green energy lab.at

2025

ATES Vienna

Final Report

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Aquifer Thermal Energy Storage Vienna

ATES Vienna

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2 Introduction

Half of the non-renewable share of total final energy consumption in Austria is attributed to the heating and cooling sector. District heating networks play a central role in the future decarbonization of the heating sector by enabling the integration of locally available alternative energy sources (e.g. waste heat from industry and commerce, waste water, geothermal and solar thermal energy) with a simultaneous efficient operation of the infrastructure. In this context, the integration of seasonal heat storages is required due to the temporal mismatch between the supply of renewable energy and the demand for heating and cooling. Essentially, there are three reasons why seasonal thermal storage systems are beneficial:

- Due to surpluses from sources like geothermal energy, the use of seasonal storage is energetically beneficial.
- Decarbonizing district heating can be achieved by integrating seasonal storage technologies
- This technology serves as a gateway for utilizing waste heat from cooling production

In the graph below, a typical district heating output (Y-axis) distributed over the year (X-axis: year/hours) is shown. Due to the surplus in Summer (e.g., from geothermal energy), this excess of heat can be stored for use in the winter months.

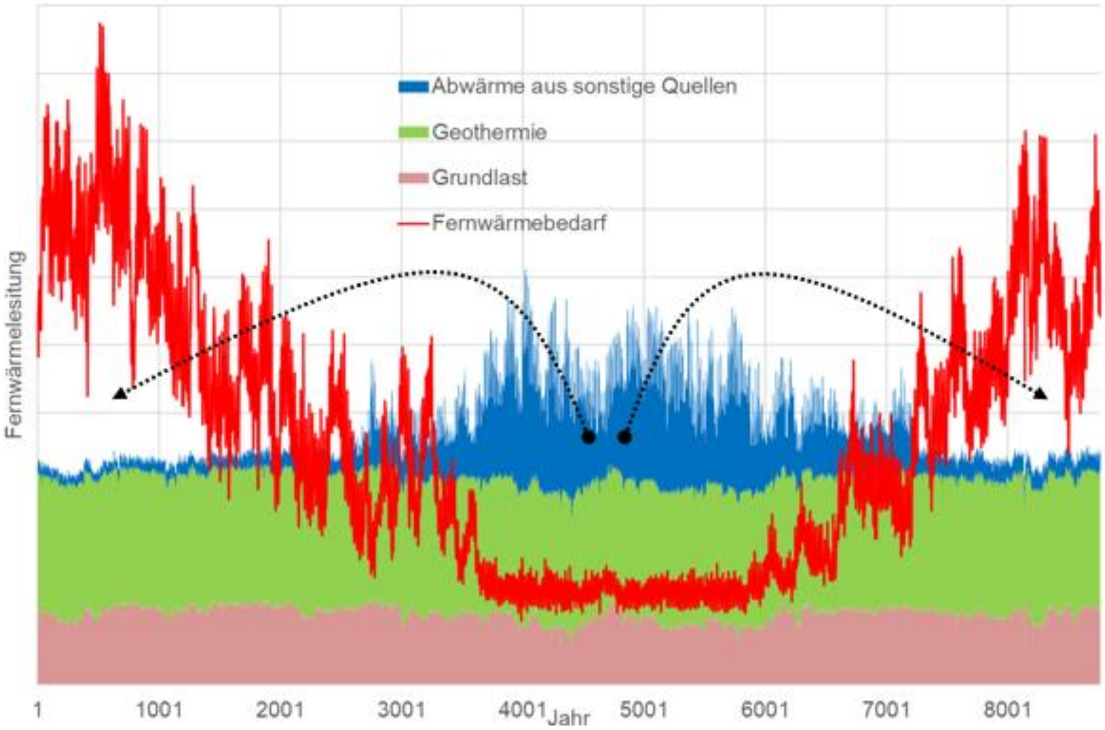

Figure 1: typical district heating output over a year

ATES (Aquifer Thermal Energy Storage) is a technology designed for seasonal heat storage, helping to balance the mismatch between heat supply and demand throughout the year. During summer, surplus heat—such as that from a district heating network—is stored underground and later utilized for heating during the colder months.

Although HT-ATES (High Temperature-Aquifer Thermal Energy Storage) technology was developed more than 30 years ago, it remains unestablished on the market with only a few systems currently in operation. While there are several thousands of low-temperature ATES systems in the world [1], examples of high-temperature storages (HT-ATES) are quite limited. An overview of existing HT-ATES systems in Europe is given in following table. The Neubrandenburg ATES is the only system with considerable greater storage depth compared to the other ATES. While it is not in operation anymore due to a mismatch in the amount of heat supply and demand [2], its targeted storage horizon is in similar depth as considered for the ATES Vienna project.

Table 1: Overview of HT-ATES Project in Europe

HT-ATES	Existing			Planned	
Project name	Neubrandenburg DE (Not in operation)	Berlin-Reichstag DE (Not in operation)	Middenmeer NE	TU Delft NE	Berlin Adlershof DE
Storage temperature [°C]	90	70	85	73	95
Depth [m]	1250	300	420	400	360-400
Thickness [m]	35	29	23	50	30
Heat production per season [MWh]	8 600	2 050	20 000		30 000
No. of boreholes	2	12	2	7 (3 hot)	2
Flowrate per well [l/s]	27.7	27.7	41	50 (Per hot well)	44
Reservoir temp [°C]	55	19	17	24	20-25
Difference in temp [°C]	35	51	68	49	70
Volume [m3]	340 000		400 000	1 000 000	

ATES Vienna (ATES – Aquifer Thermal Energy Storage) aims to develop high-temperature (> 40°C) and large-capacity (> 10GWh) deep underground aquifer thermal storage (ATES) systems, including integration options for the Austrian district heating sector.

The project addressed the identification and characterization of available aquifer resources. Based on this analysis, a technical surface and subsurface concept for the first pilot ATES in the Vienna area was developed. Furthermore, the project also analyzed the regulatory and economic framework conditions in Austria, evaluating their influence on the feasibility, cost-effectiveness, and practical implementation of

seasonal storage technologies. This comprehensive assessment helps identify potential challenges and opportunities for integrating these solutions into the existing energy infrastructure.
Overall, the project consisted of five work packages that were systematically processed. Work Package 1 focused on general project management and dissemination.

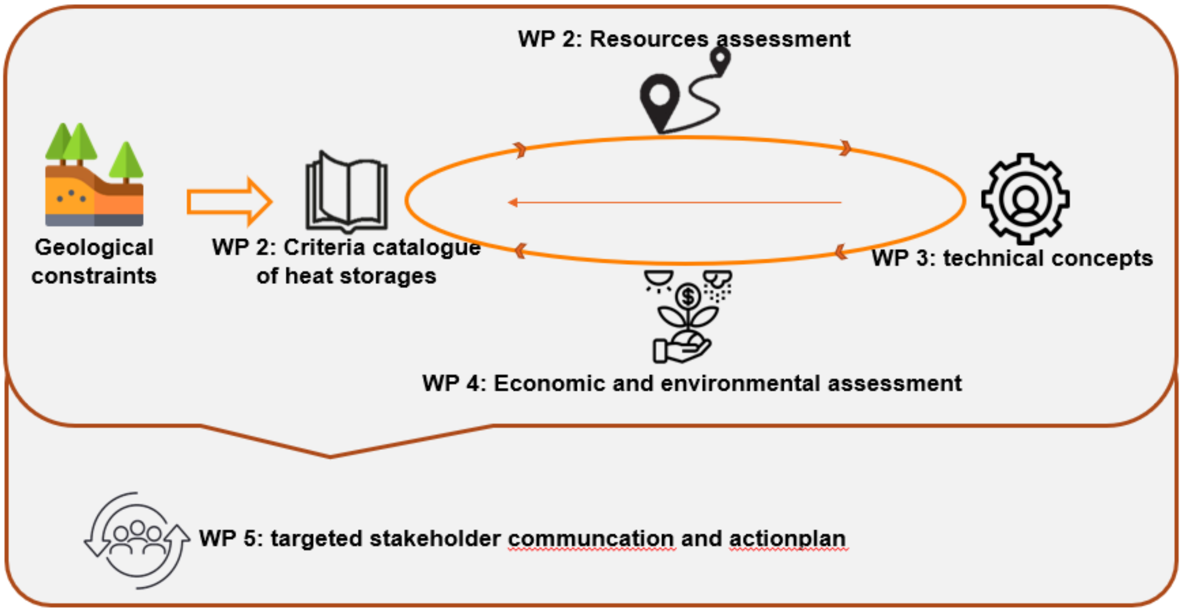

Figure 2: Overview of the Work packages

3 Content presentation

3.1 Content Overview

With the jointly developed workflow, the respective work packages were processed.

