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NWE-REGENERATIS
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D. I3.2.4 Site specific dataset for Geophysical Characterization Method

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SUMMARY

1 INTRODUCTION

The following report describes the specific dataset of Duferco that will be used to design and train the module of Geophysical Characterization from SMARTIX. First, we introduce a decision tree composed of a series of questions which has been used to develop this module. Then we present a geophysical dataset representative of the type of industrial waste and raw materials found here. In particular the latter dataset is composed of measurements of electrical resistivity tomography and induced polarization methods- which were the most suitable for the characterization.

1.1 STUDY AREA

The geophysical investigation of this site was focused on the zone of the white slags and the area of the old factory. Nevertheless, based on the geophysical measurements carried out in site and in the laboratory as well as the chemical analyses performed by CTP, in this report we focus on the area of the slag heap (see Figure 1).

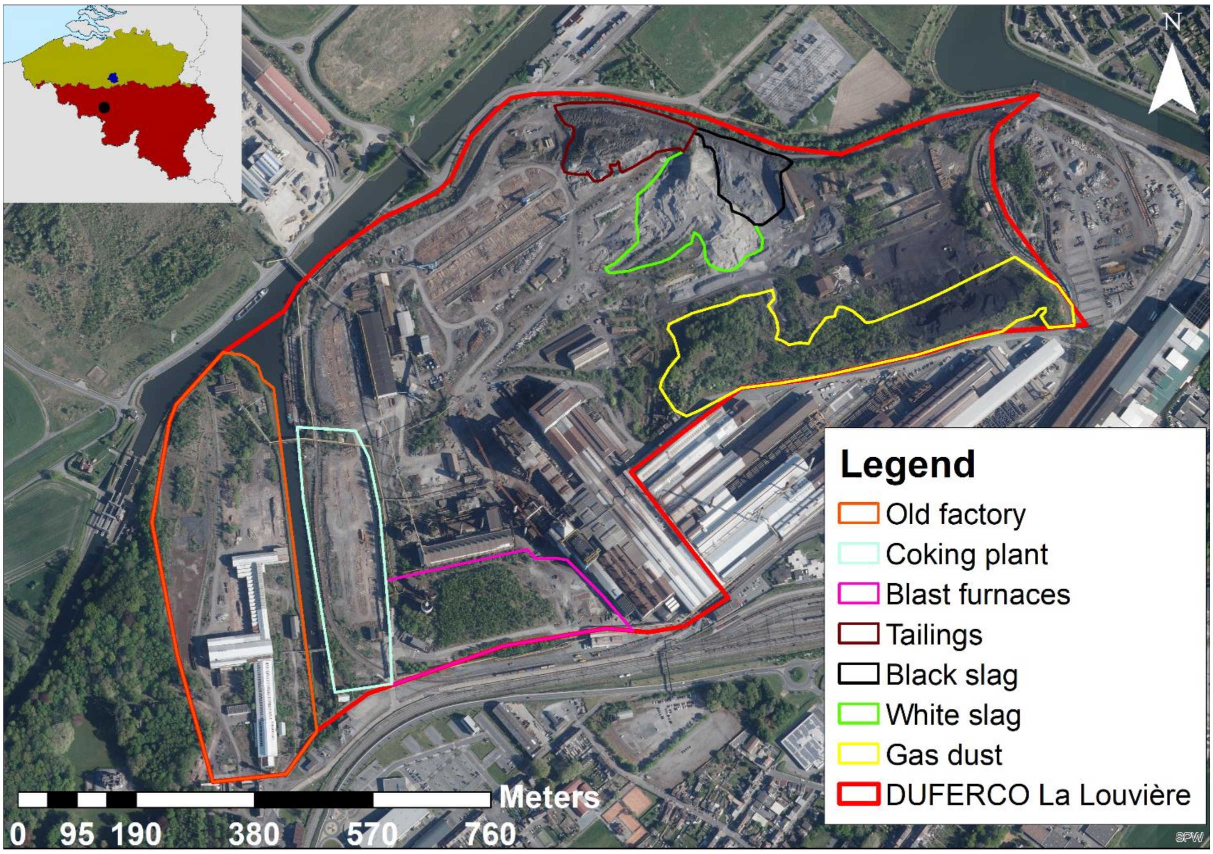

Figure 1: Aerial view of the Duferco - La Louvière site with the delimitation of several potentially interesting areas for NWE-REGENERATIS.

