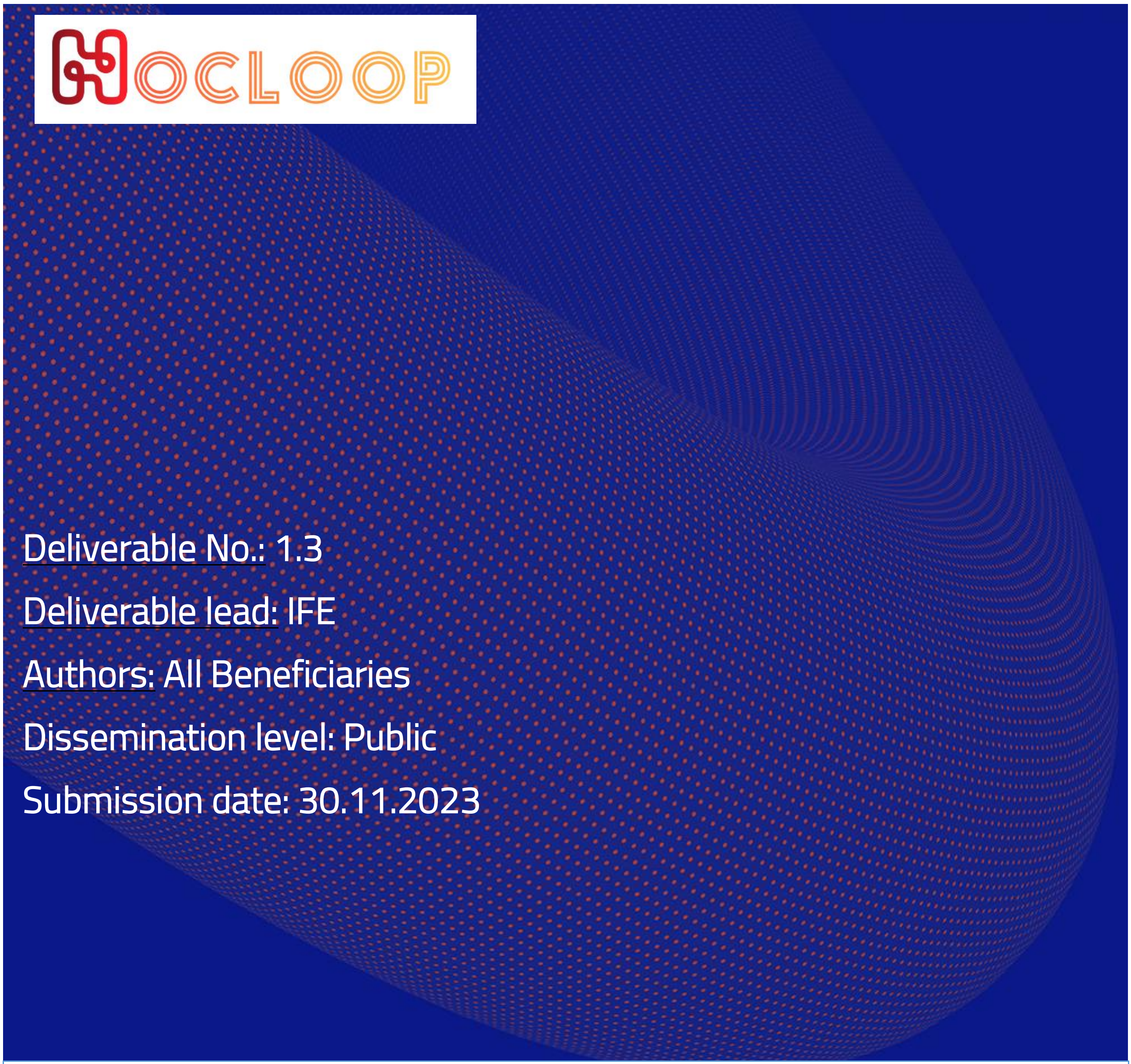
D1.3 Technical Annual Report, issue 1



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[1] Dissemination level: **PU** = Public, **SEN** = Sensitive, **R-UE/EU-R** = EU classified, **C-UE/EU-C** = EU classified, **S-UE/EU-S** – EU classified

[2] Nature of the deliverable: deliverable: **R** = Document, report; **DEM** – Demonstrator, pilot, prototype; **DEC** – Websites, patent, filings, videos etc; **DATA** – data sets, microdata, etc; **DMP** – Data Management Plan; **ETHICS**; **SECURITY**; **OTHER**

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LIST OF ABBREVATIONS

ACRONYM	DESCRIPTION
BHE	Borehole Heat Exchanger
CFD	Computational Fluid Dynamics
CPG	CO_2-Plume Geothermal
DH	Direct Heating
DHCP	Dynamic Host Configuration Protocol
DHS	Drill Heat String
DoA	Description of the Action
EGS	Enhanced Geothermal System
HLO	High Level Objective
IL	Ionic Liquid
KPI	Key Performance Indicator
SF	Smart Fluids
SO	Specific Objective
USR	User Requirements Specifications
WP	Work Package

EXECUTIVE SUMMARY

The present document summarises the activities performed, and the results obtained during the first 12 months of implementation of the HOCLOOP project (01.10.2022 to 30.09.2023), within the scope of technical work packages (WP2 – WP7). Due to the technical nature of the report and for clarity's sake, the activities related to WP1 – "Coordination, management and communication" are not included.

Developments and achievements are directly related to high-level and specific objectives to better demonstrate the progress made. A description of main activities performed, and results achieved by the individual beneficiaries is also included per work package. Whenever relevant, the detailed description of activities and results in already completed public deliverables is referred.

During the first year of the implementation, HOCLOOP's activities were more intensely focused on work packages 2, 4, and 5, in line with the implementation plan described in the Grant Agreement. However, significant efforts and achievements are also observed in work packages 6 and 7. The tasks of work package 3 are only planned to be initiated on month 18 of the project (01.03.2024). All results defined in the Grant Agreement as "sensitive" are mentioned, but not described due to their dissemination nature.

The general progress of the project is in line with the planned implementation and no significant deviations were observed in the first 12 months.

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1. Introduction

1.1. HOCLOOP project overview

Efficient production and distribution of renewable energy is a challenge to our society. Geothermal energy has the potential to reduce global CO_2 emissions and enable the transition to a low-carbon economy. Hydrothermal resources in sedimentary basins are present in multiple European countries, such as Germany, France, Hungary, Poland and Romania, however, the current exploitation of such resources is limited to thermal reservoirs that have porosity and permeability suitable for economic production. Furthermore, several risks arise from conventional geothermal exploitation: environmental leakage, corrosion, and radioactive salt deposition challenges are associated with the fluids circulating in the process. Fracturing of the rock formations implies an environmental risk for groundwater pollution and seismicity. These issues have in the past reduced the social acceptance for geothermal developments.

The HOCLOOP project concept aims to overcome the limitations of conventional exploitation technologies of geothermal resources by enabling geothermal energy production using a single-well closed loop BHE system. The general concept is depicted in Figure 1.

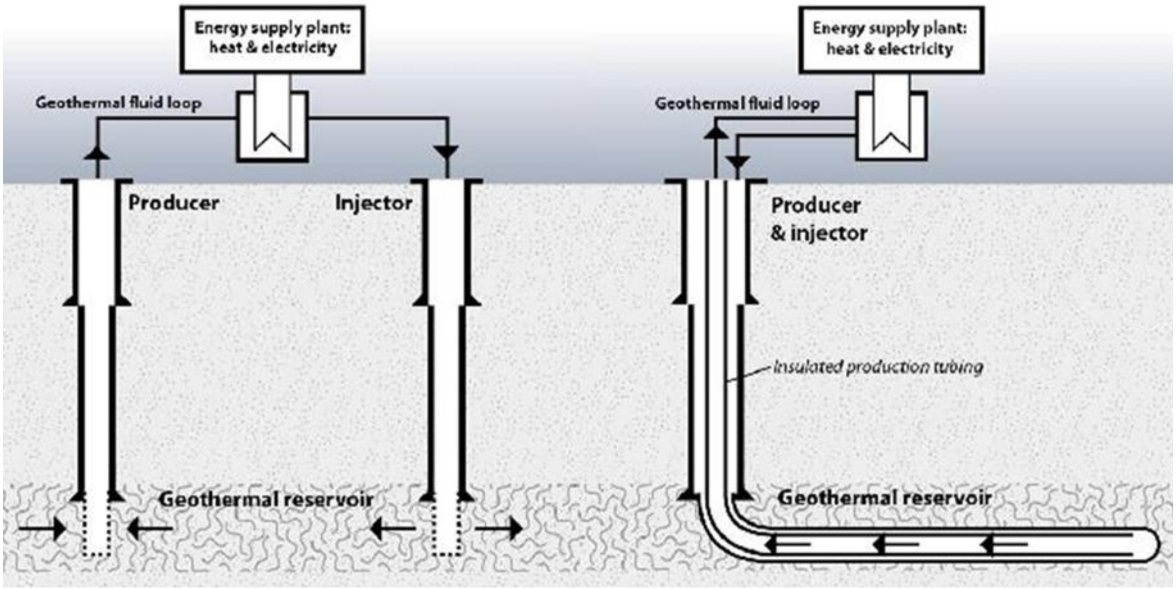

Figure 1. General HOCLOOP concept - Left side: conventional two well solution; right side: HOCLOOP single well solution.

The idea is to efficiently construct geothermal wells using a dual channel work-string arranged for deep horizontal closed loop circulation. Compared to similar proposed closed loop arrangements in the market, the proposed solution is expected to significantly improve the cost efficiency for geothermal developments. This is due to improved reach and efficiency enabled by the unique method for advanced well construction. The solution allows the exploitation of geothermal energy in new areas by avoiding the need for a geothermal reservoir, which until now has restrained the use of geothermal resources to limited areas of the earth. The solution is tuneable to local needs, for new type of community energy models to address just energy transition and sustainability and adaptable to the geothermal conditions of the local geology. Moreover, it enables the use of alternative fluids to water to further improve efficiency for electricity production compared to the conventional solutions. Table 1 summarises the expected advantages of the HOCLOOP solution in comparison to conventional geothermal exploitation.

Table 1. Overview of the conventional geothermal solution compared to the HOCLOOP.

Conventional geothermal solution	HOCLOOP solution
-Minimum 2 wells -High permeability & connectivity of the reservoir -Stability of hydraulic and thermal properties -Require use of brine with adequate chemistry	-One well -Closed-loop system -Stability of the thermal output over time -Can use alternative fluids for improved performance
Most common issues -Low permeability & connectivity of the reservoir -Rapid decrease of injectivity -Scaling/precipitation in surface installations -Risk for unproductive wells/ non targeted aquifers	***Solved issues*** -Suited for low permeability tight reservoirs -No scaling, precipitation, or corrosion issues -Avoid rock/fluid interactions - Avoid risk for unproductive wells
Adverse Consequences -Risk of induced seismicity -Loss of efficiency & performance -Project abandonment -Pollution of non-targeted aquifers -Low acceptance	***Expected benefits*** -Minimize the risk of induced seismicity -Low maintenance costs -Increase outreach of geothermal energy -Minimal environmental impact -Improved acceptance

The HOCLOOP project is being implemented by nine partners from six different countries. Table 2 identifies the composition of the consortium.

Table 2. Composition of the HOCLOOP consortium responsible for the implementation of the project

Participant	Participating Organisation Legal Name	Short name	Country
1 (CO)	Institute for Energy Technology	IFE	Norway
2	Reelwell A.S.	RW	Norway
3	University of Florence	UNIFI	Italy
4	VITO - Flemish Institute for Technological Research NV	VITO	Belgium
5	IFP Energies Nouvelles	IFPEN	France
6	Technical University of Darmstadt	TUD	Germany
7	University of Vaasa	UVA	Finland
8	University of Bari	UNIBA	Italy
9	NORCE Norwegian Research Centre AS	NORCE	Norway

1.2. Objectives and content of D1.3

The present document (Technical Annual Report, issue 1) provides an overview of the project achievements and the progress of the work within the first year of the HOCLOOP project's implementation (M1 – M12). This report focuses on the technical part of the project.

1.3. Relationship to other activities in HOCLOOP

The present report summarises the technical activities developed within the first year of the HOCLOOP and the main conclusions produced. It is a transversal description of the project's implementation following the timeline foreseen for the project. Some of the technical deliverables already produced are classified as "sensitive", thus the information relative to them presented hereafter is limited.

1.4. Structure of the present report

The report is organized as follows:

1. A summary of the achievement of the project according to the project objectives and the overview of the deliverables and milestones.
2. A summary of the progress of the work packages and tasks.
3. A summary of the technical dissemination and communication actions.
4. Technical deviations and possible consequences reported by the partners.

1.5. Contributions of the HOCLOOP beneficiaries

All beneficiary partners were involved in the preparation of the present report. IFE was responsible for compiling, organising, and formulating the presentation of the data.

2. Objectives, Achievements, and Deliverables

In this section, an overview of the implementation and results of the HOCLOOP project between M1 and M12 is presented, in line with the structure of the Annex 1 of the Grant Agreement. Summary of deliverables and milestones in the reporting period is also given in this section.

2.1. Objectives of HOCLOOP and progress towards them

Table 2 lists the specific objectives of the project, as described in ANNEX 1 of the DoA of the Grant Agreement. A summary of the progress between M1 – M12 towards the achievement of each of the project objectives is also included. Activities (ongoing and finished) in support of these achievements are also included in the table.