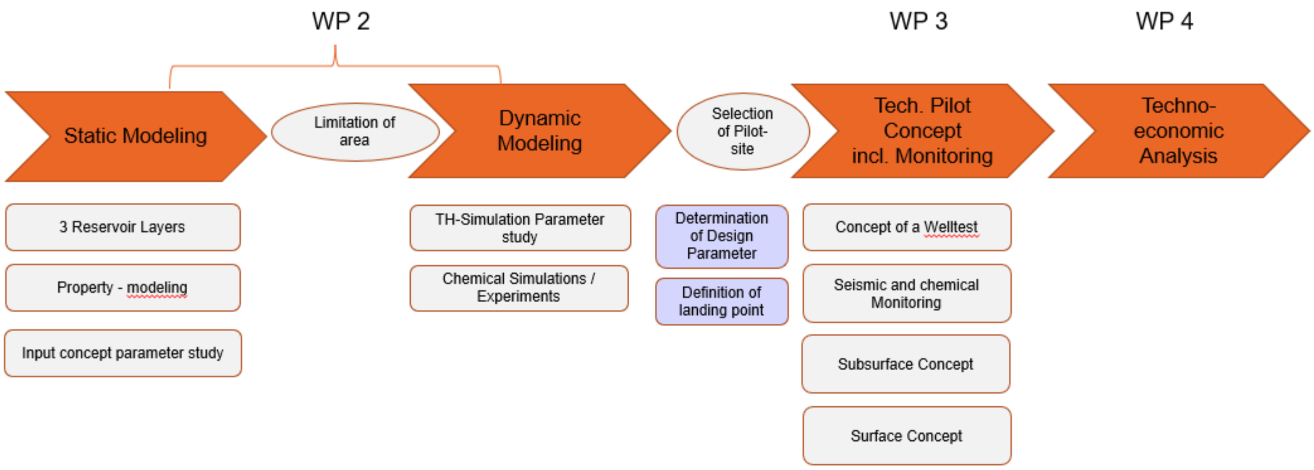

Figure 3: Overview of the workflow for the ATES Vienna Project

The workflow follows a structured approach to assessing and implementing a project, integrating geological modeling, simulations, pilot site selection, technical execution, and economic evaluation. It begins with an in-depth analysis of the subsurface conditions to understand the geological and physical properties of the reservoir. This includes both static and dynamic modeling, which help define essential parameters, simulate fluid behavior, and analyze chemical interactions.

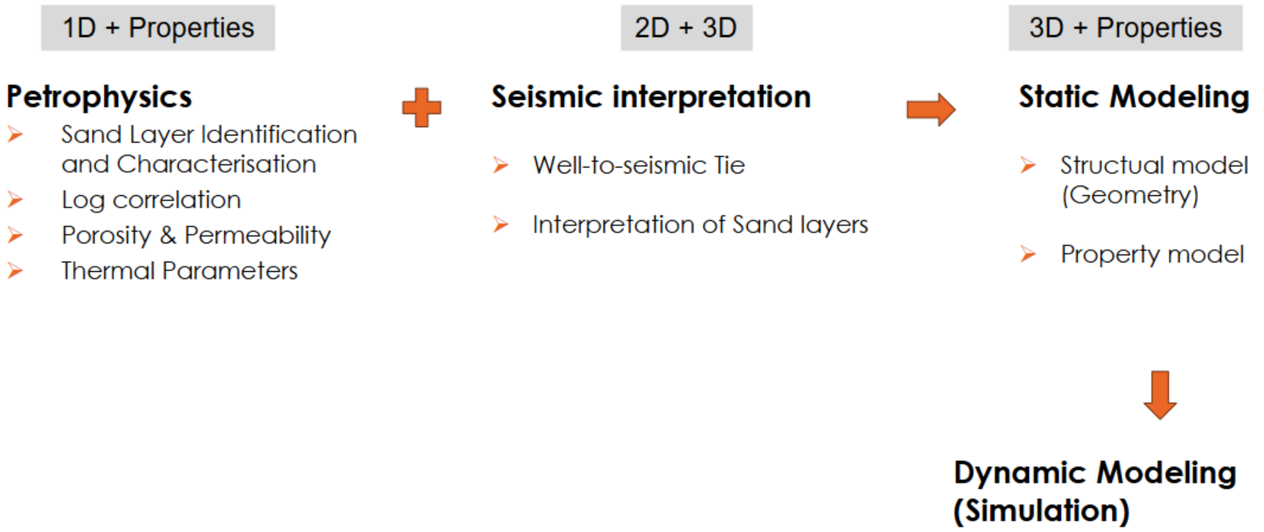

Figure 4: Excerpt from the workflow diagram for static to dynamic modeling

By setting clear limitations on the study area, the project could focus on the most relevant sections of the reservoir, ensuring meaningful results.
Following the modeling phase, the selection of a suitable pilot site takes place. This decision is based on a detailed data analysis, ensuring that the chosen location aligns with the technical requirements and project objectives. Key factors for site selection include the potential underground reservoir and proximity to the district heating network. Once the site is determined, design parameters are established, and a structured plan for implementation is created. This includes defining key operational aspects such as the well placement, monitoring strategies, and testing procedures. In addition to the underground considerations, a comprehensive infrastructure plan was developed. This is intended to ensure both the underground and the above-ground infrastructure. In addition to the technical concept for the above-ground system, a concept for integration into the district heating network was therefore also drawn up. The final phase focuses on evaluating the overall feasibility from a techno-economic perspective. By analyzing both technical performance and economic viability, the project is assessed for long-term sustainability.

The overarching work packages such as dissemination and stakeholder communication were particularly important for making the ATES technology visible. They ensured that the project results were made accessible to a broad public and promoted exchange with relevant interest groups. This raised awareness of the benefits of the technology and increased its visibility not only in specialist circles.

4 Results and conclusions

4.1 Possible reservoirs in the ATES-Project and resource assessment

4.1.1 Static and dynamic modeling

The previous “GeoTief Wien” project (2D and 3D) enabled extensive seismic data to be collected and used for the ATES Vienna project. This data played a crucial role in supporting the statistical modeling (WP2) by enabling a more precise analysis and interpretation of geological structures. This created a valuable synergy between the two research projects. Based on this data from 3D seismic investigations, the area under investigation for ATES extends to the south-eastern part of Vienna.

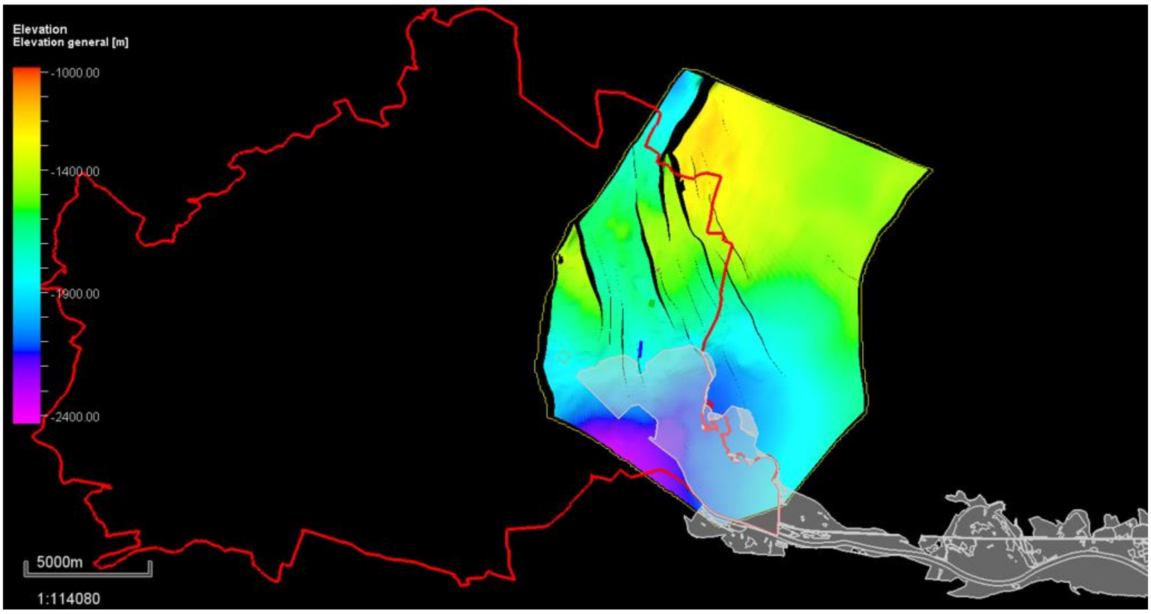

Figure 5: Potential Project Area of ATES Vienna based on availability of seismic data. The red line indicates the border of Vienna.

