D T1.4.1 Initial version of the NWE-REGENERATIS methodology - REMICRRAM

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Version 2

SUMMARY

1. Introduction

Europe is highly reliant on other nations in the world in order to satisfy its expanding ferrous and non-ferrous metal needs. Through the (re)mining of currently extant potentially contaminated sites abandoned by the metallurgical industries, some of these metals can be recovered and produced in Europe. Urban mining of Past Metallurgical Sites and Deposits (PMSD) opens up new opportunities for sustainable waste management, land and material recovery, human health protection and environmental risk reduction. Even though the social and environmental benefits of the urban mining projects have been assessed, but stakeholders are still often reluctant to start the projects due to the profitability risks associated with the lack of reliable data.

To facilitate the implementation of this kind of urban mining projects, the NWE-REGENRATIS project focuses on the extraction and revalorization of deposited materials from PMSDs. The project partners have developed an innovative methodology called REMICRRAM (REGENERATIS Methodology for Innovative Circularity to Recover Raw materials from PMSD while regenerating the polluted sites) to support the new circular economy for secondary raw materials recovered from brownfields/PMSDs.

This methodology helps the stakeholders to take the decision “to start or not to start” the valorization project on a given site/a PMSD based on the provision of best valorization options. It also facilitates the stakeholders’ decision by identifying the other drivers (economic, social and environmental).

The objective of REMICRRAM methodology is to encourage and guide those who are interested in the revalorization of PMSDs (e.g. brownfield owners, project managers, local authorities), to fully characterize a PMSD site and its economic potential for the recovery of materials, metals, soil and land. To summarize, NWE-REGENERATIS offers an accurate perspective of a PMSD, which is essential for developing a sustainable development of the project on it.

The REMICRRAM methodology consists of 3 phases:

- Phase 1: A quick screening software, composed by 16 key questions, to evaluate the valorization potential of a site/PMSD for the recovery of materials, metals, soil and land (SMART PHOENIX). In case of high potential (the number of points get is high enough), the user recieve the recommandation to proceed to the next phase;

- Phase 2: A Decision Support Tool (DST) based on artificial intelligence and algorithms to choose the best valorization processes/treatments for materials and metals present on site (SMARTIX);

- Phase 3: Business case : The structure of an evidence based business case in order to facilitate a cost benefits analysis focusing on the efficiency, effectiveness, economic, social and environmental potential of a site-specific urban mining project.

After applying the REMICRRAM methodology, the user decides whether or not to initiate an urban mining project on the site. At this point, the user will have different scenarios for the site valorization. This step helps the user to choose the best valorization option for site/materials by identifying other drivers such as: biodiversity, green energy, ecosystem services, social benefits, economic benefits, environmental revenues, etc.