Table 3. Overview of HOCLOOP's activities and achievements towards the objectives of the action.

HLO1: Demonstrate a novel geothermal closed loop solution for deep or shallow formation rocks.
SO1.1: Design, build and test the Drill Heat String (DHS) components in the workshop
1.1a) Design of the DHS Partner RW have completed the detailed design of the DHS components and assembly procedures. This information is formalised in deliverable 5.1 classified as "sensitive". D5.1 contains all necessary specifications (dimensions of components, assembly instructions, assembly procedures, and materials) to build a DHS. **1.1b) Building and testing of the DHS** Partner RW have completed the plan for workshop testing of the components and the test

arrangements. Testing to include mechanical integrity, hydraulic performance, fatigue/wear resistance and thermal properties. The detailed description of the test plans is formalised in deliverable 5.3 classified as "sensitive". The manufacturing of the DHS components is ongoing in RW's workshop and a report presenting the manufacturing results of the components and assemblies, with focus on learning points for cost efficient development of the prototype DHS, will be formalised in M18 through deliverable 5.2, also classified as "sensitive".

SO1.2: Full scale DHS test operation to TRL5

1.2a) Plan for the full-scale operation at Ullrigg in Stavanger

The HOCLOOP project foresees the execution of a "full-scale" pilot at NORCE's Ullrigg tests centre in Stavanger. The field test will run between M29 – M33. Partners RW, NORCE, and IFE have started the dialog and the planning of arrangements, logistics, and procedures for the full-scale operation to be performed at Ullrigg. Each of the partners have also defined the human resources allocated and primarily responsible for the execution of the pilot.

HLO2: Verify the capability for improved electrical energy production by use of alternative fluids to water.

SO2.1: Water loop characterisation

2.1a) Benchmarking of geothermal simulators

Partner VITO led the development of procedures for benchmarking geothermal simulators. Analytical solutions for temperatures in the injection wells and surrounding rock were developed, and cases defined for software validation. The detailed work developed is found on deliverable 2.1, defined as public.

2.1b) Model for fluid circulation in the flow pipe

Partner IFPEN led the integration of the heat flow models described in D2.1 in models for the heat and fluid flow in the annulus and the central pipe. A complete description of how a model for heat flow towards a geothermal well can be coupled with advanced state-of-the-art models for pipe flow, using both commercial software, or in-house tools. Using CFD advanced models for the pipe flow, predictions of flow regimes in the pipes (in case multiphase flow happens) were achieved, and the heat transfer coefficients that control the heat flow from the well-wall interface to the fluid were tested. Detailed numerical grids were developed for better resolution of the heat flow between the inner tube and the annulus and the structure of the near well area. The detailed work developed is found on deliverable 2.2, defined as "public".

2.1c) Heat flow model for the closed loop system

Partner IFE led the development of prototypes for numerical simulation of vertical coaxial borehole heat exchangers. Underground flow effects (natural convective heat transport within the rock) were incorporated in software intended to model closed-loop single well performance, requiring numerical fluid flow and heat models for the rock domain. Such models are required for 3D generalized groundwater flows. Nevertheless, underground flows parallel to the well trajectory can be modelled with radial 2D models, which makes the computation and wellbore-rock domains coupling faster and less complex than 3D models. Systems with arbitrary well paths through rocks of different properties, for various well sections with unique properties for well diameter, tubing material, casing and cement can now be simulated. The detailed work developed is found on deliverable 2.3, defined as “sensitive”.

SO2.2: CO_2, Smart Fluids (SF) and CO_2/ILs loop characterization

The activities towards SO2.2 will be performed within the projects WP3, planned to start in M18. Thus, no activity towards the characterization of the closed loop with CO_2, SFs, or CO_2/ILs mixtures is available for reporting.

HLO3: Identify suitable applications for the solution for various underground environments in Europe.

SO3.1: Feasibility study of the HOCLOOP concept in different geological conditions and district heating (pilot sites), representative of those occurring in the European countries.

3.1a) Data from pilot sites and integration analysis

Partner VITO led the characterisation and integration analysis from 4 European pilot sites located in Belgium, France, Germany and Italy. The pilot sites evaluated cover a wide range in underground and surface conditions. They also cover a wide range of development stages: from green field exploration to functional geothermal plants. Consequently, the degree of uncertainty in the data varies from one site to another. Based on the specific geological settings and surface energy systems of the pilot sites, a schematic overview is made on different integration options of the HOCLOOP concept, representing the first step towards the final detailed design and the integration of the HOCLOOP technology at the pilot sites. The technology user’s requirement specifications for each of the pilot sites is compiled and summarised. These specifications will be used to develop the functional design specification, to capture designs, concepts, and process flow information. This process enables the determination of the types of data required to assess the applicability of the HOCLOOP concept, concerning aspects such as underground characteristics, current and planned local energy system, expected electricity and thermal energy flows. The detailed work developed is found on deliverable 4.1, defined as “public”.

SO3.2: Key parameters for replicability of the HOCLOOP concept

3.2a) Closed loop optimization at the pilot sites

The work to define relevant parameters to obtain optimal performance of the HOCLOOP concept is ongoing, led by the partner VITO. Optimal geological conditions are benchmarked as “baseline” and initial modelling has begun. The modelling of heat extraction at the selected pilot sites is under optimisation as it incorporates the simulation tools under development in task 2.3 (ending in M18). Input parameters for each of the possible pilot sites are collected from D4.1, including thermal properties of the layers that are targeted and crossed for heat extraction, and the rock mechanical properties, when relevant.

3.2b) Design and testing of the DHS

The collection and analysis of geological KPIs to develop a conceptual design for a closed system for each site from the baseline presented if D5.1 is ongoing and expected to be concluded on M18. The results from task 5.2 (workshop test the DHS and components) are being collected to define limit conditions of operation for the DHS prototype and being included in the development of the conceptual design of the closed loop system for the different geological sites. This work is expected to be completed on M22.

HLO4: Verify adaptation to surface energy utilities and environmental-, economic-, and social sustainability.

SO4.1: Examine and enhance community and market acceptance.

4.1a) Identification of stakeholders

The partner UVA is leading the work performed to identify relevant stakeholders in relationship to the HOCLOOP exploitation concept. The work developed was based on interviews done in the project's Belgium pilot site. Clearly identified stakeholders are as follows: VITO, Hita (company), Voka (the Flemish entrepreneurial network), the local community, and the Flemish government.

4.1b) Media representation

Work led by partner UVA aimed to examine how traditional media and social media have covered deep geothermal energy deployments. The analytical approach is built on the latest technological advances to analyse sizeable "textual corpus", developed on AI tools (ChatGPT and interpreter plugin), focused on the Mol site in Belgium. A co-creation workshop in Finland titled "Co-creating carbon neutral future: How can a deep-geothermal system support just transition at the regional level?" to examine the social acceptance of deep geothermal was organized on August 10th, 2023, in conjunction with the Wasa Future Festival and attracted 17 participants. The speakers included EU Commission member Jutta Urpilainen, Minister for European Affairs and Ownership Steering of Finland Anders Adlercreutz and several members of the Finnish parliament. The analysis performed so far shows that only four articles had a negative sentiment, while only 2% of the articles mentioned any opposition. This suggests that while opposition exists, it may not be a prevailing sentiment in the broader media coverage of geothermal energy. Stakeholders in the sector must, however, address the concerns of earthquakes, environmental pollution due to the use of chemicals in extraction, radioactivity, and the cumulative soil impact effectively to ensure the sustainable development of geothermal projects. Significant job creation in both direct and indirect sectors, cost efficiency leading to consumer savings, competitive energy prices, and potential for considerable revenue generation and profitability for the companies involved, were the most commonly referred benefits.

SO4.2: Sustainability assessment

The HOCLOOP project's activities that directly target the sustainability assessment (Task 7.2 "Analysis of the market acceptance-from of geothermal energy by closed loops" and task 7.3 "Sustainability assessment: Exergy, LCA, Exergo-environmental and exergo-economic analyses"), in accordance with the project plan, had not been initiated during the first 12 months. Task 7.2 was initiated on M13 and task 7.3 will be initiated on M24. Thus, no relevant data is produced about this SO.

2.2. Deliverables and milestones

Table 3 lists the status and eventual deviations of the technic/scientific deliverables and milestones planned between M1 – M12 of the HOCLOOP project (WP2 – WP7).

Table 4. Status and deviations of HOCLOOP's technical deliverables and milestones (M1 – M12)

Deliverable/milestone	Lead Beneficiary	Due date	Status	Submission date	Deviations
D2.1 - Benchmark	VITO	30.09.2023	Submitted	27.09.2023	No deviation

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cases					
D2.2 - Flow pipe model for fluid circulation	IFPEN	30.09.2023	Submitted	27.09.2023	No deviation
D2.3 - Heat flow model for the closed loop system	IFE	30.09.2023	Submitted	18.10.2023	Preparation of the first draft delayed. No impact in the implementation of the project.
D4.1 - Pilot sites data and integration analysis	VITO	31.03.2023	Submitted	23.06.2023	Initial version submitted on 30.03.2023 but not in accordance with Art. 17 of the GA.
D5.1 - Detailed design of the DHS and components	RW	31.07.2023	Submitted	15.09.2023	Delayed due to difficulties caused by the different summer holyday months of the partners. No impact in the implementation of project.
D5.3 - Plan the workshop tests and build the workshop test arrangement	RW	31.08.2023	Submitted	28.08.2023	No deviation
MS2 - Community acceptance data collection	UVA	30.09.2023	Achieved. Verified through the organisation of an an initial stakeholder workshop. See section 3 of the present document for more details.	-	No deviation

3. Development of the Technical Work Packages

In this section, an overview of the activities performed (in accordance with the project's timeline) in the different technical WPs and summary results is presented. Detailed information can be found in the public deliverables available, and any information classified as "sensitive" is omitted.

3.1. WP2 - Modelling of subsurface heat influx into the well

WP leader: **IFE**. Period of implementation: **M1 – M18**.

3.1.1. Task 2.1 - Benchmarking the simulation software (M1-M12)

Task lead: **VITO** – Participants: **IFE, IFPEN**

Activities performed per partner:

VITO: Task 2.1 aimed at developing procedures for benchmarking geothermal simulators either commercial or in-house. The objective was to have a first stage validation of different software to be used in the modelling tasks of the project and in the design of the HOCLOOP concept. VITO, as T2.1 leader, organized bimonthly meetings with the partners involved in T2.1 to assure the good follow-up of the activities in this task and to align the efforts. First, VITO proposed a template to collect information about the different software available within the consortium including the description of the capacities, limitations, and advantages. Second, VITO took part in the definition of the reference case for the benchmarking exercises and used the simulation software COMSOL to model them. Together with the other partners involved in this task VITO analysed the results and summarized them in the deliverable 2.1, for which a template had been prepared.

IFE: together with IFPEN and VITO, IFE designed and run 8 cases to benchmark geothermal simulators for deep coaxial borehole heat exchangers. These eight cases have a progressive complexity from a simple open well in case 1 to a full closed loop system with a horizontal segment in case 8. The benchmark cases come with analytical results together with the numerical results. These benchmark cases assume that the working fluid is incompressible and has constant properties similar to water.

IFPEN: A literature review was performed to find available analytical solutions that can predict the temporal evolution of the fluid temperature in single injection wells or coaxial closed wells with or without a horizontal segment considering the heat transfer between the fluid and the hosting formation. A well-know analytical solution was further developed to consider heterogeneous formations (rocks with variable properties) and/or horizontal wells. All analytical solutions were integrated in the numerical tool GWellFM and independent scripts in Python were developed to solve these analytical solutions. The GWellFM flow simulator was benchmarked against these analytical solutions for simple and complex wells.

Main results from partners (without sensitive data):

VITO: The objective of WP2 is to develop tools and models to predict the heat flow towards a closed-loop geothermal well and the associated temperature decrease of the surrounding rock, accounting rock properties, groundwater flow and the different elements of the well completion, such as casing and cement. T2.1 aimed at developing procedures for benchmarking geothermal simulators either commercial or in-house. The benchmarking procedure considered 2 in-house simulators: GWellFM from IFPEN and GTW from IFE and the commercial simulator COMSOL (VITO). VITO benchmarked COMSOL against single injection wells and closed-loop geothermal well problems that counts with analytical solutions as well as against the 2 in-house simulators. The accuracy and the ease for setting problems are aspects considered during the benchmark process. In addition, the effects of the circulation flow rate and inner tubing's thermal conductivity on temperature and power production are explored. The aim was to validate the use of COMSOL to simulate the HOCLOOP heat extraction concept and to understand the evolution of the rock temperature in the surrounding rock and the heat transport towards the well. The sensitivity of the heat production evolution through time to rock thermal properties, internal tubing thermal conductivity and operational flow rate was analysed.

The results obtained by VITO using the COMSOL software were compared to the ones of analytical solutions to forecast the heat production from closed-loop geothermal systems in vertical and horizontal wells are available in the literature for symmetric rock domains with homogeneous properties in the radial direction and incompressible recirculation fluids. Additionally, COMSOL's results were compared with the ones using an extension of Ramey's analytical solution to consider either heterogeneous rocks properties or horizontal wells is proposed.