Preferable geological conditions for ATES systems have sufficient transmissivity and porosity so that large quantities of water can be injected and produced from the aquifer. ATES reservoirs target mainly saline aquifers with sufficient permeability and regional extension. Critical factors include the aquifer's depth, thickness, porosity, permeability, and underground temperature, all of which influence heat storage and losses. Additionally, the presence of a confining cap layer, faults, groundwater flow velocity, and groundwater chemistry are key parameters. While each storage layer needs to be evaluated for every project individually, some screening values for general hydrothermal energy storage are mentioned by [3,4]. According to the authors a reservoir should have a minimum reservoir thickness of 20 [m], minimum reservoir permeability of 250 [mD] and effective porosity of >20 %. These numbers should not be seen too strict but give a first estimate on the parameter ranges.

By correlating borehole data along several geological cross-sections, a total of six potential reservoir layers (L1-L6) were identified. Based on petrophysical calculations of porosity, permeability, heat capacity and thermal conductivity, layers 1, 2 and 3 were interpreted as the most promising. Their favorable reservoir properties make them particularly suitable for further investigation. Stratigraphically, these layers can be assigned to the Sarmatian and the upper Badenian.

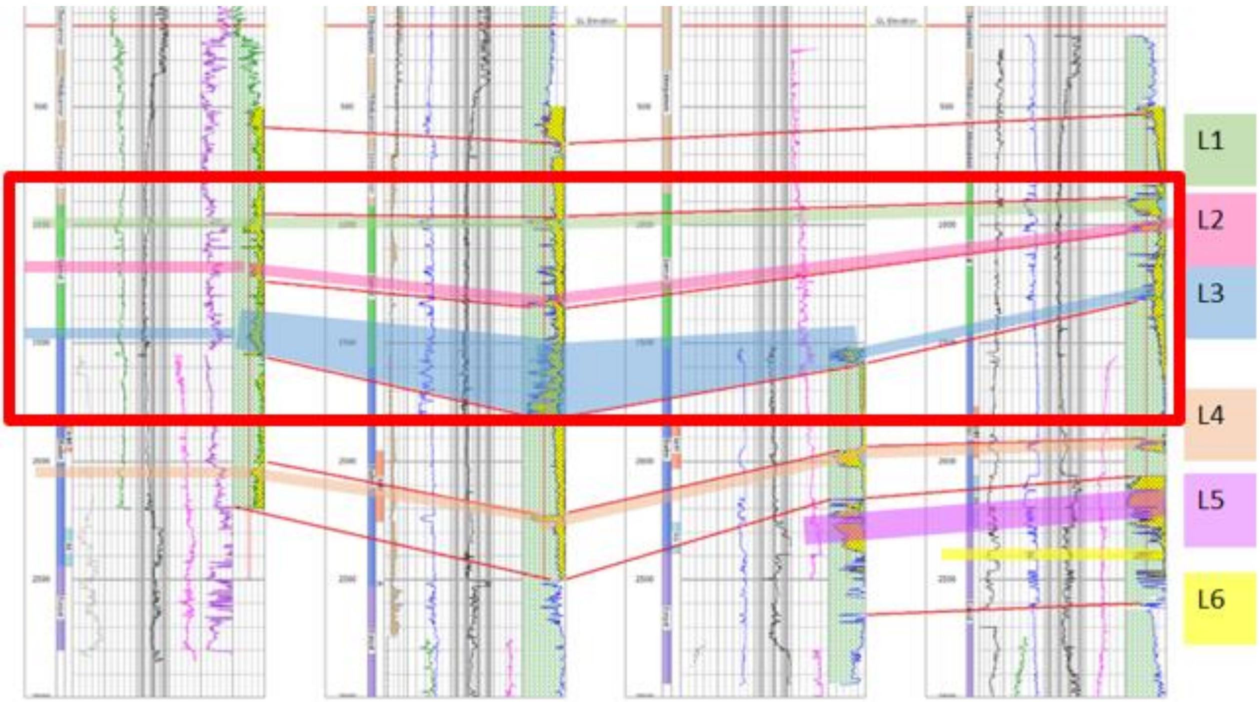

Figure 6: Potential reservoir layers. the most promising (L1-L3) are highlighted by a red rectangle.

The geological modeling confirms that Layer 3 meets the necessary requirements for a potential ATES reservoir horizon. This layer is stratigraphically located in the upper Badenian and lower Sarmatian and extends to a depth of around 1200 to 1700 meters below ground. The estimated reservoir temperature in this area is around 65 °C. These findings represent a significant milestone that underlines the suitability of Layer 3 as a potential ATES reservoir in the area of Vienna.

The dynamic resource assessment was carried out using simulations of stationary long-term operation. On delivery of the final geological model, a high resolution thermal-hydraulic simulation model has been generated. Various assumptions regarding the operating time and the charging and discharging rates were taken into account.
Different models and scenarios were tested in order to better understand the effects of property changes on the system. As part of the investigation, several simulations were carried out with varying temperatures, rates and different charging and discharging cycles. The initial reservoir temperature was kept at around 65 °C.
The evaluation of the results provided important information on temperature development, efficiency and other relevant parameters that are crucial for the evaluation of the ATES system. Attention was also paid to the material balance (Injection volume=Production volume). In the selected configuration, the two wells (C=cold and H=hot) do not interfere with each other

