PUSH-IT

Piloting Underground Seasonal Heat Storage In geothermal reservoirs

Deliverable 3.6 Workplan for cross site activities: co-simulation, control, push-pull tests and water quality

Funded by the European Union

Grant agreement number	101096566		
Project title	Piloting Underground Storage of Heat In geoThermal reservoirs		
Project acronym	PUSH-IT		
Start date	01-01-2023	DURATION	48 months
End date	31-12-2026		
Work Package No. and Title	WP3 Enabling technologies		
Deliverable number	D3.6		
Deliverable title	Workplan for cross site activities: co-simulation, control, push-pull tests and water quality		
Actual date of delivery	21-06-2024		
Nature	R	DISSEMINATION LEVEL	Sensitive
Deliverable Leader	Technische Universiteit Delft		
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Document history

Version	Description (Section, page number)	Author	Role (Organisation short name)
V0.1	First draft	Philip Vardon	TUD
V0.2	Second draft Processed of feedback received from reviewers / partners	Philip Vardon	TUD
V1.0	Final version	Philip Vardon	TUD

Quality control

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List of Abbreviations

AE	Acoustic Emissions
ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
BRGM	Bureau de Recherches Géologiques et Minières (French Geological Survey)
CGS	Ceska Geologicka Sluzba (Czech Geological Survey)
DAS	Distributed Acoustic Sensing
DTS	Distributed Temperature Sensing
EGU	European Geosciences Union
EPS	Electrical Submersible Pump
FEM	Finite Element Method
F-IEG	Fraunhofer Gesellschaft Zur Forderung Der Angewandten Forschung Ev (Fraunhofer Research Institution for Energy Infrastructures and Geothermal Systems)
GBBH	Grondboorbedrijf Haitjema
GFZ	Helmholtz Zentrum Potsdam Deutschesgeoforschungszentrum (German research Centre for Geosciences)
GHG	Greenhouse Gas
GRE	Glass-fiber Reinforced Epoxy
HPPT	(Hot) Push Pull Tests
MTES	Mine Thermal Energy Storage
SWOT	Strengths, Weaknesses, Opportunities, Threats
TDA	Technische Universitat Darmstadt (technical University of Darmstadt)
TUD	Technische Universitat Delft (Delft University of Technology)
UTES	Underground Thermal Energy Storage
VITO	Vlaamse Instelling Voor Technologisch Onderzoek

1. Introduction

1.1. Purpose of this document

This document outlines how enabling technologies and knowledge which are investigated and developed in WP3 are implemented and compared across the different field sites. The intent of this report is that the technologies which are focused on, can be made more widely applicable, rather than remaining focused on specific sites. The activities outlined here can:

- Be implemented in one of more sites, highlighting and comparing the site-specific differences.
- Be tested in multiple sites, leading to more general scientific or practical conclusions.
- Be planned for replication or further implementation of the technologies in sites within or outside the PUSH-IT project.

2. Co-simulation

2.1. Introduction

Co-Simulation involves modelling both underground thermal energy storage system (thermo-hydraulic, e.g. finite element method (FEM) model) and surface components such as heat pumps and pipe systems to evaluate the behaviour of entire systems. Two numerical modelling tools are utilized, one for each part, and they dynamically interact with each other at run time of the simulation process to assess how interactions and interdependencies affect system performance.

2.2. Planned activities across sites

Co-simulations are planned for three sites: Darmstadt, Delft, and Bochum. In Darmstadt, FEFLOW is employed to model three borehole heat exchangers with updated geometry and petrophysical properties, while surface components are simulated using Dymola. Both software are coupled through function mock-up units. The same approach is applied to the aquifer thermal energy storage (ATES) system in Delft. In Bochum, the mine thermal energy storage (MTES) system is modelled using SPRING software (developed by Delta-h) to simulate mine systems, with support from TU Darmstadt (TDA) in coupling SPRING with system modelling software. Additionally, the results from these co-simulations are used to benchmark simplified models, which play a crucial role in developing controller algorithms.

2.3. Joint aims and planned outcomes

Joint aims are to evaluate how co-simulations can be used in planning systems, assess system behaviours. For Darmstadt, results of co-simulation are important for planning extensions of SKEWs site, from 3 boreholes to 37 boreholes. For Delft, the overall system performance and integration of the heat pump is targeted. For Bochum site, results of co-simulation have significant purpose in planning and convincing stakeholders.

2.4. Dissemination plan

Co-Simulation results are planned to be disseminated via publications, scientific conferences, workshops for stakeholders. The joint results are planned to be disseminated in firstly the project deliverable (D3.3) and a dedicated scientific publication.

2.5. Planned or possible replication actions

The Co-Simulation methodology for the borehole thermal energy storage (BTES) system on the Darmstadt site is planned to be applied directly to the Litoměřice site, a project follower site. Due to recently found unexpected geological conditions in this site, ATES can be studied as an optional scenario. Therefore, the co-simulation approach developed for Delft site is proposed to be later applied.