The results show that COMSOL as well as the 2 in-house simulators were able to reproduce the mentioned analytical solutions. Depending on their capabilities, these simulators can be used with confidence in more complex cases like the use of CO_2 as energy carrier fluid, well interference and effect of groundwater flow among others. Setting the simulation case for closed-loop geothermal wells is a straightforward task in GWellFM and GTW simulators while it is time-consuming in COMSOL. The numerical modelling challenge is the large number of cells required to model deep and long deviated wells in asymmetric 3D domains. This is because the whole domain from the surface to the bottom needs to be included. This can be overcome by verticalizing the well trajectories while acknowledging for changes in temperature gradient and rock properties.

The average variation between the results from the simulators modelling closed-loop cases was lower than 5%.

For more details about the results of the benchmarking exercise, see D2.1 that summarizes the results of the modelling of the reference cases described in figures 2 and 3.

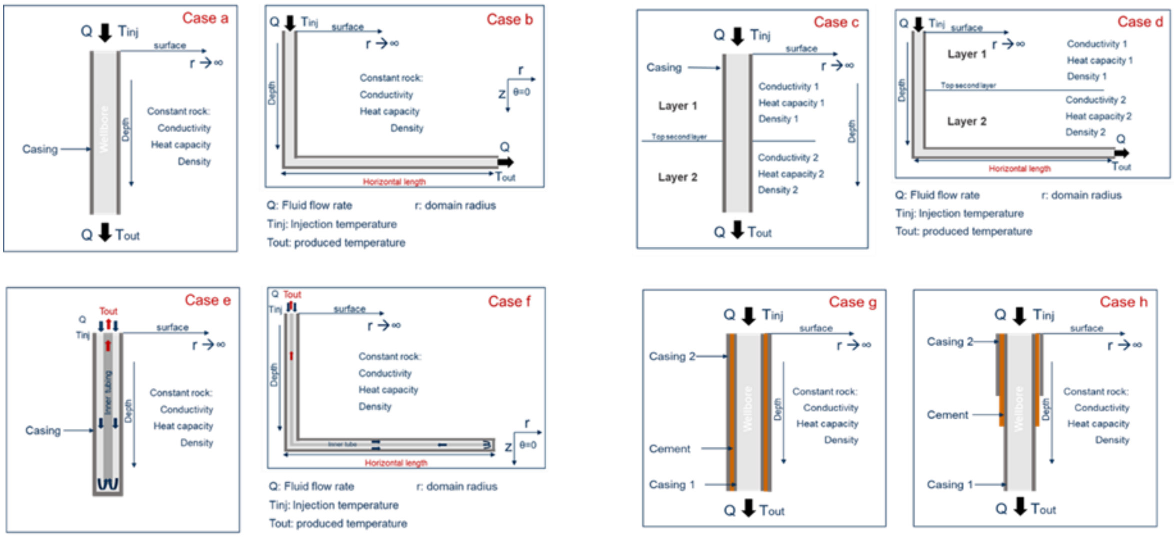

Figure 2. Reference case defined for the benchmarking in T2.1

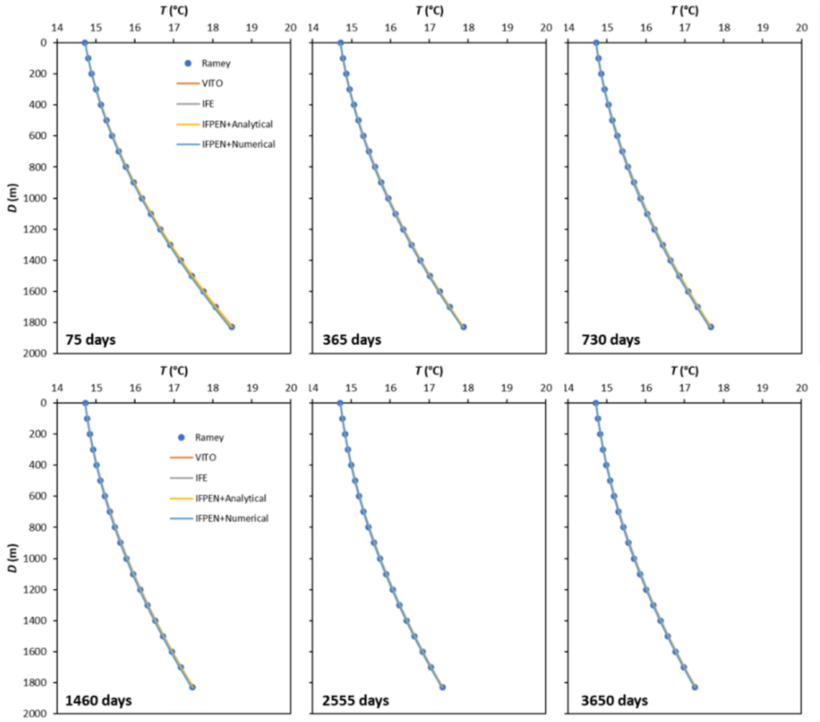

Figure 3. Example of results extracted from the benchmarking exercise. Comparison of the fluid temperature along the well of case g at different times. (figure 20 from report D2.1)

IFE: The three simulators GwellFM (IFPEN), GTW (IFE) and COMSOL (VITO) for deep coaxial borehole heat exchangers were compared with each other and with analytical solutions. We used to two analytical solutions: Ramey's solution for the temperature in an open borehole and Kabir's extension of Ramey's solution to a coaxial heat exchanger. All three simulators produced results that were in good agreement with each other and the two analytical solutions. The error is reported to be less than 5% for all cases. The full results are in the report Deliverable 2.1.

IFPEN: Four analytical solutions were identified from the literature survey and used to benchmark GWellFM simulator for the heat transfer between water flow in the well and the hosting formation. Different well configurations were considered (4 simple and 4 complex cases) and simulations were performed for a

period of 10 years. The results of GWellFM were compared with those of the analytical solutions.
Certain simplifications / assumptions were made on GWellFM to compare the results with the analytical solutions:

- The fluid flow (pressure losses) in the well were not considered.
- The physical properties of the fluid (water) in the well kept constant and independent of the temperature evolution.
- The enthalpy balance was replaced by a simplified energy balance using the temperature.
- The radius of the formation was large enough to be considered infinity.

Some of them required modifications of the source code of the simulator. In addition, the analytical solutions were integrated in the code and separate scripts in Python were developed to use them. Also, a modified version of Ramey's analytical solution was developed to consider heterogeneous formations (different type of rocks) and a combination of a vertical and a horizontal well.

The details of the simulated cases, the applied analytical solutions and the average and maximum error between GWellFM and the analytical solutions are provided in Table 4.

Table 5. Summary of maximum and average error (%) when comparing the outlet temperature of the fluid of GWellFM with the analytical solutions

Case	Type of well	Description	Analytical solution	Average [%]	Maximum [%]
a	Vertical, injection	Constant rocks conductivity	Ramey	0.031	0.171
b	Horizontal, injection		Modified Ramey	0.259	0.753
c	Vertical injection	Heterogenous formation	Modified Ramey	0.273	0.491
d	Horizontal, injection		Modified Ramey	0.288	0.677
e	Vertical, coaxial, closed	Counter-current flow	Al Saedi	0.167	0.269
f	Horizontal, coaxial, closed		Sharma	0.122	0.207
g	Same as case e	Cased and cemented well	Al Saedi	0.070	0.301
h		Partially cemented well	Al Saedi	0.033	0.206
e1		Sensitivity to tubing's thermal conductivity	Al Saedi	0.153	0.261
e2			Al Saedi	0.187	2.419

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e3		Sensitivity to mass flow rate	Al Saedi	0.228	0.300
e4			Al Saedi	0.413	0.663
e5			Al Saedi	0.169	0.289

For cases that involved injection of a fluid without recirculation (open well), the simulator presented an average error of around 0.03% when compared to Ramey's analytical solution. For heterogenous formations or a combination of a vertical and a horizontal well, the error was lower than 0.3% when compared to the modified Ramey solution.

The average error of the simulator when modelling closed-loop cases (such as the HOCLOOP concept), was lower than 0.5%. The highest difference with analytical solution was the case with the lower flow rate, which suggests that the analytical solutions are not very accurate for slow occurring phenomena.

In addition to the above comparisons, the results of GWellFM were compared, for the same cases and under the same assumptions, with two other simulators; GTW from IFE and COSMOL used by VITO. In all cases, GWellFM showed higher accuracy.

It is also worth mentioning that for all simulated cases the temperature is in transient conditions, which means that the temperature disturbance has not reached the outer boundary of the models during simulated times as shown in Figure 4 The low thermal conductivity of the rock is responsible for this behaviour. Nevertheless, in situations where more than one well is drilled in the same area, heat flow interference could take place if the well spacing is limited, this could result in the heat flow behaving in pseudo-steady state. In practice this means that larger temperature drops versus time will take place in this state than in transient state.

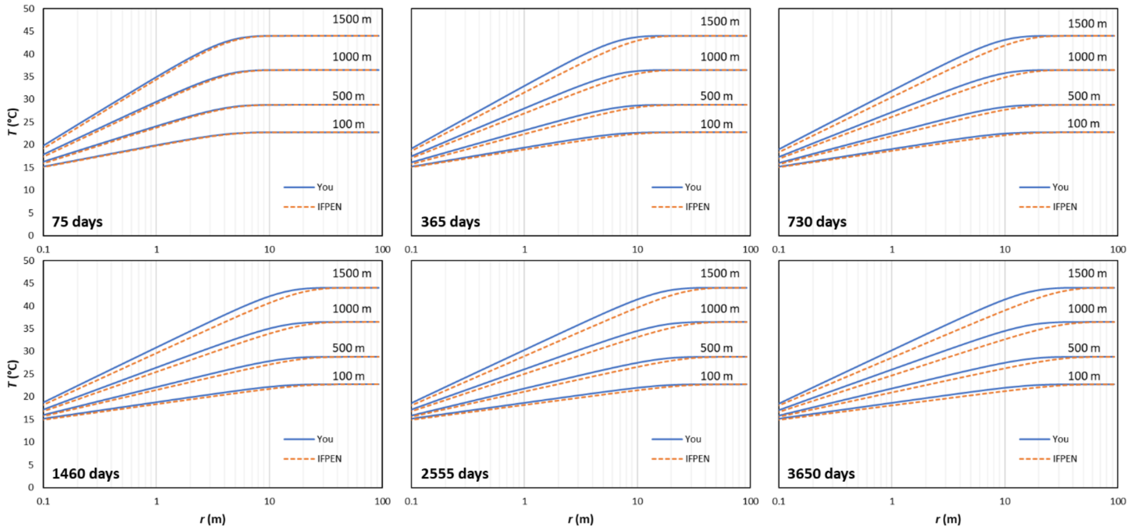

Figure 4. Comparison of temperature profiles in the rock domain at various depths and times between GWellFM and You's analytical model for case a.

3.1.2. Task 2.2 - Integration with pipe flow models (M1-M18)

Task lead: **IFPEN** – Participants: **UNIFI, UNIBA, IFE, VITO**

Activities performed per partner:

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IFPEN: Part of the simulations performed during Task 2.1 were performed by considering this time the fluid flow in the well and the dependence of the fluid transport properties on the pressure and temperature. The results were compared with the same analytical solutions to identify the impact of the fluid flow. In addition, comparisons were performed with two simulators: GTW from IFE and BHEModel from UNIFI. These comparisons showed that water's physical properties were not predicted accurately, and it is necessary to consider a new Equation-of-State for pure water.

UNIFI: UNIFI has developed a model for the HOCLOOP well extending an existing model used for theoretical analysis on geothermal systems. The original model was conceived to represent a variety of geothermal systems (EGS, CPG, BHE, etc.) simply by replacing the heating section. The model has been modified to comply with the specific HOCLOOP geometry, and compared with the results of the other partners.

UNIBA: UNIBA supported UNIFI with the definition of parameters and data inputs for the work developed.

IFE: IFE has, together with IFPEN and UNIFI, simulated cases A, B, E and F from the benchmark series regarding temperature and pressure. The working fluid was (realistic) water with pressure and temperature-dependent properties.

VITO: VITO supported IFPEN and UNIFI in the development of the extended model for HOCLOOP well including a large variety of geothermal systems (e.g., EGS, CPG, BHE, etc.).

Main results from partners (without sensitive data):

IFPEN: For Task 2.2 the same procedure as in Task 2.1 was followed with the difference that the fluid flow in the well was also modelled for 4 cases: two simple cases of open wells and two cases of coaxial wells. Now, the physical properties of the fluid were pressure and temperature dependant. The comparison showed (Table 5) that when the fluid flow was considered the error between the numerical predictions and the analytical solutions became higher.

Table 6. Summary of the maximum and the average error (%) when comparing the outlet temperature of the fluid of GWellFM with the analytical solutions.

Case	Average [%]	Maximum [%]
a	2.979	5.199
b	1.734	1.902
e	1.966	2.361
f	1.276	1.393

However, when the results of GWellFM were compared with the results of two other simulators (GWT of IFE and BHEModel of UNIFI) significant differences were observed. These large differences were attributed in the calculation of the physical properties of water between the different tools. The thermodynamic model of GWellFM was not able to correctly calculate the density, ρ, viscosity, μ, thermal conductivity, k, and heat capacity, Cp, as presented in Figure 5. According to these findings, a new EoS was decided to be integrated in the thermodynamic tool of GWellFM.

