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USES4HEAT

D5.1* Baseline Monitoring, Plan and Basic Engineering for ATES Demo

Fondazione Bruno Kessler (FBK)

Co-funded by the European Union

USES4HEAT

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Dissemination level

SEN	Sensitive, limited under the conditions of the Grant Agreement	☐
PU	Public, fully open	☒

Nature of the deliverable

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DEC	Websites, patents filing, press & media actions	☐
DATA	Datasets, microdata, etc.	☐
DMP	Data management plan	☐
ETHICS	Deliverables related to ethic issues	☐
SECURITY	Deliverables related to security issues	☐
OTHER	Software, technical diagram, algorithms, models, etc.	☐

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1. Introduction

This report presents **Deliverable 5.1***: *Baseline monitoring, plan and basic engineering for ATES demo site*, developed as the first task in work package 5 (WP5), T5.1, led by FBK with the support of all partners involved in the Work Package 5.

The deliverable is an updated version of D5.1 which was submitted on December 2024 (based on the initial ATES demo in Riva del Garda – Italy) and provides an overview of the new ATES demo site in Andel – the Netherlands, including demonstration planning, technical and non-technical requirements. Additionally, it reviews the future deployment plans for the USES4HEAT innovative technologies and establishes a baseline to track progress throughout the project timeline. A detailed action plan, complete with timelines and responsibilities, has been defined, including a review of the technical and non-technical aspects to be considered.

The document is organized into the following chapters:

- **Chapter 2**: Offers an overview of WP5 and its coordination with other tasks and work packages. It outlines the project's main objectives in this WP, details of activities undertaken.
- **Chapter 3**: Reviews the local area, including the demo site, and examines the geological studies and available data for the region.
- **Chapter 4**: Highlights the USES4HEAT demonstration plan, focusing on the deployment of technologies.
- **Chapter 5**: Identifies the technical requirements and non-technical specifications that need to be considered as the project progresses.
- **Chapter 6**: Describes the demonstration-specific timeline, detailing milestones, reporting periods, and the risk assessment process. Methods for risk mitigation are also outlined
- **Chapter 7**: Summarizes the main conclusions from the activities carried out in **Task 5.1** and reviews the next steps for the project.

This deliverable serves as a reference for tracking the project's progress, ensuring alignment with its objectives, and supporting the successful deployment of innovative technologies.

2. Work Package 5, Main Objectives and Baseline Monitoring

2.1. Work Package 5 and Coordination with Other Tasks and Work Packages

Work Package 5 (WP5) is a key work package within the USES4HEAT project, aimed at implementing, assessing, and optimizing innovative energy solutions at the ATES demo site in Andel, the Netherlands. Working in parallel with WP2, and WP3, WP5 focuses on designing, developing, and deployment of USESf4HEAT enabling technologies and energy management strategies that will form the core of the site's integrated energy system. The main objectives of WP5 include the development of hardware-level innovations—such as Aquifer Thermal Energy Storage (ATES), groundwater heat pumps (GWHP), and hybrid photovoltaic-thermal (PVT) panels—and the integration and testing of AI-driven and big-data-based predictive energy management tools developed in WP3. These technologies will be implemented on-site, tested under real operating conditions, and continuously monitored to evaluate their performance. This process will enable validation of the project's modelling activities and ensure alignment with the Key Performance Indicators (KPIs) established in Task 2.1.2, which are assessed in parallel with Task 5.1 to track project progress and outcomes.

WP5 was updated, to address main issue arrised during the first year of the project. The work package was previously structured into four main tasks that progressively build toward the operational deployment of these technologies in the demo site in Riva del Garda, Italy (Figure 1). Task 5.1, which ran from months 1 to 12, focused on baseline monitoring and planning. This task involved collecting essential data from the demo site, including GIS-based data, in-situ measurements, and performance metrics, to establish a baseline that will help track project progress and inform future decisions. This initial data gathering was crucial for identifying current energy and material flow bottlenecks, and for setting the stage to implement the necessary modifications to improve efficiency. After official withdrawal of two partners Alto Garda Power (AGP) and Cartiere del Garda (CDG) whom were the main demo owner of the demo site in Riva del Garda, WP5 was updated (Figure 2) with the tasks and timeline to align with the project timeline and other activities. The ATES demo site was shifted to Andel in the Netherlands. This approach was mainly with the focus to be in align as much as possible with the project main objectives, targets and timelines. Details about the Task5.1 for the previous demo site in Riva del Garda were reported in D5.1 Baseline Monitoring and Plan for Riva del Garda Demo.

In Task 5.2 (months 7/29), the development and realization of enabling technologies will take place. This task involves the design and construction of prototypes for the ATES system, high-efficiency heat pumps, and hybrid solar panels. Each technology will be developed in close collaboration with main project technology providers, including DTESS, HIREF, ENDEF. DTESS together with IF will focus on the design, construction, and monitoring of the innovative ATES system able to seasonally store heat at 50°C underground and provide heating and cooling for the district energy network. HIREF will develop and deploy four units of heat pump working with the groundwater on both condenser/evaporator sides and connected to both the ATES and the energy system to increase energy efficiency, These HPs are able to

provide both cooling and heating for the system during the summer and winter respectively. ENDEF will integrate hybrid solar panels into the demo site, aiming to boost both thermal and electrical energy production. These panels will be tested and validated to determine the most efficient designs for long-term operation.

Task 5.3 (months 19/30) focuses on the engineering, planning, and installation of the enabling technologies at the demo site. This includes the integration of the hardware into the future local energy grids, ensuring that the various components (ATES, GWHP, PVT panels) work in synergy with existing systems. Detailed engineering activities—such as hydraulic, electrical, and data connection work—will be carried out to ensure seamless operation. The task also includes the commissioning of all hardware and software components and the development of a monitoring and control system, in alignment with the KPIs established in T2.1.2.

Task 5.4 (months 31/48) involves the experimental campaign and critical assessment of the demo system's performance. This task aims to evaluate the overall impact of the system, including its environmental, techno-economic, and social aspects (in synergy with WP6). It will use monitoring data to validate the simulation models developed in WP2 and assess the overall effectiveness of the USES4HEAT approach. A key aspect of this task is to gather lessons learned throughout the demonstration, which will be documented and presented in the final project handbook and workshop (as from T7.2). These insights will inform future applications of the system, providing guidance for the scaling up and replication of these technologies for decarbonization and energy security in other regions.

Finally, Task 5.5 (months 7/42) focuses on the future installation of ATES system in Riva del Garda advanced replicator. This task involves identifying the best location for the future installation of ATES system in the area and further studies to support the Italian legislation in this context. HYDRA with the support of AGS will focus on improving the drilling technology for ATES well, with innovations like the Easy-Drill system for faster, automatic handling of drilling equipment and safer drilling in challenging conditions. The developed machine will be tested in the advanced replicator. AGS with the support of FBK, will lead the activities for the characterization of the deep aquifer for future ATES installation. The outcomes will be exploited in WP6 and WP7 supporting the local legislative development and setting crucial ground for future deployment of ATES solution in Italy. Information about the Riva del Garda, local district heating network and its energy demand and supply can be found on deliverable "*D5.1 Baseline monitoring and plan for Riva del Garda Demo*". Further study related to the task 5.5 will be reported on related deliverable "*D5.5 Deep Aquifer characterization, and recommendation for ATES*".

Through these coordinated tasks, WP5 will not only demonstrate the feasibility and effectiveness of the USES4HEAT technologies but will also provide valuable data and insights into their potential for future widespread adoption. The successful implementation of WP5 will significantly contribute to the decarbonization of the energy sector and the development of sustainable, efficient energy storage solutions that can be replicated globally.

The following USES4HEAT partners are actively involved in the activities under WP5, each contributing with their specific roles (Table 1).

Table 1. Partners involved in the WP5 with their specific roles.

PARTNER	ROLE
Fondazione Bruno Kessler – FBK **Part of the consortium**	**WP5 Demo Leader – Beneficiary –** FBK leads this work package and coordinates the ATES demo site in Andel, including baseline monitoring, implementation of key technologies, and experimentation, as well as preparatory studies for the future installation of the ATES system in the Riva del Garda advanced replicator. Within this WP, FBK supports all WP5 partners in research and development, obtaining demo permits, implementation, and monitoring. FBK also critically assesses the impact of the USES4HEAT project as specified in Task 5.4. Active collaboration with all WP5 partners and WP leaders (mainly WP3 and WP2) is ensured to achieve the specific objectives defined by the USES4HEAT project.
Butterfly Orchids – ANDEL **Part of the consortium**	**Beneficiary** – ANDEL act as a demo owner and organized the tasks related to engineering, installation, and commissioning at the WP5 ATES demo site in Andel. ANDEL is responsible for commissioning the executive design, requesting permits, and overseeing the construction of USES4HEAT solutions at the ATES demo site in Andel. Detailed engineering activities, monitoring, safety, and risk assessments were carried out to ensure the successful integration of the solutions. Active collaboration with Climeco, DTESS, IF, FBK, HIREF, ENDEF, Energenius is ensured.
Dutch Thermal Energy Storage Solutions – DTESS **Part of the consortium**	**Beneficiary –** DTESS together with IF acts as a technology provider. They are responsible for the design and construction of the ATES system at the USES4HEAT ATES demo site in Andel. DTESS also supports ANDEL in the commissioning of the executive design, requesting permits, and overseeing the construction of USES4HEAT solutions at the ATES demo site in Andel. Active collaboration with ANDEL, Climeco, IF, FBK, HIREF, ENDEF, and Energenius is ensured.
IF Technology – IF **Part of the consortium**	**Beneficiary –** IF together with DTESS acts as a technology provider. They are responsible for the design and construction of the ATES system at the USES4HEAT ATES demo site in Andel. Active collaboration with ANDEL, Climeco, DTESS, FBK, HIREF, ENDEF, and Energenius is ensured.
HIREF SPA **Part of the consortium**	**Beneficiary** – HIREF leads the activities for their respective technology deployment. In this way HIREF is responsible for design, development, and realization of four new GWHP units at the ATES demo site in Andel with respect to the specific objectives defined by USES4HEAT project. Research support and active collaboration with ANDEL, DTESS, IF, Climeco, and FBK is ensured.
ENDEF ENGINEERING SL **Part of the consortium**	**Beneficiary** – ENDEF leads the activities for its respective technology deployment. In this way ENDEF is responsible for design, manufacturing, and validation of PVT solar panels to be connected to USES4HEAT energy system in ATES demo site in Andel with respect to the specific objectives defined by the project. Research support and active collaboration with ANDEL, DTESS, IF, Climeco and FBK is ensured.
ENERGENIUS SRL **Part of the consortium**	**Beneficiary** – Energenius acts as technology provider, and, as such, collects and analyses data from demo sites to define a tailored monitoring and control architecture considering the specification of the technologies and assets to be installed at the ATES demo site in Andel. Research support and active collaboration with ANDEL, DTESS, IF, Climeco and FBK is ensured.

ALTO GARDA SERVIZI SPA – AGS **Part of the consortium**	**Beneficiary** – AGS with CDG and AGP acted as a demo owner and organized the tasks related to engineering, installation, and commissioning at the previous USES4HEAT demo site in Riva del Garda starting in December 2024. They were responsible for commissioning the executive design, requesting permits, and overseeing the construction of USES4HEAT solutions at the Riva del Garda demo site. Detailed engineering activities, monitoring, safety, and risk assessments were carried out to ensure the successful integration of the solutions. After the official withdrawal of AGP and CDG, AGS remained in USES4HEAT as the owner of the advanced replicator in Riva del Garda and continues to be involved in the activities defined in Task 5.5.
HYDRA SRL **Part of the consortium**	**Beneficiary** – HYDRA leads the activities related to its technology deployment. HYDRA was responsible for the construction of two ATES wells at the previous WP5 demo site in Riva del Garda, developing and improving drilling technologies in line with the specific objectives defined by the USES4HEAT project. Following the withdrawal of AGP and CDG, HYDRA is responsible for testing the newly developed drilling machine by constructing a well in the Riva del Garda advanced replicator. Research support and active collaboration with AGS, and FBK are ensured.
Climeco Engineering – Climeco **Not in the consortium**	***Supporting partner (NO Beneficiary)*** – Climeco support engineering design to reach an optimal integration of innovative technologies with the components will be installed at the ATES demo site in Andel. Support in research and obtaining demo permit with active collaboration with ANDEL, IF, DTESS, HIREF, ENDEF, Energenius and FBK is ensured.
ALTO GARDA POWER SRL – AGP **No longer part of the consortium**	~~**Beneficiary**~~ – AGP with CDG and AGS acted as a demo owner and organized the tasks related to engineering, installation, and commissioning at the previous USES4HEAT demo site in Riva del Garda starting in December 2024. They were responsible for commissioning the executive design, requesting permits, and overseeing the construction of USES4HEAT solutions at the Riva del Garda demo site. Detailed engineering activities, monitoring, safety, and risk assessments were carried out to ensure the successful integration of the solutions. AGP officially left the USES4HEAT consortium in May 2025 (M18).
GARDA CARTIERE S.P.A. – CDG **No longer part of the consortium**	~~**Beneficiary**~~ **– CDG** together with AGP and AGS acted as a demo owner and organized tasks related to engineering, installation, and commissioning at the previous USES4HEAT demo site in Riva del Garda starting in December 2024. They were responsible for commissioning the executive design, requesting permits, and overseeing the construction of USES4HEAT solutions at the Riva del Garda demo site. Detailed engineering activities, monitoring, safety, and risk assessments were carried out to ensure the successful integration of the solutions. CDG officially left the USES4HEAT consortium in May 2025 (M18).
STUDIO ASSOCIATO DI INGEGNERIA – SAI **Not in the consortium**	~~***Supporting partner (NO Beneficiary)***~~ – SAI supported engineering design to reach an optimal integration of innovative technologies with the components installed at the previous WP5 demo site in Riva del Garda. After withdrawal of AGP and CDG, the collaboration with SAI has been finished
Studio Geologico Associato GeoAlp – GeoAlp **Not in the consortium**	~~***Supporting partner (NO Beneficiary)***~~ – *GeoAlp* supported geological study and design in WP5 to find an optimal solution for ATES design. GeoALP withdrawal collaboration with the USES4HEAT on Sep 2024 due to internal reasons.

It is important to note that, for the current work package, Energenius and CARTIF are responsible for tasks related to the intelligent energy management system and predictive operation and maintenance, which are connected to Work Package 3. Their efforts include analysing historical and real-time data from the demo site. However, their contributions are documented in the corresponding deliverables under Work Package 3.

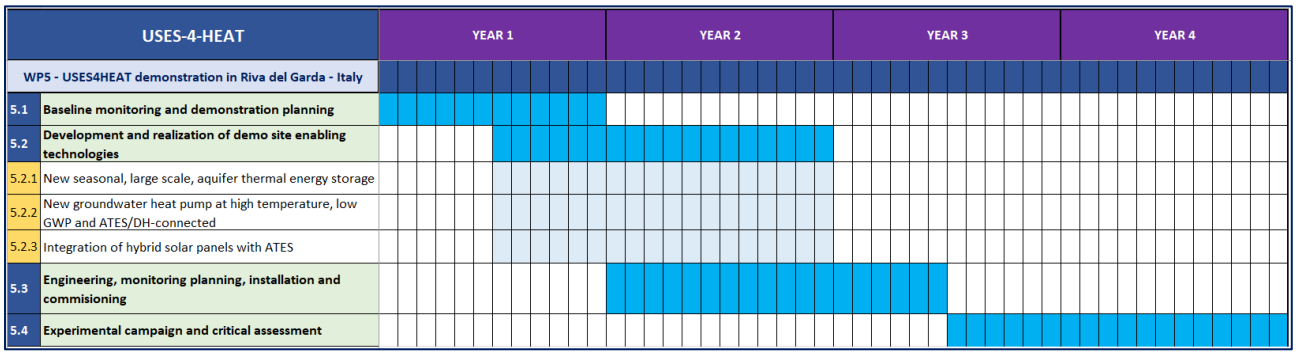

Figure 1. Previous Work Package 5 Gantt chart.

