negative way. These factors include the contamination of groundwater and transportation costs, greenhouse gas emissions, to name a few. There are many other external factors (e.g. Hermann et al., 2014). Since it is difficult to determine and quantify objectively, the next logic step is making use of scenario's within the model trying out different values for these external parameters (e.g. Frändegård, Krook, Svensson & Eklund, 2013; Borello, Kissoon & Trois, 2018).
Van Passel used two scenario's giving all parameters a minimum and maximum value. The conclusion of this survey established energy being the most important benefit of the total ELFM² project.

3.2.4. Flaminco introduces land reuse as additional factor

Flanders has always been a region with a very high population density, resulting in a very high use of land and resources on a limited surface area for centuries. Today, the results of this intense historical use are a high level of mostly small landfills scattered over the region and high pressure on the environment.
Since 1981, the Public Waste Agency of Flanders (OVAM) has been the agency to manage these landfills among other soil related activities. Some seven years ago, the databases at OVAM already contained more than 2.000 landfills, not only representing a great economic opportunity but also claiming 88 km² of the scarce available land in Flanders (OVAM, 2016).
To bring order in these landfills, OVAM developed a three step evaluation method to sort out all these landfills and finding out which of them could be interesting in a landfill mining project. The three step approach consists of mapping, surveying and mining (Behets et al., 2013; Wille, 2016). However, after these three factors were executed on the database, quite a lot of landfills remained.
The idea was therefore launched to create a decision support tool to pick out the economical most viable landfills related to the value of the land plot is was located on. The landfills were divided into categories: industrial, household, inert waste and mono-landfills. The special attention to mono-landfills was done because they are quite abundant in Flanders and also because these type of landfills would have an higher chance of feasibility compared to heterogeneous landfills.
Other criteria that were considered consist of:
- The surface area of landfills as a measure for its volume
- The type of materials
- The age of the site, determined by the period of operation. This is important because as industrial activities evolve, also the type of deposited materials and ratios change.

- Accessibility: the proximity of a road suited for larger vehicles like lorries, railways and water ways
- Land: the creation of space at the location of the landfill site and the assigning of a new land use to the landfill site.

The latter was a novelty in the DST's for landfills. Since former landfills have no longer activity of whatsoever the sites are often perfectly usable for other activities. The policy of Flanders of filling up the empty spaces in villages and cities in favor of the open land outside these centres is a perfect match in this approach (Suykens, 2017). Many landfills out of the fifties and sixties were created on the edge of a settlement and nowadays are incorporated into them. Since urbanization is a strong global trend, this development is in full transition in many other countries around the globe (Dimpal, 2012; EPA, 2014).

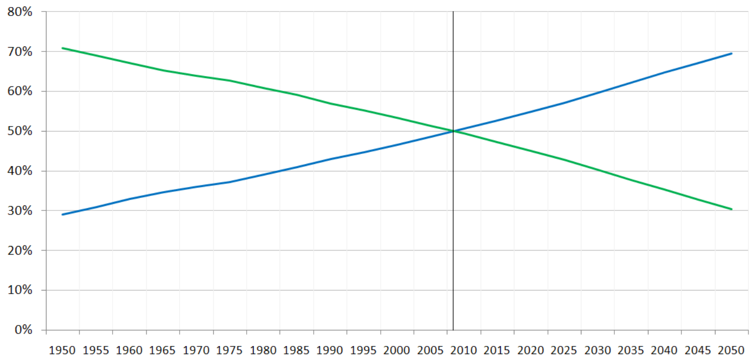


Figure 2: evolution and prognosis of the share of people living in cities (blue) and rural areas (grey).

In urban areas, these former landfill sites can be converted into high quality public spaces or buildings. The subsequent increase in value of the land plot itself and the positive influence on the direct neighborhood therefore is an important contributor to the landfill mining project. (Ready, 2005; Reichert, Small & Mohanty, 1992).

3.2.5. The RECLAF model

RECLAF is based on the same evaluation approach as used by the Public Waste Agency of Flanders (Behets et al., 2013; Wille, 2016): mapping, surveying and mining to be precise.
The external factors involved in the project were subject of a one-scenario test using software from the Vienna University of Technology (Cencic, 2008).

3.2.6. The Smart Ground model

This tool allows the user to have a first understanding of the feasibility of mining a landfill, by estimating the net income of the project, as well as the social and environmental impacts. The DST provides users with five MSW composition scenarios but entering your own waste composition data and own input parameters is also possible. The tool runs a cost benefit analysis (CBA) for nine different mining scenarios differing in the level of technology and processing effort. All scenarios are solely focused on the different way the material is excavated without the possibility of interim use.