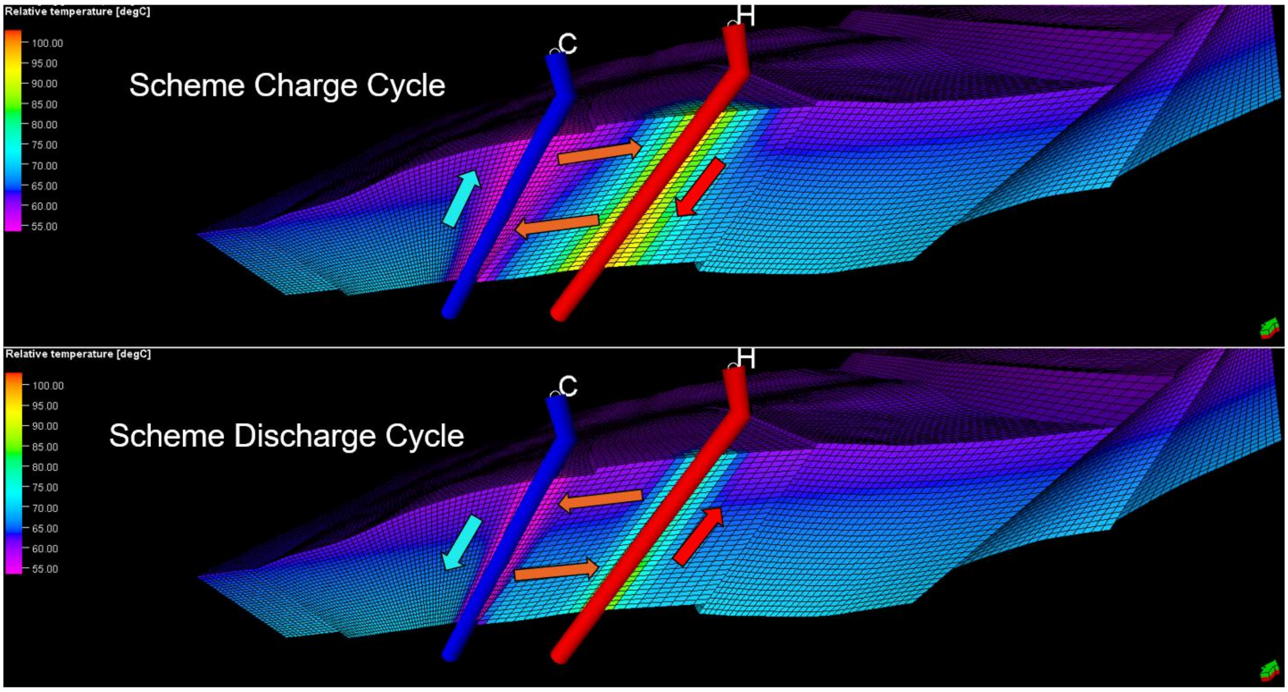

Figure 7: Simulation results of the charge and discharge process

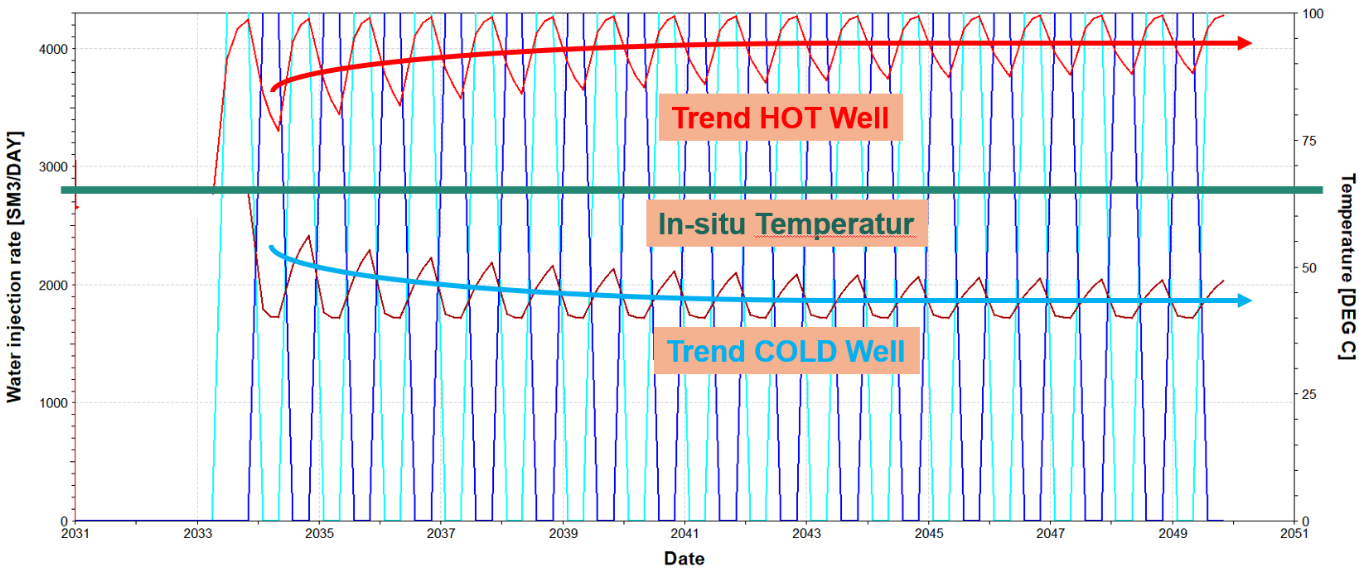

Figure 8: Simulation results showing the transient temperature as well as the temperature trends of the final simulation run with injection/production rates (50 l/s)

The results of the dynamic simulations once again confirmed the findings from the static modeling: Layer 3 proves to be the most suitable layer for the continuation of the project. Due to its favorable properties, it offers the best conditions for efficient use within the framework of ATES.

4.1.2 Consideration of water chemistry

Suitable aquifer storages must fulfil requirements on the volume with respect to the amount of heat to be stored in the water-filled pores, the hydraulic transmissivity controlling the thermal capacity of the storage and, furthermore, important aspects like sealing to prevent heat losses and negative impacts on overlying groundwater bodies, and the chemical composition of natural aquifer fluids in the storage with respect to the scaling and corrosion potential of the water in the water-bearing compounds and facilities (pipes, heat exchangers, pumps) of the HT-ATES-plant.

During the production of thermal water, changes in pressure and temperature, as well as degassing, can trigger various hydrochemical reactions. These include dissolution and precipitation processes (scaling) as well as corrosion. The mineralization level of the thermal water also plays an important role. These geothermal fluids can cause issues both within the thermal well itself and in the connected components of the surface geothermal facility.

In the well section passing through the reservoir, precipitations can also lead to changes in the porosity and permeability of the aquifer. If available, region-specific hydrochemical data from scientific literature and operational experience from existing facilities can help estimate the expected precipitation reactions in a planned ATES system.

A chemical-mineralogical modelling of the processes during the whole ATES-cycle is essential to understand risks and problems that might arise during the lifetime of the storage system. Degassing, scaling and corrosion as well as clogging can occur when pressure and temperature change during extraction, heat exchange and reinjection.

For the investigation and determination of the chemical-mineralogical data of rock samples from the subsurface of the Vienna Basin, different methods were applied. For the chemical-mineralogical and hydrogeological investigations at the Technical University Graz, drill cuttings were selected on the basis of a list provided by OMV. Since both the Sarmatian and Badenian reservoirs are target reservoirs of the ATES Vienna project, saline solutions were prepared for both waters in order to imitate the real thermal water compositions of the reservoirs on the one hand and to investigate them analytically on the other hand.

The results of the precipitation tests indicate that precipitation occurred, varying in reaction temperature and duration. These findings align with the filtrate analysis results. The primary precipitates identified are illite (left), a chemical weathering product of muscovite, as well as albite and magnesium calcite (right).

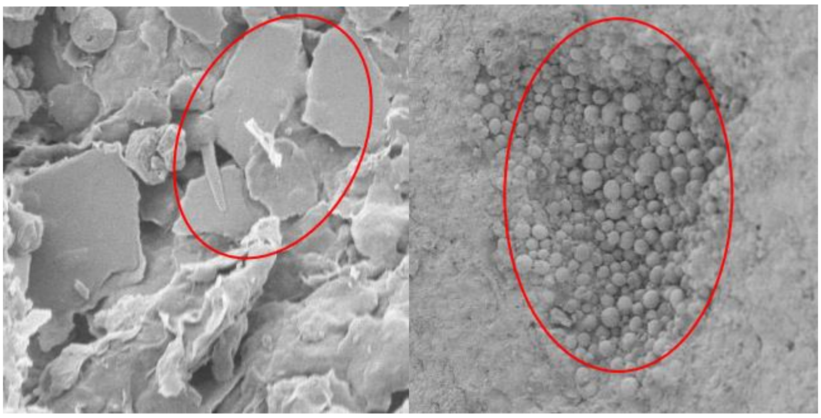

Figure 9: Illite precipitations (left), Magnesium calcite precipitations (right)

For a final hydrochemical assessment of the feasibility of a ATES plant, in-situ data are essential. These can only be obtained through a production test conducted within the target reservoir.

The insights gained from the geological conditions, based on static and dynamic modeling, as well as water chemistry analyses, provide a solid foundation for the next phase of the project. These findings are crucial for the upcoming step, which involves the technical design of both the subsurface and surface facilities. Various factors must be considered in this phase, including the optimal placement of wells, the selection of appropriate materials to prevent corrosion and scaling, and the integration of pumping technology. The close alignment between geological assessment and facility planning plays a key role in developing an efficient and reliable geothermal system for the long term.

4.2 Technical subsurface and surface concept

Similarly to deep geothermal energy systems, deep thermal water-bearing geological layers are used. An ATES facility consists of one or more production and injection wells. In summer, thermal water is extracted from the subsoil from the cold well and heated with the excess heat from the district heating system (e.g., geothermal, industrial waste heat) via a heat exchanger. The heated thermal water is then fed back underground via a second borehole in the hot well. By reversing the direction of flow in winter, the hot thermal water is pumped back to the surface and used for heat supply.