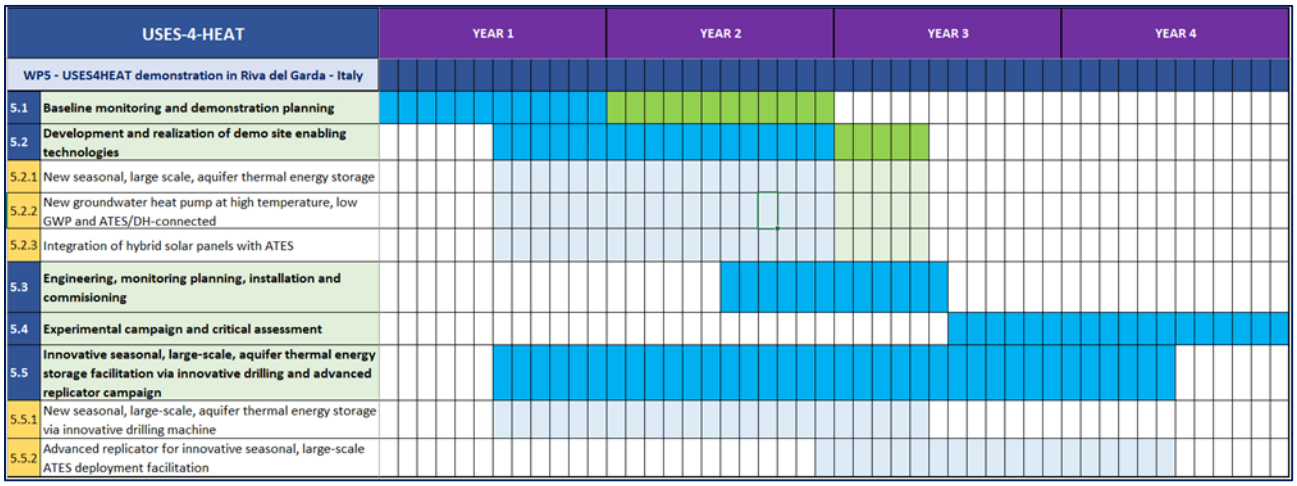

Figure 2. Updated Work package 5 Gantt chart including extension of tasks 5.1 and 5.2 (in Green).

2.2. Main Objectives of the Project

To address the challenges associated with realizing the innovative USES4HEAT technologies, the consortium has identified five main objectives, three of which are directly related to WP5 and can be summarized as follows:

- MO1: Develop and demonstrate an innovative, large-scale, cost-effective seasonal Aquifer Thermal Energy Storage (ATES) system for decarbonized heating supply, achieving a Technology Readiness Level (TRL) of 8.
- MO2: Develop and demonstrate key enabling technologies at TRL 8 to decarbonize, enhance flexibility, increase availability, and improve the robustness of the heating sector, ensuring integration with seasonal ATES systems.

- MO3: Develop and demonstrate intelligent energy management systems at TRL 8, leveraging AI, big-data analytics, and predictive operation and maintenance (O&M) for optimized performance.

These main objectives are further divided into specific objectives, each contributing to the overall goal and tracked through precise Key Performance Indicators (KPIs). For more detailed information about the KPIs and the monitoring approach, refer to Deliverable *D2.1: USES4HEAT Layouts and KPI Definitions*.

2.3. Baseline Monitoring, Planning and Layout Definitions

Within the framework of Work Package 5 (WP5), during the first year of the USES4HEAT project, extensive data were collected for the initial demonstration site in Riva del Garda, Italy to support the analysis, categorization, and monitoring of associated activities (see Deliverables *D2.1* and *D5.1* for details). These datasets included experimental measurements, sensor outputs, model simulations, literature reviews, geospatial data, technical documentation, and reports. Data collection efforts involved the preparation of questionnaires, retrieval of historical data from the local power plant, and multiple coordination meetings with key stakeholders.

However, due to regulatory challenges and administrative constraints concerning the implementation of ATES systems in Italy, the consortium decided to relocate the WP5 demonstration site to Andel, the Netherlands. This decision was made following a thorough evaluation and consultation among project partners, based on the following key considerations:

(i) alignment with the overall USES4HEAT research objectives,

(ii) adherence to the project timeline,

(iii) mitigation of risks associated with the national regulatory framework, and

(iv) improved potential for integration, demonstration, and replication of the USES4HEAT technologies.

Following the consensus reached within the consortium, the WP5 demonstration site officially transitioned to the Butterfly Orchids greenhouse in Andel, the Netherlands, in Month 19 (May 2025). Between M19 and M24, the WP5 team focused on advancing the new demonstration setup through:

- Detailed planning and scheduling of WP5 activities,
- Comprehensive site-specific data collection,
- Detailed system design and integration of the USES4HEAT technologies, and
- Initiation and follow-up of the authorization procedures supported by technical and environmental studies.

Several coordination meetings were organized during this period to ensure accurate progress tracking and effective alignment among the involved partners.

3. ATES Demo Site in Andel

3.1. Andel, the Netherlands

Andel is a small village with approximately 2,500 inhabitants, located in the southern Netherlands within the Municipality of Altena in the Province of Noord-Brabant. This Province represents an important hub for food production, where ongoing initiatives aim to balance intensive agricultural activity with environmental sustainability and nature conservation. In addition to open-field farming, the region hosts several greenhouses dedicated to the production of food crops and ornamental plants. The Province, in collaboration with local entrepreneurs, is actively pursuing innovative and sustainable energy solutions.

Greenhouses in Noord-Brabant are typically standalone installations, which poses challenges for the implementation of large-scale deep geothermal heating systems. Consequently, most facilities continue to rely on natural gas for heating, primarily through natural gas boilers or combined heat and power (CHP) systems that simultaneously generate heat, electricity, and sometimes CO_2 for enrichment purposes. In alignment with national decarbonization policies, the Dutch government has committed to a substantial reduction in natural gas consumption across industrial sectors and residential heating. To facilitate this transition, taxation on natural gas is being progressively increased, thereby incentivizing project developers and large energy consumers to adopt renewable and low-carbon alternatives.

3.2. Location Climate

The climate of Andel is classified as Cfb according to the Köppen–Geiger climate classification system. The letter “C” denotes a mild mid-latitude climate, where the coldest month has an average temperature above −3 °C and at least one month averages above 10 °C. The letter “f” indicates a fully humid climate with no distinct dry season, while “b” represents a warm summer, characterized by the warmest month averaging below 22 °C. This temperate oceanic climate supports diverse vegetation and agricultural activities, typical of Western Europe, including grassland, mixed farming, and dairy production.

As illustrated in Figure 3, average summer temperatures are generally moderate; however, occasional peaks above 30 °C occur, creating a demand for cooling. Conversely, from October to April, average temperatures remain below 15 °C, highlighting the need for heating during this period. The region also experiences steady winds throughout the year, with an annual average of approximately 14 km/h and higher speeds typically recorded during winter months.

The heating degree days (HDD) and cooling degree days (CDD) indices were calculated based on a base temperature, defined as the lowest/highest daily mean air temperature not leading to indoor heating/cooling (typically set within ±3 °C of the chosen base temperature for HDD and CDD, respectively). The base temperature depends on several factors related to building characteristics and the surrounding environment. For this study, a general climatological approach was adopted, setting the base temperatures for heating and cooling at 18 °C and 21 °C, respectively. As shown in Figure 4, HDD values

have gradually decreased over the past four years, from 2,774 (2021) to 2,441 (2022), 2,337 (2023), and 2,349 (2024), with an average of approximately 2,475. In contrast, CDD values showed an increase from 3 (2021) to around 16 (2022–2023) and 6.3 (2024), averaging about 10.5 days.

Regarding solar irradiance, the average peak intensity reaches above 800 W/m² during June and July, while winter levels drop to around 200 W/m² (Figure 5). The daily ground-level solar irradiation (Figure 6) rarely exceeds 8 kWh/m², averaging about 6.5 kWh/m². On a monthly scale (Figure 7), total ground-level solar irradiation exceeds 100 kWh/m² between April and September, with the highest values recorded in May, June, and July—approximately 180, 200, and 190 kWh/m², respectively.

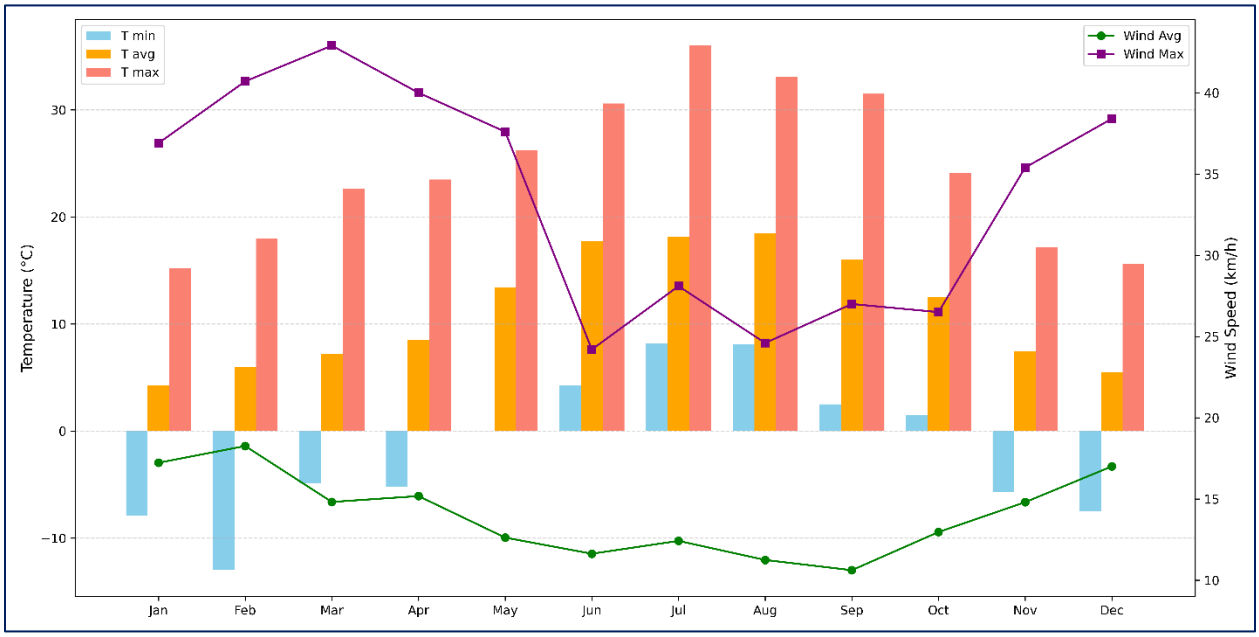

Figure 3 . Monthly climate data for the Andel site, the Netherlands [adopted from Meteostat].

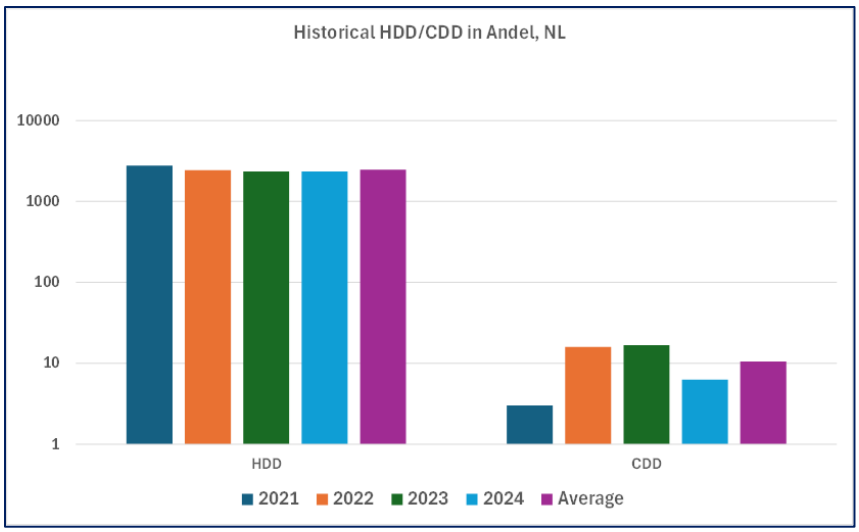

Figure 4. Historical heating degree days (HDD) and cooling degree days (CDD) from 2021 to 2024 in Andel, the Netherlands [derived from hourly climate data provided by Meteostat].

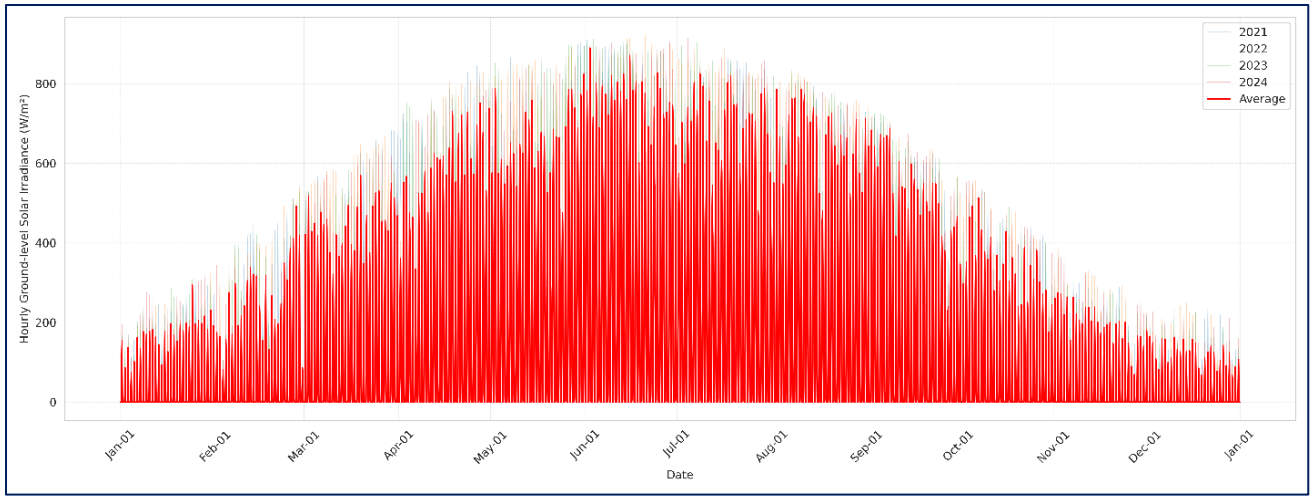

Figure 5. Hourly solar irradiance profile (W/m²) from 2021 to 2024 in Andel, the Netherlands [Renewables.ninja; Gelaro et al., 2017].

