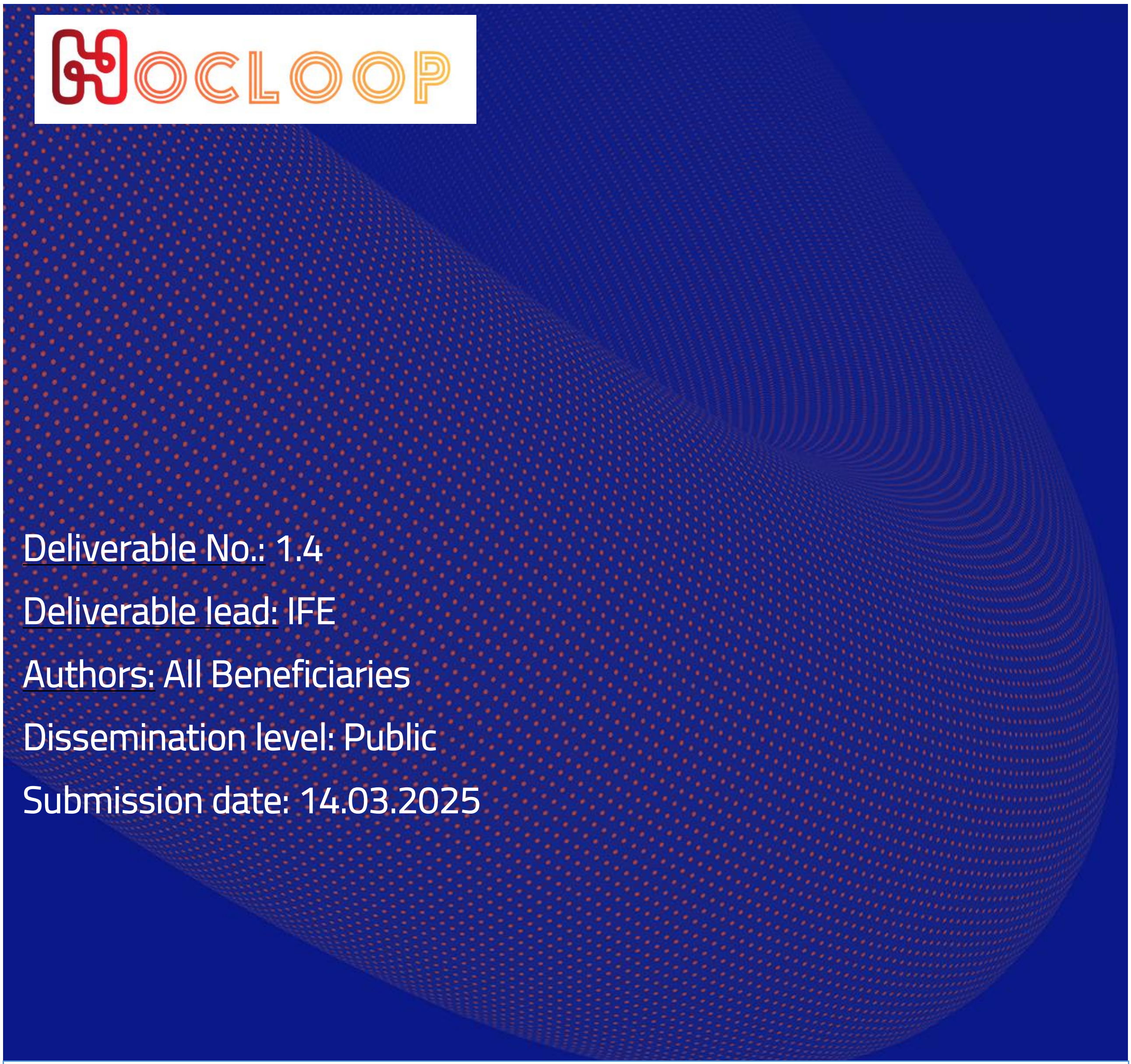
D1.4 Second Technical Annual Report



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PROJECT INFORMATION

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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
GA	Grant Agreement
HLO	High Level Objective
IL	Ionic Liquid
KPI	Key Performance Indicator
PFD	Process Flow Diagram
P&ID	Process and Instrumentation Diagram
sCO_2	Supercritical carbon dioxide
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 second 12 months of implementation of the HOCLOOP project (01.10.2023 to 30.09.2024), within the scope of technical work packages (WP2 – WP8). 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.

Using the "Hop On facility", a new beneficiary was included in the HOCLOOP project from March 01st, 2024 onwards: the "AKADEMIA GORNICZO-HUTNICZA IM. STANISLAWA STASZICA W KRAKOWIE" (AGH) from Krakow, Poland. AGH are extending the activities foreseen on WP3, WP4, and WP7, and introduce a new work package (WP8) dedicated to exploring the possible synergies for direct integration of the HOCLOOP concept in industrial energy systems.

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 second year of the implementation, HOCLOOP's all scientific technical activities were initiated and developed in line with the implementation plan described in the Grant Agreement. However, some deviations from the work plan were observed: the tasks of work package 3 suffer from a slight delay triggered by the bureaucratic challenges faced by the beneficiary UNIFI with the commissioning of their laboratory large-scale CO_2 rig. This deviation is being followed closely by the coordinator and will merit further action if needed.

The WP6 leader (RW) decided to try to anticipate the pilot of the DHS. After discussions with the other partners involved (IFE and NORCE) it was decided to initiate the test on October 2024. The test would then run for a period of 4 weeks until November 2024. Thus, more dedication was put on WP6 then what would be expected from the implementation plan. All necessary preparations for the field pilot were in place by the end of September 2024.

All activities on WP2 were successfully completed until March, 2024. The models and simulators for the heat transport, fluid flow, and geometric configuration of the HOCLOOP concept are now available through deliverables D2.1 – D2.5.

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 Italy, 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.

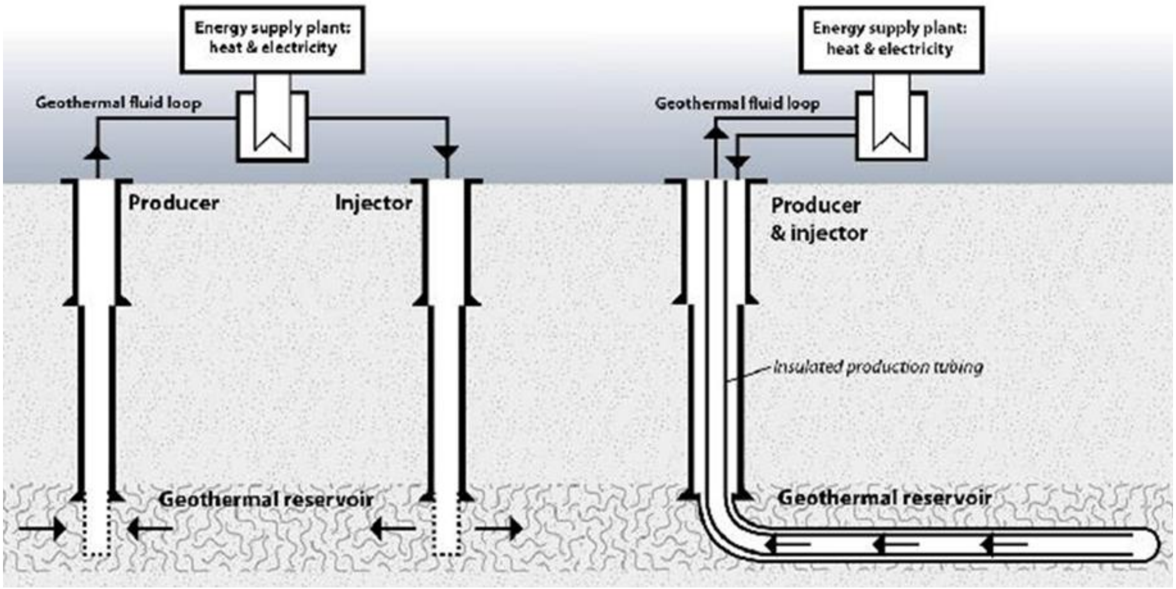

*Figure **1**. General HOCLOOP concept - Left side: conventional two well solution; right side: HOCLOOP single well solution.*

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 ten partners from seven different countries, following the inclusion of a new beneficiary (AGH) from Poland through the Hop On facility on March 01st, 2024. 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
10*	University of Science and Technology Krakow	AGH	Poland

** From March 01st, 2024 onwards.*

1.2. Objectives and content of D1.3

The present document (Second Technical Annual Report) provides an overview of the project achievements and the progress of the work within the second year of the HOCLOOP project's implementation (M13 – M24). 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 second year of the HOCLOOP and the main conclusions produced. It is a comprehensive 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 M13 and M24 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 3 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 M13 – M24 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 Following the decision to anticipate the full-scale operation at Ullrigg, and the analysis of the resources necessary, the testing of the optional drill-in solution will be performed after this test. This led to further development of the design of the DHS bringing it closer to an eventual piloting of the technology. Partner RW successfully took this effort and the additional optional work is now completed.

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1.1b) Building and testing of the DHS

The manufacturing of the DHS components was completed in RW's workshop and using the resources of manufacturing in small local ones. The process of design and testing took longer than expected, as it required an iterative approach considering both installation and operation performance. The whole process, including the optional drill-in solution, is now completed and the details will be formalized in D5.2 classified as "sensitive". D5.2 is delayed, primarily due to the focus of the resources available in the anticipation of the full-scale operation.

SO1.2: Full scale DHS test operation to TRL5

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

The HOCLOOP project implementation foreseen the execution of a "full-scale" pilot at NORCE's Ullrigg tests centre in Stavanger between M29 – M33. Partners RW, NORCE, and IFE decided that this operation would be anticipated to M25 – M29. This was primarily triggered by: i) the creation by RW of subsidiary company (Geotherma AS) dedicated exclusively to the exploration and exploitation of geothermal resources based on the IPRs related to the HOCLOOP technology, and ii) the necessary knowledge, and resources were in place to perform the test earlier, thus enabling the further development of the optional drill-in solution. By the end of September 2024, the detailed operational, logistics, and HSE plans for the full-scale DHS test had been concluded and were being implemented by all the partners involved (RW, NORCE, and IFE).

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

This objective was successfully achieved before the period covered in the present report, and is described both in D1.3 and D2.1, defined as public.

2.1b) Model for fluid circulation in the flow pipe

This objective was successfully achieved before the period covered in the present report, and is described both in D1.3 and D2.2, defined as public.

2.1c) Heat flow model for the closed loop system

The work performed and presented up to M12 in D1.3, D2.1, D2.2, and D2.3 was extended and merged. A full heat flow model (from the geological formation to the end user) for the closed loop system is now available and the details publicly available in D2.4 and D2.5.

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

The experimental activities are somewhat delayed primarily due to the long led time in the supply of the test system to UNIFI. Tests are expected to be initiated on early spring, 2025.

An initial techno-economic analysis of the performance of the closed loop system using CO2 as the heat transport fluid was initiated. Initial modelling and simulation results suggest that the optimal depth increases as the gradient decreases and the optimal horizontal length does not vary significantly. Once a certain geothermal gradient is reached, the LCOH value decreases sharply. This behaviour is due to the

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ability of the CO2 to supplement the thermal energy production with electricity generation via an auxiliary turbine, particularly significant in regions with high geothermal gradients.

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

Following the conclusion of the work on 4 European pilot sites located in Belgium, France, Germany and Italy, the inclusion of AGH extended the characterization to a new case: Poland. The work was completed and is publicly available and detailed in D4.1, ed. 2.

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 developed in task 2.3. Input parameters for each of the possible pilot sites are collected from D4.1, ed2. Part of the description of the conceptual closed loop systems designed specifically for each pilot and the different scenarios used to assess the long-term energetic performance is ready. Dynamic simulations are ongoing and all outcomes will be made available in D4.2 due on March 31st, 2025.

3.2b) Conceptual design and techno-economic feasibility

Different possible conceptual pre-designs of both the underground loop and the above ground energy system for each of the pilot sites are under development. Based on the designs a more detailed energy flow simulation is under development to calculate the different KPIs defined in the project. A multi-criteria analysis of the most promising pre-design and their corresponding preliminary P&ID plan, CAPEX and OPEX estimation will close the activities. All activities and findings will be made available in D4.3 due on March 30th, 2025.

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 and presented in D1.3 was extended and now several relevant stakeholders directly related to the deployment of the closed loop technology for exploitation of geothermal resources are identified across all the countries of the partners involved in the project.

4.1b) Media representation

Work led by partner VAASA expanded the examination of how traditional media and social media have covered geothermal energy deployments presented in D1.3.

In social media channels, public discussions were mainly about environmental benefits, seismic concerns, and local community involvement. While sentiment was largely positive, local concerns, such as seismic activity in Belgium and Italy, and opposition in specific areas like Monte Amiata, were also significant findings.

In traditional media, the analysis performed in the period of covered by the present report shows that the media coverage of geothermal energy projects is generally positive, contributing to increased social acceptance in Belgium over the years. The most commonly reported benefits are carbon emission reduction, job creation, and community heating. Despite positive sentiment, challenges such as drilling risks and seismic concerns were noted, potentially hindering acceptance. Key social actors identified were government organizations, industries, and entrepreneurial networks, indicating growing private sector involvement. The innovation of using GPT-4 for media analysis proved efficient and accurate, but there should be manual oversight to ensure the reliability of AI-generated results.

A co-creation workshop held in Darmstadt, Germany, outlined possibilities for deeper local participation. Once the site is ready, e.g., a showroom connected to the site could communicate to and educate citizens and stakeholders. This could include showing, e.g., the drilling equipment via posters, presenting the project, and communicating main messages. Real-time data from the site could be shown via monitors to show what is happening underground. The participant raised some concerns about compensation of local communities and eventual long-term negatives effects.

SO4.2: Sustainability assessment

The HOCLOOP project's activities that directly target the sustainability assessment are 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, only 7.2 was initiated on M13 and T7.3 on month 24.

The contributions to this objective are, for the moment, relatively limited, however a concept for the HOCLOOP business model workshop, and a detailed plan for the implementation of the first business model workshop were achieved. This concept can be used to systematically engage the relevant stakeholders in open discussions to define more sustainable approach to deploy the HOCLOOP technology considering all local relevant particular conditions (social, economic, geologic, and energy usage).

2.2. Deliverables and milestones

Table 4 lists the status and eventual deviations of the technic/scientific deliverables and milestones planned between M13 – M24 of the HOCLOOP project (WP2 – WP7).

