Report on overall systems dynamics

CHPM2030 Deliverable D2.4

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CHPM2030

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CHPM2030 DELIVERABLE D2.4

REPORT ON OVERALL SYSTEMS DYNAMICS

Summary:
This document provides the establishment of CHPM metadatabes archive, creates the platfrom for system dynamics evaluation and highlights the key factors of the environmental footprint of a forseen CHPM plant.

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Executive summary

This report documents Task 2.4 activities within the CHPM2030 project. Task 2.4 is a key point in the critical path of the project workflow - collecting and managing data from WP1 and WP2, and using this to provide baseline information to WP 3, WP4 and WP5. This is accomplished by the following three tasks:

- Collecting, organizing and archiving data generated during WP2 and identifying data needs or data gaps, that have to be measured to successfully complete successfully complete WP5
- Creating the basic linkages of the CHPM technology elements to establish the foundation for system optimisation (WP4)
- Identify potential environmental impacts (including any emerging phenomena) that have relevance in terms of environmental footprint for the envisioned CHPM plant.

Deliverable 2.4. shall serve as reference document for WP4 and WP5. At the same time, the subsequent WPs creating data and system integration knowledge must contribute to the data archive which is an integral part of this document. For the most efficient data backup, this document (at least some of its annexes) must be considered as a dynamic document, being constantly updated and added to with information generated in the subsequent measurement and analysis WPs.

The digital version of the metadata archive CHPM_DataArchive.xls is an incremental part of Deliverable 2.4.

1 Introduction

1.1 Scope and structure of Work Package 2

The strategic objective of the CHPM2030 project is to develop a novel technological solution (Combined Heat, Power and Metal extraction from ultra-deep ore bodies), which will help increase the attractiveness of renewable geothermal energy and also reducing Europe's dependency on the import of metals and fossil fuels[1].

In the envisioned technology, an Enhanced Geothermal System (EGS) is established within a metal-bearing geological formation at depths of 4 km or more (**Figure 1**), which will be manipulated in a way that the co-production of energy and metals will be possible. The project, at a laboratory scale, intends to prove the concept that the composition and structure of ore bodies have certain characteristics that could be used as an advantage when developing an EGS.

CHPM2030 is organised into several Work Packages, and the results presented in this report fall within Work Package 2. The overall objective of this Work Package is to understand the natural networks of hydraulically-conductive mineral veins that could function as heat-exchange surfaces, and sources of metals. Specific objectives are to: i) develop the tools and methods for orebody EGS reservoir management, and ii) test and validate the methods using simulations and laboratory experiments reaching and exceeding TRL-4.

- In order to achieve these objectives, we will test three hypotheses in this Work Package: That the composition and structure of orebodies have certain advantages that could be used to our advantage when developing an EGS.
- Metals can be leached from the orebodies in high concentrations over a prolonged period of time and may substantially influence the economics of EGS.
- That continuous leaching of metals will increase system performance over time in a controlled way and without having to use high-pressure reservoir stimulation, minimizing potential detrimental impacts of both heat and metal extraction.

Many of the technical activities within Work Package 2 are related to laboratory-scale testing and measurement, and these are implemented through several inter-related Tasks, each with a specific deliverable:

Task 2.1: Concepts and simulations for integrated reservoir management.

Task 2.2: Metal content mobilization using mild leaching.

Task 2.3: Metal content mobilization with nanoparticles.

Task 2.4: Overall systems dynamics and data for environmental assessment.

1.2 Introduction and rationale for Task 2.4.

Task identification

Annex 1 Part A of the Grant Agreement describes task 2.4 as follows: "*Data will be collected throughout the WP for the subsequent assessment of the environmental impacts of the system in WP5. In this subtask we will define the parameters that will need to be measured and collected in order to execute WP5. An additional objective is also to look for and record any emerging phenomena that can have relevance from an environmental footprint point of view, or that could affect the system optimisation and performance (W4). Of particular interest is the fate of leaching fluids, byproducts of chemical reactions, level of self-containment, etc.*"

The role of Task 2.4 in the CHPM2030 workflow

Both the above quoted task description and the actual workflow of the CHPM2030 project necessitates that the following three tasks be completed within this activity:

- Collecting, organizing and archiving data generated during WP2 and identifying data needs or data gaps, that have to be measured to successfully complete WP5
- Creating the basic linkages of the CHPM technology elements to establish the foundation for system optimisation (WP4)
- Identify potential environmental impacts (including any emerging phenomena) that have relevance in terms of environmental footprint for the envisioned CHPM plant.

It became relevant at an early stage of project activities, that Task 2.4 was going to be one of the first key points of the project task flow, due to its harmonizing role for lab activities in WP2 and its underlying role for subsequent analysing WPs.

Also Task 2.4. is the earliest point in the project to make an attempt to link the individual technology elements of the CHPM concept into one coherent framework. The goal of this exercise is far from a comprehensive system integration (please refer to WP4), however our team tried to identify the interfaces between developing building blocks of a potential future CHPM plant, together with the compatibility of its different features.

Deliverable 2.4 shall serve as reference document for WP4 and WP5. At the same time, the subsequent WPs shall create crucial data and system integration knowledge that must be added to the data archive annexed (Annex 3 and 4) to this document. For the most efficient data capture this document (at least some of its annexes) must be considered as a dynamic document, being constantly updated, and added to, with information generated in the subsequent measurement and analysis WPs.

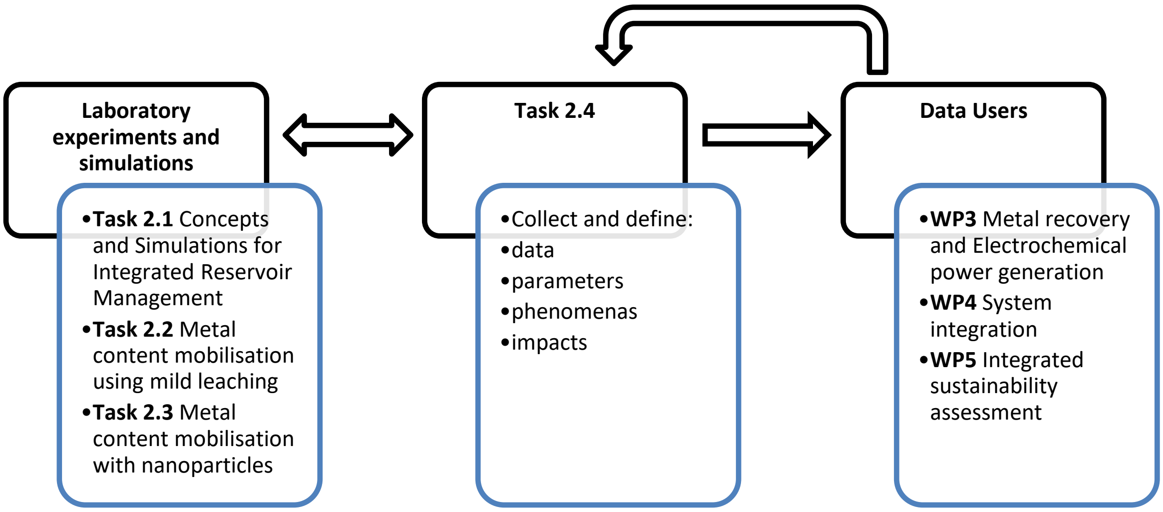


Figure 1. Task 2.4 in the context of the other project tasks, interactions and significance

Several other arguments also support the concept of maintaining this document as open with the possibility of future update:

- certain elements of the technology (especially in relation to metal recovery at the surface) are still in laboratory phase development, and some of the critical design parameters will only be available only in later phase of the project;
- all activities so far were constrained to lab scale work, technology upscaling – which is inevitable for system integration – is still to be completed;
- Some other parameter measurements are still expected to be identified in WP4 and 5 (e.g. some site specific environmental/technical issues), and the system dynamics task might demand corrective action on our dataset and system integration concept.