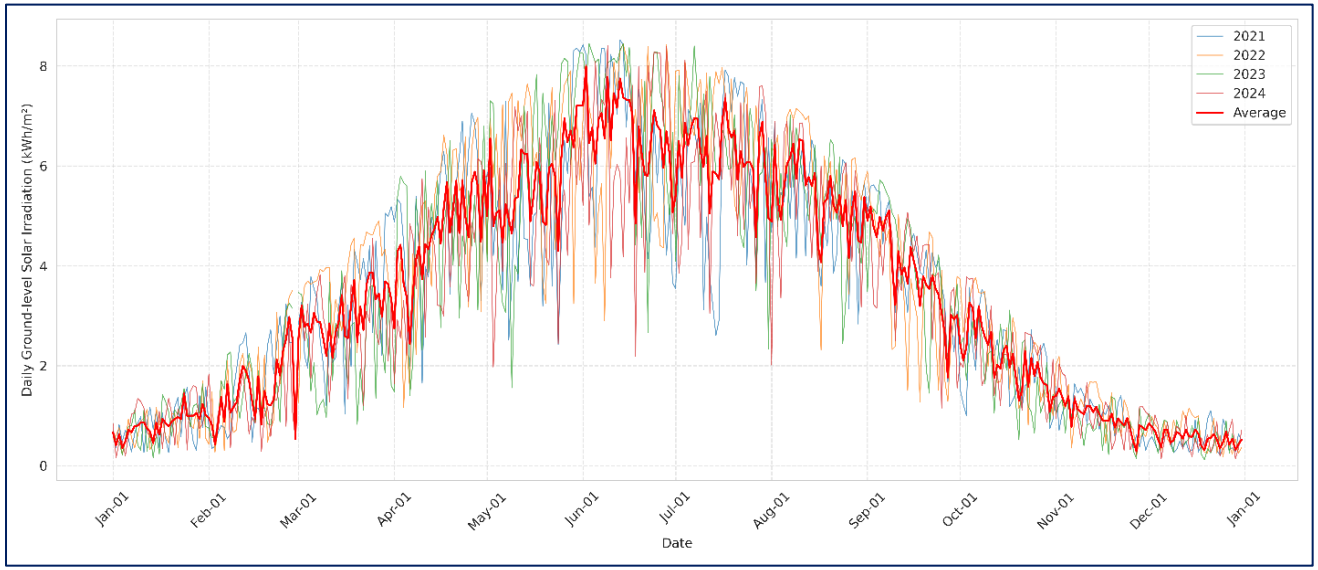

Figure 6. Daily total solar irradiation profile (kWh/m²) from 2021 to 2024 in Andel, the Netherlands [adopted from Renewables.ninja; Gelaro et al., 2017].

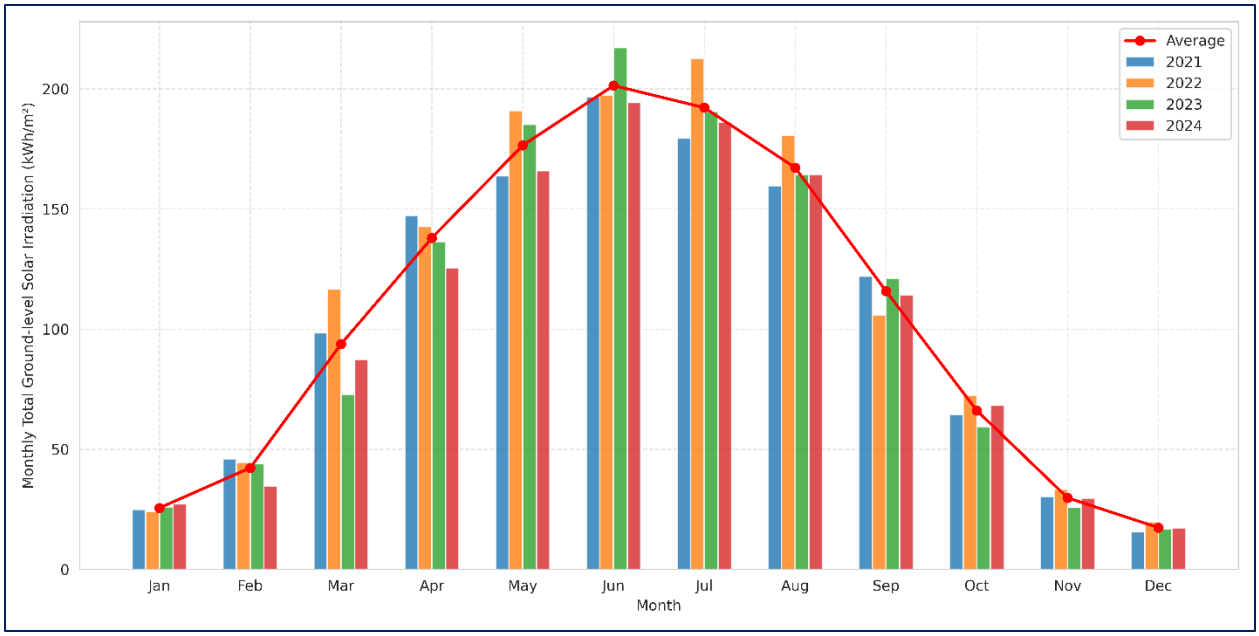

Figure 7. Monthly total irradiation (kWh/m²) from 2021 to 2024 in Andel, the Netherlands [adopted from Renewables.ninja; Gelaro et al., 2017].

3.3. Geological and Hydrogeological Framework of the Area

At the ATES demo site, two test drillings were carried out to assess the potential for implementing a medium-temperature aquifer thermal energy storage (MT-ATES) system. The first objective of those tests was to characterize the subsurface geology and evaluate whether the local conditions are suitable for the storage and recovery of thermal energy from the underground. The second objective is to obtain input parameters for the design of the wells and to improve the accuracy of the modelling work for the permit request.

The subsurface composition encountered in both boreholes is illustrated schematically in Figure 8, representing the stratigraphy at the locations of both ATES clusters — one in the warm-well area and the other in the cold-well area.

The geohydrological properties expected at the site are presented in Table 2. These values are considered representative of the actual subsurface conditions, as they have been validated through the test drillings and accompanying hydraulic and geological investigations.

Table 2. General geological composition of the study area.

Layer/ Property	Lithology	Top surface *[m b.s.l.]*	Thickness *[m]*	Transmittance/Resistance *[m²/d]/[d]*
Top layer	Clay	0 - 8	8	800 d
1st aquifer	Moderate to very coarse sand	8 - 49	41	2,050 m^2/d
1st Aquitard	Clay	49 - 75	26	26,000 d
2nd Aquifer	Moderate to very coarse sand	75 - 84	9	500 m^2/d
2nd Aquitard	Clay	84 – 88	4	4,000 d
3rd Aquifer	Fine and moderate sand with local clay layers	88 – 120	32	400 m^2/d / 600 d
Aquiclude	Sandy clay	> 120	-	-

The minimum, average, and maximum groundwater levels, along with the different aquifers are presented in Table 3. The local and regional geohydrological characteristics are summarized in Table 4.

Table 3. Water level records across different layers in the study area.

Layer/ Water level	Lowest *[m NAP [a]]*	Average *[m NAP]*	Highest *[m NAP]*
Groundwater table	-0.8	-0.6	-0.4
1st aquifer	-0.5	-0.3	0.0
2nd aquifer	-0.5	-0.4	-0.1
3rd aquifer	-0.7	-0.5	-0.3

[a] *NAP stands for "Normaal Amsterdams Peil", the official Dutch vertical reference level corresponding to the Amsterdam Ordnance Datum.*

Table 4. Summary of local hydrogeological characteristics.

Parameter	Unit	Value
Groundwater natural flow velocity (storage package)	*[m/year]*	18
Groundwater natural flow direction (storage package)	*[-]*	Southeast
Groundwater temperature (storage package)	*[°C]*	12
Fresh/brackish interface (chloride 150 mg/l)	*[m b.s.l.]*	≈ 125 (in 3rd separating layer)
Brackish/salt interface (chloride 1,000 mg/l)	*[m b.s.l.]*	≈ 175

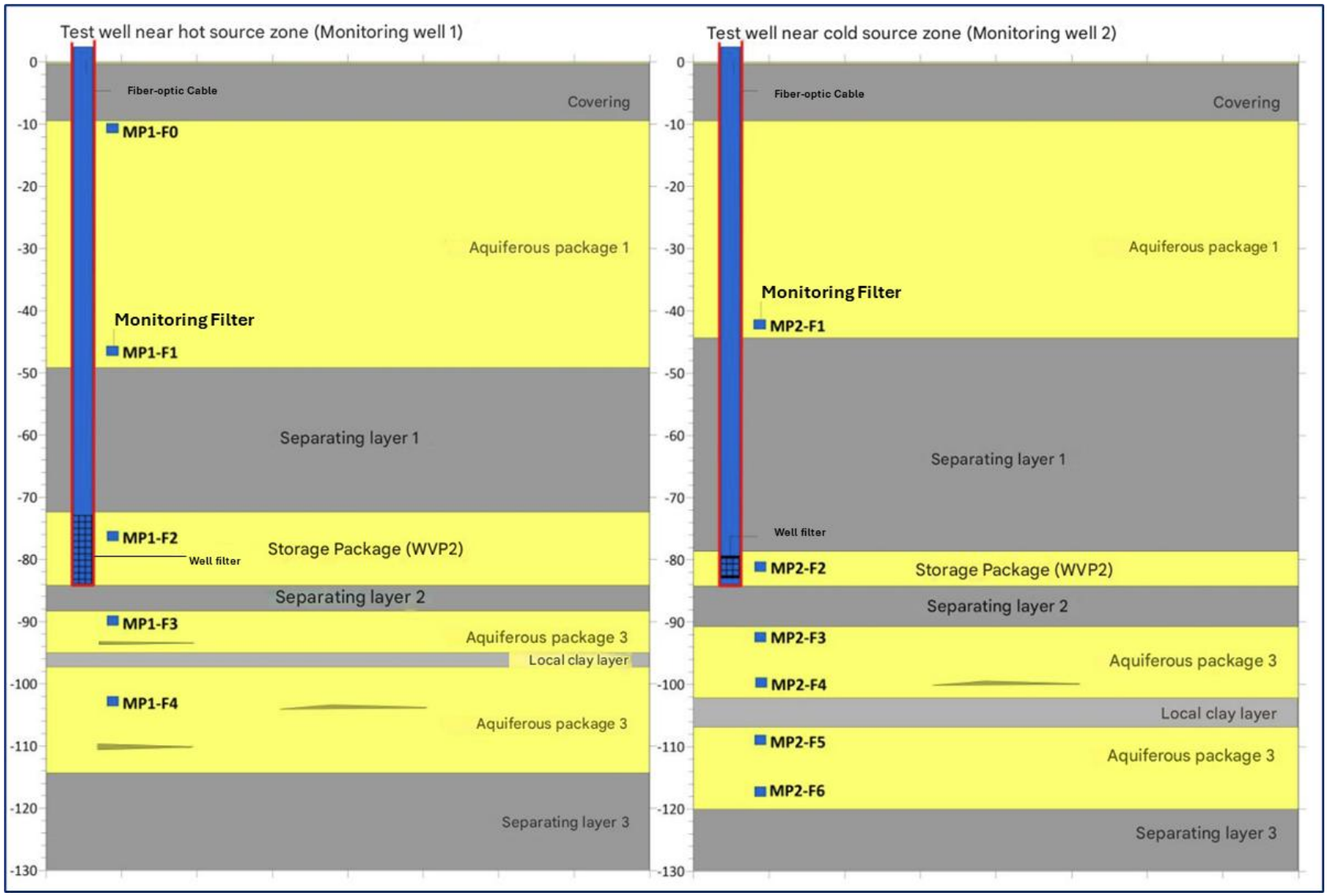

Figure 8. Schematic representation of the underground layers, highlighting the position of the test wells and monitoring filter screens.

3.4. Site Overview

At the demonstration site in Andel, the existing greenhouse covers approximately 3.5 hectares and is dedicated to orchid cultivation. The facility currently operates with gas-fired boilers, CHP, HPs and a low-temperature (5–25 °C) ATES system (Table 5) consisting of four wells (K1, K2, W1, W2) that provide both heating and cooling, supported by a heat pump and photovoltaic (PV) panels that supply power for LED lighting. Depending on current energy prices and PV generation, the most cost-effective heating and thermal buffering strategy is selected.

Table 5. Features of the ATES system currently operating in the existing greenhouse at the demonstration site.

Energy Concept	LT–ATES
Storage Aquifer	Shallow Aquifer (20-55 *m b.s.l.*)
Number of Wells	2 cold wells – 2 warm wells
Injection Temperature Max	25 *°C*
Flow rate Max	150 m^3/h
Heating Power	1,750 *kW*
Cooling Power	1,050 *kW*
Storage Capacity	2,600 *MWh*

Butterfly Orchids is now planning to expand its facilities by adding an additional 12 hectares of greenhouse area (Figure 9). For this new development, no natural gas connection will be installed. The two greenhouses will be interconnected via a pipeline system. Moreover, the energy system in the current existing greenhouse is connected with the swimming pool nearby to meet its heat demand.

The site is located approximately 400 meters from the village of Andel, which has a population of about 2,500 inhabitants. In the future, the system could potentially support a district heating network (DHN), providing renewable heat to the local community.

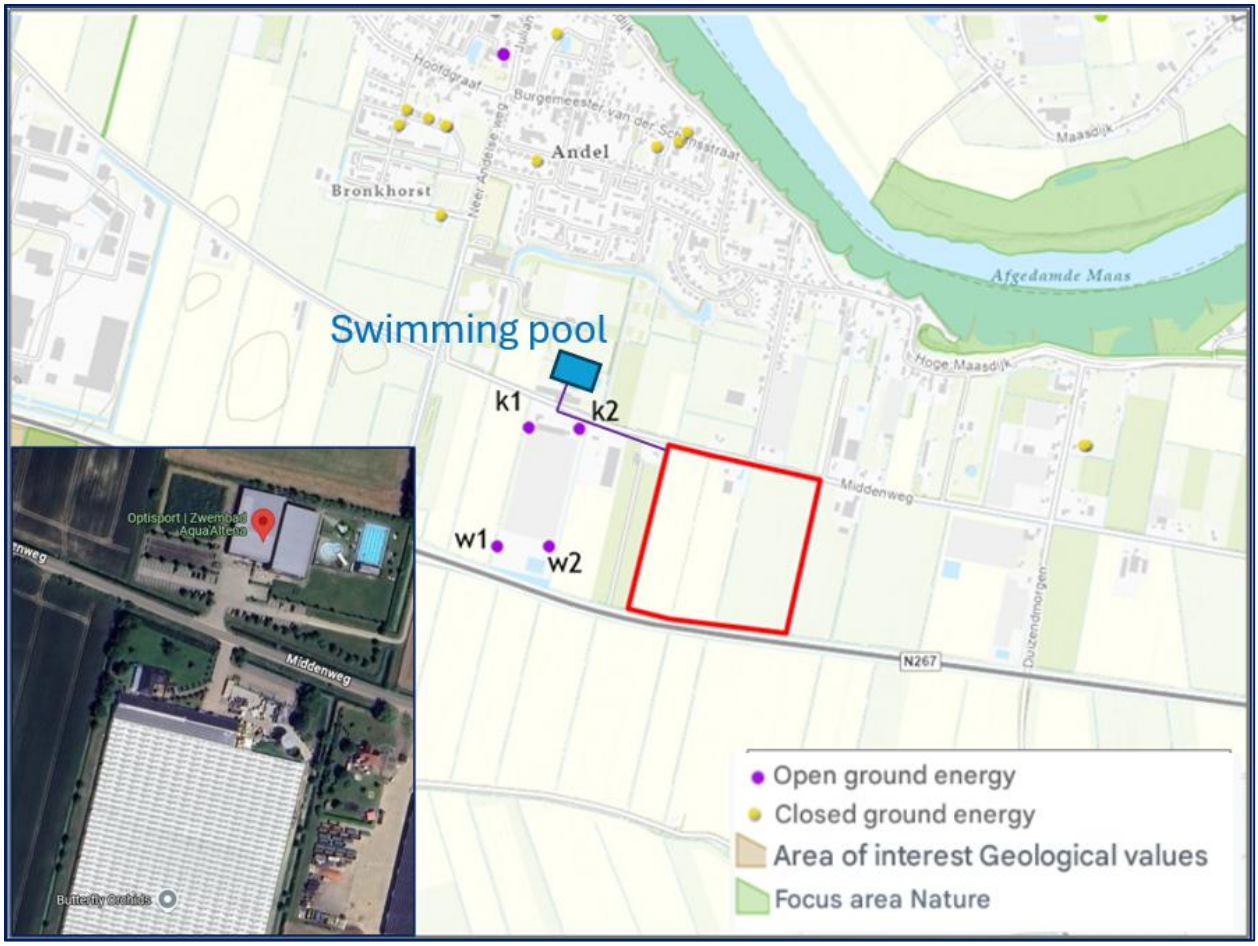

Figure 9. Demo area in Andel, the Netherlands, highlighting the location of the new greenhouse (in red) and the connection between the energy system, existing greenhouse, and swimming pool.