Table 4. Status and deviations of HOCLOOP's deliverables and milestones (M13 – M24)

Deliverable/milestone	Lead Beneficiary	Due date	Status	Submission date	Deviations
D1.3 – Annual report I	IFE	30.11.2023	Submitted and approved	30.11.2023	-

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D1.7 – Innovation exploitation, communication and dissemination plans	IFE	30.11.2023	Submitted and approved	25.01.2024	Delayed submission*
D2.4 – Optimized design for the closed loop	IFE	31.12.2023	Submitted and approved	19.12.2023	-
D5.2 – Manufacturing of the DHS components	RW	31.03.2024	Pending	Pending	Pending*
D2.5 – Validation of cylinder geometry-based simulation of the closed loop geothermal system	IFE	31.03.2024	Submitted	08.05.2024	Delayed submission*
D5.4 – Workshop test report of the DHS assembly and individual components	RW	31.07.2024	Pending	Pending	Pending*
D6.1 – Plan for the full-scale operation at Ullrigg in Stavanger	RW	31.07.2024	Pending	Pending	Pending*
D6.2 – Risk considerations, alternative back-up solutions and contingencies	RW	31.07.2024	Pending	Pending	Pending*
MS3 – Model for subsurface heat influx	IFE	31.03.2024	Achieved	28.03.2024	-
MS4 – Manufacturing of the DHS components for workshop testing	RW	31.03.2024	Achieved	15.03.2024	-
MS5 –Workshop test fulfilled for the DHS assembly and components	RW	31.07.2024	Pending	Pending	Pending*
MS6 – Commissioning of CO2 test bench	UNIFI	30.09.2024	Pending	Pending	Pending*

* See section 5 for detailed information

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. This being the technical report for the second year of implementation, all work presented was performed from M13 (October 2023) up to M24 (September, 2024).

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**

All activities of T2.1 were successfully completed in M12 and are thus presented in D1.3 – Annual Technical Report 1.

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

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

Activities performed per partner:

IFE: Following the benchmarking of the different available tools for well modelling and results for different well configurations using water as pipe-fluid presented in D2.2, the findings were optimized for integration with the pipes flow models to generate the necessary overview for the completion of T2.3.

IFPEN: Various configurations of the wellbore were investigated through 1D simulations, considering the thickness, the materials, the possibility of inserting some innovative geometries or even to create some small portion of vacuum. The simulations also tested different well-radii, bottomhole depths, rock heat conductivities and geothermal gradients. Deliverable D2.4 was prepared under the coordination of IFPEN and concluded in line with the implementation plan.

UNIFI: UNIFI's code was used, together with the code of the other participants in the task, to evaluate the impact of different parameters on the expected outcomes of the well. More specifically, UNIFI has evaluated the impact of well insulation thermal conductivity and geothermal gradient.

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

Main results from partners (without sensitive data):

IFE: Results transferred to T2.3 to enable its completion.

IFPEN: Within Tasks 2.2 and 2.3 (D2.4), the impact of different parameters on the performance of the closed-loop solution proposed in the HOCLOOP project was investigated by performing detailed simulations, considering, however, a realistic well configuration. A compilation of the main findings is presented in the description of T2.3 due to the interlinked nature of both tasks.

UNIFI: Using the code (BHEModel2.0), which has been previously benchmarked with the other partner's models, UNIFI has performed a set of calculations to assess the impact of some design parameters. This was part of a collaborative effort lead by IFPEN in performing an overall sensitivity analysis. In this scope, UNIFI was tasked to perform the calculations for changing well insulation thermal conductivity and geothermal gradient.

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

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

Activities performed per partner:

IFE & IFPEN: Following the benchmarking of the available in-house codes in WP2.1 and WP2.2, as detailed in deliverables D2.1 and D2.2, the next goal was to validate the simulations in cylinder coordinates. The validation has considered the size of grid cells necessary to represent steep temperature gradients close to the well, the initial time step and the required radius of the surrounding rock to avoid boundary effects. The comparisons were based on available analytical solutions. This task also studied the geometric optimization of the pipes. This work is an extension of the work reported in D2.4, where the effect of eccentricity was reported. Through this study, the shape of the outer pipes is morphed using a parametrization, and its effect on the performance parameters is assessed.

VITO: The detailed simulations performed on the concentric pipes were analysed and reported by VITO. Additionally, VITO investigated ways to increase the heat transfer of the concentric pipe system by studying different rib geometries on the outer section. This was achieved by performing detailed numerical simulations of the concentric pipes with different kind of ribs. The analysis and key outcomes of this study were reported by VITO.

Main results from partners (without sensitive data):

IFE: The inner pipe will not always be centred in the well. This may be a problem in horizontal wells where gravity drags the inner pipe down. The degree to which the inner pipe is offset is measured with the eccentricity. Zero eccentricity is a completely central inner pipe and 100% eccentricity is an inner pipe that touches the outer pipe (maximally displaced). To understand the effect of eccentricity on the thermo-hydraulic performance of the pipes, simulation for eccentric pipes was done in steps of 10% from 0% till 90%.

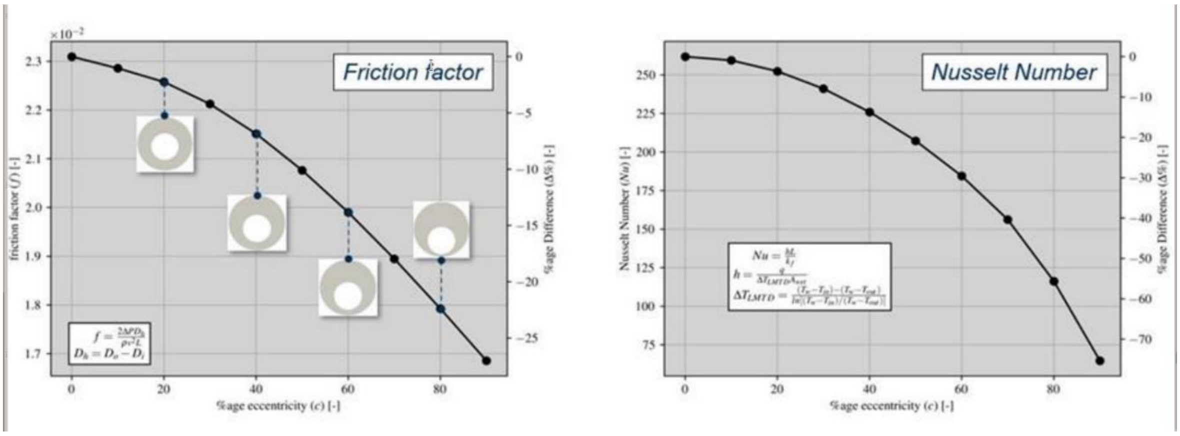

*Figure **2**. (left) The friction factor as a function of eccentricity. (right): The Nusselt number as a function of the eccentricity*

Figure 2 shows that the friction factor is dropping by a factor of 0.7 when the eccentricity increases from 10% to 90%. It is considered a modest reduction in friction. On the other hand, the Nusselt number decreases by 0.3. Therefore, increasing eccentricity reduces the heat transfer.

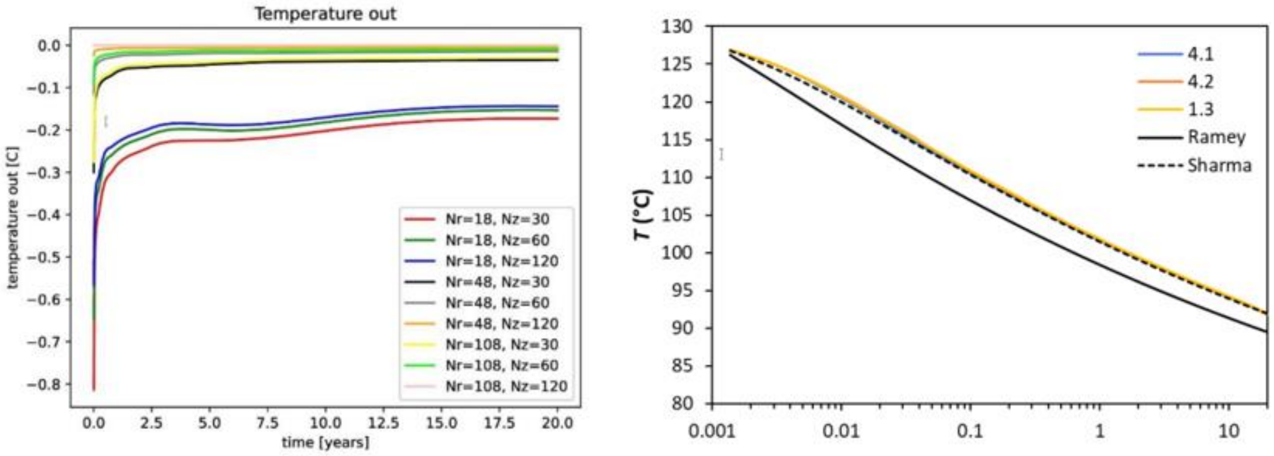

*Figure **3**. (left) The difference in output temperature for different grid resolutions. (right) The output temperature for different factors for increasing the time step.*

The accuracy of a numerical solution depends on the grid resolution and the time steps. We have tested how the output temperature depends on the grid size and the time step by running a series of cases with different grid resolutions and time steps. Figure 3 shows the sensitivity with respect to the grid resolution. The sensitivity is plotted as the difference between the cases and the case with the highest resolution. From the plot we see two things: Firstly, the difference in output temperature is small for the different resolutions. Secondly, an increasing resolution makes the output temperature closer case of finest resolution. Figure 3 (right) shows that different time step sizes has little impact on the output temperature. We can therefore conclude that the simulations are robust regarding the grid resolution and the time steps.

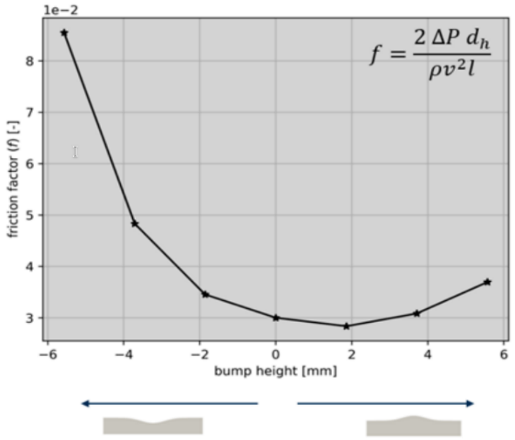

*Figure **4**. The friction factor increases with the size of the surface irregularities.*

The work performed included a study of how surface irregularities impact the heat transfer and the friction. The irregularities can be either small bumps in the surface of the size of 1 mm to 3-4 mm or cavities of the same sizes. Figure 4 shows that the friction increases slightly with increasing unevenness of the surface. The same applies also for the heat transfer (the Nusselt number). A rough surface produces a higher friction

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and a smooth surface and a rough surface transfer more heat.

IFPEN: The well generally consists of an external casing and two inner tubes. Between the inner tubes a layer of insulation material is placed. The fluid is injected at the surface in the space between the casing and the second inner tube, whereas it returns to the surface through the first inner tube. The diameters of the vertical and the horizontal wellbore aren't the same, because a smaller drilling bit is used to open the horizontal section.

A reference case that corresponds to a realistic well configuration was initially constructed. Then, several input conditions, geometric parameters and geological conditions were chosen as parameters to be modified for the sensitivity study. The objective was to cover a range of different operational conditions and geological settings where the closed loop solution could be integrated. IFPEN's tool was used to simulate the reference case, and the impact of the insulation thickness, casing diameter, and rocks conductivity (Figure 5).

The vertical rock conductivity of the formation and the insulation thickness have a low impact in the performance of the system, whereas the diameter of the casing both in the vertical and the horizontal sections have no practical impact, at least on the range tested in the study.

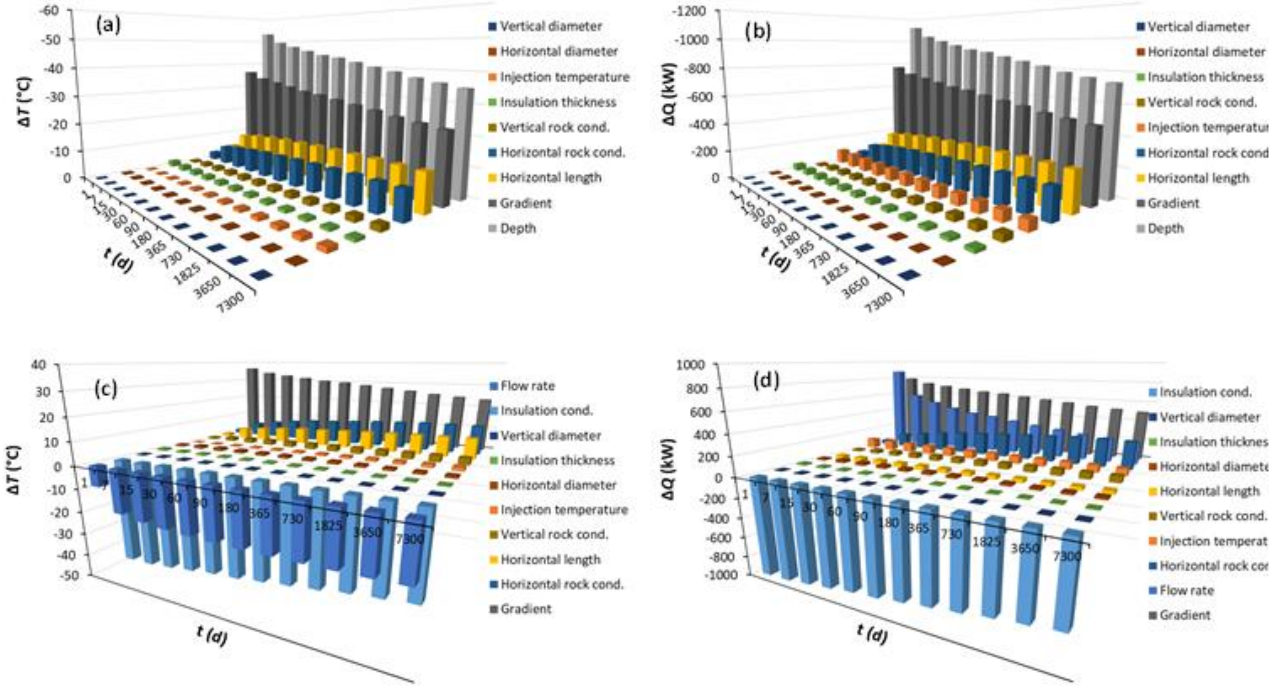

*Figure **5**. Impact on (a, c) the outlet temperature and (b, d) the power production of (a, b) increasing and (c, d) decreasing the values of the input parameters.*

While drilling and installing the dual pipe, a second annulus is formed between the casing and the rock. This section of the completion may be filled either with mud or with a fluid which is present in the reservoir during the drilling, which can be a water-based or an oil-based fluid. In addition, part of the annulus may be filled with one fluid (e.g., mud) and another part with another fluid (e.g., water- or oil-based).

A series of simulations was performed using GWellFM to study the impact of the presence of this fluid. The

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results (Figure 6) showed that the higher the thermal conductivity (mud has the higher conductivity, whereas oil-based fluid the lower) of the fluid, the lower the heat losses. In addition, the evolution of the outlet temperature and the power production is similar as in the reference case (without annulus side). The heat losses between the water-based and the oil-based fluid correspond to around 2 °C and 47 kW, whereas between water and mud they correspond to about 1 °C and 22 kW.

