D. T1.4.2 Practical guide of the REGENERATIS methodology (REMICRRAM)

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Laurie Lommel and all NWE-REGENERATIS project partners

Atrasol

Version 2

SUMMARY

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1 INTRODUCTION

North-West Europe countries and regions heavily rely on other nations to meet its increasing demand for ferrous and non-ferrous metals. An alternative solution lies in the urban mining of Past Metallurgical Sites and Deposits (PMSD), which offers new opportunities for recovering and producing some of these metals by promoting sustainable waste management, land and material recovering, human health protection and environmental risk reduction. Even though the social and environmental benefits of the urban mining projects have been assessed, stakeholders are still often reluctant to start the projects due to profitability risks associated with the lack of reliable data.

The NWE-REGENERATIS project aims to facilitate the implementation of material recovery projects on PMSD. To achieve this goal, an innovative methodology called REMICRRAM (REGENERATIS Methodology for Innovative Circularity to Recover Raw materials from PMSD while regenerating the polluted sites) has been developed. This methodology aids stakeholders (e.g. brownfield owners, project managers, local authorities) in acquiring relevant data necessary to comprehensively characterize a PMSD site. By using this methodology, stakeholders can effectively assess the economic potential of the site for recovering four distinct types of materials: metals, minerals, clean soil, and ecocatalysts. It also assists in identifying other drivers, such as economic, social, and environmental factors, which can further influence stakeholders' decision-making processes.

REMICRRAM is a 3 stages step-by-step methodology. Each stage is linked to a go-no go tool that decides whether to move or not on to the next stage. The decision to start a recovery project is the ultimate step, so it can only be positive if all the stages lead to a favourable result (Figure 1):

- Phase 1: The first phase of the methodology is a rapid initial assessment of the project's viability. The SMART PHOENIX tool is used at this step, which is a quick screening excel tool composed of 16 questions, allowing to give a first scoring of the PMSD potential for metal / mineral recovery, soil enhancement, and eco-catalyst synthesis.
- Phase 2: This phase involve the use of the innovative NWE-SMARTX AI tool, which takes technical parameters into considerations and offers guidance for identifying the best valorization process option.
- Phase 3: This last step allow to assess the financial viability of valorisation option selected and take economic aspects into considerations. The business case software tool is used at this stage, and offer guidance to realize a complete cost-benefit analysis of PMSD.

After applying REMICRRAM, the user will be able to decide whether or not to launch an urban mining project on the site, on the strength of the proposed recovery processes and in the light of criteria such as biodiversity, green energy, ecosystem services, social benefits, economic benefits, environmental income, etc.

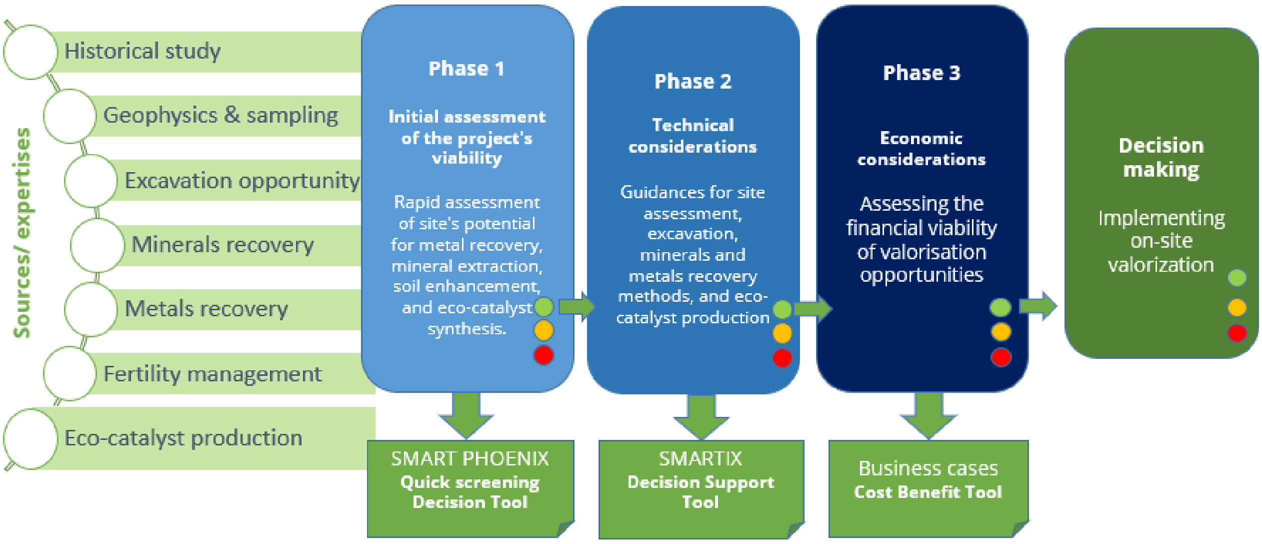

Figure 1: The REMICRRAM methodology workflow

This guide offers you a practical overview of the REMICRRAM methodology and how to use it effectively. It outline the process of identifying sites with recoverable resource potential and provide insights into preparing a basic design of a technical solution to maximize raw material recovery, all designed to empower stakeholders to harness the potential of urban mining and contribute to a more sustainable and resource-efficient future. The following sections of this report first delve into the methodology's key components and step-by-step guidelines, and then illustrate them by using a real case study, the DUFERCO- La Louvière PMSD in Wallonia.

2 DATA MANAGEMENT AND EXPERTISES IN THE METHODOLOGY

2.1 THE LINK BETWEEN DATA MANAGEMENT AND REMICRRAM

The lack of a standardized framework for making economically informed decisions on launching raw material recovery projects on Past Metallurgical Sites and Deposits (PMSD) presents a significant challenge. Current inventories for PMSD were rather created to contain information useful for the rehabilitation of these sites (remediation, environmental aspects, history, etc.), but they did not necessarily address the potential of these sites for the recovery of secondary materials. Moreover, traditional methods used to assess viability are expensive and require costly analyses and sampling, which further complicates the process. All these aspects make it difficult for stakeholders to assess the suitability of their site for material recovery projects.

To address these obstacles and challenges, the NWE-REGENERATIS project has generated an array of new tools, data sets, and guidelines, aimed at facilitating the development and consolidation of crucial data for material recovery project. The development of all these tools and the application of the REMICRRAM methodology required the involvement of experts in many fields: geophysics, mineral processing, metal/mineral recovery, civil engineering techniques, historical studies, eco-catalysts production, etc.