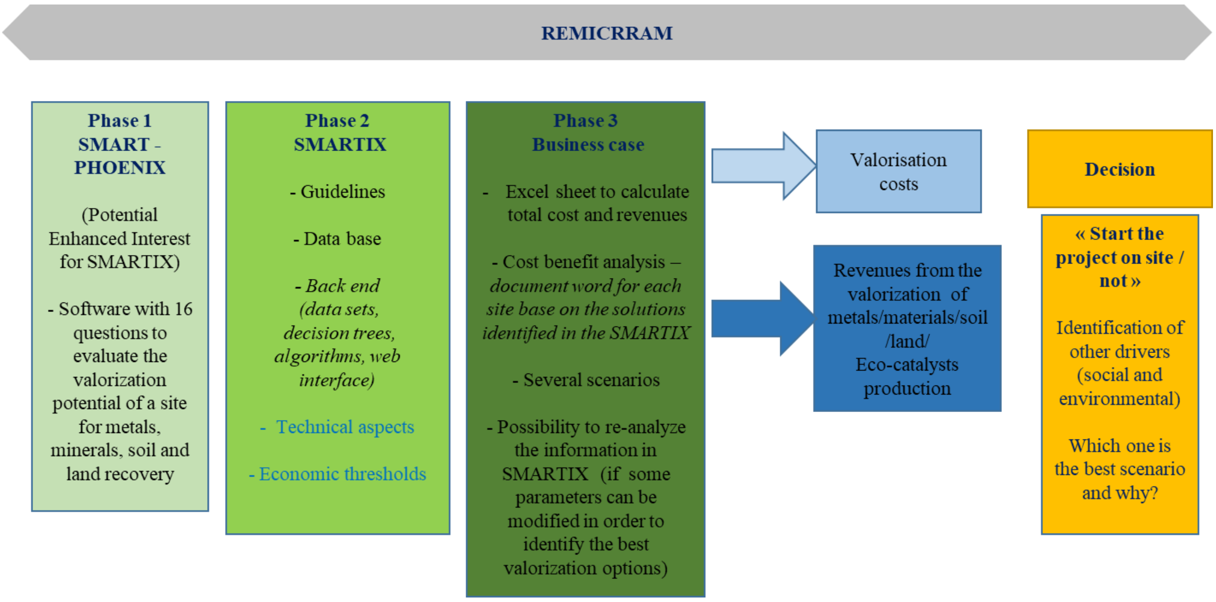

Figure 1: REMICRRAM methodology workflow from a brownfield database to the selection of a profitable urban mining project.

In addition, other tools developed within the framework of NEW-REGENERATIS project are useful for the REMICRRAM, essential for the application of the methodology :

- New methodology and data sets for historical studies;
- Metallurgical Sites Inventory Structure (MESIS);
- Geophysical investigations methods.

At the beginning, the stakeholders should be focused on obtaining reliable data about a given PMSD site to conduct a preliminary study. Existing methodology for historical studies and prelimanary investigation focuses more on environmental and health risks rather than on the assessment of economic and valorization potential of a site and deposits. In order to estimate the economic potential of a PMSD and to encourage urban mining initiatives, the NWE-REGENERATIS project partners have developed a methodology to characterize the contents of PMSDs. This methodology allows to identify the different solutions and to facilitate the implementation of an urban mining project on site. The guidelines for the new methodology to conduct historical studies specially oriented to identify the valuable raw materials were developed under the NWE-REGENERATIS project framework.. In addition to the existing parameters to conduct the historical studies, the NWE-REGENERATIS project introduces other important parameters by focusing on economic evalauation and valorization potential of sites and deposits.

The NWE-REGENERATIS gobal methodology aims to guide whom is interested in brownfiels revalorization (e.g. brownfield owners, project manager, local authorities), to fully characterize a brownfield and its economical potential for waste, land and energy recovery. It also addresses the short term and long term interim use options, when a brownfield is not currently suitable for urban mining for technical reasons (e.g. stability, presence of biogas) or due to the market price for secondary raw material. To summarize, NWE-REGENERATIS offers an accurate perspective of a brownfield, which is essential for developing a sustainable management project on it.

2. REMICRRAM

2.1 Phase 1 – SMART PHOENIX

This open-source tool[1] is destined to allow the stakeholders to evaluate the valorization potential of a site/PMSD. The tool can be applied on one site/PMSD or on several, to prioritize them based on their potential for materials and land reclamation. The user must answer the 16 multiple-choice questions related to the characteristics of a site/PMSD. These questions were selected and designed by considering the user-friendly aspects. Each answer of these questions is associated with the specific scoring system, which gives scores based on the level of confidence of the provided information.

The total scores of these 16 questions determine the best valorization options for a site/PMSD, which are divided into 3 main categories: metal recovery, mineral recovery, soil fertility to produce eco-catalyst. High scores in any of these categories indicate that the site has potential for valorization, and it requires more investigations through phase 2. Low scores indicate that the site has no specific interest and there is no need to investigate it further in phase 2, this happens due to insufficient and unreliable information.

The confidence level of the information filled buy the user in the tool has an impact on the evaluation of the site. If the site get high scores, but with low confidence, the user is invited to re-analyse the situation in order to provide information with high confidence score.

The user can verify/ modify the answers to the questions and see if the new scores recommend to proceed to the phase 2.

An extract of the SMART PHOENIX and a presentation of the tool is attached in the **Annex 1.**

2.2 Phase 2 – SMARTIX

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 (SMARTIX). 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.

SMARTIX[2] is an open-source software, developed with the data from 9 pilot sites of the project located in UK, Belgium and France and additional data from 40 sites. SMARTIX indicates the best valorization processes and treatments for metals and materials based on the decision trees and algorithms related to the civil engineering methods, mineral processing, metallurgical extraction processes and eco-catalyst production on site.

The users must fill the input parameters in the tool and then the outputs are indicated: recommendations about what geophysical prospection method is applicable on site, what civil engineering technics are adapted, what extraction process should be applied based on the materials and residues identified on site, what treatment. 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).