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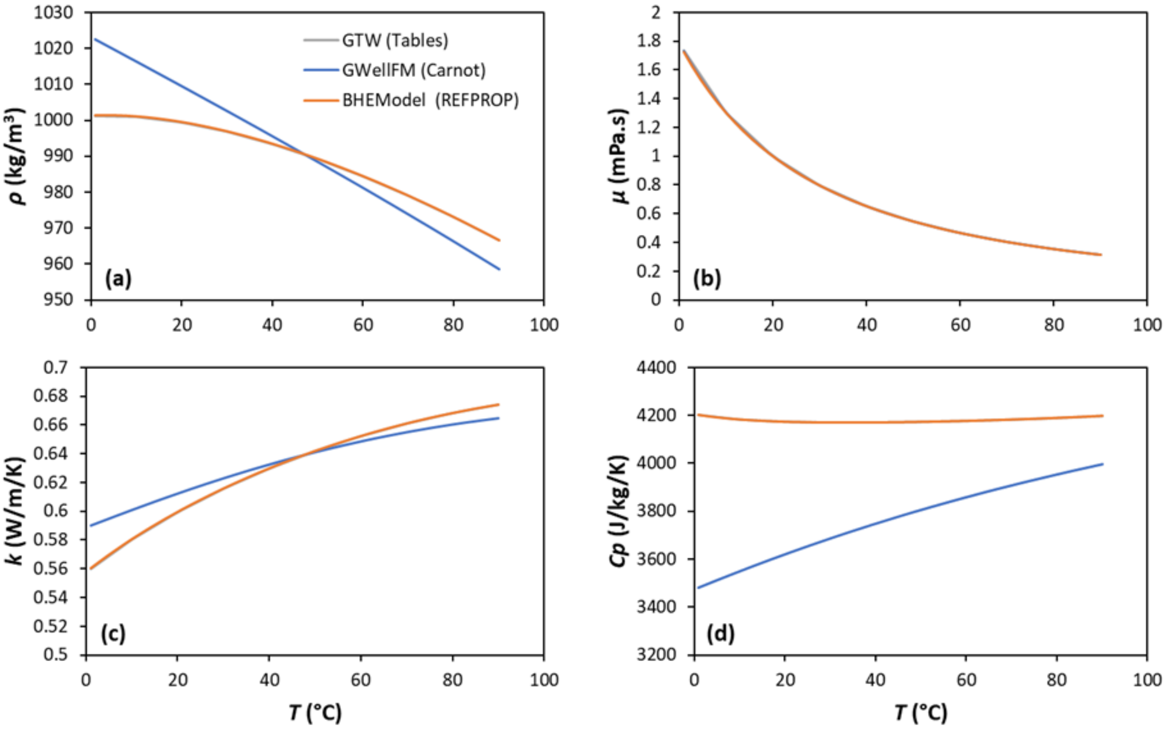

Figure 5. Comparison of (a) density, (b) viscosity, (c) thermal conductivity and (d) heat capacity for water at 30 bar and temperatures between 1 and 90°C as calculated by the three simulators.

UNIFI: In the scope of the task, the model developed by UNIFI (BHEModel2.0) has been compared with the results provided by the software prepared by other partners. The model developed by UNIFI is based on python and make use of some analytic correlation for the estimation of the heat transfer in the rocks. The models have been compared over 4 different well geometry scenarios using water has working fluid. The results have been presented in D2.2 and shows good agreement between the different models as depicted in Figure 6.

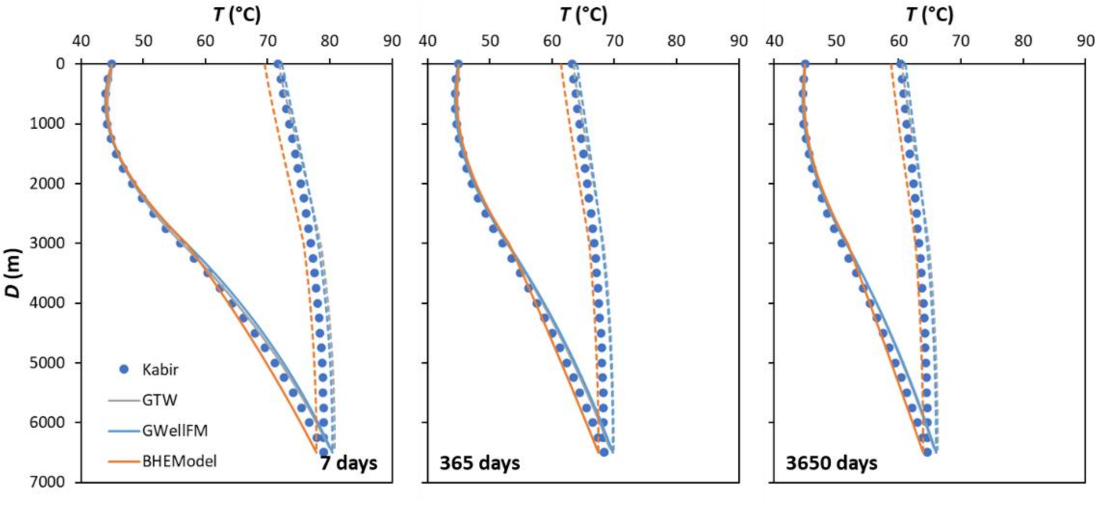

Figure 6. Model comparison results for a specific test case, as presented in Deliverable 2.2.

IFE: The three simulators GwellFM (IFPEN), GTW (IFE) and COMSOL (VITO) for deep coaxial borehole heat

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exchangers were compared with each other on benchmark cases A, B, E and F with realistic water as the working fluid. The results of the tests showed a good match between the simulators for the temperature along the borehole. The only discrepancies between the three codes were observed in the early time steps. Computing the heat extraction as the difference in the enthalpy between outlet and inlet for cases E and F resulted in the highest error when all three codes were compared. The differences that appeared could be traced back to different models for the thermodynamic properties of the water. The overall agreement between the simulators is good. The full results are in the report Deliverable 2.2.

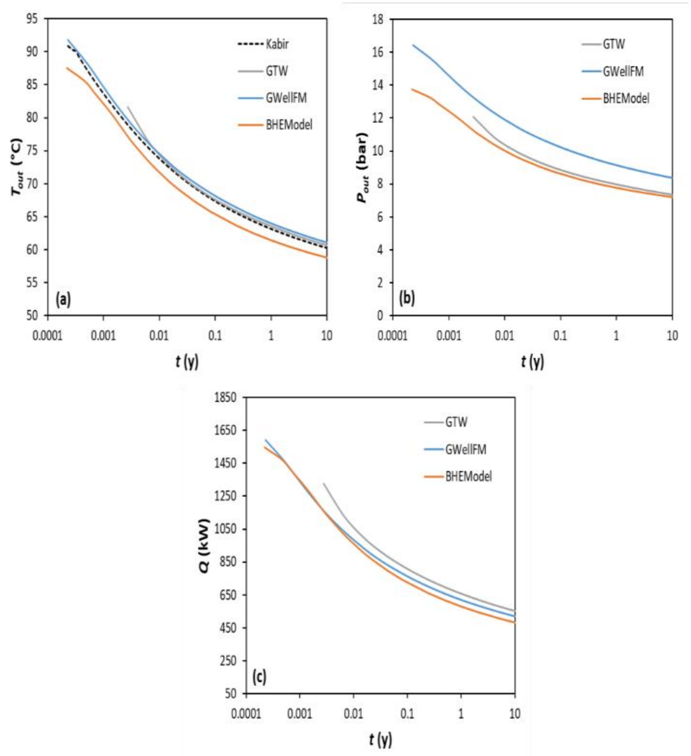

Figure 7. Model comparison results for a specific test case, as presented in Deliverable 2.2.

3.1.3. Task 2.3 - Modelling of heat extraction and calibration (M1-M18)

Task lead: **IFE** – Participants: **VITO, IFPEN**

Activities performed per partner:

IFE: Task 2.3 aimed at developing numerical procedures for modelling the effect of groundwater flow on closed-loop single well performance. Tests were run on cases where there is fluid flow in the rock. We designed the test cases to show how heat transported by the fluid flow can change the power produced by a closed-loop geothermal well. IFE did only the cases where the fluid flow is parallel with the borehole because its simulator assumes cylinder symmetry.

VITO: In this task VITO supported IFE and IFPEN in the modelling of defined reference cases that highlight the impact of groundwater flow linked to faults/permeable porous media in the subsurface. The COMSOL software that VITO is using was particularly useful in this task as incorporation of underground flow effects perpendicular to the well trajectory, requires numerical fluid flow and heat 3D models for the rock domain.

Such flows cannot be modelled with 2D radial models such as the ones developed by IFE. The later radial 2D model is however able to model underground flows parallel to the well trajectory, which makes the computation and wellbore-rock domains coupling faster and less complex than 3D models. The results from VITO were used as a reference for improving IFPEN in-house simulator. VITO summarized the results of the COMSOL simulations in D2.3 together with the results of IFE and IFPEN.
The simulations done are focussing on the concept with concentric pipe in pipe system. However it is expected that, especially in the sloping and horizontal part the return pipe is not concentric in the injection pipe. In order to get a better insight into the impact of the eccentricity of the return pipe towards the performance of the geothermal plant an indepth study has been performed by VITO in this task.

IFPEN: The GWellFM well flow simulator was coupled with an internal reservoir simulator (FraXim) to consider the underground flow effects (natural convective heat transport within the rock). A coupling procedure was developed, and simulations were performed for two different cases of a horizontal well. The results were compared with the GTW simulator and COMSOL package.

Main results from partners (without sensitive data):

IFE: The objective of task 2.3 was to study and define numerical methodologies to include convective heat transport in permeable rocks when modelling closed-loop geothermal single wells. VITO used the general-purpose commercial simulator COMSOL to perform this task and the results obtained were compared to the ones of the two in-house simulators (coupled FraXim-GWellFM from IFPEN and GTW from IFE). IFE implemented heat advection parallel to the well-bore in their simulator GTW and compared the simulation results with two other codes, GWellFM coupled with FraXim (both IFPEN) and COMSOM (VITO). Both FraXim and COMSOL are full 3-D codes. Results show that the initial temperature of the rock is the same when it is influenced by heat advection. A series of simulations where the rate of fluid flow was increased by a factor of 10 for each case, show a good agreement between different software. Figure 8 illustrates an example, and the complete results are available in D2.3.

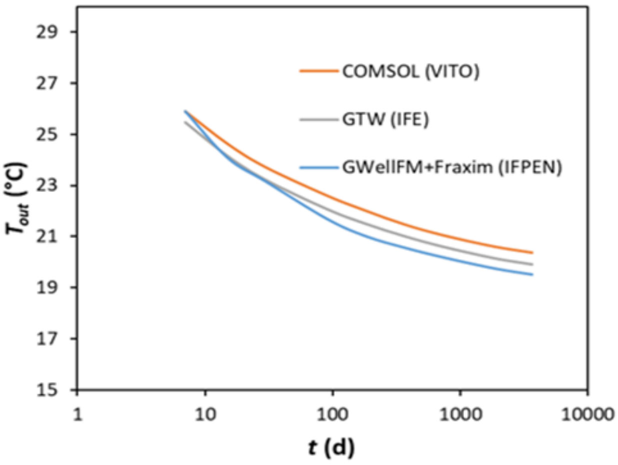

Figure 8. Comparison of the output temperature when the Darcy flux 1e-5 m/s vertically upwards uniformly around a vertical well between the three simulators used.

VITO: To address the effect of fluid flow through porous rocks on wellbore heat exchange, VITO used the porous media module from COMSOL. With this module it was possible to model fully couple 3D fluid and

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heat flow in the wellbore and rock. Thus, the wellbore was modelled as a porous media with a porosity of 1 and a high permeability for the annulus an internal tubing while the tubing is considered impermeable. Pressure losses in pipes are not handle under this approach. The equations that rule the system are the Darcy's Law for steady state conditions and the diffusive-convective heat transport equation. See D2.3 for more details. To solve these equations, the rock and wellbore domains are discretized with either tetrahedral or radial elements or a mixture of both. Radial elements are more suitable for vertical wells while tetrahedral elements can be used for complicated 3D domains like those related with horizontal wells. COMSOL uses Finite Element as the numerical method to solve the mentioned equations. To account for the convective heat transfer coefficient h at the inner casing and tubing interface, VITO computed an equivalent approximated thermal conductivity coefficient $k_{equivalent}$ for the casing and tubing.

Two scenarios of thermal underground fluid flow were modelled: (i) parallel (case 1) and (ii) orthogonal (case 2) to the well trajectory (see figure 3). On one hand, the effect of the flow parallel to the well trajectory was modelled by the three simulators. The results of the COMSOL and of the two in-house simulators are shown in Figure 4 for the two scenarios. Similar results were obtained in terms of temperature along the annular and tubing sections of the closed-loop single well (difference lower than 5%). No major challenges were faced during setting and modelling this case. On the other hand, the case of flow orthogonal to the well trajectory was only modelled by the simulators GWellFM-FraXim and COMSOL. GTW didn't model the orthogonal flown due to its limitations. Differences in terms of output temperature are lower than 5% as well.

The main conclusions of T2.3 are that including underground flow effects (natural convective heat transport within the rock), in software intended to model closed-loop single well performance, requires numerical fluid flow and heat models for the rock domain. These models are required for 3D generalized groundwater flows. Nevertheless, underground flows parallel to the well trajectory can be modeled with radial 2D models, which makes the computation and wellbore-rock domains coupling faster and less complex than 3D models.