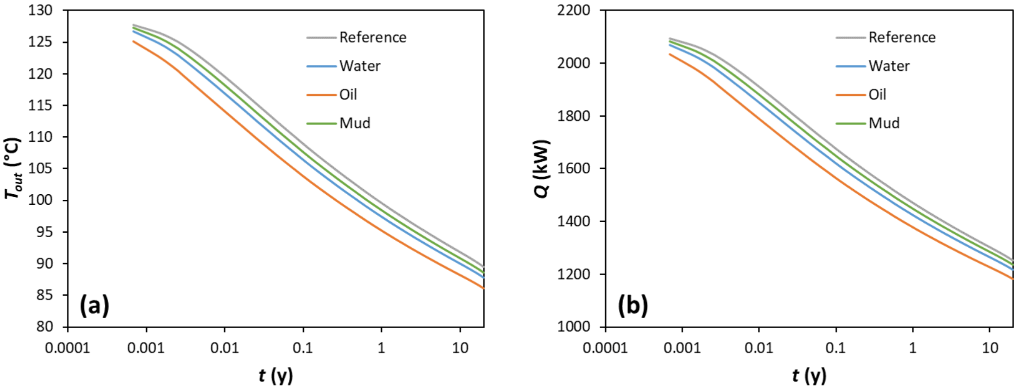

*Figure **6**. Impact on (a) the outlet temperature and (b) the power production by the presence of a fluid in the annulus part of the well completion.*

In addition, more cases were run where the annulus section along the horizontal part was partially filled with mud, water or oil-based fluids. The annulus part in the vertical well is always full of mud. Partially filled annulus results in slightly higher temperature and power when compared to the water case and in lower outcome when compared to the reference case.

A realistic well configuration of the HOCLOOP solution was selected to study the impact of the numerical parameters (mesh, time step and domain size) on the results (Deliverable 2.5). The well consists of an external casing and two inner tubes. Between the inner tubes, a layer of an insulation material was placed. Here, and in contrast with the actual well configuration that was used in study of deliverable D2.4, the diameters of the vertical (depth) and the horizontal (length) wellbore were the same. Also, the properties (density, thermal conductivity and heat capacity) of the rocks were constant in the whole domain (homogeneous hosting formation). The selection of these parameters was done to meet the constrains of the analytical solutions.

Sensitivity studies were performed on 1) the grid size close to the wellbore, Δr1, 2) the total number of radial cells in the rock domain, N, 3) the initial time step, t_0, 4) the time step increasing factor, Δt, and 5) the radial size of the domain, R. The difference between fluid's outlet temperature calculated by the model and analytical solutions, δ, and the total calculation time was compared (Table 5).

*Table **5**. Summary of GWellFM's results and set of tested numerical parameters.*

Case	Time (min)	δ (%)		Sensitivity parameter	Δr_1 (cm)	*N*	t_0 (h)	Δ*t*	*R* (m)
		Min	Max						
1.1	145	1.186	3.681	Decrease size of 1st radial cell	**10**	50	12	1.5	50
1.2	127	0.204	0.914		**1**	50	12	1.5	50

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1.3	124	0.000	0.580		**0.1**	50	12	1.5	50
1.4	124	0.006	0.560		**0.05**	50	12	1.5	50
2.1	95	0.002	0.379	Increase number of radial cells	0.1	**15**	12	1.5	50
2.2	106	0.006	0.550		0.1	**30**	12	1.5	50
3.1	-	-	-	Increase initial time step	0.1	**50**	1	1.5	50
3.2	152	0.000	0.801		0.1	50	**2**	1.5	50
3.3	144	0.000	0.757		0.1	50	**3**	1.5	50
3.4	124	0.000	0.529		0.1	50	**6**	1.5	50
4.1	229	0.001	0.491	Increase time step	0.1	50	12	**1.2**	50
4.2	109	0.000	0.661		0.1	50	12	**2**	50
5.1	102	0.100	67.612	Increase domain radius	0.1	30	12	1.5	**5**
5.2	117	0.063	30.615		0.1	30	12	1.5	**15**
5.3	119	0.006	4.529		0.1	30	12	1.5	**30**
5.4	101	0.000	0.653		0.1	30	12	1.5	**100**

Refining the cell grid closer to the wellbore gave better results in comparison to the analytical solution. There was an optimal size (1 mm) below which the results remained the same, without affecting the computational time. Refining the mesh in the formation domain by increasing the number of the grids but keeping constant the size of the grid close to the wellbore had not practical impact, while the computational demands are slightly higher.

For smaller initial time steps, the deviation with the analytical solution increased at the early stages, while after few time steps were converging giving the same results as before. The impact of the time step size was significant in the simulation time, as it increased considerable for smaller steps. For the smaller time step tested, the numerical tool couldn't converge for the specific numerical set-up, which could be attributed to the fact that flow in the wellbore had not reach the steady-state. The numerical tool assumes that the fluid and heat flow inside the wellbore is always (for every time step) at steady-state. Modifying the increment step of the time step didn't have a practical impact on the results but only on the computational demands. The smaller the step increase, the higher the required time because more time steps were required.

The radius of the domain had a big impact on the results. The smaller the domain, the more profound was the impact on the results. The boundary condition of null heat transfer in the limit of the domain affected the temperature of the fluid in the well. For each tested case, there was a specific time at which the results started to be affected by the boundary condition. Before this time, all results were almost identical. For 20 years of operation a radius of 50 m seemed to be sufficient.

VITO: To enhance the heat-transfer in the concentric pipe, bump like ribs were simulated using computational fluid dynamics (CFD). The bumps on the tube were defined in two configurations, inward bump and outward bump (Figure 7).

*Figure **7**. Illustration of different rib configuration on the concentric pipes.*

To have a feasible comparison, a small section of the concentric horizontal pipe was simulated using streamwise periodic flow solver. The mass-flow across the section was fixed as that of the baseline pipe (see Figure 7) and the parameter of interest was set to heat-flux.

The numerical simulations were performed using a standard incompressible Reynolds Averaged Navier Stokes (RANS) flow solver with modifications related to streamwise periodic flow. The solver used a Shear-stress turbulence model (SST) to close the turbulence equations and the density was assumed to be constant. The numerical simulations were performed for 6 bump configurations, as listed in Figure 8.

Test case	Bump height Δr [mm]
-3	- 5,57
-2	- 3,71
-1	- 1,86
+1	+ 1,86
+2	+ 3,71
+3	+ 5,57

$-\Delta r$

$+\Delta r$

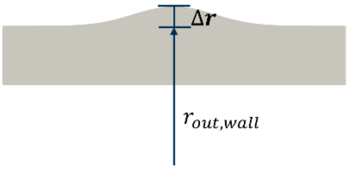


*Figure **8**. Specifics of different rib configuration simulated using CFD*

Based on the numerical simulations performed and the results obtained following Nusselt number and friction factor plots were obtained (Figure 9).

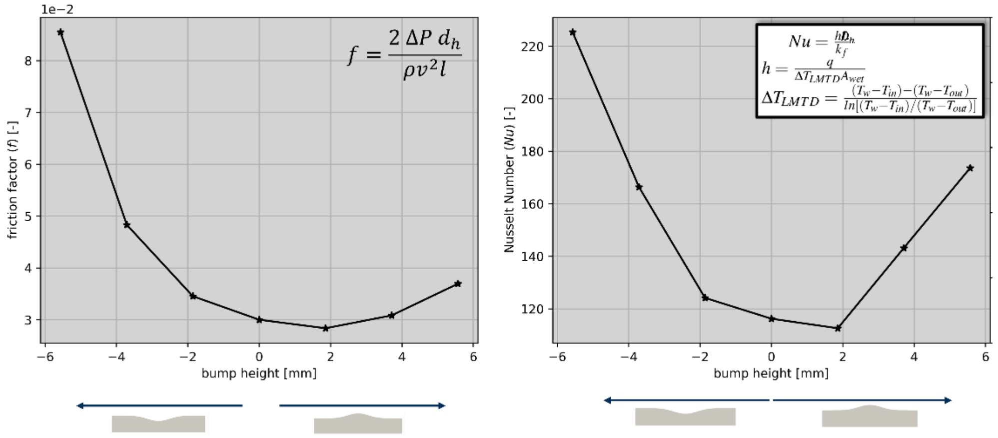


*Figure **9**. Variation of friction factor (left) and Nusselt Number (right) with different bump heights of the concentric pipes.*

Hence, based on the results obtained, configuration with +2mm was proposed as an optimum solution as it provides approximately 5.5% reduction in friction factor with less than 3% reduction in Nusselt number.

Deliverable D2.5 submitted in March 2024 marked the completion of the work within WP2.

3.2. WP3 - Heat transport to surface with CO2 mixtures and alternative fluids

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

3.2.1. Task 3.1 - Experimental activity at laboratory scale and alternative fluids characterization (M18-M36)

Task lead: **UNIBA** – Participants: **RW, UNIFI, IFE, AGH**

Activities performed per partner:

UNIBA: During this period, UNIBA performed experimental activities on the thermal properties of supercritical CO2 (sCO2). Specifically, three ionic liquids (ILs) were tested. The experimental setup was established for the sCO2 experiments and then implemented in the presence of the ILs. A detailed characterization was provided, showing the effects of the ILs on the viscosity of sCO2 and also the effect on thermal behavior as a function of pressure.

UNIFI: During this period, we have finalized the contracts for the acquisition of the main experimental setup to be used in the HOCLOOP project. Support systems, such as the cooling plant and the heating system for the test section has been designed and commissioned as well. In addition, a secondary test bench designed specifically for the evaluation of the heat transfer between the rocks and the well has been designed and commissioned, with the testing phase scheduled to start in the near future.

AGH: AGH's activities within the period covered by the present report focused on analysis of the parameters of working fluids anticipated for use in HOCLOOP in terms of planned laboratory tests and in planning of experiments.

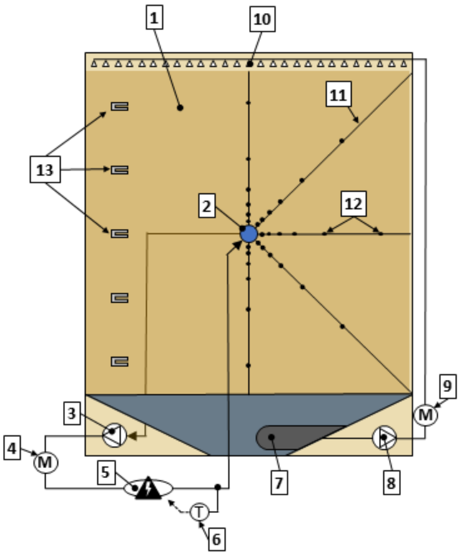
Main results from partners (without sensitive data):

UNIBA: The results are promising for using an IL-sCO2 combination depending on the working temperature, i.e. the geological features. All findings will be detailed in the upcoming deliverables relative to WP3.

UNIFI: To optimize measurement precision and operational simplicity, the experiment proposed in the grant agreement will be conducted using two distinct test benches. The first and more complex bench will be used to examine the thermodynamic behaviour of the working fluids (CO2 and its mixtures) within the well, specifically focusing on natural pressurization and convective heat transfer resistance between the fluid and the pipe. The second bench aims to analyse the heat transfer processes between the pipe and the surrounding rocks, with particular emphasis on scenarios where the fluid movement within the rock matrix may significantly improve the heat transfer.

About the initial bench, whose design has already been detailed in last year's report, this year works has focussed on components acquisition and refining design details. The bench is now commissioned, designed and under construction. It is expected to be delivered in few months (beginning of spring 2025).

Regarding the development of the second test bench, this year it has been envisioned, designed and commissioned, with the testing phase expected to begin in January 2025. As illustrated in Figure 1, this bench comprises a plexiglass box measuring 40 cm x 40 cm x 10 cm (HxLxD). The box is filled with sand and permits water at a controlled temperature to flow vertically through the medium. The water's flow rate is meticulously regulated by a peristaltic pump, allowing precise definition of the Peclet number within the medium. Inside this sand medium, the well is represented by a heated cylindrical element with 0.5 cm diameter, which contains an internal thermal resistance. By measuring the power supplied to the thermal resistance and the temperature of the cylinder and of the sand allow for a precise evaluation of the heat transfer coefficient between the well and the surrounding media. Figure 10 illustrates the basic design concepts for this second test bench.



#	Componente
1	Terriccio
2	Tubazione Riscaldamento
3	Pompa Riscaldamento
4	Misuratore Portata Riscaldamento
5	Riscaldatore Elettrico *(controllato da 6)*
6	Sensore di Temperatura Riscaldatore
7	Tubo di Drenaggio
8	Pompa di drenaggio
9	Sensore Portata Drenaggio
10	Distributore Acqua Irrigazione
11	Filo da pesca *(sostegno termocoppie)*
12	Termocoppie
13	Sensori Umidità Terreno

*Figure **10**. Scheme of the secondary test bench*

AGH: A summary of the physical properties of selected liquids and research to date was produced. Determination of research objectives in connection with planned laboratory experiments. Development of preliminary research methodology.

3.2.2. Task 3.2 - Modelling heat transport within the borehole through alternative CO2 based fluids (M18-M36)

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

Activities performed per partner:

UNIFI: The main activities of UNIFI in this task focused on the development of both simplified and detailed models for the evaluation of the heat transfer and natural pressurization of the CO2.

UNIBA: UNIBA provided the viscosity information obtained in task 3.1 to incorporate in the models, and participated in their optimization.

IFPEN: The in-house tool GWellFM was updated to consider the flow of CO2 in the well. A specific Equation-of-State (GERG-2008) capable of calculating the state and the properties of CO2 has been integrated through the thermodynamic library already available in the tool. Preliminary steady-state calculations were performed to show the ability of the model to capture the thermosiphon effect. Detailed calculations are on-going, and the results will be included in the Deliverable D3.2.

Main results from partners (without sensitive data):

UNIFI: Both detailed and simplified models of the well for CO2-based systems have been developed and used to assess the performance of the system under different conditions. For a comprehensive description of the model please refer to Pietro Ungar's PhD Thesis (listed among the publication and dissemination activities). The model uses REFPROP to retrieve fluid thermophysical properties. Both the simplified and complex model have been uploaded on GitHub.

3.2.3. Task 3.3 - Optimization of the geometry of the loop for an efficient thermo-siphon effect, and evaluation of the gain using alternative solutions and integration with surface plants (M24-M42)

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

Activities performed per partner:

IFPEN: IFPEN initiated the preparations for the development of the task (discussion with partners, planning of activities, etc.), however, only 1 month of work is covered in the present report. The activities about a "preliminary thermo-economic optimization" were initiated by UNIFI.

UNIFI: Preliminary thermo-economic optimization of the HOCLOOP concept for integration with a surface plant, including the identification of optimal geometric parameters based on geological conditions.

Main results from partners (without sensitive data):

IFPEN: No results are yet available for this task.

UNIFI: The aim of the preliminary thermo-economic optimization of the HOCLOOP concept for integration with a surface plant is to determine the optimal geometric characteristics of the HOCLOOP system, based on geological conditions, for its integration with a surface energy conversion plant. To ensure the general validity of the results, both the well and surface plant models have been significantly simplified. This approach allows the analysis to remain independent of specific geological conditions, critical for the implementation of complex models, while also minimizing the computational costs. A validation with detailed models will be performed on specific case studies in the following months.

