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RAWFILL PROJECT: INNOVATIVE CHARACTERIZATION OF LANDFILLS AND SMART DECISION-MAKING AS PART OF THE CIRCULAR ECONOMY, THROUGH LANDFILL MINING OPERATIONS

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ABSTRACT: The landfill mining is a sustainable waste management supporting the circular economy and reducing the environmental risks related to landfills. The benefits from landfill mining are multiple: from the recovery of materials (e.g., metal, plastic, organic wastes) and land, the development of new economical projects and infrastructure constructions, through to the improvement of human health. To facilitate and encourage stakeholders to launch and develop landfill mining projects in NW Europe, RAWFILL has developed three tools. The first one is an evidence-based, cost-effective enhanced landfill inventory framework (ELIF). The second tool is a new innovative landfill characterization methodology combining geophysical imaging and guided sampling. The last tool is a two-step Decision Support Tool (DST) to allow smart LFM project planning, prioritization and interim use. The ultimate goal of these three RAWFILL tools is to assess the economic potential of landfill mining projects.

Keywords: RAWFILL, landfill mining, geophysical data, inventory, decision support tool, circular economy, urban mining

1. INTRODUCTION

As circular economy is one of the main priorities to the EU, Dynamic Landfill Mining (DLM) is an efficient solution to the transition from traditional waste management to sustainable material management. In the future, the recovery of resources from urban mining will become essential as the reserve of primary natural resources are slowly being exhausted. Following this concept of circular economy, RAWFILL (Acronym for “Supporting a new circular economy for RAW materials recovered from landFILLs”) is a EU-funded landfill mining project gathering partners and associated partners of

Northwestern European regions, which focus on the remnants of the linear economy: former landfills.

Although the EU-average landfilling rate is less than 40% and diminishing, estimations identified a huge number of former landfills (over half a million). Most of them consist of unsanitary municipal solid waste landfills, predating the EU Landfill Directive (1999). Due to the lack of environmental protection systems, unsanitary landfills can provoke severe local pollution leading to land-use restrictions and even global impacts. Landfill mining (LFM) offers a more sustainable management to reduce environmental risks related to the landfills.The main benefits of LFM are:

- (i) recovery of materials (e.g., metal, plastic, organic wastes) and land,
- (ii) development of new economical projects and infrastructure constructions,
- (iii) improvement of human health.

In Northwestern Europe, more than 100,000 landfills have been inventoried giving an incredible potential for developing LFM in this area.

In order to implement LFM widely, the RAWFILL project needs to face several challenges:

- (i) the lack of reliable data regarding landfill content and its recovery potential;
- (ii) the prohibitive cost of the traditional characterization methods;
- (iii) the profitability assessment of LFM projects.

2. RAWFILL

To facilitate the implementation and the development of the landfill mining project in Europe, RAWFILL develop (i) an evidence-based, cost-effective enhanced landfill inventory framework (ELIF), (ii) an innovative landfill characterization methodology by combining geophysical imaging and guided sampling, and (iii) a two-step Decision Support Tool (DST) to allow smart LFM project planning, prioritization and interim use (Fig. 1).

