detritus | Multidisciplinary Journal for Waste Resources & Residues

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CEDALION AND ORION: A TWO-STEP DECISION SUPPORT TOOL TO ALLOW SMART ELFM PROJECT PLANNING, PRIORITISATION AND SUSTAINABLE INTERIM USE (RAWFILL PROJECT)

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Article Info:
Received:
15 December 2021
Revised:
11 February 2022
Accepted:
28 February 2022
Available online:
31 March 2022

Keywords:
Decision support tool
Enhanced landfill mining
Dynamic landfill management

ABSTRACT

(Enhanced) landfill mining (ELFM) is a sustainable waste management strategy which supports the circular economy and reduces the environmental risks related to landfills. To facilitate and encourage stakeholders to launch (E)LFM-projects, RAWFILL has developed (1) an Enhanced Landfill Inventory Framework (ELIF), (2) an innovative landfill characterization methodology combining geophysical imaging and guided sampling (HADESS) and (3) a two-step Decision Support Tool (DST) to allow smart (E)LFM-project planning and prioritization. Based on the Interreg Europe COCOON experiences, the (E)LFM-concept was broadened to Dynamic Landfill Management (DLM), a sustainable and active long-term management of former landfills. DSTs improve decision-making by increasing the efficiency and lowering the uncertainty. The two-step approach offers an efficient and cost-effective solution. The DST 1 (Cedalion) requires limited data and provides guidance to the next step. The result is a ranking score on 4 scenario's: waste to materials, waste to energy, waste to land interim use. The DST 2 (Orion) provides an overview of relevant tools that can assist the user in the further project development, like estimations about the feasibility of a business case, simulating scenario's or finding sustainable interim solutions. The latter, interim use, is the novelty in this dual DST and should be seen as a loop in the roadmap. To summarize, the innovative approach of RAWFILL is the broadening of the resource scope at landfills and their comprehensive management, spanning the whole project cycle: from first screening to final redevelopment, including sustainable management and interim uses.

1. INTRODUCTION

The development of the circular economy has triggered the transition from traditional waste management in a linear economy to sustainable material management in a circular economy. Primary natural resources are finite and in the future, we will have to find another way to gather the resources that we need to sustain our economy and wellbeing (Heuss-Aßbichler et al., 2020). To achieve this, mining secondary resources will need to play a significant role. RAWFILL (Acronym for "Supporting a new circular economy for RAW materials recovered from landFILLs") therefore explored the potential of mining former landfills in order to recover raw materials. In that aspect, RAWFILL aims at including the end-point of a former linear economy back into the circular economy.

Besides a resource scarcity of materials, North-West Europe and many other regions across the world, are facing a scarcity of land and soil because of the growing hunger for space (EC, 2021). This puts an enormous pressure on the available land and its value. This is also endorsed by the EU Soil Strategy for 2030 that wants to achieve a limited land take and soil sealing with a circular use of land. In the strategy they emphasize the importance of land recycling: constructing in or rehabilitating already previously built-up or underused areas. This can spare more natural areas and will benefit biodiversity, green spaces, land for food, biomass, water and rainfall regulation (EC, 2021). Knowing that in Europe over 500 000 landfills are present, obstructing a big amount of land for important

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https://doi.org/10.31025/2611-4135/2022.15165

functions and services for nature and society. Estimates have revealed that 90% of these landfills are "non-sanitary" landfills, which predate the EU Landfill Directive and have limited environmental protection technologies (Jones et al., 2018). Land pressure is therefore a typical phenomenon in which landfills no longer count as a threat, but can also provide a solution. Landfills can play an important role within the second step of the hierarchy of land planning (Figure 1) by providing underutilised recycled land for redevelopment.

When the principal goal of landfill rehabilitation is land recycling, landfill mining is not a requirement as it will increase the costs of the rehabilitation project significantly, exceeding the benefits of rehabilitation. Thereby, it is important that a safe use of the site is guaranteed and it should be ensured that there are no human and environmental risks due to contamination. In the Netherlands, groundwater monitoring, conducted in the period 1999-2004, provided insights into the groundwater quality around old landfills. This indicated a minor influence of the landfill material on the groundwater quality and only small dispersion risks. Therefore, no follow-up measures were deemed necessary for most of the landfills (In 't Veld & Krol, 2005). The same is experienced in Flanders, where only 10% of the old landfills require remediation according to the Soil Remediation Decree. For these landfills, landfill mining can be a solution, or containment measures should be set in place. This means that for the other 90% of the landfills, no remediation is necessary and another (sustainable) management strategy should be installed (according to the concept of dynamic landfill management).

These current transitions oblige policy makers, landfill owners, environmental experts, etc. to look at landfills through another lens. We need to change our perspective on landfills in order to propose new and innovative solutions for the remnants of the linear economy.

2. FORMER LANDFILLS AND THEIR ROLE IN THE CIRCULAR ECONOMY

2.1 Dynamic Landfill Management

For a long time, landfills have been considered as static end points of the linear economy. These 'final' waste disposal sites were tended to remain in an eternal safe and controlled situation. That behaviour has resulted in a static concept of landfills, keeping them untouched for as long as possible. Taking the current policy challenges in the European Union (Circular economy) into account as well as the UN Sustainable Development Goals, landfills are to be considered as dynamic stocks of resources (materials, energy, land). As a result, the containment and monitoring model of landfills is becoming under pressure. Maintaining a static situation in a dynamic environment is not a sustainable answer and will come at some costs (COCOON, 2018).

Hence, there is a need for a new model for landfills. A model that can be integrated into the circular economy and the current challenges in view of sustainable development. A new comprehensive, long-term and multi-phased concept was developed within the COCOON project: Dynamic Landfill Management (DLM) (Figure 2).