2.6. Planning

Who	What	Where	When
TDA	Co-Simulation for Darmstadt site	Darmstadt	Q1 2025
TDA, TUD	Co-Simulation for ATES Delf site	Darmstadt	Q4 2024, Q1 2025
TDA, F-IEG	Co-Simulation for MTES Bochum	Bochum	Q4 2024
TDA	Provide models for F-IEG ATES	Darmstadt	Q3 2024
TDA	Integrate findings from Co-Simulation investigations and form general conclusions and recommendations	Across sites	Q3 2025

3. Smart district heating network controller

3.1. Introduction

Underground storage systems require large capital investments. To maximize contribution to greenhouse gas (GHG) emission reduction and the efficiency and the economy of these expensive storage system, a smart controller is developed, optimizing the charging and discharging of the underground system (long-term control). Furthermore, the controller also aims to influence the heat demand profile of the network to optimally fit the underground system requirements (short-term control).

3.2. Planned activities across sites

The controller is anticipated to be tested in the 3 demo sites (Delft, Darmstadt, Bochum). The framework of the controller algorithms, combining the long-term and a short-term control time scales, will be similar for each site. Nonetheless, since the nature of the underground storage systems for these sites differs (ATES, BTES, MTES) as well as the size, also the controller algorithms will need to be tailored for the specific demo sites.

3.3. Joint aims and planned outcomes

The evaluation of the performance of the controller is planned to be based on the same key performance indicators, in order to be able to evaluate the 3 demo sites on the same basis.

3.4. Dissemination plan

The plan is to disseminate the results of the tests of the controller performance via the project deliverable (D3.4), conference contributions and through scientific articles. We aim to compare the performance of the different demo sites and their respective underground systems amongst each other, focusing on the impact of the control system. Each of the sites has proven to be attractive as demonstrations and the control system will be highlighted during site visits. Promotional material will be added in visible locations to key places on the sites.

3.5. Planned or possible replication actions

As a replication action, based on the performance evaluation for the demo sites, by the end of the project we foresee to conduct an impact study on the developed controller features of the network and specifically the strongly varying underground systems. This will yield qualitative and quantitative estimates of benefits of the controller with respect to the control objectives to be achieved for the follower sites.

3.6. Planning

Who	What	Where	When
TUD, F-IEG, TDA, VITO	Installation of monitoring equipment for cross-site evaluation	Bochum, Delft, Darmstadt	Q2 2025
VITO	Collection of benchmark data for cross-site evaluation	Bochum, Delft, Darmstadt	Q4 2024-Q3 2025
VITO, TUD, F-IEG, TDA	Tests of the improved control algorithms + cross-site performance evaluation	Bochum, Delft, Darmstadt	Q4 2026
VITO, TUD, F-IEG, TDA	Impact studies for the follower sites	Follower sites	Q4 2026

4. Push-pull tests

4.1. Introduction

The hot push-pull test (HPPT) is based on push-pull tests (PPT) known in hydrogeology, which are used for the hydraulic and/or geochemical characterization of aquifers. In the HPPT, the injected groundwater is heated and injected at a higher temperature and provided with one or more tracers. The temperature serves as a kind of tracer to determine the thermal properties of the aquifer. In particular, the impact of higher temperatures on potential geochemical and microbiological effects is of great significance and is investigated through a continuous sampling program conducted during the test.

4.2. Planned activities across sites

(H)PPT's are planned to be carried out at the Delft, Berlin and Bochum sites. The test will serve to characterise the storage horizon across all sites. Some research questions are the same at all sites, some are different, which means that the test design must be adapted accordingly.

- Delft: A HPPT will be performed at the first ATES well, the initially planned HPPT at pilot well has been cancelled since temperature limit of 60°C due to casing material (PVC)
- Bochum: first, PPT / cross-hole test with tracer planned, later, depending on results a hot push pull test is considered, currently permission is pending
- Berlin: 5 step HPPTs are planned to heat up the near wellbore region stepwise until storage target temperature of 90°C, currently test permission is pending

4.3. Joint aims and planned outcomes

The experience gained from the planning, execution and evaluation of the test procedure and test results should contribute to the characterisation of the specific storage horizons, but above all to the further development of the test itself and its evaluation, and in particular to the qualification of the test for different storage types (ATES, MTES).

- Delft: estimate thermal behaviour of aquifer with focus on storage thermal efficiency, determine effect of heating on geochemical groundwater quality
- Bochum: first aim is to identify / characterise flow paths -> hydraulic conditions, evaluation of storage volume
- Berlin: main research questions are to determine the thermal and hydraulic behaviour of the target horizon, as well as geochemical and microbial effects triggered by high temperatures

4.4. Dissemination plan

- Project deliverable (D3.2)
- Scientific publications
- Conference talks and papers
- Consideration of the results in the development of design guidelines is intended

4.5. Planned or possible replication actions

It is planned to develop the HPPTs as a general test methodology for ATES test/pilot wells. PUSH-IT will also investigate in what way the method can be extended/adapted to MTES sites.

The main objective is to develop a test method for storage wells to estimate the thermal, hydraulic, geochemical and microbial storage behaviour in the exploration phase to obtain important information for storage design in advance. It should therefore be available for all future ATES/MTES storage locations and provide the necessary data for the future storage operation.

4.6. Planning

In the following a general overview on (H)PP-Test planning and the involved partners are listed. More detailed activity plans are included in site work plans.

