Interreg
EUROPEAN UNION
North-West Europe
DGE-ROLLOUT

DGE Guidance Concept Report

Deliverable LT2.1

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Disclaimer

This report is provided for as guide for the development of deep geothermal in the region of Interreg North-West Europe. It is based on the experience with the development of deep geothermal projects of the project partners. It also takes into account lessons learned in the context of DGE-ROLLOUT.

The report provides general information to local, regional, and national public authorities, project developers, politicians and enterprises with heat demand. Although the report is set-up as a guide for the development of deep geothermal projects, it does not replace the own independent evaluation of the usefulness and impact of the different development steps. Nor does it replace any local regulation or guides on good practices. Good project management and an appropriate evaluation and management of both technical and societal risks is fundament of a successful deep geothermal project and has to be done carefully by a professional.

The authors do not guarantee, and accept no legal responsibility whatsoever arising from or in connection to the accuracy, reliability, currency, correctness or completeness of any material contained in this report.

Contents

Introduction

It is the intention of the partners of DGE-ROLLOUT to install a lasting non-profit guidance system for the development of deep geothermal in the region of the Interreg North-West-Europe programme (Interreg NWE) after the project-end. Many of the project partners, as long-lasting institutions, are already assigned to guidance of end-users in geological questions and to support local governments in developing a policy that is related to the subsurface. The intended guidance system may have a safe place for the future there, but other structures are possible as well.

This report discusses the structure of the guidance system that the project partners intend to develop. The report starts with a short motivation for the transnational collaboration to develop deep geothermal in the Interreg NWE area. The next chapter gives an overview of the current situation. It sets the scene for the guidance system by looking at the policy framework, the level of deployment of deep geothermal in the area and existing national and transnational initiatives to share knowledge and experience.

Next, the report presents the guidance system. This chapter starts with an evaluation of the opportunities and threats for a guidance system on deep geothermal. Then the organisational structure and the business model of the system are presented. This is followed by an evaluation of the strengths and weaknesses, and a discussion of measures that could be taken to strengthen the impact of the intended guidance system. The last chapter tells the story of the demonstration cases of the DGE-ROLLOUT project: the Balmatt deep geothermal-plant and heating grid in Mol (BE), TRUDI in Bochum (DE), and the district heating grid at the TU Darmstadt (DE). These stories highlight the benefits of transnational collaboration and knowledge sharing.

More information about the objective and organisation of the network that will provide the guidance to the developed to deep geothermal in the NWE-region can be found in Deliverable LT 1.1 Network Concept Report.

Motivation

The resource mapping (see D.T1.1.5) and the market/investor correlation (see D.T1.2.2) performed in the context of DGE-ROLLOUT prove that there is a large potential for the development of geothermal energy in the project area. The mapping conducted in activity 1 of WP T1 highlighted areas where there is an overlap of a deep geothermal potential and a high heat demand (see D.T1.2.1). At these locations, deep geothermal energy can be a viable heat source for both existing and new district heating systems. Other identified options are the use of geothermal as a source of industrial heat and (low-pressure) steam, or for heating at agricultural enterprises.

The evaluation shows that in the densely populated metropolitan regions and the industrial areas of the NWE region there is a high need of continuous heat and energy supply for private households, industrial use and at the same time limited space for wind mills and solar panel parks. Geothermal Power Plants require little space and therefore leave nature preserves and recreation areas largely untouched.

Today, the utilisation of deep geothermal in the area is limited. The poor use of deep geothermal energy has main two reasons: unawareness and risks:

1) Awareness: the characteristics, potentials and advantages of deep geothermal energy are barely known and poorly understood by politicians, municipalities, companies and citizens. As a consequence, deep geothermal is often not taken into account when developing energy plans or alternative energy supplies for district heating or applications in the industry or the agriculture.
2) Risks: development and usability risks, as well as the initial investments for deep geothermal plants are high in comparison to other renewables. Therefore companies that are aware of deep geothermal in most cases avoid these investments and chose for alternatives.

The challenge to develop deep geothermal at its full potential is to raise knowledge and awareness of the technology and to provide solutions that reduce exploration and financial risks. Linked to this challenge is the question, how the heat supply for NWE can be produced with renewables. It will be a big challenge for the future to replace the big power and heating plants, fired by fossil fuels, by renewable energy sources.