Drawing on the previously mentioned considerations, the well model was significantly simplified through the adoption of several assumptions, including the adiabatic nature of the ascending and descending sections, the neglection of pressure drops, and the use of a dimensionless parameter to estimate the heat absorbed in the horizontal section. Similarly, the surface system, designed to supply a medium-temperature district heating network with 80/40°C supply/return temperatures, was intentionally simplified, as illustrated in Figure 11:

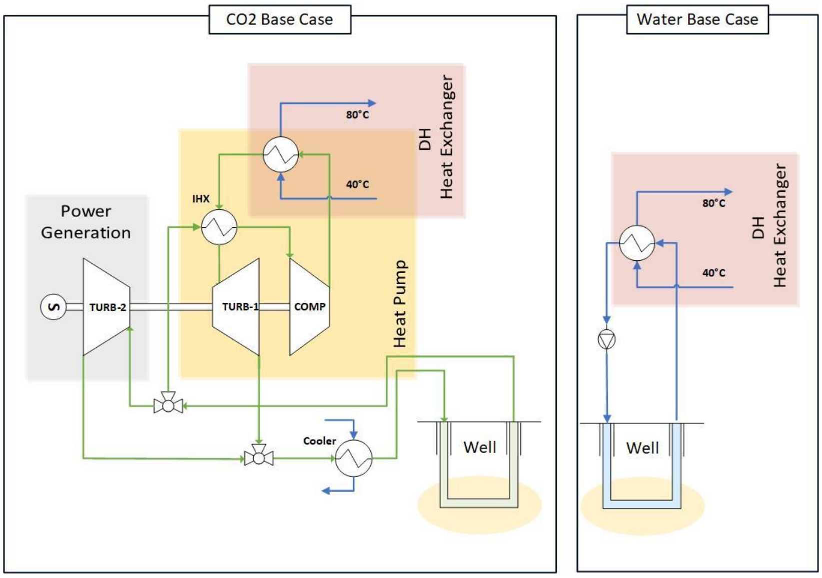


Figure **11**. Surface Plant Scheme for Different Working Fluids (a) CO_2 (b) Water

Two different working fluids, water and CO_2, have been considered, leading to distinct surface plant configurations. In particular, the CO_2-based configuration is slightly more complex due to the inclusion of a parallel turbine, aimed at exploiting the natural fluid pressurization generated by the thermosiphon effect in specific geothermal conditions.

The optimization was carried out by minimizing the Levelized Cost of Heat (LCOH), an economic metric accounting for costs associated with both the surface plant and the well. Beyond geological parameters such as average gradient and depth, the analysis primarily focuses on the length of the well's horizontal section. In the CO_2-based case, the fraction of fluid directed to the auxiliary turbine represents an additional interesting parameter. The power demand of the district heating network was assumed to be constant at 1 MW. The results for the water-based system are shown in Figure 12:

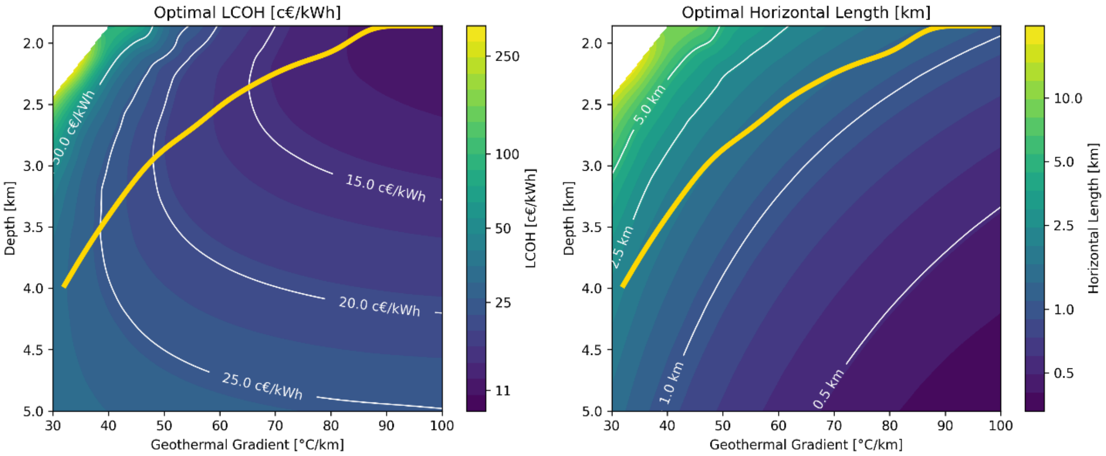


Figure **12**. Optimization Result for the Water-Based Scenario for Different Well Depths and Geothermal Gradients.

As may be observed, for each geothermal gradient, an optimal combination of depth and horizontal length minimizing the LCOH can be found, ranging between 12 and 30 c€/kWh in the areas of interest. Specifically, the optimal depth tends to increase as the geothermal gradient decreases, suggesting that the primary factor influencing the depth is the need to reach a given rock temperature, suitable for supplying the DHN. Conversely, the horizontal length remains relatively stable, varying between 1 and 2 km. These findings provide a valuable foundation for future analyses on complex surface plants. The results for the CO2-based system are shown in Figure 13:

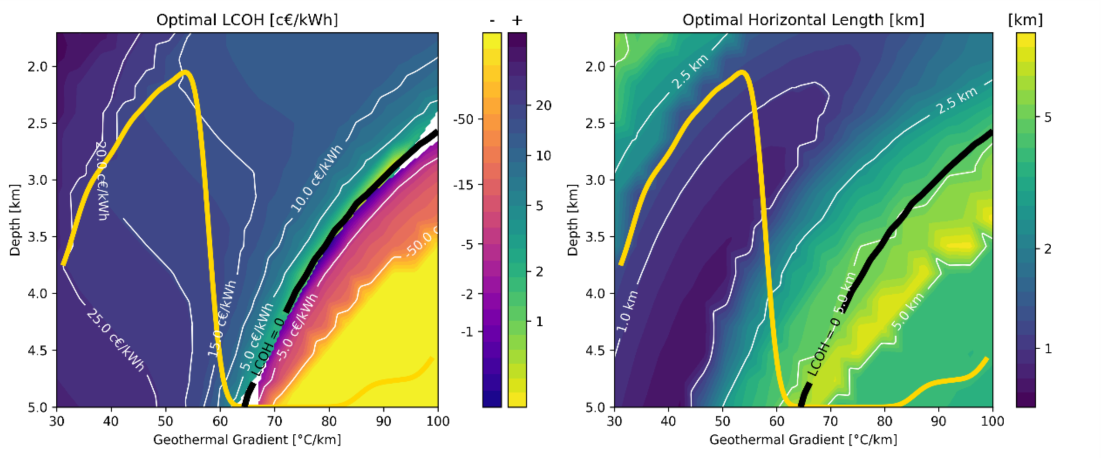


*Figure **13**. Optimization result for the CO2-Based Scenario for Different Well Depths and Geothermal Gradients.*

As observed, the system exhibits a behaviour similar to the previous case for low geothermal gradient values, with the optimal depth increasing as the gradient decreases and the optimal horizontal length undergoing very modest changes. Differently from the previous case of water, once a certain geothermal gradient is reached, the LCOH value decreases sharply. This behaviour is due to the ability of the CO2 to supplement the thermal energy production with electricity generation via the auxiliary turbine, a parameter which becomes particularly significant in regions with high geothermal gradients.

3.2.4. Task 3.4 - Modelling calibration (M36-M42)

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

Task not yet initiated.

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)

This task is completed and described in D1.3 – Annual Technical Report I. Nevertheless, following the Hop Facility process with AGH, a pilot site data collection and integration analysis in Poland using the same methodology of the HOCLOOP project was performed and included in D4.1, edition 2.

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, AGH**

Activities performed per partner:

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VITO: As Task 4.2 leader, VITO is still organizing bi-monthly 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, during the second year of the project, VITO continued the modelling activities initiated in year 1. They consist in modelling the heat extraction at the Balmatt site using the simulation tools developed in T2.3 by IFE. VITO prepared a template for D4.2 that has been shared with the other pilot leaders to standardize the reporting for the different sites.

VITO evaluated, for two defined production scenarios, the long-term energetic performance of the HOCLOOP system (production temperature, thermal output, COP). The scenarios evaluated include the deployment of the HOCLOOP concept in the existing MOL-GT-03 well for 1/ pre-heating the working fluid of VITO geothermal plant and 2/ heating new buildings on the VITO site.

The results of the modelling are reported in D4.2 and serve as an example for the other sites.

TUD: Data from T4.1 is 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.

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

IFPEN: The simulations of the French site with the HOCLOOP solution are in progress. Different well configurations (vertical or L-shaped coaxial) are considered, whereas the conditions of the fluid in the well are controlled either by the flow rate or the inlet temperature in order to deliver a flow with constant outlet temperature. The deliverable D4.2 is under preparation.

AGH: Numerical model of Polish site preparation. Modelling of system work with different injection flow rates and temperatures for water.

Main results from partners (without sensitive data):

VITO: VITO completed the modelling of the heat extraction at the Balmatt pilot site using the simulation tools developed and validated in T2.3. Two different integration options of the HOCLOOP concept at VITO's facilities were envisaged as possible ways to provide heat to the existing heating network and/or new buildings (Singh, et al. 2023). For both scenarios, the existing dry well (MOL-GT-03) of almost 5000m trajectory is considered for the possible installation of the HOCLOOP concept and the estimation of its thermal performance.

The integration scenarios considered in this deliverable are as follows:

- Application of the HOCLOOP concept in MOL-GT-03 to preheat the working fluid transferring heat between the Balmatt geothermal plant and VITO's high-temperature (>70°C) heat network (Figure 14-a).
- Use of the HOCLOOP concept in MOL-GT-03 to supply low-temperature (<50°C) heat to modern heating systems in new facilities near the Balmatt site (Figure 14-b).

These integrations scenarios impose different operating conditions on the HOCLOOP system. A detailed analysis of the performance of the system and its impact on the heating facilities are described in D4.2.

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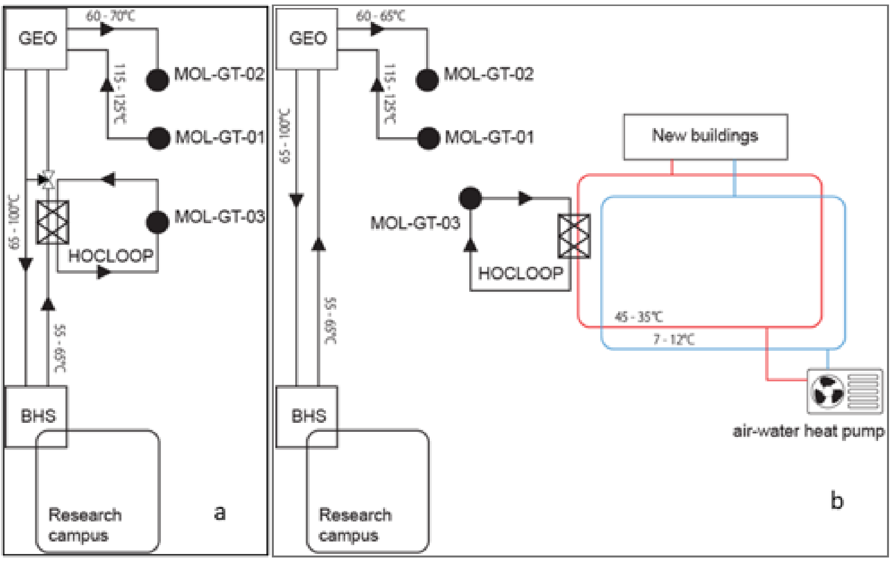

*Figure **14**. Possible integration schemes of HOCLOOP concept installed in well MOL-GT-03 with VITO's facilities. (a) Pre-heat the working used to carry the heat between Balmatt geothermal plant 'GEO' and VITO's research campus facilities. (b) provide heat to a new building development.*

<u>Scenario a: Pre-heating the working fluid of VITO geothermal plant</u>

For the scenario that consider using the HOCLOOP system to preheat Balmatt's surface water network, different cases have been tested considering either the original well trajectory or adding a horizontal to the original well:

- Case a-1: Original trajectory
- Case a-2: Original trajectory + 500m horizontal section
- Case a-3: Original trajectory + 1000m horizontal section

Table 6 and Figure 15 summarize the results, showing that the HOCLOOP system in well MOL-GT-03 can preheat the Balmatt campus working fluid from 65 °C to 69 °C in winter and from 70 °C to 73 °C in summer, achieving a temperature gain of 4 °C and 3 °C, respectively. The average extracted thermal power is approximately 290 kW over 20 years. Higher thermal power could be achieved with lower injection temperatures, as water injected at 65 °C loses heat in the first 1550 m due to the rock temperature being lower.

*Table **6.** Summary of injection conditions and main outputs – Pre-heating working fluid of VITO geothermal plant*

Case	**Water injection rate [kg/sec]**	**Injection temperature W – S [°C]**	**Increase in temperature W - S [°C]**	**Output power @ 20 years W - S [kW]**
Case a-1	5	65 - 70	4 - 3	300 – 250
Case a-2	5	65 - 70	5 - 4	400 – 320
Case a-3	5	65 - 70	6 – 5	490 - 410

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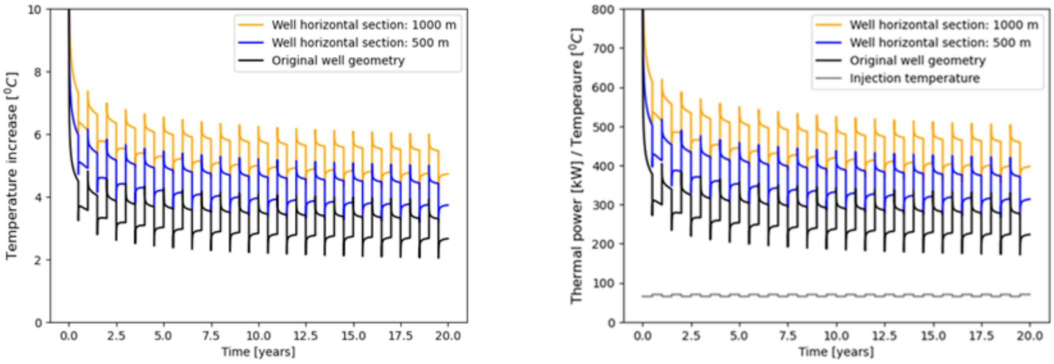

*Figure **15**. Comparison of temperature increase of the Balmatt – research campus working fluid and produced thermal power when considering the well MOL-GT-03 with the original well geometry and by adding additional horizontal sections at the bottom. The well is continuously producing heat but injection temperature changes during summer and winter.*

Adding a horizontal well section at the bottom (4900 m) increases the working fluid's final temperature compared to the original MOL-GT-03 geometry. The temperature rise ranges from at least 3 °C in summer with the original geometry to up to 6 °C in winter with a 1000 m horizontal section.