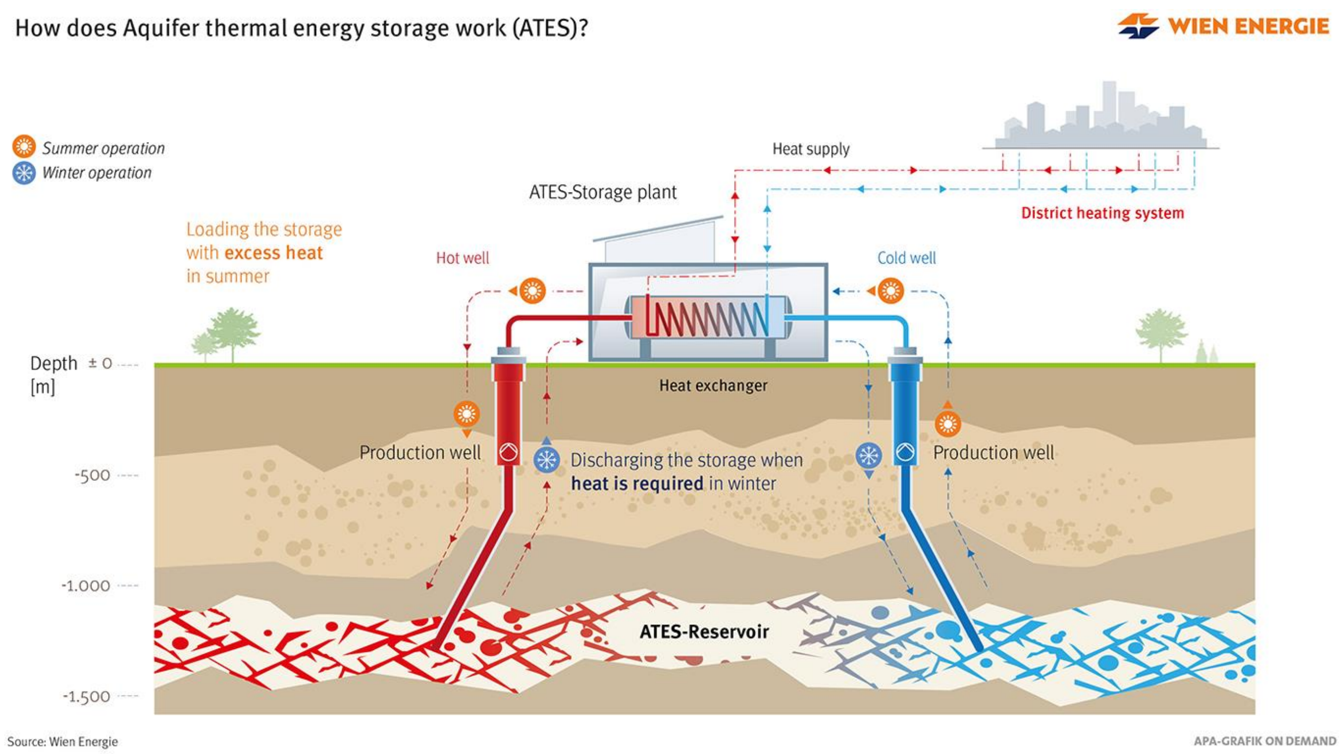

Figure 10: Functionality of an ATES

Through geological modeling—encompassing static, dynamic, and thermo-hydraulic analyses—a potential ATES reservoir has been delineated in the subsurface. The next step is to identify suitable landing points within the reservoir, which will serve as the basis for well planning. In this process, the design of the surface facility must be considered from an early stage, as there are numerous interfaces between subsurface and surface planning.

A key aspect is the integration of the production pump, whose technical requirements and operational characteristics influence both well trajectory and facility design.

4.2.1 Subsurface Concept

For well planning, an initial well path design was developed based on the geological landing points in the subsurface and the available surface area on the property. In addition, a completion concept was designed, defining aspects such as casing diameters, sectioning, and cementing.
In order to minimize costs, the borehole was designed with standardized pipe diameters so that no custom-made products were required. At the same time, the design had to be such that both wells could be operated both as producers and as injectors.
The push-pull-method represents the more common approach where flow directions within the wells are alternated to increase the performance. Heat stored in the summertime is regained by reversing the flow direction during the seasons with heat demand. This approach does not depend on hydrological connections of the wells and is especially suitable when operating with big temperature differences between the injected water and the aquifer.
The subsurface planning concept includes two wells, each with two casing strings. Additionally, a conductor pipe was incorporated to ensure groundwater protection (see Figure 11: Well schematic).
The diameters in the upper section are designed to allow the installed production pump to be used in both wells. In the reservoir section, the casing can be implemented using either a slotted or perforated liner. This design is essential to ensure proper flow from the reservoir into the well or, conversely, to allow for the injection from the well into the reservoir. The choice between a slotted or perforated liner depends on the specific requirements of the project, such as the desired flow rate and the characteristics of the reservoir.
Furthermore, the wells were designed to be drilled from a single drilling site or land property. This is particularly important when considering the well's deviation and inclination during planning. A key advantage of this approach is cost efficiency, as land in urban areas is expensive.
To avoid a thermal breakthrough in the subsurface, the landing points of the wells must be located a few hundred meters apart. From a drilling perspective, however, the wells are not very deep, with an average depth of 1500 meters. As a result, drilling the wells from a single site requires a directional drilling plan.

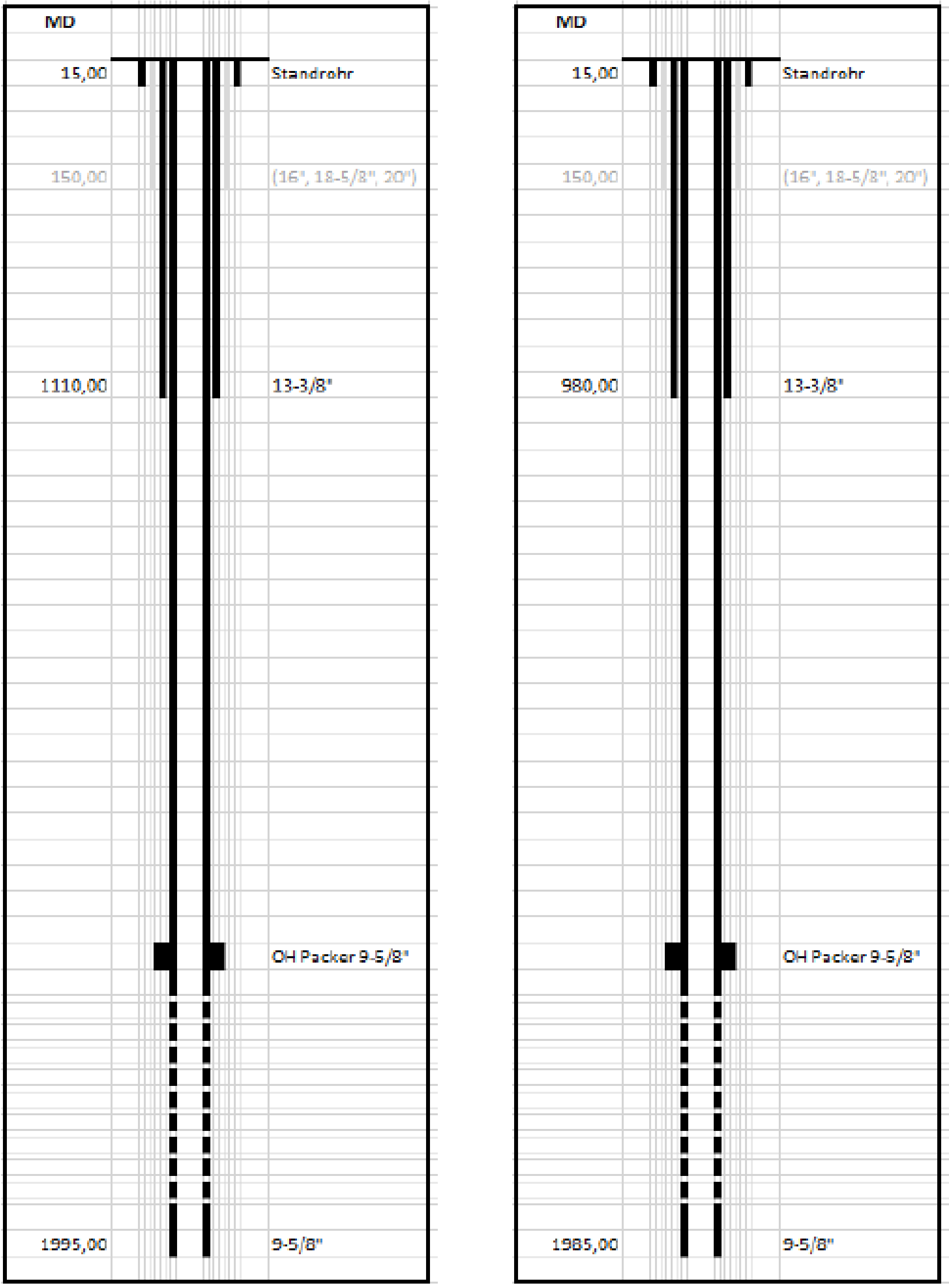

Figure 11: Well schematic of the two wells for ATES ("hot well", "cold well")

4.2.2 Concept of a welltest

Some technical risk such as e.g. induced seismicity, scaling, clogging, and sand production can be minimized by monitoring. Furthermore, monitoring of HT-ATES systems is crucial for understanding the storage behaviour and heat plume propagation.

With a well test after drilling operations, following parameters can be determindes:

- Hydraulic and thermal properties of the reservoir
- Chemical composition of the thermal water

Only a well test can provide insights into parameters in the respective reservoir.

The table below shows some examples of parameters which can be measured during al welltest.