2.2 A PROPOSED WORKFLOW FOR USING GEOPHYSICS TO CHARACTERISE PMSD

Geophysical prospecting methods are rapid, non-invasive, surface-based techniques, used to measure bulk ground properties, such as electrical conductivity (or its inverse, electrical resistivity), magnetic properties, density or stiffness. Geophysical survey techniques provide many advantages over traditional "intrusive" studies and should always be considered at the outset of a project when trying to build a conceptual ground model, and/or establish the resource potential of an existing PMSD. The most effective use of geophysical surveying relates to the ability to investigate relatively large areas, in order to delineate (map) areas of contrasting material properties. As geophysical methods are largely non-invasive, they do not present the same risk of cross-contamination or damage to contamination barriers associated with conventional invasive sampling such as trial pitting and drilling. Characterising a large site without using geophysics would require a large number of boreholes to identify and delimit potentially homogeneous zones, which would therefore represent a very high cost and a high risk of cross contamination. In comparison, multiple geophysical mapping techniques could be undertaken across the site in a fraction of the time and at considerably reduced cost. They provide much more comprehensive information on the spatial heterogeneity of a site, compared with the use of point measurements alone (e.g. intrusive boreholes/trenches or point sensors), and enable sampling to be targeted so that the geophysical signal can be correlated with the characteristics of the materials.

Carrying out geophysical survey allows to improve the characterisation of PMSD thanks to the wider spatial coverage, while providing accurate information of the composition and distribution of metallurgical waste in the deposit volume. The effective construction of a Raw

Material and Pollution Distribution Model (RAPIDM) model dedicated for PMSD is ensured by applying specific workflow process. Specific areas selected using geophysical imagery are chosen for verification through a small number of targeted sampling (e.g. boreholes, trenches). The combination of geophysical imagery and ground truth allows to identify the PMSD's extent and structure, as well as to quantify changes in metallic content of the different deposits. Ultimately, the obtained model describes the spatial/volumetric distribution of indicative parameters of the metallurgical materials, at a scale suitable to assess the economic viability of potential PMSD mining operations.

A geophysical survey must be carried out in the right way in order to obtain reliable results. It should be kept in mind that geophysical methods are indirect techniques and the measured physical property might point to different possible interpretations. As an example, high conductivity indicates both, increased clay or metal content. Therefore, in order to reduce this uncertainty, it is highly recommended to apply a combination of complementary geophysical methods, which measure different and unrelated bulk ground properties. Furthermore, especially due to the highly heterogeneous structure of PMSD, it is mandatory to use targeted intrusive samples both in order to verify the geophysical results and to calibrate the geophysical processing and modelling. Another limitation is that geophysical techniques can only detect a target if it is large enough in comparison to the geophysical method resolution, and causes a significant contrast in the measured material property. Conductivity maps measured with electromagnetics for example, will only efficiently delineate a metallic body if the conductivity contrast between the slag and the host material is high enough. However, the sensibility of geophysical methods decreases with depth, meaning a geophysical anomaly might be detected at the surface, while it remains invisible at depth.

A new workflow, proposed by the NWE-REGENERATIS project completely describe how to set-up a geophysical survey from the data collection to the interpretation and validation, this workflow is available via the e-library. This must be used in combination with the table describing the suitability of geophysical methods for several application related to PMSD study. Indeed, every geophysical method has different advantages and limitations. Some methods are better to map lateral changes whereas other methods are able to measure up to greater depths. The required time and staff for geophysical acquisition and processing can vary significantly. Possible applications of main near-surface geophysical methods for PMSD characterisation have different requirements in term of staff required to deploy them, acquisition and processing times. Moreover, the correct choice of methods is site-dependent and requires accurate knowledge of site conditions (expected heterogeneities in material properties), combined with the knowledge of the survey objective/target.

2.3 A NEW FRAMEWORK FOR HISTORICAL STUDIES

Historical studies are important to conduct as they can provide valuable information regarding past industrial activities that were carried out on site. However, current traditional historical studies are more oriented towards environmental and health risks and does not consider the data collection to assess economic and valorization potential of material deposits present on site (e.g., Guide de bonne pratique pour études historiques by SPAQuE, 2010).

The novel historical study guidelines formulated within the framework of the NWE-REGENERATIS project, aim to retain the existing focus on environmental and health risk analysis while placing greater emphasis on identifying potential resources, particularly valuable deposited material on PMSD. The new approach is devised to efficiently identify valuable materials present on the site, utilizing a five-part methodology to ensure overall efficiency of the project and that all the various information are comprehensively represented in the study. The steps are outlined as follows:

1. Site identification ;
2. Legal and administrative procedures ;
3. Site documentation review ;
4. Deposit investigation ;
5. Previous investigation campaigns.

Guidelines and data sets for conducting historical studies are accessible via the e-library, and provide complete guidance to users.

2.4 THE NWE-MESIS INVENTORY STRUCTURE

Given the difficulties associated with the collection of suitable data for estimating the recovery potential of PMSD, it becomes essential to establish an inventory encompassing all key parameters relevant to recovery projects. To address this need, the NWE-REGENERATIS project has developped the MEtallurgical Sites Inventory Structure (NWE-MESIS), an inventory structure designed to be utilized directly for creating an inventory or as a valuable addition to existing ones. It contains crucial parameters for developing material recovery projects from PMSD and includes some parameters that are also part of the REMICRRAM tools. NWE-MESIS is a valuable resource for stakeholders who are considering launching recovery projects on PMSD, as it includes historical studies, site visits, pre-investigation estimates, and other relevant data. However, NWE-MESIS does not contain any datasets or analysis results.

The NWE-MESIS structure is provided in the form of the excel file "NWE-MESIS-fin.xlsm" which is composed of 6 main sheets by default (as a minimum):

1. Welcome to NWE-MESIS (how to use it),
2. General PMSD ID-cart,
3. Surroundings and site,
4. Deposit 1…Deposit 5
5. Data sources,
6. SMART PHOENIX.

The Deposit sheet can be duplicated up to 5 times depending of the number of deposits identified on a site (up to five).

The advantages of using NWE-MESIS is that users can directly identify important missing information that could be useful for launching recovery project. The NWE-MESIS is also directly linked with the first step of REMICRRAM as it contains the SMART PHOENIX tool. When used in NWE-MESIS, it allows the ranking of several sites, or several deposits within a site, in order to select the project that is likely to be the most profitable.

The decision to launch a recovery project depends on various drivers, such as economic, environmental, and social factors, all of which are included in NWE-MESIS. The inventory structure can be accessed via the elibrary, and more information on how it works and how to complete it can be found in the NWE-MESIS guidebook.

3 THE REMICRRAM METHODOLOGY

3.1 PHASE 1 : SMART PHOENIX

Stage 1 of the REGENERATIS methodology aims to provide an initial overall estimate of the viability of a recovery project on a PMSD, as well as for 4 categories of material: the potential for metal recovery, mineral recovery, soil enhancement for ecocatalyst production and ecocatalyst production. This is done by using the SMART PHOENIX tool, which is accessible via the NWE-MESIS (MEtallurgical Sites Inventory Structure) (see section 2.3), or as a standalone tool.

The SMART PHOENIX tool consists of 16 questions referring either to the site, or to the deposit. Next to each answer, you are asked to indicate the confidence level. In this way, you can have an indication of the reliability of each given answer. Each answer is associated to 4 scores, one score per category of material, which represent estimates for the material recovery potential of a site. A global total score is also calculated which is a weighted sum of the 4 scores.

A user guide is available to help you fill the SMART PHOENIX and interpret the results.