The user can decide which criteria are used to determine the best scenario in his case. The outcome is displayed under the "Results" tab. Also, the tool allows the estimation of the amount of Rare Earth Elements present in the landfill, as well as the potential value.

3.2.7. The Rawfill model

The latest project in landfill management will develop an improved decision support tool by building further on previous research between 2017 and 2020. A detailed description of the structure of RAWFILL's dual DST can be found in chapter three.

3.3. Related DST's and parameter frameworks

3.3.1. Holistic Management of Brownfield Regeneration (HOMBRE)

The HOMBRE project was active between 2010 and 2014. The project had four different objectives (Grotenhuis, 2010):

- A zero brown-fields strategy: urban, industrial and mining sites are screened to get a better picture of them. The origination of brownfields in these settings is necessary to device a successful overall brownfield redevelopment program.
- Assessment of brownfield regeneration scenarios: development of an improved sustainable spatial planning. Parallel to the latter also decision making processes to enhance the uptake of brownfield regeneration projects. A holistic approach is used in these processes.
- Integrated Regeneration Technologies: partners investigated so called technology trains. These are different methods, actions or strategies that are combined to have a reciprocal enhanced effect. The investigated combinations consisted of energy + water; building materials + soil; soil + water; urban greening + restoration and bio-energy and remediation.
- Intermediate Renewal: targeting the improvement of vegetation, landscaping and facilities on brownfield sites to ensure social, economic and environmental cohesion with the surrounding land use.

Similar to the approach of creating a decision supporting model for landfill sites, one of the targets of HOMBRE was to create such a model for brownfield management and contained environmental, economic and social factors. The Brownfield Navigator integrated legislation with modelling and mapping (GIS) technology to deliver qualitative support to its users. The long term outcome would be zero brownfields in the participating countries and secondly in the whole EU.

3.3.2. Flanders' Spatial Model (Ruimtemodel Vlaanderen)

Flanders is one of the most urbanized areas in Europe (Tempels, 2011). Authorities therefor need to keep permanently a balance between new residential space and locations for economic activity as well as fragmentation; air quality; water quality and so on.

Although Flanders is a very densely built area with about 500 inhabitants per square kilometer, the costs of utilities are comparatively high because of the scattered way of building from the past. The main reason for this is the very late legislation on spatial planning. The first Belgian law on spatial planning, the Organic Law on Town and Land Planning, only dates from 1962 (Hanocq, 2011). Prior to that there was no enforcement at all. This gave Flanders - and more generally Belgium - its reputation for the variety of building styles, different alignments along the same road and linear settlement.
Still, it would take until the late 90's before the legislation was strictly respected. To give a comprehensive impression of the current situation, VITO started the development of a spatially-dynamic land use model. The aim: charting as accurately as possible, and at a high resolution of 1 ha, the existing situation and possible development (up to 2050) of the changing land use in Flanders. This was achieved by means of time series of land use maps with 28 different categories and spatial indicators derived from land use.
Nowadays, the categories are extended to 40 and is widely used by cities, provinces and governmental agencies.

3.3.3. United Nations Classification Framework (UNFC)

The United Nations Framework Classification for Resources (UNFC) is a tool created to be used in the energy and mineral resources industry (UNECE, s.a.). The energy sources are both fossil fuels (oil and gas) as well as renewable ones. The mineral resources consist of secondary resources recycled from residues and wastes, among other principles as for instance regular mineral mining but also the more pioneering technique of storing carbon dioxide in porous rock beneath the planet's surface. These secondary resources are obviously complementary to the field of study of the RAWFILL project.
UNFC, in its core principles, includes the management of all socio-economical, technological and uncertainty aspects of energy and mineral projects. The main aspect of UNFC is de-risk projects from costly failures by putting the project maturity and resource progression into the model of UNFC. It is a tool to protect the investments in the sector. UNFC fully integrates social and environmental considerations and technology required to bring clean and affordable energy resource projects into the market.
The same methodology can be applied to landfill projects (Winterstetter, 2016) and therefore is an interesting system to involve in the used knowledge base of our dual DST tool.

3.3.4. Municipal Solid Waste Management Decisions (EPA)

One of the first organizations that developed a decision support tool of any kind was the Environmental Protection Agency of the United States. At the beginning of the nineties, many counties in the US worked inefficiently to collect and process their MSW because the information they had at hand was limited or conflicting. In order to facilitate the whole chain of events concerning waste management the EPA made a DST. This DST was improved and extended throughout the years based on new insights (Thorneloe, 2016).