2 Decision tree – Geophysical characterization module

2.1 Description

The main objective of this decision tree is to define, set-up and carry out a geophysical survey in order to estimate the volume(s) of material(s) of interest. Secondary objectives of the decision tree include the potential detection of water table(s), cavities and large concrete blocks. This information would be valuable for the definition of the recovery plan. The inputs of this decision tree are the historical studies and available online data (e.g., remote sensing: aerial images) as well as the information obtained during site visits (i.e., current physical situation of the site).

The header of the diagram defines first the different mapping and profiling geophysical methods which can be used in the field survey. We also introduce the initial Relevance (R) for each method, as a parameter that defines the suitability of using a method according to available information, and which is defined from 0-100 %. The relevance rating of the output is explained in Table 1.

The decision tree is composed of modules which are displayed in numerical order. Each module has a set of questions which are ordered continuously through all modules. Module 1 is oriented to gather and organize information from historical studies of the site and information available online, such as the evolution of aerial images through time. Based on this, the Relevance of each method is updated. The Module 2 aims to update the method's Relevance after site visits where the current physical situation is considered, e.g., level of slopes and vegetation. Based on Module 1 and 2, Module 3 defines whether or not it is possible to estimate volume(s) of deposits of interest using geophysical imaging (together with ground truth data from sampling).