2.3 Phase 3 – Business case

After applying SMARTIX, the user can choose to develop a business case for a specific site based on the recommendations received. The user will have at his/her disposal the structure and examples of the business case[3] . 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 (i.e. how much they will spend and in return how much

[1] There is no need to be an expert to use the SMART PHOENIX tool.
[2] To use the SMARTIX it is recommended to be an expert/have an expert’s assistance.
[3] Available to free download on the NWE-REGENERATIS website.

they could get) 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 evidence-based and transparent decision-making process for the decision-makers, stakeholders, brownfield owners/managers, municipalities, public/private or any other concerned authority to analyze the economic potential of an urban mining project before launching it. In future, it is also planned to provide a cost comparison between the traditional rehabilitation works on polluted sites and REMICRRAM proposed recovery options for the site/materials in this phase.

3. Other tools

3.1 New Methodology and data sets for historical studies

Historical studies for site rehabilitation have been paramount over the years across all regions in the EU and beyond. However, different regions have different legislations and approaches to historical studies. While some have a direct field search approach, most European regions deem source-based historical search essential. However, the historical study guidelines in these regions intended to meet the objectives at the time of their development, hence they are not entirely put into perspective other aspects of making a historical study. Before we zone down some of the North West European regions, we can first take a look at the general EU context about historical studies for contaminated site remediation.

In 2011, the European Environmental Agency (EEA) indicator assessment “progress in management of contaminated sites” proposed four management steps for managing and controlling soil contamination4. The first of these four steps is “site identification, preliminary studies and preliminary or historical investigations”. This goes on to indicate that at the European level all sites are targeted to be kept as clean as possible in so much as they get contaminated, rehabilitative actions need to start with a historical investigation. Prior to this assessment, there had been other directives which aimed at remedying polluted sites and soils such as the 2004 European Environmental Liability with regards to the prevention and remedying of environmental damage (ELD), Directive 2004/35/EC, which operates emphasis on the need for remediation actions on polluted soils.

Drawing from some of these directives and legislations, many EU regions and most NWE regions like Wallonia, Flanders, France, UK and Germany created distinctive guidelines for historical studies. A benchmark of these guidelines was done in the framework of the REGENERATIS project.

All historical study guidelines consulted in this benchmark aim to discover all past activities carried out on site which allows for either a reconstruction of a conceptual model or try to associate these activities to some prospective pollutants that may be present. They all point out the usefulness of documented information about sites and the need to ensure the accuracy of this information. Similarly, parameters of interest that cut across them include the location of site, the type and nature of activity, chronology of these activities on site and the reasons leading to the closure of sites.
Furthermore, it is worth noting that all guidelines from various regions and countries emphasis on the need to do an actual survey on site. For obvious reasons, a survey on a site allows experts to fully observe the situation in reality and match it to information that has already been gathered from their sources. In some instances, one may find that some details as presented on paper may be slightly different or totally absent on site. Hence, in order to conduct a proper historical study, it is imperative to visit the site under review.

On the other hand, it is observed that existing historical study guidelines are more focused on the identification of pollutants, triangulating sites and activities. Over the years these have been the guiding principles for contaminated sites. Heavily polluted sites which come off as very difficult to remediate or manage within the guiding principles are generally left unmanaged and seen to be of little or economic value.

[4] Step 1: site identification; Step 2: preliminary investigations; Step 3: main site investigations and Step 4: implementation of risk reduction measures (EAA, 2011).

Contrary to existing guidelines focusing mostly on pollutant identification, the NWE-REGENERATIS project wishes to consider other and unusual historical information which may be collected, with as ambition the economic exploitation of the site. In the framework of this project, new historical guidelines proposal must be able to assist with making economic use of sites also, especially Past Metallurgical Sites and Deposits (PMSD). The guidelines provided by this project sets out to prove and go further than what existing guidelines achieve on a regular basis. In regard to the NWE-REGENERATIS project, there should be a standardized guide which considers more parameters and information that not only allow experts to have complete historical information about a site, but will also provide adequate information if economically it's interesting to make use of these deposits on site.

Conducting a historical study is a very important step to make decisions about how economically valorise materials extracted from PMSD. Hence, in accordance with the NWE-REGENERATIS project the following structure is proposed. This structure is developed based on the benchmark of historical study guidelines in NWE and on the careful analysis of various key parameters which were selected in consultation with NWE-REGENERATIS project partners and experts. This ensures a well-rounded guideline which is set to identified the valorization potential of the PMSD.