4. Demonstration Plan

4.1. Overview

As discussed in Chapter 2, the primary objective of the demonstration plan is to develop and implement an ATES system that functions as a seasonal thermal energy storage solution, storing excess heat generated during the summer and utilizing it during the winter.

The existing greenhouse currently relies on natural gas as its primary heating source during the winter months. To support decarbonization and increase the share of renewable and waste heat utilization, several scenarios have been studied (to be reported in *Deliverable D2.2 — USES4HEAT Impact in Deep Decarbonisation Scenarios*).

It is important to note that while renewable electricity production accounted for approximately 53% of total national electricity generation in 2024 (CBS, Statistics Netherlands), the Dutch national grid continues to experience congestion issues, particularly during winter. As a result, electricity prices may rise by up to 100% compared to summer prices (Figure 10).

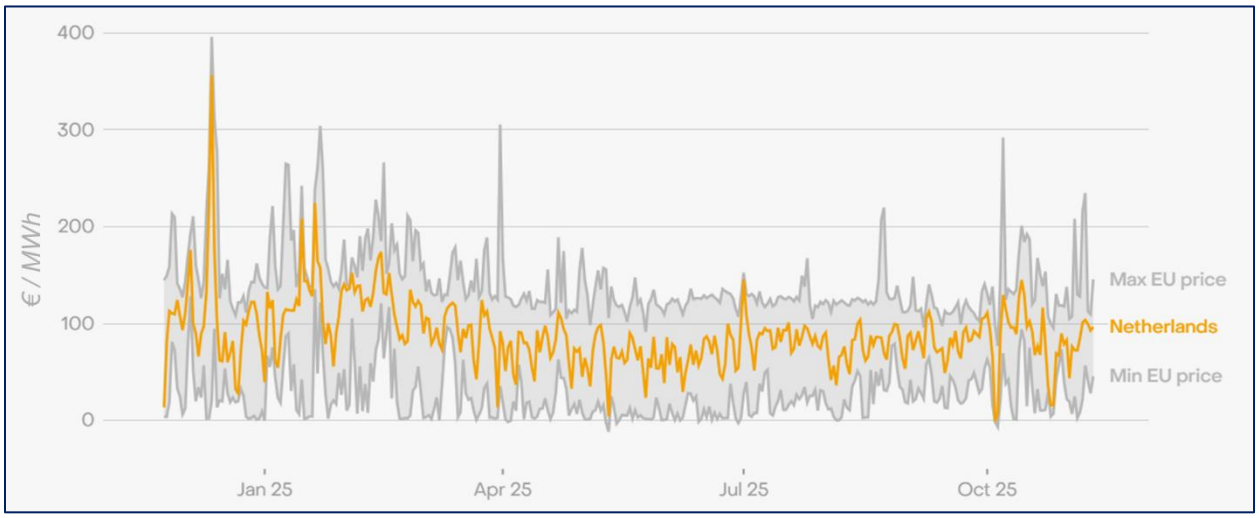

Figure 10. Wholesale electricity prices in the Netherlands from Nov 2024 to Nov 2025. Prices are average day-ahead spot prices per MWh sold per time period; Max and min prices refer to the highest and lowest average values of any country in the EU in that period [EMBER-Energy.org].

One of the key objectives of the USES4HEAT ATES demonstration is to take advantage of lower-cost electricity during the summer by operating groundwater heat pumps (GWHPs) to charge the ATES system. This allows the storage of thermal energy for cost-effective heating during the winter.

The schematic representation of the overall energy concept is shown in Figure 11. During the summer, heat will be extracted from the greenhouse (cooling function) and the surrounding surface water. This heat will be amplified using GWHPs and photovoltaic–thermal (PVT) panels, and subsequently stored

seasonally by injecting water at 50–55 °C into the warm wells of the medium-temperature ATES (MT-ATES) system.

Depending on weather and market conditions, the electricity required for the GWHP units will be supplied from the national grid, PV, and USES4HEAT PVT panels. During the winter, heat recovered from the MT-ATES system will be used for direct greenhouse heating or in combination with HPs when the recovered temperature is below 35 °C, ensuring a stable heat supply. This configuration enhances energy system flexibility and provides a sustainable, low-carbon solution for both heating and cooling needs.

In line with the national strategy to increase the share of renewable energy in the electricity mix, the integrated system is expected to operate on 100% renewable energy in the near future.

Figure 12 highlights the designated area in Andel for the construction of the new greenhouse, while Figure 13 illustrates the planned construction phases in greater detail, including the areas allocated for the cold and warm zones of the MT-ATES system, the technical room, and the open pool.

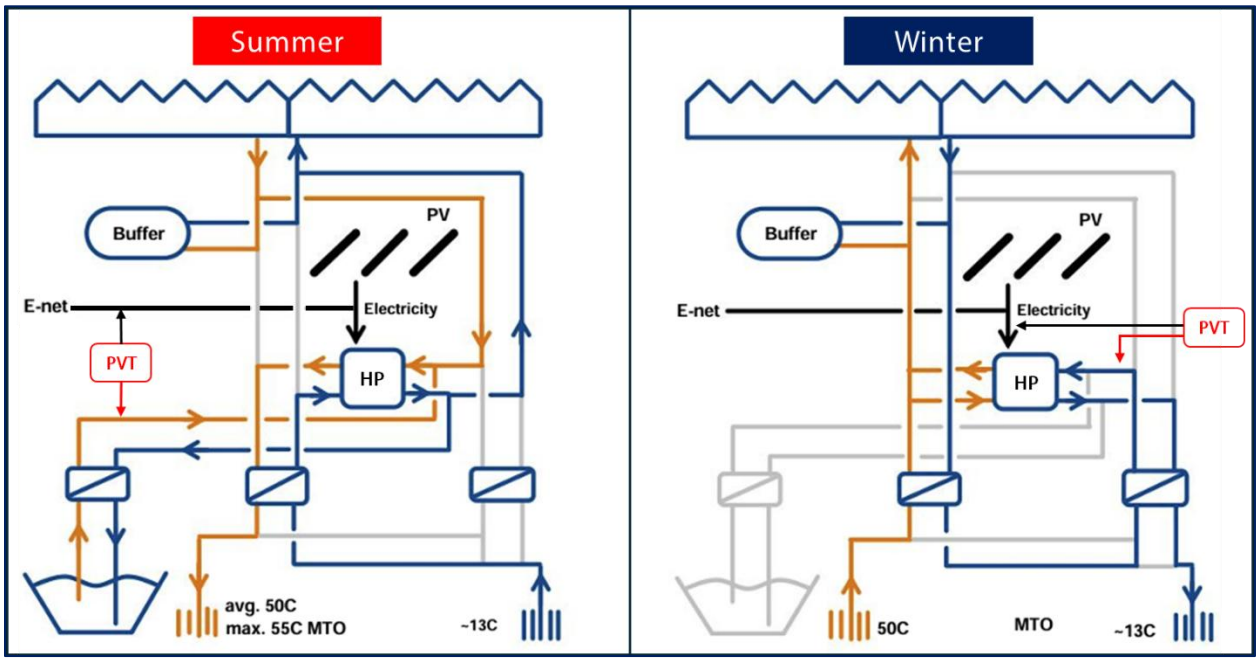

Figure 11. Schematic representation of the energy system and the integration of its components across the seasons.

Figure 12. Highlighting the area (in orange) planned for the construction of a new greenhouse adjacent to the existing Butterfly Orchids and the technical room (red cross) located in the southern section.

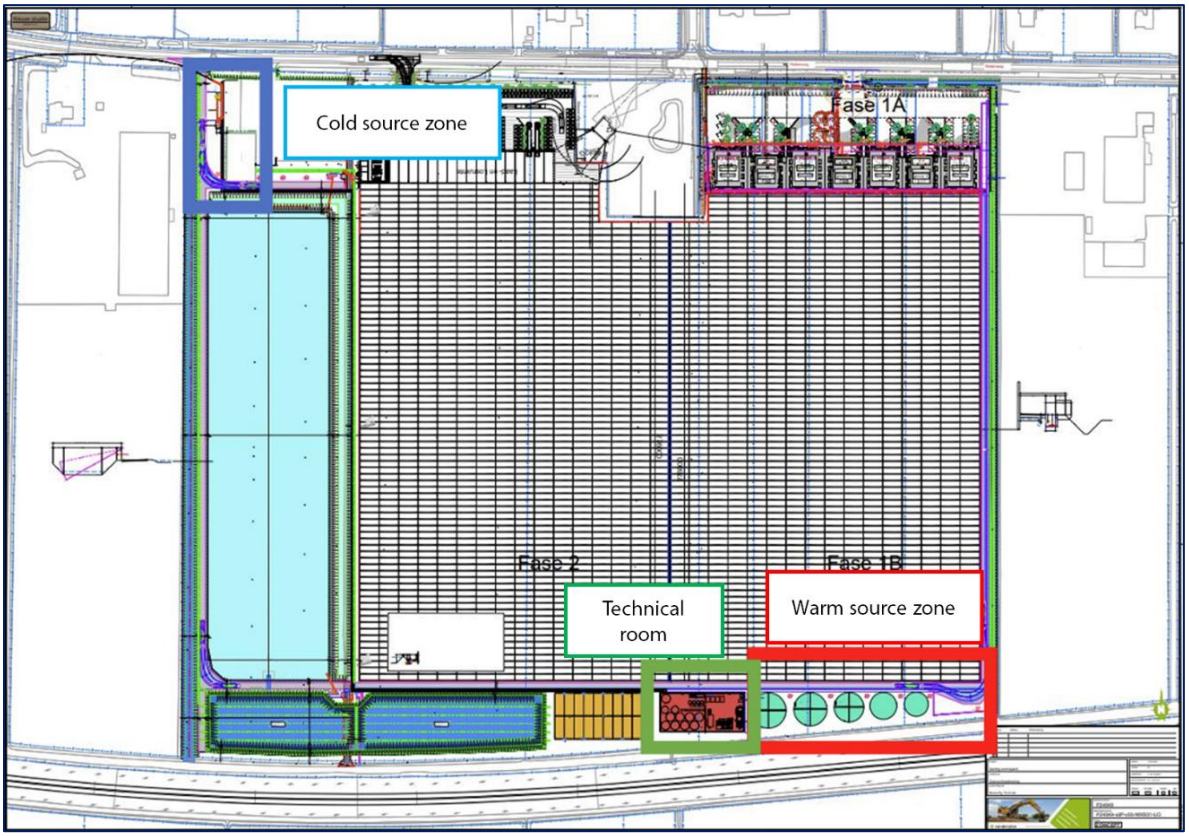

Figure 13. Planned phases for the construction of the greenhouse and the areas designated for the warm and cold clusters of the MT-ATES system.

4.2. Development and Realization of Enabling Technologies

4.2.1. New Seasonal, large-scale, Aquifer Thermal Energy Storage

As illustrated in Figure 11, an MT-ATES system is planned to be installed as the key component of the greenhouse energy system, functioning as a heat source during winter and as a heat sink during summer. The MT-ATES is an open-loop groundwater energy system consisting of two main zones: a warm zone (with four wells) and a cold zone (with six wells). The operational principle is to store surplus heat in the warm zone during summer while simultaneously providing cooling (if needed by the greenhouse) through the cold zone. Conversely, during winter, the warm zone acts as a heat source, and the cold zone serves as a return of the cooled groundwater.

To ensure stable and efficient operation, a comprehensive monitoring plan has been designed to continuously assess system performance and environmental impacts using monitoring wells and dedicated instrumentation, as described in the following chapter.

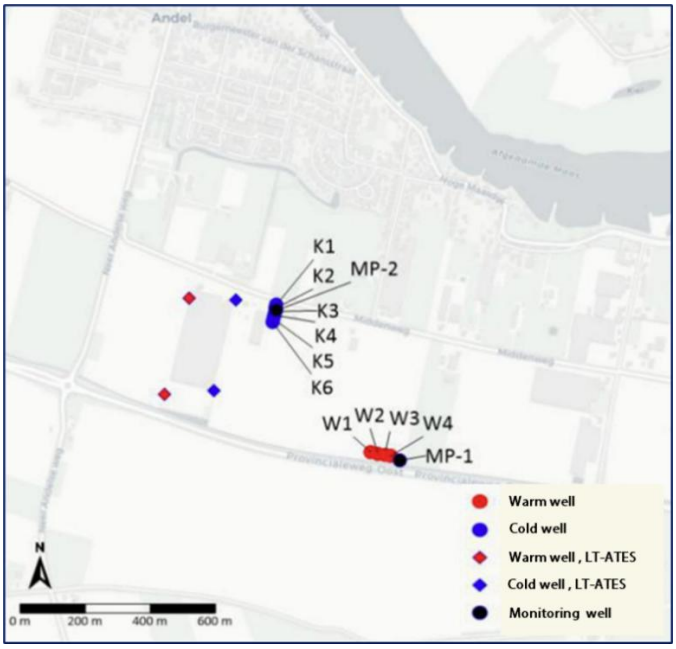

Figure 14. Planned locations of the warm, cold, and monitoring wells for the MT-ATES system within the site area, along with the existing LT-ATES wells in the shallow aquifer.

4.2.1.1. General Specifications

During the summer, the MT-ATES system is designed to store heat at approximately 50 °C in the warm zone, while during the winter, heat is extracted from this zone down to about 25 °C. According to a study conducted by IF Technology, the system is expected to achieve a thermal recovery efficiency of approximately 40% during the first five years of operation, as the storage aquifer gradually warms up. From the sixth year onward, the recovery efficiency is projected to increase progressively, reaching around 60% by the tenth operational cycle. The general design specifications of the MT-ATES system are summarized in Table 6 below.

Table 6. MT-ATES system principles and general characteristics.

Parameter	Winter *[Unit]*	Summer *[Unit]*
Production/Injection volume (Max)	750,000 *[m^3/season]*	620,000 *[m^3/season]*
Production/Injection volume (Avg)	635,000 *[m^3/season]*	520,000 *[m^3/season]*
Production/Injection flow rate (Max)	390 *[m^3/h]*	390 *[m^3/h]*
Injection temperature (Avg)	13 *[°C]*	50 *[°C]*
Injection temperature (Min/Max)	5 *[°C]*	55 *[°C]*
Cut-off temperature	25 *[°C]*	-
Energy displacement (Avg)	17,000 *[MWh/season]*	21,000 *[MWh/season]*

4.2.1.2. Wells placement and design

As described previously, the MT-ATES system consists of two well clusters installed within the storage aquifer, where the groundwater flow direction is toward the southeast. The cold cluster comprises six wells (Figure 15) spaced approximately 11 meters apart and is planned to be installed in the northwestern corner of the site. The warm cluster consists of four wells spaced about 20 meters apart (Figure 16) and will be located in the southeastern corner of the site, adjacent to the technical room.

Considering the storage volume, while a closer spacing between clusters could potentially improve heat storage performance, the cold zone also serves as a cooling source for the system. Therefore, maintaining a distance equivalent to approximately three times the thermal radius ($3 \times R_{th}$) is regarded as an optimal configuration for this well placement.

The wells will be placed in a borehole of 90 m depth with a diameter of 500 mm. The recommended drilling technique is the reversed rotary drilling with air lifting. During the drilling of each meter a soil sample will be taken and analysed. This will give an accurate view of the alternating clay and sand layers and result in a final decision of the filter screen trajectory.