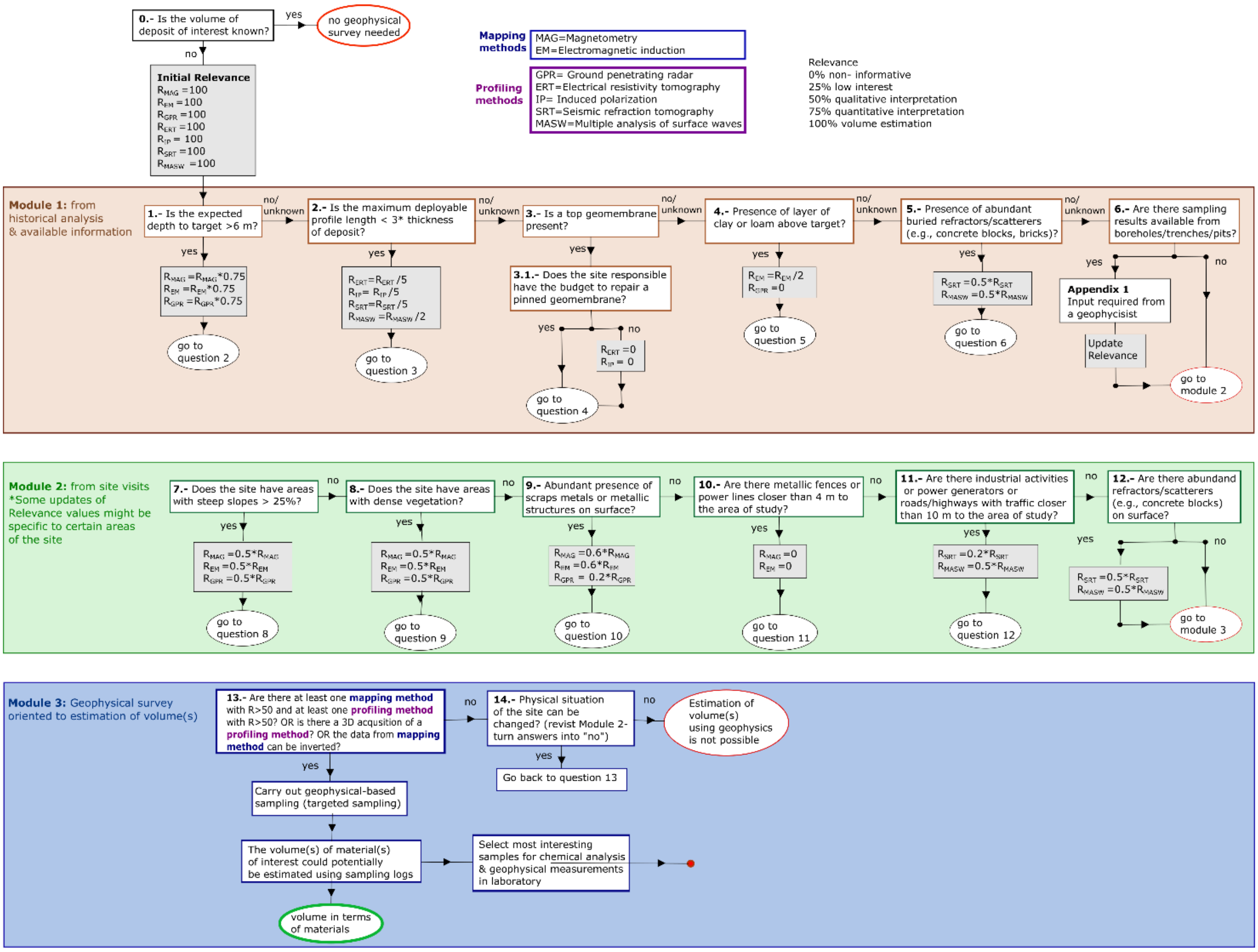

Figure 2: Decision tree for the Geophysical Characterization module

Method Relevance (R)		Description
0%	Non-informative	selected methods may be non-informative or non-applicable to the site
25%	Low interest	0< R≤ 25 % refers to methods of low interest
50%	Qualitative interpretation	if selected methods have a relevance of 25< R≤ 50 % a qualitative interpretation can be developed
75%	Quantitative interpretation	50< R≤ 75 % selected methods can be used to obtain a quantitative interpretation
100%	Volume(s) estimation	if 75< R≤ 100% an estimation of volume(s) is possible

Table 1: Final Relevance (R) rating in selected methods of the output

2.2 Input of the decision tree

In Table 2 we illustrate the information from Duferco site as input in the decision tree. The far right column indicates with 1's and 0's the answers "yes" and "no" respectively.

Questions			Description	Duferco
Module 1 : from available information	Q1	Is the expected depth to target >6m?		1
	Q2	Is the max deployable profile length <5 * thickness of deposit?		0
	Q3	Is a top geomembrane present?		0
	Q4	Presence of layer of clay or loam above target?		0
	Q5	Presence of abundant buried refractors/scatterers?		1
Module 2 : from site visits	Q7	Does the site have areas with steep slopes >25%?	if yes, it might only be in certain areas and not the entire site	0
	Q8	Does the site have areas with dense vegetation?	if yes, it might only be in certain areas and not the entire site	0
	Q9	Abundant presence of scraps metals or metallic structures on surface?		1
	Q10	Are there metallic fences or power lines closer than 4m to the area of study		0
	Q11	Are there industrial activities or power generators or road with traffic closer than 10m to the area of study?		0
	Q12	Are there abundant refractors scatterers?		0

Table 2: Input of decision tree according to Duferco site

2.3 Relevance per method

After answering questions Q1- Q12 the final Relevance obtained per method are the following:

Methods	**Relevance (R)**
GPR	75%
ERT	100%
IP	100%
SRT	25%
MASW	25%
EMI	75%
MAG	75%

Table 3: Final relevance per method as output of decision tree

Therefore according to R, the methods that could have been excluded from the field survey were the seismic refraction tomography (SRT) and the multiple analysis of surface waves (MASW). On the other hand, the methods that could have applied to have a quantitative data interpretation were the ground penetrating radar (GPR), the electromagnetic induction (EMI) and magnetometry (MAG). However in the field survey carried out in 2020, previous to the creation of the decision tree, we used the electrical resistivity tomography (ERT), induced polarization (IP), SRT, MASW and MAG.

After data processing and interpretation of the methods used in the geophysical survey, we concluded that the most useful methods were ERT and IP. The measurements of magnetometry were saturated across most of the slag heap surface and therefore the method was not suited for this site. Lastly, the seismic methods of SRT and MASW were also used in the field but the former targeted very shallow depths while the data from the latter presented high noise level. Both methods were non-informative of the seismic properties of the slag heap.