The objective of DLM is to bring landfills in harmony with their environment by preventing or reducing negative effects as far as possible. Furthermore, it tends to maximise and optimise the positive effects that can be created by conducting a dynamic landfill management. Of course, this should be done with respect to the current Landfill Directive. Moreover, it should take into account the European policies and legislations in the broadest sense (waste and resource management, green deal, climate change, flooding (Wille, 2018), soil sealing, no net land take, land stewardship…). This concept of 'Land(fills) as a resource' is fully in line with EU-needs to restore degraded land and encourage land recycling, in particular by supporting the regeneration of brownfields such as landfill sites. With the DLM concept, a new framework integrates multiple goals ranging from pollution prevention, land reclamation and restoration, reclaiming void space and setting up sustainable interim uses to the recovery of materials and energy resources (Jones et al., 2018).

2.2 Enhanced Landfill Mining as optimal DLM strategy

As a result of the 2nd ELFM European Parliament Seminar (Jones et al., 2018), there was a consensus that the way forward is to prioritise the incorporation of the more comprehensive, multi-phased concept of Dynamic Landfill Management into European legislation rather than focussing only on its most ambitious part, i.e. Enhanced Landfill Mining. It was agreed that Enhanced Landfill Mining (ELFM) remains a highly valuable concept, albeit as one specific, more advanced component within the broader DLM concept. Within the concept of ELFM, the valorisation and recycling of materials and energy is maximized and performed as sustainable as possible (Hogland et al., 2010). This concept aims at maximizing four different aspects:

- Recycling of materials
- Generation of energy
- Reclamation of space and land
- Safeguarding drinking water supplies

ELFM projects tend to generate opportunities for economic development by creating new (local) jobs, all within the context of a EU-wide transition to a resilient, low-carbon, circular economy (COCOON, 2018).

Unfortunately, it is not yet feasible to start up ELFM projects on a large scale. In a study of Laner et al. (2019) only a minor share of the landfill mining projects are deemed profitable. This profitability mainly depends on the system conditions (markets for materials and energy, value of reclaimed land,…) which can not be controlled within the project implementation. Within these system conditions, it also appears that revenues from recovered materials are relatively insignificant to revenues from reclaimed land when determining profitability (Laner et al., 2019). Hence, material valorisation cannot be the mere driver of an ELFM project. However, there are already promising cases of ELFM projects but most of the time,

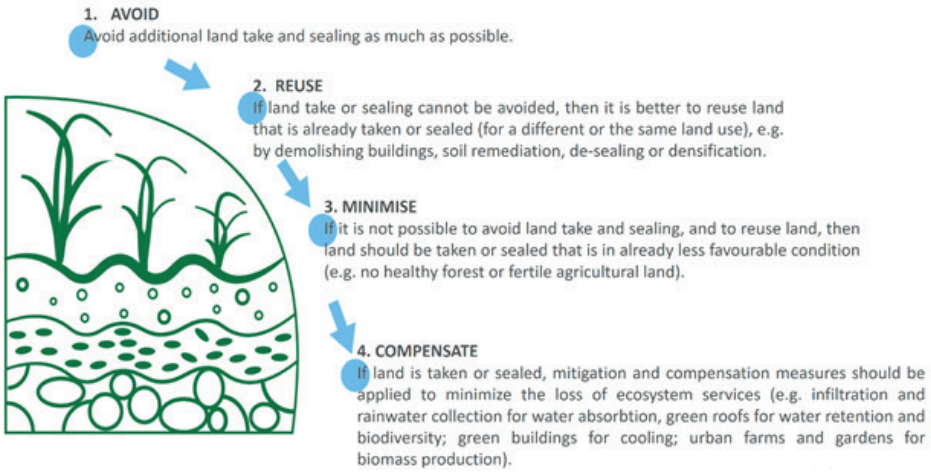

FIGURE 1: Land take hierarchy. Source: EU Soil Strategy for 2030, 2021.

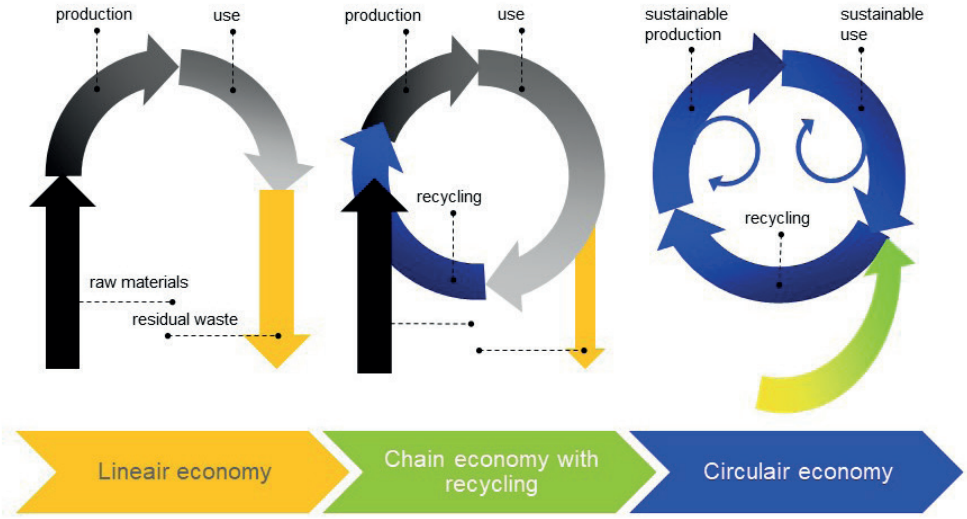

FIGURE 2: The transition of landfills in a circular economy: from waste to resources. Source: COCOON project.

these concern the landfill mining of homogenous, easy to process materials in mono landfills (Jones et al., 2013; Blengini et al., 2019).

2.3 The DLM warehouse

In order to bring the Dynamic Landfill Management concept into practice, the Public Waste Agency of Flanders (OVAM) proposed the need for interaction between three main system components for a first time in through MINEA (Mining the European Anthropocene), the pan-European expert network on assessment of anthropogenic resources in view of secondary raw material production. These three components are also seen as crucial in protecting health through urban redevelopment of contaminated sites by the WHO regional office for Europe (2021):

- "Orgware – represents how a process is organized, coordinated and regulated, and whether there are political and technical frameworks supporting remediation and redevelopment projects (e.g. enabling policies, such as grants or specific (financial) programmes; regulations and legal mandates; communication and engagement activities);
- Hardware – including equipment and techniques as well as procedures for risk assessment and site cleaning (e.g. machinery and tools for remediation, and sampling techniques);
- Software – assuring adequate evaluation procedures and calculation instruments (e.g. data collection, risk modelling and decision support tools)".