2 Data supporting system dynamics

2.1 Defining system dynamics

System dynamics uses theoretical and empirical algorithms to describe and explain the behaviour of complex systems, with special focus on its economics, engineering, and environmental impacts. System dynamics methodology provides a framework for analysing how actions and reactions influence each other, and how and why elements and processes in the system change. In this way, it allows interested parties to understand how the system works and to predict how situations might develop over time (Forrester, 1993).

During Task 2.4 exercises the involved partners identified the main technological elements of the CHPM system, began to conceptualise the system's behaviour and identified a set of design parameters for plant operation.

2.2 Defining main elements of the technology

The WP2 team identified 7 distinct technological elements of the proposed CHPM plant, and recommended use of the following names and ID numbers for the single units:

1. Underground heat exchanger
2. Production wells
3. Electrolytic metal recovery
4. Heat exchanger
5. Gas Diffusion electroprecipitation
6. Salt gradient power generation
7. Injection wells

A colour coding was assigned to the conceptualisation of the system (shown in **Figure 2**), and consequent use of these IDs and colours was recommended throughout the following steps.

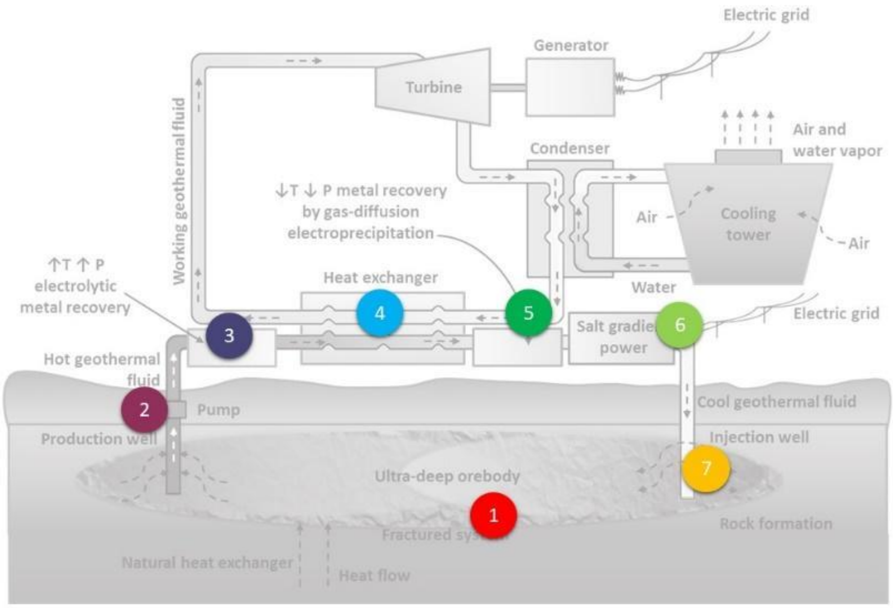


Figure 2. CHPM distinct technology elements (names, IDs and colour codes)

2.3 Design parameters

Design parameters are those critical technical conditions identified for each of the CHPM technological building blocks that must be met for the technology to be operational. The availability of design parameters is not trivial especially for those technology steps that are in the early laboratory testing phase. However, even if lab-scale system are run under well-constrained conditions, it does not necessarily mean that these exact conditions will exist during full-scale operation, or that a full range of these parameters will be known. During the later part of WP2 activities, CHPM partners responsible for technology development provided their inputs as the most important design parameters relevant for the technology elements 1-7 defined above (**Tables 1-7**).

Parameter name and unit	Parameter value	
	min	max
Permeability range flow impedance (MPa/kg/s;)	0,1	-
Hydraulic conductivity (m/s)	1,00E-07	
Well head temperature (°C)	150	
Size/density and distribution of fractures (1/m)	2	-
Heat flow range (mW/m^2)	50	150
Minimum flowrate for operation (m^3/h)	200	
Range of pH and redox potential (-)		
Ratio of fluid loss tolerated (%)	-	20
Volume of the underground heat exchanger (m^3)	2,00E+08	
Heat exchange volume (m^2)	2,00E+06	
Fracture density (1/m)	2	
Lifetimes (year)	30	
Amount of accessable metal (t)		
Pressure (bar)	300	500

Table 1. Design parameters for CHPM technology element 1 – Underground heat exchanger

Parameter name and unit	Parameter value	
	min	max
depth (m)	3000	4500
Discharge, flow rate (m^3/h)	200	-
Well head temperature (°C)	150	
Pressure (bar)	300	400

Table 2. Design parameters for CHPM technology element 2 – Production wells

Parameter name and unit	Parameter value	
	min	max
Flow rate	Part of current research	Part of current research
Metal content of the liquid (ppm)	50	Solubility limit of the metal salt
Presence of multiple phases?	Part of current research	Part of current research
Metal recovery rate (g/h)	Part of current research	Part of current research
Temperature (°C)	20	200
Pressure (Bar)	1	40

Table 3. Design parameters for CHPM technology element 3 – Electrolytic metal recovery

Parameter name and unit	Parameter value	
	min	max
Temperature (°C)	120	-
Flow rate (L/s)	350	-
Salinity (ppm)		
Metal content (ppm)		
Usable amount of heat (ΔT); (°C)	60	
Pressure (bar)	1	40

Table 4. Design parameters for CHPM technology element 4 – Heat exchanger

Parameter name and unit	Parameter value	
	min	max
pH	-	Depends on the precipitation pH of the metal to be removed; The buffering capacity is important
Metal composition (mg/L)	rpm range	g/L range
Temperature (°C)	5	70
Pressure (bar)	1	3
Electrolyte conductivity	Equivalent to brackish waters	Equivalent to brines with 150 g/L NaCl

Table 5. Design parameters for CHPM technology element 5 – Gas Diffusion electroprecipitation

Parameter name and unit	Parameter value	
	min	max
Temperature (°C)	20	60
Flow rate (m^3/h)	50	-
salinity (g/L)	30	-
Metal content	-	Part of research program
Secondary Water circle demand	Same as flow rate geothermal brine	-
Secondary water salinity (M)	0,02	-
Pressure (bar)	1	3

Table 6. Design parameters for CHPM technology element 6 – Salt gradient power generation

Parameter name and unit	Parameter value	
	min	max
Temperature	90	150
Flow rate		
Depth		
Pressure (bar)	500	600

Table 7. Design parameters for CHPM technology element 7 – Injection well

Design parameters provide useful information on the operability of the single CHPM technology building blocks, however by comparing them one can retrieve the first hints on a crucial question of the CHPM innovation undertaking, namely the compatibility of these elements. The CHPM2030 project promises a technology to be framed together from engineered concepts that have never been connected into a system before. Task 2.4. creates the basic setting for system optimization, which starts to identify interfaces between system elements.