The four warm wells will have a liner to 73 m b.s.l. with a diameter of 280 mm. A stainless-steel winding wire filter will be mounted with a slot size of 0.5 mm. The filter will be positioned from 73-83 m b.s.l. Below the filter 2 m liner will be installed as a sand trap. The selection of the type of material of the liner needs to be made in the design phase.

The six cold wells will have a PVC liner to 80 m b.s.l. with a diameter of 250 mm. The PVC slotted filter screen will be placed between 80 – 83 m b.s.l. with a slot size of 0.5 mm. Also, the cold wells will have a sand trap with a length of one meter.

In each 500 mm borehole, three piezometers will be installed simultaneously with the installation of the well. The piezometers will have a diameter of 40 mm and are of PVC. They have a 2 m filter zone with a slot size of 0.5 mm. The first piezometer will be placed in the phreatic groundwater layer (above the target

aquifer). The second just above the clay layer which is above the target aquifer and the third piezometer at the same depth as the filter zone of the well. This piezometer will have a pumping chamber for the first 45 meters with a diameter of 63 mm. This makes it possible to abstract groundwater at greater depth by using a small submersible pump.

The remaining space in the borehole will be filled with filter gravel, swelling clay and coarse gravel. The filter gravel has a size of 0.6-1.0 mm and is placed at the same depths as the filter zones of the wells. The coarse gravel is used to restore the aquifer layers and the swelling clay to restore and close the penetrated clay layers.

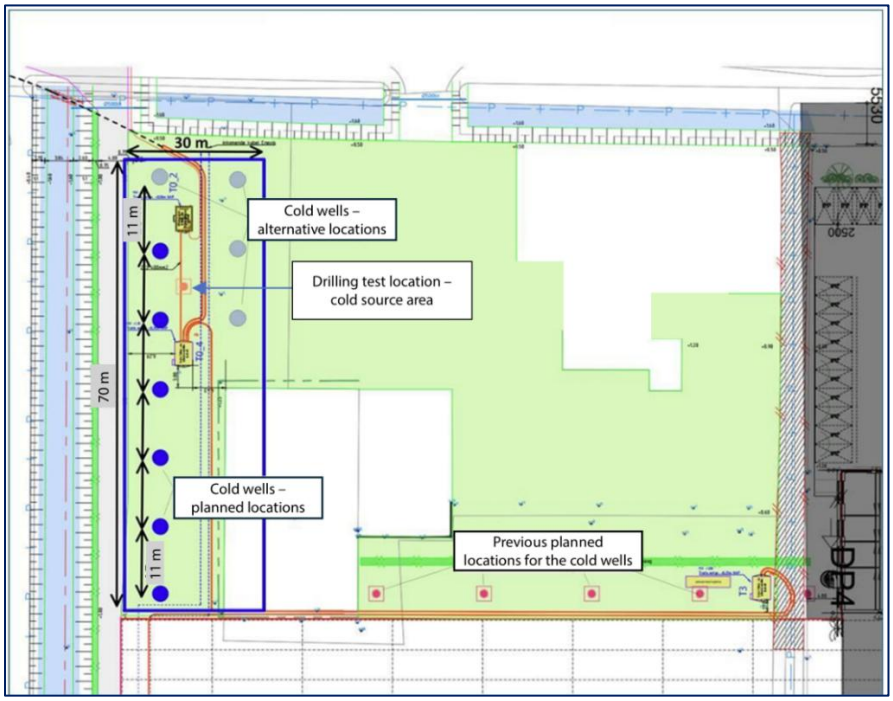

Figure 15. Northwestern side of the new greenhouse area, highlighting the planned locations of the cold wells and monitoring well, along with their spacing.

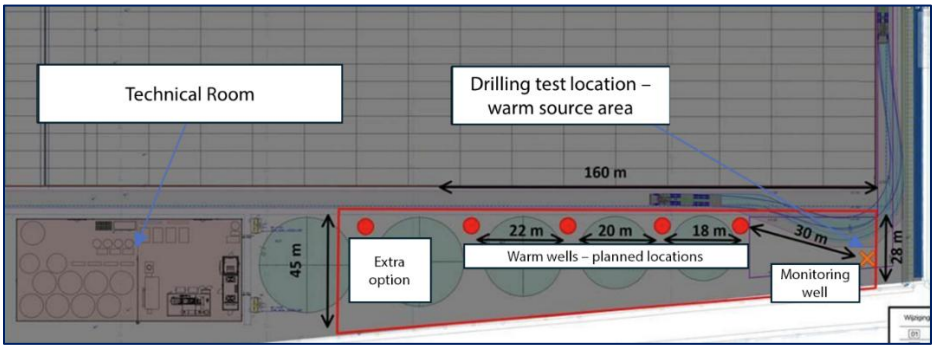

Figure 16. Southeastern side of the new greenhouse area, highlighting the planned locations of the warm wells, along with the monitoring well and the location of the technical room.

4.2.2. Groundwater Heat Pump for both Heating and Cooling and Low GWP

The XVA1281W DX unit by HIREF (Figure 17) will provide both heating and cooling for the new greenhouse, operating in conjunction with the ATES system as a smart and efficient thermal source. During summer operation, the heat pump will use internal circuit water as its thermal source, supplying cooling to the greenhouse. Any excess thermal energy will be directed to the ATES system for seasonal storage. During winter operation, the heat pump—non-reversible in design—will continue to supply heating to the greenhouse, this time drawing heat from the ATES warm zone. Since the ATES water temperature will be significantly higher than the natural groundwater temperature, this configuration will enhance system efficiency by improving the heat pump's COP.

Figure 17. XVA1281W DX – HIREF GWHP

The technical specifications of the heat pump unit (1.5 MW) are presented in Table 7. The project design includes two heat pump systems, each consisting of two units arranged in series (Figure 18) on the user side and in parallel on the source side, providing a total peak heating capacity of 3 MW per system (6 MW in total for the project). Tables 8 and 9 summarize the operational performance of each unit under worst-case winter conditions, when well water is used as the heat source. Under all other conditions, the thermal source temperature will be more favourable, allowing the units to modulate output while maintaining a stable 3 MW heating capacity. Figure 19 illustrates the operational envelope of the unit under varying temperature and load conditions.

Table 7. General characteristics of each unit of the GWHP system.

Characteristics	Unit	Value
Maximum absorbed current (FLA) [without options]	A	878
Start-up current (LRA) [without options]	A	1253
Sound power level Lw (base unit) [without options]	dB (A)	105
Sound pressure level Lp (base unit) [without options]	dB (A)	77
Compressors/Circuits	-	2/2
Power Supply	-	400 / 3+N / 50
Refrigerant	-	R515B
GWP	-	299
Preliminary Length/Depth/Height	mm	6200/2050/2600

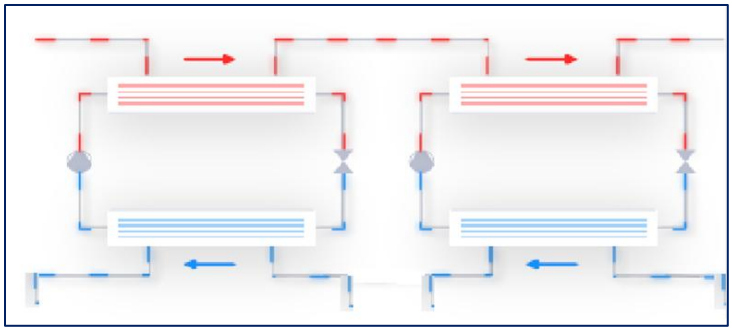

Figure 18. Simplified schematic of the series connection between the two heat pump units.

Table 8. Preliminary simulation results for the first unit of the GWHP in a series configuration.

	Characteristics	Unit	Value
Unit 1 – Series Configuration **Condenser input/output temperature** **25/37.8 °C** **Evaporator input/output temperature** **12/6 °C**	Heating capacity	kW	1572.8
	Water Flow user side	l/h	105676
	Water Pressure drops user side	kPa	66
	Water Flow source side	l/h	187941
	Water Pressure drops source side	kPa	59
	Total Power input	kW	275.4
	Total Absorbed Current	A	470
	COP	W/W	5.71

Table 9. Preliminary simulation results for the second unit of the GWHP in a series configuration.

	Characteristics	Unit	Value
Unit 2 – Series Configuration **Condenser input/output temperature** **37.8/50 °C** **Evaporator input/output temperature** **12/6 °C**	Heating capacity	kW	1490.2
	Water Flow user side	l/h	105046
	Water Pressure drops user side	kPa	66
	Water Flow source side	l/h	166125
	Water Pressure drops source side	kPa	44
	Total Power input	kW	348.6
	Total Absorbed Current	A	595
	COP	W/W	4.27

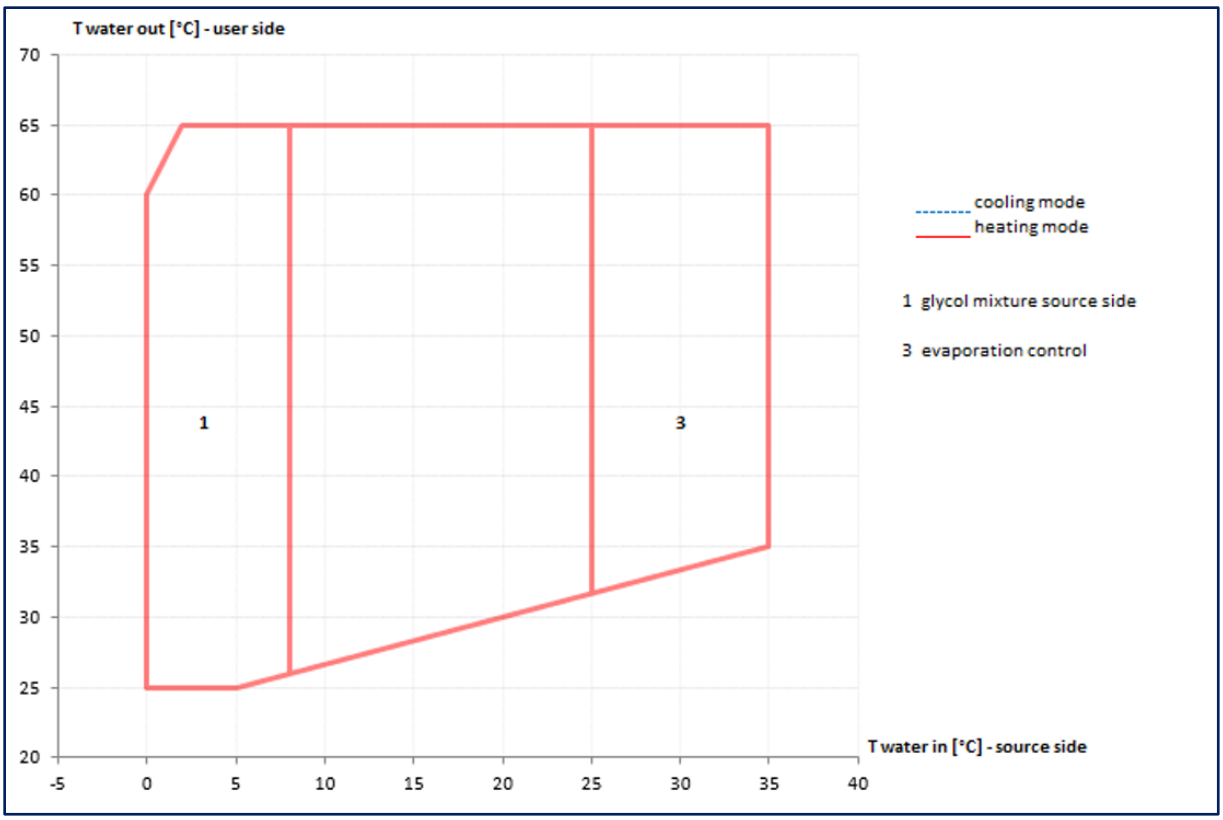

Figure 19. Working envelope of the GWHP showing the operational temperature range for the heating modes.

4.2.3. Integration of Hybrid Solar Panels with ATES

The roof proposed for the ENDEF PVT installation is a two-sided building, oriented N-S, with a total horizontal surface of 1,710 m^2. PVT field is planned to be installed in the south-oriented roof (855 m^2), which has a deviation of 13° to the west and an inclination of 10°. Panels will be mounted over a 30° structure, leading to a 40° of final inclination, with the aim to be closer to the latitude.

The first layout of the PVT field is presented in the Figure 20. This layout considers a total of 120 PVT collectors, distributed in 5 rows of 24 units each. Each PVT collector has a total surface of 2.7 m^2 and an electrical peak power of 600 W_{el}. Based on these unitary data, the PVT field proposed rises to 72 kW and 324m^2 of solar area.

The distance between collectors has been selected based on the height of the sun rays during winter. Distance has been set assuring at least 4 hours of peak sun over the panels per day, without creating any shadows (Figure 21).

To evaluate the overload of weight resulting from the solar system, it has been considered the weight of each collector, plus the piping, structures and water inside. This makes a total of 63.57 kg per PVT collector, i.e. 7628.4 kg in the whole south roof. This weight is distributed over the south roof, 855m^2 of horizontal surface, adding an overload of 8.92 kg/m^2 With 72 kW of electrical power installed, and considering the average environmental conditions of the location of Andel (51.775, 5.055), the expected

total annual production of electrical energy raises to 74,484 kWh. The monthly distribution of the electrical production is presented in the Figure 22.

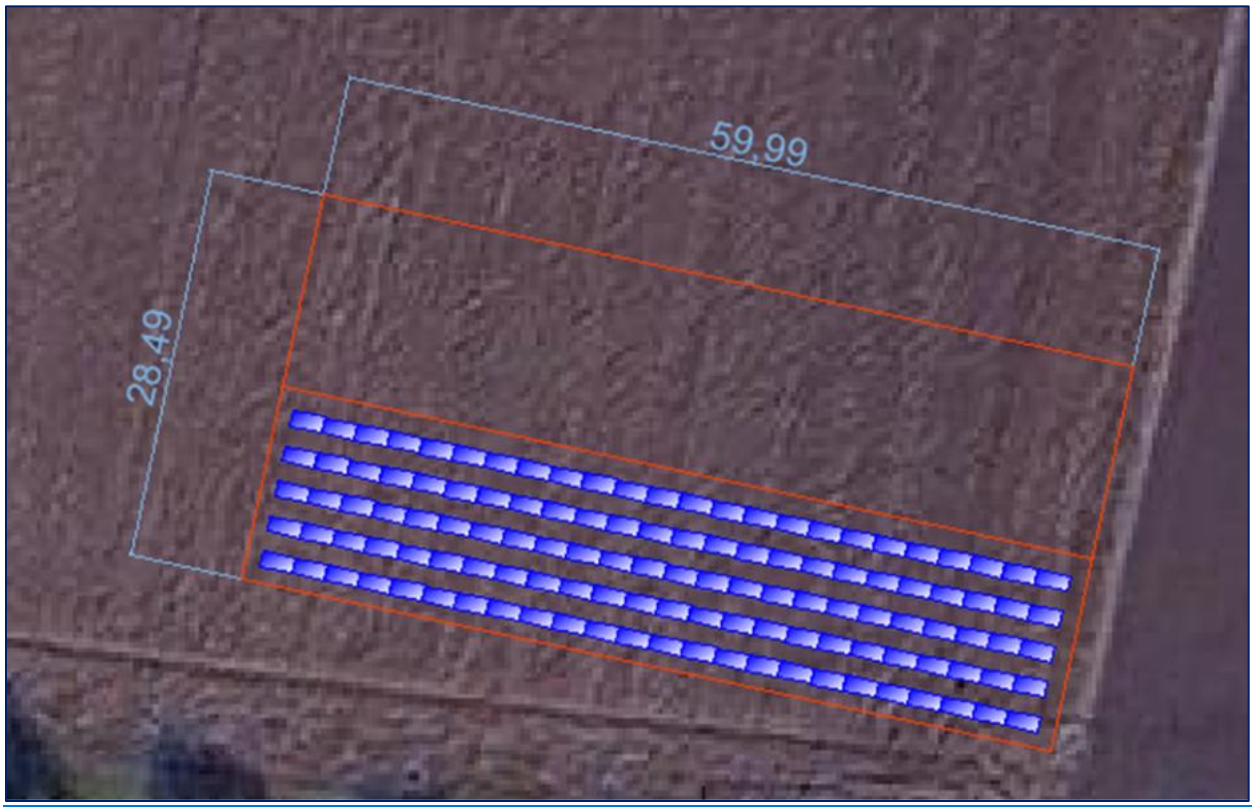

Figure 20. Top view of the planned layout for PVT panel installation on the roof of the future technical room in the new greenhouse.