Together, these components are called the DLM Warehouse. To reach a sustainable and health-enhancing redevelopment of contaminated sites, a combination of all three components is needed. In case of landfill mining and dynamic landfill management, there has been a lot of focus on developing hardware and software. However, without a proper development of the orgware, the hardware and software will not be sufficient to promote landfill rehabilitation projects in the field. This is also illustrated by Laner et al. (2019), where policy intervention (orgware) is deemed crucial to launch profitable ELFM projects. Therefore, we want

to stress that using the developed decision support tools will not be sufficient to realize landfill mining or rehabilitation projects in the field. Instead, their use should be supported through the orgware.

3. THE IMPORTANCE OF DECISION SUPPORT TOOLS

Within the RAWFILL project, a lot of effort was put into developing specific software to support the implementation of Dynamic Landfill Management and to detect smart Enhanced Landfill Mining projects. For the landfill stock of 500 000 landfills in Europe, the available data of the landfill features and its waste content will be very diverse. A quick survey of all these landfills will result in a huge financial effort (500.000 sites, 10.000 euro/site: approximately 5 billion euro) and a short execution period will also pose capacity problems on available experts. Therefore, RAWFILL developed an integrated method to collect and analyse large datasets of landfill data.

Based on this dataset, policy makers, landfill owners, spatial developers, etc. need to be able to identify and rank the most promising landfills in terms of valorisation potential and project feasibility. Making decisions is part of life and humans do not continuously rely on instincts to make them. In that way, Decision Support Tools (DST) can improve decision-making by increasing the efficiency and lowering the uncertainty of the decision-making process.

3.1 The two-step decision support tool within the RAWFILL methodology

Data collection and analysis are part of economic and operational processes that have their limits. Therefore, the question rises on how to proceed with minor data supply but still make informed and intelligent decisions. A stepwise approach offers an efficient and cost-effective solution, limiting the efforts in the early stage of characterization and evaluation. In that view, Interreg RAWFILL developed a Decision Support Tool build on a two-step approach that aims at building up data capacity based on:

- the accessibility of the data (data mining); and
- the relevance for further investigation and planning.

In Figure 3, the role of the decision support tools within the RAWFILL methodology is illustrated. The two-step approach is realized by a combined DST named after Cedalion (DST 1) and Orion (DST 2). The DSTs take into account data on the characteristics of the (i) content of the landfill (e.g. grade, waste type, stability) and (ii) context of the landfill (e.g. accessibility, land pressure, climate change, vulnerability). This kind of data is collected and stored in the Enhanced Landfill Inventory Framework (ELIF) and can be easily exported to Cedalion. A first screening of the ELIF database with the Cedalion tool, allows to select the most promising landfills that require additional information for further analysis with Orion. This additional information can be gathered by using innovative landfill content characterization methods through geophysics and guided waste

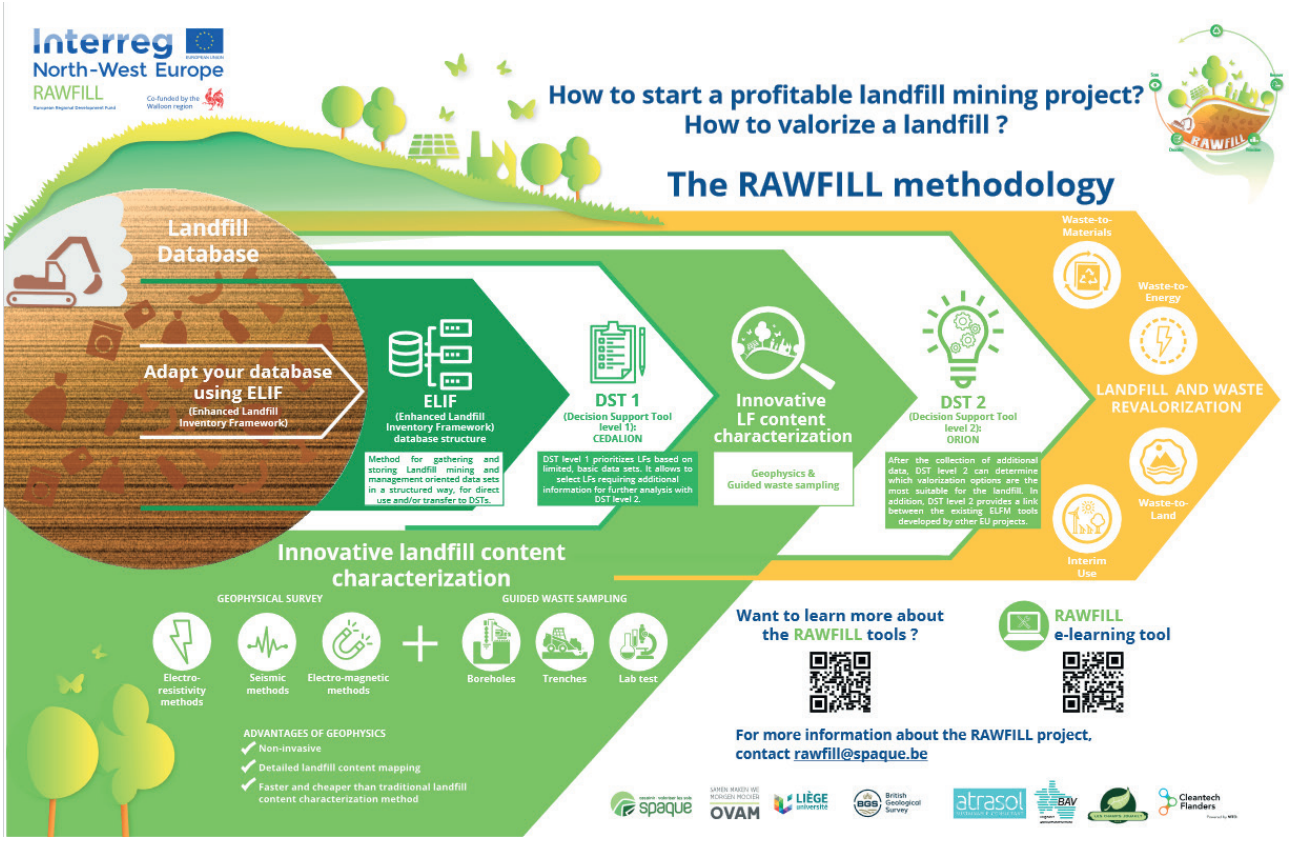

FIGURE 3: Infographic of the RAWFILL methodology. Source: RAWFILL project.

sampling (HADESS). With the detailed information gathered by HADESS, the Orion tool can be used to determine the most suitable DLM strategy for the valorisation of the landfill (and the waste if ELFM is profitable).