A remarkable feature in this DST is the display of sensitive and non-sensitive parameters. Like in other tools, users can enter their own value or use default values for certain factors. As an extra way of confirming the response the creators give users an idea of the consequences of this (non-) modifying deed. The importance of the parameter is displayed by the color of its input box.
The model consists out of four parts: materials flow models, process models, optimization routine and user-interface.

3.4. Conclusions

When breaking up the previously discussed papers into their applied criteria the following pattern emerges:

	van der Zee	Van Passel	Gaeth & Nispel	Flaminco	Fellner	Reclaf	Smart Ground
Accessibility				X		X	
Air pollution							X
BEP		X					
Content	X	X	X	X	X	X	X
Depth				X		X	
Energy		X	X	X	X	X	X
IRR		X					
Land reuse	X			X		X	X
Location	X	X		X		X	X
NPV		X			X		X
Period of dumping				X		X	
Size	X	X	X	X		X	X
Society		X			X		
Water				X	X	X	X

Table 1: overview of all applied criteria per paper, pointing out that some criteria return frequently, others don't.

Roughly three criteria stand out: the content of the landfill, energy and size. During the next phase of the RAWFILL project, these findings will be compared with the Enhanced Inventory Framework of WP T1 by Atrasol. Together a consensus will be determined and subsequently a decision will be made if these criteria and which other ones should be certainly included into the body of DST 1.

For DST 1 OVAM will create a modified version of their Flaminco tool (Behets et al., 2013). The original Flaminco tool has the right framework for this, since it is also a ranking tool. However, the current weighing of the indicators as well as the indicators themselves create a ranking not consistent with reality (e.g. in terms of project feasibility). This is easily demonstrable by the fact the first fifty project in Flaminco are not worth investigating and executed projects done by OVAM are done on landfills ranked only in the middle of the generated priority list. Also the characteristics of the executed projects will be used to create a trustworthy combination of weighing and indicators.

3.5. Related subjects

3.5.1. The doughnut economy theory

From the sixties onwards, when mass production became standard for a lot of large economies, landfills functioned as some sort of last frontier for products or packaging material that no longer had any use or economic value.

Since then, society and industry have evolved and learned to make use of every last piece or gram of some raw materials and started recycling. Still, is wasn't before the early nineties that for instance electronics started to be recycled (Swico, s.a.).

Figure 3: Visual presentation of the doughnut-shaped economy of Raworth.

In today's world, economic factors are beneficial enough to look at landfills as a potential and especially cheap(er) source of basic components to create new ordinary utensils. The RAWFILL project among other parties and projects sees a landfill as part of a future circular economy, since it is one of the last missing links between the disposal of an old product and the creation of a new one.

An interesting point of view concerning the creation of a circular economy is the doughnut-theory as formulated by Kate Raworth (2012). As she stated, one of the main elements for sustainable development within a nation is the constraint of the use of natural resources up to a point the planet can manage the demand.

Without being the ultimate solution, mining landfills could contribute to return or stay within the planetary boundaries (e.g. chemical pollution, climate change due to CO_2, N_2O and CH_4 emissions, …), in other words: everything we can use for our society without changing the macro conditions of the planet we experienced for the last 11.000 years (Rockström et al., 2009a, Rockström et al., 2009b). Translated to the model this would be

the outer layer of the doughnut. Already today landfill gas is collected, washed and distributed to households or used on site as a heat source (Sullivan, 2010) or converted into electricity as one form of interim use (CEC, 2013). Mining on the other hand could prevent the leaching of hazardous components into the soil ecosystem or groundwater, even when the landfill is build following current regulations, e.g. the EU waste legislation (European Commission, 1999). Current HDPE foils of 2,5 mm thickness used to seal of a landfill won't last for centuries when applied on site (Peggs, 2003). Replacing them is a costly undertaking.
Apart from being a way of reducing consumption in the industrialised countries, also the change of land use is part of the same story, since Earth's surface is finite too. Land reclamation is one piece of the puzzle the RAWFILL project tries to establish within the model that is been developed: rather than starting up a landfill mining project to recover its content. The weighing of land value is much more decisive e.g. when certain terrains can be transformed into residential area or sports complexes. One shouldn't make the mistake that the reuse of the landfill content isn't considered as a part of the circular economy. Based on the opinion of the RAWFILL partners, it is just a minor argument compared to previously performed studies.

3.5.2. The effect of commodity prices on landfill mining projects

The recovery of materials out of landfills play an important role in a landfill mining project since they make out up to one third of the income on a LFM project (Krüse, 2015). Some researchers (e.g. Smart-ground, 2017; Gaeth & Nispel, 2012; Franke, Mocker & Faulstich, 2010) therefore have correctly suggested that a future increase in metal prices is decisive in a landfill project.