<u>Scenario b: Heating new buildings in VITO using existing well MOL-GT-03</u>

The HOCLOOP solution could heat two new office buildings. A seasonal heat demand of 7 months operation and 5 months downtime (Table 7 and Figure 16) was analysed to assess the well's thermal capacity. A rate-control algorithm was developed to handle irregular demands. Additionally, the daily heat demand for the buildings (Figure 17) was studied to evaluate the system's ability to handle daily peaks and determine corresponding flow rates.

*Table **7.** Heat requirements for the heating network of the new buildings.*

Period [Years]	Demand [MWh/y]	Minimum input required temperature [°C]	Output temperature [°C]
0 – 10	2500	45	35
10 - 20	3400	45	35

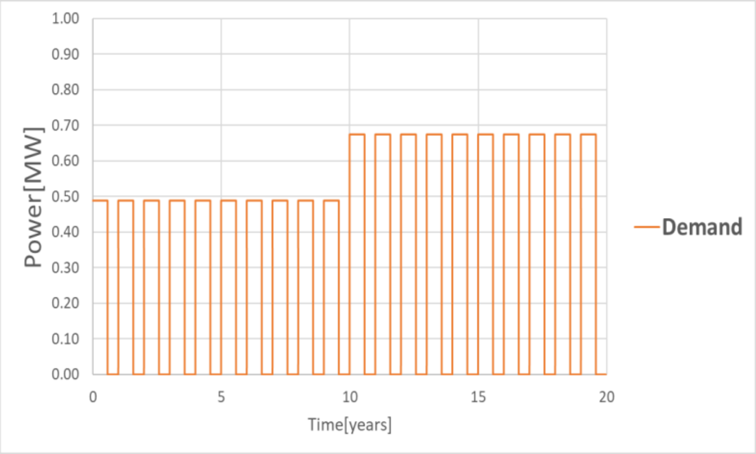

*Figure **16**. Referential seasonal average demand of heat for the new buildings during a period of 20 years. It is assumed*

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that the energy demand takes place during 7 months per year at constant load.

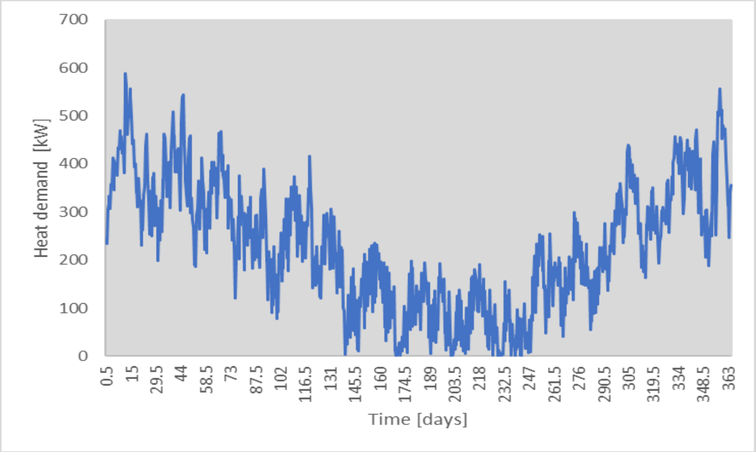


Figure ***17****. Estimated 12-hour heat demand profile from the new buildings during a period of 1 year.*

In total three cases were modelled in integration scenario b as described in Table 8. These cases consider different well trajectories and different demand profiles.

Table ***8.*** *Cases considered for simulation of scenario b: Integration of HOCLOOP system with the new buildings*

Tested cases for scenario ‘a’	Description
Case b-1	The original well trajectory of MOL-GT-03 and seasonal heat demand for testing flow control algorithms and power potential of the well.
Case b-2	A 500 m horizontal section was added to the well to test flow control algorithms and assess its power potential under seasonal demand.
Case b-3	The original well trajectory of MOL-GT-03 and daily heat demand expected for the new buildings.

Results of Case b-1

In the 7-month seasonal usage scenario, the well meets the 0.49 MW heat demand during the first 10 years and increasing to 0.68 MW afterward. However, the output temperature declines annually, requiring increased flow rates to compensate. After 10 years, the well cannot sustain the heat output above 45°C as demand rises. By the end of each cycle, the output temperature drops to 45°C, and flow rates decrease over time to maintain this threshold, reducing power output accordingly.

Results of Case b-2

Adding 500m horizontal sidetrack at the base of the well results in a higher production temperature and lower required flowrate for a given heat demand. The well is predicted to be able to deliver the required heat demand for the entire 20 years.

Results of Case b-3

The well's ability to meet peak demands exceeding seasonal averages was assessed. Figure 18 shows it can fully meet the 12-hour heat demand in year 5, requiring a maximum flow rate of under 3 kg/s. This indicates the well is overdesigned for the planned VITO office building's predicted heat demand.

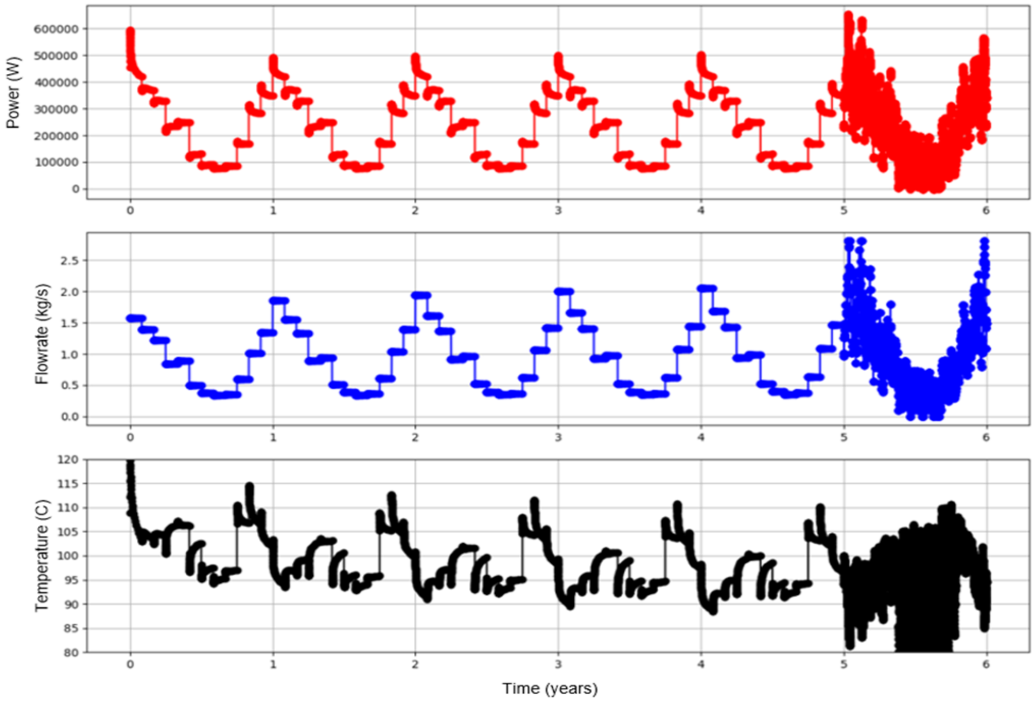


*Figure **18**. Estimated well performance for 5 years of monthly averages, followed by a single year of 12-hourly demand values. Power output (red – top figure) in W, flowrate (blue – middle figure) in kg/s, and outflow temperature (black – bottom figure) in °C. The x-axis is years.*

For case b, the main conclusions are that:

- Irregular heat demand from the buildings can be covered, including the daily peaks.
- The flow rates must be increased year by year to fulfil the heat demand.
- The produced fluid temperature is much higher than the required temperature (45°C).

The well can easily cover the buildings heat demand, the system is in fact oversized compared to the demand on site.

Conclusion of the Belgium case:

To determine whether the integration schemes are feasible economic analyses are required in addition to the technical analysis. This will be performed as part of T4.3. One advantage is that the well is already drilled, thus most of the capital investments were already done.

TUD: TU Darmstadt aims to achieve a CO_2-neutral energy strategy as soon as possible. To this end, various options are being explored. One option is the construction of a medium-depth borehole thermal energy storage system (750 m deep, 19 boreholes, totalling 14 km in length). Another option is to integrate the HOCLOOP system into the district heating network. Due to the low thermal gradient in Darmstadt (2.1°C/100 m), producing electricity from a HOCLOOP well is not feasible.

Data collected from WP4.1 was used to develop an up-to-date model for the Darmstadt site. For the HOCLOOP configuration (Figure 19), various scenarios were investigated. The vertical borehole depth ranged from 1,500 m to 3,000 m, and the horizontal length ranged from 1,000 m to 3,500 m. All simulations were run over a 30-year period, assuming a constant flow rate. For the HOCLOOP well in the

Darmstadt case, the optimal flow rate is 6 l/s. With an injection temperature of 30°C, after 30 years, a well depth of 3,000 m combined with a horizontal length of 3,500 m can achieve a heat extraction power of nearly 500 kW. To meet the minimum requirement of 1 MW for use as a storage option, two boreholes would be necessary.

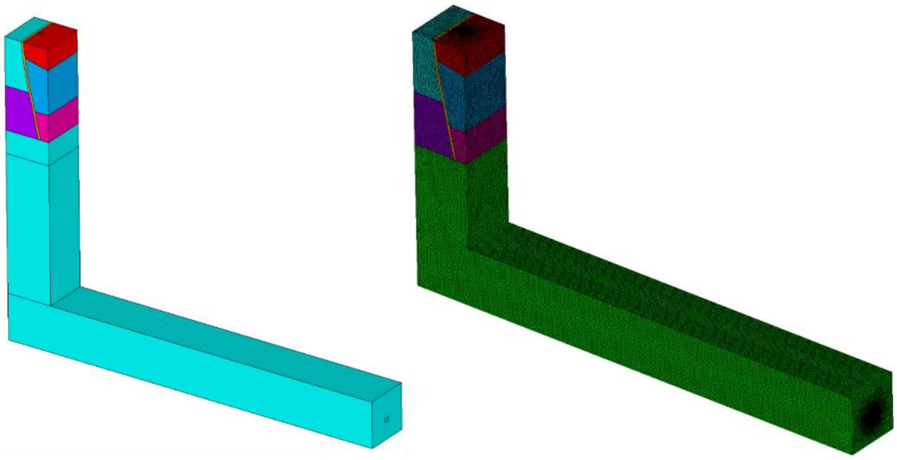


*Figure **19**. Finite element model for Darmstadt site based on data collected from T4.1.*

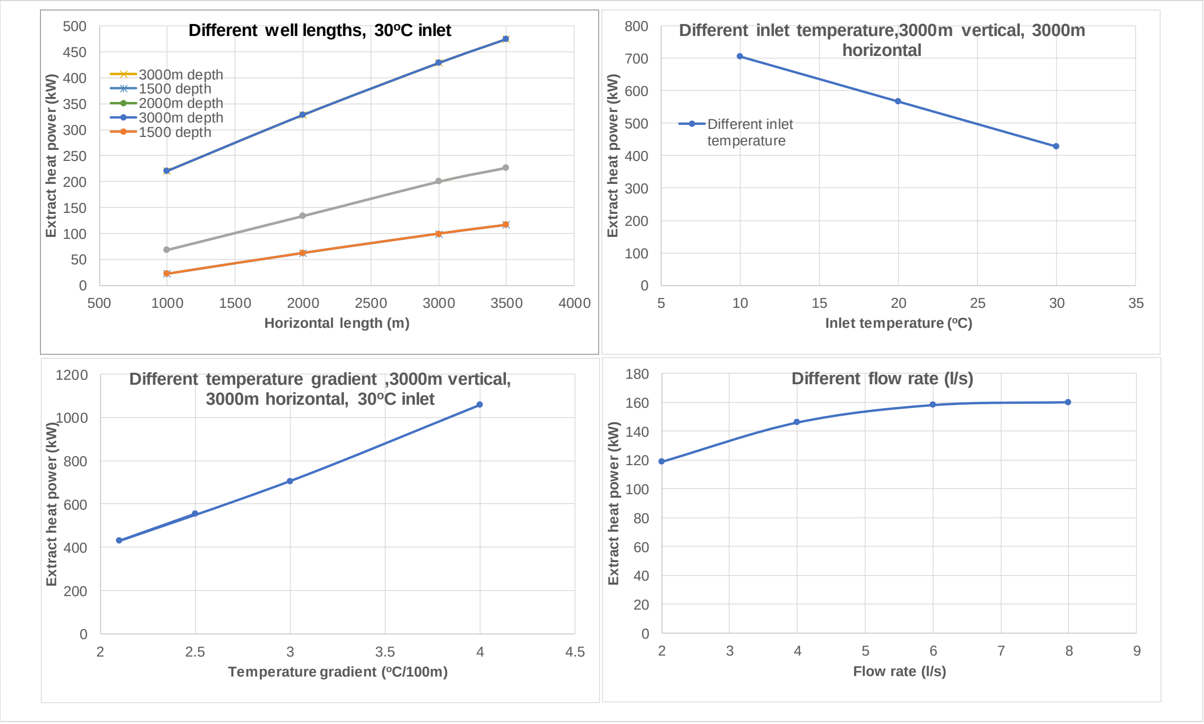


*Figure **20**. Simulation results with HOCLOOP well configuration for different scenarios.*

IFPEN: Detailed simulations were performed using the GWellFM simulator for the selected French site using the site data collected on Task 4.1 (Deliverable 4.1) and considering the HOCLOOP solution. The reuse of an existing well without or with a horizontal extension was modelled. The results showed (Figure 21) that with the existing deviated wellbore, the output temperature was relatively low and decreased rapidly with time due to the cooling of the hosting formation. When a horizontal extension of 2 km was considered the performance of the system was improved. However, and when compared to the actual geothermal production of the open well (73°C, 70 kg/s), the performance of the closed-loop was low.

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

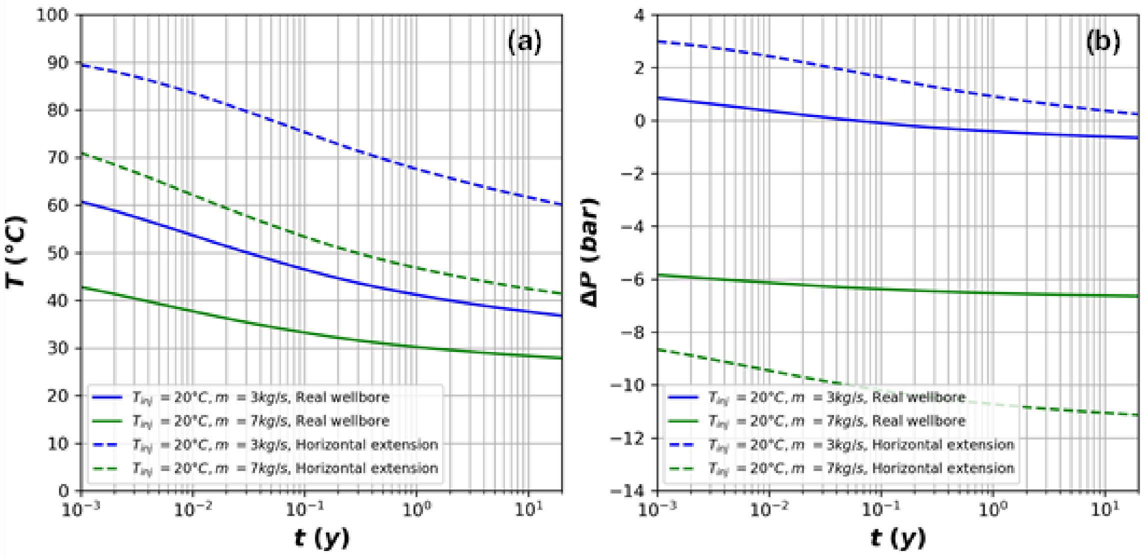


*Figure **21**. Comparison of the temporal evolution of (a) the outlet temperature and (b) the pressure difference between outlet and inlet without and with a 2 km horizontal extension of the GFR-3 well in the French site.*

AGH: An evaluation of the performance of the HOCLOOP system under Polish test site conditions for variable input parameters is ongoing, however, no results are yet available.