Who	What	Where	When
GFZ	Detailed test planning and setup	Berlin	Q1/Q2 2024
GFZ, BRGM	Performing HPPT	Berlin	Q3 2024
TUD, GFZ	Detailed test planning and setup for testing first ATES well	Delft	Q2-Q3 2024
TUD, GFZ, BRGM	Performing HPPT	Delft	Q1 2025
F-IEG, GFZ, BRGM?	Detailed planning of PPT	Bochum	Q2-Q3 2024
F-IEG, GFZ, BRGM?	Performing PPT	Bochum	To be scheduled

5. Water quality

5.1. Introduction

Water quality issues represent technical challenges for thermal energy storage. Considering geothermal and heat storage feedbacks, main issues relate to corrosion and scaling in wells, to clogging and loss of injectivity/productivity in near-well areas, and to possible geochemically and microbiologically induced alterations in shallower (drinking) aquifers due to thermal changes. Industrial companies have already potential solutions to manage water quality for low temperature thermal energy storage systems, but specificities of higher temperature thermal energy storage need to be thoroughly investigated. The role of microbiology in thermal energy storage systems is potentially more sensitive than for geothermal applications and should therefore be considered carefully.

5.2. Planned activities across sites

The task is divided in 4 subtasks:

- Subtask 3.2. What might occur in the geothermal reservoir? This is a main concern for ATES (Delft & Berlin) and to a lesser extent for MTES (Bochum & Cornwall)
- Subtask 3.3. What might occur in the well (scaling and corrosion)? Delft, Berlin and Bochum will be studied.
- Subtask 3.4. What might occur in the shallow aquifers? Berlin, Darmstadt and Litoměřice will be studied.

Subtask 3.1 is an umbrella subtask and aims to step back, taking into account the expertise of partners, the state of the art, and feedback from experiences on other projects.

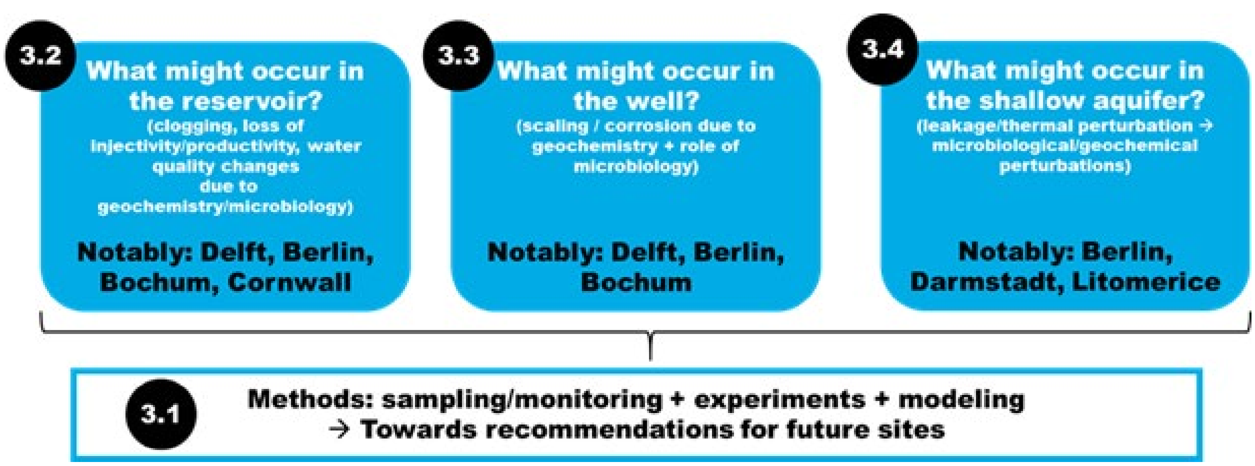

Figure 1: Schematic of water quality tasks within PUSH-IT and their relation

5.3. Joint aims and planned outcomes

Integration with sites and water quality: The water quality research is first guided by site-specific needs. This creates a strong interaction with each of the sites, enhancing the alignment between research and practical application. In a first step, a site-by-site approach was used to draw a clear picture of each site, with a focus on water quality. The summary of these discussions was summarized in *Milestone M6 (M6 - June 2023): Framework for water quality control and monitoring (TUD).*

Joint aims across sites: The task intends to go beyond the basic feedback on the experience from pilot sites by providing recommendations to anticipate and deal with water quality issues for future sites. Matrix organization is currently being deployed, featuring both site-specific activities and cross-site activities on each topic. For the cross-site activities, we intend to:

- Review the relevant state of the art in water quality assessment and treatment, not restricted to underground thermal energy storage (UTES) (geothermal applications will of course be considered, as well as any other relevant field).
- Use site specific experience to make recommendations on sampling, testing and modelling needed for future UTES sites.
- Facilitate experience feedback on other UTES sites. We will try to organize interviews with other UTES's sites to collect their experience feedback and best practices for water quality.
- Develop (geochemical) models and approaches to carry out modelling for the different systems that can be applied to any well/UTES site.
- Organize brainstorming sessions with partners, topic by topic, to share expertise, and try to identify key features, then discuss to what extent our learnings can be used to provide recommendations for future sites or what future investigation is needed. The tentative list for brainstorming topics is the following:
    - Phenomena occurring in the reservoir (maybe distinct sessions for ATES and MTES)
    - Corrosion
    - Scaling
    - Possible impact for shallow aquifer
    - Impacts of microbiology (reservoir and shallow aquifer). This will be a focal point as UTES systems are characterized by process seasonality and microbiology questions have often been neglected up to now. As a consequence, the readiness for prediction, monitoring, management is lower than for other topics. Exploratory research will also be necessary to identify main questions that need to be addressed in the future. The results of the PUSH-IT project concerning microbiology will consist of scientific progress, maybe also new insights concerning operational management, and also the identification of main research questions that should be addressed.