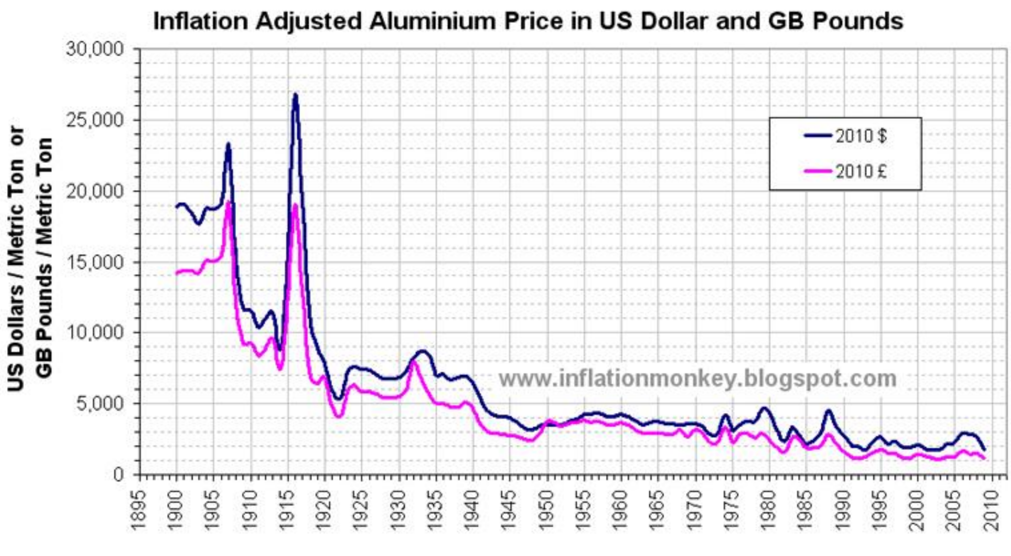


Figure 4: inflation adjusted price of aluminum from 1900 onwards in 2010 US$ and £. (source: inflationmonkey.blogspot.com)

However, one could pose the question: will metal prices indeed increase within the coming decades? Geath and Nispel for example, extrapolated the pricing of aluminum, copper and steel based on the price fluctuations of these three between 2001 and 2011. What they found out be doing this was an expected average linear increase in pricing of about 18€/t for steel; 400€/t for copper and 15€/t for aluminum. For each prognosis a best and worst case scenario was calculated to be able to create a general best and worst case scenario for the total landfill mining project.

When zooming in on for instance aluminum, a famous example of its use is the apex of the Washington Monument in the United States. At its inauguration in 1884 it was the largest single piece of aluminum in the world (AASMH Landmark, 2012), at a cost equivalent to 225 days of 10 hour labour (Binczewski, 1995). In today's money this would be about $50.500 (Trading Economics, 2018) or $505 per ounce. To compare: one ounce of gold in 1884 was worth about 21 dollars (OnlyGold, 2015) or a month worth of labour wages.

In 1888, the Bayer-process meant the definitive breakthrough of aluminum production on a feasibly industrial scale. Also in the 21st century it still is the single most used process for aluminum production (Aluminum Association, s.a. a). Since this industrial discovery, the value of aluminum has steadily dropped to the levels we know today and will continue to do so. After all, the continuing technological improvements that create equal or higher outputs with less energy (e.g. Aluminum Association, s.a. b; International Aluminum Institute, 2010); more efficient pathways from mineral to metal (e.g. Fafard & Alamdari, s.a.) and the abundance of bauxite, the most important mineral in the aluminum industry (USGS, 2018) preserve this trend.