Once the 16 straightforward questions answered, you obtain a clear indication of whether a PMSD is worth exploring further for material recovery purposes. Beside the single potential of one site or deposit, It can also be used to rank several sites and/or deposits in order to select the most profitable project. This first go/ no-go phase is essential in order to assess whether it is worthwhile investigating the site/deposit in more detail, by moving on to phase 2 of the REMICRRAM methodology: the NWE-SMARTX tool.

3.2 PHASE 2 : NWE-SMARTX

In case of getting high score in one of the valorization categories mentioned in phase 1 (SMART PHOENIX) and good score for the confidence level, the user can proceed to phase 2, the NWE-SMARTX. In this phase the user can assess the site's valorization potential in detail and identify some technical and economical thresholds associated with the site.

The NWE-SMARTX is provided as an Open Source application based on artificial intelligence that runs locally on the end user computer. It has been trained through the gathering of data from 9 pilot sites of the NWE-REGENERATIS project (3 pilot sites and 6 additional sites, from UK, Belgium and France) and additional expert data and. Its objective is to suggest innovative valorization paths for the materials present on site based on the site and material characteristics. Five distinct predictive modules have been developed: geophysics, metals, minerals, excavation, eco-catalysis. In the geophysical module, the user will get recommendation of geophysical methods that can be applied to gain better knowledge of the volume and location of residues on the metallurgical sites. The civil engineering module will advise the user on how to optimize the excavation and pre-treatment of the material. In the mineral, metal and ecocatalyst module, suitable valorisation options and process will be given to the user, based on site characteristics, material volumes, and types of materials present on site.

3.3 PHASE 3 : BUSINESS CASES

After applying the smart decision support tool NWE-SMARTX, the user can choose to develop a business case for a specific site based on the recommendations received. A structure and example of a business case are available in the e-library of NWE-REGENERATIS project. This phase helps the user to assess the economic viability of such a project based on the data provided in phase 1 and 2. It provides a realistic cost-benefit analysis with a detailed consideration of all the associated risks and affecting factors. It provides a record of the return on investment from a financial perspective and summarizes all the benefits delivered directly and indirectly. This business model structure is a management tool for an evidence-based and transparent decision-making process for brownfield owners/managers, municipalities, public/private or any other interested stakeholder to analyse the economic potential of an urban mining project before launching it. Similarly, the quantification of costs can be done for several scenarios, for example, by comparing the costs of traditional rehabilitation works on polluted sites to those of remediation using the recovery options proposed by REMICRRAM.

4 AN INSPIRING CASE STUDY, DUFERCO- LA LOUVIÈRE (WALLONIA)

4.1 INTRODUCTION

This part of the report presents the results of the full application of the REMICRRAM methodology to a practical case: the DUFERCO site in La Louvière. After an overview of the industrial and historical context of the site, which initially reveals a certain potential for the recovery of certain materials, the next section presents the step-by-step approach for applying the REMICRRAM methodology to the DUFERCO-La Louvière PMSD. Each stage will be illustrated in a practical way by explaining the application of the REMICRRAM tools, as well as the investigations required to collect key data. This section will also give some insight about how the expert appraisals are required to reach a decision on the recovery potential.

4.2 OVERVIEW OF HISTORICAL STUDY

DUFERCO – La Louvière site is located in Wallonia, in the province of Hainaut, between Le Roeulx and Morlanwelz (Figure 2). The parcel covers more than 120 ha extending to the north of the urban area of La Louvière.

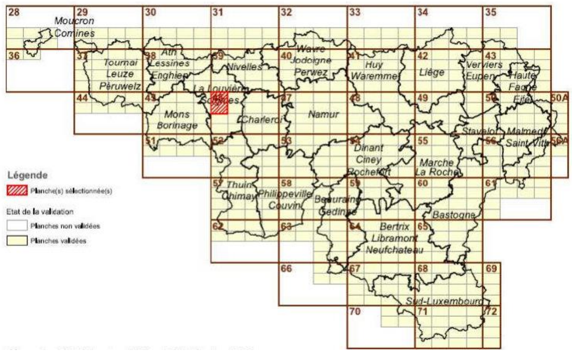

Figure 2: Location of the site in Wallonia Region (source: Maps from sector plan 46/1)

The surface of the site is occupied as follows:

- About 30 hectares are occupied by buildings, mainly the old factory, the old buildings of the FIBO[1] and the steel mill, as well as administrative and office premises;
- About 50ha are occupied by storage areas, scrap, slag;
- About 30% of the surface is occupied by a green or park area (40ha), located in the south-west of the site of the site.

Since 1853 to until the end of industrial activities at DUFERCO-La Louvière site, the main activity was the manufacturing of iron. The site was undergoing demolition in May 2022. Figure 3 shows all the buildings that have been demolished since the DUFERCO period and the red perimeter presents the area dedicated to the project NWE-REGENERATIS. It can mainly be observed that one of the main buildings of the steel plant has been demolished, the slag mill hall as well as a large part of the buildings of the old plant. It is still planned to demolish some buildings of the steel plant, the area of the agglomeration, the old factory, the brick store of blast furnaces, and several small buildings of the pump room, electrical substations, workshops, etc.

The topography of the site has been heavily reworked, filled in, and leveled so that its surface is relatively flat. The average altitude of the site is around 120 - 125 meters. Examination of the geological map indicates that the major surface formation on the site is represented by the Yprésian (Tertiary) sandy-clay complex of the Carnière Formation. This formation is characterized by very heterogeneous clay, silt and gravel fractions.

[1] *The FIBO hall is occupied by the steel wire manufacturing train from the billets of the COBIL line*

Figure 3 : Map of demolished buildings; green: buildings are already demolished; orange: buildings scheduled for demolition in May 2020

In term of hydrogeology, following water tables can be found:

- A surface water table in the fills, discontinuous, heterogeneous and periodic;
- An alluvial water table near the Thiriau du Luc small river, linekd with its level;
- A water table in the quaternary silts superimposed on the Ypresian aquitard materials;
- A semi-captive and not very exploitable water table in the deep formations of the Houiller (Carboniferous shales with some sandstones). The piezometric level of this deep-water table is expected to be between 20 and 30 meters deep.

The site is not included in the protection perimeter of a sensitive area such as a catchment associated with the public water supply or a protected natural area.

In terms of hydrology, the site is located on the edge of the Canal du Centre and is crossed by a canalized part of the Thiriau du Luc[2].The stream meanders underground through the site and its course is today only perceptible on the ground by the implementation of a few inspection chambers or access stacks. The watercourse reappears on the surface at the level of the elevator n°1 of the Canal du Centre. This watercourse is exposed to the industrial discharges of the DUFERCO - Louvière basin and its quality can be qualified as poor. It is estimated that the discharge from the industrial site into the Thiriau represents 60 to 70% of the stream's flow before its confluence with the Haine river. The qualitative impact of the industry on this surface water is therefore qualified as significant.

