DELIVERABLE WP T2.1.1
Table of DST indicators

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1. Introduction

One of the goals of the RAWFILL project is to support the implementation of landfill mining projects across NWE regions. To achieve this, a two-level multicriteria decision support tool was developed to support decisions of companies, governments, etc.

The rationale behind this research program is the large quantity of landfills to be managed. Estimations pointed out that the EU has about 350,000 to 500,000 landfills (Hogland *et al.,* 2010). Based on additional data in some (regions of) member states, a correlation between the number of municipalities and the mapped landfills was made. The extrapolation to the EU-level revealed an even higher number of potential landfill sites: up to 1 million (Wille, pers. com.[1]). Most of them are no longer operational but the former exploitation and closure procedures were not always in line with the standards of sanitary landfills as described in the EU Landfill directive 1999/31/EC.

In order to set up sustainable and comprehensive management plans, data collection and data processing should be well established to make good decision-making possible. For that purpose, Enhanced Landfill Inventory Framework (ELIF) was developed within the RAWFILL project. It combines all aspects related to landfills: administrative, environmental, social, technical and economical. The added value of this landfill inventory structure is that it includes parameters regarding the economic potential and the social impact of landfill sites. Based on the ELIF's indicators, the most relevant parameters were selected and included in the two-level decision support tools (DST 1-Cedalion, DST 2-Orion). This document aims at describing the indicators that were included in the DSTs.

[1] Estimations made in preparation of Eurelco workshop in EU-Parliament 20th October 2015.

2. Selected indicators for the DST 1 - Cedalion

The ELIF provides a detailed list of indicators that are essential to describe a landfill site from an environmental, social, technical and economical point of view. In order to develop the DST 1 - Cedalion, the ELIF's indicators were divided into seven main criteria:

0. General information
1. Type of landfill
2. Age of the landfill
3. Volume of the landfill (geometry)
4. Use of the landfill
5. Accessibility of the landfill
6. Surroundings of the landfill

The selected indicators were used to calculate the ranking scores for the landfills included in the DST 1 (see ***Deliverable WPT2.2.1 - Weighting of selected indicators***).

2.1. General information : The landfill ID-card

The landfill ID-card contains all necessary information to correctly locate and name a landfill. The landfill ID indicators that were included in the DST 1 - Cedalion are listed in **Table 1**. The DLM ID and the landfill name are crucial to properly identify a landfill within a large (regional) landfill database. It is important that each landfill has a unique DLM ID in order to efficiently analyze the data and to retrieve the source information for a certain landfill.

The other indicators concern the location of the landfill. To locate a landfill, the municipality, postal code, street name and number were included as well as the cadastral codes and X,Y coordinates. Based on the coordinates, data can also be imported into a GIS system, for instance for spatial analysis purpose.

Table 1: Indicators for general information of the landfills

Information	Input
DLM ID	Number
Landfill name	Text
Municipality	Text
Postal code	Number
Street	Text
N°	Number
Cadastral codes	Text
X coordinate	Number

Y coordinate	Number

2.2. Selected indicators for criteria 1: Type of waste

This criteria focuses on the landfill content and contains is 14 waste type indicators (**Table 2**). This criteria includes the type of waste deposits (11 possible options), the harmfulness of the waste materials present on site as well as the internal structure of the landfill (i.e., heterogeneous, layered or monolandfill).

The following eleven types can be distinguished:

- Municipal solid waste (MSW),
- Industrial waste, dredging materials,
- Waste water treatment (WWT) sludge,
- Inert materials,
- Fly ash, asbestos,
- Metal slags,
- Mining waste,
- Military waste
- Other.

The type “Other” can be used for some monolandfills that have a very specific content which is not abundantly found in other landfills across the EU. For instance, Flanders reports having monolandfills containing gypsum, whereas the state of Brandenburg possesses some kroon and steel deposits (COCOON, 2018).

Table 2: Indicators for criteria 1: Type of waste

Indicator	Input in DST 1
MSW	Y/N
Industrial	Y/N
Dredging materials	Y/N
WWT sludge	Y/N
Inert	Y/N
Fly ash	Y/N
Asbestos	Y/N
Metal slags	Y/N
Mining waste	Y/N
Other	Y/N

Military waste	Y/N
Nature of mixed landfill?	Heterogenous Layered N/a (monolandfill)
Mono landfill?	Y/N
Harmful waste spotted?	Y/N

2.3. Selected indicators for criteria 2: Age

Depending on the main period of landfill activities, the landfill content as well as its valorization potential can vary. A timeframe was assigned to each type of waste material in order to reflect the variation in valorization potential based on known or documented activity of the landfill site. To work properly, DST users must indicate the period in which the landfill was most active, and thus received the most waste, in case the activity goes beyond the given timeframes. For the DST 1, we identified four timeframes (**Table 3**). The last timeframe (<1999) was divided into two different categories: documented and not documented[2].

The division into four different classes was based on the following considerations:

- MSW, industrial, mixed and some landfills placed under ‘others’ with a peak **activity before 1955**. These landfills have a low economic value for landfill mining (LFM) projects. Also the potential for energy recuperation is inert materials are abundantly present. The lower age limit of each waste type was based on the oldest known landfills of that specific type in the OVAM's databases.
- The massive consumption of plastics can be taken as a first game changer in the composition of our wastes. Large scale production of the most common plastics we know today began in the 1950s (Wallace, 2017). Most of these plastics end their product cycle the same year they were produced (Dengler, 2017). OVAM took **1955** as a reference year, halfway the plastic emerging decade.
- At the end of the seventies, the recycling of plastics took off (Geyer et al., 2017), but a new type of waste emerged: electronic waste. The ‘Kian Sea’ waste incident in 1986, is still one of the best examples of the disposal attitude in that decade and lead to the Basel Convention to restrict countries in exporting their e-waste abroad (CDR Global, 2015). Therefore, **1980** marks the start of the third time interval.

[2] Based on the EU Council directive 1999/31/EC.

The Council directive **1999**/31/EC of the EU (European Commission, 1999) marks the transition from a undocumented landfill policy to a controlled, consequent managing of waste streams. However, we cannot avoid the fact that some regions like Germany, Flanders and the Netherlands already possed a well-developed waste policy by that time (COCOON, 2018).

Table 3: Indicators for criteria 2: Age of the landfill

Indicator	Input in DST 1
Period of main activities	< 1955 1955 – 1980 1980 – 1999 >1999 documented >1999 not documented

The different time intervals per waste type are listed in **Table 4**. Part of the weighting was based on this table (see ***Deliverable T2.1.2 Weighting of the DST indicators***).