3.1.1 Enhanced Landfill Inventory Framework – ELIF

Conventional inventories merely contain administrative and environmental data. However, to get a view on the landfill resource potential, the feasibility of a possible landfill mining project or another sustainable management method, the RAWFILL project designed an enhanced landfill inventory framework. Within this framework, the emphasis is on the available resources in terms of materials, energy carriers and land. The framework also includes economic, technical, social and environmental threats and opportunities regarding landfill mining or other project developments. In that sense, it should be stressed that it is not only a question of "mining". Namely, all the information present in the ELIF is suitable for the evaluation of various DLM strategies, including interim use. The inventory structure is Excel based and serves as input for the first decision support tool Cedalion.

3.1.2 Decision Support Tool 1 - Cedalion

In the first step of the DST, Cedalion, a low investment in exploration cost will be sufficient, as the data can be exported from the ELIF into the DST. In order to get other stakeholders involved, a user-friendly application supports the use of the DST by allowing non-experts to update or add information (Figure 4). This application also enables local employees to evaluate and promote opportunities for DLM. The DST 1 performs an initial screening of the landfill database and guides the user to the next level. The output is not simplified to a yes/no decision, but the result will be a ranking for different possible pathways:

- waste to materials;
- waste to energy;
- waste to land; and
- interim use.

This ranking is based on a selection of simple parameters from the ELIF database: the type of waste within the landfill, the age of the landfill, the volume of the landfill, the design/use of the landfill, the accesibility and the surroundings of the landfill. At this level, a first overview of the opportunities is generated. It is not the goal to provide a detailed cost-benefit analysis. This will be done in the next step of the DST as a cost-benefit estimation requires more thorough data collection.

In the first place, RAWFILL introduced this method in view of large scale prospection campaigns. However, if you're not evaluating a database with that many landfill sites, the Cedalion tool will give you also results for an individual landfill. Furthermore, landfills can obtain a 'quick response' that indicates the start of setting up a long term management plan wherein ELFM might be an option. This approach is in line with the concept of Dynamic Landfill Management which aims at a long term active management of landfill, going beyond containment measures.

By means of this prioritization and classification, Cedalion can identify the landfills for which it is worth to invest in more detailed characterization by means of geophysical estimations (HADESS).

3.1.3 High-performing Acquisition of landfill Data by using a geophysical Exploration and Surveying Strategy - HADESS

When correctly applied, geophysical surveying methods can help to better understand the content of landfills (Isunza Manrique et al., 2019; Lamair et al., 2021). In that aspect, geophysical methods should be used in combi-

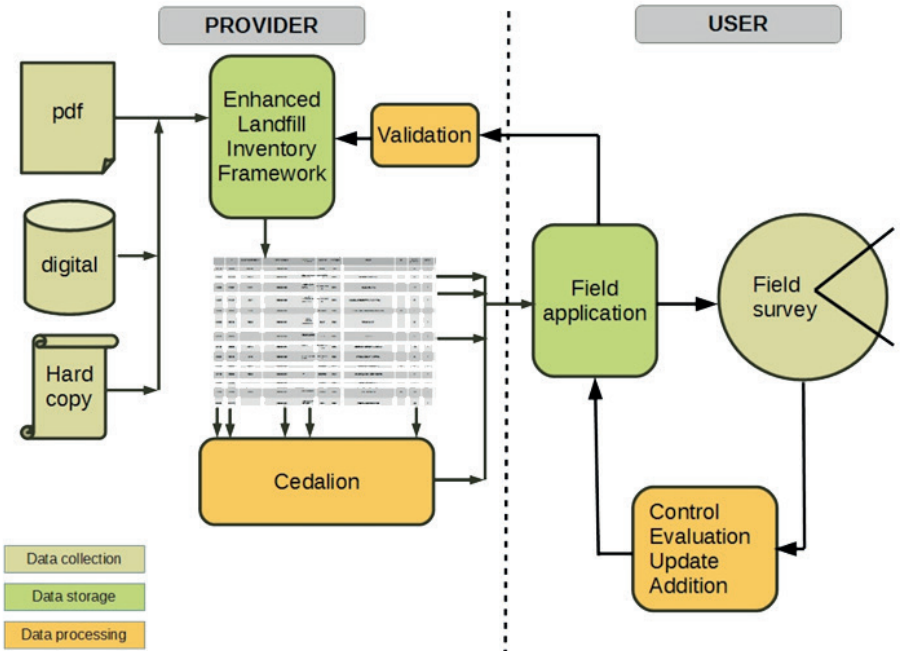

FIGURE 4: Scheme on the data collection, data storage and data processing within the Cedalion DST 1. Source: RAWFILL project.

nation with a priori data collection (see Section 3.1.1 on the ELIF) and targeted sampling (e.g. through boreholes, trenches). Geophysical prospection methods have a lot of advantages compared to conventional sampling: they are rapid, non-invasive, surface-based and they can be used to measure bulk ground properties such as electrical conductivity, density or stiffness. Due to these properties, relatively large areas can be investigated and areas with contrasting material properties can be delineated through mapping. The final step in the workflow of HADESS is the building of a Resource Distribution Model (RDM) that contains the spatial and volumetric distribution of indicative parameters of the landfill materials. For more information, we refer to the Landfill Miner Guide developed in the RAWFILL project (RAWFILL, 2021). The collected data can be used as input for the second step of the two-step DST: Orion.