External participants might be invited in the brainstorming sessions (online meetings).

For each brainstorming topic, we will take a structured approach, illustrated in Figure 2, which includes:

- In the preliminary steps of a project, how to identify the main issues (identification of key features)?
- How to predict and anticipate?
- To what extent is it possible to adjust the design of the project to limit the issues?
- How to size the monitoring plan, considering the necessary compromise between efficiency and cost?

- How to manage and/or remediate in case of occurrence of a feared issue and its consequence?

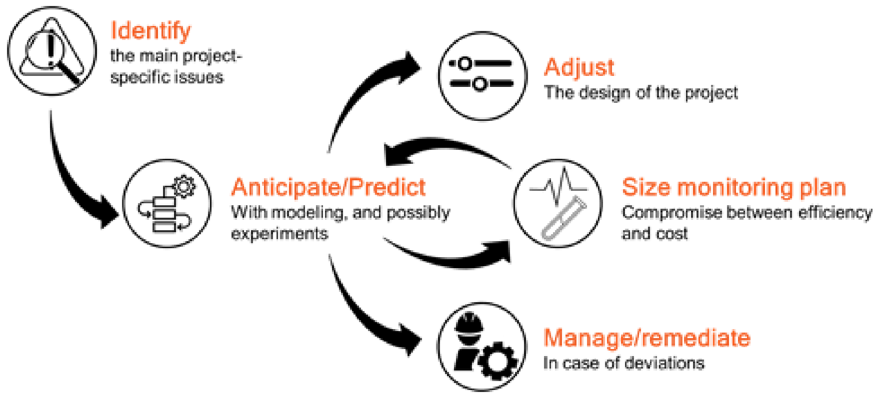

Figure 2: Schematic of the brainstorming structure in order to generate future site recommendations

5.4. Dissemination plan

The objectives and methods have been presented at European Geosciences Union (EGU) 2024 (Loschetter et al., 2024). We intend to pursue the valorization and dissemination of joint results all along the project in conferences and scientific articles, as well as the project deliverable (D3.5).

5.5. Planned or possible replication actions

Subtask 3.1 will explicitly deliver recommendations for future sites, which will be disseminated and can be applied outside the project by others.

5.6. Planning

In the following a general overview on water quality planning and the involved partners are listed, focusing on main actions. More detailed activity plans are included in site work plans.

Who	What	Where	When
BRGM + All	Organize cross-sites brainstorming sessions and related activities	Online (cross-sites)	Q2/Q3 2024
BRGM, GFZ, TDA, KWR, TUD, F-IEG	Site monitoring (geochemistry and microbiology) and modelling	All sites, following the sites' implementation	All along the project
GFZ, BRGM, TUD	Follow water quality in HPPT	Berlin, Delft, Bochum	See Section 4.6 with sites' planning.
BRGM, GFZ	Laboratory experiments	Delft, Berlin	Q3 2024 to 2025

6. Other technologies

Other technologies that are included in WP3 have had cross-site activities identified that go beyond the activities that were initially presented in the proposal and these are summarised below.

6.1. Composite casing

Introduction: Glass-fiber Reinforced Epoxy (GRE) tubulars can be used in well completions as casing production tubing inside the cased well, as liner or for see-through sections because it is transparent to logging. While GRE tubulars are quite accepted in numerous industrial surface flow line applications, its use is limited in well completions.

Planned activities across sites: Installation of GRE-casing is anticipated in Bochum (MTES) and Delft (ATES). Feasibility and design studies will be performed for both individual sites, and installation depends on the outcome of the feasibility studies. A comparison of the feasibility study outcomes and eventual performance (if installed) will be carried out, with an evaluation (e.g. SWOT analysis) produced on the implementation of GRE casing in heat storage.

Joint aims: Establish the range of technology and geological conditions where GRE casing is applicable in UTES.

Dissemination plan: The results of the feasibility evaluation (at both sites and combined) will be presented within the project deliverables (D3.1). If the GRE casing is installed, there is opportunity to also communicate the pilot test to the business community through social media.

Possible replication actions: This depends largely on the findings of the pilot. If successful, the product can be marketed towards UTES systems through the business channels of Huisman.