4.3 REMICRRAM PHASE 1- FIRST SCANNING OF SITE'S VALORIZATION POTENTIAL: SMART PHOENIX AND SITE SCREENING

A. NWE-MESIS

As part of the first phase of the REMICRRAM methodology, the NWE-MESIS (MEtallurgical Sites Inventory Structure) clearly make the link between the need for standardised data and the REMICRRAM tools. It is an inventory structure containing relevant parameters useful to launch a valorisation/ rehabilitation project following NWE-REGENERATIS methodology.

[2] *The Thiriau du Luc is a 2nd category stream (water mass reference HN02R), it is 13km long and its basin covers an area of 35.3km².*

In practice, in the case of DUFERCO – La Louvière site, filling in the inventory is useful firstly to directly identify important missing information before starting the materials recovery project. Secondly, as the SMART PHOENIX tool is directly included in NWE-MESIS, it allowed to give a first estimation of the recovery potential of the DUFERCO – La Louvière site. The NWE-MESIS filled in with DUFERCO information can be accessed via https://vb.nweurope.eu/media/20588/nwe-mesis-fin.xlsm

B. SMART PHOENIX

Estimating a site's potential for material recovery requires a systematic approach, which start by answering the 16 SMART PHOENIX questions and assign a confidence level for each answer. These questions are designed to gather general information about the site as well as specifics about the deposits. The Figure 4 shows the 16 SMART PHOENIX answers to the questions concerning the DUFERCO – La Louvière site and the deposit that was investigated during the REGENERATIS project.

N°	QUESTIONS	SITE		DEPOSIT 1	
		Answer	Confidence	Answer	Confidence
1	Does the site contain a landfill, deposit or backfill with significant amount of metallic residues (mainly Pb, Cu, Zn and Fe)? ①	Yes	Very high (100%)		
2	Is the site a PMSD*? ①	Yes			
3	Is the site registered in a database? ①	Yes	Very high (100%)		
4	What main kind of residues (from metallurgical origin) are present? ①				
	Slag			Yes	Very high (100%)
	Metal scraps			Yes	↑ please only indicate confidence just above for all types of residues
	Ashes			Yes	
	Dust			Yes	
	Sludges			Yes	
	Refractories			Yes	
	None from the list			No	
5	Estimated total volume of the residues from metallurgical origin (m^3) in the deposit ①			1000000	Very high (100%)
6	Estimated surface occupied by the deposit (m^2) ①			1000000	Very high (100%)
7	Are the residues clearly separated from each other, or mixed? ①			Mixed	Very high (100%)
8	Surface occupied by constructions: ①	50 to 75%	Very high (100%)		
9	Surface occupied by trees: ①	0 to 50%	Very high (100%)		
10	Is there historical data available? ①	Yes	Very high (100%)		
11	Is the site easy to access for trucks and heavy equipment? ①	Easy to access to the site and on the site	Very high (100%)		
12	Is the site considered as hazardous? ①	Moderate risk (usual risk, e.g. moderately hazardous contamination such as heavy metals)	Very high (100%)		
13	Must the site / an area of the site be rehabilitated? ①	Yes, from others aspects (urban planning, biodiversity, etc.)	Very high (100%)		
14	Is there a known interest for the reconversion of the site (public or private projects/interests) ? ①	Yes			
15	Surface occupied by low vegetation: ①	0 to 25%	Very high (100%)		
16	Current use of this surface, regardless of the official use of the deposit ①			Activities still present (industry, use by people, etc.)	Very high (100%)

Figure 4: SMART PHOENIX completed with information from the DUFERCO – La Louvière site for the deposit that is being investigated in the NWE-REGENERATIS project

Once the information and confidence levels for the responses have been filled in, the results are obtained in the form of scores, illustrated in figure 5 for the DUFERCO – La Louvière site. A legend, also shown in figure 5, aim to help you to interpret the scores.

YOUR SCORE:

	DEPOSIT 1		DEPOSIT 2		DEPOSIT 3		DEPOSIT 4		DEPOSIT 5	
	SCORE	RATING (%)	SCORE	RATING (%)	SCORE	RATING (%)	SCORE	RATING (%)	SCORE	RATING (%)
METAL recovery potential score	910	100%								
MINERAL recovery potential score	910	100%								
SOIL improvement (for the growing of ecocatalyst) potential score	100	50%								
ECOCATALYST production potential score	310	78%								
TOTAL SCORE	3895	93%								
CONFIDENCE LEVEL		100%								

WARNING: Make sure your confidence level is high enough in order to ensure your score is meaningful!

	DEPOSIT 1	DEPOSIT 2	DEPOSIT 3	DEPOSIT 4	DEPOSIT 5
number of questions whose confidence is below or equal to 50%	0				
number of questions whose confidence is not indicated	0				

LEGEND : Score above which the site has an interesting recovery potential

Metal	>450
Mineral	>450
Soil	>100
Ecocatalyst	>200

TOTAL SCORE

Bad	0 - 2100
Medium	>2100
Good	>3000

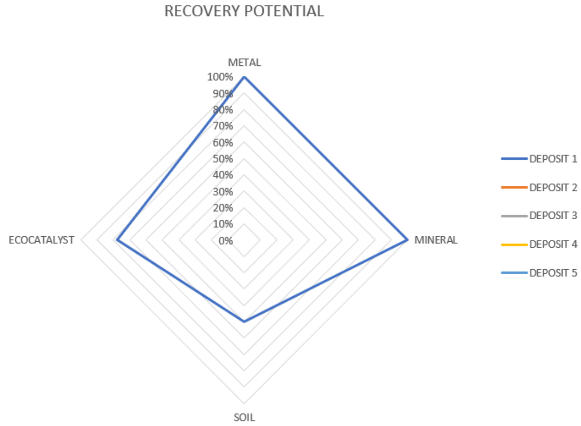

Figure 5 : Scores and graphes obtained after filling in the information for the DUFERCO – La Louvière site for the deposit that is being investigated in the NWE-REGENERATIS project.

The ranking proved to be excellent for the recovery of metals and minerals (100%), which means it is highly relevant to investigate/characterise the deposit in more detail regarding metal/mineral recovery possibilities and thus move to step 2 of the REMICRRAM methodology. On the other hand, it can be seen that the prima facie estimate of the site's fertility is not that optimal (ranking of only 50%, with a score just above the threshold value). Since soil fertility improvement and ecocatalyst production are related parameters, a poor estimate of soil fertility implies a prediction of poor potential for ecocatalyst production. Therefore, it will be impossible to achieve maximum potential for ecocatalyst production if the soil fertility estimate is poor. Thus, it can be infered that the potential of this deposit for ecocatalyst production would not be excellent either, which is indeed the case. Despite the score for ecocatalyst production being above the satisfactory threshold, its ranking is 78%. All ranking for each material recovery category are graphically displayed.

Globally, the analysis of the total scores for each category of material of the DUFERCO – La Louvière site deposit shows that all scores are sufficient to reasonably assign a favorable diagnosis to further investigate the potential of this deposit for material recovery. It is therefore appropriate to proceed to step 2 of the REMICRRAM methodology: the NWE-SMARTX.