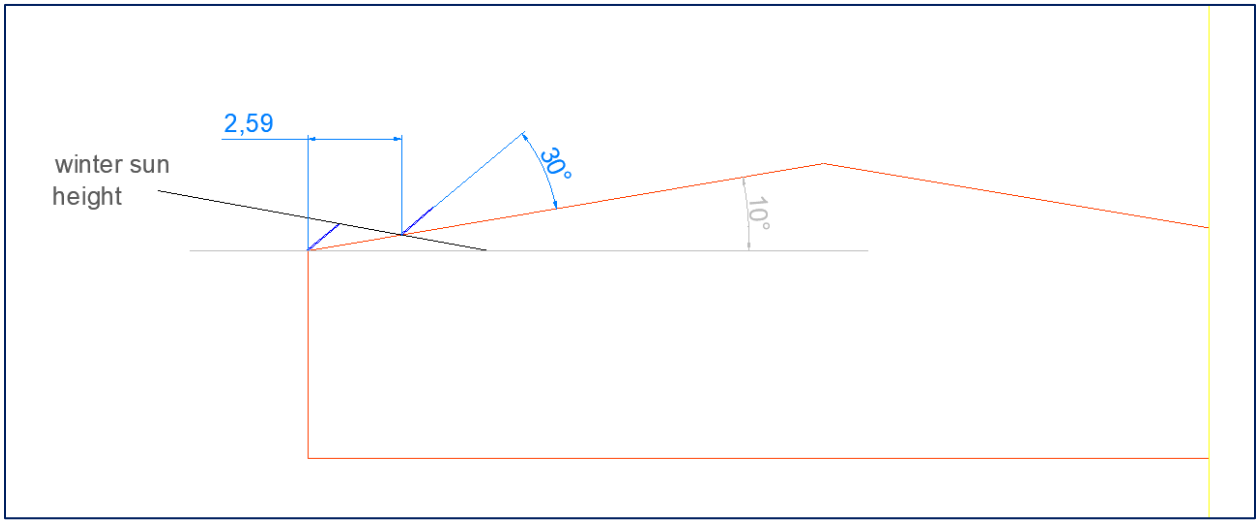

Figure 21. Distance between PVT panels determined by the sun's elevation angle during winter.

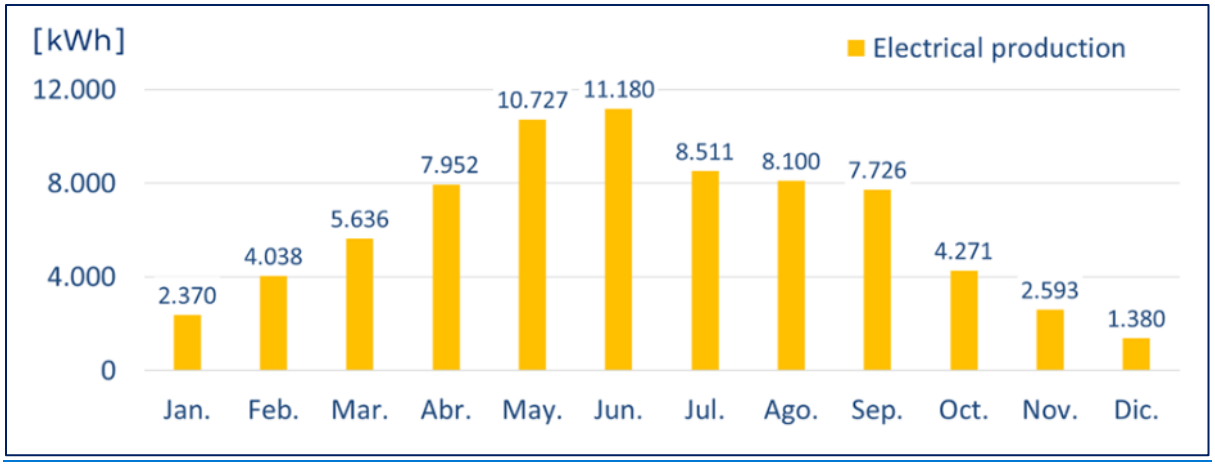

Figure 22. Preliminary simulation results showing the monthly electrical production from the PVT panels.

Table 10. Summary of preliminary results for the PVT panel layout, total output power, and energy production.

Collector level	Unit	Value
Electrical peak power	*kW*	0.6
Thermal peak power	*kW*	TBD
Collector Area	m^2	2.7
Weight (empty collector)	*kg*	53.6
Weight (collector+aux)	*kg*	63.57
Tilt (collectors)	°	40
Orientation	*°(deviation from S)*	13 SW
Full installation	**Unit**	**Value**
No collector	*units*	120
Total electrical peak power	*kW*	72
Total thermal peak power	*kW*	TBD
Weight (PVT field)	*kg*	7,628.4
Area (solar)	m^2	324
Area (south-oriented roof)	m^2	855
Yearly electrical production	*kWh/year*	74,484
Yearly thermal production	*kWh/year*	TBD

**Note: The PVT panel to be installed in the Andel demo is currently in the design and testing phase. Although the electrical component has already been selected, its thermal performance is still under evaluation, and the final results for each unit will be reported in Deliverable D5.2. Therefore, the current description of the planning and installation is based on available data and reasonable estimates. The final installation may differ slightly from the plan presented here. The complete engineering design will be developed during Task 5.3 and presented in Deliverable D5.3.*

5. Technical Requirement and Non-Technical Specifications

This chapter outlines the technical and non-technical specifications (e.g., requirements, contractual aspects, permitting) that must be aligned with the overall project progress in T5.2 – T5.3 and WP2-3 to ensure the successful deployment of project activities at the demo site.

5.1. Technical Requirements and Design Aspects

In this subsection, the technical requirements for the development and realization of USES4HEAT technologies are reported.

5.1.1. Realization of Aquifer Thermal energy Storage

5.1.1.1. Wells placement and design aspects

The construction of the ATES wells must adhere to the following technical requirements:

- The indicative filter length is at least 3 meters for the cold wells and 10 meters for the warm wells.
- The expected depth of the storage layer is 79–84 m below ground level (m b.s.l.) for the cold cluster and 72–84 m b.s.l. for the warm cluster.
- The cold wells will be constructed entirely of PVC. This serves as the initial assumption for the tendering process but is not yet finalized.
- The liner of the warm wells will be constructed of PVC or GRE (Glass Reinforced Epoxy). PVC is much cheaper than GRE, but even with a high-pressure class of PN16, it will become weaker due to the high (max. 55 °C) injection temperatures. During the design the weakening risks will be evaluated, and a final decision of the liner material will be made. The filter will consist of stainless-steel wound wire with 0.5 mm perforations and appropriate fittings based on soil composition. A sealing coupling must be installed between the stainless steel and PVC sections. Each warm well must also include a minimum 2-meter sand trap.
- The dimensioning and specifications of the pump chamber, riser pipes, filters, and connections must be carried out by the contractor and submitted to the client for approval.
- The minimum well flow is set at 60 m^3/h for the cold wells and 91 m^3/h for the warm wells. The final design flow will be determined during the detailed design phase, considering the following:
    - After drilling, the final filter length and achievable flow will be confirmed. Wells must be designed to accommodate higher extraction rates, and the pump chamber's diameter or depth must not be limiting factors.

  - The injection pressure and permit conditions define operational limits. Extraction and infiltration standards must not be exceeded by more than a factor of 2, as verified during test well operations. Minor exceedances are expected.
  - The safety factor for injection pressure and protection methods will be determined in consultation between the client and the contractor.
- The expected transmissivity of the storage layer is 500 m^2/d at the cold well and 541 m^2/d at the warm well. At the cold test well, a specific capacity of 9.5 $m^3/h/m$ was measured after development, while the warm test well (before development) recorded 11.5 $m^3/h/m$.

5.1.1.2. Construction aspects

The construction of the MT-ATES wells must comply with technical, environmental, and regulatory requirements as outlined below.

General Provisions

- The drilling contractor must comply with the SIKB BRL protocol 2101, which governs Dutch drilling regulations.
- Since the new greenhouse is still under development, ANDEL will provide steel-plate or rubble access paths to and around the well locations.
- The drilling area should be fenced off to prevent unauthorized access and, if necessary, secured against vandalism or theft. (This is not required for the test wells.)
- ANDEL will manage the removal of excavated soil.
- Power supply will be provided by the drilling company.
- Water discharge during construction: assumed nearby unrestricted; during maintenance via sewer/surface water with a T-piece at the well

Drilling

- Drilling technique reversed rotary drilling combined with the airlift method, with an average drilling speed of approximately 10 m/hour, using at least three settling tanks.
- Soil sampling: samples must be collected and dried at 1-meter intervals, stored in sample boxes, and described according to NEN 5104, including M50 grain size values.
- The contractor is responsible for ensuring a stable borehole and maintaining adequate overpressure (working water level). The use of drilling additives should be minimized, and bentonite is not permitted.
- **Borehole specifications:**
  - Diameter: 500 mm
  - Depth: 90 m below ground level (m b.g.l.)

- Geophysical logging: performed on three wells (two in the cold cluster, one in the warm cluster), including gamma-ray (GR), single-point resistance (SPR), and long/short normal resistivity (LONO/SONO) measurements.

Pumping and Recovery Tests

- After completion, each well and its monitoring wells shall be pumped clean for approximately one day, with the flow gradually increased. Monitoring wells must be flushed for at least four hours until clear water with a stable electrical conductivity (EC) is achieved.
- After cleaning, a pump-stop test shall be performed on each well following this protocol:
    - All groundwater extraction systems (including ATES systems) must be shut down one day before the test and restarted only after completion of the test.
    - At the end of the day prior to the test, divers (automatic pressure sensors) must be placed in all monitoring wells and in the test well, recording water levels every 10 seconds. Each diver must remain submerged at all times to ensure accurate readings.
    - The wells are left at rest overnight while water levels are continuously recorded.
    - The capacity test starts from static conditions with 2 hours of extraction at design flow (±5%) followed by a 2-hour stop test. Flow adjustments during the test are not permitted.
    - Water levels are recorded continuously in both the test and monitoring wells using divers and verified by manual readings.
    - Raw diver data (CSV format) must be submitted to the project management on the same day.
    - Any disturbances (e.g., pump adjustments, nearby extractions, or valve changes) invalidate the test, requiring it to be repeated at the contractor's expense.
- After well development, a second pump-stop test shall be conducted, consisting of 2 hours of extraction and 1 hour of stop test, following the same protocol.

5.1.1.3. Integration with the energy system and operational aspects

The ATES system consists of the following equipment:

- **Hot wells** – four wells in the final situation. Hot wells will store heat at high temperature up to 55 ˚C during storage period and release it in cold periods to a cut off temperature of 25 ˚C.
- **Cold wells** – six cold wells will be constructed in the final situation. Groundwater from the cold wells will be abstracted to cool the greenhouse of to be the heat carriers to add high temperatures to it, during the summer. During the cold periods, The cold wells will function as return wells of the abstracted water from the warm wells.
- **Piping** – The cold and warm wells will be interconnected through a dedicated piping network, routed via the technical room. The section of piping between the warm wells and the technical room will be thermally insulated to minimize heat losses.

- **Heat exchanger:** in the technical room the cold and warm piping will be connected by using a heat exchanger. This will also connect the building circuit to the groundwater circuit.
- **Sand filter:** in the piping or by using a by-pass, a sand filter system will filter the abstracted groundwater and take away the released sand or clay particles to keep the injected groundwater clean.
- **Heat pumps:** heat pumps are connected to the heat exchanger and the greenhouse. During the summer, the input temperature will be increased to 50-55 °C for storage while during the winter, the increased temperature will be used for direct heating of the greenhouse.
- **Buffers:** buffers are used (one cold and one warm)to increase the flexibility of the heat pump and to create a stable operation.
- Aquathermal system: an Aquathermal system is installed to abstract water from the canals around the greenhouse. The abstracted water is filtered and the heat is taken out by a heat exchanger.
- **PVT panels:** the PVT system will supply heat to the greenhouse, the warm ATES wells, or the heat pump. The generated electricity will be used to power the greenhouse, the technical room, the heat pumps, or be fed into the national grid
- **PV panels:** PV is installed to feed the artificial lamps, pumps, ventilators, heat pumps and all other technical equipment.

Heat charge operation

The purpose of the ATES system is to store a surplus of summer heat to be re-used in winter. During summer, three heat sources can be used as input for the heat pump. First, heat from the surface water bodies (small canals along the greenhouse) will be abstracted by using an aquathermal system. Water from the canal will be abstracted, filtered and the lead through a heat exchanger to harvest the heat. Second, on very warm days, cold groundwater (13 ˚C) will be used to cool the greenhouse, and the heated return water will be used as input temperature for the heat pumps. Third, hot water from the PVT will be used to store directly into the hot wells or also used to feed the heat pump. The heat pump will increase the temperature level of the supplied sources and will have an output temperature of 50 to max 55 ˚C. The hot water will be injected into the hot wells of the ATES system and stored for re-use in cold periods. The heat pumps will get its electricity from the PVT panels, PV or from the grid. The purpose is to use the electricity from the grid when the costs are very small or when you get paid for using electricity.

Heating mode

When heat is required in the greenhouse, the main source will be the ATES system, and the PVT will contribute to a smaller content. When heat is required, the hot wells will produce hot water to be used directly in the greenhouse. At the start of the heating mode, temperatures of about 50 °C can be abstracted, but during time the temperature will decrease to the given cut off temperature (25 °C). Depending on the greenhouse needs, direct heating can be achieved to about 35 °C. Below this output temperature of the hot wells, the heat pumps will be used to increase the temperature level to the greenhouse. Therefore, there is always a heat source available for the greenhouse, but a higher supply temperature, means a higher heating efficiency.

5.1.1.4. Monitoring Plan

Since the storage temperature of the new MT-ATES system can reach up to 55 °C, which differs significantly from the temperature of the existing nearby LT-ATES system (25 °C), there is potential for changes in the chemical and microbiological composition of the groundwater due to altered chemical equilibria. To address these potential effects, a monitoring plan has been developed by IF.

Chemical Effects

Based on the available literature and previous studies, the following considerations apply:

- Limescale deposition and silicate dissolution generally occur at temperatures above 60 °C, and are therefore not expected to be relevant for this project.
- In terms of redox processes, drilling tests indicate that sulphate is nearly absent in the area, and the presence of organic matter is minimal. Consequently, methanogenesis is expected to be negligible within the operational temperature range of 25–40 °C.
- The mobilization of dissolved organic carbon (DOC) may occur at temperatures exceeding 40 °C; however, due to the absence of oxidizing agents, no significant effects on redox balance or microbiological activity are anticipated.
- Regarding the desorption of trace elements (e.g., arsenic and heavy metals), slight mobilization may occur with increasing groundwater temperature. Nevertheless, as the natural concentrations in the storage aquifer are low (e.g., arsenic: 1.2 µg/L), any potential increase is expected to be minimal. Furthermore, heavy metals tend to bind more strongly to soil at elevated temperatures, making extensive monitoring unnecessary at this stage. A reference sample will be taken.