3.1.4 Decision Support Tool 2 - Orion

Landfills selected by Cedalion as having a high potential for redevelopment are referred to the DST 2. Orion is an interactive tool that can assist the user in analysing the most suitable strategy for DLM on a specific landfill site. RAWFILL has identified several decision support systems in order to integrate them in an overarching DST. Each model or tool has its own strengths and weaknesses. Hence, the best decisions would be made by using them in combination.

When using the Orion tool, the user should start by going through the roadmap. This roadmap includes a sequence of straightforward but more in-depth questions about the characteristics of the landfill like the heterogeneity of the waste, the hazardousness of the waste, the geometry of the landfill, economic feasibility… The answers to these questions will lead to a possible outcome for a landfill in terms of valorisation or rehabilitation potential (Figure 5). However, to answer these questions, the user will need to invest more in data collection. Methods of geophysical explorations (cfr. HADES method developed in the RAWFILL project) are perfectly fit to gather the right information. The possible outcomes of the roadmap are the following suggestions:

- Develop a remedial action plan;
- Develop an enhanced landfill mining project;
- Develop a business case; and
- Set up an interim use.

When arriving at these end-points, Orion will redirect the user to the dashboard (Figure 6) and the relevant tools which can assist the user in the further progress, will be lightened up. From there on, the user can discover and explore the different tools that are indicated for further use. The central part with the steering wheel is symbolizing the landfill. The features inside are useful to evaluate the characteristics and fate of the landfilled waste. The Biogas button links you with a model designed to predict landfill gas production. SMART GROUND offers a tool to choose the best available techniques to process the landfilled waste (Pastre et al., 2018). OnToL (Online tool for the economic and ecologic evaluation of landfill mining) developed by TU Wien, was given a central position because of its relation with the United Nations Framework Classification for Anthropogenic Resources. Out of the inner circle of the steering wheel, the instruments are more related to effects and impacts coming from outside the landfill (the context). Floodrisks and erosion are typical phenomena, which could cause harmful situations and damage to the landfill. Land pressure is often a driver to undertake action on landfill redevelopment and specific regional models can provide prognosis on future land use and pressure. The period between the present and the rehabilitation might be relatively long e.g. sometimes decades. Interim use can be considered and green energy production might be an option in the meantime. For the latter, the US EPA model on renewable energy might support the user's choices. The redevelopment of the landfill is comparable with the process of brownfield revitalization. The Brownfield opportunity matrix is therefore also a relevant tool. When the redevelopment starts, quite often large quantities of waste or recycled materials must be transported to treatment facilities. Many countries have specific tools to choose the most sustainable option. More information on these models and tools can be found on the web pages behind the dashboard buttons.

Using the Orion tool will help the user with estimations about the feasibility of a business case, simulating certain scenario's or finding sustainable interim solutions. The latter, interim use, is the novelty in this dual DST and it should be seen as a loop in the programme. The landfill will be given a function that is beneficial for nature and/or society while bridging time until a better valorisation might be profitable. Interim use can go from one year up to several decades.

3.2 Practical implementation of the DST in frame of nature development

In Flanders, a large scale application of the DST was set up, to support the project "Landfills and nature redevelopment opportunities on landfills". This project is related to the ambition of the Flemish Minister of Environmental Affairs to achieve 4.000 ha of additional forest by 2024. In Flanders, open space is scarce and hence, it is not easy to find space for nature. As landfills are often abandoned areas that have low societal value, OVAM explored the possibilities of afforestation or nature development on landfills as a mid- or long term interim use with a high value for the society. To do so, OVAM implemented the knowledge and tools that were created within the RAWFILL project.

3.2.1 Exploration phase

In a first step, we used our Flemish Cedalion database with 3318 records to explore the theoretical possibilities of afforestation and nature development on landfills by doing a large scale prospection. This prospection resulted in the identification of the high potentials for afforestation or nature development (Figure 7).

Furthermore, we used the Orion Dashboard to further analyse these high potentials. Therefore, for the Flanders region, the RuimteModel Vlaanderen from VITO is present behind the land pressure button in the dashboard. With this model, the external drivers and limitations were analysed to see if afforestation or nature development would match

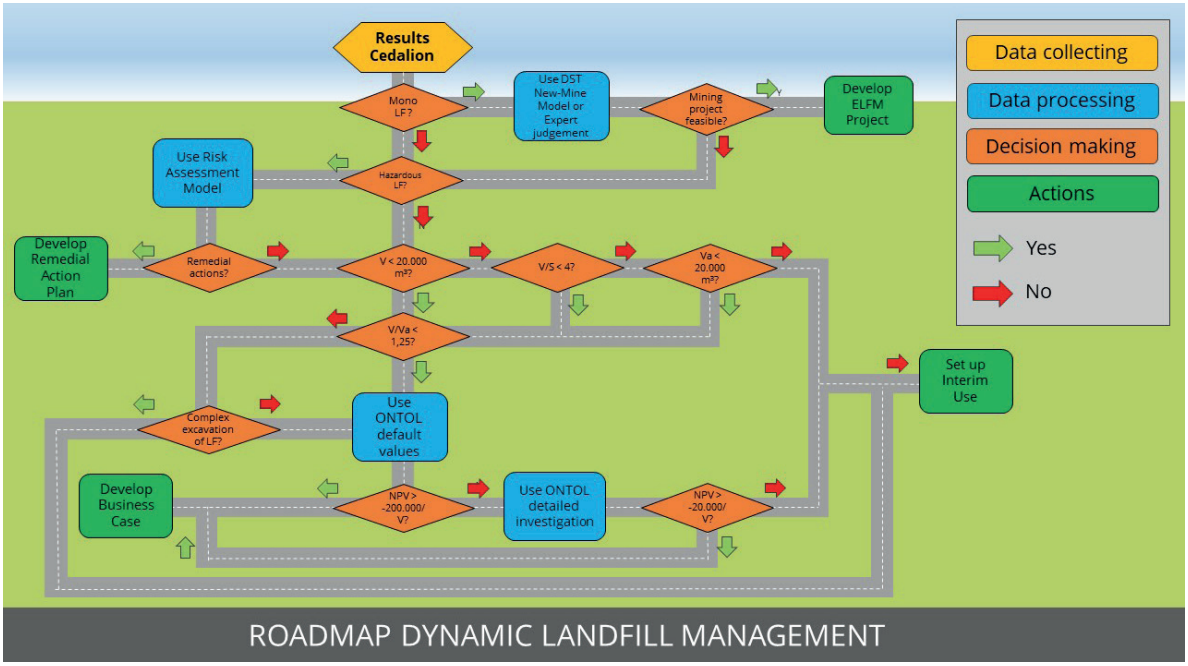

FIGURE 5: The Orion Roadmap. Source: RAWFILL project.