This approach can be done in six steps in order to ensure overall efficiency of the project and that all the various information is well represented in the study. The steps are outlined as follows:

- Step 1 – General PMSD description;
- Step 2 – Legal and administrative procedures;
- Step 3 – Site documentation review ;
- Step 4 – Deposit(s) Investigation(s) for valorization purposes;
- Step 5 – Previous investigation campaigns related to environmental studies;
- Step 6 - Site visit - check list - oriented towards historical survey and infrastructures present on site.

The guidelines and the data sets of historical studies are useful for the SMART PHOENIX and allow the user to have a better comprehension of the site.

3.2. MESIS

MESIS means "MEtallurgical Sites Inventory Structure**".**

Each NWE regions have developed one or more databases of contaminated sites, including PMSDs. These databases can be quite simplified or detailed but focus on human health and environmental risks and issues. The main reason is that it has never been expected to give a second life to the contaminated sites by recovery of metallic streams and other valuable raw materials. The situation is however changing in the current economic situation.

The MESIS harmonized database structure include a bunch of technical and economical parameters oriented to estimate the valorisation potential of the PMSD.

MESIS contains relevant indicators that are helpful to launch a project following NWE-REGENERATIS methodology, regarding historical information, ore and processes, geophysical prospection, sampling, content in valuable metals and materials, ecocatalyst production opportunities, site rehabilitation information…

MESIS is used to describe PMSD not only in terms of environmental and risk issues but focuses on the quality and the quantity of dormant materials lying on them. It complies with sustainability and durability principles and contains physical, chemical, environmental, technical, and social indicators.

This approach is innovative, as no known inventory among these analysed contains such metal and material recovery driven information.

MESIS structure will be proposed in 5 parts:

- PMSD ID Card, gathering administrative information, historical information and site status
- Surroundings and site access,
- Site and deposit geometry,
- Surface information and ecocatalyst opportunities,
- Relevant analysis of metals and materials content.

It will be developed as a spreadsheet, will be linked to the NEW-REGENERATIS open access platform, and presented to emphasize most important indicators first (http://nwe-regeneratis.eu/).

MESIS is helpful:

- To directly identify important missing information that will have to be obtained,
- To feed the SMART PHOENIX go/no go tool,
- To assess feasibility, business plan & business cases for launching profitable projects.

3.3 Site Investigation by using geophysical prospection

This chapter presents a proposed workflow for the use of geophysical survey techniques to characterise PMSD in order to guide their future regeneration. Geophysical survey techniques provide many advantages over traditional "intrusive" studies and should always be considered at the outset of a project when trying to establish the resource potential of an existing PMSD.

Geophysical survey methods may be used to enhance the characterisation of PMSD sites, in terms of the spatial extent/volume and/or the composition/distribution of metallurgical materials across a site. Rather than providing a detailed description of individual techniques (e.g. see benchmark on geophysical investigation report D 1.3.1), this chapter presents a high-level approach for the design of a geophysical survey through the development and subsequent improvement of a conceptual ground model. The final aim of the process described is to construct a Raw Material and Pollution Distribution Model (RAPIDM) which 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.

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), density or stiffness. 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. In addition, geophysical methods are largely non-invasive and 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.

Geophysical surveying can capture much greater information concerning spatial heterogeneity across a site, or vertically, and is more cost effective than point measurements alone (e.g. intrusive boreholes/trenches or point sensors). For example, to identify anomalies of a minimum area of 25 m^2 (at ~1 m depth) with confidence within a site of dimensions 100 * 100 m, using intrusive methods alone would require over 600 trial pits of 1 m^2 to be dug - a significant cost, both financial and in terms of the time/resource required. In comparison, multiple geophysical mapping techniques could be undertaken across the site in a fraction of the time and at vastly reduced costs. Specific areas selected using geophysical imagery could then be 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. The NWE-REGENERATIS proposed workflow to set-up a geophysical survey from the data collection to the interpretation and validation is summarised in Figure2.

Principles on how to use Geophysics

A correct application of a geophysical survey is critical in order to achieve reliable results. First, 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.