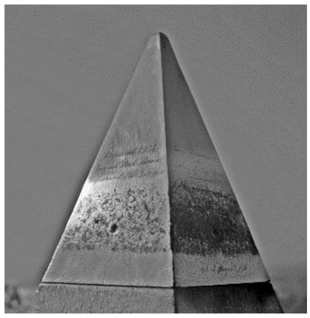
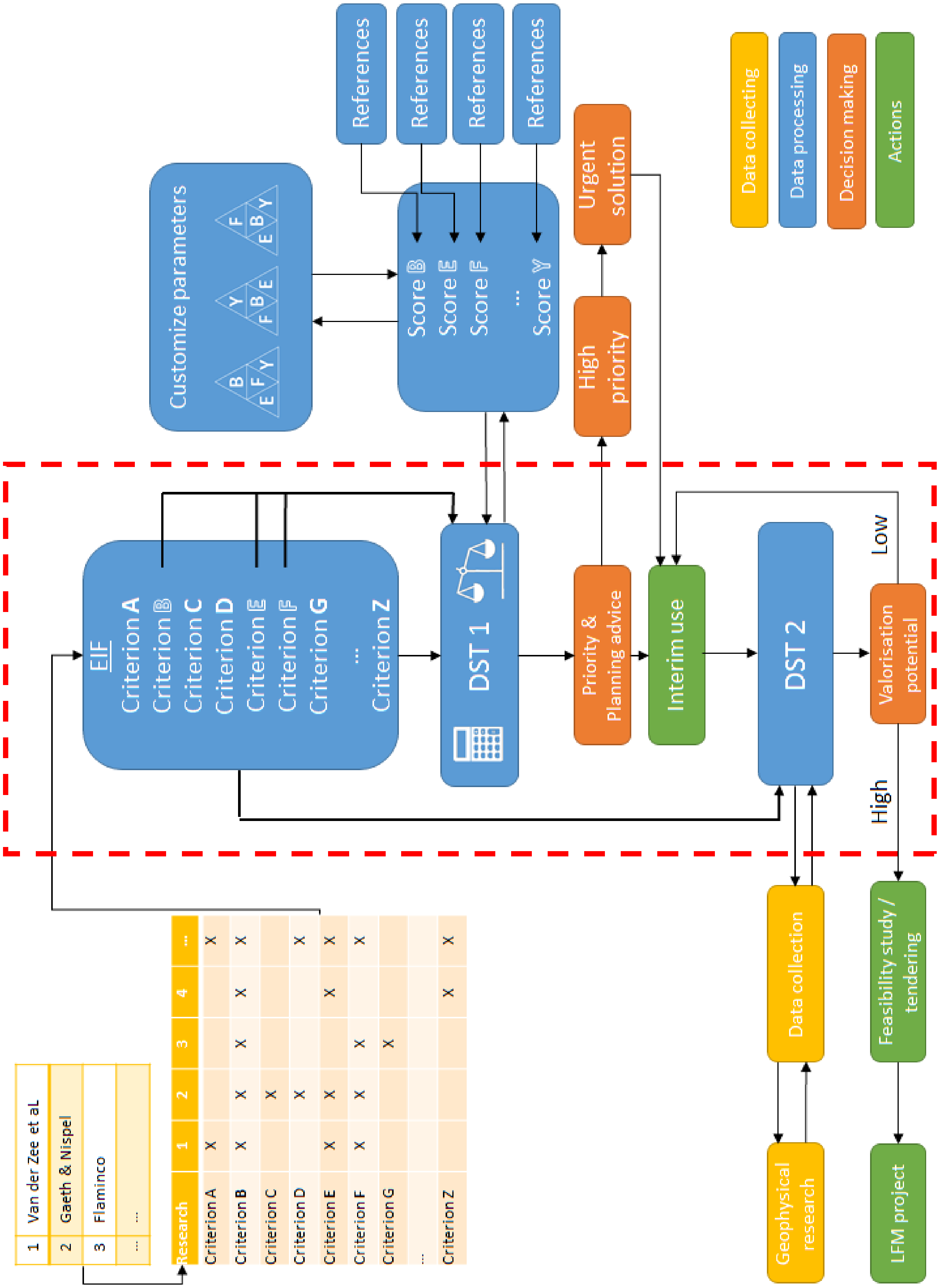


Figure 5: the apex of the Washington Monument during its restoration in 1934. (source: wikipedia.org)

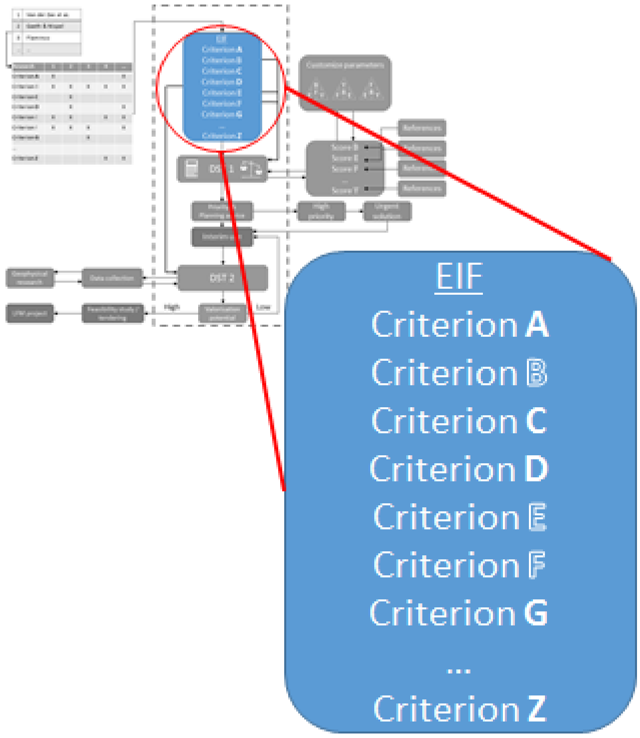
Large financial institutes therefore project even lower prices in the future, in terms of inflation adjusted currency (World Bank, 2017). The latter is the case for most metals found in landfills, like aluminum, copper, iron and zinc. The only positive outlook is nickel, with a possible 40% increase in price by 2030.