As seen above, some technology development steps still require the finalisation of design parameters, however based on the two most critical system dynamics parameters (T; P) the compatibility of the technology loop can analysed. **Figure 3** shows the change of viable temperature ranges between each technology element. The bars illustrate the tolerable temperature ranges for the single technology steps, while the black lines delineate an approximate scenario range for the operation. Thus,where the shift of temperature range between neighbouring elements is positive, the system might require energy input, which needs consideration with regards the feasibility of the technology. Based on the available information the most dramatic temperature drop is observed between elements 4 and 5, where withdrawal of excess heat might be necessary. This issue must be analysed in more detail for the reinjection well (element 7), as higher temperatures would be desirable for optimal reinjection performance.

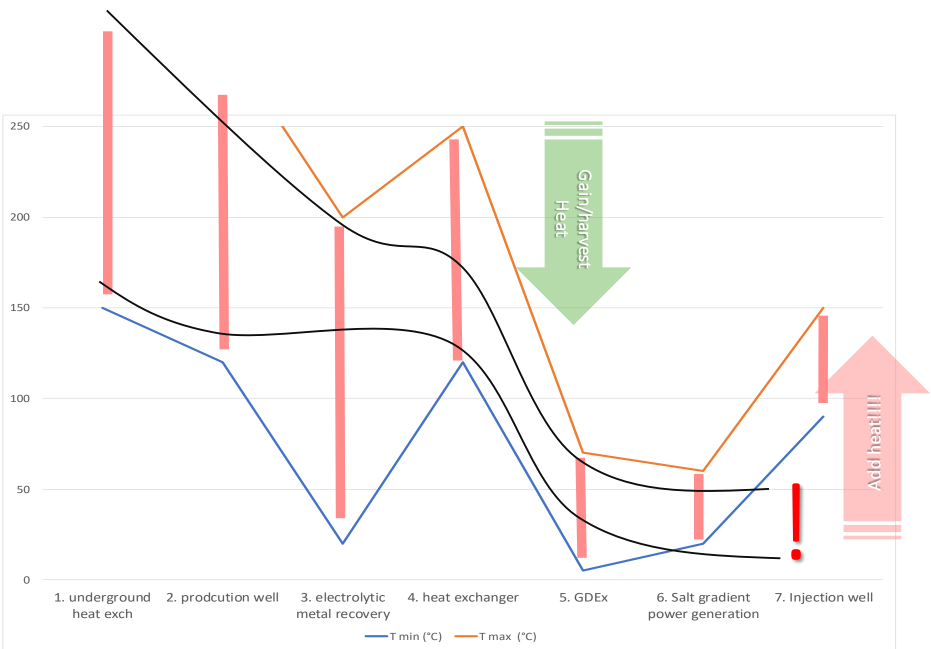


Figure 3. The change of critical temperature range (°C) throughout the CHPM technology loop

Similarly **Figure 4** shows the connectivity of tolerable pressure ranges along the CHPM loop, though note that some estimated design parameters had to be used in the analysis. In this case the major question is not the technical feasibility, but rather the pressure zones of the system and its impacts on factors such as saturation of leaching fluids, plus clogging and scaling of dissolved metals along the loop.

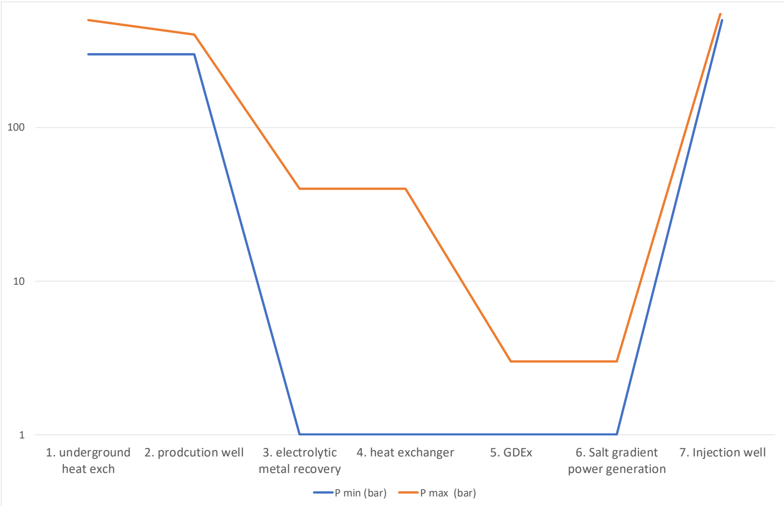


Figure 4. The change of critical pressure range (bar) throughout the CHPM technology loop

3 Data archive and metadata

3.1 Purpose of the metadata archive

One objective of Task2.4 is data collection throughout WP1-2 (and WP3), which can be achieved by creating uniform database with the most important features of different types of measurements during the project. The main requirement for such a database is to organize the key information from lab experiments, but it is also needed to be easily handled, and should be dynamic in such a sense that it accommodates adding newly generated data types in a later phase of the project. It is also expected that each partner can have access to the scope and structure of the generated data and can use them for his/her own research tasks.

It is not the goal of the data archive however, to collect and archive all lab measurement data and their details – as agreed by the consortium. Each partner is responsible for the orderly and safe maintenance of the generated project data. It is our goal to provide the necessary metadata (link to the data holder) and the key features of previously accomplished lab measurements for parties both inside and outside the CHPM2030 consortium.

Data are generated in the project at least for three reasons. There is a major task throughout project activities to quantify environmental impacts of any future CHPM plant (referred to as: enviro dataset), while other data give insights to system integration (deign parameters dataset) and economic aspects of the operation (economy dataset). This later one is beyond the scope of the deliverable presented in this report (**Figure 5**).