Parameter	Measurement
Pressure and temperature measurement (P/T) at reservoir level [bar]; [°C]	Initial static pressure, pressure trend during production, pressure trend during the buildup phase, Initial reservoir temperature, production temperature
Pressure and temperature measurement (P/T) TKP [bar]; [°C]	Initial static pressure, pressure trend during production, pressure trend during the buildup phase, Initial reservoir temperature, production temperature
Wellhead pressure (P) [bar]	Pressure trend during production
Production temperature (T) [°C]	Temperature trend during production
Flow rate and volume production Q and Q total [l/s]; [m³]	Q and Q total during production
Gas measurement [ppm]	Monitoring gas content during production
Electric conductivity [µS/cm]	Trend during production
pH Value [ ]	Trend during production
Discharge temperature [°C]	Monitoring of discharge
Discharge rate and volume [l/s]; [m³]	Monitoring of discharge
Electric conductivity [µS/cm] (Discharge)	Monitoring of discharge
pH Value [ ] (Discharge)	Monitoring of discharge

Table 2: Measured parameters during a well test

4.2.3 Surface facility Concept

For the conceptual planning of the surface facility, the main components such as the production pump, heat exchanger, plant construction, building, electrical systems, control technology, heating, ventilation, and air conditioning were planned with rough dimensioning. Additionally, a concept for the thermal connection line from the site was developed to the district heating network, also with initial rough dimensioning. This also includes the general integration of the ATES in the wider Vienna DH system and different options to make use of the storage capacity. The pilot-site selection is determined not only by the subsurface planning but also by the surface planning, due to its proximity to the district heating network.

For planning the surface facility, three different scenarios were considered:

1. **Charge of the aquifer storage through the district heating network**.
   This process occurs during the summer months, from April to September, when the demand for heating is lower. During this period, excess heat from the district heating network can be used to recharge the aquifer storage. This results in a charging capacity of 11 MWth and a stored thermal

energy of 50 GWh for the system. The charging temperature from the district heating network was assumed to be 100°C.

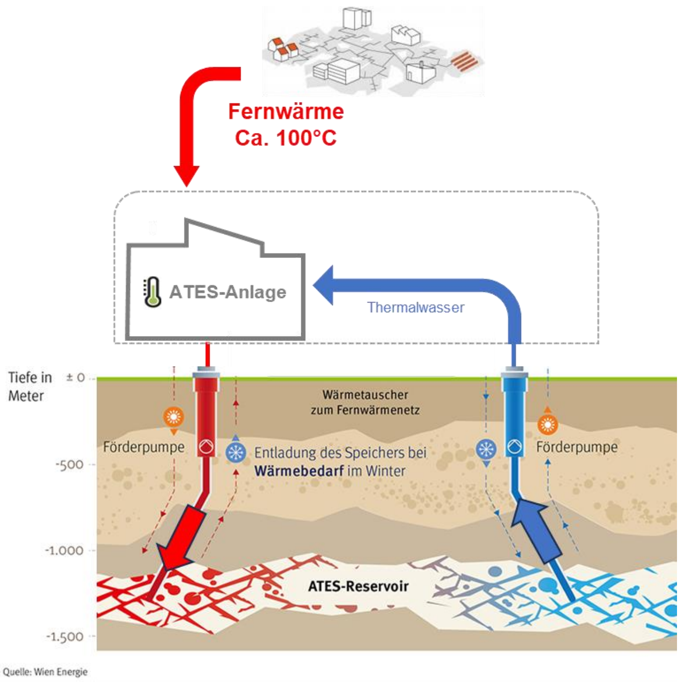

Figure 12: Charge of ATES through district heating network

During the discharge phase in the winter months, two scenarios are discussed, which are relevant for the ATES surface facility. These scenarios consider different operational strategies to ensure efficient energy delivery from the aquifer storage to the heating system, depending on the specific demands and conditions during the colder months.

2. Discharge – Direct Feed into the District Heating Network

If the temperature of the ATES system ($T_{ATES} > T_{FW\text{-}VL}$) is higher than the district heating supply temperature (district heating inlet temperature, $T_{FW\text{-}VL}$), for example, at the beginning of the heating season in autumn, direct discharge into the district heating network is possible. The system is designed for stable operation after approximately five years.

At the start of the discharge phase, the hot well temperature in the reservoir is below 100 °C and decreases to around 85 - 90 °C by the end of the discharge period. Heat losses during production, including losses in the well and heat exchanger, are estimated at approximately 5 Kelvin.

Based on reservoir simulations, the production flow rate is set at 50 kg/s, resulting in a thermal discharge capacity of approximately 5.5 MW. The reinjection temperature is around 60 °C, corresponding to the return temperature of the district heating network.

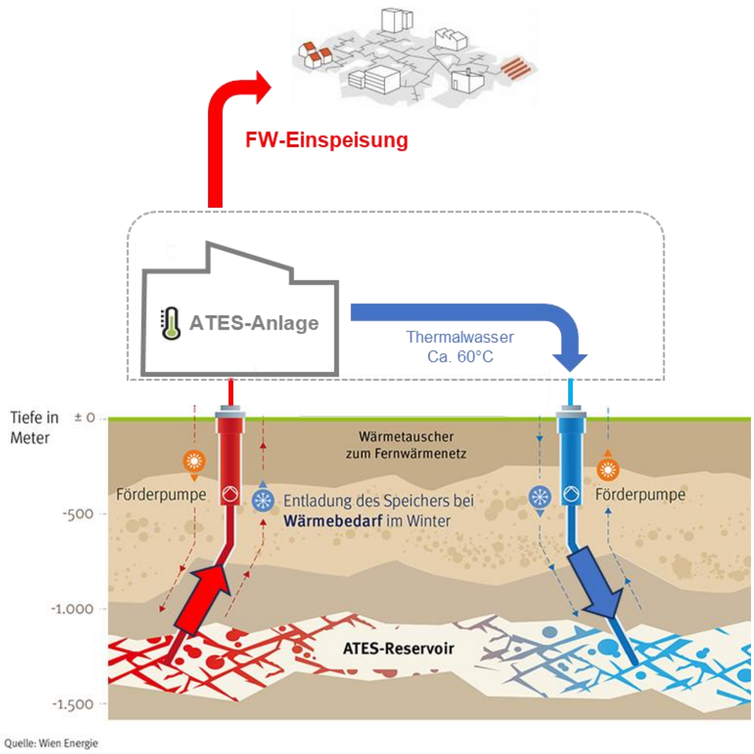

Figure 13: Discharge – Direct feed into the district heating network

3. Discharge – Temperature Increase and Storage Optimization via Large Heat Pump

In contrast to the previous scenario, where the thermal energy is directly fed into the district heating network, this approach utilizes a large heat pump to increase the temperature of the extracted water. If the ATES temperature is lower than the district heating supply temperature ($T_{ATES} < T_{FW\text{-}VL}$), the system is designed to reach stable operation after approximately five years. At the beginning of the discharge phase, the hot well temperature (BHT) is below 100°C and gradually decreases to 85 - 90°C by the end of the discharge period. During extraction, heat losses in the well and heat exchanger amount to approximately 5 Kelvin. The production flow rate, based on reservoir simulations, is set at 50 kg/s. After passing through the heat pump, the reinjection temperature drops e.g. to 40 °C, ensuring efficient energy extraction. The discharge phase takes place between October and March, with the combined output of the ATES system and the heat pump reaching 12 - 14 MW_{th}. This setup significantly improves the thermal storage efficiency and maximizes heat utilization for district heating. This allows for a significant enhancement in system performance, raising the discharge capacity from 5.5 MW_{th} to approximately 12 - 14 MW_{th}, thereby optimizing the utilization of the thermal storage.

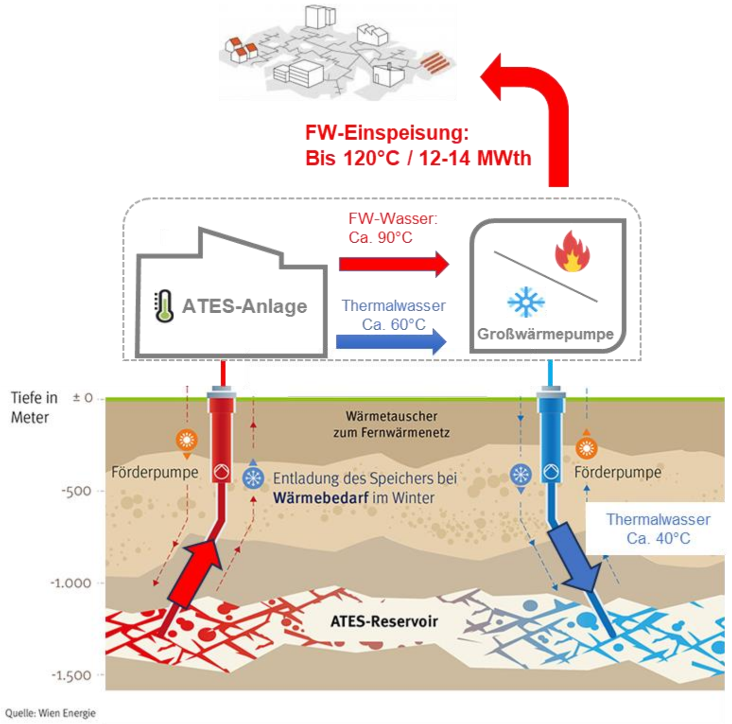

Figure 14: Discharge – Temperature increase and storage optimization via high-temperature heat pump

4.2.4 Onsite Monitoring

Two different types of monitoring play a role in the operation of ATES systems: seismic monitoring and chemical monitoring. These must already be considered during the conceptual planning phase.