From the phenomenological point of view, underground flows orthogonal to the well trajectories are forecasted to have a larger effect on closed-loop production temperature than flows parallel to the well trajectories (considering an equal well length). This effect can be either detrimental or favorable depending on the temperature of the underground flow with respect to the fluid in the wellbore. The coupling of generalized 3D flows with the wellbore represents the major challenge in closed-loop single well modelling when considering underground flow effects.

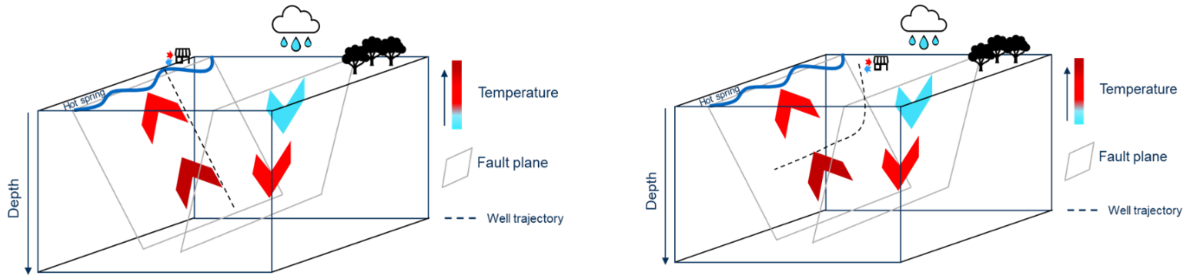


Figure 9. Illustration of a) a well drilled parallel and b) orthogonal to a hot underground flow. Convective geothermal system driven by faults and recharged by rain. Arrows indicate convective flow direction. (figures 5 and 6 from report D2.3).

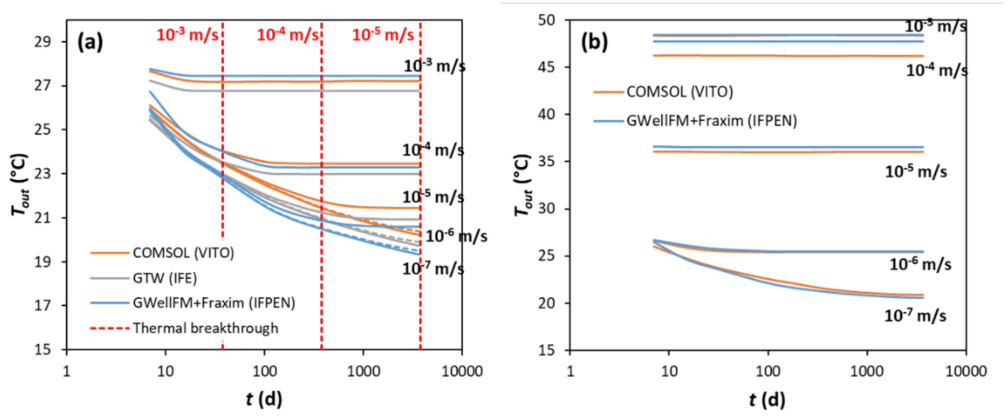
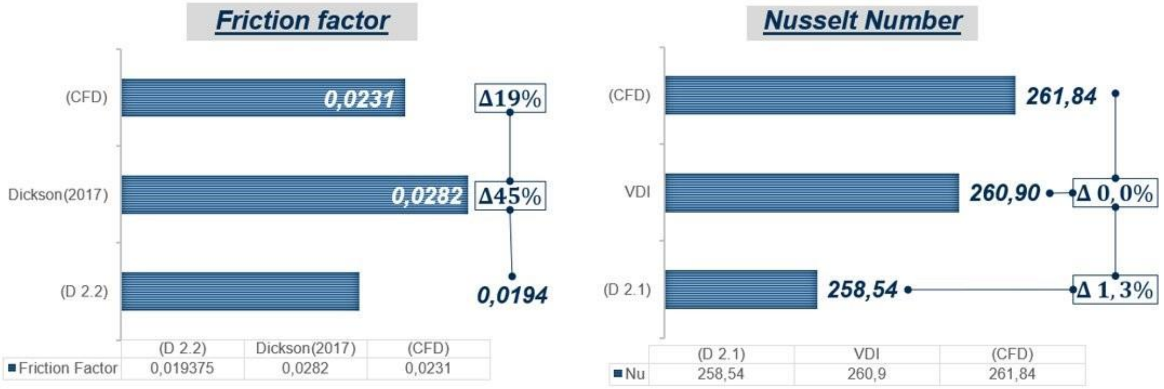


Figure 10. Impact of different (a) parallel and (b) orthogonal to the well trajectory underground fluid flows on well fluid's outlet temperature.

Next part of the work in this task was to quantify the deviation on thermal and hydraulic performance due to eccentricity configuration of the return pipe. In this study VITO focusses on the case f reported in D2.1. More detailed description of the study can be found in D2.4.

In order to quantify the impact, the concentric configuration of the pipe in pipe system has been simulated using computational fluid dynamics (CFD). The CFD results were compared with the corelations used in deliverables D2.1. Besides, corelations from open literature were also used to verify the CFD results. For this the Nusselt Number correlation were used as per Dickson 2017 and friction factor was calculated using the VDI Heat Atlas.

Hence, it can be concluded that Nusselt Number obtained from CFD corelated well with that obtained from D 2.1, whereas friction factor shows large deviations (figure 11).



	(D 2.2)	Dickson(2017)	(CFD)
■ Friction Factor	0,019375	0,0282	0,0231

	(D 2.1)	VDI	(CFD)
■ Nu	258,54	260,9	261,84

Figure 11. Comparison of the Friction factor and the Nusselt Number (CFD, literature and D2.1/D2.2)

To study the effect of eccentricity on the thermal-hydraulic performance of the pipes, the inner pipe is offset from the centre, which maintain the boundary layer discretization and the overall volume discretization of the flow passage. The extend of eccentricity is referred in term of percentage, wherein, 0% means concentric pipes and 100% mean that the inner pipe is touching at the bottom of the outer pipe.

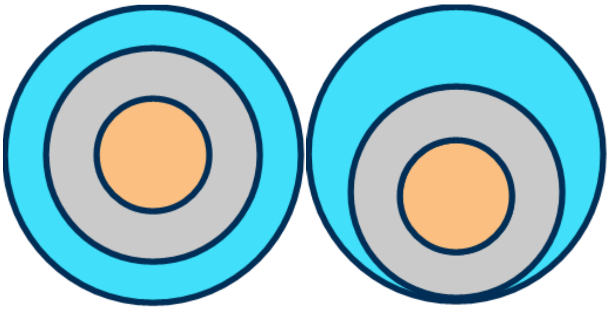


Figure 12. Cross section of the Hocloop system with concentric (picture on the left, C=0%) and most eccentric situation (inner pipe on the bottom) (picture on the right, C=100%)

Figure 12 illustrates the two extreme cases with no eccentricity (0%) and maximal eccentricity (100%). In order to have a better understanding of the eccentricity on the thermos-hydraulic performance of the pipes, simulation for eccentric pipes has been done in steps of 10% from 0% to 90%.

In Figures 13 and 14, spider plots of the mass averaged flow properties are presented. The spider plots consist of (1) the heat transfer coefficient (h), (2) the area distribution, (3) the delta T LMTD and (4) the velocity magnitude. Based on the results of the simulations it can be observed that the local heat transfer coefficient at the bottom of the pipe is reducing with C drastically. This change in local heat transfer coefficient can be attributed to the increase in the local Delta T LMTD. In addition, for the velocity magnitude it can be observed that the velocity at the bottom of the pipes (or locations with smaller cross-sectional area) is lower as compared to the concentric case, and vice-versa for the large areas.

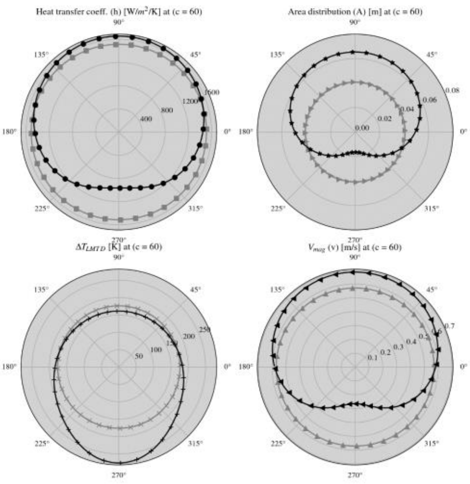


Figure 13. Spider plot with eccentricity of 60%

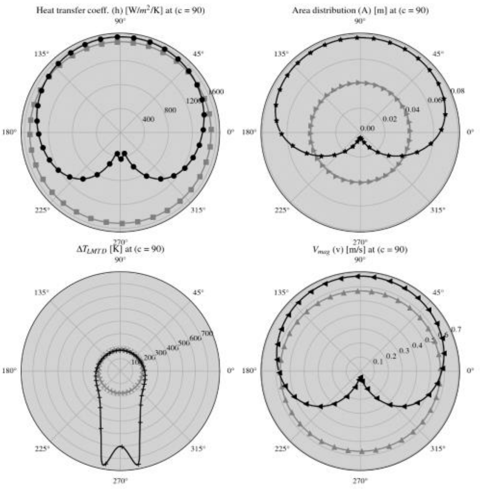


Figure 14. Spider plot with eccentricity of 90%

Figure 15 shows the results of the impact of the eccentricity on the friction factor and the Nusselt number. It can be concluded that a higher eccentricity reduces the friction factor, so less pumping energy is needed. Unfortunately, a higher eccentricity reduces also the Nusselt number which has a negative effect on the heat transfer. At an eccentricity of 90% the reduction of the Nusselt number is around 75% compared to the concentric case.

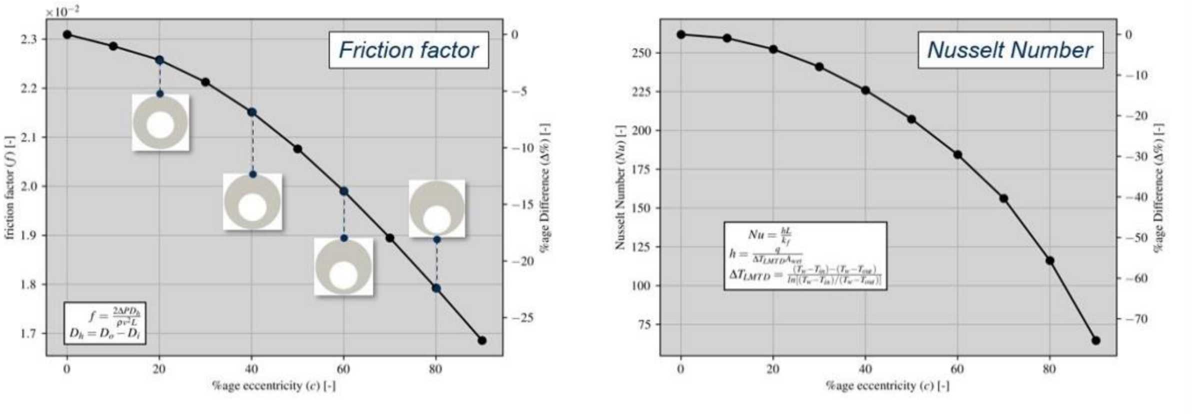


Figure 15. Impact of the eccentricity on the friction factor and the Nusselt number

IFPEN: In Task 2.3, the underground flow effects (natural convective heat transport within the rock) had to be incorporate. In this study, FraXim, IFPEN's internal tool for simulating multiphase fluid flows with heat exchanges in a potentially fractured porous medium in three dimensions, was coupled with GWellFM to accurately model exchanges of heat between the well and the reservoir. The downhole temperatures along the well were calculated numerically using the coupled code. GWellFM was used to calculate the 1D fluid and heat flow in the wellbore under steady conditions, whereas FraXim calculated the transient heat transfer in the rock domain. The wellbore domain included the fluid(s), the casings and any other materials (cement, tubing, insulation).

A coupling methodology was developed. After initialisation of both domains (wellbore and formation), the quasi-dynamic method starts by a steady-state fluid calculation and continuous with the thermal transient calculations in the formation. At every time step (tn), a steady-state calculation is performed by imposing the formation temperature from the previous time step (semi-implicit Dirichlet boundary condition) at the wellbore interface. Then, the updated wellbore conditions are given to the solid, for the beginning of the first coupling period (explicit Dirichlet boundary condition). Each coupling period, between t_n and $t_{n+1} = t_n + \Delta t_n$, is divided into several wellbore time increments, δt_s (with $\Delta t_n = v\delta t_s$) and composed of the below steps (Figure16):

1. Steady-state computation
2. Exchange of fluid conditions from the wellbore to the formation domain
3. Transient calculations in the solid
4. Exchange of interface conditions from the formation to the fluid
5. Convergence satisfied: Go to next time step.
6. Convergence not satisfied: Repeat one more iteration between tn and tn+1

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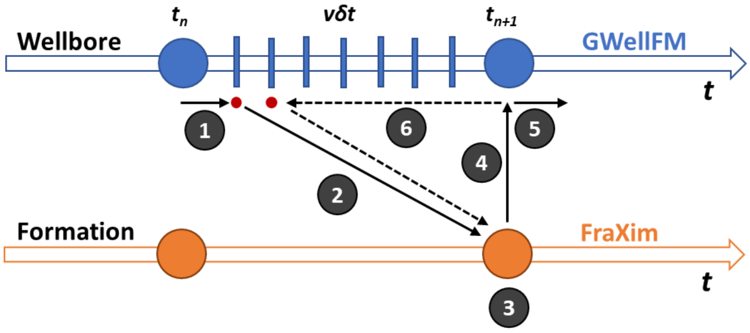


Figure 16. Quasi-dynamic coupling algorithm of GWellFM and FraXim

Details on the coupling procedure can be found in Deliverable D2.3.