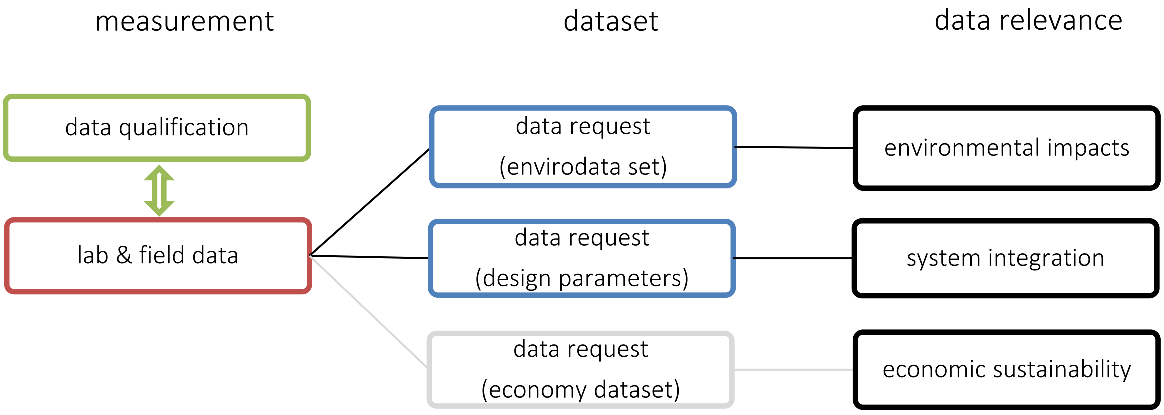


Figure 5. Ideal data structure chart during the project

A summary table of rock samples being studied in the project was created during WP1. It contains all the important information from samples, their individual identification numbers, sampling site, sample type, borehole depth, mass, etc., which were circulated among the partners to facilitate rock sample tracking and follow up. It is reasonable that this table is also an integrated part of the data archive compiled in D2.4.

Two google forms were prepared to collect information about lab measurements performed during the project (WP1 and WP2). Google form is a very effective way of collecting information from the partners and also easy to evaluate its results.

The first form is called 'CHPM Lab experiment Metadatabase', which contains the basic information on measurements, especially the type of parameters that were measured by the partners during the lab experiments. The second one is called 'Data attribute table', which focuses on the features and attributes of measured parameters. The two forms were filled in by the project partners who performed lab experiments, and UNIM being the responsible partner for Task 2.4 did the follow up work to compile the database.

3.2 Methodology and elements of the metadata archive

The 'CHPM Lab experiment Metadatabase'provides information on each type of lab experiment completed by the partners. The different types of measurements can be separated based on either the type of equipment used (e.g. the triaxial and uniaxial compressive strength measurements can be handled separately), or the type of measurement (e.g. leaching test is handled as one type regardless of the equipment used). Furthermore, in some cases the same type of measurement was done by two partners – measurements termed 'leaching test' were conducted by both USZ and the BGS -, but in this case, the purposes and measured parameters were significantly different, as is clear by looking at the tables.

Annex 1 of this document contains the google form of the project metadatabase, and it is an incremental part of this deliverable in both printed and digital form.

The 'Data attribute table' is completed by each measured parameter separately within each type of lab measurement. Data were provided by responsible project partners, UNIM as partner leading Task 2.4. evaluated, summarized and did follow up data quality check on the database.

Annex 2 of this document contains the google form of Data attribute table of the CHPM project, and it is an incremental part of this deliverable in both printed and digital form.

Elements of the CHPM2030 project 'Lab experiment Metadatabase'

The purpose of this google form (see **Annex 1**) is to collect and organize key data from laboratory experiments and the measured parameters during the CHPM2030 project activity. The google form questionnaire contained the following records:

1. *Responsible Partner* (type: multiple choice) Partners who performed lab measurements up to M24 are *BGS, VITO, USZ, UNIM, Ku Leuven.* VITO and Ku Leuven shall contribute their data in M36 of the project after the closure of WP3.
2. *Type/Name of lab experiment* (type: short answer)
3. *Work Package* (type: multiple choice) The following work packages contained lab experiments: *WP1.3, WP2.1, WP2.2, WP2.3.*
4. *Person responsible for lab experiment (name, email)* (type: paragraph)
5. *Data confidentiality* (type: multiple choice) Basic information about all the lab measurements conducted during CHPM2030 project is *public*, but among some key measured parameters, or any specifications for particular equipment can have *confidential* aspects
6. *Data accessibility* (type: multiple choice) Data accessibility means the accessibility of results of the measurements. Data can be *non-available*, uploaded to *CHPM google drive*, or can be available through *contacting responsible person*.
7. *Purpose of the measurement (give brief description)* (type: paragraph)
8. *Used equipment(s) (give specification, parameters)* (type: paragraph)
9. *Other specification of the test (if necessary)* (type: paragraph) This point can contain specification, like special circumstances of the test (applied pressure and temperature), the type and concentration of leaching fluids, sampling periods, etc.
10. *Sample ID(s) (list all measured sample)* (type: paragraph) Samples, tested in the project, are numbered. Sample's ID, types and properties are summarized in a database (CHPM_rock_samples_followup.xlsx), which can be found in the drive (CHPM\Work Packages). Partners were asked to use and list the tested samples' ID consequently.
11. *Sample type* (type: check boxes) For lab experiments samples can be used in *granulate, powder*, or *core*, or *thin section* format.
12. *Sample preparation (describe if relevant)* (type: paragraph) Sample preparation can include sieving, coating, polishing etc.
13. *Measured parameters (list all measured parameters detected during the experiment)* (type: paragraph) The partners were asked to list recorded parameters during the lab experiment, because these are the main outputs of the measurements.

Elements of Data attribute table

The purpose of this google form (see **Annex 2**) was to gather all parameter features that are necessary for environmental, technical feasibility or economic sustainability analysis of the CHPM concept.

The following records contribute to the Data attribute database:

1. *Contributing Partner* (type: multiple choice) Partners who performed lab measurements up to M24 are *BGS, VITO, USZ, UNIM, Ku Leuven.* VITO and Ku Leuven shall contribute before M36.
2. *Name and unit of the parameter* (type: short answer) The Data attribute table should be filled for each parameters which was measured during one type of experiment. For chemical composition data it is considered unnecessary to list all elements separately. Chemical composition means major and trace elements in standard SI units, and other physical parameters like TDS, EC, pH, ORP.
3. *The lab experiment in which the parameter was measured* (type: short answer)
4. *The range of measured parameter* (type: short answer)
5. *Technology element relevance* (type: check boxes) All the technological elements of the system were listed, all relevant element could be selected.
6. *Parameter relevance* (type: check boxes) Three possible areas were identified where recording, or monitoring the parameters can have importance: *environmental impact*, *system feasibility* and *economic feasibility*. More options can be chosen, because several parameters can be relevant even in all the three cases.
7. *Confidence in measurement* (type: multiple choice) There can be parameters even in laboratory scale, which cannot be *directly measured*. *Indirectly measured* means when a parameter is derived from another directly measured data. *Estimated data* could occur when the technology will be upscaled into site-scale dimension.
8. *Technology lifecycle relevance* (type: check boxes) In a geothermal power plant lifecycle four main phases can be determined: *site investigation, installation & test operation, operation,* and *post operation/monitoring*.
9. *Time dependency* (type: multiple choice) Time dependency means that the measured parameters can change over time in site scale. Thus measurements performed at a lab scale can be upscaled to an operational scale. It is not required to specify here, that this time dependency can happen spontaneously or directly during the investigation, installation or operation phases.
10. *Spatial variability* (type: multiple choice) Measured parameters can also change in spatial extent at site-scale.

3.3 Results and evaluation of the metadata archive

After the partners filled the forms, the answers were summarized in tables automatically by google, which were downloaded. Some modification, data quality checking, editing and formatting activities were needed.