All of this is in strong contrast with to the earlier mentioned researches and model and this the reason for RAWFILL to shift the center of attention from landfill content to other factors.

4. Proposition of the model applied in RAWFILL



4.1. Enhanced Inventory Framework (EIF)



ATRASOL, a project partner from Rawfill is in charge to create the Enhanced Inventory Framework. Basically this is a basket of criteria based on extensive research, represented by the yellow tables in the scheme and discussed in chapter two. The research is delivered by other RAWFILL partners involved in landfill inventories (BAV, LCJ, OVAM and SPAQuE) and landfill characterization (ULG and NERC). It will also collect information from public & private landfill owners from North-West European countries.

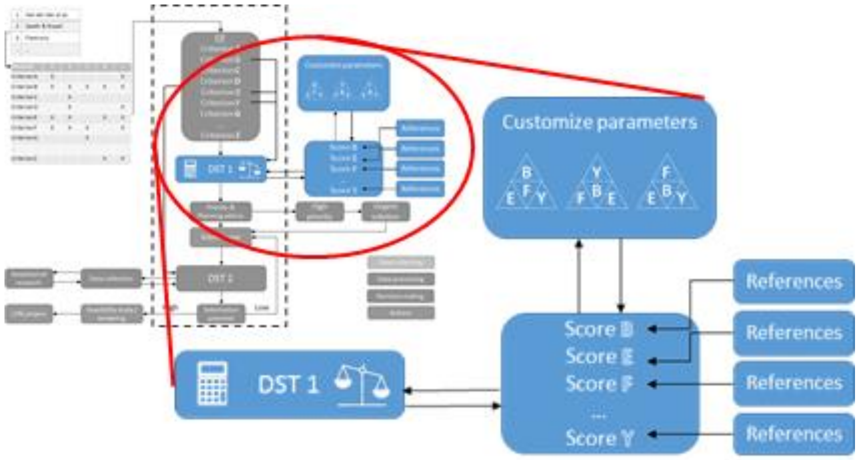
A select number of these criteria will be used in DST 1. Two factors are important to be permitted into the DST 1:

- The criterion should be often or always used in references about landfill mining projects.
- The criterion should be available at our target group or the target group should have quick and easy access to it.
- The criterion should be related to real life cases, in this way the most realistic output will be produced by both DST tools.

In short, the threshold to use DST 1 will be kept as low as possible to encourage local authorities to use it, thus creating a greater support for the concept of landfill mining. Since the conditions of each landfill site is unique, users will be able to change the weighing to a certain extent. By offering this possibility, Rawfill wants to avoid creating yet another decision support tool with a narrow operational margin.
All other criteria are used in DST 2 and will ask for more survey, means and time. DST 1 is meant to help users deciding which landfill site is worth investing in to obtain more data before an actual economic profit is negotiable.

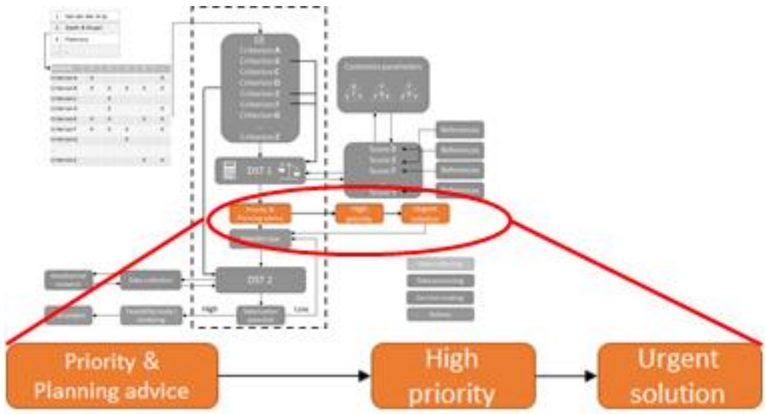
4.2. DST 1

As previously stated, DST 1 should be a tool with a low threshold to encourage its use. It only needs very general data, most of which are already available on a national, regional and even local authority level or don't need much research to obtain them. The DST 1 will select landfills with a priori interesting potential that need further historical investigation or geophysical survey.
DST 1 will generate three possible outlooks on a landfill: landfills with a low potential, an average potential and a high potential. These different degrees of potential will be discussed in the interim use.