Planning:

Who	What	Where	When
Huisman, F-IEG	Design and feasibility study	Bochum	Q1-Q2 2024
Huisman, TUD, GBBH	Design and feasibility study	Delft	Q1-Q2 2024
Huisman	Produce GRE-casing	For all sites	Q3-Q4 2024
Huisman, F-IEG	Install GRE in well	Bochum	2025
Huisman, TUD, GBBH	Install GRE in well	Delft	2025

6.2. Well pump performance monitoring

Introduction: Downhole production pump, e.g. electrical submersible pumps (ESP), and their monitoring will help to improve overall UTES / geothermal efficiency, pump performance and lifetime durability. Within PUSH-IT, a predictive monitoring and maintenance concept will be launched, tested and investigated. Pump monitoring, besides user-based logging of performance data logging like flow rate, voltage and amperage etc., will be based on acoustic emissions (AE).

Planned activities across sites: A subsurface, external AE based sensor sub will be developed and tested, independent from a special type ESP or well installation scenario. This way, the sub is more universal regarding its use and downhole setup, while delivering the desired parameters needed for better and extended pump monitoring and lifetime / predictive maintenance surveillance. Initial development and tests will be done at IEG´s headquarter in Bochum. Final field and downhole testing are planned for the well sites in Bochum and Delft. Based on the results, concepts for more specific, future arrangements of AE based monitoring in ATES or MTES type boreholes for monitoring are being suggested and potentially developed.

Status/Joint aims: First lab results indicate that this kind of AE based logging and monitoring could potentially be linked with the fibre optic type technology used for strain evaluation. This is targeted to be examined with fibre optic data from the sites.

Dissemination plan: Results will be presented within the project deliverables (D3.1) and highlighted to site operating organisations and pump suppliers on the tested sites.

Possible replication actions: Some of the technology has been developed and being used some already for machinery and equipment on surface in the industry. However, subsurface equipment monitoring is much more challenging due to depth, pressures, temperatures, expose to partially aggressive formation fluids or brines etc. That's why an approach independent from e.g. water environment (salinity or pressure) is chosen to meet a broader market field for the different UTES technologies. Replication actions are planned via pump suppliers.

Planning:

Who	What	Where	When
F-IEG	First raw blank of a sensor sub (i.e. the electronical components) tested under reservoir conditions <=90 °C)	Bochum	2023
F-IEG	Improvement of condition specific electronical components	Bochum	Q1-Q3 2024
F-IEG	Establishment of a first prototype in lab environment	Bochum	Q4 2024
F-IEG	Well Performance tests (sensor sub attached to downhole pump)	Bochum	2025 or 2026
F-IEG+TUD	Well Performance tests (sensor sub attached to downhole pump)	Delft	2025 or 2026
F-IEG+TUD	Evaluation	Bochum/Delft	2026

6.3. BTES borehole verticality

Introduction: Borehole verticality has been measured at the Darmstadt BTES project (see Figure 3). Deviations were caused by variations of geological and hydrogeological conditions leading to adjustments in drilling techniques. This deviation and its effect on the storage efficiency was then modelled (Figure 4 and 5), with various angles of deviation and from subparallel to fan organisation of the BTES field. This revealed that deviation could impact the maximum efficiency substantially, reducing by around 20%. Subparallel deviations were shown to be able to maintain the maximum efficiency.

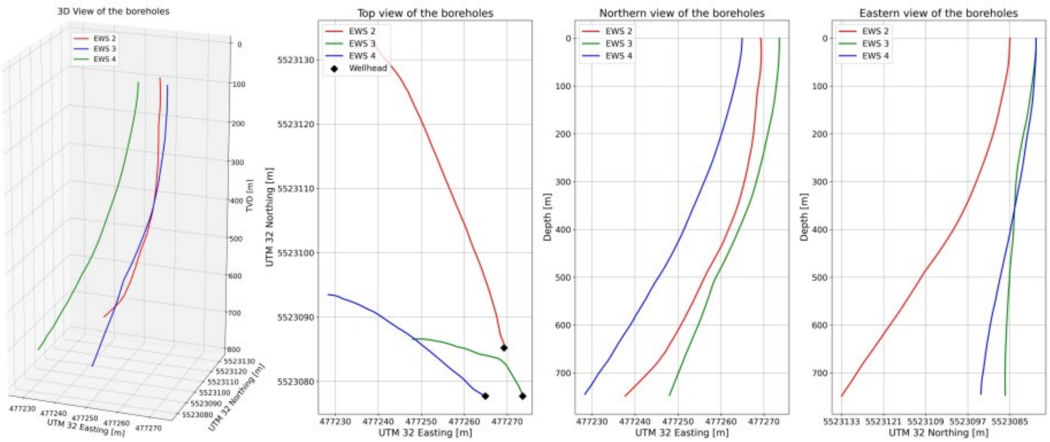

Figure 3: Borehole path measurements: 3D view, top view and side views of the borehole path deviations measured in the three boreholes before installation of the heat exchangers.