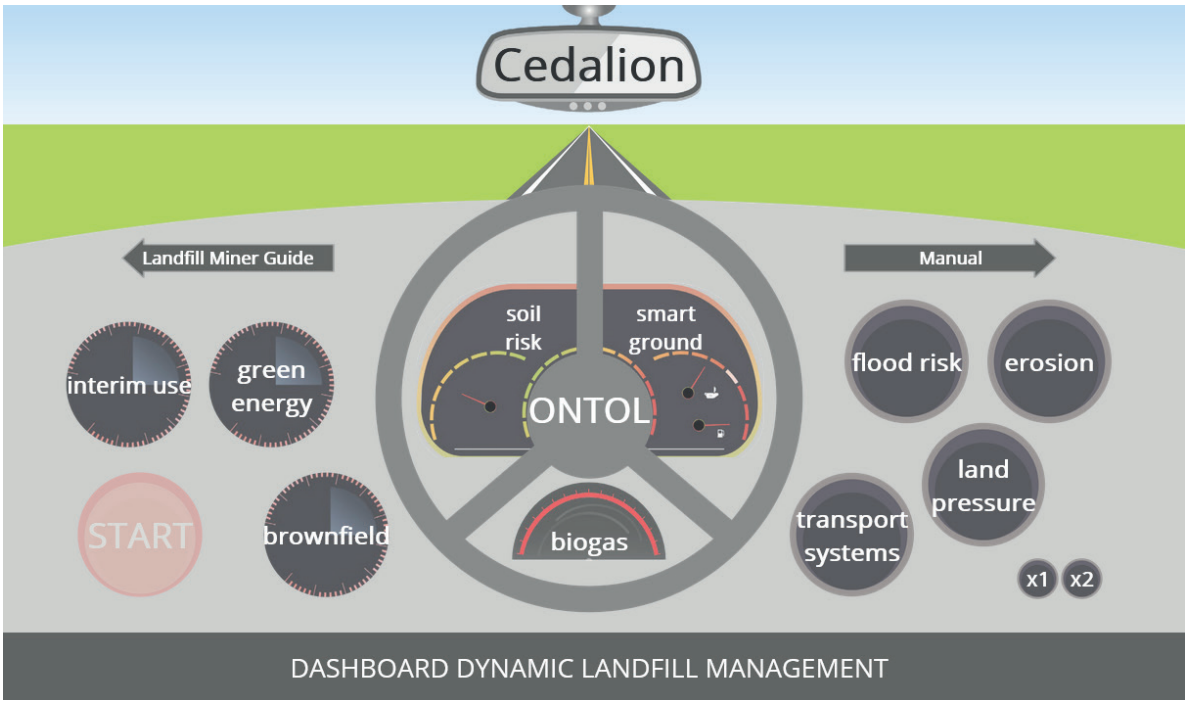

FIGURE 6: The Orion Dashboard. Source: RAWFILL project.

with the needs of the surrounding environment at these specific locations. Also the land pressure was taken into account: when the land pressure is lower, the land value will also be lower and the potential for afforestation or nature development increases.

3.2.2 Implementation phase

Based on the results of the first exploration with the RAWFILL tools, OVAM developed an implementation plan in cooperation with the governmental Agency for Nature and Forest to realize additional forest on landfills in Flanders. The approach was mainly oriented at the local authorities, as they have the best view on the actual possibilities on site. An on-site check with owners and stakeholders is always necessary to affirm the actual potential.

In practice, we send a letter to all local authorities for which OVAM documented old landfills in the Cedalion da-