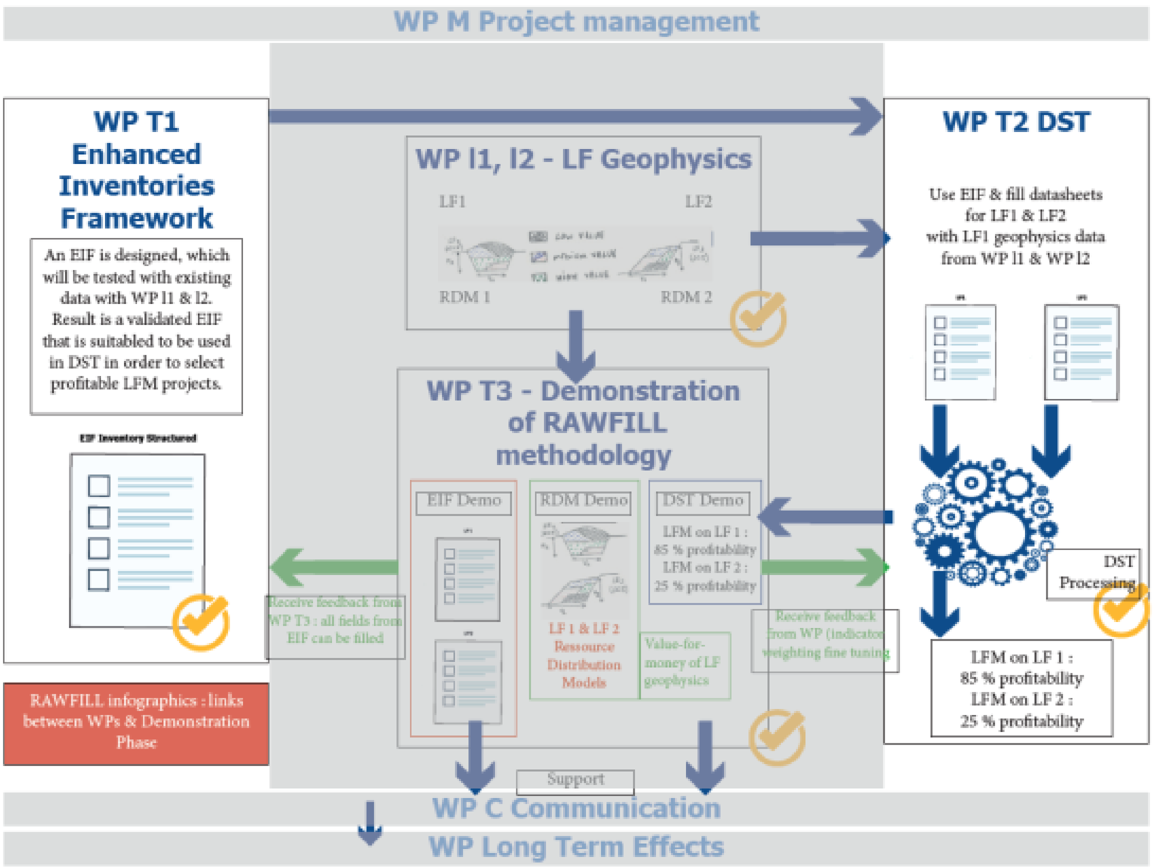

Figure 1. RAWFILL workflow diagram.

2.1 Enhanced Landfill Inventory Framework (ELIF)

The main challenge for stakeholders involved in LFM is the profitability risk due to the lack of reliable data on the recovery potential of a given landfill. Even in the NWE region, containing some 100,000 sites, existing inventories held by public agencies or the private sector are incomplete, as they lack relevant data on the landfill economic potential (quantity, quality & global value of recycled materials). The ELIF concept is designed to supply stakeholders with an inventory framework that can "easily" be filled with specific "LFM data" suitable to evaluate the landfill potential regarding materials and energy valorization, directly or through the use of the DST described hereunder. Please note that RAWFILL ELIF is a database structure that contains no information about any particular site. It will have to be filled with information by the users of the system, and the challenge is to present a useful, easy-to-use, cost-effective and reliable structure that can be used in every NWE region or elsewhere. ELIF is a list of "fields" containing information. When this information is destined to be processed by the DST, the "field" is named "indicator" and is accompanied by a specific weight depending on its interest for a LFM project.

A brief review of existing inventories at EU level has shown that most of them describe existing landfills in terms of generic information (name, location, dates of landfilling, ownership, sometimes waste volume estimation, etc.) and, for the most complete, in terms of environmental & human health issues (type of wastes, physical state, presence of leachates and biogas, geology, hydrogeology and hydrology, environmental impacts surrounding population, etc.). Information about the precise quantity, distribution inside the waste volume and composition of buried waste is always missing. To launch profitable LFM projects, this information is crucial.

One of the RAWFILL challenges is to define the suitable information with enough level of accuracy for relevant use, and to define a practical way of obtaining it at very reasonable cost. Obviously, there will be two types of information: the existing one (because already documented in some inventories, i.e. the landfill volume) and the missing one.

Missing information can be obtained from two sources: one from documentary works prior to visiting the sites and one received from site investigations. Documentary works include historical investigations that, in many cases, will not supply anything relevant as it may simply not exist. Ideally, historical investigations are supposed to specify some important information about the waste, but it can also be used to supply a guideline for further site investigations, performed with the RAWFILL innovative combination of geophysical imaging and guided sampling described hereafter. Geophysical imaging will show the distribution of homogenous zones inside the landfill and link the identified zones with information about the average waste composition and physical conditions (metal, organic materials, water content, etc.). The result will be a 3D map - global, conceptual "resource distribution model" specific for each surveyed landfill, that will also feed the ELIF and the DST with some valuable data.