Table 4: the different time intervals per waste type

Waste type	Time intervals
Municipal Solid waste	1930-1955 1955-1980 1980-1999 >1999
Industrial waste	1910-1955 1955-1980 1980-1999 >1999
Mining (high-grade metals)	1960-1980 1980-1999 >1999
Waste water sludge	1950-1980 1980-1999 >1999
Metal slag	1960-1980 1980-1999 >1999
Fly ash	1950-1980 1980-1999 >1999

Dredging materials	1940-1980 1980-1999 >1999
Inert waste	1950-1999 >1999
Asbestos	1930-1999 >1999
Mixed	1930-1955 1955-1980 1980-1999 >1999
Other	1900-1955 1955-1980 1980-1999 >1999

2.4. Selected indicators for criteria 3: Volume

The third criteria, the volume of the landfill, concerns four different indicators describing the volume and geometry of the landfill (**Table 5**). The surface area of the landfill site (m^2) was included to get an idea of the lateral extent of the landfill. Further, also the vertical extent was taken into account by means of either the depth below ground level (m) and the height above ground level (m). Lastly, the volume (m^3) was also included and could be roughly estimated based on the three preceding indicators.

Table 5: Indicators for criteria 3: volume

Indicator	Input in DST 1
Surface area (m^2)	Number
Depth below ground level (m)	Number (negative)
Height above ground level (m)	Number
Volume (m^3)	Number

Using the Flemish landfill database as a reference, the definition of a small, medium and large landfill were defined. As the actual volume of many landfills still needs to be collected, the categorization (small, medium, large) was calculated by multiplying the surface area of land plots, known historical waste deposition and an assumed average waste depth of three meters (OVAM, 2013). The total number of records that was used was 3318 (**Fig. 1**). These records were divided in intervals of 1,999 m^3 (e.g. 0-1,999 m^3; 2,000-3,999 m^3 and so on). After this, the cumulative percentage of frequencies was used to determine the three categories of volume (small, medium, large):

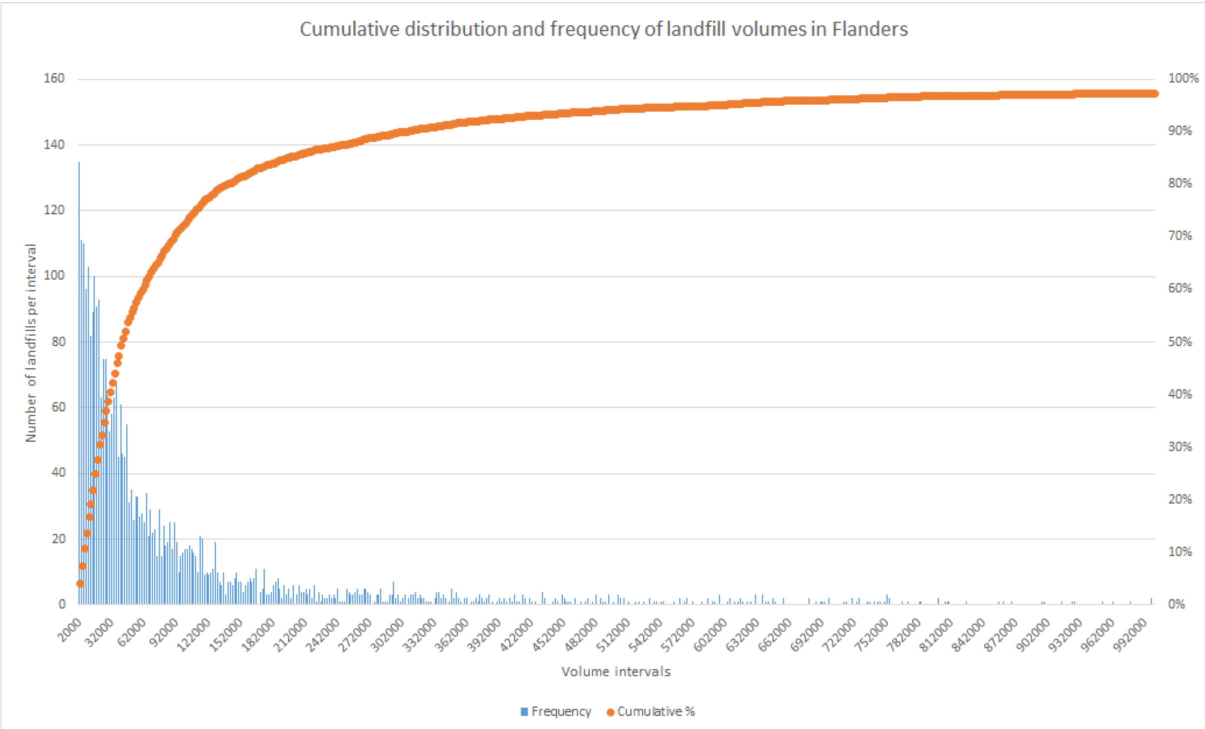

Figure 1: Cumulative distribution and frequency of landfill volumes in Flanders.

1. All landfills with a volume less or equal to 29,999 m^3, corresponding to the lower 40% of the landfills are considered to be small;
2. All landfills between 30,000 m^3 and 299,999 m^3, corresponding to 50% of the total are considered to be average;
3. All landfills greater than 300,000 m^3, corresponding to the upper 10% of the total landfills are considered to be large.

The volume can be either estimated or calculated based on for instance geophysical imaging, topographic survey). It is also possible to use default values in Cedalion.

2.5. Selected indicators for criteria 4: Use

This criteria consisted of the following parameters: the type of cover used on the top of the landfill, the surface conditions and the slope of the landfill (**Table 6**). All the selected parameters are strongly related to the possibilities of redevelopment on site. For example, sometimes the waste can be stacked at a certain angle. This influences the possibilities to access the terrain with vehicles (e.g. for agricultural purposes or constructio). Vehicles are always tested for their ability to withstand rollover. Tolerances of up to 28 degrees apply in different countries (UK parliament, 1990; Tromp, 1997). However, these are values for static testing. In practice for agricutural purposes, a maximum slope of 15 degrees is handled. This is about 30%. When doing a walkover, the user will therefore be asked to estimate the maximum slope of the terrain, so that it can be determined whether vehicles can safely do their work across the entire site.

Also an indication of the erosion status on site was included.

Table 6: Indicators for criteria 4: Use

Indicator	Input in DST 1
Type of cover	Geomembrane Mineral cover Soil
Surface conditions	Grass Rough Shrubs Trees Other
Slope angle	Flat Less than 15° More than 15°
Erosion	None Weak Severe Potential

2.6. Selected indicators for criteria 5: Accessibility

This criteria was used to evaluate the accessibility of the landfill. It concerned both on-site accessibility (possibility for the road to support heavy trucks, presence of paved roads on the landfill itself) and connectivity of the landfill site with different transport systems (distance to the road network, proximity of a train station, proximity of a CEMT canal). Accessibility is important when you start a landfill mining project. During a LFM project, a lot of heavy machinery will be necessary and a large volume of waste materials will need to be transported to e.g. treatment facilities.