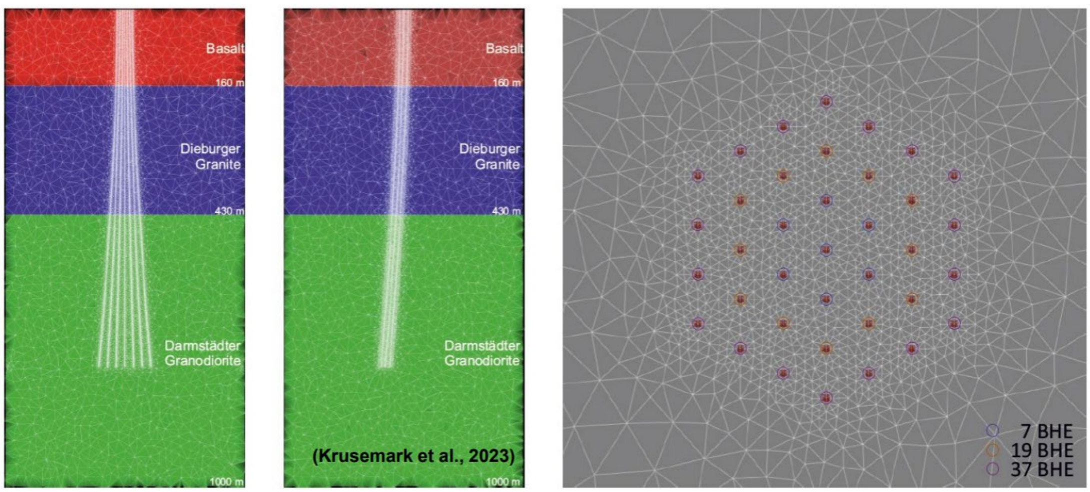

Figure 4: Simplified geological model with mesh and integration of BHE configuration (fan on the left, sub-parallel on the right), and top view of the concentric organisation of the BTES field, with 7, 19 and 37 BHE.

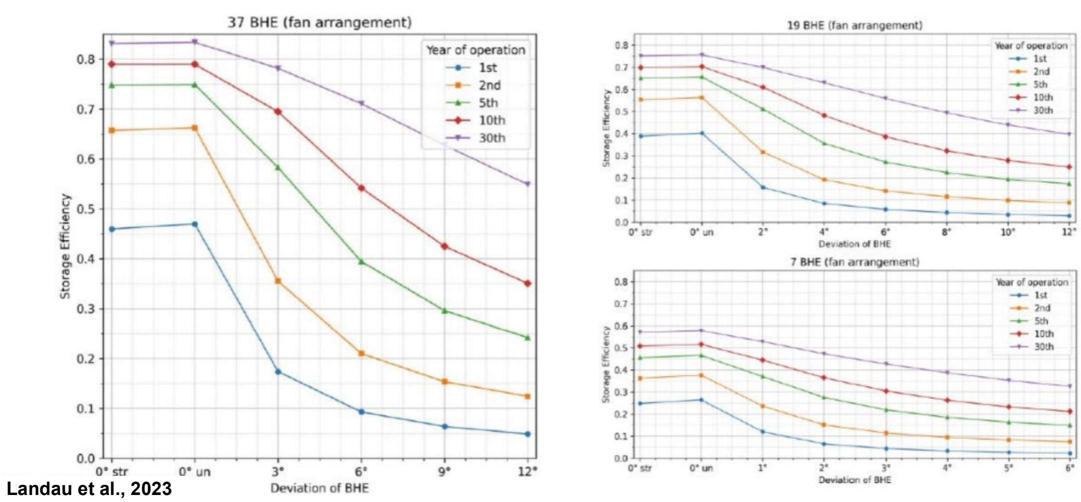

Figure 5: Simulation of the BTES field efficiency for 30 years with various numbers of BHE in a fan configuration.

Planned activities across sites: Within the project, only the measurements of verticality are planned at Darmstadt, but the experience from the Darmstadt measurements and the implications of the modelling work will be discussed in detail with the follower site at Litoměřice, and input into the measurements and modelling work within the Litoměřice project. This activity is already ongoing, with the experience being (a) fed into the plans and funding application for the energy system at Litoměřice, and (b) discussions on cost-effective borehole directional control being instigated. The impact of the site specific work on BTES verticality will be integrated in a BTES efficiency evaluation process (i.e. moving from a single well approach), which will be developed and made general suitable for replication.

Joint aims: Develop the experience from the site specific Darmstadt measurements and analysis into a generic evaluation process and apply the experience to another project in a different geological formation.

Dissemination plan: The results of the site specific analysis have already been published and the efficiency evaluation process will be presented within the project deliverables (D3.1) and in international literature.

Possible replication action: The approach has been implemented for Darmstadt site and will be now rolled out for Litoměřice site, for BTES, and for the other sites having to do drilling activity for general drilling performance – including the associated the drilling phases and eventual collapses / instability zoomability.