4.4 ON-SITE INVESTIGATIONS NEEDED FOR PHASE 2 AND 3 OF REMICRRAM

4.4.1 Design and results of geophysical investigations and lab tests

Before proceeding to phase 2: NWE–SMARTX, in this sub-chapter, we summarize the geophysical investigation of a slag heap from the site of DUFERCO-La Louvière. This sub-chapter will focus on the acquisition strategy, data processing, and geophysical interpretation to illustrate the application of the NWE-REGENERATIS methodology.

The heap (**Erreur ! Source du renvoi introuvable.**6.a) is a pile of white slag deposits accumulated from 1994 to 2012 during the deferrization activities of the site. The slag heap is mainly composed of raw materials and by-products of the iron and steel making activities, although heterogeneous waste is likely to be present (e.g., scrap metal, wood, aluminum ingots, refractories, plastics). The geophysical survey objectives were to (i) image the internal structure of the slag, and (ii) identify deposits of interest according to metallic content.

Due to the steep slopes of the deposit, a quasi 3D ERT and IP acquisition was planned to provide a dense coverage of the whole white slag heap. It is composed of 4 2D profiles containing 64 stainless steel electrodes spaced by 2 m. Data acquisition was carried out simultaneously on combinations of two profiles and inline and crossline measurements were collected to obtain a 3D model of resistivity and chargeability. In the resistivity model, **Erreur ! Source du renvoi introuvable.**6.b, the shallower part of the heap appears more resistive than the bottom. Two resistive anomalies are present at the surface in the center of the heap (in yellow). The chargeability model is more heterogeneous (**Erreur ! Source du renvoi introuvable.**6.c). Most of the heap is characterized by low chargeability values, inferior to 10 mV/V, with high chargeability anomalies (up to 250 mV/V). Finally, the resistive anomalies are consistent with low chargeability zones, while the chargeable anomalies are located in average resistivity areas.

In order to interpret these resistivity and chargeability variations, eight pits have been excavated and samples were collected at three different depths (1, 3 and 5 m), to obtain a total of 24 samples. First, laboratory measurements of ERT, IP, and spectral induced polarization (SIP) were carried out. Then, X-ray fluorescence (XRF) analyses were made on the same samples volumes to obtain the chemical composition. These measurements provide a more complete information of the geophysical properties of the samples and allow to explore the link between chemical composition and geophysical properties. In the correlation studies, we observed that the Fe is correlated with the chargeability (R = 0.67), while Si is related to low chargeability and high resistivity values. Intermediate concentrations of Fe could be linked to intermediate values of chargeability and a broad range of resistivity values. In most of the samples we observed an intermediate to large concentration of Ca, independently of the Fe concentration. Therefore, we identified three groups of residues with different chemical composition: (1 - red) high Fe concentration; (2 – orange) intermediate Fe and Ca concentrations; and (3 – blue) high Si content probably due to the presence of inert waste. Finally, we carried out a probabilistic approach to interpret the ERT and IP inverted models through a classification of the field data in terms of the three identified groups. At the end we obtain the 3D distribution of each cluster within the slag heap or a resource distribution model (RDM), see **Erreur ! Source du renvoi introuvable.**6.d. This RDM enables to locate waste of interest for potential urban mining or for construction purposes and estimate its potential volume. At DUFERCO – La Louvière site , the volume of the high Fe concentrations materials (group 1 in red) is about 45 000 m^3, representing up to 25% of the investigated slag heap.

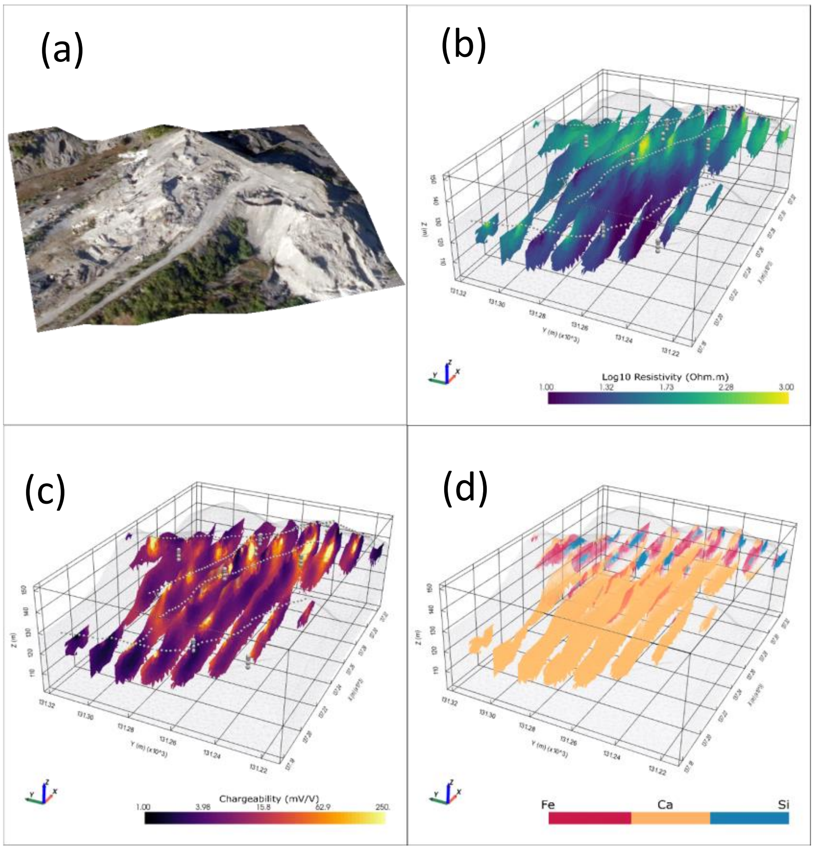

Figure 6 – 3D view of the white slag heap: (a) orthophotography of the deposit; slice of the 3D (b) resistivity model, (c) chargeability model, and (d) RDM. Small and large gray spheres are the positions of the electrodes of the quasi-3D ERT/IP acquisition and the sampling positions respectively.

4.4.2 Pilot test design and results

The slags found on DUFERCO are a potential alternative material to obtain a new material with enough improved geotechnical and engineering properties to build trafficable platforms for roads.

As a first step, the soil stabilization capabilities of fine slag particles were assessed at a laboratory scale. These initial tests have shown that a formulation incorporating both 0.5% quicklime and 10 to 15% of freshly crushed slag of less than 10mm leads to the improvement of the soil-bearing capacity similar to that obtained through treatment with commercial quicklime introduced at a rate of 2%. Thanks to these very encouraging results, the implementation of this protocol was led at a large scale on the DUFERCO site based in La Louvière (Belgium).

A mobile processing unit allowed to treat over 3,000 tons of slag material with the purpose to refine the in-situ conditions treatment and to produce three experimental test slabs.