Two scenarios of thermal underground fluid flow were modelled: (i) parallel (case 1) and (ii) orthogonal (case 2) to the well trajectory. On one hand, the effect of the flow parallel to the well trajectory was modelled by three simulators: GWellFM+FraXim of IFPEN, GTW of IFE and COSMOL from VITO. Similar results were obtained in terms of temperature along the annular and tubing sections of the closed-loop single well (difference lower than 5%). On the other hand, the case of flow orthogonal to the well trajectory was only modelled by the simulators GWellFM-FraXim and COMSOL. Differences in terms of output temperature are lower than 5% as well.

The response of the two cases is that the higher the underground fluid velocity the higher the output temperature of the closed-loop single well. This response is more pronounced in the case of flow orthogonal to the well trajectory, where the output forecasted temperatures were higher than in the case with fluid flow parallel to the well. It is important to mention that this orthogonal flows to the well trajectory can be also detrimental if it transports colder water than the water injected in the closed-loop single well system.

3.2. WP3 - Heat transport to surface with CO_2 mixtures and alternative fluids

WP leader: **UNIFI**. Period of implementation: **M18 – M42**.

Activities within WP3 will be initiated on M18 and no work has been performed. Thus, nothing is reported in the present document.

3.3. WP4 - Surface integration, potential pilot sites and forward portability

WP leader: **VITO**. Period of implementation: **M1 – M42**.

3.3.1. Task 4.1 - Pilot sites data collection and integration analysis (M1-M6)

Task lead: **VITO** – Participants: **TUD, UNIFI, UNIBA, IFPEN, RW**

Activities performed per partner:

VITO: The objective of Task 4.1 was to facilitate the future integration of the HOCLOOP innovation at the pilot sites by gathering and processing of data about the underground characteristics and above ground energy system at the different selected pilot sites. VITO coordinated the work of T4.1 by organizing WP4 meetings and planning the workshops dedicated to the different pilot sites with the full consortium. The goal of the workshops was to collect pilot sites data and information related to the local geology, as well as the current and future above-ground energy system. Possible integration options of the HOCLOOP concept in the different energy systems were considered and discussed. In addition, VITO defined and distributed to the pilot leaders a template to collect the URS for each site. As a site pilot leader VITO was responsible of the Balmatt site. For this site, VITO summarized the data concerning aspects such as underground characteristics, current and planned local energy system, expected electricity and thermal energy flows to enable the optimal integration of the HOCLOOP in a synthetic table. Based on the data collected for the Balmatt site, the USR was prepared. It will be used to develop the functional design specification, to capture designs, concepts, and process flow information as inputs for the next tasks (T4.2, T4.3, T4.4, T4.5) and for work packages (WP3, WP5, WP6). Based on the specific geological setting and surface energy system, VITO made a first schematic overview on different integration options of the HOCLOOP concept in the energy system of the Balmatt geothermal site. VITO oversaw D4.1 and prepared the template for this deliverable before distributing it to the site leaders to gather their contributions. VITO made sure that D4.1 was handled in due time to the reviewers before submission. The document acts as a step towards the final detailed design and the integration of the HOCLOOP technology at the pilot sites.

TUD: At the Campus Lichtwiese of TU Darmstadt, three medium-depth borehole heat exchangers have been constructed since 2022 as part of the SKEWs project (Seasonal Crystalline Borehole Thermal Energy Storage), funded by BMWK, the Federal Ministry for Economic Affairs and Climate Action of Germany. This facility is currently in the testing phase and will be integrated into the district heating network system of TU Darmstadt as part of the EU-funded project PUSH-IT. The HOCLOOP project aims to assess the feasibility of implementing HOCLOOP's solution at this pilot site.
All relevant data, including information on geology, geophysics, thermal petrophysical rock properties, and the district heating network system, have been collected and documented. These data will be utilized to create geological structure models, surface component models, and a Co-Simulation model. These models will be instrumental in evaluating the technical and economic efficiency of HOCLOOP's solutions in comparison to the underdeveloped solution.

UNIFI: Selection and data analysis of suitable DHCP case studies in Italy for the application of HOCLOOP technology: Gavorrano site (in collaboration with UNIBA), Mount Amiata site and Gargano site. Analysis of heat demand and possible layout of the HOCLOOP technology to serve the civil and industrial utilities in these areas.

UNIBA: Preliminary collection of structural data was carried out in the Gavorrano area. The dataset is constituted by: geological map of the area, geological sections and distribution of fractures and their characterization: connectivity, width, length, frequency. These parameters are crucial to define permeability of the rock-volume where a possible HOCLOOP borehole system can insist.

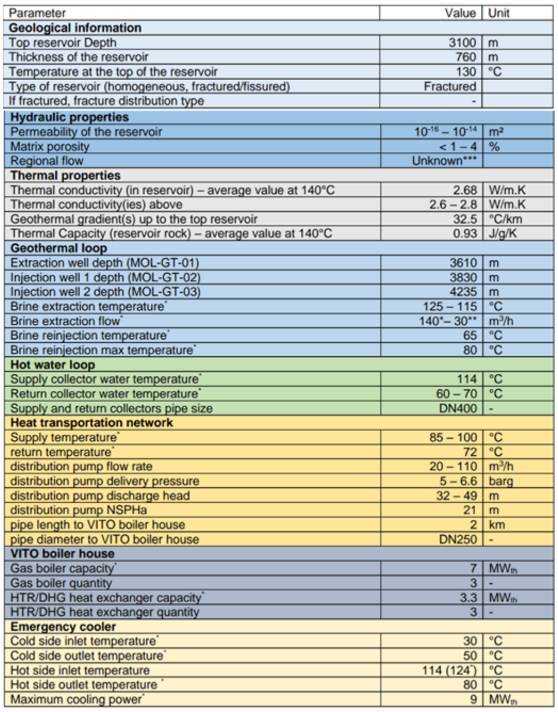
IFPEN: Data collection and analysis of the Paris basin. The data gathered consists of a geological map of the basin, geological sections and distribution of fractures, characterisation of connectivity, width, length, occurrence, preliminary collection of existing oil and well prospection wells, stratigraphic information, and the respective temperature data.

RW: RW participated in the development of the task (through meetings and data analysis) to tackle challenges with the original BHE concept. Results from the data analysis were used to ensure that the current DHS design is consistent with the modelling results, and in accordance with the geological conditions of the case studies.

Main results from partners (without sensitive data):

VITO: In T4.1, pilot sites data and information related to the local geology and current/future above ground energy system were presented to the full consortium by the pilot leader to gain an in-depth knowledge of the business and technical issues to be studied, and the businesses' attitudes and procedures. VITO organized the kick-off meeting of the HOCLOOP project at its headquarters at which occasion the Balmatt pilot site was presented. A site visit was organized to show the partners the above ground installations as well as the location of the deep boreholes. For the Balmatt site, the user requirements have been captured by VITO into a traceable document (see D4.1 for the full details): the User Requirements Specification (USR). A first schematic overview has been made on different integration options of the HOCLOOP concept in the energy system for this site based on existing installations and potential future applications possible for this site (Figure 17). The USR will be used to develop the functional design specification, to capture designs, concepts, and process flow information as inputs for the next tasks in WP4 and for work packages (WP3, WP5, WP6). The Balmatt site has the largest dataset as result of three deep boreholes that have been drilled at this location and the knowledge that has been acquired over the last years of its development. For this site, all necessary data about the underground is available for simulation of thermal power and temperatures. The main future challenges concern the optimal integration of the HOCLOOP technology with the existing geothermal loop, the control of both sources for combined heat and power delivery, and the impact of the HOCLOOP solution on the stress conditions within the targeted limestones. The summary table (Table 6) was prepared to give an overview of the geological information, the hydraulic and thermal properties as well as on the geothermal loop and surface installations.

Table 7. Summary table for the Balmatt site



Parameter	Value	Unit
Geological information		
Top reservoir Depth	3100	m
Thickness of the reservoir	760	m
Temperature at the top of the reservoir	130	°C
Type of reservoir (homogeneous, fractured/fissured)	Fractured	
If fractured, fracture distribution type	-	
Hydraulic properties		
Permeability of the reservoir	$10^{-16} – 10^{-14}$	m²
Matrix porosity	< 1 – 4	%
Regional flow	Unknown***	
Thermal properties		
Thermal conductivity (in reservoir) – average value at 140°C	2.68	W/m.K
Thermal conductivity(ies) above	2.6 – 2.8	W/m.K
Geothermal gradient(s) up to the top reservoir	32.5	°C/km
Thermal Capacity (reservoir rock) – average value at 140°C	0.93	J/g/K
Geothermal loop		
Extraction well depth (MOL-GT-01)	3610	m
Injection well 1 depth (MOL-GT-02)	3830	m
Injection well 2 depth (MOL-GT-03)	4235	m
Brine extraction temperature*	125 – 115	°C
Brine extraction flow*	140*– 30**	m³/h
Brine reinjection temperature*	65	°C
Brine reinjection max temperature*	80	°C
Hot water loop		
Supply collector water temperature*	114	°C
Return collector water temperature*	60 – 70	°C
Supply and return collectors pipe size	DN400	-
Heat transportation network		
Supply temperature*	85 – 100	°C
return temperature*	72	°C
distribution pump flow rate	20 – 110	m³/h
distribution pump delivery pressure	5 – 6.6	barg
distribution pump discharge head	32 – 49	m
distribution pump NSPHa	21	m
pipe length to VITO boiler house	2	km
pipe diameter to VITO boiler house	DN250	-
VITO boiler house		
Gas boiler capacity*	7	MW_{th}
Gas boiler quantity	3	-
HTR/DHG heat exchanger capacity*	3.3	MW_{th}
HTR/DHG heat exchanger quantity	3	-
Emergency cooler		
Cold side inlet temperature*	30	°C
Cold side outlet temperature*	50	°C
Hot side inlet temperature	114 (124*)	°C
Hot side outlet temperature *	80	°C
Maximum cooling power*	9	MW_{th}

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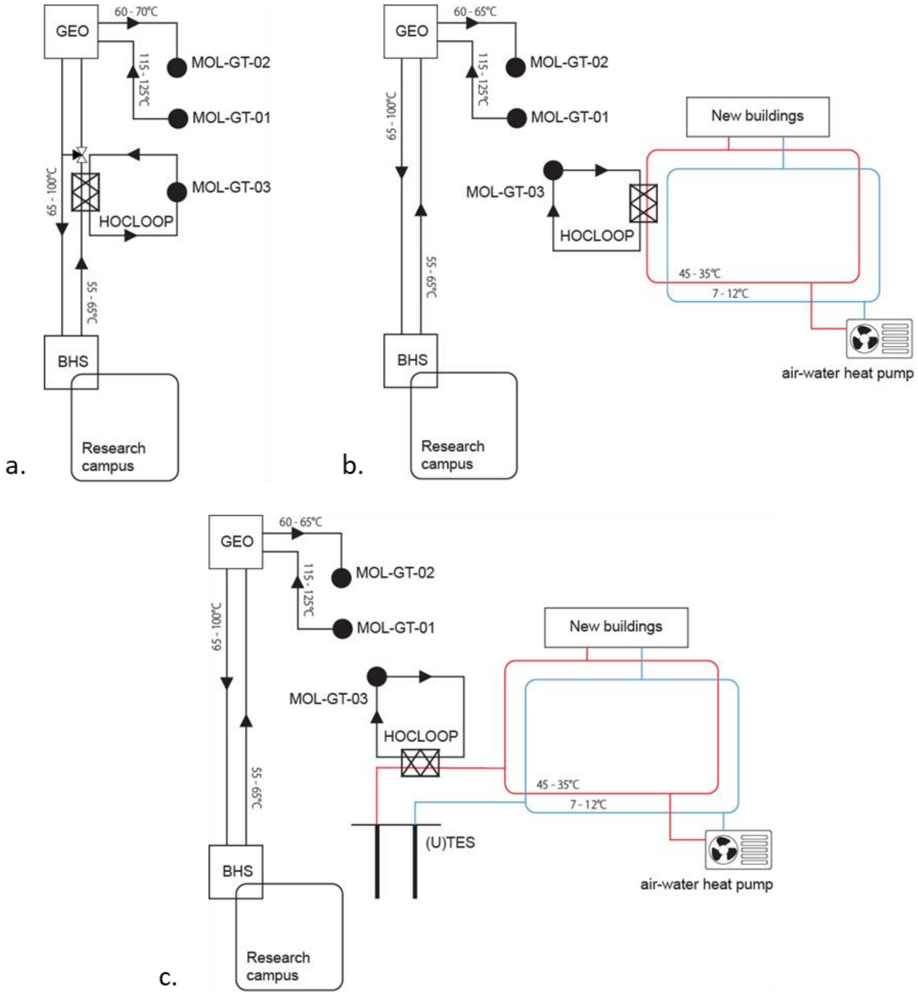

Figure 17. Integration options for the HOCLOOP technology at the Balmatt geothermal site. a.) Integration in the existing geothermal district heating system; b.) as a heat source in for a new cold and heat net for the new developments; c.) as a heat source in for a new cold and heat net for the new developments in combination with thermal energy storage.