2.4 Output of the decision tree

Here we describe the main and secondary objectives that were or were not achieved based on the methods used in the geophysical survey (see Table 4). As the ERT and IP acquisition was performed in a 3D protocol, then it was possible to map the lateral and vertical variations of the electrical resistivity (ρ) and the chargeability (*C*) in the slag heap. Therefore, together with the targeted sampling to calibrate the geophysical data with ground truth data, it was possible to develop a quantitative interpretation as well as an estimation of volumes (as lateral and vertical variations were mapped).

Objectives	Achieved?	Description
Coverage of lateral vatiations	Yes	3D ERT and IP acquisition
Coverage of vertical variations	Yes	3D ERT and IP acquisition
Qualitative interpretation	No	From the mapping methods EMI was not applied and MAG was non-informative.
Quantitative interpretation	Yes	Possible with the 3D ERT and IP acquisition + targeted sampling
Estimation of volume(s)	Yes	Volume estimation possible with ERT and IP + targeted sampling + chemical analysis
Identification of cavities	No	Secondary objectives not achieved
Identification of water table(s)	No	

Table 4: Output of objectives achieved and not achieved

3 SITE-SPECIFIC GEOPHYSICAL DATASET

In this section we present the geophysical dataset that we obtained from the ERT and IP measurements in time-domain both in the laboratory and in the field. In particular we present ranges of electrical resistivity (ρ) and chargeability (*C*) values for the slags (industrial waste category) and ranges of chargeability values for three different concentrations of iron. Additionally we present the measurements of spectral induced polarization (SIP) carried out in the laboratory which are representative of the slags.

First, although the slag heap is mainly composed of raw materials and by-products from the iron and steel making activities, inert waste can also be found. Therefore Figure 3 shows the bi-variate Gaussian distributions of the resistivity and the chargeability values measured in the field at the same position of the sampling for the slags and the inert waste. These distributions represent a range of values of both resistivity and chargeability for which we have different probabilities of belonging to slags or inert waste. For instance, the largest probabilities for characterizing the slags are centered at around $\{log_{10}(\rho) = 1.7\ \Omega\mathrm{m}, log_{10}(\mathrm{C}){=}2\ \mathrm{mV/V}\}$ while the highest probabilities of describing the inert waste have slightly smaller values of chargeability and increase resistivities $\{log_{10}(\rho) = 2.1\ \Omega\mathrm{m}, log_{10}(\mathrm{C}){=}1.6\ \mathrm{mV/V}\}$.

Furthermore, measurements in the laboratory indicated a strong linear correlation of R = 0.65 between the chargeability and the iron concentration. Therefore we selected the chargeability measured in the field - at the position of the sampling- and present a range of values for a low, intermediate and high iron (Fe) content. Figure 4 shows the Gaussian distribution of this parameter for the different iron concentrations. Here we can see that the range of *C* values is very similar for high and intermediate concentrations of iron, with probabilities larger than 0.6 for $1.8 < log_{10}(\mathrm{C}) < 2.7$ mV/V. Nevertheless the largest values of C correspond to the highest content of Fe. Finally, materials with the lowest Fe content are more likely to have values of $log_{10}(\mathrm{C}) < 1.8$ mV/V.