Transportation via road is the most obvious way in delivering goods or removing waste from a site. However, not every road type is suitable for trucks and other heavy equipment. To indicate how easy and fast large quantities of material can be transported away from a landfill site, the distance to the nearest highway or regional access roads was included.

Transport by train was incorporated into the DST 1 by selecting in the ELIF the nearest train loading platform station in the proximity of the landfill. The possibilities for transport by ship are considered by including the closest CEMT canal to the landfill (UNECE, 2012).

Table 7: Indicators for criteria 5: Accessibility

Indicator	Input in DST 1
Paved roads?	Y/N
Accessible with heavy equipment?	Y/N
Stations	Text
Max. distance to road network (km)	Number
CEMT canals	Text

2.7. Selected indicators for criteria 6: Surroundings

For the criteria 'surroundings', the most relevant parameters to describe the general context of the landfill were selected. The proximity of drinking water protection areas, presence of Natura 2000 areas or other conservation areas and general land use, were included (**Table 8**).

The potential threat of groundwater contamination is an important decisive factor that needs to be taken into account when performing landfill mining activities (and therefore proceed to DST 2). To be able to introduce this criterion with objective data, we suggest using the concentric areas defined in **groundwater source protection zones**. For this indicator, regional policies vary because other definitions/classifications of groundwater protection zones. However, often three different zones are used (Vlaamse Milieumaatschappij, s.a.; Chelmi, 2015; InfoMil, s.a.). In Flanders, for instance, three zones are defined:

1. The 24-hour zone (i.e. "critical" in Cedalion) corresponding to a restricted area where contamination can reach the source of drinking water within 24 hours;
2. The bacteriological zone (i.e. "severe" in Cedalion) corresponding to the zone surrounding the 24-hour zone. Contamination can reach the source within 60 days or is located within a 300 m radius;
3. The chemical zone ("acceptable" in Cedalion) corresponding to the largest zone: contamination is present within a maximum radius of 2 km.

Also **flooding risk** is an important aspect to take into account when prioritizing landfills for LFM projects. Climate change affects landfill management in many ways. One of them is water. Over time, landfills located in lower areas can get susceptible to flooding due to prolonged periods of rainfall or extreme rainfall locally. Also the sea level rising is a problem for landfills close to the coast or tidal rivers. Nowadays, many EU countries have data or models in use that can predict the situation at a certain point in the future, or use the approach of a thousand-year storm (Vlaamse Milieumaatschappij, 2018; UK Government, 2019; Bij12, 2018). Landfills located in areas with a high flooding risk could pose a significant threat to the environment. On the one hand, flooding will increase the amount of erosion, which can result in increased amounts of eroded waste ending up in rivers and seas. On the other hand, when a landfill site is flooded, the volume of generated leachate will increase due to increasing percolation of water, resulting in a higher rate of leachate leakage ending up in the environment. Both pathways could affect protected areas in the vicinity of the landfill. Therefore, the flooding risk on a landfill will have a strongly affect on the prioritization of LFM projects on landfills.

The **spatial development type** is strongly correlated with the value of the land and therefore, this can be a vital indicator to ensure a profitable landfill mining activity. However, in case the conditions are not favorable enough and interim use (IU) is necessary, it can also help to determine which form of interim use suits the best according to the surrounding neighborhood. The spatial development type is included under the different land use categories that fall under the ‘Future …’.

In general, there are eight types of land use (LUCAS, 2009) of which seven are relevant to the context of landfills in Europe. The seven types are:

- Artificial land
    - Residential areas (e.g. houses, apartments)
    - Commercial areas(e.g. parking’s, malls, hotels)
    - Industrial areas
    - Recreational land (e.g. resorts, golf courses, ball fields, camping);
- Cropland (e.g. permanent crops, arable land);
- Grassland: same function as pastureland, but with native vegetation;
- Woodland: deciduous, coniferous and mixed forests;
- Water (e.g. streams, canals, lakes, reservoirs);
- Wetlands (e.g. marshes, coastal and tidal wetlands);
- Bareland including beaches, quarries, gravel, sand and clay pits.

In the ELIF and DST 1 - Cedalion, these land use types are rearranged into five classes:

1. Residential area,
2. Industrial area,
3. Recreational/touristic area (including commercial areas and recreational land),
4. Agricultural area (including crop-, grass- and woodland)
5. natural area (including water, wetlands, shrubland and forest).

Table 8: Indicators for criteria 6: Surroundings

Indicator	Input in DST 1
Drinking water protection area	None Critical Severe Acceptable
Nature area	Y/N
Flooding risk	None High Medium Low
Present residential land use	Y/N
Future residential land use	Y/N
Present recreational/touristic land use	Y/N
Future recreational/touristic land use	Y/N
Present agricultural land use	Y/N
Future agricultural land use	Y/N
Present industrial land use	Y/N
Future industrial land use	Y/N
Present natural land use	Y/N
Future natural land use	Y/N

3. Indicators for the DST 2 - Orion

For the DST 2 - Orion, we have chosen to include different indicators within an online survey format: the Orion Roadmap. The indicators are straightforward but require an extra investment in data collection (e.g. by means of geophysical research). The indicators were selected from the ELIF to determine for a specific landfill if:

- Remediation actions are necessary;
- An LFM project is feasible;
- A business case can be developed; or
- An interim use should be set up.

From here on, these different possible outcomes were called the 'endpoints' of the roadmap. The indicators were chosen in order to determine the most suitable endpoint for a landfill with specific and unique characteristics.

The main criteria that were taken into account when developing the DST 2 were the following:

1. Heterogeneity of the waste
2. Hazardousness of the waste
3. Ecological and health impact
4. Geometry of the landfill
5. Economical feasibility

Based on these five criteria, selected indicators from the ELIF were first included in a static flowchart (**Fig. 2**). Thereafter, the flowchart was translated into a dynamic and interactive online roadmap.

Table 9: Overview of DST 2 indicators in the structure of the Orion Roadmap. For each indicator, the overarching criterion is given as well as the next step in the roadmap depending on the answer (Yes or No). Each indicator will lead to another indicator, to an endpoint (green) or to a mid-point (orange/pink).