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, AGH**

Activities performed per partner:

IFPEN: The well flow model has been coupled with a process simulator (COFE, developed by AmsterCHEM) in order to model both the underground loop and the above energy system. Preliminary simulations of the coupled tools have been performed for the French site considering a simplified surface installation system (Figure 22).

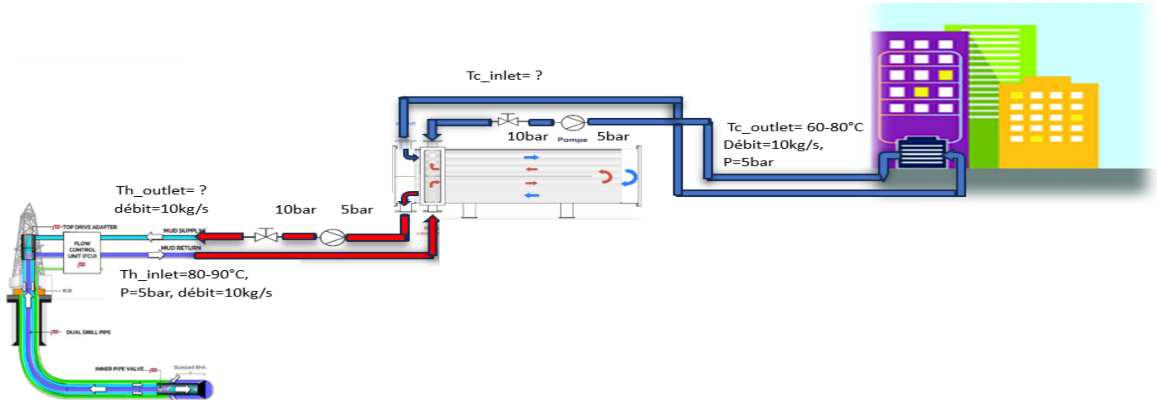


*Figure **22**. Process diagram of the complete heat production system.*

UNIFI: Thermo-economic analysis of the potential application of the HOCLOOP technology within a District Heating Network (DHN) based on the Gavorrano case study. Comparison between a conventional water-based approach and a new generation CO_2-based solution.

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

AGH: The development of the conceptual predesigns for both the underground loop and the above ground energy system for Goleniow location was initiated.

Main results from partners (without sensitive data):

IFPEN: For the coupled simulations of the well and surface installations of Task 4.3, two cases have been considered and preliminary simulations have been performed to validate the workflow. In the first, a constant injection temperature was chosen (25 °C) and the coupled model calculated the flow rate required in the well (Figure 23), whereas in the second case, the flow rate was fixed and the model calculated the injection temperature (Figure 24). The design of the heat exchanger (heat transfer coefficient, heat transfer area and secondary fluid flow rate) was fixed in both cases.

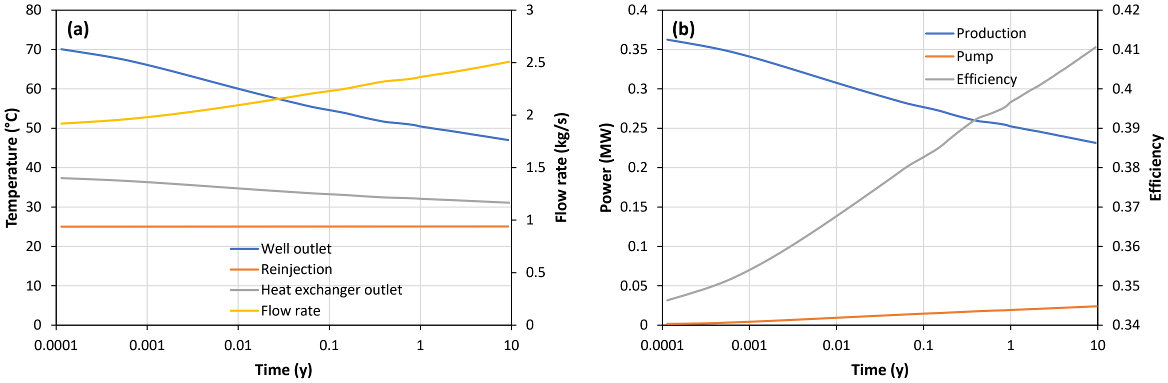


*Figure **23**. Coupled simulations of the underground loop and the surface installation for fixed injection temperature: (a) Evolution of well outlet and inlet temperature, outlet temperature of the heat exchanger and flow rate, (b) Evolution of heat exchanger efficiency, and power produced by the heat exchanger and consumed by the pump.*

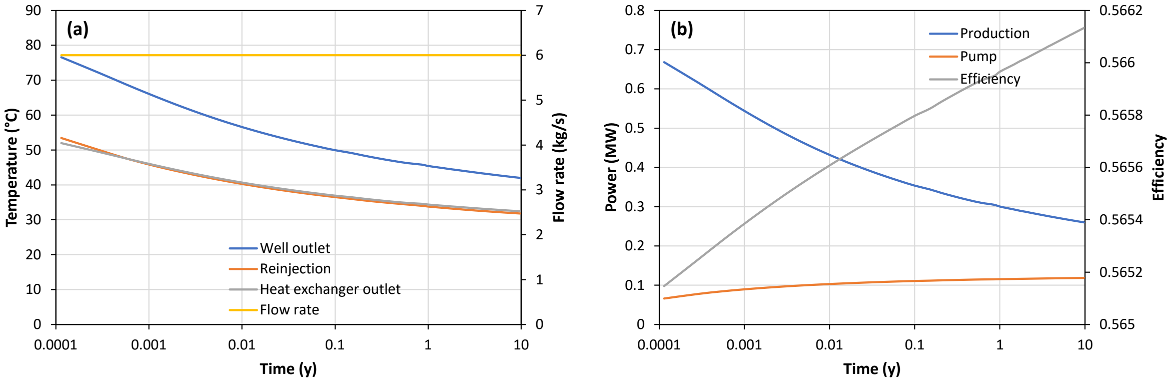
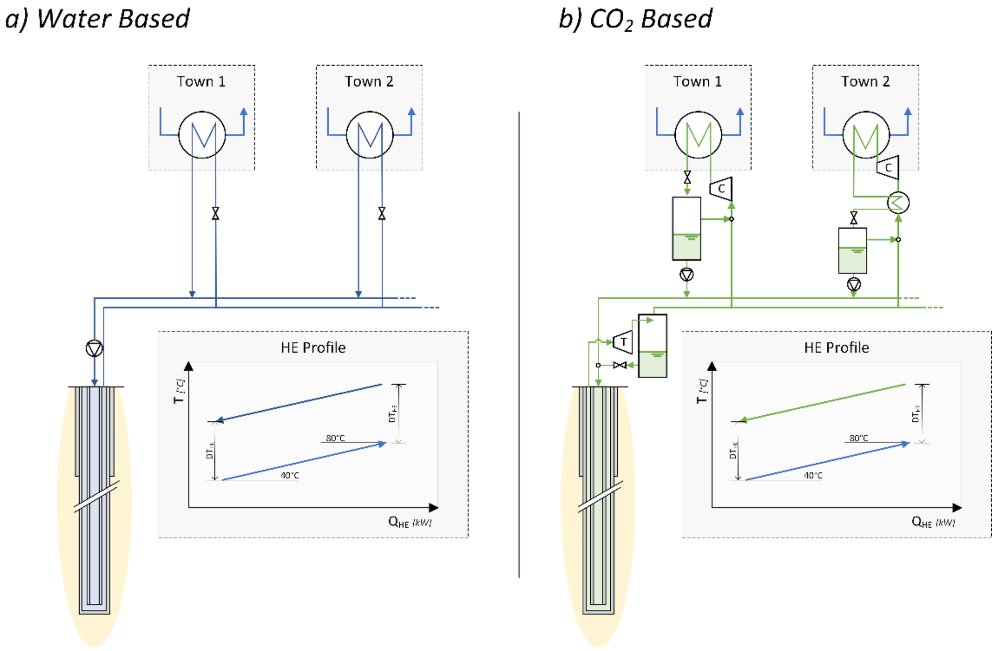


*Figure **24**. Coupled simulations of the underground loop and the surface installation for fixed injection flow rate: (a) Evolution of well outlet and inlet temperature, outlet temperature of the heat exchanger and flow rate, (b) Evolution of heat exchanger efficiency, and power produced by the heat exchanger and consumed by the pump.*

The results show that for the two cases, the well outlet temperature decreases with time because of the cooling of the hot rocks around the wellbore. With constant injection temperature higher flow rates were needed to compensate for the decrease of the outlet temperature. However, the flow rate remained relatively low the power consumption was low. On the other hand, with constant flow rate but higher than in the first case, more energy was produced by the heat exchanger with higher, however, consumption from the pump. Also, the outlet temperature from the heat exchanger decreased faster in comparison to the previous case, following the decrease of the well temperatures.

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

UNIFI: Drawing on the findings from Task 4.1, as detailed in D4.1, the Gavorrano case study stands out as one of the most promising among the proposed Italian case studies for district heating applications. This is attributed to both the favourable conditions of the geothermal field and, most importantly, its proximity to residential and industrial settlements, identified as potential heat users. Consequently, a complete thermodynamic and economic analysis was conducted for two different DHN layouts covering the Gavorrano area: a traditional water-based network and an innovative CO_2-based solution. The scheme of the proposed heating networks is shown in Figure 25:


a) Water Based

b) CO_2 Based

*Figure **25**. Scheme of the Proposed Heating Networks: (a) Water-Based, (b) CO2-Based.*

The main heating network is coupled to a HOCLOOP system and feeds several sub-networks, one for each municipality (Gavorrano, Bagni di Gavorrano, Scarlino Scalo, Follonica). The sub-networks have been designed as medium-temperature networks, with 80/40 °C supply/return temperature. In the CO_2-based network, featuring a slightly more complex layout incorporating a turbine at the wellhead to harness energy from the natural pressurization induced by the CO_2 thermosiphon effect, the network temperature was varied between 15 °C and 25 °C to determine the optimal value. The results of the thermodynamic analysis are shown in Figure 26.

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

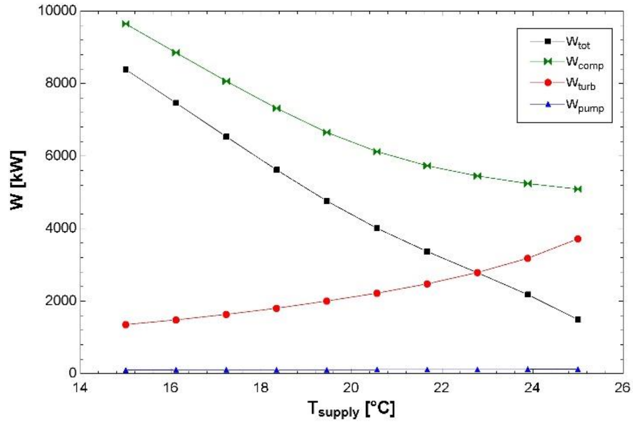
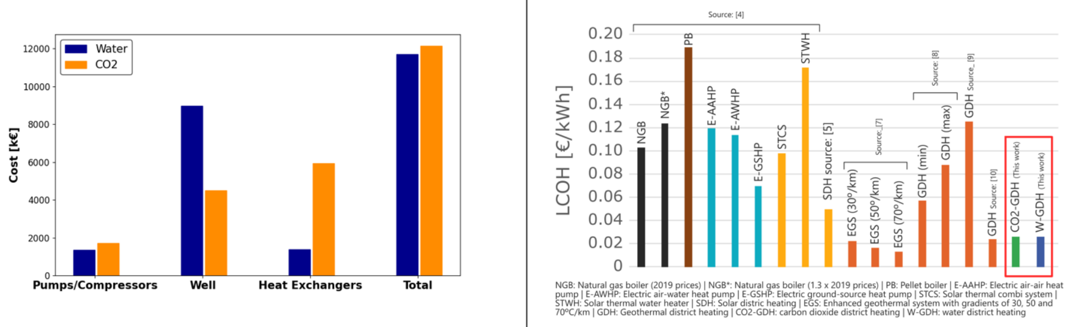


*Figure **26**. Electric Power Values in The Network Vs Network Supply Temperature.*

As it may be observed, increasing the supply temperature results in a decrease of the required compression power. The gap between the temperature required by the users and the network temperature becomes narrower, reducing the compression specific work. In addition, the energy recovered at the turbine increases. The reason behind is that the turbine mass flowrate becomes higher, as less vapor is being recirculated from the separator to the users. Consequently, the net power requested by the DHN decreases, suggesting that the use of higher network temperatures may be beneficial. The results of the economic analysis are summarized in Figure 27.



(a) (b)

*Figure **27**. (a) Cost Comparison (b) LCOH Values of Different Technologies.*

As it may be observed, the LCOH value of the water network is almost equal to that of the CO_2 network. Since the water network exchanges heat directly with the utilities, it requires higher temperature values at the wellhead and therefore greater drilling depths. This implies a higher cost for the well, as shown in Figure 7a, which offsets the higher costs associated with the CO_2 surface system. Finally, when comparing the obtained LCOH values of the HOCLOOP DHN solutions working with both water and CO_2 with those reported in the literature, it may be observed that HOCLOOP technology is rather competitive. The CO_2-based network proposal outperforms natural gas, pellet, electric heat pump, and solar technologies, as shown in Figure 7b, allowing to potentially cover the heating demand at very competitive LCOH.

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**

This task was not yet initiated within the period of the present report.

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, AGH**

Activities performed per partner:

UNIBA: Key parameters for forward replicability such as fracture distribution, permeability and lithology were collected in the Gavorrano and Mt. Amiata areas and calculated for Gavorrano.

Main results from partners (without sensitive data):

UNIBA: UNIBA provided key parameters to better optimize the model. The task is under early development and relevant findings will be reported in the next period report.