Microbiological Effects

According to the literature, temperatures below 35 °C are unlikely to affect microbial activity. Between 35 and 70 °C, certain microorganisms could theoretically proliferate; however, due to the lack of oxygen, sulphate, and nutrients, these effects are expected to remain negligible in practice.

Monitoring Strategy

To validate these assumptions and ensure safe operation, baseline groundwater data must be collected prior to system commissioning (time zero) for both the warm and cold well clusters. This baseline assessment should include all relevant chemical and microbiological parameters identified in the previous section.

Subsequent monitoring will include:

- Annual measurements of temperature development in the warm cluster, recorded after both storage and recovery cycles.
- Annual sampling for oxygen, sulphate, DOC, and adenosine triphosphate (ATP).
- Heavy metal analysis after the first and second years of operation to assess whether continued annual monitoring is necessary.

**Note: These analyses relate specifically to the environmental aspects of the system and are additional to the USES4HEAT monitoring activities described and reported through the KPI framework in Deliverable D2.1.*

Monitoring Infrastructure

Two completed test boreholes will be repurposed as monitoring wells, with their locations shown in Figures 14 & 15. Additionally, several piezometers will be installed within each test borehole to facilitate groundwater sampling and observation before and during ATES operation (identified as MPx–Fx in the Figure 8).

A Fiber-optic Distributed Temperature Sensing (DTS) cable will be attached externally to the test well to enable high-frequency temperature monitoring. This technology is under active development and is also being tested at the ATES demonstration site in Andel.

Technical Specifications

- Three PVC monitoring wells will be installed per production well: one at the well depth, one above the clay layer, and one in the phreatic zone. For warm wells, pressure class PN16 will be applied.
- Installation of a DTS temperature cable and baseline measurement at selected wells.
- Backfilling will be performed using a tremie pipe, restoring the natural stratification with gravel and swelling clay. Clay plugs will be placed above and below the filter. Filter gravel (0.6–1.0 mm) must comply with the KIWA product certificate for sand and gravel used in drinking water production.

5.1.2. Developing Groundwater at Pump

Each heat pump unit is designed and guaranteed to operate with a maximum of six on/off cycles per hour. The frequency of these cycles directly influences the service life of the compressors and other circuit components; therefore, stable operation is desirable to minimize wear and extend equipment lifespan. The admitted water quality parameters for proper operation of the heat pump units are summarized in Table 11.

The water–glycol mixture used as a heat transfer fluid may degrade over time, producing acidic by-products that can initiate corrosion of system components. Additionally, degradation of glycol can promote biological growth, such as bacterial proliferation, which further increases corrosion risk.

To mitigate these effects, the glycol solution must contain suitable corrosion inhibitors.

Maintenance and Monitoring Guidelines

- Corrosion inhibitors have a limited lifespan (typically 1–2 years); therefore, the glycol concentration and inhibitor levels should be verified periodically.
- In the event of system “top-ups,” where water is added due to low fluid levels, the glycol concentration must be adjusted to maintain the specified mixture ratio.

- The key parameters requiring routine monitoring are the antifreeze concentration and the pH of the water–glycol mixture.

The recommended inspection schedule is provided in Table 12.

Table 11. Water quality requirements for heat pump operation.

Properties	Value	Unit
pH (25°C)	6.8 – 8.4	-
Electrical conductivity (25°C)	< 800	µS/cm
Chloride ion	< 150	mg Cl^-/l
Chlorine molecular	< 5	mg Cl2/l
Sulphate ion	< 100	mg SO_4^{--}/l
Sulphide ion	none	S^{--}/l
Sodium nitrate	< 100	mg NaNo3/l
Alkalinity	< 100	mg $CaCO_3$/l
Total Hardness	< 200	mg $CaCO_3$/l
Iron	< 1.0	mg Fe/l
Copper	< 1.0	mg Cu/l
Ammonium ion	< 1.0	mg NH_4^+/l
Silica	50	mg SiO_2/l
Dissolved Oxygen	< 8	mg/l
Maximum particle size to pass through heat exchanger (filtration limit)	0.87	mm
Total dissolved solids	< 1500	mg/l
Maximum glycol concentration	50%	-

Table 12. Recommended periodic checks for water–glycol mixture quality control.

Parameters	Periodicity	Note
Concentration of glycol	3 months	Always equal to requirement depending on working conditions but never less than 20%
pH	3 months	Never less ~7 and never less than one unit of starting value of water-glycol mixture
Water quality limit	6 months	Not to exceed values in table 11

5.1.3. Integration of Hybrid Solar Panels

5.1.3.1. Operation mode

The PVT field will be connected to the rest of the system through a heat exchanger. The cold loop from the system will be running between 4 to 20 °C, so it will be the inlet to the heat exchanger from the demand side. The solar field will run in a close loop, delivering heat to the system (Figure 23). The water within the solar loop will be driven by a circulating pump, installed in the cold side, which will be activated when the temperature of the outlet of the panels will be at least 4 °C over the inlet from the system. The 4 °C of hysteresis is needed to ensure that the PVT circulation is activated only when additional heat can be supply.

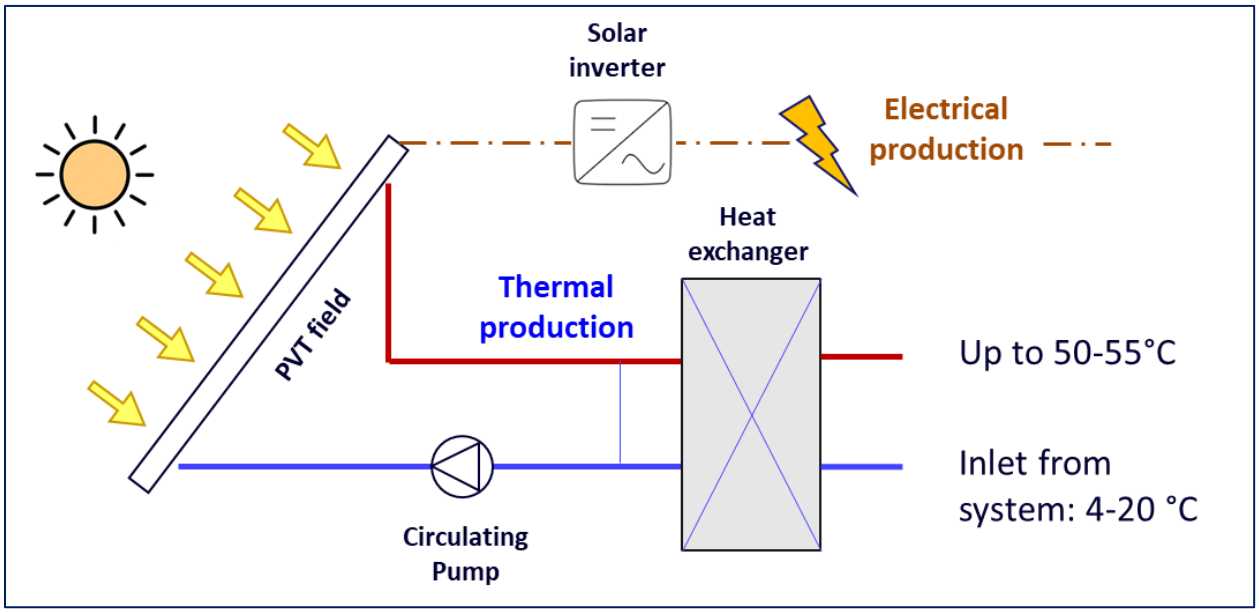

Figure 23. Schematic representation of the PVT panel operation.

5.1.3.2. Numerical model

A numerical model has been developed to simulate the behaviour of the entire system and the contribution of hybrid solar panels to the system (Figure 24). This model has been generated using Polysun software, one of the few programs that can simulate the behaviour of hybrid panels. So far, the electrical data of the panel and the thermal demand values on the cold side of the exchanger have been entered, modelling the rest of the system as a heat process for the sake of simplicity. The model is

currently converging, and we are waiting to define the thermal behaviour of the final prototype in order to calculate the thermal generation data for the entire PVT solar field.

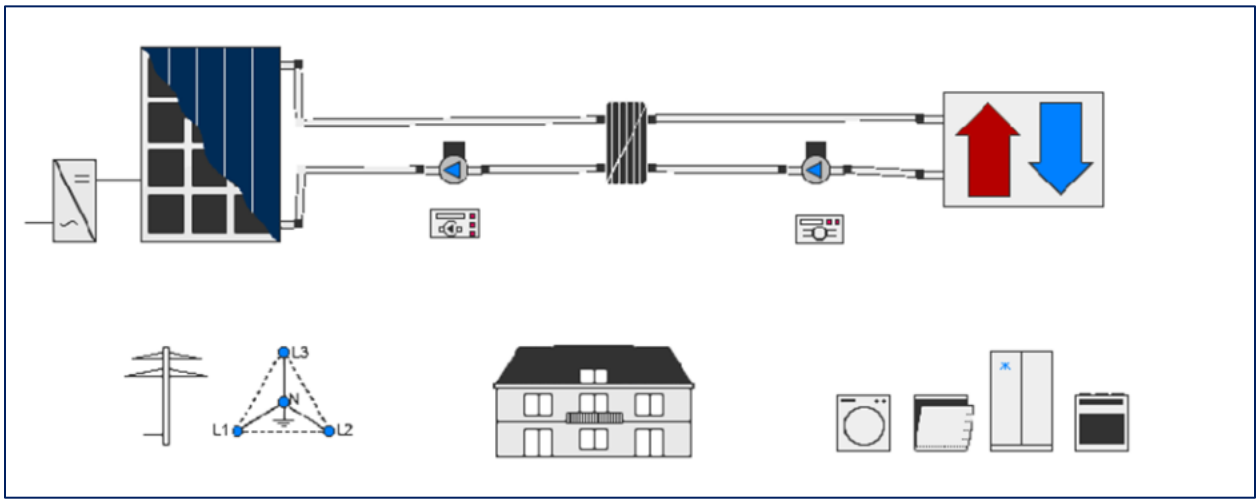

Figure 24. Numerical model generated in Polysun software.

5.1.3.3. Technical engineering project

Hydraulic installation: panels will be installed in the roof following the Tichelmann loop, or inverse return, so that the pressure drop between collector rows is equilibrated and the flow is distributed through the field in a homogeneous way. A basic scheme is shown in Figure 25.

Electrical installation: panels will be distributed in two inverters, Huawei SUN2000-36KTL-M3 model, with four MPPT trackers each. In each string, 15 panels will be connected in series. The panels distribution per string is shown in Figure 26.

The full engineering plan is still under development. Further information will be developed and provided in the upcoming reports.

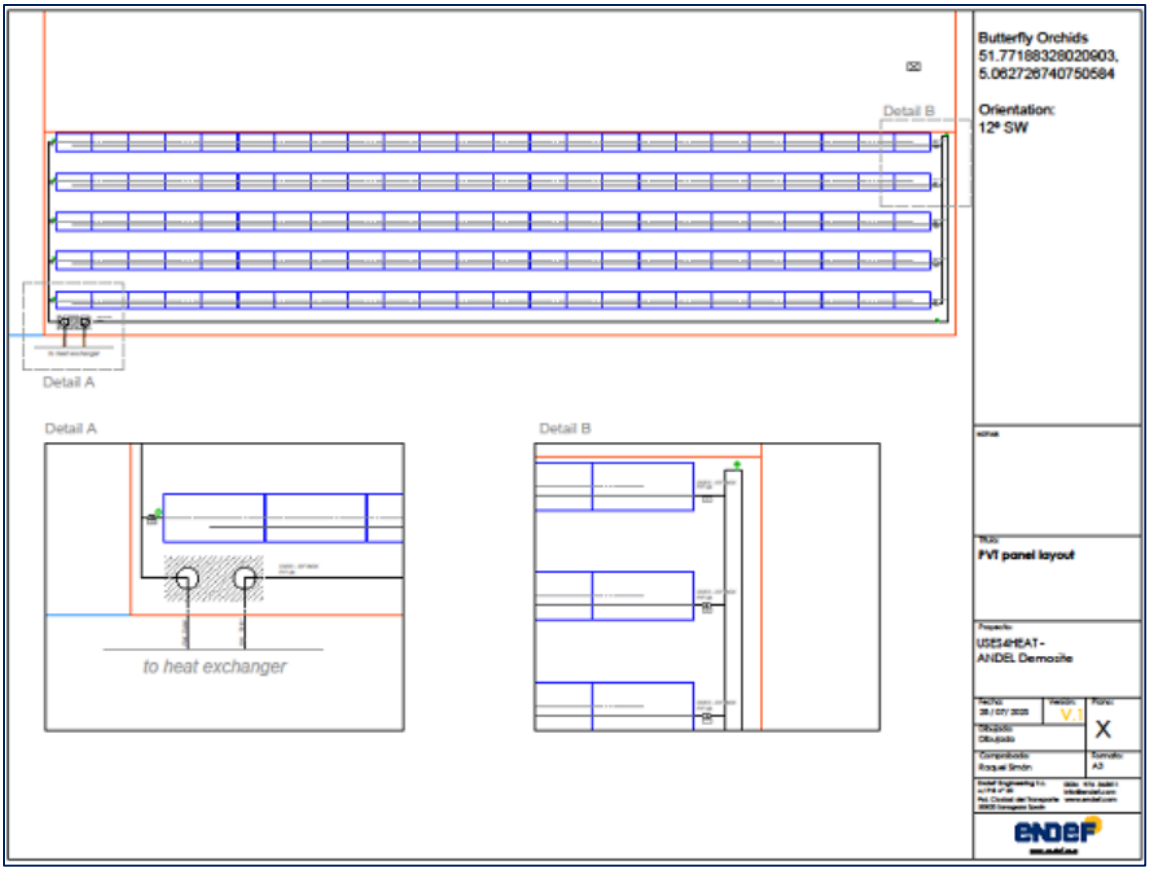

Figure 25. Detail of the hydraulic circuit of PVT field on the roof of technical room.

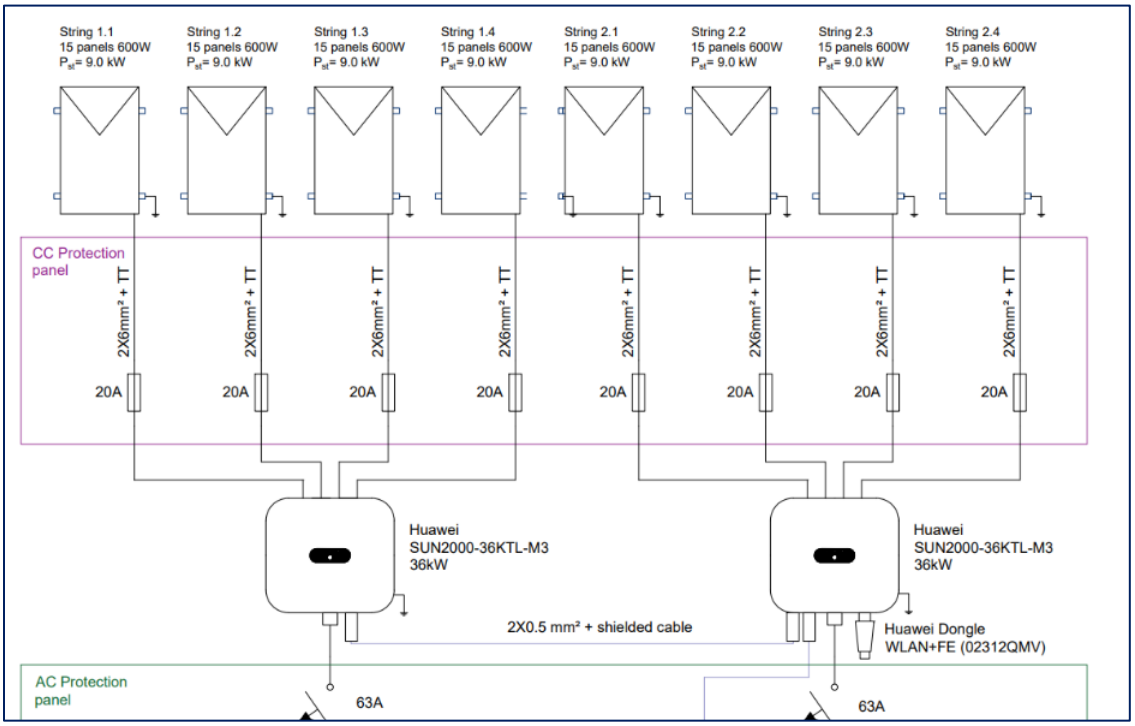

Figure 26. Detail of the electrical circuit of PVT field on the roof of technical room.