This pilot test took place in two successive phases:

Phase 1: Recovery of reusable materials such as aggregates and fines from slag (March - April 2023)

The treatment process involved preparing the various fractions (fines, aggregates) using mineral processing techniques (crushing, screening, magnetic separation). Firstly, the 3,000 tons of slag were deferrized and screened to obtain two batches of materials with grain sizes of 0-32 mm and +32 mm. The 0-32mm aggregates were further deferrized before passing through a trommel, which separated them into 3 categories of aggregates: 0-10mm, 10-20mm, and 20-32mm. Products with a particle size of +32mm were sent to a jaw crusher before being screened to obtain the same particle size fractions as before.

Figure 7: Jaw crusher before screening

All of these materials have been stored on the site pending the completion of Phase 2. Table 1 below shows the different masses of the fractions obtained.

Table 1 : Masses of the various fractions obtained

Type	Mass (tons)
Materials subjected to the process	3047
Ferrous metals	57,69
0/10 screening 1	1484,6
10/20 screening 1	342,5
20/32 screening 1	295,4
0/10 crushed + screening 2	198,5
10/20 crushed + screening 2	56,1
20/32 crushed + screening 2	108,9
Non-crushable materials	32,8
Sludge	34,2
Crushed (maximum crusher setting)	192,9

Loss to ground	243

Phase 2: Demonstration that fines can be used to stabilize soils and as sub-bases for aggregates (June 2023).

In order to do this, three test slabs were built on-site. The two former test slabs refer to soil stabilization using the 0-10 mm fraction and the last one to subbase or subgrade 1 road layers realization using the coarser aggregates fractions (10-20 mm + 20-32 mm).

For the first and second test slabs, 90m³ of loamy soil have been spread on the ground and compacted over a total area of 225m² (9m x 25m x 0.4m depth). Before spreading, the soil has been previously mixed and homogenized with binding materials following three different formulations of crushed fine slags (test slab n°1) and screened fine slags (test slab n°2).

Figure 8: The two first test slabs before the final testing

The third test slab concerns road layers obtained by compacting the coarsest fractions. It consists of a 100m² surface composed of a 0.5m-thick layer of slag aggregates. This test slab is obtained by spreading and then compacting a suitable mixture of 10-20mm and 20-32mm aggregates (screened aggregates + crushed and screened aggregates) to comply with the particle size listed in section 4.4.1. of chapter C of Qualiroutes * (area 3 - tests n°19 to 21). In order to ensure enough bearing capacity and to allow a better compaction a little bit amount of the screened 0-10 mm slag fraction has been added.

Results

According to Belgian legislation (Qualiroutes), the test reported in the technical standard applicable for road construction in Belgium and which allows to assess the material performance is the plate loading test CME50.01. The plate bearing tests confirm that depending on the considered grain size fraction the slag can be used either for soil stabilization or for road construction sublayers.

Based on those results, it clearly appears that the screened as well as the ground fractions composing the slag stream can be valorized.

4.5 REMICRRAM PHASE 2: THE USE OF NWE – SMARTX'S DST

As we got high scores in several of the valorization categories mentioned in the SMART PHOENIX and good score for the confidence level, the user can proceed to phase 2 (NWE-SMARTX).

In this phase the user can assess the site's valorization potential with more technical details and identify useful process and methods to be mobilized or investigated for material recovery from the site.

The NWE-SMARTX tool indicates the best valorization processes and treatments to be used for metals and materials recovery in circular economy opportunities. This is based on decision trees and Machine Learning algorithms related to five expert's domains:

- geophysical techniques for potential resources mapping,
- civil engineering methods for raw material excavation,
- mineral processing processes for mineral recovery,
- metallurgical extraction processes for metal recovery,
- eco-catalyst production potential evaluation.

After downloading and installing the software, the user must fill the input parameters (site specification, samples characteristics…) in the tool. When user valid the input parameters, the generated outputs indicate for five available modules (related to five expert domains) recommendations or forecasts for further investigations.

The input data and the results for the mineral module of the DUFERCO – La Louvière site are visible in Figures 9 and 10.

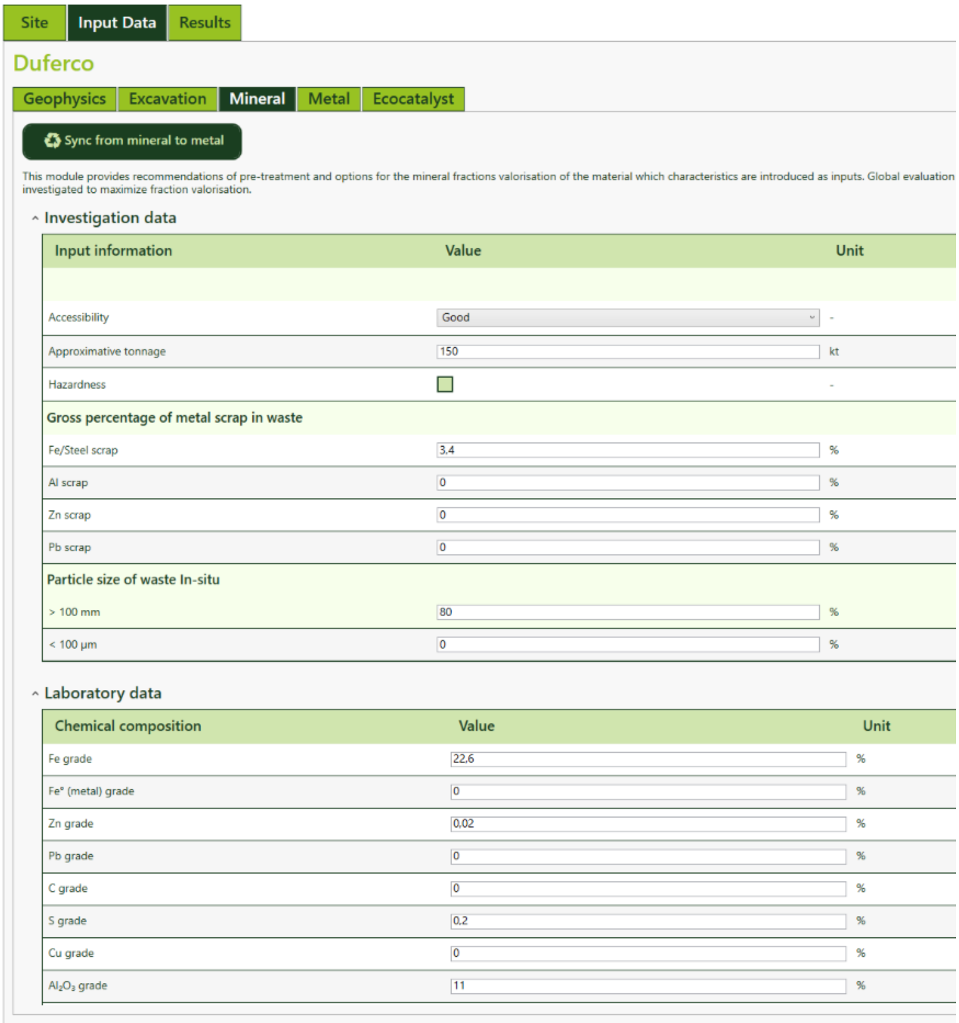

Figure 9: Input datas for the mineral module of the NWE-SMARTX tool for the DUFERCO – La Louvière site laddle slag deposit