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: In the last annual meeting it was agreed to deviate the original plan and rather go for early full-scale testing at Ullrigg already in the fall of 2024, instead of in 2025 as originally planned. Therefore, all efforts in the start of the period were focused on the design and building of the required components for workshop testing of the basic completion solution to be used in this test. The main elements needed for the full-scale test are the DHS pipe joints with centralizers and connectors, Bottom Hole Sub, DualLink Modem Sub, Tension Anchor and the Tubing Hanger Adapter. In addition, the DHS handling tool and other special rig tools for the installation of the DHS needed design, manufacturing and testing prior to the full-scale test. FMECA analysis indicated that high priority should be given in on the iterative design and testing of the centralizers. The DualLink Modem Sub, Bottom Hole Sub and Tension Anchor required significant design efforts prior to manufacturing.

Since the manufacturing of the tools and components often are hampered by long lead times, the search to find reliable supplier workshops was important. Most of the required components were ordered and manufactured and workshop tested by Q2 of 2024.

IFE: IFE participated in the material selection part related to the activities in this task.

Main results from partners (without sensitive data):

RW: The design work was focused on the basic version of the DHS pipe joints with centralizers and connectors, Bottom Hole Sub, DualLink Modem Sub, Tension Anchor and the Tubing Hanger Adapter. Since there were several various possibilities for assembling the DHS for the operation, significant work was connected to clarifying the potential risks and consequences of the various operation possibilities for the overall operation performance.

The design of components and tools need to consider both installation and operation performance. Thus, the design needs an iterative approach, especially the new components with reliable operation demand. The centralizers were through a series of workshop tests before settling on a low cost and sufficient robust design. The workshop tests revealed that the proposed design would have sufficient margins to sustain the expected loads to be experienced during the operations, see details in the test reports.

The TTC connector was selected for the inner string, based on risk considerations and operational reasons. A special TTC connector design was developed for the inner pipe and manufactured for testing.

Of reasons mentioned above, also the Tension Anchor design went through a series of iterations before settling on a final design for the manufacturing of the prototype tool. The Tension Anchor was manufactured by a local machine shop and prepared ready for test.

The DualLink Modem Sub and Bottom Hole Sub with modem were designed around the existing downhole electronic measurement arrangements owned by Reelwell, to minimize the amount of work required for downhole sensor developments in the project.

The DHS handling tool and other special rig tools for the installation were finally designed and then manufactured in local workshops.

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

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

Activities performed per partner:

RW: The DHS centralizers were subjected to significant workshop testing, because they were judged as components with risks for the system operation. The centralizers needed to sustain high contact forces and other demands, but still be low cost for economic reasons. Special test rigs were built and used for the testing. Various designs were tested in campaigns, to settle on a proper and low-cost design for the centralisers.

A test rig for thermal testing of the DHS components was built to investigate and document the thermal insulation properties of the DHS joints. Workshop-testing was performed with this test rig in campaigns.

The BHS and Modem Sub were tested for proper DualLink communication, as well as for pressure. The Tension Anchor, TTC connectors and pipe welds were all tension- and compression tested in a special rig in the workshop, to document that the capacities was within the safe operation envelope prior to the full-scale test at Ullrigg.

Main results from partners (without sensitive data):

RW: An external local workshop was selected for the testing of the DHS centralizers, due to the availability and good facilities for such testing. The testing allowed to use high forces up to more than 10 tons force in a special test arrangement for the centralizers. After several series of testing and modifications of the centralizer design, the final designs for the centralizers were selected for the full-scale test.

The thermal testing of the DHS components was conducted in a special test arrangement in the Reelwell workshop. The test set-up consisted of a 12m long 5.5" outer pipe, with special end caps, and with a slightly shorter 4" inner pipe filled with wate contained inside. This test arrangement was placed inside of a large oven, that enabled the enclosure of the 12 m long DHS test arrangement. The DHS test arrangement was instrumented with temperature and pressure measurements and enabled to vacuumize the annular volume inside the DHS test sample. The thermal testing gave valuable insight to the DHS thermal insulation performance, see further details in the dedicated test report.

The BHS and Modem Sub were tested for proper DualLink communication, as well as for pressure, as required for the full-scale test.

The Tension Anchor, TTC connectors and pipe welds were all tension- and compression tested in a special rig in the workshop, to document that the capacities was within the safe operation envelope prior to the full-scale test at Ullrigg see further details in the dedicated test report. The DHS handling tool was subjected to surface tension testing, and the performance was excellent compared to the required capabilities for the expected load exposure in operation.

3.5. WP6 – Full scale test operation

WP leader: **RW**. Period of implementation: **M1 – M37**.

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

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

Activities performed per partner:

RW: Due to the foreseen long lead times for the DHS pipe joints, the search for suitable pipe joints started early in the period. It was found that the less risky approach would be to order used tubulars, and to refurbish these for the Ullrigg test. Suitable used 5.5" tubing was found from a Norwegian supplier, whereas suitable used 4" tubing was found from a supplier in The Netherlands. The required number of pipes were ordered and shipped to selected machine workshops in Norway that was able to perform the refurbishment and adaptation of the tubulars.

The planning of the operation was performed in a co-operation between Norce, IFE and Reelwell, where there was produced two documents, i.e. D6.1 Plan for the operation, and D6.2 Risk and contingencies. It was found most convenient to rent the tanks and heating equipment required to perform the Thermal Response Test from a suitable rental company located outside Stavanger. For practical reasons, the Ullrigg yard was the selected location for the final assembly of the DHS pipe joints prior to the test. The Ullrigg mechanical workshop was used for various equipment preparations prior to the test.

IFE: IFE participated in conducting a risk assessment plan and took the leadership in the specification and procurement of the necessary surface equipment to ensure the successful completion of the test.

NORCE: As owner of the pilot test site, NORCE was heavily involved the planning for the full-scale operation in cooperation with RW and IFE. A workshop has been arranged to prepare the test program. NORCE was also involved in the planning of handling the Dual Heat String in an efficient and safe manner was of importance and presenting this to the crew to ensure a common understanding and safe operation.

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Main results from partners (without sensitive data):

RW: Several meetings were held between Norce, IFE and Reelwell during the planning period. The work resulted in the plan document D6.1, and a risk/contingencies document D6.2.
An important discovery from this work was that the original outline plan did not cover back-up temperature sensor arrangements for the thermal response test, in case the primary DualLink sensors for some reason should fail. It was therefore decided to include back-up temperature sensor arrangements in the test-plan.
It was decided to perform the Thermal Response Test similar to a recent test performed at the TU Darmstadt, i.e. conducted during the Hocloop annual meeting in the fall of 2023. The planning of the Thermal response Test was therefore performed in co-operation with TU Darmstadt. It was found most cost efficient to rent the required surface equipment for the Thermal Response Test from a local company.
The required amount of used 5.5" tubing for the full-scale test was identified and ordered from a Norwegian supplier. The tubing was shipped to a qualified pipe inspection company for inspection and approval of the pipes and threaded connectors. The approved tubulars were thereafter sent to Ullrigg for preliminary storage, awaiting assembly and testing.
The required amount of used 4" tubing was sourced from Wintershall in The Netherlands. The pipes were ordered and imported to a selected machine workshop in Norway. These pipes needed new connectors; hence it was decided to cut-off the existing connectors and to each pipe joint weld on short pipe joints with pre-made TTC-connectors. The length of the 4" inner pipe joints were at the same time adapted to fit the length of the respective 5.5" outer pipe joints, for which it was foreseen to be installed inside. The tension testing and performance of the TTC-connectors and the tubular welds were performed in a separate workshop. There were discovered an issue with the welding, that resulted in a slightly bent inner pipe. This was corrected by means of using an alignment bench during welding. However, the slightly bent inner pipe later showed to give operation challenges during the pipe installation. After the 4" pipes were completed with tool joints and protectors they were sent to the Ullrigg test site for assembly with the 5.5" outer pipes.
The assembly of the DHS pipe joints was performed in the yard at the Ullrigg test-site. Here the DHS pipe joints were assembled and prepared prior to the full-scale test.

IFE: A PFD a P&ID were produced and analysed by the WP6 team to refine the control and sensing strategy. A MATLAB/Python code was subsequently developed to calculate the expected pressure drop as a function of the volumetric flow rate and to predict the system's expected behaviour. An inventory of equipment specifications, such as type, sensitivity, and accuracy, as well as signal I/Os, was conducted to identify prospective equipment suppliers. The surface test set-up was simulated, and the necessary equipment available at NORCE's premises and nearby rental companies was sourced.

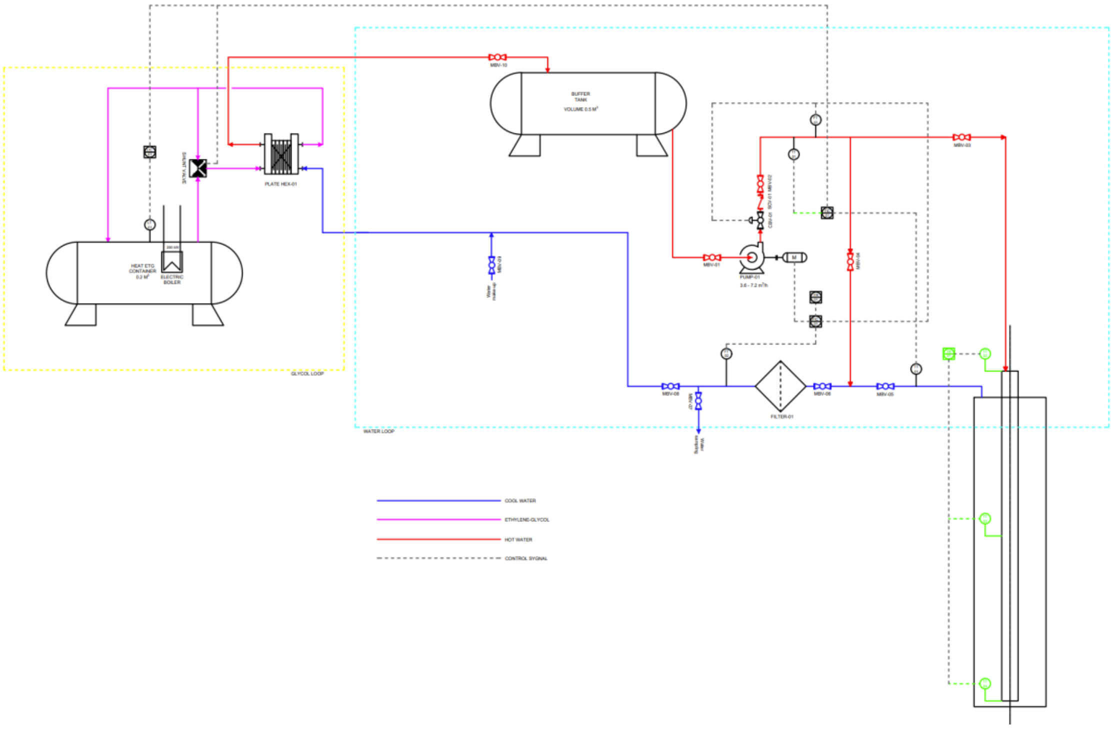

*Figure **28**. Surface Test Rig P&ID*

The results presented align with the objectives of T6.1, with a negative cost impact on the planned budget outlined in Grant Agreement 101083558. These activities were detailed in an internal report (D6.1 Plan for Full-Scale Operation at Ullrigg), which assessed risks, potential technical and financial impacts, and proposed mitigation actions. An extensive HSRA (Health and Safety Risk Analysis) was also conducted to ensure the safe operation of all personnel involved in the process.

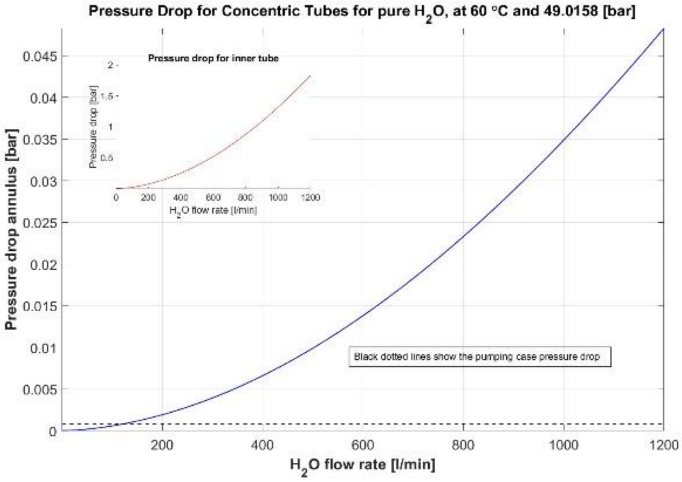

*Figure **29**. Pressure drop calculation for DHS as function of water flowrate*

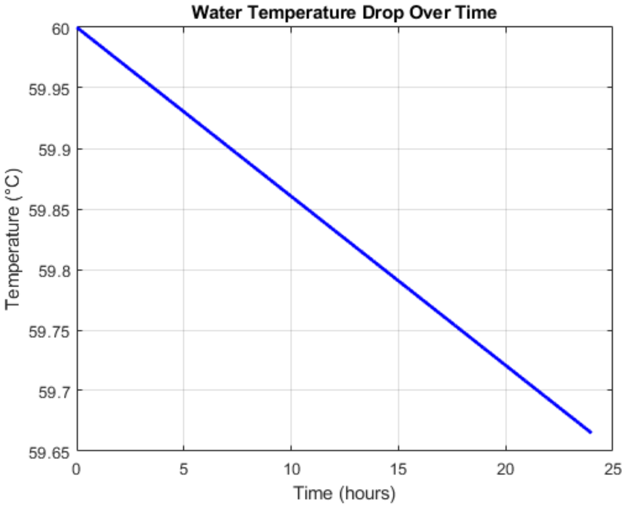

*Figure **30**. Heat loss calculation for insulated buffer tank for Stavanger average expected weather conditions in October and November.*

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

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

Activity not initiated within the period covered by the present report.

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

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

Activity not initiated within the period covered by the present report.

3.6. WP7 – Full Social acceptance, citizen engagement and environmental assessment

WP leader: **VAASA**. 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: **VAASA** – Participants: **IFE, UNIBA, AGH**

Activities performed per partner:

VAASA: The activities within task 7.1 include completing the media study (based on social media and traditional media) as well as setting up and implementing a community co-creation workshop in one of the HOCLOOP pilot sites.

The media analysis under task T7.1 uses HOCLOOP pilot sites to examine how social media and traditional media have covered and presented deep geothermal energy deployments.

Social media study

We conducted a social media analysis for all four pilot site case studies to better understand how citizens, media sources, and organizations perceive deep geothermal energy projects.

To find data and discussions of importance for our geothermal energy projects, closely relevant keywords were developed for each case study. The dominant social media platforms were checked for suitability for the study, but the data collection showed that all except Twitter (X) had minimal geothermal discussion coverage.

Data from Twitter was cleaned by filtering out and removing spam, advertisements, irrelevant mentions, and duplicate items. The analysis was conducted to find common themes, message sentiment, and social media activity development over the years. Particular attention and focus were put on environmental, social, and economic benefits, future potential of the technology, and concerns, as well as energy justice aspects.