	Indicator	Criterion	Yes	No
1	Mono landfill?	Heterogeneity of the waste	Use DST New-Mine Model or expert judgment	Hazardous waste?
2	Output DST New Mine or expert judgment: mining project?	Economical feasibility	Develop ELFM project	Hazardous waste?
3	Hazardous waste?	Hazardousness of the waste	Risk assessment	Volume < 20 000 m³
4	Output risk assessment: remedial actions?	Ecological and health impact	Develop remedial action plan	Volume < 20 000 m³
5	V < 20 000 m³	Geometry of the landfill	V/Va < 1,25	V/S < 4
6	V/S < 4	Geometry of the landfill	V/Va < 1,25	Va < 20 000 m³
7	Va < 20 000 m³	Geometry of the landfill	V/Va < 1,25	Set up IU
8	V/Va < 1,25	Geometry of the landfill	ONTOL	Complex excavation?
9	Complex excavation?	Geometry of the landfill	ONTOL	Set up IU
10	Output ONTOL: NPV > -200 000/V	Economic feasibility	Business case	NPV > -20 000/V
11	Output ONTOL: NPV > -20 000/V	Economic feasibility	Business case	Set up IU

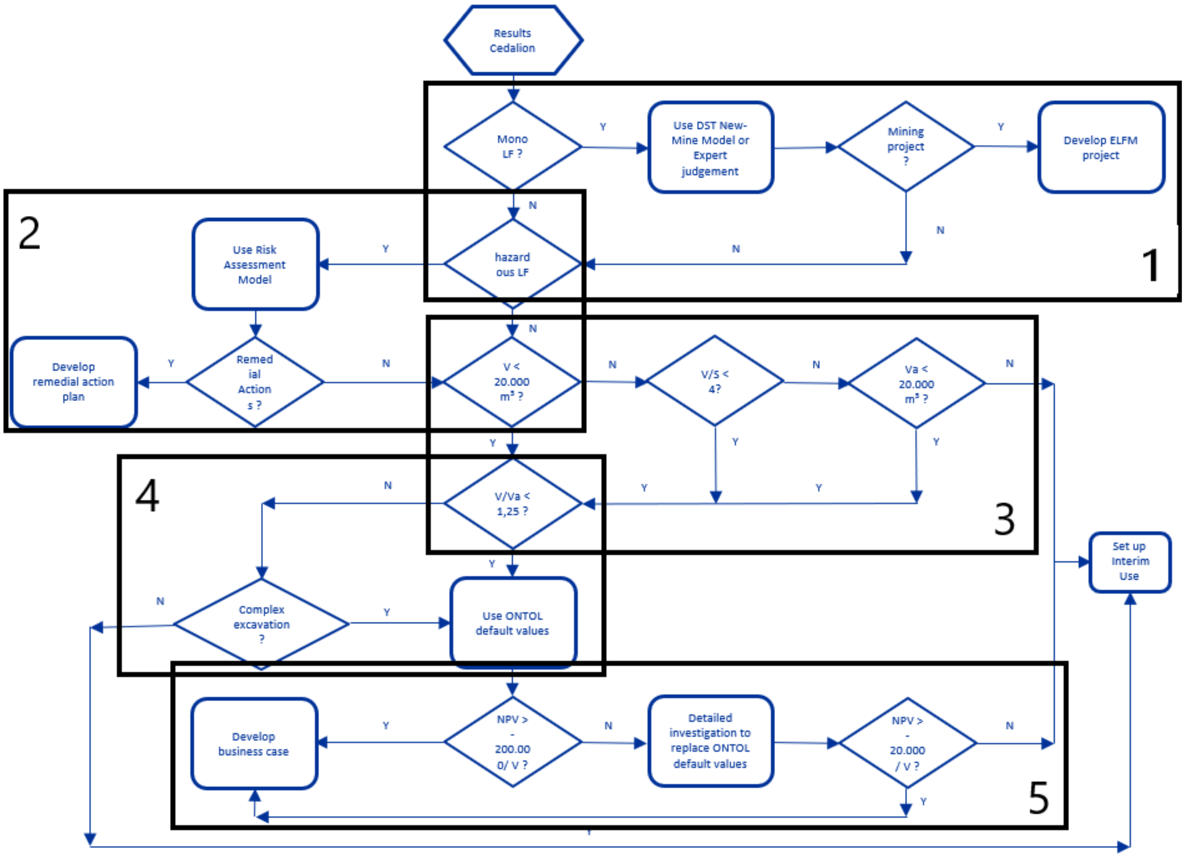

Figure 2 : Static flowchart of the DST 2 - Orion.

3.1. Indicators of phase 1

Phase 1 (**Fig. 3**) of the roadmap determines if an Enhanced Landfill Mining Project would be feasible or not (**Table 10**). To determine this, two criteria are included in this phase: the heterogeneity of the waste and the economical feasibility.

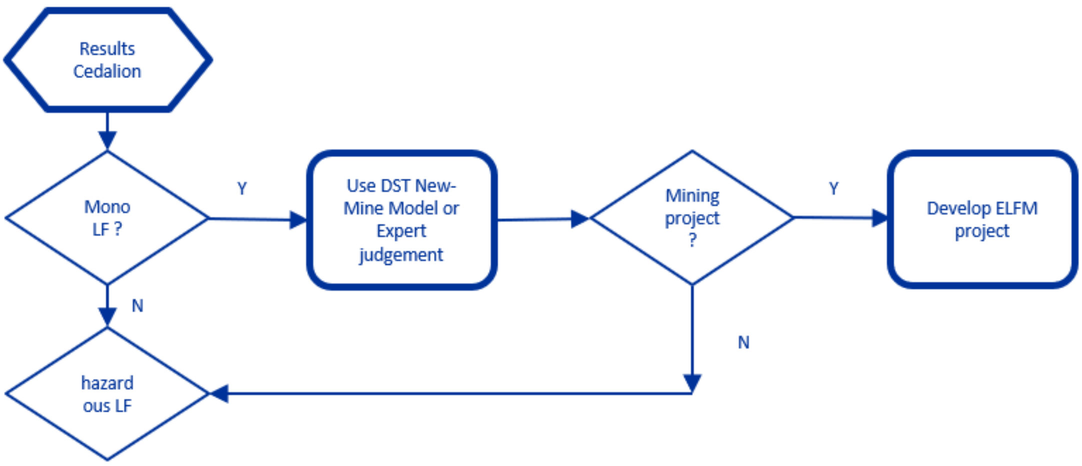

Figure 3 : Static flowchart of the Phase 1 of the DST 2 - Orion.

Table 10: Overview of DST 2- Phase 1 indicators in the structure of the Orion Roadmap. For each indicator, the overarching criterion is given as well as the next step in the roadmap depending on the answer (Yes or No). Each indicator will lead to another indicator, to an endpoint (green) or to a mid-point (orange/pink).

	Indicator	Criterion	Yes	No
1	Mono landfill?	Heterogeneity of the waste	Use DST New-Mine Model or expert judgment	Hazardous waste?
2	Output DST New Mine or expert judgment: mining project?	Economical feasibility	Develop ELFM project	Hazardous waste?