Chemical Monitoring

Once the boreholes have been drilled and a production test is conducted, the initial phase of the test involves removing contaminated formation water from the well.

After this initial phase, water samples are taken at regular intervals for a comprehensive analysis of various parameters. These include chemical components (trace elements, isotopes, gases), microbiological factors, and physical properties such as density, pressure, viscosity, and temperature. This geochemical monitoring provides essential insights into the reservoir conditions and ensures the long-term stability and efficiency of the ATES system.

The collected samples and results serve as a basis for laboratory testing of water-material interactions, supporting the detailed planning of the future geothermal plant, particularly regarding material selection.

Even after the geothermal plant has been commissioned, a long-term hydrochemical monitoring program should be implemented during operation. This ensures that any changes in the thermal water can be detected in time, allowing for appropriate countermeasures to be taken if necessary.

Seismic Monitoring

Seismic monitoring is an essential component of risk management, as it records natural seismicity and ground disturbance. Deep geothermal energy and ATES (Aquifer Thermal Energy Storage Systems) can

lead to associated seismicity (both induced and triggered). This risk can be reduced through an appropriate response plan based on real-time data from seismic monitoring.
The purpose of seismic monitoring is to enable the detection of earthquakes below the perceptibility threshold and to facilitate the localization of seismicity near the potential ATES facility. The measurements should be continuously provided as input parameters for a warning system with a traffic light system.
Human activities cause stress and temperature changes in the subsurface, which can lead to induced seismicity. Unlike natural seismicity, human-induced seismicity can, in principle, be influenced by operational measures. Measuring local seismicity using a well-developed seismic monitoring network is the foundation for understanding local processes and implementing a control and/or warning system.
To limit the maximum magnitude of induced earthquakes to a defined threshold through a control system, it is assumed that earthquake strength increases with the duration of operational activities and that stronger earthquakes are preceded by weaker foreshocks. It is necessary to define operational measures to prevent future earthquakes or limit their intensity. Post-operational effects must also be considered. Consequently, the detection threshold of the monitoring network must be significantly lower than the defined target threshold. The detection threshold is primarily influenced by the distance between measurement stations and the source, as well as the seismic noise level at the stations. A dense local network and careful site selection are the most effective steps to lower the detection threshold. In areas with strong noise sources, such as industrial facilities, wind farms, or urban environments, it is necessary to install monitoring stations in boreholes.
A very high localization accuracy is required to differentiate between natural and induced seismicity and to capture subsurface processes. A uniform azimuthal distribution and a spatial arrangement of measurement stations adapted to the source depth are particularly important. Since the seismic noise is unevenly distributed and suitable locations are not always available, a practical compromise must be found.The network planning takes into account the required detection threshold and the achievable noise level at the locations. The optimization is performed by minimizing a mathematical cost function. Before the network is established, the localization accuracy is simulated.
The seismic monitoring network is divided into an immissions-network and an emissions-network, each with distinct tasks and requirements. These networks can be operated together or separately, but data exchange is strongly recommended.

4.3 Economic portfolio analysis

The increasing demand for sustainable and cost-efficient district heating solutions has driven the need for advanced optimization models for economic impact assessments. Our approach involves the open-source energy system modelling tool Calliope [5], which enables detailed energy system analysis. One of the key innovations in this analysis is the integration of Aquifer Thermal Energy Storage (ATES). This significantly enhances the flexibility of the district heating system while reducing reliance on fossil fuels.
For investigating the impact of an ATES to a district heating portfolio, an artificial average district heating model was created, representing a mixture of technologies used in many central European cities. The total demand for an average year increase from 1.95 TWh to 2.4 TWh in 2045, the peak load increases from 750 to 950 MW, network extension is assumed due to the phasing-out of fossil gas in domestic decentral heating.

The district heating portfolio comprises a CHP plant with a thermal capacity of 250 MW, including a fuel switch to green gas, waste incineration with carbon capture by 2040, waste heat, biomass and a power to heat plant. The main growth is expected to apply for heat pumps, their thermal capacity will increase from 50 to 270 MW. Hot water boilers will cover peak load demand and are also decarbonize with green gases. The main future production technologies will be heat pumps and geothermal energy. Short-term storage, such as pressurized hot water tanks, will increase the flexibility of daily operation. As visualized, the installed thermal capacity of short-term storages is quite high compared to the ATES. Although the ATES will only hold a small part of the installed thermal capacity portfolio, the storage capacity is quite high compared to short-term storages. This highlights the ability for seasonal storage.

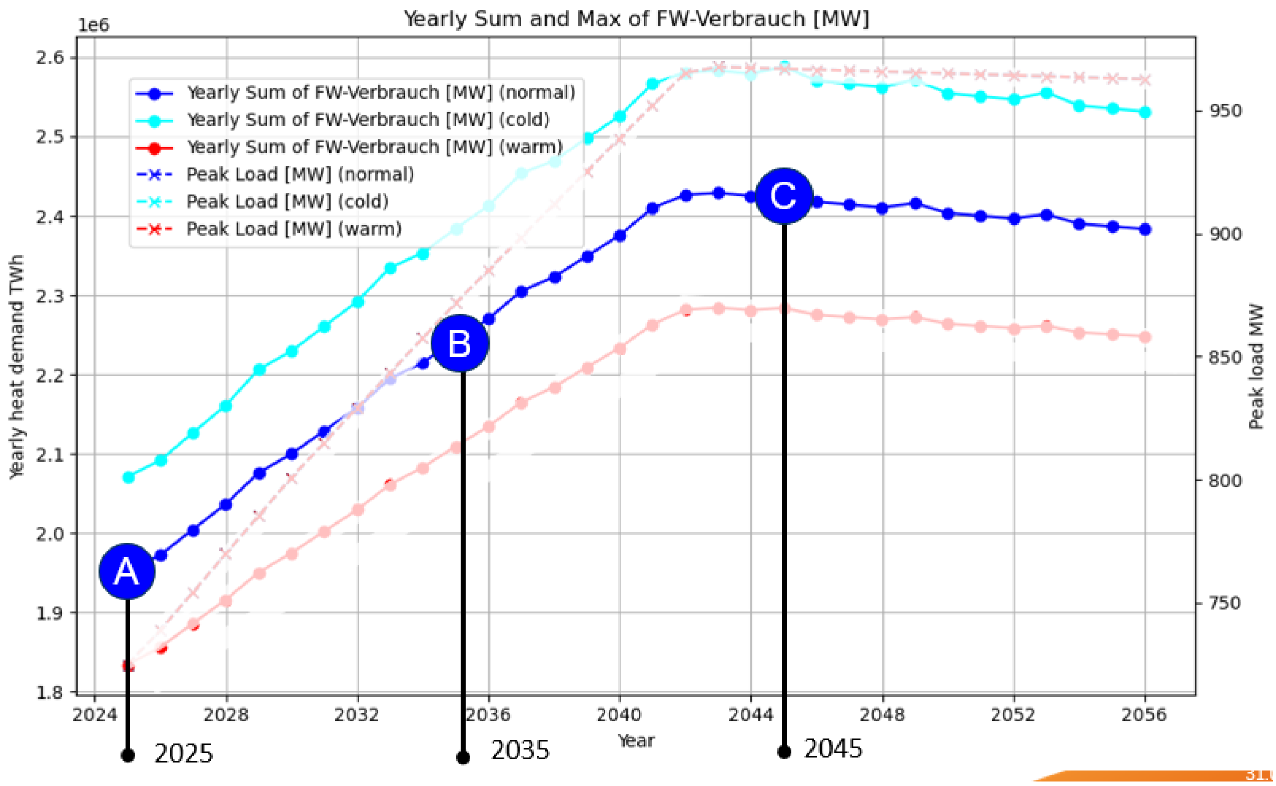

Figure 15: average city – demand and peak load development

Due to the volatility of commodity prices and heat demand, the operation of individual plants and storage systems fluctuates significantly. While geothermal heat is cost-effective compared to hot water boilers, the operation of a geothermal plant represents a "baseload" facility, whereas hot water boilers are peak-load technologies. The operation of an ATES system may look different in 2028 than in 2038, as different technologies and commodity prices become available, but the seasonal operation is the main operation mode due to technical restrictions.