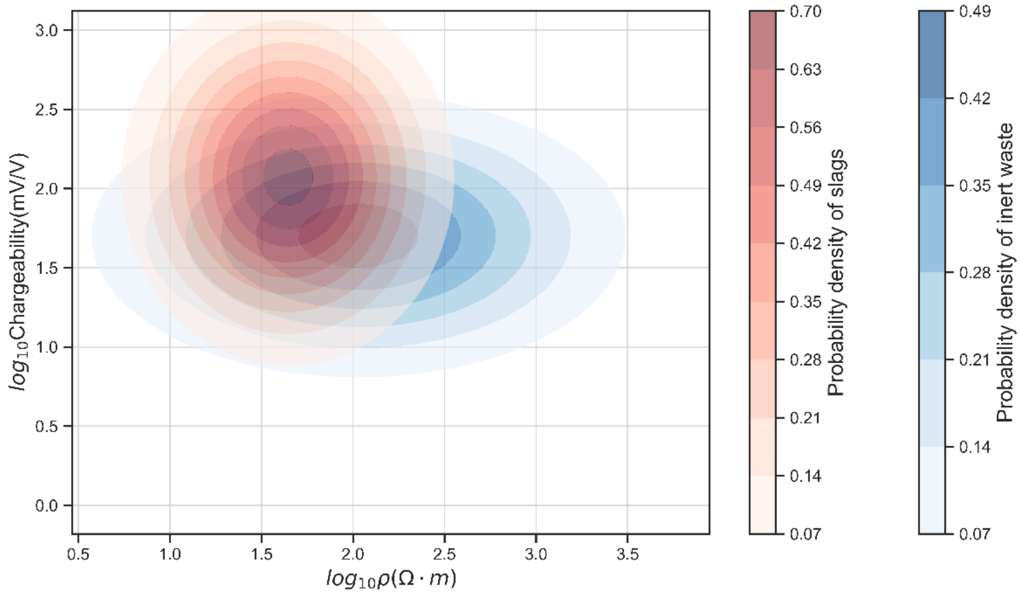

Figure 3: Bivariate Gaussian distributions for the slags (red) and the inert waste (blue) given the resistivity and chargeability field measurements co-located with sampling

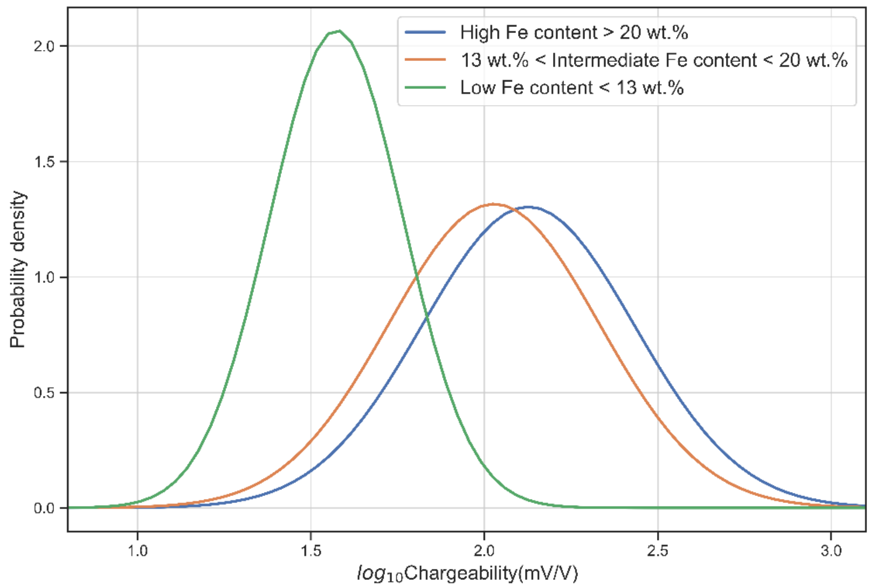

Figure 4: Gaussian distributions of de chargeability field measurements co-located with sampling for a high (blue), intermediate (orange) and low (green) iron content.

The measurements of resistivity and chargeability carried out in the laboratory were conducted using columns of 1.5 dm^3 filled with the material from the samples collected in the field. For more information on the sampling survey see deliverable DI3.2.1. Each sample was measured using a stack = 2 to assess the data quality. Then, CTP conducted the chemical analyses (XRF) using the same volume of material. Finally, Table 5 presents the values of ρ and *C* as well as the average content of Fe and silicon (Si) as an indicator of inert waste.