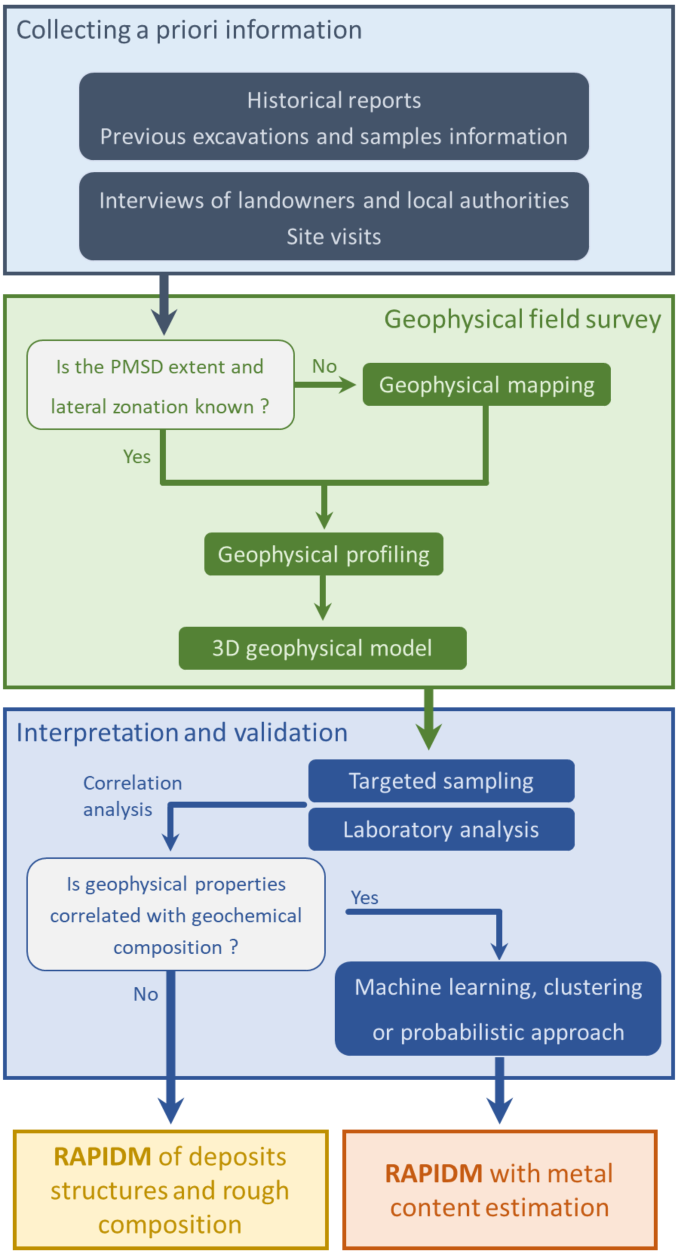

Figure 2: Main steps of the suggested workflow on how to use geophysical techniques to build a RAPIDM.

A geophysical technique 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.

Furthermore, 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. Table 1 gives an overview of possible applications of main near-surface geophysical methods for PMSD characterisation together with the staff required to deploy them, acquisition and processing times. However, the correct choice of methods is site dependent. Therefore, it is crucial to choose the primary geophysical technique(s) and the associated measurement parameters based on a priori knowledge of the site conditions (expected heterogeneities in material properties) and the objective/target of the survey.

Table 1: Suitability of geophysical methods for different applications related to PMSDs study. Abbreviation list: EMI – Electromagnetic induction, MAG – Magnetometry, ERT – Electrical resistivity tomography, IP – Induced Polarization, MASW – Multi-channel analysis of surface waves, SRT – Seismic refraction tomography, GPR – Ground penetrating radar, HVSRN – Horizontal to vertical spectral ratio of noise, SP – Spontaneous potential, GRA – Gravimetry.

		Mapping		Profiling							
		EMI	MAG	ERT	IP	MASW	SRT	GPR	HVSRN	SP	GRA
PMSD structure	Lateral extent	Green	Green	Yellow	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Yellow
	Cover Layer thickness	Yellow	Red	Green	Green	Yellow	Yellow	Green	Yellow	Red	Red
	Vertical extent	Yellow	Yellow	Yellow	Green	Green	Green	Red	Green	Red	Yellow
	Buried utilities	Green	Green	Yellow	Yellow	Red	Red	Green	Red	Yellow	Red
PMSD characterisation	Slag zonation	Green	Green	Green	Green	Green	Yellow	Red	Yellow	Yellow	Green
	Metallic content	Green	Yellow	Green	Green	Red	Red	Red	Red	Red	Yellow
Environmental conditions	Host material	Red	Red	Green	Yellow	Green	Green	Red	Yellow	Red	Yellow
	Groundwater table	Red	Red	Green	Yellow	Yellow	Green	Yellow	Red	Red	Red
Staff required for survey		2	1	2	2	3	3	1	1	2	1
Required time for survey		1	1	2	2	3	3	1	1	2	3
Required time for processing		1	1	2	2	3	3	3	1	2	2