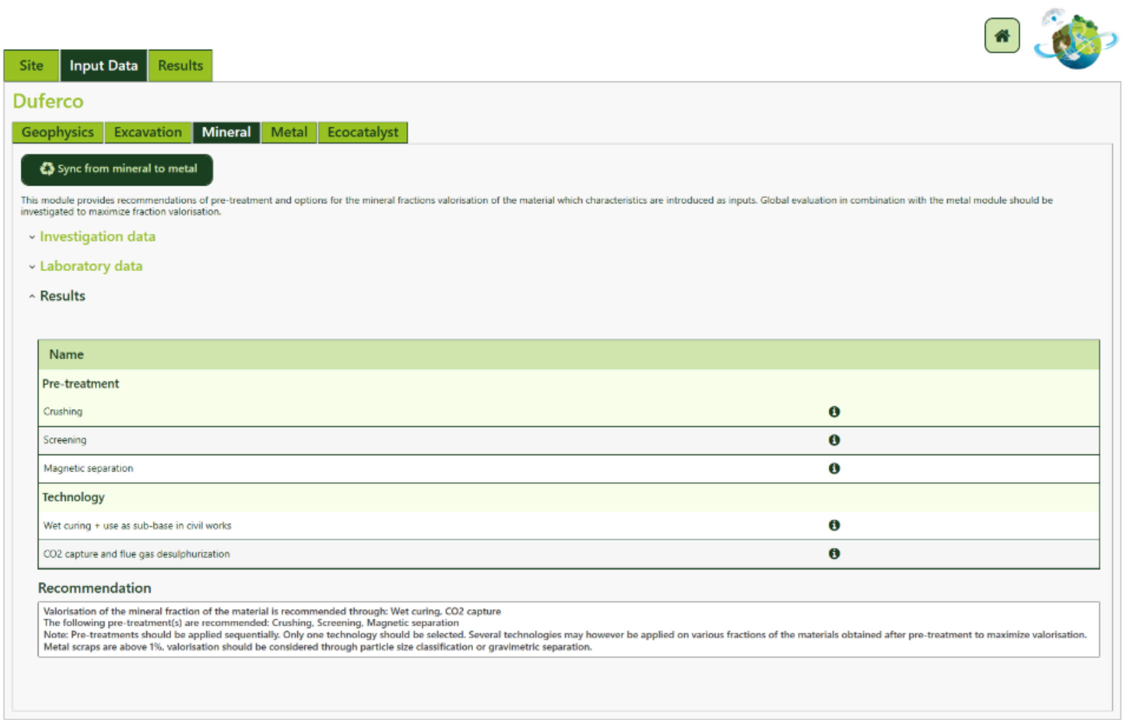

Figure 10: Results of the mineral module of the NWE-SMARTX tool for the DUFERCO – La Louvière site laddle slag deposit

Input data come from investigation and site visit or from laboratory analyses. The values are entered through drop down lists, check boxes or directly into the interface. The results are computed in the Results section by hitting the 'Calculate results' button. They are displayed in a dedicated section or module by module as can be seen in Figure 11.

In this case, based on the Investigation data and Laboratory data, the mineral module recommendations are:

- To valorize the material by using it for CO_2 capture and flue gas desulphurization or as a sub-base material in civil work after wet curing to prevent swelling.
- The recommended preprocessing treatments include crushing, screening, and magnetic separation.

In addition to this mineral module, recommendations from the tool concern what geophysical prospection methods are applicable on site, what civil engineering techniques are adapted for excavation, which metal extraction process should be applied on the materials and residues identified on site, what treatment could be used and what could be the potential of using local ryegrass to synthesize bio-based catalyst.

The full results, as presented in the Results page of the tool, can be seen in Figure 11:

- For geophysics, the recommended methods are ERT and IP which are the ones that were used on site.
- For excavation, the module recommends performing a stability check and warns the user that drainage and water treatment might be necessary. The cost of these operations should then be taken into account in the business case.
- For the eco-catalyst potential, the module estimates the soil fertility and the expected Zn content in ryegrass. Combining those results the production is not recommended in this case due to limited fertility or its profitability should at least be carefully weighted. Onsite experimentation faced predicted fertility issues and valuable eco-catalyst synthesis.
- For metal valorization, several options are available. A report on pilot scale tests is available in report DT2.2.2.
- For the mineral module, several options are available. In the pilot test of the project, the 'wet curing + use as a sub-base material' recommendation was investigated. Results are available in the report I3.3.2 available in the e-library.

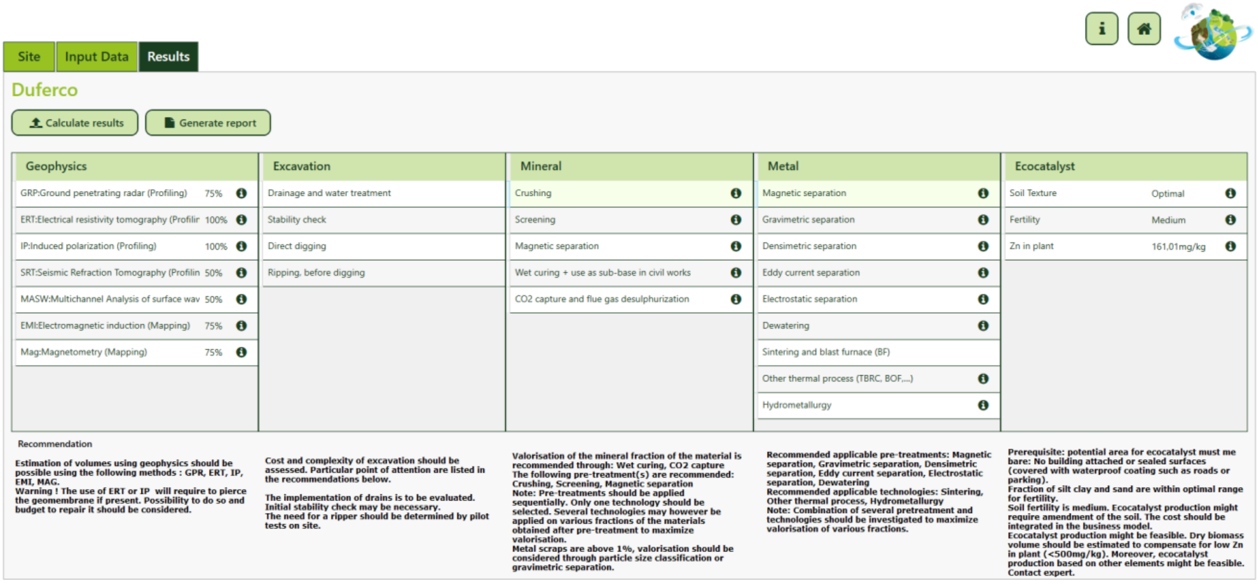

Figure 11 : Results of the NWE-SMARTX

More detailed information on how to use the tool can be found in the NWE-SMARTX guidebook available in the e-library or by clicking the 'Practical guide' in the software. The procedure to improve NWE-SMARTX Machine Learning algorithms training with end-user additional data can be found in the guidebook for NWE-SMARTX calibration improvement available in the e-library.