Sample	ρ (Ωm)	*C* (mV/V)	Fe content (wt. %)	Si content (wt. %)
S1_3	19.37600312	50.89593541	21.7	6.7
S1_5	39.93539979	77.69206871	19	5.8
S2_1	57.28206289	126.2914755	17.5	5.4
S2_3	30.62067778	145.0554763	15.8	5.34
S2_5	41.53269752	139.620227	25.1	5.3
S3_1	33.5451003	35.38003929	14.5	5.8
S3_3	26.29603586	57.85406173	13.3	5
S3_5	24.36167857	55.26721374	19.4	4.9
S4_1	25.10331296	62.26093467	14	4.3
S4_3	73.44582122	29.85296421	13.1	16.5
S4_5	88.49367328	13.17607818	6.7	24.5
S5_3	176.4948079	4.573296107	3.7	29.5
S6_1	38.16507509	148.4770398	18.7	4.5
S6_3	31.32587905	115.4696603	24.2	4.8
S6_5	25.4455168	115.462905	24.8	4.9
S7_1	40.77519528	72.90802101	15.9	6.4
S7_3	48.35144999	59.37758339	18.6	5.9
S7_5	45.74942035	59.98397732	14.5	5.4
S8_1	148.3880936	81.11404726	25.5	6.2
S8_3	43.62270141	87.62366954	22	5.1
S8_5	37.36205639	66.45559514	17	4.9

Table 5: Laboratory measurements of resistivity and chargeability for the samples collected in the field. In the sample's name column, the number after the underscore indicate the depth at which samples were taken.

Finally, SIP is also known as complex resistivity method and it can be seen as an extension of ERT, yet the SIP measurements are performed in frequency-domain and using an alternating current injection. The measurements of SIP showed two different types of spectra for the samples mostly composed of slags (rich in Fe) and the samples mostly composed of inert waste (low Fe content and large Si content). Figure 5 shows the spectra of all samples using a colormap that represents the average Fe content.

Figure 5 shows the plot with the real component of the conductivity σ', the imaginary component of the conductivity σ" in the middle and the phase spectra (Φ) on the bottom. We can note that the intermediate-larger magnitudes of σ' are in agreement with a larger Fe content. The σ" spectra corresponding to samples of intermediate to large Fe content present the same shape (spectra decrease at a frequency of around 1 Hz). Finally in the phase spectra we can observe a peak of maximum amplitude centered at around 1 Hz for all the samples corresponding to slags (not visible for the samples of inert waste). Table 6 shows the magnitudes of SIP spectra for σ', σ" and Φ at the frequency of relaxation (frequency where the maximum magnitude of Φ is observed) together with the Fe average content for all the samples.