TUD: The information related to the geology, status, and future strategy of the Darmstadt site was presented to the project consortium during the project workshop. These data also contribute to deliverable D4.1. To construct the geological structural model, various data sources and measurements were utilized, including data from seismic campaigns, electrical resistivity tomography, gravimetric profiles, the local geological map, cuttings from boreholes, well logging, and cross-borehole tomography. The most recent interpretation of all these data is presented in Figure 18.

The project site is situated in an area featuring various trench systems divided by faults. At the three borehole locations, distinct layers are present. The uppermost layer comprises basalt with high permeability and is approximately 200 meters thick. Beneath this layer lies the basement. We assume that the lithology described above remains relatively consistent when extrapolated to several kilometers in depth.

The temperature along the boreholes were recorded. Unfortunately, the temperature gradient is lower than our expectation. In previous study, we expected 40 °C at 1000 m depth. However, data from the fiber optic cable installed in the boreholes show that the temperature at 750 m depth is 27°C. This information will be considered of a regional model to extrapolate the temperature at deeper depth, where HOCLOOP's concept is targeted.

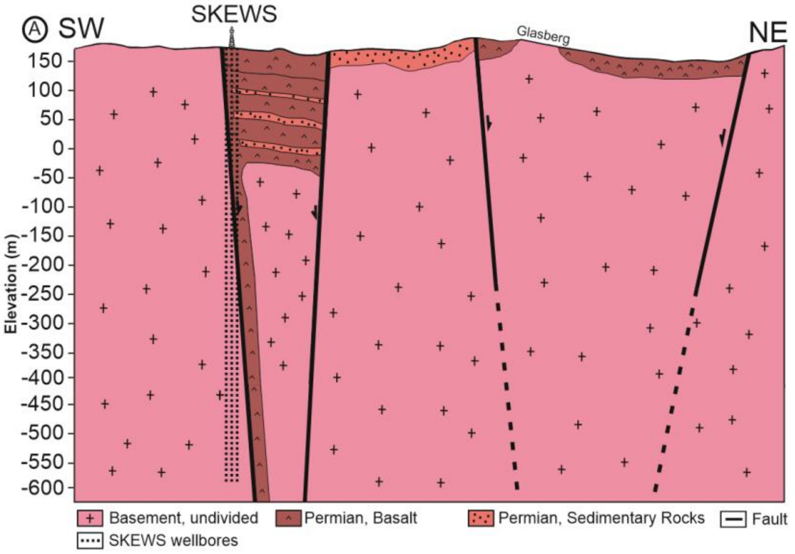

Figure 18. Final interpretation of the geology condition for the Darmstadt site using different methodologies and data sources

Along with the geological data, the information about the district heating network was also collected (Figure 19). At TU Darmstadt, various projects have been under developments to reduce energy consumption and lower the temperature of the network, and geothermal energy plays a vital role in this strategy.

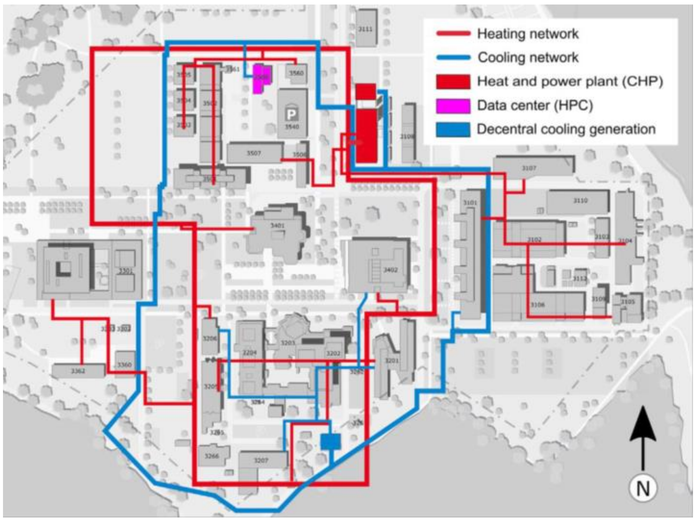

Figure 19. The district heating network system of TU Darmstadt

UNIFI: The selection focused on 3 possible Italian sites and the analysis of the energy demand of some possible utilities surrounding the geothermal fields exploited by the HOCLOOP technology.

The **Gavorrano** geothermal area is located on the hills close to Follonica, a small town on the Tuscan coast. Between the geothermal area and the coast there are multiple locations, shown in Figure 20, in which there is a substantial demand for heat.

This project has received funding from the European Union's Horizon Europe research and innovation program under grant agreement No 101083558

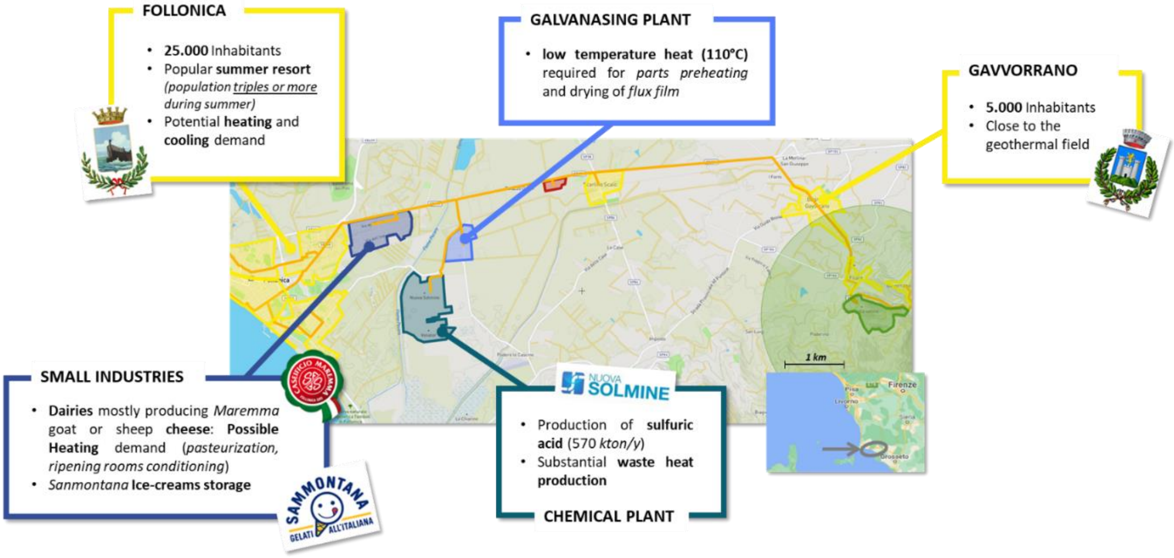

Figure 20. Possible DH network connecting the Gavorrano geothermal area with Follonica.

Highlighted in the map are: the **geothermal field** (in green – in dark green is the **abandoned mines** that originated the geological study), **residential areas** (in yellow), a **shopping centre** (in red), **industrial areas** (in different blue scales): **small business** including some **dairies** (Violet), **galvanising plant** and other manufactories (Light Blue), **chemical hub** containing the Nuova Solmine Plant (Dark Blue). In orange a **possible DH network** fuelled both by the geothermal wells and by the chemical plant waste heat

The **monte Amiata** site is located close to an important geothermal field that has been intensively exploited in the past decades for power production purposes. Excluding the geothermal power plant, the surrounding area is sparsely populated with few industrial activities.

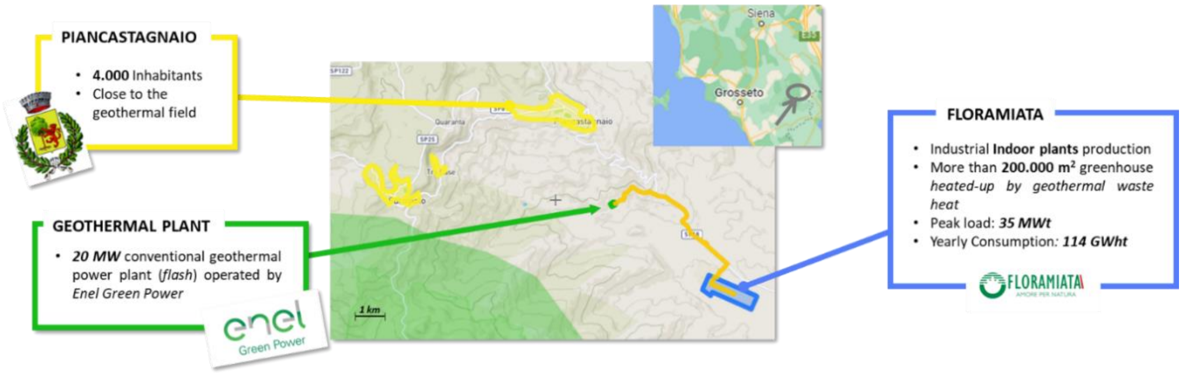

Figure 21. Existing activities in the monte Amiata Area.

Highlighted in the map are: the targeted geothermal field (in green), residential areas (in yellow), **Floramiata industrial area** (in blue), "conventional" **geothermal power plant** (in dark green). In orange an existing **DH network** that provide residual heat from the geothermal power plant to Floramiata.

In the **Gargano** site the targeted geothermal reservoir is located close to Manfredonia, a city in northern Puglia. The city has 50.000 inhabitants hence, despite the required heating demand is generally lower due to the higher temperatures in southern Italy, around **130 GWht** are expected to be required for residential heating purpose. Moreover, substantial cooling demand are expected during summer period. Heat demands assessment has been made following the same methodology described for the Gavorrano case.

Figure 22. Existing activities in the monte Gargano area

Highlighted in the map are: the targeted **geothermal field** (in green), **residential areas** (in yellow), **Flat glass production plant** (in blue), and an **Industrial fish market** (in violet).

UNIBA: The first evaluation in the Gavorrano area indicates a permeability in the order of 10-13-10-14 m^2, to be used to evaluate the influence of the HOCLOOP concept in the presence of hot fluids circulating in the fractured geothermal system.

IFPEN: To facilitate the future integration of the HOCLOOP innovation at the pilot sites, IFPEN gathered and summarised all necessary requirement specifications. These specifications will be used to develop the functional design specification, to capture designs, concepts, and process flow information as inputs for the other tasks. This process led to the determination of the types of data required to assess the applicability of the HOCLOOP concept, concerning aspects such as underground characteristics, current and planned local energy system, expected electricity and thermal energy flows.

For the Paris basin, data about the target formation is available from 49 existing geothermal projects and advanced basin modelling. The site of Fresnes has been selected as a case study because of presence of the different aquifers, the availability of the data, and the large need for renewable heat and cold at the surface. Information about the thermal conductivity of the different lithologies is limited and comes with a large uncertainty because no direct data is available. The values proposed in the report result from modelling exercises. In the absence of data, no calibration on existing data has been carried out.

The Fresnes geothermal site is based on 3 wells targeting the Dogger reservoir: 2 injection and 1 production well. In the present configuration, the geothermal district heating network covers 76% of collective housing and public equipment. A network enlargement is planned, and an additional production well might be needed in the future. This enlargement might be difficult in an area with a high density of geothermal wells already drilled or planned.

The HOCLOOP technology could be an alternative solution to the drilling of an additional production well. The best option in that case, would be to target layers at different depths than the Dogger reservoir. During the HOCLOOP project, the optimization of the depth of the horizontal part of the well, its length, the diameters, insulation and the nature of the heat transfer fluid will be analysed to obtain the best heat production over time.

The detailed work developed is available in D4.1 classified as "public".

3.3.2. Task 4.2 - Underground simulations of the HOCLOOP concept at the selected pilot sites (M6-M30)

Task lead: **VITO** – Participants: **TUD, UNIFI, UNIBA, IFPEN, RW**

Activities performed per partner:

VITO: As task leader, VITO is organizing bimonthly meetings with the partners involved in T4.2 to assure the good follow-up of the activities in this task and to align the efforts of the different pilot leaders. In this task, VITO has started to model the heat extraction at the Balmatt site using the simulation tools developed in T2.3 by IFE. The input parameters for the simulations are based on the ones collected in T4.1. They include thermal properties of the layers that are targeted and crossed for heat extraction but can also include the rock mechanical properties when relevant. VITO aims at evaluating, for a few defined production scenarios, the long-term energetic performance (production temperature, thermal output, COP) and, when relevant, impact on stress distribution in the subsurface under selected production scenarios. The scenarios are the ones derived from the USR (T4.1) and include different injection flow rates and injection fluid temperatures for water. So far, VITO has modelled 2 scenarios based on preliminary conceptual designs that will be refined in the coming months.

TUD: Data from WP 4.1 is being used to create geological structure models, surface component models, and a Co-Simulation model. These models will be instrumental in evaluating the technical and economic efficiency of HOCLOOP's solutions in comparison to the underdeveloped solution.

UNIFI: To the moment, UNIFI has been contributing with data for the simulations developed by other partners, as well as participating in the task meetings and discussions.

UNIBA: Like UNIFI, UNIBA has been contributing with data for the simulations developed by other partners, as well as participating in the task meetings and discussions.

IFPEN: In the first six months of task, IFPEN has primarily assisted VITO with the modelling work developed.

RW: Like in task 4.1, RW joined the development of the task (through meetings and data analysis) to contribute to improve models and designs for the HOCLOOP concept.