3.1.1. Indicator 1: Monolandfill?

A landfill can be either homogenous or heterogenous. At the level of the waste, a landfill can be homogenous when it contains only one type of material, such as lime, fly ash, metal slags or other industrial waste streams. In this case, only one layer of waste will be distinguished by means of geophysical exploration methods. However, it is important to note that a landfill can be homogenous on the scale of the landfill, but heterogenous on the scale of the waste (i.e. if different waste types are present but each sample will show a similar waste composition).

When assessing the feasibility of a potential landfill mining project, monolandfills seem to be most promising. Here, we are talking about homogeneity on the level of the waste within the landfill. Currently, commodity prices and demand for recycled materials are relatively low, but monolandfills have a high grade content, are easy to process and have well-known characteristics. Therefore, they are currently the most promising landfills to mine and redevelop. In Flanders, a policy already exists since the early eighties, to promote monolandfilling as much as possible, because the future costs to mine/remove/reuse the site would be much cheaper (EMIS, 1981).

Hence, the heterogeneity of the landfill is an important aspect to take into account when assessing the feasibility of a potential landfill mining project. Therefore, the classification of a landfill as a monolandfill was chosen as the first indicator in the DST 2. This indicator will help to determine if a landfill has potential for a landfill mining project or not. Hence, the only way to achieve the endpoint ‘Develop ELFM project’ is if the landfill under consideration is a mono landfill. These monolandfills will be redirected to the New Mine model or experts, in order to determine if a mining project is indeed feasible or not.

Sub-indicators

Also some sub indicators are included in case the user does not know if he is dealing with a monolandfill or not. To determine that the flowchart in **Figure 4** should be used. There, three sub indicators are included:

- Type of waste – examples of monolandfill waste types
- Well layered & uniformity – Less than 4 layers (RDM)
- Link to one type of production

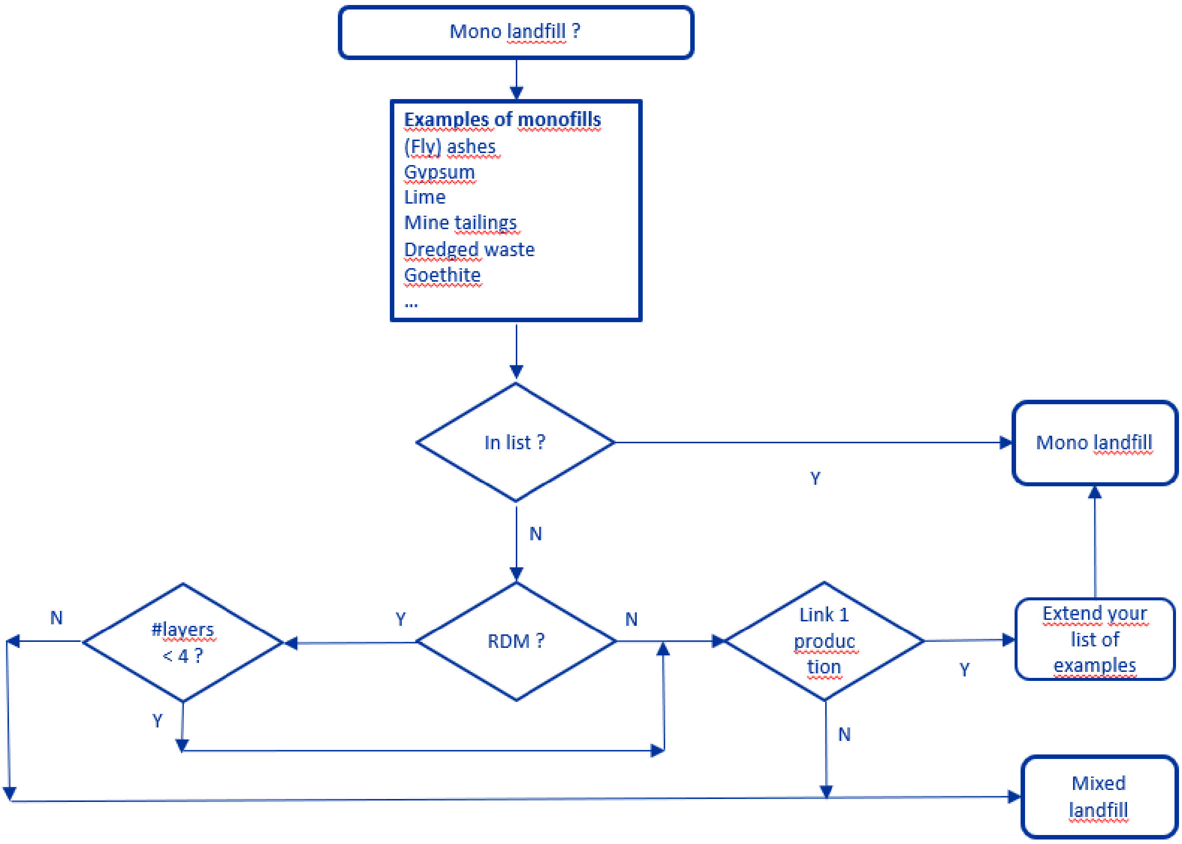

Figure 4 : Static flowchart of the Phase 1 of the DST 2 – Orion.

3.1.2. Indicator 2: output DST New-Mine/expert judgment

As discussed in the previous section, monolandfills will be redirected to the New Mine model or experts, in order to determine if a mining project is feasible or not. Here, the second criterion ‘economic feasibility’ comes into place.

The New-Mine project aims specifically at the recycling of waste to materials and for many landfills, the types of waste defines the viability of the project. Through the development and application of systems analysis methods and approaches, the one objective of the New Mine project is to facilitate systematic and trustworthy assessments of economic, environmental and societal impacts of ELFM.

If this model points out that a mining project would be feasible, the user can start developing its ELFM project. If not, the user will have to go to phase 2 of the roadmap.

3.2. Indicators of phase 2

Phase 2 (**Figure 5**) of the roadmap determines if an a risk assessment should be performed and if a remedial action plan needs to be developed (**Table 11**). To determine this, two criteria are included in this phase: the hazardousness of the waste and the ecological and health impact.