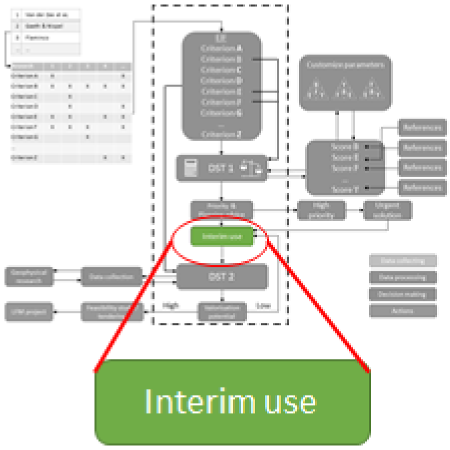
4.3. Priority and advice planning

One of the reasons DST 1 should be a quick and easy to use device is the possibility to apply it in high priority situations where there's no space for extensive decision making.
Take for instance a road construction site. Infrastructure projects like these have a big impact on communities (socially, mobility, etc), thus proportionally a big impact on local authorities too. To keep society happy, a strict planning is applicable. Having a known/unknown landfill underneath the construction site is not part of that planning. A situation like this isn't purely hypothetical e.g. VertaseFLI (s.a.) has done a project containing a landfill in the middle of the trajectory of a planned bypass.



DST 1 could help answering questions like: is the materials stable enough be to part of the infrastructure? Does the landfill need to be excavated/remediated on-site/off-site? Some components of construction waste (e.g. bricks, concrete) have the right composition to serve as road construction material (NSW, 2016; Herrador, 2011), and therefore could be used in the project itself on the condition that it fully complies with health and safety regulations. Experiments with other types of waste exist too (Kwabena Appiah et al., 2017; Subramanian, 2016; Tay et al. 2001).

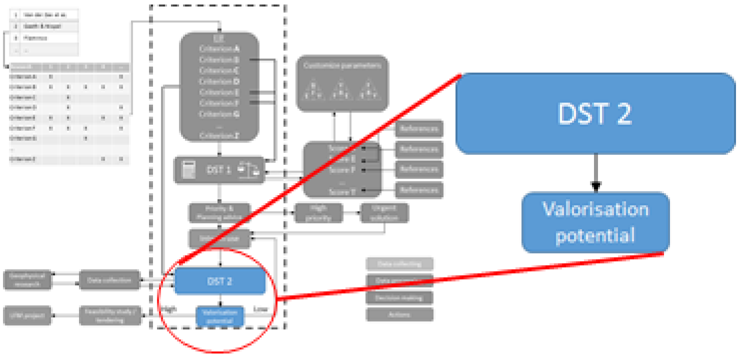
4.4. Interim use



When comparing previously executed researches, e.g. Van Passel et al. (2012) and Van der Zee (2003), the focus is stressed on answering the question: is a landfill profitable when mined or not? Because of this material-oriëntated way of thinking, the low concentration of valuable components will often lead to unprofitable scenario's (Lederer, Laner & Fellner, 2014). There's lesser attention to the solution in between in case the answer would be negative.
The Rawfill model introduces "interim use" as a third possible answer when landfills are screened, based on the experiences of the project partner OVAM (2016).
Landfills with a low potential have no chance to be economically feasible, even on the long term. Long term interim use will be the only solution for this landfill, but nevertheless the rea could provide some services towards the society. For instance: if orientation and slope angle is correct: policy makers could decide to put on solar panels and generate income from electricity production. If there's no slope at all and the landfill is situated in a rural environment, one could choose to harvest energy crops like rapeseed (*Brassica napus* L.). Harmless waste with sufficient stability could be a potential residential site and so on. In any of these cases, the use of DST 2 and thus additional (geophysiscal) research won't be necessary at all.
Landfills with an average potential will be treated based on the outlook of this potential. When the outlook is negative i.e. chances are very low that the landfill will ever be economically mineable, the followed pathways will be nearly identical to the pathways of landfills with a low potential. If the outlook is positive, one should consider an interim use of an intermediate length in line with a possible analysis by DST 2. Policy makers could use DST 1 to decide with type of interim use is most useful in the meantime. When all actors are good enough to proceed to DST 2, it will be made clear if additional research is necessary and to which extend a mining project is possible.
Landfills with a high potential will almost immediately continue to DST 2. DST 2 will determine if additional geophysical or other research is necessary to give a reliable output. This output obviously is linked to the mining potential and the degree of an economically achievable project. Since the scientific research could take some time, policy makers could decide to do make use of some form of interim use. Nevertheless this interim use will be very short to non-existent when dealing with this type of landfills.
However, the actual interpretation of this interim use and services a landfill could provide is work in progress. There isn't yet an available all-encompassing document or source of

information. Nevertheless, projects like the Interreg 3C Sufalnet4eu are one step in the right direction (Interreg 3C, 2009).