Main results from partners (without sensitive data):

VITO: Task 4.2 started recently with modelling of the heat extraction at the Balmatt pilot site using the simulation tools developed and validated in T2.3. The input parameters used for the modelling are collected from D4.1 as well as the scenarios to be modelled which are derived from the USR.
VITO is responsible to evaluate the long-term energetic performance (production temperature, thermal output, COP) and the impact on stress distribution in the subsurface under selected production scenarios. VITO will include different injection flow rates and injection fluid temperatures for water.
At this stage, VITO is evaluating the possibility of reusing its well MOL-GT-03 as drilled (without drilling an additional horizontal section to the existing well).
Two scenarios are considered so far:

a. Heating new buildings:

2500MWh/y (0.49 MW) 1st 10y @ T>= 45°C.

3500MWh/y (0.68 MW) 2nd 10y @ T>= 45°C.

b. Preheating Balmatt's surface water network @ T>55°C.

The preliminary design for scenario 'a' consists in 1/ HOCLOOP completion down to the bottom, 2/ Flow rates: 3kg/s (1st 10y) and 12kg/s (2nd 10y) and 3/ a heat booster required after 10y.
The preliminary results obtained for this scenario are presented in Figure 23.

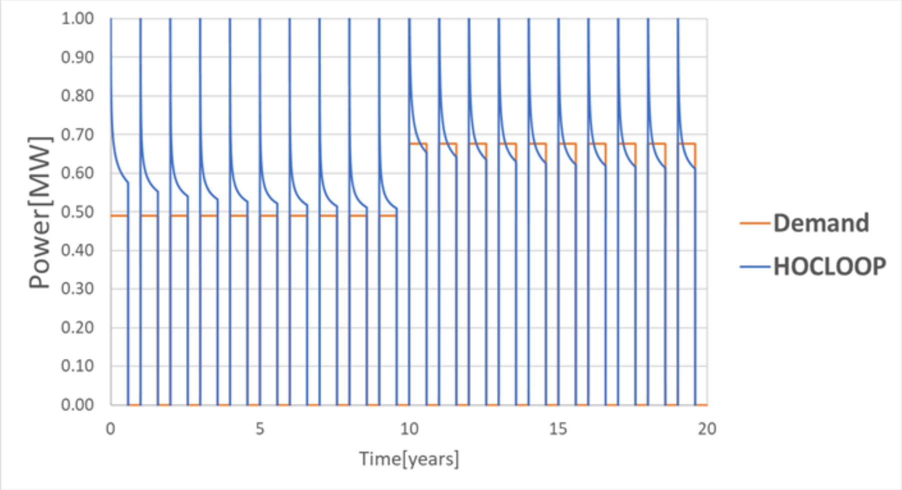

Figure 23. Preliminary results illustrating the Power output for scenario 'a' assuming a 7months/year operation of the system.

The modelling results presented in Figure 23 is performed using the GTW simulator developed by IFE and validated in WP2.
The next step will consist in developing flow rate optimization strategies and test the impact of adding a horizontal well section to the existing well configuration.

3.3.3. Task 4.3 - Conceptual design and techno-economic feasibility study (M15-M36)

Task lead: **IFPEN** – Participants: **TUD, UNIFI, UNIBA, VITO, RW, IFE**

The task is yet to be initiated.

3.3.4. Task 4.4 - Preparation of Pilot site documentation for future implementation and demonstration of the HOCLOOP concept (M30-M41)

Task lead: **RW** – Participants: **TUD, UNIFI, UNIBA, IFPEN, VITO, IFE**

The task is yet to be initiated.

3.3.5. Task 4.5 - Key parameters for forward replicability of the HOCLOOP concept at other locations (M18-M42)

Task lead: **UNIBA** – Participants: **UNIFI, RW, IFPEN, TUD, IFE**

The task is yet to be initiated.

3.4. WP5 - Drill Heat String - design, build and workshop test

WP leader: **RW**. Period of implementation: **M1 – M22**.

3.4.1. Task 5.1 - Design and build the Drill Heat String (DHS) and components (M1-M18)

Task lead: **RW** – Participants: **IFE**

Activities performed per partner:

RW: Detailed design of the DHS and components. This has been the main activity for Reelwell in the period. The result of the work is reported in D5.1. Also the plan for the workshop tests and build the workshop test arrangements is reported in D5.3. The work has been performed and the test plan was completed in August 2023. Manufacturing of the DHS components for workshop testing. The work has started and is the main ongoing activity. Special focus is on the critical components for the DHS, i.e. Centralizer, Tension Anchor, Bottom Hole Sub, Tubing Hanger and the DHS Handling Protector.

IFE: The corrosion specialists at IFE assisted RW in the work developed in task 5.1 in the analysis of risks of corrosion and mitigation through material selection for the DHS.

Main results from partners (without sensitive data):

The detailed results produced in the present task are described in deliverables 5.1 and 5.3, both classified as "sensitive" and thus will not be presented in the present document. No significant deviations from the original implementation plan occurred.

3.4.2. Task 5.2 - Workshop test the DHS and components (M7-M22)

Task lead: **RW** – Participants: **IFE**

Activities performed per partner:

RW: Most of the necessary elements for the testing of the DHS on RW's workshop are determined and the process is ongoing. Assembling of the required of the infrastructure required at the workshop is initiated.

IFE: the main role of IFE is to assist RW (whenever necessary) with knowledge and skills to develop the required experimental infrastructure.

Main results from partners (without sensitive data):

All results produced by the present task are classified "as sensitive" and will be detailed in D5.2 and 5.4, due on M18 and M22, respectively, of the project implementation.

3.5. WP6 - Full scale test-operation

WP leader: **RW**. Period of implementation: **M1 – M22**.

3.5.1. Task 6.1 - Plan and prepare the full-scale test (M1-M29)

Task lead: **RW** – Participants: **NORCE, IFE**

Activities performed per partner:

RW: Plan the full-scale operation at Ullrigg in Stavanger. The work has started, several meetings have been performed between NORCE and Reelwell. NORCE is in the process of drafting a test plan document to be finalised when the Reelwell workshop testing has been performed.

NORCE: Together with RW, NORCE are participation the elaboration of the plan for the full-scale test at Ullrigg and preparing its execution. The work developed from M3 – M12 (NORCE joined the project as beneficiary on M3) is focused on considerations about well-head design, and potential re-use of the equipment at other possible pilot sites.

IFE: IFE has initiated the evaluation of the logistic requirements for the test and sequence of operations. Alternative plans are also under consideration. IFE are developing the plan to manage all necessary suppliers to be involved in the test.

Main results from partners (without sensitive data):

At the moment, no relevant results are available. Task 6.1 consists primarily of planning and preparation, and so when it is completed, all details will be formalised in D6.1 due on M22 of the project implementation, classified as "public".

3.5.2. Task 6.2 - Perform the full-scale test operation (M29-M33)

Task lead: **NORCE** – Participants: **RW, IFE**

The task is yet to be initiated.

3.5.3. Task 6.3 - Analysis and reporting (M33-M37)

Task lead: **RW** – Participants: **NORCE, IFE**

The task is yet to be initiated.

3.6. WP7 - Social acceptance, citizen engagement and environmental assessment

WP leader: **UVA**. Period of implementation: **M4 – M42**.

3.6.1. Task 7.1 - Analysis of the community acceptance of geothermal energy by closed loops (M4-M36)

Task lead: **UVA** – Participants: **IFE, UNIBA**

Activities performed per partner:

UVA: The activities include stakeholder identification via interviews done in HOCLOOP pilot sites (4 interviews) and a media study. The media analysis under task T7.1 uses HOCLOOP pilot sites to examine how traditional media and social media have covered deep geothermal energy deployments. In our analytical work so far, we have focused on the analysis of Mol site in Belgium. This will help us better understand how deep geothermal energy is represented in media and how to foster social acceptance in future projects.
Our analytical approach is built on the latest technological advances to analyze sizeable textual corpus. We decided to develop our analytical tools on artificial intelligence (AI) tools (ChatGPT and interpreter plugin). The news database included 86 local newspaper articles, three radio station audio clips and three TV news

video clips.

We organized a co-creation workshop in Finland on 10.8.2023 titled “Co-creating carbon neutral future: How can a deep-geothermal system support just transition at the regional level?” to examine the social acceptance of deep geothermal. The workshop was organized in conjunction with the Wasa Future Festival and attracted 17 participants. The University of Vaasa was a prominent part of the Wasa Future Festival Week programme in 2023. The event took place from the 7th to the 12th of August and gathered skilled and motivated doers from companies, universities, and decision-makers to solve problems and create solutions in the fields of economy, technology, and culture. The speakers included EU Commission member Jutta Urpilainen, Minister for European Affairs and Ownership Steering of Finland Anders Adlercreutz and several members of the Finnish parliament. The co-creation workshop included an introduction framing the conditions and the context for the collaborative part, which was carried out based on the world café method. Three discussion groups circulated at three facilitated discussion tables focusing on three main topics: Participation and regulation, benefits and challenges, and long-term view.

IFE: Short contributions to meetings and discussions of technical questions regarding the general HOCLOOP project vision.

UNIBA: Exchange of insights based on UNIBA’s experience acquired in the context of geothermal energy exploration and exploitation.

Main results from partners (without sensitive data):

UVA: *Stakeholder identification*. The stakeholder identification under task T7.1 is based on interviews and media studies. The analysis was done for Mol pilot site in Belgium. The key stakeholders include VITO, Hita (company), Voka (the Flemish entrepreneurial network), the local community, and the Flemish government.

Media study. We performed a sentiment analysis of the texts. The results of the analysis indicated that only four articles had a negative sentiment. We also analyzed if opposition to geothermal was discussed in the articles. Only 2% of the articles mentioned any opposition. This suggests that while opposition exists, it may not be a prevailing sentiment in the broader media coverage of geothermal energy. However, stakeholders in the geothermal energy sector must address the concerns of earthquakes, environmental pollution due to the use of chemicals in extraction, radioactivity, and the cumulative soil impact effectively to ensure the sustainable development of geothermal projects.

In the analysis of economic benefits, the most common benefits were significant job creation in both direct and indirect sectors, cost efficiency leading to consumer savings, competitive energy prices, and potential for considerable revenue generation and profitability for the companies involved. The articles underscore various social benefits, including providing geothermal heating and electricity to vast areas, benefiting thousands of households and businesses. Improvement of community engagement, quality of life, and living environments, fostering trust and increasing tourism and recreational opportunities. Stimulation of local entrepreneurship and economic growth.

Examining social acceptance via a co-creation workshop arranged as a part of the Wasa Future Festival in August 2023.

The aspects raised in the discussion can be summarized as follows: Benefits and challenges, as well as a range of questions, were related to economic, environmental, technical and social aspects of the solution, which should be considered in the social acceptance context. Examples of benefits highlighted were that the solution has a long life-cycle (economic), that it is an excellent addition to a renewable mix, not intermittent, an infinite source (environmental), that it is a reliable energy source (technical) and that the solution can enable just energy transition by focusing on the middle class typically living in houses with district heating (social). Examples of challenges discussed were the high investment and maintenance costs (economic), the risk of earthquakes (environmental), that the technology needs to be replaced in a long-term perspective (technical) and that people in rural areas are not getting any positive benefits (social). In addition, various communicational, participatory and regulatory aspects were highlighted, which should be utilized to foster social acceptance. Examples of communicational aspects were the need for open and transparent communication also about the risks and the possibility of using existing solutions, e.g. geothermal wells for houses, as a touchpoint in communication. As a participatory aspect, the need for expectation management was raised, calling for the need to have a plan B scenario in the case of drilling failure and to use larger events and social media for engagement (and not only information) with stakeholders. Concerning regulatory aspects, e.g. the need for new regulations regarding land use compensation and the need for incentive mechanisms to support market introduction were raised.

The task is ongoing and in its early phase. The detailed methodologies and conclusions will be presented on M36 of the implement of the project in D7.1 classified as "public".

4. Technical Dissemination and Communication

Table 8 summarises the technical dissemination and communication actions chronologically, describing the nature and lead partner responsible, between M1 and M12 of the project implementation.

Table 8. Technical dissemination and communication performed within the HOCLOOP (M1 – M18)

Date	Nature	Lead Partner	Description
15.12.2022	Talk	RW	The general HOCLOOP concept was presented at the "Matchmaking Geothermal" in Oslo, Norway. Event organised by the Norwegian Geothermal Association (CGER).
14.03.2023	Talk	RW	Challenges and opportunities for the implementation of the HOCLOOP concept were presented at the conference "Energy Norway 2023".
22.03.2023	Poster	UVA	The HOCLOOP project, with focus on UVA's contribution, was presented at "Vaasa Energy Week" in Finland (22nd March 2023) at the city hall of Vaasa, Finland.
31.05.2023	Talk	RW	Production of geothermal heat from closed loop systems – the HOCLOOP, at CGER GeoEnergy in Bergen.

01.09.2023	Thesis	UNIFI	The UNIFI model used in Task 2.2 is an extension of the model presented in the PhD Thesis of Pietro Ungar which is currently under review and will be published in 2024. In the thesis a specific chapter is devoted to the model description.

5. Deviations to the Technical Implementation

One of the original beneficiaries of the HOCLOOP decided not to participate in its implementation. The plan and subsequent amendment process to include NORCE as beneficiary and redistribute the tasks caused a small delay in the progress of WP6, however, the activities are ongoing at a good pace, and we do not foresee any negative impacts to the implementation of the project at this stage.

Partner RW reported slight delays in the implementation caused by the abnormal difficulty in securing the necessary manpower. Two new engineers are hired for the project since June 2023, and the progress should be up to date soon.