Green: Primary method — Yellow: May be used but not the best method — Red: Unsuited

4. Conclusion

The developement of the REMICRRAM methodology is entirely based on the discussion between different experts (involved in the project) associated with the fields of material recovery, consultancy, civil engineering, academia, biomass production, and artificial intelligence. Each phase of the REMICRRAM is designed based on the real cases studies. This methodology provides transparent and evidence-based scenerios for optimal material, metals, soil and land reclamation. It opens up new pathways to the circular economy with a more sustainable approach while encourging stakeholders to initiate urban mining projects by allowing them to asses the potential of their sites through different prospectives to avoid profitability risks before launching the project on site.

List of weights in the SMART PHOENIX for each 16 questions:

N°	Questions	recovery of minerals	recovery of metals	soil im-provement	ecocatalyst production
1	**Does it contain a landfill, a deposit or a backfill with significant amount of metallic residues (Pb, Cu, Zn, Fe)?**				
	Yes	120	120	0	0
	No	20	20	0	0
2	**Is the site a PMSD?**				
	Yes	200	200	0	200
	No	0	0	0	0
3	**Is the site registered in a database/inventory?**				
	Yes	10	10	0	0
	No	0	0	0	0
4	**What main kind of metallurgical residues (from metallurgical origin) are present?**				
	slags	100	100	0	0
	metal scraps	400	0	0	0
	ashes	0	75	0	0
	dusts	75	75	0	0
	sludges	50	25	0	0
	refractories	0	400	0	0
	None from the list	0	0	0	0
5	**What is the total volume of the residues from metallurgical origin (m3)?**				
	0 to 100 000	0	0	0	0
	100 000 to 500 000	10	10	0	0
	> 500 000	20	20	0	0
6	**What is the site area occupied by residues/ backfill from metallurgical origin (m2)?**				

	0 to 10 000	10	10	10	0
	10 000 to 100 000	10	10	10	20
	> 100 000	10	10	10	20
7	**Are the residues/backfill clearly separated or mixed?**				
	visually separated	20	20	0	0
	mixed	10	10	0	0
8	**what is the surface still occupied by constructions?**				
	0 to 50%	20	20	20	20
	50 to 75%	10	10	10	10
	> 75%	0	0	0	0
9	**What is the surface still occupied by trees?**				
	0 to 50%	20	20	20	20
	50 to 75%	10	10	10	10
	> 75%	0	0	0	0
10	**Is there historical data easily available?**				
	Yes	20	20	20	20
	No	10	10	10	10
11	**Is the site easy to access for trucks and heavy equipments, from a physical point of view?**				
	To the site and on the site	20	20	20	20
	On the site (deposit) but not to the site	10	10	10	10
	to the site but not on the site	10	10	10	10
	not accessible	0	0	0	0
12	**Is the site considered as hazardous?**				
	low risk (no industrial activity identified and no pollution)	20	20	20	20
	moderate risk (usual risk, e.g. moderately hazardous contamination such as heavy metals)	20	20	20	20
	high risk (contamination that requires the use of special measures or equipment, e.g. asbestos, tar, toxic chemical products)	10	10	0	0
	unknown	10	10	0	0
13	**Must the site/an area of the site be rehabilitated/ valorised ?**				
	Yes, from environmental/legal point of view	20	20	10	10

	Yes, from others point of view (urban planning, biodiversity,etc.)	20	20	10	10
	No it musn't	10	10	20	20
14	**Is there a known interest for reconversion of the site (public or private projects/interests)?**				
	Yes	10	10	0	0
	No	0	0	10	10
15	**What is the surface still occupied by low vegetation - grass, bushes (i.e. soil suitable for ecocatalyst)**				
	0 to 25%	0	0	10	10
	25 to 50%	0	0	15	15
	> 50%	0	0	20	20
16	**What is the current use of the area occupied by metallurgical residues (mentionned in the question no. 6)?**				
	Abandoned area, but not protected from environmental point of view	20	20	20	20
	Abandoned area, but protected from environmental point of view	10	10	10	10
	Activities still ongoing (industrial activities, recreational activities, residential area, etc.)	0	0	0	0