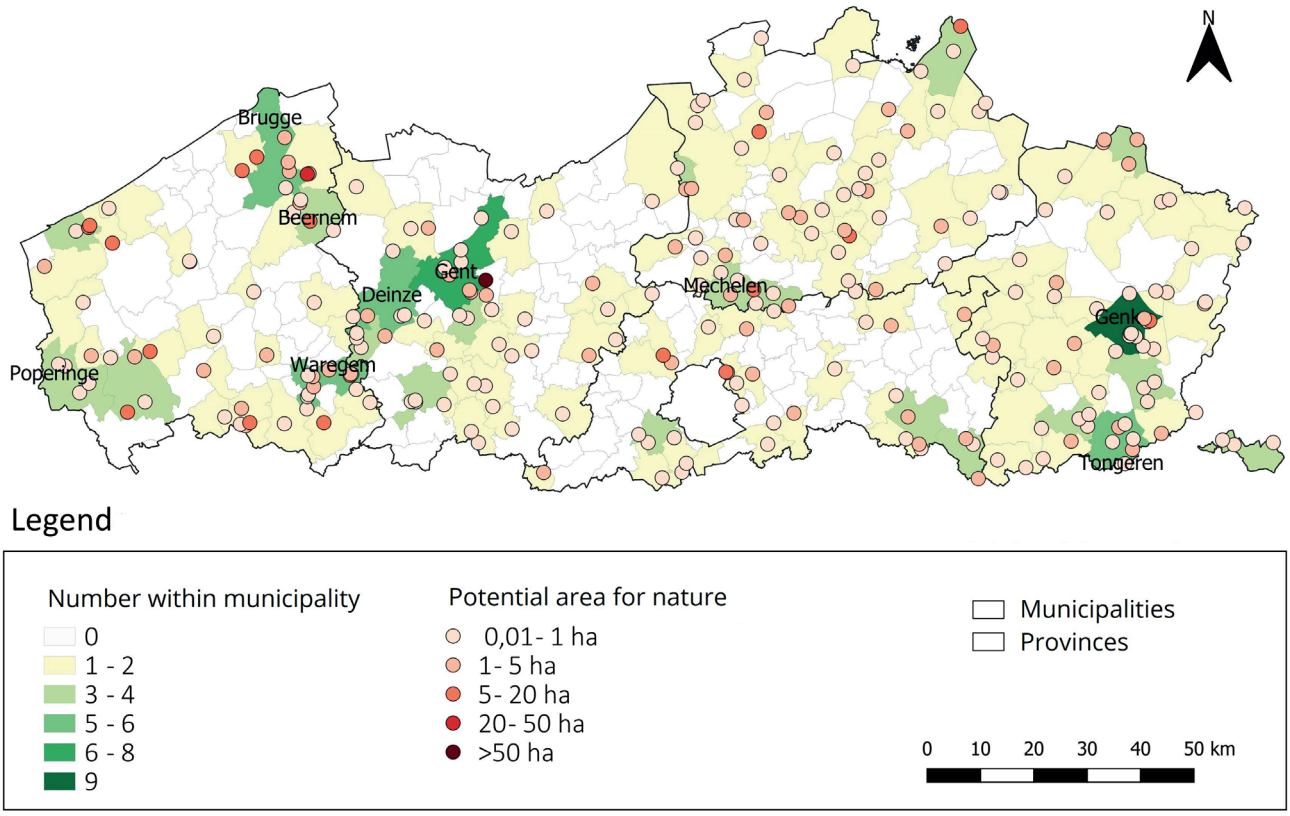

FIGURE 7: Map of landfills in Flanders with a high potential for afforestation or nature development resulted from a large scale prospection campaign. Source: OVAM.

tabase (296). Each local authority received (1) a letter send from the office of the Minister of Environmental Affairs, stating the purpose, conditions and benefits of the project and (2) a map with the identified landfills present in the Cedalion database.

On the map, the QR code of the Cedalion field application was included. In that way, the local civil servants are able to digitally share information on the landfills with OVAM by means of a simple smartphone device. This sort of civil servant science provides OVAM information on the interest of municipalities to set up nature conservation and/or forestation projects. Furthermore, the Cedalion database is validated and updated based on the local knowledge of the local authorities.

If the local authorities intend to upgrade a landfill to a forest or other natural landscape, and a Preliminary Soil Investigation is not performed yet, OVAM will perform the investigation at its expense. During that investigation, OVAM will also analyse the afforestation potential from an environmental technical point-of-view. To determine this potential, a flow chart was developed in order to determine that (1) afforestation is possible, (2) afforestation is possible under certain conditions or (3) afforestation is not possible. Thereby, also specific advice is given on measures that should be taken when you afforest a specific landfill and which prevention measures should be taken to guarantee the safety of the users. This scheme will be included in the DST 2.

4. RESULTS AND DISCUSSION

Although Circular Economy is the new paradigm, former landfills will remain as remnants of the Linear Economy. Estimates have revealed that 90% of Europe's 500,000+ landfills are "non-sanitary" landfills, which predate the EU Landfill Directive. These landfills 'claim' an estimated one million hectares of space (60 times the Brussels agglomeration) in the EU. On the other hand, natural primary resources and land are becoming scarce in Europe. These 500.000+ landfills doesn't only pose risks but could also be regarded as potential zones for secondary resources (Winterstetter et al., 2016; UNECE, 2019).

The variety of landfills (size, composition,...) and its surroundings (vulnerability, demands,...) necessitates structural support to evaluate the potential valorisation and long-term monitoring. The decision support tools developed by RAWFILL process the data provided by the geophysical prospection (HADESS) and which were uploaded in the landfill inventory (ELIF). The dual system was chosen to allow assessments on landfills with limited datasets (Cedalion) and more detailed analyses (Orion).

Cedalion extracts data from the ELIF and a field application makes it possible to verify, adapt and add data to the database. Although the number of data is limited, it acts as a driver to visit landfills, pay attention to the current situation and initiate new initiatives. The interest of public and private actors in former landfills increases if data is provided and more sustainable use options are put in place.

Traditionally, EU-policies refer to 3Rs or more Rs (refuse, reduce, reuse, repurpose, recycle,…) but in the particular case of landfills, maybe 'rethinking the long term management' is the most crucial element.

The DSTs are applicable on a large number of landfills and can be used as prioritization tool to select the most promising landfills for further investigation and appropriate actions. The Orion dashboard is easy to customize to local conditions and demands. It also puts the landfill sites in the broader perspective of the surrounding systems (ecological, economics). The DSTs take into account both the content and context of the landfill. These system conditions might trigger the management actions in case of threats (flooding risks, health risks) and/or opportunities (redevelopment, mining).

The DSTs use basic concepts from traditional mining to estimate the mining potential: characteristics of the deposited waste: grade (distribution, homogeneity, concentration) and accessibility of the landfill (depth, stability, transport, weather conditions). Although similarities exist between the geogenic mining and the mining of anthropogenic stocks, their differences require an appropriate approach (contamination, spatial pressure, liability, long term effects, …) and this was taken into account in the development of the DSTs. By looking in 4D, the most appropriate management can be chosen and combined with an interim use of the landfill site.

5. CONCLUSIONS

Management of non-operational landfills was often limited to containment and monitoring. If actions were undertaken, the driving forces were related to the negative impact on the environment. By introducing the concepts of Dynamic Landfill Management and Enhanced Landfill Mining, a new and broader focus was put on landfills. The RAWFILL-project provided several tools to inventorise, investigate and evaluate landfills in view of a sustainable long-term management and valorisation. This long-term management will be important in the frame of the EU Soil Strategy that emphasizes the need for land planning according to the land take hierarchy. In that view, landfills no longer count as a threat, but can also provide a solution.

The decision support tools Cedalion and Orion allow site-ranking, smart (E)LFM-project planning, prioritization and interim use options. The capacity-tests pointed out that thousands of landfills can be evaluated and Cedalion is suitable as a prospection tool in order to select the best suited landfill sites for mining, land redevelopment, forestation, etc. The Orion-dashboard offers the option to add region-specific models and tools, a customization which is crucial with regard to the variety of landfills and regional demands/threats.