The question of data accuracy can easily be solved by giving a different score to the ELIF indicators regarding what we know about their precision (for instance: give higher score to a waste volume if it has been measured with precision and less if it has only been roughly estimated). This is the simplest way to avoid too much complexity.

We must keep in mind that another interest of the ELIF is to remain useful while LFM is only an option among others, related to a broader scope named now Dynamic Landfill Management (DLM).

The ELIF structure contains 63 fields and a conceptual waste distribution model of maximum five layers, each of them characterized by 16 additional fields. It is divided into four sections:

(i) Landfill ID Card,
(ii) Surroundings,
(iii) Landfill Geometry (regardless of waste information) and
(iv) Waste.

<u>The ELIF structure can be downloaded from RAWFILL website : http://www.nweurope.eu/rawfill</u>

2.2 A new landfill characterization methodology

In the framework of the RAWFILL project, an innovative landfill characterization methodology was developed. This methodology couples geophysical investigations (e.g., electrical resistivity tomography, induced polarization, magnetometry, seismic refraction tomography, among others) and guided waste sampling allowing us to reconstruct a three-dimensional map of the landfill. It has been proved by benchmarking the existing waste characterization methods that the use of multiple methods was a prerequisite for obtaining relevant data. This 3D map provides valuable information regarding the volume and the type of waste materials contained in the landfill. By comparison with traditional exploration methods which require the analysis of multiple excavated waste samples, this new characterization methodology is cheaper, faster and provides more detailed information about the content and the geometry of the waste deposits. It is currently being tested through seven pilot sites across NW Europe. The first results for the Walloon pilot site are presented in a dedicated paper (*Innovative landfill characterization: the case study of Onoz (Wallonia, Belgium)*).

2.3 Smart decision planning process

As mentioned above, NW Europe faces an estimated burden of 100,000 landfills, mostly dating from before the EU Landfill Directive. A quick survey of all these landfills would result in a huge financial effort (100,000 sites at an average cost of 10,000 €/site: approximately 1 billion €) and a short execution period would also pose capacity problems (e.g., available experts, equipment). In order to tackle this financial and operational problem, RAWFILL team is working on a two-level Decision Support Tool aiming at building up data capacity based on accessibility of the data (data mining) and the relevance for further investigation planning.These two levels can briefly be described as:

- “**Selection**”: a first level of quick screening to identify landfills with a prior interesting potential but which need further historical investigations and (geophysical) survey. The DST 1(Cedalion) guides the user to the next step on his journey of DLM.
- “**Ranking**”: a prioritization tool to rank preselected and fully investigated landfills of economic interest for raw material recovery purposes. This second level of the DST (Orion) is a more dynamic and complex model integrating the landfill in its physical, economic and social environment, including safety aspects of the operations.

This two-step method reminds us of the Greek mythology, where the blind giant Orion carried his servant Cedalion on his shoulder and who led Orion to Helios who restored his sight. This metaphor of dwarfs standing on the shoulders of giants expresses the meaning of "*discovering truth by building on previous discoveries*". Its most familiar expression in English is by Isaac Newton in 1675: "*If I have seen further it is by standing on the shoulders of Giants.*". This is in line with the objectives of DST 1 (Cedalion): a handy guide bringing you to the next level where the more sophisticated DST 2 (Orion) takes over.

Main future users of Cedalion will be landfill owners, developers and investors in charge of landfill mining projects. In addition, public bodies could use Cedalion as part of their tasks in the field of policy making and data management of landfills. Once, the decision is made to continue the valorization process, experts should take over and rely on Orion to assess the feasibility of the project.

2.3.1 Decision Support Tool (DST 1 - Cedalion)

The first step in the planning process is Cedalion, a straightforward easy to use decision support tool. Cedalion is based on a simplified Conceptual Site Model that focuses on easy accessible data on the landfill and its environment. The objective is a quick scan of the landfill site potential and delivering guidance to the next steps to take. Given the expected low success rate of exploration and the long duration between the exploration phase and the effective mining, an interim use phase will follow after first level screening. An overview of those usages will be given. The overarching management will be explained in a Roadmap and delivered as a Landfill Miner Guide.