5.2. Non-Technical Requirements

While no specific authorization is required for the installation of PVT panels and heat pump (HP) units, the ATES system is subject to regional regulatory constraints. In the Province of North Brabant, the current groundwater energy regulations allow the installation of ATES systems under specific operational conditions, some of which differ from the parameters proposed in the USES4HEAT project. These conditions are summarized below:

- The permitted operational temperature range for ATES systems is 5–25 °C.
- The maximum allowable depth for well perforation is 80 m b.s.l. for both extraction and injection wells.
- The long-term thermal energy balance of the system must be maintained to prevent net heating or cooling of the subsurface.

The MT-ATES system planned for installation in Andel exceeds some of these regulatory limits. It is designed to operate with a higher storage temperature (up to 55 °C) and to provide both heat storage and direct heating. Consequently, a special permit will be required to authorize these deviations.

In addition, the storage aquifer in the warm cluster is located between 72 and 84 m b.s.l. (approximately 12 m thick). The depth of the aquifer at the cold cluster is located between 79-84 m b.s.l. (only 5 m thick) Limiting the well perforation to 80 m b.s.l., as prescribed by regulation, would prevent full penetration of the aquifers, leading to reduced injection rates especially in the cold cluster, increased costs, and no measurable environmental benefit. Therefore, it is technically justified to request an exception to allow full perforation of the storage layer.

Simulation studies further indicate that, with a cut-off temperature of 25 °C, the recovery efficiency during the first five years of operation would be approximately 40%, resulting in an initial subsurface heat surplus of about 250% as the storage volume equilibrates thermally. Over time, as the aquifer warms up, the injected water temperature in both warm and cold clusters will remain above the natural groundwater temperature, producing a residual heat surplus of around 170% after ten years of operation.

Given the different operational principles and objectives of the MT-ATES system compared with conventional LT-ATES systems currently regulated in the Netherlands, special authorization is required to address these three main deviations:

1. Higher storage temperature (up to 55 °C),
2. Full aquifer perforation beyond 80 m b.s.l., and
3. Heat surplus during operational years.

The insights and operational experience gained from this demonstration will contribute directly to policy development for MT-ATES systems in the Netherlands and across Europe, facilitating future large-scale deployment of medium-temperature underground thermal energy storage technologies.

6. WP5 Planning, Timeline, Risks and Mitigations

6.1. Planned Activities and Timeline

To implement the USES4HEAT innovative technologies at the ATES demo site in Andel, a series of activities have been planned, with specific timelines and milestones as shown in Figure 26. The activities can be categorized into four key areas; it should be noted that the activities on task 5.5 are also listed here.

i. Baseline Monitoring and Demonstration Planning:

- Actions completed by the end of November 2025, and already explained in the section 2.3. (1)
- Following up regularly with the authority to receive the full permit by the end of December – DTESS/IF/ANDEL (2)

ii. Development and Realization of Demo Site Enabling Technologies:

- Finalization of the ATES design in accordance with the requested permit and such as well borehole/screen/backfilling design, well housing and above ground installation (controlling/monitoring/heat exchangers/ filters) – DTESS/IF (3)
- Request for tender for drilling the ATES boreholes – DTESS/IF (3)
- Starting the drilling of the boreholes, construction wells and sampling materials – DTESS/IF (4)
- Finalization of design and operation type of HP units – HIREF/Climeco (5)
- Ordering materials for four units of GWHP – HIREF (6)
- Start assembling and testing the four GWHP units – HIREF (7)
- Delivery of GWHP units and on-site installation – HIREF/ANDEL/Climeco (8)
- Performing state-of-the-art analysis, material selection, and component testing for PVT – ENDEF (9)
- Conducting small-scale testing of PVT materials – ENDEF (10)
- Design and develop new PVT layout for the ATES demo site – ENDEF/Climeco (11)
- Full PVT prototype testing – ENDEF (12)
- Manufacturing and delivering PVT panels to the demo site – ENDEF (13)

iii. Engineering, Monitoring, Planning, Installation, and Commissioning:

- Detailed integrated design of the ATES, HP, and PVT systems, including the monitoring plan – ANDEL / Climeco / IF / DTESS / ENDEF / HIREF / FBK (14)

- Completion of the technical room construction and preparation of the designated area for borehole drilling – ANDEL / Climeco (15)
- Installation and commissioning of all technical equipment for the three integrated technologies, ensuring full operational readiness – ANDEL / Climeco / DTESS / IF / HIREF / ENDEF (16)

iv. Experimental Campaign and Critical Assessment:

- Starting the one-year full operation of the system and monitoring – ANDEL/DTESS/IF/FBK (17)
- Evaluating the local-level impact from environmental, techno-economic, and social acceptance perspectives related to WP6, validating simulation models developed in WP2, and assessing the effectiveness of the project via the KPI panel. Critically assessing the lessons learned at both technical and non-technical levels, and reporting in the final project handbook – FBK/WP5 partners (18)

v. Innovative seasonal, large-scale, aquifer thermal energy storage facilitation via innovative drilling and advanced replicator campaign:

- Developing the drilling machine and purchasing the materials necessary for construction of one ATES well – HYDRA (19)
- Drilling site preparation; start drilling and sampling materials – HYDRA/AGS (20)
- Finalization of site selection for drilling the borehole, & informing the PAT (Provincia Autonoma di Trento) about the exploratory drilling – AGS/FBK (21)
- Conducting pumping test, Geophysics test, and water quality analysis – HYDRA/AGS/FBK (22)
- Evaluating the validation of advanced drilling machinery and outlining the key characteristics of deep aquifers, along with insights for feasibility assessment and the development of local regulations for ATES deployment – FBK (23)

6.2. Deliverables and Milestones

Milestones and Deliverables:

The following milestones and deliverables, along with their respective timelines, are listed below:

- **Deliverables:**
    - *D5.1 – Baseline Monitoring and Plan for Riva del Garda Demo* [Nov 2024]: A report on baseline monitoring data and planned demonstration activities for the Riva del Garda site.
    - *D5.1* - Baseline monitoring, plan and basic engineering for ATES demo site [Nov 2025]: Report of baseline monitoring, demonstration planning basic engineering for ATES demo site.*
    - *D5.2 – Development of Enabling Technologies for ATES Demo* [April 2026]: A report on the design, development, and realization of enabling technologies, including new realization of MT-ATES system, groundwater heat pumps, and hybrid solar panels, with performance data, descriptions, and schematic drawings.

- *D5.3 – ATES Demo Full Description* [May 2026]: A detailed engineering report on BOP, installation, and commissioning of hardware and software enabling technologies.
- *D5.4 – Lessons Learned from the Demonstration Campaign in ATES Demo Site* [Nov 2027]: A report on lessons learned and insights for future replications from the demonstration campaign.
- *D5.5 – Deep aquifer characterization, and recommendation for ATES [May 2027]:* Report discussing the validation of advanced drilling machine and describing the main characterization of deep aquifer and insights for local normative for ATES deployment.

- **Milestones:**
  - *MS2 – Baseline Monitoring Data Acquired for Riva del Garda Demo* [Aug 2024]: Completion of the baseline data collection for the Riva del Garda demo site, including all relevant data and KPI reporting.
  - *MS6 – Shipping and realization of All Enabling Technologies to ATES Demo* [April 2026]: Shipment and realization of all enabling technologies and components from HIREF, ENDEF, IF and DTESS to/in the demo site.
  - *MS8 – Commissioning of All Hardware and Software Enabling Technologies for ATES Demo Completed* [May 2026]: Full operational status of ATES demo site according to the KPI plan.

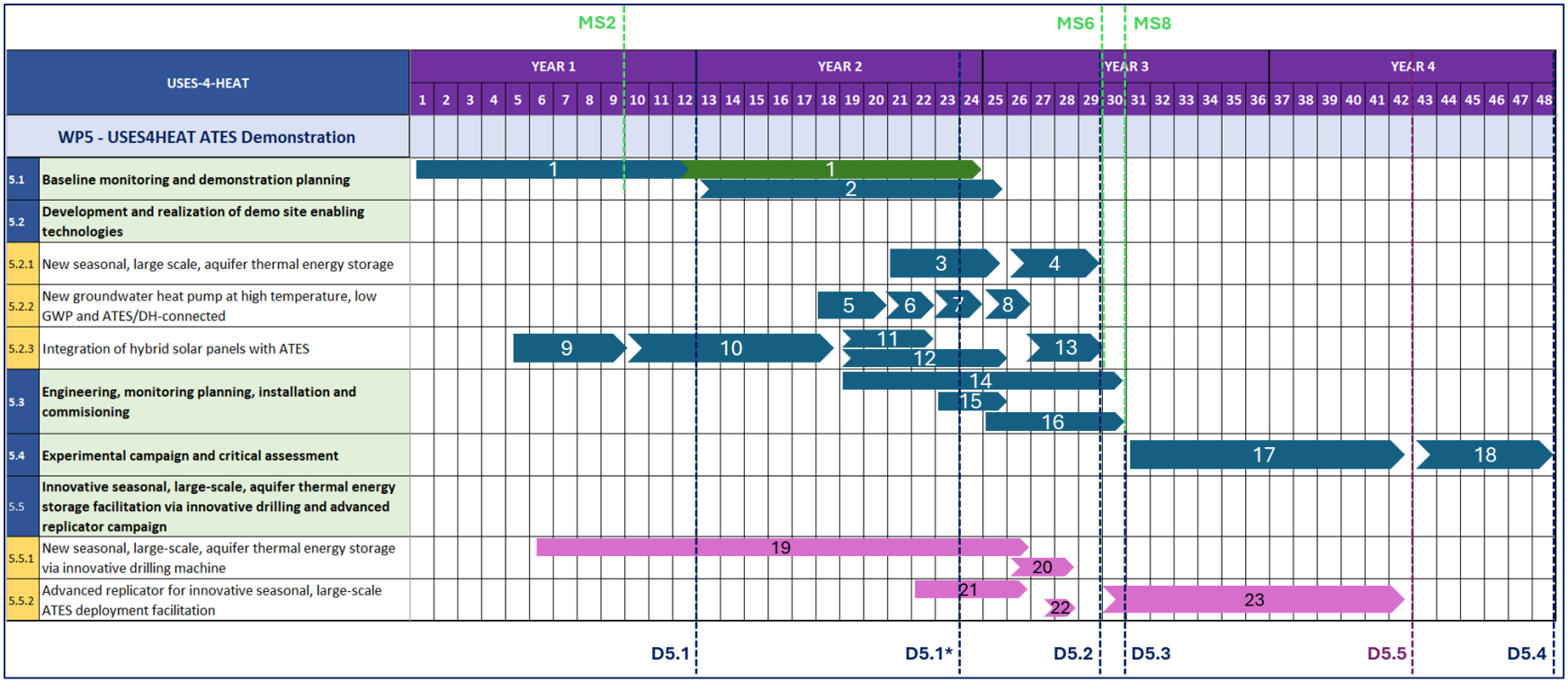

Figure 27. Timeline of future activities in Work Package 5, including milestones and deliverables.

6.3. Risks and Mitigations

In the current subchapter, the main project risks foreseen in Work Package 5 have been reviewed in Table 13, outlining the severity of each risk in the current situation and the proposed mitigation methods for the future.

Table 13. Risks description and mitigations categorized by severity levels.

#	Risk Description	Mitigation	Severity
1	Delays in key enabling technologies manufacturing and procurement	Project main innovations have been already conceptually/modelling investigated and tested (TRL5-6).	Low
2	Delay in obtaining permits at demo sites	Environmental impact and risk assessment in addition to monitoring plans have been studied for the MT-ATES system in the area and reported to the local authority. Positive feedback from the local authority received and the requested documents for the permit have been submitted to complete the permitting procedure and receive the formal authorization by the end of year (Dec 2025).	Low
3	Delay in additional equipment procurement and demo permitting.	Conservative time estimation for the task definition. All the equipment will be order as soon as designed finalized.	Low
4	Delay in construction of the UTES	Conservative time estimation has been considered in the task definition. Ensuring active collaboration of the partners involved. Start drilling first borehole (Feb/March 2026 – depends on climate conditions).	Low
5	The technologies are more expensive due to inflation and materials crisis	ANDEL planned to co-invest in the project and cover the required budget.	Low
6	The enabling technologies do not attain the expected performances or do not function as expected	The proposed technologies have already been extensively designed and de-risked (starting TRL 5-6). Additional validation works will be carried on at the beginning of the project. The modularity of the integration schemes proposed at the demo sites ensures that even if one technology does not perform fully as expected the whole concept can be still demonstrated in its full capacity.	Low
7	Demonstrated tech/O&M solutions are too specific to demo sites.	Thanks to partners' DH and TES expertise, it will be possible to identify how to replicate innovations in relevant cases, serving as a basis for de-risking.	Low
8	Low stakeholders' engagement for future widespread of USES4HEAT.	Partners, including EHP and IEA TPC Task participants, are experts in innovative energy systems, ensuring broad stakeholder reach through existing networks, with potential collaboration with international associations.	Low

9	WPs resources not well balanced.	PC continuously monitors and reallocates resources with WP leader approval, if needed.	Low
10	COVID-19 pandemic situation or external issues do not allow to organize meetings, etc.	Partners proficiently manage project activities using web collaboration tools for remote support, inspections, and meetings.	Low
11	Slow or ineffective communication between PMO and consortium.	Enhanced internal communication within the consortium will be emphasized at the KOM and sustained thereafter, with targeted initiatives such as problem-solving workshops if required.	Low
12	The different technologies involved in USES4HEAT demonstrations and replications have issues in integration.	Initial phases of WP5 will study and define USES4HEAT demo layouts and technology integration, leveraging flexibility and modular technologies for installation.	Low
13	The new groundwater heat pump cannot achieve the target COP at the lowest source temperature conditions (the most challenging operation).	HIREF has a wide experience in heat pump development, and the proposed technology is an upgrade of existing commercial products and preliminary de-risking and testing have already been performed. In case of lower performance of the heat pump the demonstration could still be operated.	Low

7. Conclusion and Next Steps

The primary focus of Task 5.1 within Work Package 5 was to analyse all relevant data from the ATES demonstration site in Andel. This included a comprehensive review of the local context—geological and hydrogeological framework, climate data—and the identification of optimal approaches for developing each USES4HEAT technology and integrating them into the overall energy system, thereby establishing a baseline and development plan.

All technical requirements and non-technical specifications necessary for project progress have been documented, and a detailed timeline of future activities has been defined. A risk assessment was also performed, accompanied by targeted mitigation strategies.

This deliverable serves as a reference for project development under Tasks 5.2 and 5.3 and provides guidance to related work packages (WP2 and WP3) to ensure coordinated deployment of project activities. Additional technical information related to the development of USES4HEAT technologies at the ATES demo site will be compiled—with contributions from all partners—and reported in Deliverable D5.2, to be finalized by the end of April 2026.