Deep geothermal can play a key role in this transition. The mapping exercise conducted under WP T1 of DGE-ROLLOUT shows that there is a vast, largely unused and to the market unknown energy reservoir present in large parts of the project area: the Lower Carboniferous Limestone. This energy reservoir can provide solutions for a sustainable and CO_2 neutral heat supply and the re-use of existing heating grids (change from fossil to renewables). The knowledge about this reservoir and the experience to develop deep geothermal projects is scattered and only shared by a small group of experts. Bringing the knowledge and expertise together in a transnational collaboration, creates opportunities to combine forces for the exploration of the geothermal potential and the development of more effective solutions to produce and utilise the geothermal energy. This will reduce the costs and risks of individual projects. As such it may help to overcome the financial risk barrier that deep geothermal is confronted with.

Current situation

Policy Framework

The EU Renewable Energy Directive (Directive 2018/2001/EU) aims to reduce greenhouse gas emissions (GHG) and increase the share of renewable energy in a way that is inclusive and leaves no one behind. Building on the 2020 targets, the directive strengthened the renewable energy targets and put forward measures for the different sectors of Europe’s society to reach the targets of 32% for renewable energy by 2030 and carbon neutrality by 2050. To meet these targets, it will be essential to improve the energy efficiency and green the heating and cooling of our buildings, which are now responsible for about 40% of Europe’s energy consumption and 36% of the CO_2 emissions.

The Renewable Energy Directive is one of the pillars of the “Clean energy for all Europeans package” that was published in May 2019 (Clean energy for all Europeans - Publications Office of the EU (europa.eu)). The package includes 8 new laws that should help Europe to move away from fossil fuels and to come to a more efficient and cleaner use of energy. It is the ambition of the “Clean energy package” to make this transition in a way that brings considerable benefits for the consumers, the environment, and the economy

In July 2021, an even higher ambition was put forward in a proposal to the European parliament of a revision of the Renewable Energy Directive (COM/2021/557 final). The revision increases the 2030 targets for renewable energy to 40%. This means doubling the current renewables share in one decade. To meet the ambition, the proposal comprises measures to foster the development of new technologies, to boost electrification, to add flexibility to the energy system and to remove barriers for the use of renewables. Along with the measures to accelerate Europe's energy transition, the revision defines clear sector-specific targets at national level:

- 49% renewables use in buildings by 2030
- A benchmark 1.1 % annual increase in renewables use in the industry
- A binding 1.1 % annual increase in renewables use for heating and cooling, with specific indicative national top-ups
- An indicative 2.1 % annual increase in the use of renewables and waste heat and cold in district heating and cooling.

The revision is part of the European Green Deal which seeks to make Europe the first climate neutral region in the world (COM/2019/640 final). To make this happen, Europe will have to transform its economy and societies in a fundamental way. This causes tension and anxiety but also creates new opportunities for investments and jobs. Realizing the Green Deal may also reduce Europe's external energy dependency and may help to abate energy poverty.

The Green Deal defines 8 work areas. DGE may directly contribute to 3 of these areas: affordable and secure energy (area 2), industry for a clean and circular economy (area 3), and energy and resource efficient buildings (area 4).

To meet Europe's energy and climate ambition, the Junker Commission defined the Energy union strategy (COM/2015/080 final). The strategy includes regulation on the governance of the energy union and the climate action. One element of the governance mechanism are the National Energy and Climate Plans (NECPs). They are meant to translate the European targets into national actions and regulation. The NECPs cover the period 2021 – 2030. Progress is evaluated every 2 years.

The NECPs give the ambition and targets set by the members states with respect to greenhouse gas emission reductions and renewable energy. An important measure to reduce the impact of the energy use in the residential and tertiary sectors is the integration of renewables in existing district heating systems and the development of new district heating and cooling schemes. This opens opportunities for geothermal.

The Renewable Energy Directive recognizes geothermal energy as "*an important local renewable energy source which usually has considerably lower emissions than fossil fuels, and certain types of geothermal plants produce near-zero emission.*" [Directive 2018/2001/EU, preamble 46]. Although the commission knows that under certain geological conditions "*the production of geothermal energy may release greenhouse gases and other substances from underground fluids, and other subsoil geological formations, which are harmful for health and the environment*", they suggest facilitating the deployment of geothermal systems with a low environmental and climate impact.

To meet the targets for renewable heating and cooling, the directive urges the members states to take steps for the developing district heating and cooling where relevant. This will create opportunities to developing large renewable energy facilities like deep geothermal [article 20.3]. The urgent request of the European Parliament and of the Council has been accepted by the member states as most of them foresee actions to advance district heating and to stimulate the use of renewable energy sources for heating and cooling.