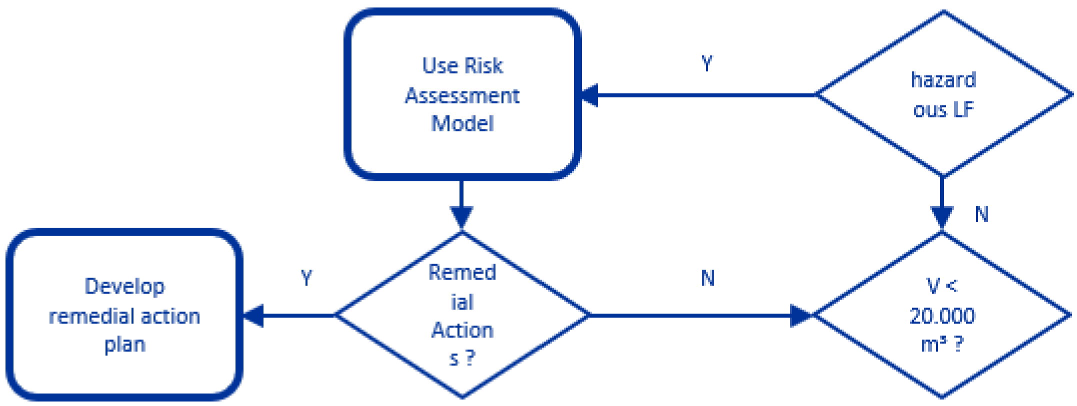

Figure 5 : Static flowchart of the Phase 2 of the DST 2 – Orion.

Table 11: Overview of DST 2- Phase 2 indicators in the structure of the Orion Roadmap. For each indicator, the overarching criterion is given as well as the next step in the roadmap depending on the answer (Yes or No). Each indicator will lead to another indicator, to an endpoint (green) or to a mid-point (orange/pink).

	Indicator	Criterion	Yes	No
3	Hazardous waste?	Hazardousness of the waste	Risk assessment	Volume < 20 000 m³
4	Output risk assessment: remedial actions?	Ecological and health impact	Develop remedial action plan	Volume < 20 000 m³

3.2.1. Indicator 3: hazardous waste?

The prevention of pollution, ecological impact and impact on human health remains the essential goal and should be taken into account at all times. Therefore, a first step is defining the risks that are associated with the landfill. If hazardous waste is present, the risks will be magnified and investigated for each exposure pathway: soil, air and water. However, only considering remedial actions when hazardous waste is present, is a simplification. Also landfill gas or leachate could pose threats to the environment or human health. This approach is in line with the conceptual site models and risk assessments in order to eliminate the exposure pathways and potential hazards for human health and the environment. Therefore, if only there is an indication of the presence of hazardous waste, a risk assessment should be performed to guarantee the environmental safety of the landfill site.

3.2.2. Indicator 4: output of the risk assessment

The risks associated with old landfills mainly depend on the waste composition of the landfill and the exposure of contaminants towards people and the environment. These risks should be identified and assessed in function of the (future) land use, when considering the rehabilitation or valorization of old landfills. In this way, it should be guaranteed that a potential rehabilitation or valorization project does not pose any threats to its surroundings. In DST 2 - Orion, the S-risk tool is included to perform a risk assessment and to propose site specific remediation objectives if necessary. If the assessment shows that the risks are too high, remediation measures should be taken in order to control impact and minimize negative effects.

3.3. Indicators of phase 3

Phase 3 (**Figure 6**) of the roadmap determines for which landfills it will not be suitable to develop a business case and which should consider the implementation of an interim use (**Table 12**). To determine this, the geometry of the landfill is considered as criterion that should be taken into account.

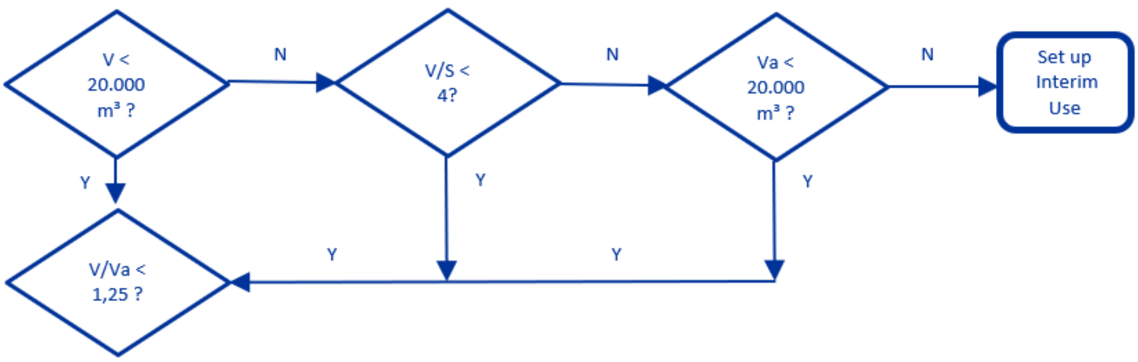

Figure 6 : Static flowchart of the Phase 3 of the DST 2 – Orion.

Table 12: Overview of DST 2 - Phase 3 indicators in the structure of the Orion Roadmap. For each indicator, the overarching criterion is given as well as the next step in the roadmap depending on the answer (Yes or No). Each indicator will lead to another indicator, to an endpoint (green) or to a mid-point (orange/pink).

	Indicator	Criterion	Yes	No
5	V < 20 000 m³	Geometry of the landfill	V/Va < 1,25	V/S < 4
6	V/S < 4	Geometry of the landfill	V/Va < 1,25	Va < 20 000 m³
7	Va < 20 000 m³	Geometry of the landfill	V/Va < 1,25	Set up IU

3.3.1. Indicator 5: V < 20 000 m^3 ?

If the landfill under consideration is no monolandfill and there are no remedial actions necessary, the volume will determine the redevelopment potential of the landfill in the first place. The volume of a landfill is important in the determination process for a landfill mining project, and the bigger a landfill is the bigger the chances are for a profitable landfill mining project. DST will diverge from this. Out of practical experiences we now know that large landfills are not the common standard, and are not necessarily the first landfills that are mineable in the ranking. Heterogenous landfills will have higher costs for material recycling as all materials will need to be separated and sorted. Furthermore, costs for the mining, transportation and treatment should be limited in order to ensure a feasible project. Therefore, only for small volumes it will be viable to excavate the waste.

3.3.2. Indicator 6: V/S < 4 ?

Landfills that have a volume larger than 20 000 m^3 can still be excavated if the surface of the landfill is relatively big in relation to the total volume of the landfill. For example, the difference in the surface area between landfills can be many times smaller/greater while containing the same volume of waste deposits. This strongly influences the return on investment because the value of the reclaimed land is proportionate to the surface area. If the same volume is excavated over a way bigger surface area, a business case becomes more feasible.

Therefore, a second indicator was included in case of landfills with bigger volumes. If the ratio between the volume of the landfill and the surface of the landfill is smaller than 4, it should be feasible to develop a business case (based on the criterion ‘volume of the landfill’).

For example, if you have a landfill of 50 000 m^3 a surface area of at least 12 500 m^2 would be required in order to develop a successful business case.