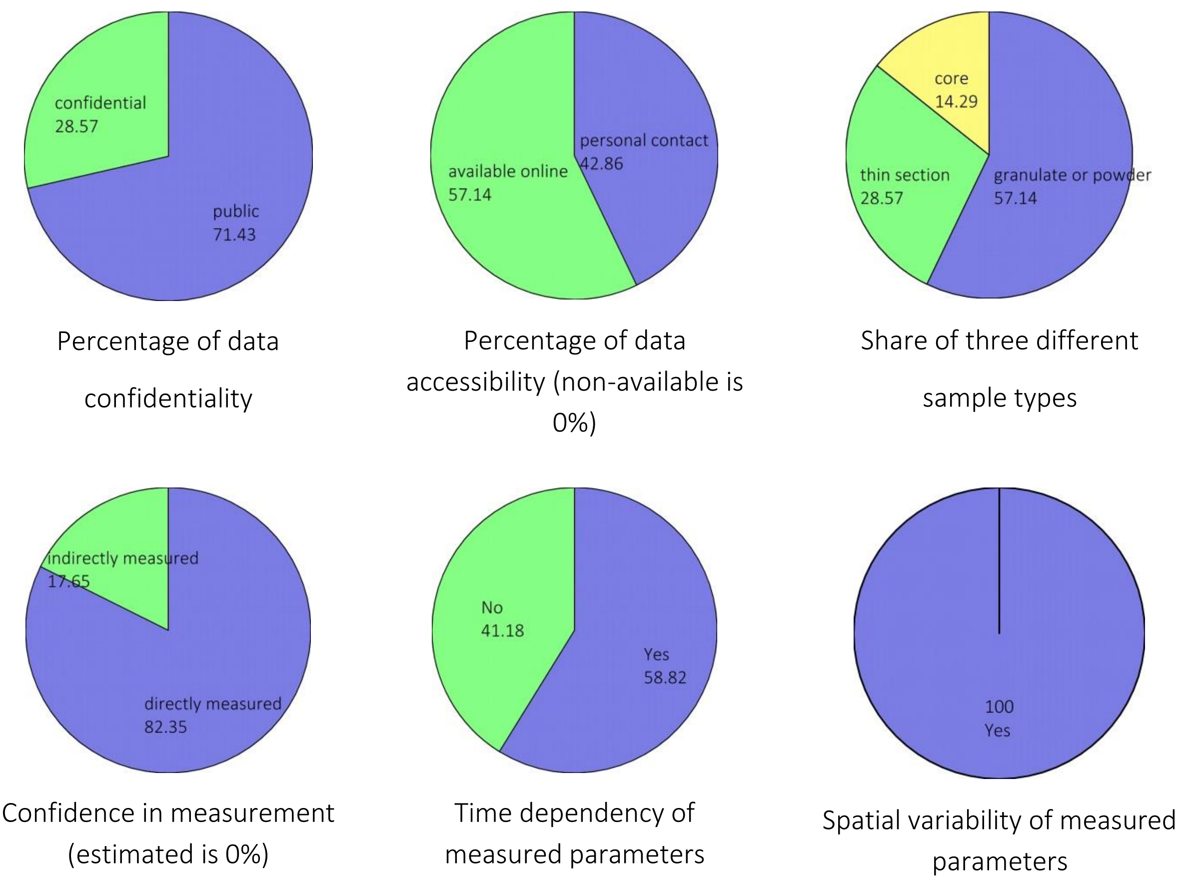
Annex 3 contains the current CHPM2030 metadatabase entries as submission of this deliverable. The data in this annex are an incremental part of Deliverable 2.4, being a result achieved during Task 2.4. activities.

Annex 4 contains the CHPM2030 data attribute table entries as a submission of this deliverable. As per Annex 3, the data in this annex are an incremental part of Deliverable 2.4, being a result achieved during Task 2.4. activities.

The digital version of the metadata archive was created using Microsoft Excel. This metadata archive contains three spreadsheets:

- Sheet 1: Samples (CHPM2030 rock sample ID, data and sample tracking information)
- Sheet 2: Lab experiments (parameters measured in lab experiments by partners)
- Sheet 3: Data attribute (key features and attributes of the parameters measured)

The CHPM_DataArchive.xls file is an incremental part of Deliverable 2.4 by containing and archiving all metadata in relation to the CHPM lab activities. The file is accessible on the google drive of the CHPM2030 project.



Percentage of data confidentiality

Percentage of data accessibility (non-available is 0%)

Share of three different sample types

Confidence in measurement (estimated is 0%)

Time dependency of measured parameters

Spatial variability of measured parameters

Figure 6. Analysis of parameter attribute data, as reported by project partners

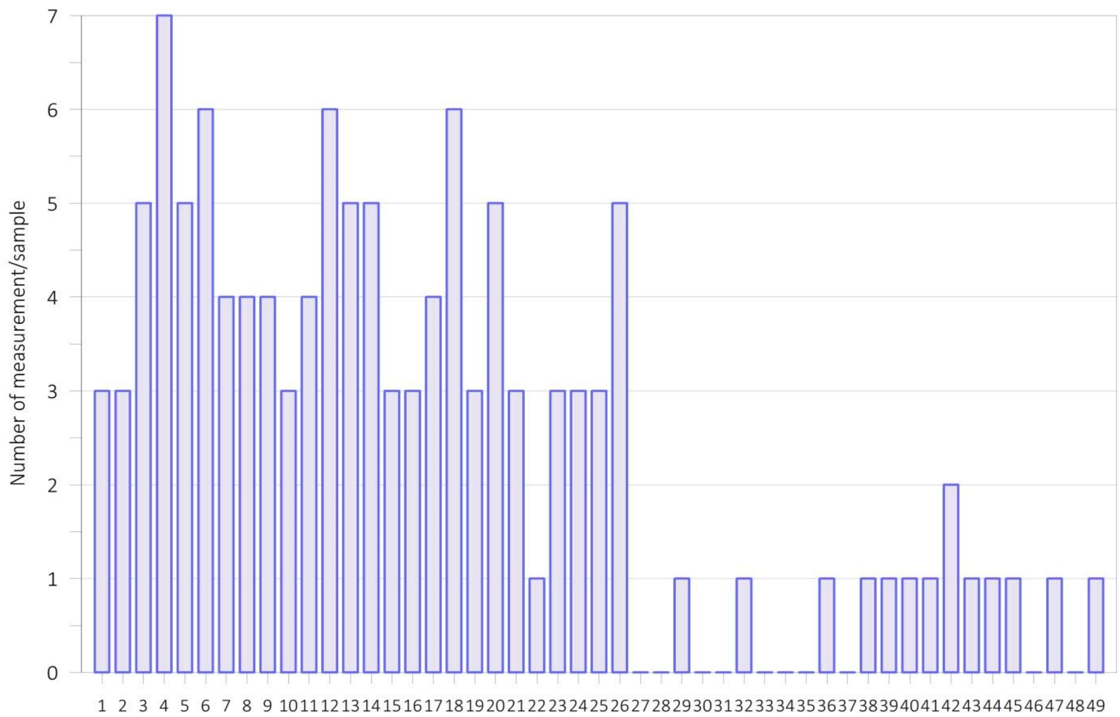


Figure 7. Tested samples with the number of different measurements (sample IDs on x axis, number of different measurements on y axis)