Planning:

Who	What	Where	When
TDA	Models of verticality	Darmstadt	Q1-Q3 2023
TDA+GFZ+CGS	Model for Litoměřice	Litoměřice	Q4 2024 – Q1 2025
TDA+GFZ+CGS	When pilot borehole is completed at Litoměřice, take verticality measurements and model on impact of BTES efficiency in various lithologies	Darmstadt and Litoměřice	2025

6.4. Sensoring technologies

Planned activities across sites: The Delft, Bochum, Darmstadt, Litoměřice and Berlin sites will all use fibre optic technologies to measure temperatures in the drilled heat storage boreholes/wells and in monitoring boreholes. The majority of the sites will monitor temperature, with limited strain and acoustic measurements planned. For example, in the Berlin and Delft sites fibre optics will be installed outside of the casing and at the production tubing including the filter section. In Delft, additional fibre optics will be placed through the reservoir and overburden at several distances from the wells. Information exchange on installation methods, instrumentation locations, data process and eventually site performance will be carried out. Based on the results, concepts for the arrangement of optical cables in the ATES boreholes for monitoring temperature and strain are being developed. First results from Berlin indicate that temperature monitoring during cementing can provide valuable information on the completion of the well. Additionally, it was possible to use strain measurements along the tubing for the determination of the fixed point (see PUSH-IT Deliverable 1.3 Commissioning report Berlin).

Joint aims: Develop monitoring strategies for demonstration and production heat storage systems to aid operation, control and performance evaluation.

Dissemination plan: The results will be included in project deliverables and in international literature to allow easy replication at other sites.

Possible replication action: The open dissemination and availability of fibre optic technology will allow wide replication without the involvement of the project partners

Planning: The planning of the sensor installation integrates with the site installation, and a separate planning has not been produced. Comparison will be undertaken coordinated with the project partners depending on the progress and commissioning of the sites.

6.5. Well integrity

Introduction: In order to prevent pollution of ground water, it is important that the confining function of subsurface layers that are drilled is restored after drilling. This is done with different methods depending on the depth, local regulations/practices and UTES system. In the MTES and BTES systems a cementitious grout is injected into the borehole annulus, whereas in the shallow(er) ATES system the injection of a group of swelling clay (backfilling material) is used after completing the well.

Planned activities across sites: At the Delft site, we plan to compare in the lab (and perhaps in the field) the confining properties of various backfilling material (in conjunction with thermal properties - see Section 6.6) after various temperature load cycles. Distributed Temperature Sensing (DTS) fibre optics will be used, and this offers the opportunity for the teams developing integrity monitoring via DTS to obtain additional data. The load cycles for HT-ATES are much more severe than ATES or geothermal wells because they change more and faster over time. At the Darmstadt site, the borehole integrity will be monitored via datasets acquired on DTS and Distributed Acoustic Sensing (DAS) fibre optics along the boreholes, to ensure mechanical and thermal stability of the casing and of the cement. At the Bochum site, a combination of downhole logs (sonic logs) and DTS and DAS fibre optics are proposed.

Joint aims: To understand the performance of the confining properties and installation of various backfilling material for UTES systems.

Dissemination plan: The work will form the basis of an evaluation (e.g. Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis) which will be presented in the project deliverables (D3.1), with both a focus on the suitability for different conditions and cross-site analysis. During installing of various materials, there is opportunity to also communicate to industry through social media.

Possible replication actions: This depends largely on the findings of the pilot. If successful, the product can be marketed through the industry links we have in PUSH-IT, e.g., the grout suppliers. At Delft, for example, the major grout suppliers have provided samples for laboratory testing and have agreed the results will be publicly disseminated to build trust in the products.

We will also regularly exchange results within the consortium to facilitate decision making on use of backfilling material within the pilots and follower sites.

Planning:

Who	What	Where	When
TUD	Compare alternative technologies, mainly in lab tests	Delft	Q1-Q3 2024
TUD + suppliers	Design and purchase material	Delft	Q4 – Q1 2025
TUD + GBBH	Install backfilling material	Delft	2025
TDA	Monitoring of well integrity	Darmstadt	Q2 2024 onwards
F-IEG	Monitoring of cement integrity	Bochum	2025
TUD, TDA, F-IEG	Comparison and evaluation of well integrity and evaluation methods	Bochum, Delft, Darmstadt	Q4 2025

6.6. Thermally insulative casing

Introduction: Thermally insulative casings limit heat loss from the casing, limiting heating of the penetrated formations above the production zone and limit possible side effects on the shallow ground water quality. There are various options to achieve isolation: vacuum casing, other isolation material around the casing, thermal isolation backfilling material installed in the annulus around the casing.

Planned activities across sites: Various options for insulation of casing material will be compared. The focus of this activity lies on the Delft site, with initial theoretical analysis being followed up with field testing. Insulative backfilling material will also be assessed in terms of well integrity and performance, with a focus at the Darmstadt site (see Section 6.5).

Joint aims: Assess the thermal performance of available casing and backfill.

Dissemination plan: A performance evaluation (e.g. SWOT analysis) of various technologies to insulate a casing will be presented in the project deliverables (D3.1), with the data and analysis presented in scientific publication as part of the system performance. During installing of various material, there is opportunity to also communicate the business community through social media. The performance of the thermally insulative backfill will be presented in the project deliverables and scientific literature.

Possible replication actions: This depends largely on the findings of the pilots. If successful, the products can be marketed through the business channels of its suppliers, alongside the publicly available performance data. The materials that have a positive performance can potentially also be applied to the follower sites (Litoměřice and Berlin) – when the design requires thermal insulation. We will therefore regularly exchange results within the consortium to facilitate decision making on use of backfilling material within the pilots.