3.3.3. Indicator 7: Va < 20 000 m³ ?

Va stands for the waste volume above ground level (m³). This is visualised in the conceptual site model included in **Figure 7**. High volumes below ground level have a negative impact on the feasibility of landfill mining as this requires more investments in excavation, especially when in contact with groundwater. If a significant part (but not too big) of the landfill is located above ground level (Va), the feasibility can increase as the excavation costs decrease. If this is not the case, a business case will not be feasible and it will be recommended setting up an interim use.

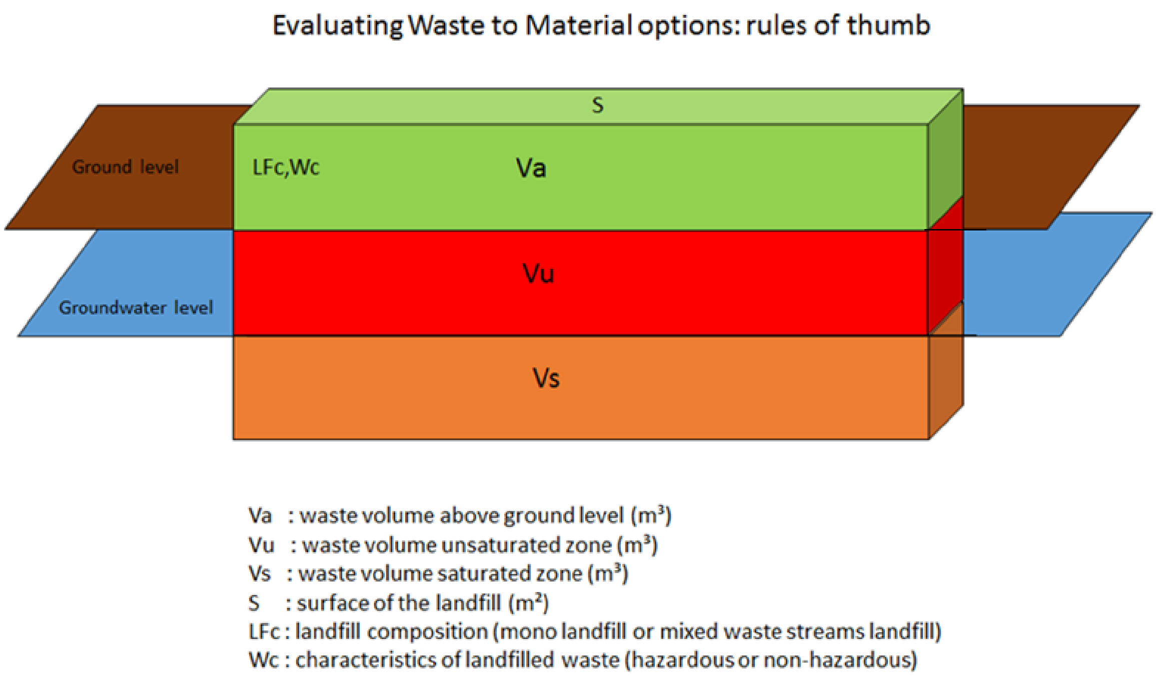

Figure 7: Conceptual site model of a landfill

3.4. Indicators of phase 4

Phase 4 (**Figure 8**) of the roadmap determines which landfills will not be suitable to develop a business case and which should consider the implementation of an interim use (**Table 13**). To determine this, the geometry of the landfill is considered as criterion that should be taken into account. The focus of this phase is on the complexity of a possible excavation of the landfilled material.

Table 13: Overview of DST 2 - Phase 4 indicators in the structure of the Orion Roadmap. For each indicator, the overarching criterion is given as well as the next step in the roadmap depending on the answer (Yes or No). Each indicator will lead to another indicator, to an endpoint (green) or to a mid-point (orange/pink).

	Indicator	Criterion	Yes	No
8	V/Va < 1,25	Complexity of the landfill	ONTOL	Complex excavation?
9	Complex excavation?	Complexity of the landfill	ONTOL	Set up IU

3.4.1. Indicator 8: V/Va < 1,25?

The ratio between the total volume of the landfill and the above-ground volume (Va) of the landfill is important when considering excavating a landfill. If this ratio is lower than 1.25 (i.e. a large proportion of the waste is present above ground level) a business case could be suitable when considering the excavation aspects of a potential project.

For example, if for a landfill with a total volume of 20 000 m^3, the above-ground volume (Va) is 16 000 m^3, it should be easy to excavate the landfill. At this point, we can start looking at the economic potential with the ONTOL tool (see next phase).

3.4.2. Indicator 9: Complex excavation?

When we don't have a beneficial ratio of V/Va < 1,25, the complexity of a possible excavation should be investigated in more detail. It could be the case that the user already knows that the excavation of a landfill would be too complex. It could also be possible that the user has no idea. Therefore, some sub-indicators were determined to estimate if an excavation would be too complex.

Sub-indicators

The sub indicators are visualized in the scheme in **Figure 8**. The sub-indicators concern:

- The ratio between the volume of the landfill in the unsaturated zone and the saturated zone (**Fig. 7**): Vu/Vs > 5?
- The volume within the saturated zone < 250 m^3
- Presence of hazardous waste?
- Distance to infrastructure > 10 m?

The volume in the saturated zone should be limited in order to not make an excavation too complex and expensive. In case hazardous waste is present, it will be suggested to perform an excavation because it is important that the landfill represents no threat to the environment. Furthermore, there should be no infrastructure present in the vicinity (10m) of the landfill to avoid damage to pipelines, drainage pipes, … Finally, the advice of an expert could overrule the conclusions of the roadmap.

If an excavation is too complex, there will be suggested to set up an interim use while awaiting landfill mining to become more profitable in the future. If the excavation should be feasible with limited costs, the ONTOL tool should be used to determine the economic feasibility of a potential business case.