The availability of the RAWFILL-products shows already effect in the mind of policy makers and environmental companies. Attention is paid to former landfills and programmes were set up to rehabilitate landfill sites.

AKNOWLEDGEMENTS

RAWFILL was funded by Interreg North West Europe. COCOON was funded by Interreg Europe.

REFERENCES

Blasenbauer, D., A. Bogush, T. Carvalho, P. Cleall, C. Cormio, D. Guglietta, J. Fellner, M. Fernández-Alonso, S. Heuss-Aßbichler, F. Huber, U. Kral, M. Kriipsalu, J. Krook, D. Laner, J. Lederer, B. Lemière, G. Liu, R. Mao, S. Mueller, M. Quina,D. Sinnett, J. Stegemann, M. Syc, K. Szabó, T.T. Werner, E. Wille, A. Winterstetter, and G. Žibret (2020). Knowledge base to facilitate anthropogenic resource assessment. Deliverable of COST Action Mining the European Anthroposphere. DOI:http://dx.doi.org/10.5281/zenodo.3739164

Blengini, G.A.; Mathieux, F., Mancini, L.; Nyberg, M.;Viegas, H.M. (Editors); Salminen, J.; Garbarino, E.; Orveillon, G.; Saveyn, H.; Mateos Aquilino, V.; Llorens González, T.; García Polonio, F.; Horckmans, L.; D'Hugues, P.; Balomenos, E.; Dino, G.; de la Feld, M.; Mádai, F.; Földessy, J.; Mucsi, G.; Gombkötő, I.; Calleja,I. (2019) Recovery of critical and other raw materials from mining waste and landfills: State of play on existing practices, EUR29744EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-08568-3, doi:10.2760/600775, JRC116131.

Cossu, R., Grossule, V., Lavagnolo, M.C., 2020. What about residues from circular economy and role of landfilling? Detritus, Volume 09, 1–3. DOI: 10.31025/2611-4135/2020.13920

European Commission (EC) (2021) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Soil Strategy for 2030 – Reaping the benefits of healthy soils for people, food, nature and climate. Brussels, 17.11.2021, COM(2021) 699 final.

Grossule, V., Stegmann, R., 2020. Problems in traditional landfilling and proposals for solutions based on sustainability. Detritus. Volume 12, 78-91. DOI 10.31025/2611-4135/2020.14000

Heuss-Aßbichler, S., Z. Horváth, U. Kral, A. Løvik, S. Mueller, M. Simoni, J. Stegemann, P. Wäger, and A. Winterstetter (2020). Strategic Roadmap on Sustainable Management of Anthropogenic Resources. Deliverable 3 of COST Action Mining the European Anthroposphere. DOI: http://dx.doi.org/10.5281/zenodo.3739269.

Hogland, W., Hogland, M., Marques, M. (2010) Enhanced Landfill Mining: Material recovery, energy utilization and economics in the EU (Directive) perspective. Proceedings of the International Academic Symposium on Enhanced Landfill Mining. Houthalen-Helchteren, Belgium, p. 233-245.

Interreg Europe – COCOON (2018) Report on mapping. Analysis of the March 2017 COCOON Questionnaire. https://www.interregeurope.eu/fileadmin/user_upload/tx_tevprojects/library/file_1577114467.pdf

Isunza Manrique, I., Caterina, D., Van De Vijver, E., Dumont, G., Nguyen, F. (2019) Assessment of geophysics as a characterization and monitoring tool in the dynamic landfill management (DLM) contxt: opportunities and challenges. Sardinia 2019

Jones, P.T., Wille, E., Krook, J. (2018) Why we need to develop a broad Dynamic Landfill Management stratehu and vision for Europe's 500,000 landfills. 2nd ELFM Seminar in the European Parliament: 5 lessons Learned. NEW-MINE Policy Brief.

Jones, P.T., Geysen, D.,Tielemans, Y., Van Passel, S., Pontikes, Y.,Blanpain, B.,Quaghebeur, M., Hoekstra, N. (2013) Enhanced landfill mining in view of multiple resource recovery: a critical review, Journal of Cleaner Production, vol. 55, p. 45-55.

Lamair, L., Necalau, C., Aziz, I., De Rijdt, R., Caterina, D., Isunza Manrique, I., Inauen, C., Watlet, A. (2021) Cost-benefit analysis of HADESS charaterization methodology (Rawfill project). Sardinia 2021

Laner, D., Esguerra, J.L., Krook, J., Horttanainen, M., Kriipsalu, M., Rosendal, R.M., Stanisavljević, N., 2019. Systematic assessment of critical factors for the economic performance of landfill mining in Europe: What drives the economy of landfill mining, Waste management, vol. 95, p. 674 – 686.

In't Veld, M., Krol, J. J. (2005) Advies Nazorg Voormalige Stortplaatsen. http://www.nazorgstortplaatsen.nl/VM/docs/Advies%20Nazorg%20Voormalige%20Stortplaatsen%20(NAVOS),%20april%202005.pdf

Pastre G., Griffiths Z., Val J., et al., 2018. A decision support tool for enhanced landfill mining. Detritus, Volume 1, Pages 91-101
RAWFILL Project partners (2021) Landfill Miner Guide https://www.nweurope.eu/media/13061/rawfill-landfill-miner-guide.pdf
UNECE (2019) The United Nations Framework Classification for Resources. United Nations
WHO Regional Office for Europe (2021) Protecting health through urban redevelopment of contaminated sites: planning brief. Copenhagen. Licence: CC BY-NC-SA 3.0 IGO.
Wille, E. (2018) Flooding risks at old landfill sites: linear economy meets climate change. 4th International Symposium On Enhanced Landfill Mining , Mechelen.
Winterstetter, A., Laner, D., Wille, E., Nagels, P.,Rechberger, H.,Fellner, J. (2016) Development of a resource classification framework for old landfills in Flanders (Project RECLAF). SUM2016, 3rd Symposium on Urban Mining, IWWG, Bergamo, Italy.