Planning:

Who	What	Where	When
TUD	Compare alternative technologies	Delft	Q1-Q3 2024
TDA	Monitoring of BTES thermally insulative backfill behaviour	Darmstadt	Q1-Q4 2024
TUD + suppliers	Design, produce	Delft	Q4 2024 – Q1 2025
TUD + GBBH	Install insulative casing	Delft	2025
TUD	Monitoring of thermally insulative casing behaviour	Delft	>2025

7. Overall planning

The planning of the individual activities relates closely to the site plans. Each activity has coordinated activities with different sites, which has been integrated into the site plans. This means that the overall planning needs to be flexible and reactive to the details of the individual site progress.

The broad cross site activities are planned as below and will be reported in the deliverables D3.1, D3.2, D3.3, D3.4 and D3.5.

Cross site activity	Which sites	When
Site monitoring (geochemistry and microbiology) and modelling	All sites, following the sites' implementation	All along the project
Beginning of installation of monitoring equipment for cross-site evaluation of heat network performance	Bochum, Delft, Darmstadt	Q4 2024
Collection of benchmark data for cross-site evaluation of heat network performance	Bochum, Delft, Darmstadt	Q4 2024-Q1 2025
Organize cross-sites brainstorming sessions and related activities to form general conclusions and water quality framework	Bochum, Cornwall, Delft, Darmstadt, Litoměřice	Q2/Q3 2024
Microbiological laboratory experiments	Delft, Berlin	Q3 2024 to 2025
Analyse water quality during (H)PPTs	Berlin, Delft, Bochum	Following site planning
Comparison of (H)PPT results and form general conclusions and recommendations	Berlin, Delft	2025
BTES verticality transfer and testing	Darmstadt, Litoměřice	2025
Integrate findings from Co-Simulation investigations and form general conclusions and recommendations	Bochum, Delft, Darmstadt	Q3 2025
Comparison and evaluation of well integrity and evaluation methods	Bochum, Delft, Darmstadt	Q4 2025
Evaluation of composite casing installation and performance	Bochum, Delft	2025 onwards
Tests of the improved control algorithms + (cross-site) performance evaluation	Bochum, Delft, Darmstadt	Q4 2026
Comparison and evaluation of well / borehole insulation performance	Delft, Darmstadt	2026

Cross site activity	Which sites	When
Evaluation of well pump performance monitoring	Bochum, Delft	2026
Tests of the improved control algorithms + cross-site performance evaluation	Bochum, Delft, Darmstadt	Q4 2026
Impact studies for the follower sites	Follower sites	Q4 2026
Cross site activity	Which sites	When

8. Summary

Cross site activities are planned in activities linked to the main development and testing of supporting technologies for high temperature thermal energy storage across all sites developed in the PUSH-IT project. There are key activities in the co-simulation, smart district heating network controller, the Hot Push-Pull Tests to test reservoir behaviour and in water quality management. In addition, more limited cross-site activities and comparisons are planned to be carried out in examining novel casing materials and completions which have technology specific focus (and therefore more limited cross-site applicability). The planning inevitably follows site plans, which requires the cross-site evaluations and comparison needing to be managed flexibly and reactively in response to the site progress.

References

Landau, M., Seib, L., Bossennec, C., Handke, H., Muhl, J., Stumpf, J., Schindler, U., and Sass, I.: Drilling engineering experience gained from MD-BTES construction phase of SKEWS demo-site, EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-7241, https://doi.org/10.5194/egusphere-egu23-7241, 2024.

Loschetter, A., Watkinson, M., Regenspurg, S., Rad, S., André, L., Lassin, A., Blöcher, G., Stéphant, S., Hartog, N., van der Schans, M., and Vardon, P. J.: Water concerns in UTES: what can be learnt from geothermal experience & what issues need to be specifically addressed?, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-10957, https://doi.org/10.5194/egusphere-egu24-10957, 2024.

The EU aims to have a net-zero greenhouse gas (GHG) economy by 2050, with 55% reduction on 1990 levels by 2030. At present, heating and cooling represent around 50% of the final energy demand in Europe and are mainly supplied by fossil fuel derived energy. It is therefore essential for heating and cooling to decarbonise to achieve EU ambitions.

A challenge for decarbonizing heat systems is the size of the seasonal mismatch between demand for heat and heat generation from sustainable sources – this mismatch is much larger than the equivalent intermittency in electricity supply and demand. The two main solutions to address this mismatch are: (i) to install a large capacity, so that peak demands can be met even at low production levels; or (ii) to store energy for later use if it is not needed at time of conversion. Many sustainable heat supply systems are characterised by high capital expenditure and low operational costs. Therefore, an installed capacity tailored at peak demand is not cost effective, while extending the annual operation period is advantageous for meeting energy needs, reducing levelised cost of energy (LCOE) and decarbonisation. Optimal utilisation of sustainable heat requires storing large amounts of heat to account for seasonal supply and demand fluctuations. Various technologies have been proposed for large-scale heat storage in geothermal reservoirs and low temperature storage is routinely applied. PUSH-IT focuses on extending storage temperature ranges to high temperatures. We will tackle remaining barriers, demonstrate applicability, increase public engagement, and optimise and de-risk operations. We will showcase three technology options that are fit for a wide variety of geological conditions covering most locations in Europe.

Funded by the European Union