The financial viability of the project remains highly sensitive to the assumed capital expenditures (CAPEX), making accurate cost forecasting and risk assessment crucial for long-term success. In the investigated portfolio optimization, the ATES reaches economic feasibility only through high green gas prices during winter, strict legal restriction on fossil emissions and great support on the capital expenditures.

5 Outlook and recommendations

A successful decarbonization strategy within district heating systems fundamentally requires seasonal storage like ATES. The foundation for the utilization of ATES lies in methodical and comprehensive analyses of the subsurface, based on 3D seismic measurements, which serve as the basis for resource underground assessments.

Additionally, the comprehensive technological evaluation—including drilling and surface plant planning—with an economic assessment (portfolio integration), shows the necessary conditions for implementing ATES.

Figure 16 depicts a clear way forward from desktop analysis (if sufficient data are available) up to the implementation of an ATES-Pilot e.g. in Vienna. The next step after ATES-Vienna (desktop study) is the "ATES-Exploration", focusing on practical testing in an e.g. already existing well. A key element is the development of a well test, which evaluates the functionality and efficiency of ATES. At the same time, a development program for ATES is developing, incorporating insights gained from the well test. Finally, this phase includes the design of an ATES pilot project, laying the groundwork for the next significant step toward practical implementation.

The final stage is the development and implementation of the "ATES-Pilot." In this phase, the ATES pilot project is realized based on previous studies, tests, and concepts. The goal is to implement the system and to test its functionality under real conditions within several years. Furthermore gather valuable insights for potential large-scale applications will be established.

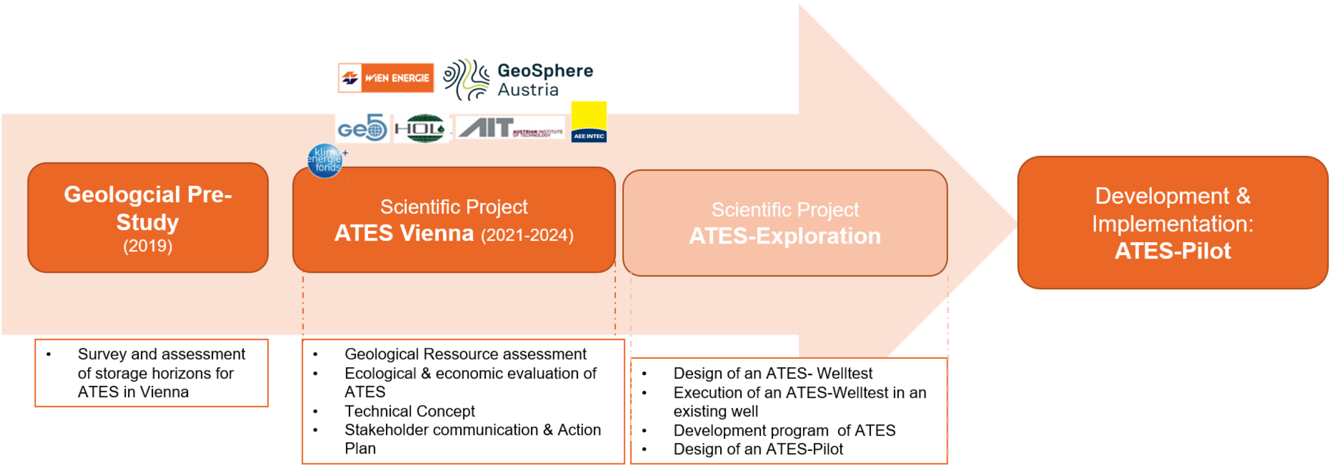

Figure 16: ATES → way forward from scientific project to pilot-project

We want to ensure the ATES technology within an energy infrastructure system (e.g. district heating system). An economic evaluation leads to concrete measures that guarantee the integration.

Despite of a correct technical implementation of ATES, as described, a successful integration of ATES in an existing energy infrastructure would be based on two more pillars:

1) ATES oriented funding program from exploration to testing pilots

An economic viability of ATES is currently not given, because of calculated high investment and resulted heat productions costs. The situation results in lack of interest of district heating systems operators investing in needed exploration activities for planning a successful pilot project at the end. Therefore, an extension of the funding program “Tiefengeothermie” powered by Klima- und Energiefonds” encouraging ATES-Exploration activities, is recommended.
The realization and operation of pilots must be based on investment support (more than 35% of total investment) including an operational support based on discharged heat amount within a year.

2) Regulatory adaptions before realization of ATES-Pilots

The storage of heat is not explicitly regulated under the Austrian Mineral Raw Materials Act or the Water Rights Act, a legal framework for ATES does exist. The establishment of an ATES pilot project will encourage the responsible authorities to engage more intensively with the legal framework for high-temperature heat storage in Austria. The approval for the implementation of an ATES storage system requires three different permits (water law-, mining law-, commercial law- authorization). To minimize investment risks and shorten the project development timeline, we recommend establishing at least a one-stop-shop for regulatory approvals.
Figure 17 summarizes the main tree pillars technical stages, support schemes and regulation requirements for a long-term and system based integration of ATES

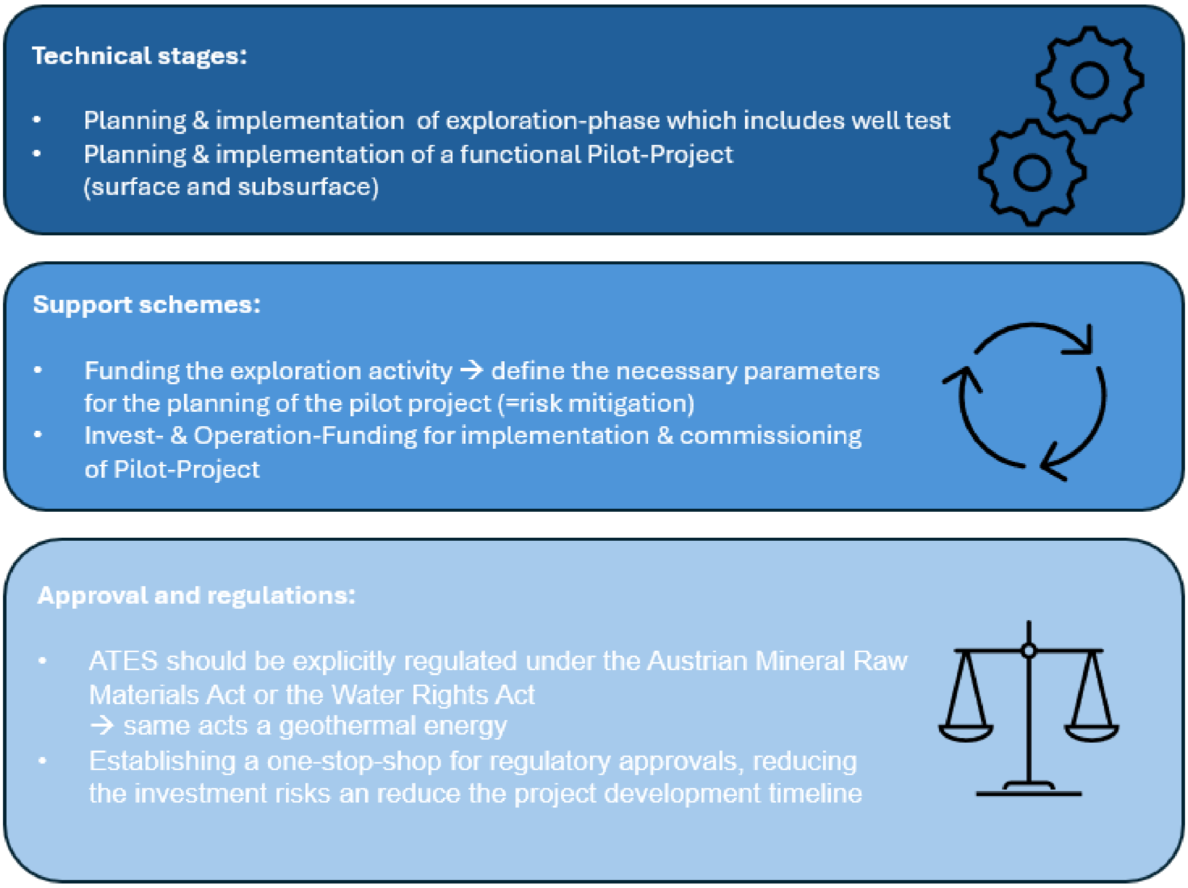

Figure 17: Summary of the three main pillars of ATES implementation

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