Traditional media study

The main objective of the traditional media study is to identify the key factors that influence the social acceptance of deep geothermal energy. The research focused on a media dataset comprising 81 articles written about a specific deep geothermal energy project in Belgium, assembled over its period of active operation. Our multistep methodology involved data collection via the Auxipress media service. We utilized GPT-4, a large multimodal language model built by OpenAI, to conduct sentiment and content analyses, assess media opinions, and identify key themes on the social acceptance of deep geothermal energy. The media coverage significantly reflected social acceptance of deep geothermal energy, primarily through its environmental, economic, and social benefits.

Co-creation workshop

We organized a co-creation workshop in Darmstadt on 11.12.2023 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 solutions. This second community co-creation workshop within T7.1 was organized together with the HOCLOOP University of Darmstadt research team. The workshop included 17 participants. 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: 1) Participation and regulation, 2) Benefits and challenges, and 3) Long-term view.

UNIBA: Primarily involved in sharing of knowledge based on UNIBA's experience in the exploration and exploitation of geothermal energy, particularly for the citizens of Gavorrano.

AGH: AGH focused on adapting the social acceptance study methodology adopted in the project to the Polish conditions.

Main results from partners (without sensitive data):

VAASA: The activities performed within the period of the present report may be summarized as follows:

Social media

The public discussions were mainly about environmental benefits, seismic concerns, and local community involvement. While sentiment was largely positive, local concerns, such as seismic activity in Belgium and Italy, and opposition in specific areas like Monte Amiata, were also significant findings.

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

Sentiment analysis revealed that the general public was positive towards deep geothermal energy. Further, the peaks in tweet volume at the Belgium site often aligned with project milestones or local events, which led to various news articles and public discussion, but other than those there needed to be more public engagement. A spike in the volume of tweets in 2019 coincided with Vito announcing its plans to scale down resulting in criticism from locals.

At the Balmatt site, although people had concerns about seismic events, such as small earthquakes, they were outweighed by the positivity, as the people were aware of and appreciated the long-term benefits of geothermal energy projects for sustainable, pollution-free heat networks.

Overall, most tweets were from environmental-related webpages, researchers, and experts, with very little interest from the local public. This shows that although the scientific and environmental communities are interested in the project, more efforts are needed to engage the broader local population and build community interest.

The general public showed clear interest and optimism in the future of geothermal energy and such projects. The project leads can use this to get further support and funding for further research and development. This research should be centered around common challenges, such as induced seismicity, which can create a more skilled labor force.

The job postings, particularly from VITO, were widely reposted, significantly boosting the project's visibility. This broader reach raised awareness about the HOCLOOP geothermal initiatives and highlighted the project's role in creating job opportunities and fostering a positive public perception.

Traditional media

The sentiment analysis revealed that the media coverage of geothermal energy projects is generally positive, contributing to increased social acceptance in Belgium over the years. The most commonly reported benefits are carbon emission reduction, job creation, and community heating. Despite positive sentiment, challenges such as drilling risks and seismic concerns were noted, potentially hindering acceptance. Key social actors identified were government organizations, industries, and entrepreneurial networks, indicating growing private sector involvement. The innovation of using GPT-4 for media analysis proved efficient and accurate, but there should be manual oversight to ensure the reliability of AI-generated results.

Co-creation workshop in Darmstadt, Germany

The workshop outlined possibilities for deeper local participation. Once the site is ready, e.g., a showroom connected to the site could communicate to and educate citizens and stakeholders. This could include showing, e.g., the drilling equipment via posters, presenting the project, and communicating main messages. Real-time data from the site could be shown via monitors to show what is happening underground. The participant raised some concerns about compensation. What are the compensation models if vertical drilling affects a larger area with many existing houses and buildings? Finally, the workshop participants discussed the long-term effects. A small surface footprint allows future generations to utilize the land above the site. Earthquakes were seen as a potential issue in the future. The concerns included the durability of the used material as well as the maintenance needs of the system.

AGH: The map with the main stakeholders (excluding citizens) in Poland is ready and will be used as baseline for the evaluation of their acceptance/resistance to the large-scale deployment of the HOCLOOP technology.

3.6.2. Task 7.2 - Analysis of the market acceptance-from of geothermal energy by closed loops (M13-M42)

Task lead: **VAASA** – Participants: **IFE, UNIBA, AGH**

Activities performed per partner:

VAASA: The activities within T7.2 include the conceptualisation and planning of a business model workshop. In the conceptualisation stage, we collected and reviewed relevant scientific literature and project material. To support the codesign approach of the workshop, we decided to use energy community archetypes as a starting point and adapted these to the deep-geothermal setting. We added the Business Model Canvas to be able to explore further details of the business model with the stakeholders in the workshop. The conceptualisation and the detailed planning of the business model workshop in one of the HOCLOOP sites were carried out in close collaboration with the HOCLOOP partner AGH.

AGH: AGH closely developed with VAASA the planning of the business model workshop in one of the HOCLOOP sites, in this case, Poland. The workshop took place in October, 2024.

IFE: IFE participated in small details in the planning of the business model workshop in Poland.

Main results from partners (without sensitive data):

VAASA & AGH: T7.2 activities resulted in a concept for the HOCLOOP business model workshop, and a detailed plan for the implementation of the first business model workshop.

3.6.3. Task 7.3 – Sustainability assessment : Exergy, LCA, Exergo-environmental and exergo-economic analyses (M24-M42)

Task lead: **UNIFI** – Participants: **IFE, RW, VAASA, AGH**

This task is yet to be initiated.

3.7. WP8 – Synergies between borehole closed loop and industrial energy systems

WP leader: **AGH**. Period of implementation: **M24 – M42**.

All activities within this work packages are yet to be initiated. The main reason for this being the delay in the formalization of the contract (GA) with CINEA, which limited the access to financial resources for implementation. Nevertheless, and following the implementation plan, in the best-case scenario only one month of work would be covered in the present report.

4. Technical Dissemination and Communication

Table 8 summarises the technical dissemination and communication actions chronologically, describing the nature and lead partner responsible, between M13 and M24 of the project implementation.

*Table **9**. Technical dissemination and communication performed within the HOCLOOP (October 2023 – September 2024)*

Date	Nature	Lead Partner	Description
November, 2023	Conference Proceedings	IFPEN	"The HOCLOOP Project: Tools to Model Heat Extraction from Horizontal Closed Wells", 4th EAGE Global Energy Transition Conference and Exhibition, Paris-France, November 2023, https://doi.org/10.3997/2214-4609.202321044.
November, 2023	Poster	UNIBA	EGW 2023, held in Utrecht. poster communication on: "Ionic Liquids as Candidates for Heat Transfer Fluids in Geothermal Applications".
November, 2023	Talk	UNIBA	EGW 2023, held in Utrecht. oral communication on: "Mining heat in a regional brittle shear zone: The potentiality of the Gavorrano area (Southern Tuscany, Italy)", by Domenico Liotta, Martina Zucchi, Andrea Brogi, Walter Wheeler.
March, 2024	Talk	RW	"Update from closed loop deep geothermal projects", at the National geothermal seminar arranged by the Geothermal Energy Association of Norway at the University in Stavanger.
March, 2024	PhD Thesis	UNIFI	Pietro Ungar, "Use of CO2 as working fluid in geothermal systems", DOI:10.13140/RG.2.2.33357.45286.
March, 2024	Poster	VAASA	Poster about the social acceptance of closed-loop geothermal systems at the Vaasa Energy Week 2024.
April, 2024	Poster	UNIFI	The HOCLOOP project, with a focus on the CO2, CO2 mixtures and alternative fluids experimental campaign, was presented at EGPD 2024 (European Geothermal PhD Days) in Delft, Netherlands.
June, 2024	Conference Proceedings	IFE	"Simulation of Closed-Loop Geothermal Systems", 85th EAGE Annual Conference & Exhibition, Oslo-Norway, DOI: https://doi.org/10.3997/22144609.202410516.
July, 2024	Talk	AGH/IFE	Participation in a Transnational Seminar "EU funding opportunities under Horizon Europe: Focus on WIDENING calls" July 3, 2024 in Tunis.
July, 2024	Conference Proceedings	UNIFI	"Thermo-Economic Analysis of Geothermal-Based High Temperature Heat Pump", was presented at ECOS 2024 in Rhodes, Greece.

August, 2024	Talk/Award	RW	"New closed-loop solution to construct geothermal wells", ONS Innovation Award Finalist. International Petroleum and Energy Conference and Exhibition, Stavanger.
August, 2024	Talk	UNIBA	"Ionic Liquids as Efficient Media in Organic Synthesis and Geothermal Applications", at the SCI2024 XXVIII Congresso Nazionale della Società Chimica Italiana, Milan, Italy.
September, 2024	Conference Proceedings	UNIFI	"Thermo-Economic Analysis of Geothermal-driven District Heating Network: Comparison between water-based and CO2-based grid", was presented at SDEWES 2024 in Rome, Italy.
September, 2024	Conference Proceedings	VITO	"Thermo-hydraulic performance analysis of concentric pipes for geo-thermal application.", 5th SU2 Conference 2024, Varenna, Italy.

5. Deviations to the Technical Implementation

Next, we report by category all deviations observed within the period of the present report (01.10.2023 to 30.09.2024) relevant to establish a comprehensive overview of the work performed within the implementation of HOCLOOP. Any direct comments from the partners are also included.

5.1. Deviations to the implementation plan

5.1.1. Inclusion of new Beneficiary and new WP

The Coordinator and the University of Science and Technology Krakow (AGH) submitted a successful application to the "Hop On" facility of the WIDERA program. AGH was, after a longer than ideal process (see section 5.2), included has full beneficiary in HOCLOOP from March 01st, 2024 onwards. This brings to HOCLOOP a new work package (WP8) intitled "Synergies between borehole closed loop and industrial energy systems", that will study the better way forward for direct integration of the HOCLOOP technology in heavy-energy demanding industrial systems. This new WP starts on M24 and ends on M42.

5.1.2. Anticipation of the full-scale test operation on WP6

WP6 leader (RW) created a company dedicated to the exploration and exploitation of geothermal resources based on the IPRs they own on the core technologies of the HOCLOOP project. In line with their business plan, and to facilitate bringing to the market the innovations of the project (thus increasing its impact), RW proposed to anticipate the full-scale test operation (T6.2). T6.2 was originally planned to be performed on M29 – M33. The three partners involved in the pilot (RW, NORCE, and IFE) agreed with the proposal from RW and thus resources were focused on planning and mobilization for T6.2 to be implemented on M25 – M29, 4 months earlier than the original plan. This also has the following implications for the work in WP5:

The activities on the design and workshop testing of the tools and equipment required for the optional drill-in solution therefore needed to be postponed until after completion of the activities connected to the full-scale Ullrigg test. It is suggested that the result from these design and testing activities are reported as additions to the existing deliverable reports of WP5 and WP6, when the activities are completed. This process is under analysis by CINEA.

5.2. Administrative deviations with impact on the project implementation

5.2.1. Amendment to include AGH as beneficiary following the Hop On facility application

On September 2023, the Coordinator and AGH submitted an application to the Hop On facility to extend the scope and impact of the HOCLOOP project by spreading the excellence to one of the biggest targets of the Widera program: Poland. On January 31st, 2024, the European Research Executive Agency (REA) informed the Coordinator of HOCLOOP that their Hop On application with AGH was successful. The work plan proposed in the referred application defined that AGH's activities would start on March 01st, 2024. Unfortunately, the amendment process to include AGH was abnormally long, not clear, and only signed by CINEA on November 2024. Furthermore, only in October 2024 were the Coordinator and AGH informed that all projects under the Hop On mechanism would not receive pre-payment of the costs, unlike regular grants.

5.2.2. Inclusion of new Beneficiary and new WP

On November 2023, the Coordinator was informed by RW about the establishment of a company (Geotherma), fully under their control, which would dedicate to geothermal exploration and exploitation, based on the HOCLOOP technology under development. All IPRs and activities related to geothermal energy were to be transferred to this new company, and so RW also wanted to transfer their activities in the HOCLOOP to them. This was primarily due to the need felt by RW to separate the Oil and Gas activities from the Geothermal ones, and to try to facilitate market uptake by Geotherma leveraged by the HOCLOOP. The Coordinator evaluated this as a highly impactful outcome of the project and informed the Project Officer (PO) on December 2023 about their plans to ask for an amendment to formalize Geotherma as an "affiliated entity" of RW, that would take over most of the scientific/technical activities within HOCLOOP. The PO was positive to this idea and the discussions about the formalization on an amendment initiated and eventually the request formalized. Unfortunately, this process is also taking an abnormal amount of time and is not yet completed. If approved, Geotherma will be a part of the project from November 01st, 2024 onwards and will assume most of the tasks assigned to RW.

5.3. Deviations in the submission of deliverables and milestones

D1.7 – This deliverable was an update to D1.6 which was also submitted late (see D1.3, technical annual report for more info). Thus, the Coordinator decided to delay D1.7 to include a larger period of new information in an attempt to provide a better overview of the activities during the implementation of the project.

D2.5 – This deliverable was originally submitted in time, on March 28, 2024. The apparent delay is due to the request from the PO to correct a "clerical error" in one of its figures on April 22, 2024.

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

D5.2 – This deliverable is yet to be submitted. This is mostly due to two factors: i) the leader of WP5 (RW) decided to advance with the optional development of the DHS. This was an optional part of the work to be performed in WP5 as per GA, dependant on the availability of resources for it, and ii) the decision to anticipate the full-scale operation at Ullrigg in Stavanger to M25 on WP6 (also led by RW), which had as consequence the refocusing of resources on this part of the work. The anticipation this operation is also motivated by the creation of a new company fully owned by RW which is focused on the exploration and exploitation of geothermal resources (Geotherma AS). The Coordinator is aware and monitoring this, and considers that the focus of the partnership on performing the work and attempting to bring the main innovations of the project to the market, should be prioritized over the reporting of the developments.

D5.4 – This deliverable is yet to be submitted. The justifications for this are basically the same as for D5.2. The performance of optional work (increasing the impact of the project) and the anticipation of the pilot on WP6.

D6.1 & D6.2 – Both deliverables have yet to be submitted. This is because they are targeted in the ongoing amendment request to include Geotherma AS as an affiliated of beneficiary Reelwell. These deliverables are defined as "public" in the present GA and are requested to become "sensitive" due in the amendment request due to the relevant information for the plans of Geotherma they will contain. They will be processed as soon as possible once CINEA makes a decision about the amendment request under evaluation.

MS5 – The means to verify this milestone are "*workshop testing completed*". This milestone on WP5 was not achieved within the planned date because of the extension of the work to the DHS (the optional drilling part) as well as the test-tunning caused by the feedback of analyse of the results vs the test well conditions for the pilot on WP6.

MS6 – The means to verify this milestone relative to WP3 are "*First experimental results with s*CO_2". The WP leader (UNIFI) reported delays caused by internal bureaucracy issues on the commissioning of their sCO_2 test rig. At the end of the period of this report, the rig is yet to be commissioned. The Coordinator is following the situation closely and planning the appropriate mitigation measures.

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