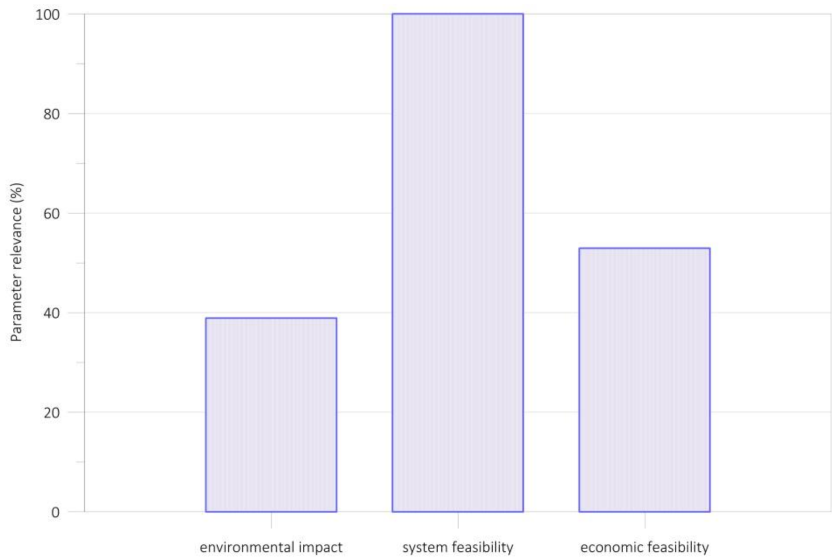


Figure 8. Parameter relevance

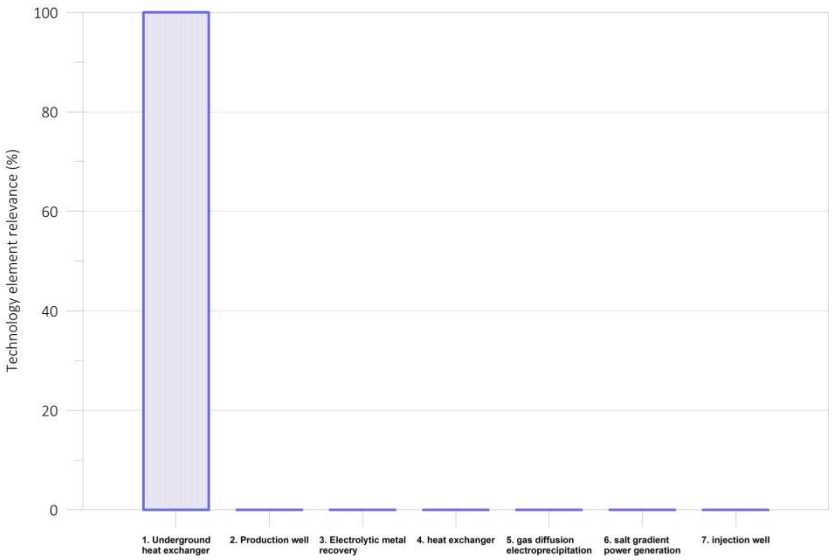


Figure 9. Technology element relevance

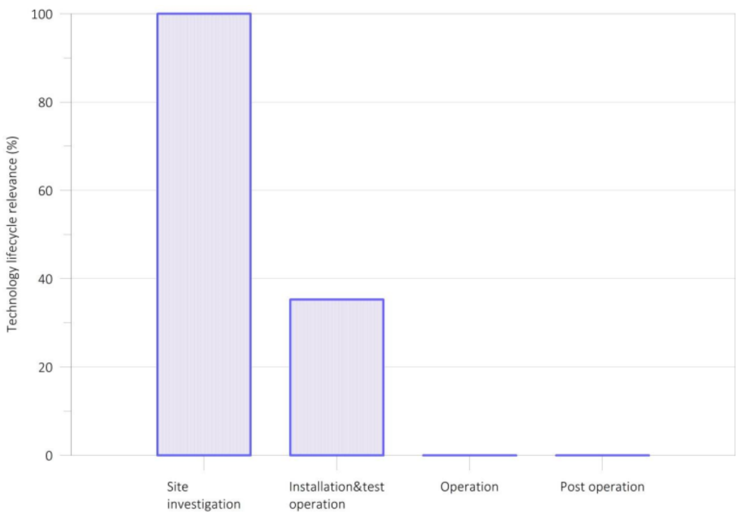


Figure 10. Technology lifecycle relevance

Some of the most important features of data generated during WP 2 are as follows (see **Figure 6-10**).

- Partners claim confidentiality to some (almost 30%) of their lab measurement data.
- Almost 60% of data (not just metadata) is available on the project google drive, a bit more than 40% is accessible only by contacting the relevant partners.
- Almost 60% of lab measurements were done on granular or powdered samples, less than 30% on thin sections and almost 15% on cores.
- 82% of parameter quantifications were classified as direct measurements by partners, 18% as indirect measurements.
- 55% of the measured parameters were qualified as time dependent parameters and all of them are evaluated as space dependent data.
- Partners evaluated that all of their parameters have relevance to system dynamics, 40% of them has environmental and 50% has economic feasibility relevance.

- In case of the technological elements of the system, partners assigned all of their data to the underground heat exchanger.
- The lab experiments of WP1-2 are typically fit to the site investigation phase, because they focus on type, mineral and chemical composition, strength of rock samples, and soluble metal content by different leaching fluids.
- When the CHPM plant lifecycle was outlined, partners believe that the relevance of their measurements is mainly related to site investigation and somewhat to installation, but not to the operation of the plant.

3.4 Metadata archive follow up

As stated before, the metadata archive of the CHPM2030 project will best serve its purpose if it contains information (metadata and parameter features) on all data generated during the project. Therefore, subsequent WP data (especially that of WP3) must be incorporated into the database.

WP4-6 shall be beneficiaries of this effort to provide as wide a knowledge on the data as possible.

4 Data for environmental impact assessment

4.1 Potential impacts and related parameters

EGS technology is considered as one of a prospective environmentally sound technology, that is capable of energy production with minor environmental footprint. CHPM technology aims to enhance the economic feasibility of EGS by high added value raw material production, with much lower environmental impact than any conventional raw material encrichment activities. The CHPM concept is dedicated to incorporate in its technological loop, only environmentally benign materials/technologies and well established monitoiring protocols. To achieve that goal one of our first step is to take into consideration all potential environmental impacts – in the broades possible sense -, that must be investigated, minimized or elimintated by the time of full scale operation is reached.

In order to define which parameters must be recorded to trae and quantify the environmental impacts of CHPM technology, first the potential impacts have to be identified. Detailed evaluation of environmental impact assessment shall be completed in later phases of the project (Task 5.4, as highlighted in GA Annex 1). However a brief summary of the potential environmental impacts based on literature and preliminary studies can be given.