Based on those recommendations, several scenarios could be applied for the same site. It's up to the user to choose one of them and then to prepare the cost benefits analyses (phase 3).

4.6 REMICRRAM PHASE 3: BUSINESS CASE : COST-BENEFIT ANALYSIS AND SIMULATION

The third phase of REMICRRAM is the business case development phase. The business case tool takes economic considerations into account and calculates costs and benefits to choose the best valorization scenario based on the recoverable material present on site and site's characteristics. All the necessary information to characterize the deposit are collected, a preliminary assessment of recovery potential and processes has already been made using the SMART PHOENIX and NWE-SMARTX. A resource distribution has already been modelled, as well as any other investigations required for the preliminary work and to design the project (including additional survey). All that remains is to calculate woks cost based on the needs and characteristics of DUFERCO-La Louvière site. The earthworks should thus be designed (e.g. the number of shovels needed, the flowsheet, the stockpile management) and the business case tool support you to do that (Figure 12).

The results of the pilot test have been extrapolated to encompass the entire deposit of white ashes, revealing an estimated recovery potential of 381,3480 tons of fine and aggregates slag and 8,439 tons of metal scrap available on the site. Additionally, there is an opportunity to backfill approximately 92,895 m³ of void space. These figures demonstrate the significant quantity of recoverable materials present within the deposit.

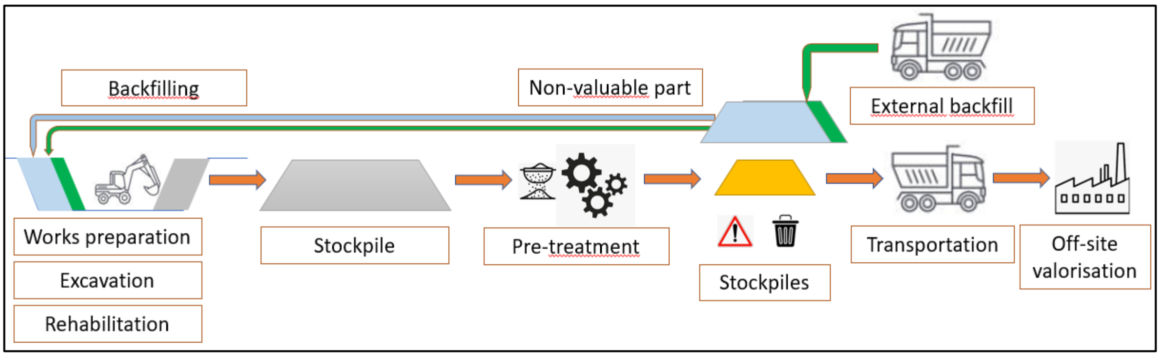

Figure 12 : Earthwork assignment

After calculating the value of the deposit and all the costs for the DUFERCO – La Louvière site's deposits, as described above in figure 12, we obtain the summary table shown in Table 2.

Table 2 : Summary of the cost-benefit analysis for the DUFERCO – La Louvière site

Estimated value of materials [€]	8,753,372
Preliminary studies costs [€]	-115,000
Project studies costs [€]	-145,250
Work costs [€]	-5,413,327
Transportation costs [€]	-1,997,183
Total Net [€]	1,082,612

The valorization of the materials (whites ashes for soil stabilization as lime substitute and subbase subgrade embankment) and the void value (backfill) can lead to a significant profit.

The business case for the material recovery project has demonstrated the potential for valuable resource extraction from the identified site. It's a valuable tool that allows the project manager to test different scenarios and adapt it during the design of the project. It makes it easy to compare different scenario and to make a sensibility analysis of the variation of price of a material. Through careful analysis and evaluation of various factors, including the estimated value of materials, costs of preliminary and project studies, work expenses, and transportation, we have gained insights into the financial viability of the project.

The estimated value of materials presents a promising opportunity for revenue generation, indicating the presence of recoverable resources within the site. However, it is essential to consider the costs associated with preliminary studies, project studies, works, and transportation. These costs play a crucial role in determining the overall financial outcome of the project.

Despite the expenses incurred during the preliminary and project studies, works, and transportation, the net result of the business case demonstrates a positive value. This suggests the potential for a profitable venture in the material recovery sector.

It is important to note that this business case report provides a preliminary assessment of the financial aspects of the material recovery project. Further detailed analysis and evaluation, including environmental considerations, regulatory compliance, and market dynamics, will be required for a comprehensive understanding of the project's feasibility and long-term sustainability.

With proper planning, effective implementation, and ongoing monitoring, the material recovery project holds the promise of not only generating economic returns but also contributing to environmental sustainability by utilizing valuable resources that would otherwise go to waste.

The business case report serves as a foundation for informed decision-making, enabling stakeholders to evaluate the project's potential, assess risks and benefits, and make well-informed investment decisions. By leveraging the estimated value of materials and carefully managing costs, the material recovery project can pave the way for a sustainable and profitable future.

The business case demonstrates that the material recovery project presents an opportunity to transform a previously underutilized site into a valuable resource hub, contributing to economic growth, environmental stewardship, and a circular economy.

5 CONCLUSION

The REMICRRAM innovative methodology was designed to help the stakeholders making economically, socially and environmentally informed decision for the implementation of a valorisation project on a given PMSD. The methodology provides tools for assessing the potential of PMSD for recovering four types of materials (mainly metals and minerals), identifying the best recovery options, and finally carrying out a cost-benefit analysis based on the recovery scenario chosen. The application of this methodology opens up new opportunities for identifying mining strategy options as a solution for site regeneration, and empower stakeholders to harness the potential of urban mining and contribute to a more sustainable and resource-efficient future

The practical case study located in DUFERCO- La Louvière (Wallonia) shows us that the application of the steps of the REMICRRAM methodology to the DUFERCO-La Louvière site would not have been possible without a large number of expert assessments. Historical studies were used to gather information and results relating to the recovery potential of the deposit and the site. Geophysics was used to determine the volume of the deposit at 235,056 m³ (all categories combined), and to determine the ideal sampling location. All this valuable information was collected in NWE-MESIS and used to implement the entire methodology.

In this way, the scores obtained using the SMART PHOENIX tool (in the NWE-MESIS structure) gave a promising signal for moving on to stage 2 of the methodology. Continued use of NWE-SMARTX made it possible to objectify the recovery potential and provide guidelines for the recovery process. The pilot test resulted in the effective recovery of 2,484 tonnes of fine and aggregate slag and 57 tonnes of metal scraps at the DUFERCO-La Louvière site. This quantity, together with the data from the pilot test and other investigations, extrapolated to the scale of the business cases, led to an estimate of 381,3480 tonnes of fine and aggregates slag and 8,439 tonnes of metal scrap that can be recovered on the site. The excellent potential for recovery of the materials means that a net income of €1,082,612 can be estimated for full recovery on the site, while the rehabilitation without valorisation would cost millions of € depending on the selected options.