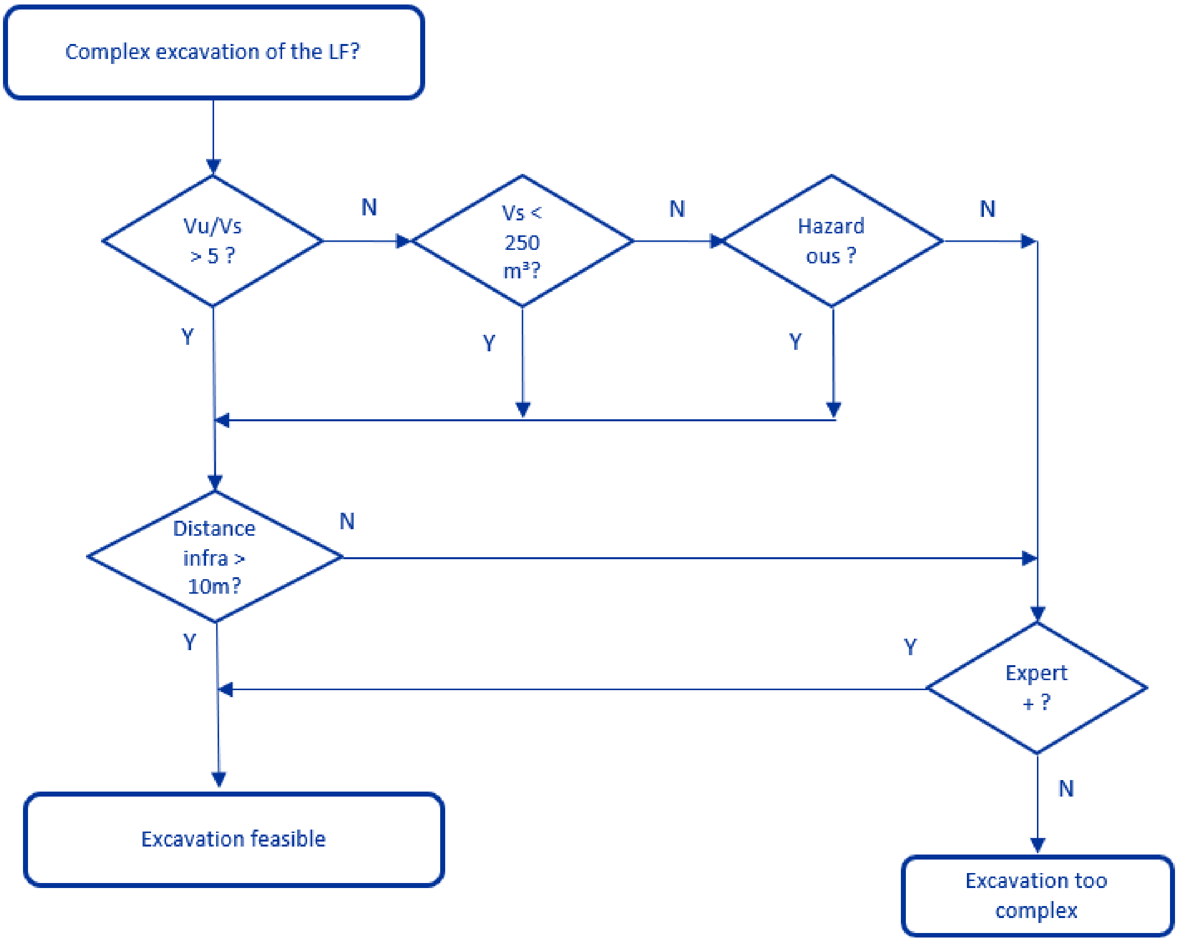

Figure 8 : Static flowchart of the Phase 4 of the DST 2 – Orion.

3.5. Indicators of phase 5

Phase 5 (**Figure 9**) of the roadmap determines which landfills it will not be suitable to develop a business case and which should consider the implementation of an interim use (**Table 14**). To determine this, the economical feasibility of a potential landfill project is considered as criterion that should be taken into account.

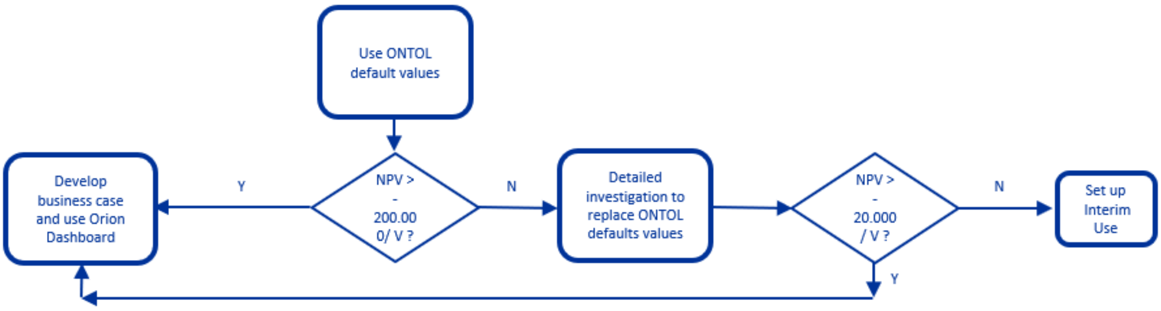

Figure 9 : Static flowchart of the Phase 5 of the DST 2 – Orion.

Table 13: Overview of DST 2 - Phase 4 indicators in the structure of the Orion Roadmap. For each indicator, the overarching criterion is given as well as the next step in the roadmap depending on the answer (Yes or No). Each indicator will lead to another indicator, to an endpoint (green) or to a mid-point (orange/pink).

	Indicator	Criterion	Yes	No
10	Output OnToL: NPV > -200 000/V	Economic feasibility	Business case	NPV > -20 000/V
11	Output OnToL: NPV > -20 000/V	Economic feasibility	Business case	Set up IU

3.5.1. Indicator 10: NPV > - 200 000/V (Output OnToL)

In this phase, the OnToL model was introduced: the Online Tool for the Economic and Ecologic Evaluation of Landfill Mining. The OnToL tool enables the user to evaluate a potential landfill mining project with respect to the economical aspect, but also the climate aspect. The main output of OnToL is the total net present value (NPV) of the project and is based on the net present values of all costs and revenues of the project. Therefore, in addition to the indicators selected from the ELIF, the NPV was chosen as an additional economic indicator for the DST 2.

If the value is negative, there will be no revenue for the landfill mining project and OnToL will characterize the project as not economically viable. However, no potential revenue for the further rehabilitation of the landfill site is taken into account. Therefore, the Orion roadmap suggests that projects with negative NPV's could also be considered as viable business cases when there is a promising opportunity identified for rehabilitation of the landfill site. Land availability as well as geographic location are also important to include in the reflexion in case of negative NPV.

In a first step, the OnToL default values can be used to gain a first idea on the economic potential without investing too much time in running the model. If losses are lower than 200 000 euro/total volume, DST 2 will suggest looking at a potential business case for the landfill. If losses are bigger, the user can invest in more detailed research and refine the OnToL-input to acquire a more realistic view on the possibilities.

If OnToL cannot be used because of practical limitations, you can estimate the NPV of your ELFM project by consulting experts on the field in combination with information on the local market conditions in your region.

3.5.2. Indicator 11: NPV > - 20 000/V (Output OnToL)

In order to lower costs and time needed for this evaluation, a first assessment uses OnToL default values. When these default values are not enough to detect no economically viable landfill mining project (NPV > -200 000), one should invest in a more detailed assessment with realistic and specific values for the case under consideration.

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