When summarizing the environmental risks, two kinds of theoretical approach can be followed:

- The first approach is to define impacts of a common EGS technology and add potential impacts of metal recovery. The schematic figure of the combined environmental impacts is presented in **Figure 11.**
- The second approach uses the theory of system integration, where each technological element is defined. There are common potential impacts of the whole CHPM system, but there can also be technology element specific impacts and risks. This approach is visualized in **Figure 12**.

Each of these is described in more detail below.

For the first of these approaches, a schematic figure of the combined environmental impacts is presented in **Figure 11.**

The potential environmental impacts that should be considered the following:

- Thermal pollution (on the surface and underground)
- Surface impact and disturbance (including land use, visual impact, noises from surface plant)
- Generated solid wastes
- Generated liquid wastes
- Well integrity failure
- Microseismic activity
- Underground fluid loss
- Natural radioactivity (which can only cause health risk if concentration of radioactive elements get high enough, and the additional environmental problem (and financial problem) of small amount of NORM – Naturally Occuring Radioactive Material)

There have been are several studies and specific projects about Enhanced Geothermal Systems, which give detail information on the environmental footprint of this type of geothermal energy recovery (see references). For example the risk of natural radioactivity can occur in a traditional EGS. Another example is the possible relatively short-term excessive water demand of the technology which can be necessary during several stages of development and operation of an EGS system (drilling, stimulation and operating the reservoir, as cooling water, etc.). At the same time, additional water may be needed for the technology element of salt gradient power generation, where a second water circle is used. Fluid loss underground might also have an additional potential impact such as through induced changes in deep fluid flow patterns, or through mobilisation of metals. It is dependent on the type and chemical composition of the leaching fluid.

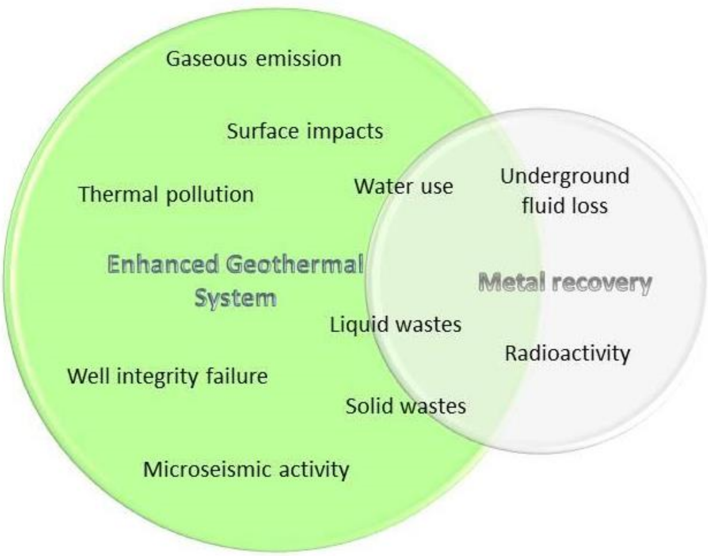


Figure 11. Potential environmental impacts of CHPM based on combination of EGS and metal recovery

The second approach for the identification of environmental impacts comes from the theory of system integration where each technological element is defined. There are common potential impacts of the

whole CHPM system, but there can also be technology element-specific impacts and risks. This approach is visualized in **Figure 12**.

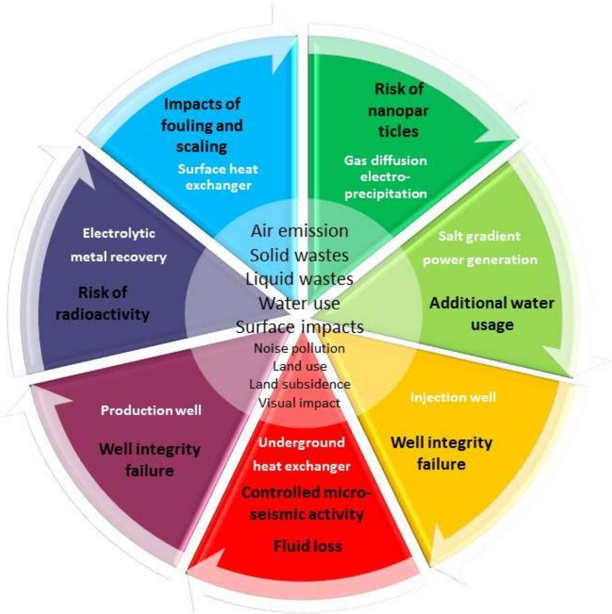


Figure 12. Potential environmental impacts of CHPM based on technological elements

In **Table 8**. we give a preliminary list of parameters assigned to each area of potential environmental impact. It lists those parameters which could be measured to understand how the system is behaving, and could be controlled over the scope and magnitude of the environmental and health impact of the operation.

Impact	Parameter	Comments
Gaseous emission	Humidity	Water vapour content of emitted gas phases
	Particulate matter concentrations	M/L^3
	Temperature	^oC
	Chemical composition	Most important gas content: NO_x, SO_2 , CO_2 , H_2S, Mercury (Hg), Total organic gases (TOG): methane, ethane, propane, benzene etc., Ammonia (NH_3), Boron, Radon
Other Surface impacts	Noise pollution	dB
	Land use	L^2/MW
	Land subsidence	L/T
Solid wastes	Amount	M/T
	Composition	M/M
	Radioactivity	Bq/M (qualification of wastes based on activity concentration)
Liquid wastes	Amount	L^3/T
	Composition	M/M^3
	Radioactivity	Bq/M (qualification of wastes based on activity concentration)

	Temperature	°C
	pH, conductivity, redox potential	
Impacts of Underground Heat exchanger	Induced seismicity	space, time and magnitude information of microseismic events
	Thermal pollution	space, time information of underground temperature
	Fluid loss (%)	The amount of lost fluid between injection and production point of the technology (along the wells, and underground) has two impacts: (1) Contaminated water release to the underground environment, secondly the lost amount of the leaching fluid must be replaced from a water source, which can have environmental and also cost issues
	Fluid parameters	see at liquid waste
	Fracture characteristics	density (L^{-1}), fracture aperture (L), space distribution
	Hydraulic conductivity	L/T
Impacts of Surface technological elements	Additional water usage	Second water-circle of salt gradient power generation measured in L^3/T
	Fouling	The presence of H_2S, NH_4^+ in condensed steam may facilitate microbe growth and cause bio-fouling in condensers and cooling towers.
	Scaling and erosion	Silica (SiO_2), calcium carbonate ($CaCO_3$) or iron (Fe) in geothermal brines creates a potential for both formation of mineral scales and erosion of the injection system, injection wells and heat exchangers.
	Leakage	Hydrocarbon-based working fluids used in binary geothermal plants, pose a risk of fire or air pollution, in the event of a leak.
	Risk of nanoparticles	
Impacts of failures in Well integrity		Including: higher risk of corrosion, risk for loss of well control, risk of casing collapse, fluid loss, solid and liquid wastes generated during scaling removal. Well integrity: „Application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well." (NORSOK D-010 standard, August 2004, used in petroleum industry, but it can be accepted based on recommendation of GeoWell) project)