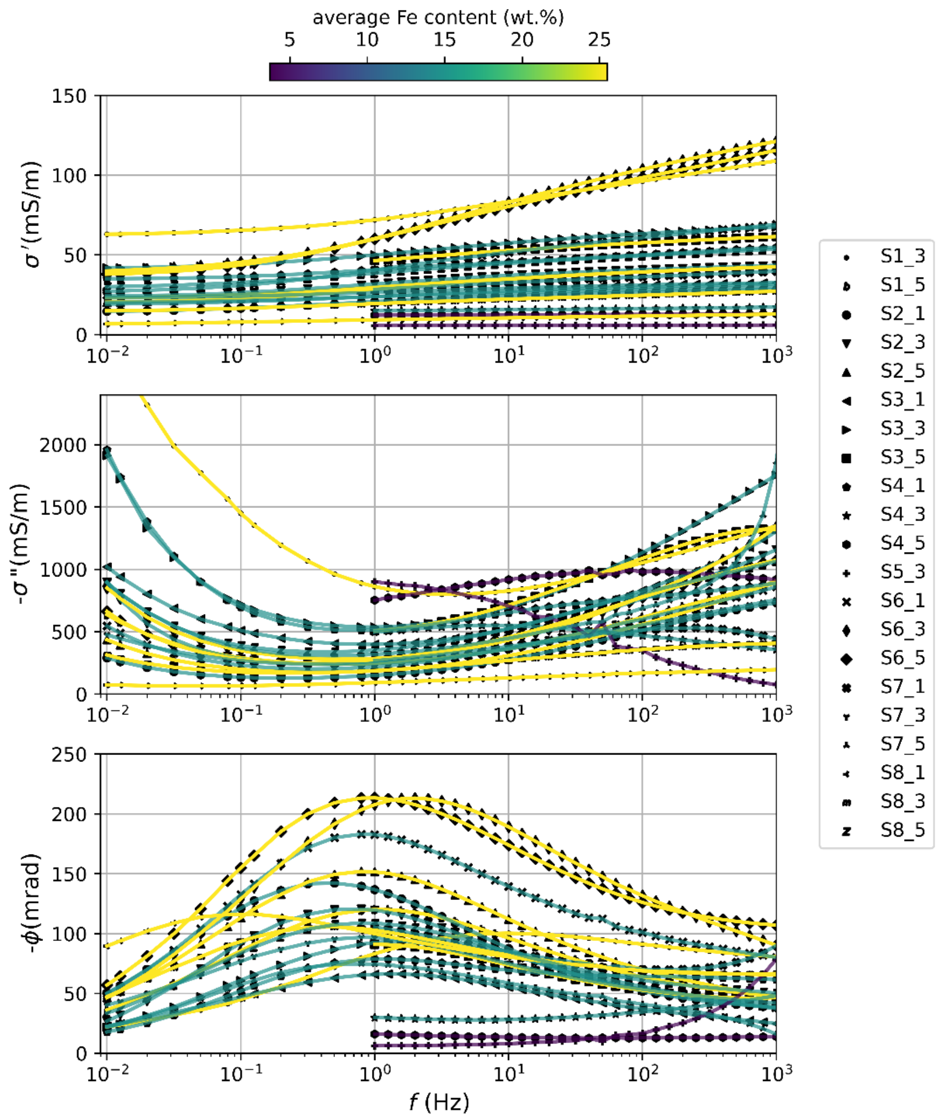

Figure 5: SIP spectra of all the samples together with the iron average content. Intermediate to large Fe content represent the slags and the low concentration of Fe represent the samples mostly composed of inert waste.

Sample	| σ '| (mS/m)	| σ "| (mS/m)	|Φ| (mrad)	Fe content (wt. %)
S1_3	83.36	828.15	100.32	21.7
S1_5	29.75	246.56	120.09	19

S2_1	19.34	135.03	142.25	17.5
S2_3	31.09	256.73	120.54	15.8
S2_5	27.70	180.92	151.96	25.1
S3_1	26.66	401.56	66.314	14.5
S3_3	51.40	546.36	93.812	13.3
S3_5	37.61	525.17	71.504	19.4
S4_1	41.12	521.06	78.759	14
S4_3	14.89	497.08	29.963	13.1
S4_5	12.14	753.37	16.115	6.7
S5_3	5.771	675.74	8.5410	3.7
S6_1	39.33	212.38	183.10	18.7
S6_3	66.71	308.19	213.16	24.2
S6_5	59.89	276.41	213.38	24.8
S7_1	28.32	267.94	105.33	15.9
S7_3	23.47	241.62	96.858	18.6
S7_5	23.49	313.58	74.783	14.5
S8_1	7.985	68.337	116.32	25.5
S8_3	18.48	174.20	105.72	22
S8_5	37.79	345.83	108.85	17

Table 6: Laboratory measurements of SIP spectra. We show the magnitudes of σ', σ'' and Φ at the relaxation frequency which is around 1 Hz for the samples mostly composed of slags.

4 CONCLUSION

In this report we presented the dataset of the slag heap investigated on the site of Duferco. On one hand, this dataset is the information of the site that will be used to design the module of Geophysical Characterization of SMARTIX and on the other hand, the dataset representing the geophysical signature of the type of industrial waste found in site.

For the former we present a decision tree composed of several questions, we tested it using the information from the site and discussed the information from the output. The results we obtained with all the methods applied in this site acted as decision support tool to design the decision tree. Therefore this is not a fixed diagram and may be modified after the experience gained from the investigation of other sites.

For the latter, we used the ERT and IP measurements carried out in the field and in the laboratory as these geoelectric methods proved the most useful to investigate the site. We presented ranges of resistivity and chargeability for the different types of waste found on the heap and also a range of chargeability values found for a low, intermediate and high Fe content in the materials deposited in the heap (field measurements). Furthermore, we also presented the measurements of resistivity and chargeability in time domain as well as SIP, carried out in the lab for the collected samples. Overall the resistivity and chargeability (time domain) parameters and the spectra of for σ', σ'' and Φ, were suitable to distinguish two types of residues deposited in the heap. Additionally the chargeability and the $|\Phi|$ values at the relaxation frequency increase with the iron content.