4.5. DST 2



While DST 1 is a selection tool, DST 2 is a prioritization tool. In this phase of a landfill mining project, an authority will be able to decide on which sites it will be most feasible to invest in. The DST 2 will need the results of the same geophysical research techniques as used by Rawfill among other information to make a ranking of the pre-selected landfill sites on economic interest. However, DST 2 not only narrows things down on economic purposes only, also physical, ecological and social factors are included.

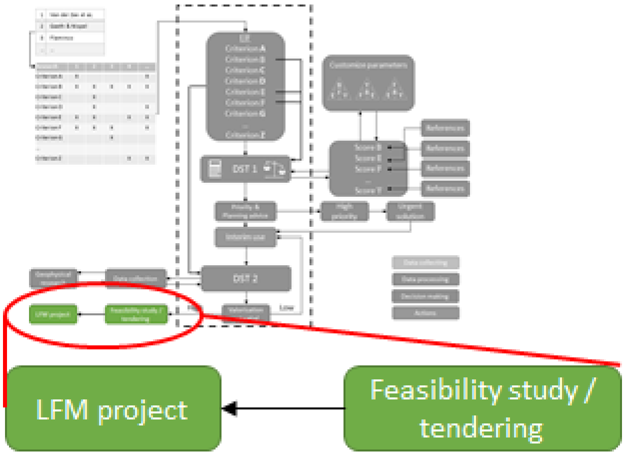
4.6. Data collecting/geophysical research

One of the key aspects in determining the potential of a landfill is the type and amount of waste. When specific date about the deposited materials isn't present; e.g. in landfills before any compulsory documentation of the activities; one could dig samples to make an estimation. This approach however is very expensive, not accurate and thus strongly constrains the potential of an average landfill mining project leading to the growing need for an inexpensive and fast method (Belghazal et al., 2013).
Geophysical research is based on one to four principles: seismicity, magnetism, electromagnetism and electric conductivity. It reflects conductive fluids and buried metals three-dimensionally up to depths of 6,4 meters (Wille & Van de Vijver, 2017) making it an accurate way to determine the buried volume as long as the background conductivity is satisfactory (Hutchinson & Barta, 2000).

4.7. Feasibility study and LFM project

DST 2 will receive the output of DST 1 and will ask two questions: "do I have enough data to provide a reliable output?" If the answer on this first question is negative, DST 2 will ask itself "What additional information do I need so I can provide a reliable output?".

In case DST 2 has all the information it needs, it will be able to give a very accurate estimation of costs and incomes of the landfill mining project. However, policy makers should be aware the chances of having all the necessary information is very low, since this requires a lot of investments, drillings, analysis, etc. prior to the actual situation were the potential of the landfill is been investigated, let alone any profit is generated.



This is also the reason why DST 1 will act as some sort of sieve where only the most promising landfills will get a recommendation to be thoroughly examined. This is to minimise the chance on useless investments when landfills turn out to be worthless when all fieldwork has been carried out, so municipalities or companies won't have a financial hangover afterwards.

5. General conclusion

The DST tool as suggested by the Public Waste Agency of Flanders (OVAM), leader of the WP T2 of the RAWFILL project, will consist of a dual tool: DST 1 and DST 2.
With DST 1, RAWFILL will provide a tool to its users that will be very cheap, very simple and very easy to interpret. The criteria used in this tool are a blend of desk research by OVAM and the Enhanced Inventory Framework of Atrasol. Municipalities, companies, provinces, etc. will get an answer on the potential of the landfills they own. When potential is low, one or more forms of interim use will be provided as a solution for the specific site. Policy makers can choose for themselves what is the most feasible one for their situation. Average potential will lead to interim use on a long term or midterm scale if the outlook of the landfill is respectively negative or positive. A positive outlook could establish an analysis by DST 2 and subsequently a landfill mining project.
High potential landfills will have no or very short interim use, depending on how much and if additional scientific research is appropriate. The short interim use could be the period in which the analysis is executed.
DST 2 will be a much more complex tool, requiring a lot of data to generate a trustworthy output. This is why DST 2 will only applicable when conditions on the landfills analysed by DST 1 are favorable. It will reduce the chances on pointless investments on site. DST 2 will subsequently provide a feasibility study of the possible landfill mining project on that particular landfill site that was targeted by the user.

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