Cedalion uses a limited number of characteristics, extracted from the ELIF, for which a specific weight is given. A first run of the tool delivers an evaluation based on the valorization potential of the landfill and the environmental impact of the landfill. The latter is based on the traditional risk assessment concept of Source - Pathway - Receptor. The user receives a preliminary report indicating the potential for valorization of Waste to Materials, Waste to Energy, Waste to Land and the Environmental impact of the landfill.

This initial ranking provides information to conduct a site visit and control the model output with the real situation. During this visit, the user can also observe opportunities, drivers, barriers, etc. and add this information to the ELIF. This should allow a straightforward planning in the short term. If no actions are required in the short term, an interim planning and use will be provided.

2.3.2 Decision Support Tool (DST 2 - Orion)

While Cedalion is guiding the user to the next step, Orion will take into account a broad spectrum of data from the ELIF in order to point out if there is a potential business case or not. The generated reports will provide information on the degree of uncertainty about the knowledge on the landfill composition, the potential recovery of resources/land and the necessity of remedial actions. Winterstetter (2016) proposed a coherent concept in which different technical, environmental and socio-economic parameters are integrated to determine the mining potential of a specific landfill. The method is in line with United Nations Framework Classification for Resources (UNFC), which is applicable on geogenic resources (UNECE, 2010). In a cooperative project (RECLAF) between the TU Wien and OVAM this method was tested with success on specific Flemish landfills (Winterstetter et al., 2016).

3. RESULTS AND DISCUSSION

3.1 Identification of landfill mining drivers

LFM drivers of existing, pilot or large scale, urban mining projects have also been benchmarked during the RAWFILL desk studies. It has clearly been established that the main drivers are :

(i) the need for high-value land and
(ii) (ii) the need to solve an urgent environmental and/or health issue.

Among other identified drivers, we can mention:

(i) Improve the quality of a site, from a visual point a view, if a landfill is open and near the see,
(ii) The need to build roads and other infrastructures on a landfill,
(iii) The need to avoird pollution on drinking water areas located near landfills,
(iv) The need to create some biodiversity areas on the landfill;
(v) The need to recover raw materials considered as waste in the past (as ashes, lime, etc.).

Recovering materials and/or energy has been until now a by-product of these past projects. This can change when pressure on raw materials and energy carriers increases in EU for any availability or geopolitical reason. At this time, complete inventories of landfills following ELIF structure will have a very high added value for ensuring economic transition.

3.2 Classification of Landfill mining sites and interim use

The first reports on Enhanced Landfill Mining had a high material-orientated way of thinking. Reintroducing landfilled waste into the circular economy was a high-level objective. However, the low concentrations and prices of valuable components often lead to unprofitable scenarios and interest in further action fades. The concept of Dynamic Landfill Management is not a binary system. The RAWFILL model introduces “interim use” as a third option.

Landfills with a low potential have no chance to be economically feasible, even in the long term. Long term interim use will be the only solution for these landfills and could provide services towards society. Depending on the surface characteristics (orientation and slope angle) solar panels could be installed and generate income from electricity production. If there is no slope at all and the landfill is situated in a rural environment, harvesting (energy) crops is an option.

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 Orion (DST 2). Policy makers/local and regional authorithies/etc. could use Cedalion (DST 1) to decide which type of interim use is most useful in the meantime.

Landfills with a high potential will almost immediately continue onto Orion. This output obviously is linked to the mining potential and the degree of an economically feasible project. Even in those cases, the preparation of the valorization project and the permitting could take several years and create room for interim use. The Interreg 3C Sufalnet4eu can be very inspiring on this issue.

The DST 1-Cedalion and the DST 2-Orion will be tested this year on at least 30 sites. The first results are expected by the end of this year. The DST 1 will be tested on more than 20 sites whereas the DST 2 will require more data and therefore will be only tested on the eigth RAWFILL pilot landfills located in Belgium, France, UK, Germany.

4. CONCLUSIONS

The innovative approach of RAWFILL is the broadening of the resource scope at landfills and the comprehensive management, spanning the whole project cycle: from first screening to final redevelopment and providing systematic interim uses. In order to facilitate the implementation of new profitable LFM project, RAWFILL has developed three tools: (i) an enhanced landfill inventory framework (ELIF), (ii) a new landfill characterization methodology by combining geophysical imaging and guided sampling, and (iii) a two-step Decision Support Tool (DST). The methodology is currently being tested on several pilot sites across the NWE region.

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