M: unit of mass; L: unit of length; T: unit of time, °C – celsius, W – Watt, Bq – Becquerel, dB - decibel

Table 8. Enviro dataset - parameters of monitoring environmental impacts of CHPM technology

4.2 Link between lab measurements and the potential environmental impacts

In the WP2 phase of the project all the lab experiments focus on the underground heat exchanger, so a linkage between the lab measured parameters and the envirodataset can be realized only for this technological element. Parameters that were measured and can have relevance in environmental impacts are the following:

- temperature: it must be measured to know the magnitude of thermal pollution of the environment for different parts of the system. In lab scale this parameter was arbitrarily determined and kept constant during the leaching tests.
- pressure: changes of pressure during the technological phases can cause precipitation, chemical changes in the working fluid, failures etc., which all can have minor consequenses to the surface plant and the environment. In lab experiments pressure is also kept constant during the leaching tests.
- chemical composition of the leaching fluid: from environmental point of view it will determine which chemical elements can occur in the liquid wastes of the system, or can threaten environment in the unlikely event of fluid loss. In lab scale it was tested which type of leaching fluid is the most effective for metal solution.
- chemical composition of the rock samples: it will determine which elements can be dissolved, i.e. can be released into the environment because of fluid loss, failures etc. In lab measurements chemical composition of rock samples was determined to know the soluble metal content and the also the modifications after leaching tests.

5 Emerging phenomena

At the current state of CHPM2030 project implementation some of the technical and environmental phenomena are well understood and described, while others are either under investigation, or even are considered as issues to be addressed later during the project or even later in a post-implementation period. Some of these issues are foreseen site-specific phenomena, that should be planned for or managed during plant operation. In this subchapter we give the list of those potential emerging phenomena that the consortium or later technology implementers will face.

<u>Keeping dissolved metals in solution</u>

One of the earliest critical comments against the CHPM idea related to increasing the amount of dissolved content in the geothermal brine. It is a well known experience that geothermal well operators struggle with continuous operational challenges related to clogging and scaling. Further increasing the dissolved metal content might create more complex problems.

Mineralogical analyses after leaching indicated that sulphide mineral dissolution (copper, lead, zinc phases) occurred during the tests, however re-precipitation of these metal was observed close to the sites of active mineral dissolution. This indicates the re-precipitation of leached compounds may occur in the formation, even before the fluid reaching the production well .

<u>Leaching fluid – operation compatibility</u>

The CHPM2030 consortium is committed to develop technology with the possible smallest environmental footprint. For this reason we have chosen to investigate the use of mild or relatively environmentally benign leaching agents, for example organic acids. If we move to more acidic leaching

fluids, that might increase metal productivity, but could have a negative impact in terms of corrosion of production well and surface equipment. High concentrations of Cl^- also enhance corrosion. In case of high dissolved solids, the high TDS (or above mineral saturation as temperatures drop) there is a risk of scaling in the production well and the surface technology elements.

The full CHPM plant operation can be influenced by microbial processes causing some operational problems. Biofouling during reinjection or in the lower temperature ranges of the surface facilities microbiological activity can be a factor in effectiveness of plant.

Leaching radioactive material

The CHPM technology users shall very likely dissolve and circulate naturally radioactive materials during the operation. In many targeted ore formations it is inevitable that the operators shall have to deal with safety and health issues related to radioactivity in their facility and/or handling naturally radioactive scales and waters throughout their operation.

Change of fluid chemistry – multiphase operation

In the process of screening potential leaching agents the possibility of changing fluid composition was raised. By doing so the dominant processes achieved by the fluid (heat transfer, enlarging fractures, metal specific dissolving, etc.) can be changed in time. Changing the composition of the recirculating fluid after a period of time can be used to mobilise some initially-precipitated metals, and produce a 'pulse' of suitably metal-enriched water (i.e. periodic enhanced release of certain metals [e.g. silver] rather than continuous, lower-level release). In fact significantly altering fluid composition may define different phases of operation (e.g. heat transfer only) that can be used for bypass operation or maintenance purposes.

Water demand of the technology

The CHPM plant may have water demand, with controlled fluid loss through the rock formations, that can be a challenge to provide at certain locations. The additional water demand of the salt gradient power generation (technology element 6) has an additional water demand, comparable to that of the main technology but with different salinity level. This factor has an important element on facility siting and the overall environmental impact of the technology.

6 Summary, Conclusions and Recommendations

Task 2.4. is not an extensively detailed task in the Work description of the Grant Agreement. Three main constitutes of the task are summarized as a (1) data harmonization and management task; (2) system integration subtask and a (3) preliminary identification of environmental impacts.

Deliverable 2.4. is the summary document of Task 2.4, and its major contributions to the project are the following:

1. The collection, harmonization and management of data generated in WP1 and WP2, also creating the platform to integrate data generated in subsequent WPs, especially WP3. The document explains the procedure of creating CHPM metadata archive. Deliverable 2.4. contains the hardcopy database of Metadata archive (**Annex 3**) and the digital version of the archive (please refer to CHPM_DataArchive.xls on CHPM google platform)

2. Collecting parameter attribute information from all relevant partners about all parameters measured during laboratory activities. The document explains the procedure of the database construction and includes the hardcopy Data attribute table (**Annex 4**) and the digital version of the table integrated into CHPM_DataArchive.xls, accessible on the CHPM google drive.
3. CHPM_DataArchive.xls integrates rock sample tracking and follow up database as well.
4. Deliverable 2.4. clearly states that the CHPM Metadata archive is not a finished product of Task 2.4, must be extended with information (metadata, and data attributes) and data generated in the future actions of the CHPM project.
5. Partners involved in Task 2.4 initiated the first framework for overall system dynamic assessment. As a part of this exercise:
    a. The technological elements of the CHPM plant were identified
    b. Responsible partners provided the set of design parameters for each technical element These parameters define the technical environment which must be met for fluent operation of the whole facility. Some technology element developments are in an early stage and were not able to provide the design parameters when this report was written.
    c. Preliminary analysis of the compatibility of the technology loop was conducted, specifically for Temperature and Pressure conditions.
6. Deliverable 2.4. establishes the list of potential environmental impacts to be investigated during WP5. The most important data need is listed, to enable designers and operators to measure and control potential environmental impacts. The list of environmental impacts is just the first step to be followed by detailed Environmental Impact Assessment (EIA).
7. Deliverable 2.4. identifies those emerging phenomena that are beyond the scope of this task (in some cases even beyond the project), but should be kept in mind when considering CHPM plant installation.

The authors of Deliverable 2.4. submit the document with the following recommendations:

1. D2.4 needs follow up activities, especially its Annexes, to provide the most comprehensive metadata archive for project purposes, and post-project activites
2. D2.4 establishes the stage for WP4 and 5 analysis
3. D2.4 especially its system integration initiation, must serve as a platfrom for scenario development targeting pilot CHPM operation

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