In Belgium, the Flemish government approved a heat plan to encourage investments in the environmentally friendly production of heat and the construction of district heating. The goal is to increase to quadruple the annual heat delivery by district heating by 2030. The Walloon government also adopted a renewable heat transition plan that includes actions to remove obstacles to the development of district heating systems and stimulate the development of renewable energy sources including geothermal. By 2030, the combined efforts of the regions and the federal state will result in a reduction of the greenhouse gas (GHG) emissions by 35 % compared with 2005 levels for non-ETS sectors and generation of 17.4 % of Belgium's gross final energy consumption from renewable energy sources

Target of The Netherlands is to reach a share of renewables of about 14%. As a high emitter of GHG and its strong gas reliance, its plan is to turn from gas to DGE. Demonstration projects are being implemented like the Ultra-Deep Geothermal Project. The Dutch NECP contains measures that aim to achieve a 49% reduction in GHG emissions by 2030 compared with 1990. The 2030 target for renewables is set at a minimum of 27%. By that time, a substantial part of the buildings will no longer be heated using natural gas. This requires major investments in the energy infrastructure including new district heating systems, as well as a connecting exiting district heating to other energy sources such as deep geothermal.

Germany wants to increase renewables to 18% and is expecting significant increase from DGE systems, following the German EU action plan. The successful start of DGE is expected to be implemented on hydrothermal systems. Federal NRW government stated that the potential of deep geothermal energy should be used. The German NECP has the objective to reach a national climate goal of a GHG emissions reduction of at least 55 % compared to 1990 and a share of renewables of 30 % of the gross final energy consumption in 2030.

The target of France is to reach a share of renewables of 23%. The Grenelle Environment Forum wants to increase the volume of renewable energy mobilized via heating networks in 2020, in particular by using geothermal energy (Paris Basin). Here, DGE-ROLLOUT and the Guidance system will help to establish DGE for additional regions with high potential, as Hauts-de-France. The French NECP targets a reduction of GHG emissions of 37% and a share of renewables in the gross final energy consumption of 32% in 2030. By that time, at least 60% of the heat and cold supplied by district heating should come from renewables or recovered heat and cold.

Deployment of geothermal energy

In 2015 geothermal energy represented only 3.1% of EU's total renewable energy production. Geothermal sources are currently used to a limited degree, considering their enormous potential (2600TWh by 2045).

Sharing of knowledge and expertise

Geology and geological exploration

Information and knowledge about geology and exploration results is collected, analysed and disclosed at various levels. At European level, the national and regional geological surveys play a central role. At the level of the member states and regions, several public bodies provide geological information. They also conduct or manage geological research, often in a context of policy support.

EuroGeoSurveys: is a not-for-profit organisation representing 38 national geological surveys and some regional surveys in Europe. It is the mission of EuroGeoSurveys to provide public earth science knowledge to support the EU's competitiveness, social well-being, environmental management and international commitments. EuroGeoSurveys is active in all fields of geological research. In 2016 they launched the first version of the European Geological Data Infrastructure (EGDI).

EGDI is a data system to manage and provide pan-European, transnational and national geological datasets EGDI also acts as the gateway for geological data and digital services of to EuroGeoSurveys the European Plate Observing System (EPOS).

The objective of EPOS is to establish a comprehensive, multidisciplinary research platform for earth sciences in Europe. It is the long term goal of EPOS to facilitate the access and (re-)use of data, data services and research facilities to a broad community of users. In addition, EPOS is also working on tools for the use of the data in analysis and modelling.

R&D on deep geothermal

At the European level, the research and development on deep geothermal is coordinated by four network organisations. The activities are coordinated by the Implementation Working Group on deep geothermal (DG-IWG), of the SET plan. The DG-IWG was created to realize the Deep Geothermal Implementation Plan, that was endorsed by the SET Plan Steering Committee on 24 January 2018. The DG-IWG is structured on participation of EU, the SET-plan countries, the geothermal industry, the research community and the public sector. These stakeholders are represented by:

- The Joint-programme on Geothermal Energy of the European Energy Research Alliance (EERA-JPGE): is a membership-based, non-profit association and brings together universities and public research centres that are active in geothermal. Together they allocated a total of 420 person-years to support ongoing and planned research activities and share research infrastructure and facilities for the advancement of geothermal.
- The European Technology & Innovation Platform on Deep Geothermal (ETIP-DG): is an open stakeholder group, endorsed by the European Commission under the Strategic Energy Technology Plan (SET-Plan). The platform brings together over 300 companies, universities, research centra, governmental organisations and sectoral organisation to define long-term research and development needs and goals, with the overarching objective to enable deep geothermal technology to proliferate and reach its full potential everywhere in Europe.
- The European Geothermal Energy Council (EGEC): is a non-profit organisation that bring together private and public bodies. The mission of EGEC is to promote the European geothermal industry and enable its development both in Europe and worldwide, by shaping policy, improving business condition, and driving more research and development.
- ERANET GEOTHERMICA: originated from the geothermal ERA-Net to support public-public partnerships and to combine financial resources and know-how derived from nationals and

European geothermal research and innovation programmes. GEOTHERMICA offers (financial) support to bring innovative solutions for development of geothermal in Europe to the market.

Experience in project development of geothermal projects

The Deep Geothermal Implementation Working Group of the SET-plan stresses the relevance of two cross-cutting issues to advance the development of deep geothermal in Europe and to overcome technical and non-technical barriers:

- Sharing and transferring knowledge and organizing training including peer-to-peer learning and research infrastructures;
- Developing an open-access policy to geothermal information to facilitate access to geothermal information at the European level via the linkage of and development of information platforms, and the creation of standard and common data models.

The requests for sharing of data and knowledge, open), and for access for providing information, education and training are also raised by the ETIP-DG and by the EERA-JPGE. They also underline the need for research and training infrastructure.

To some extent, exchange of data and experience is organized at a national or regional level, e.g.:

- Research & Innovation in Geothermal – Egec (gogeothermal.eu)
- GeotIS Information System for geothermal energy
- News Tiefe Geothermie | Informationsportal Tiefe Geothermie
- Bundesverband Geothermie: Nachrichten
- Praxisforum Bayern | (praxisforum-geothermie.bayern)
- Geothermie Nederland
- Geothermie | NLOG
- Les géothermies | France
- Geothermie | DOV (vlaanderen.be)
- Plateforme géothermie profonde en Wallonie

At the level of the Interreg NWE region, a structural collaboration does not exist. There are however geological and societal aspects that make the advantages of such a collaboration plausible. Different parts of the region share common geothermal resource in deeply seated, fractured carbonate deposits. Moreover, all over the region there are urbanized and industrial areas with a high heating demand. These areas are facing the common challenge to convert the heat supply from predominantly fossil energy to renewable energy sources in the medium to long term. Geothermal district heating has the potential to become an important technology to make this transition.

Interregional collaboration

Transnational cooperation already started by preparing the proposal for DGE-ROLLOUT. The combined efforts on resource mapping, exploration and production optimization conducted in the context of the project reveal the potential of deep geothermal as a regional driver of the energy transition to the market. It can be the start of a roll-out of DGE in NWE. By planning, exploring, testing and monitoring over the national borders, it will be possible to develop the potential more effectively.

Different levels and parts of knowledge is scattered over NWE; when putting it together, better solutions can be expected and that can also be transferred to Ireland, Luxemburg and the UK, to form a strong network on DGE in NWE to reduce CO_2 emissions and to develop the branch as an industrial cluster.

Beyond DGE-ROLLIOUT

General observations

The deployment of a technology can only be successful in case it is socially accepted. This is certainly the case for deep geothermal energy in the NWE region. Next to the fact that the potential is barely known to the public and concerns about risks are easily found on the internet, development of deep geothermal will affect the way we foresee in our heating demand. In places where deep geothermal plants can feed into existing district heating networks, the transition from fossil fuels to renewables can pass almost unnoticed. In other places, the construction of deep geothermal plants may coincide with the development of district heating networks. Besides the physical impact of the works, this will call for a new view of the citizens, who are now used to solitary heating systems, on heating. This new view will be confronted with other, still solitary solutions, like heat pumps and solar heating.

Development of deep geothermal for industrial applications may ask for a rethinking of production processes. Today, many processes work at elevated temperatures or with medium to high-pressure steam. These working conditions can be easily met by combustion processes but are out of reach for deep geothermal in most of the NWE -region. To utilize the available geothermal potential, the production processes can be redesigned so that they work at lower temperatures. As an alternative one may think of combining deep geothermal with other technologies to lift the temperature to the desired level, or the construction of hybrid heating plants. All these options ask for further R&D, with deep involvement of the industry. This is only possible in case the industrial actors are aware of the potential of deep geothermal and willing to take the risk to transform long-proven processes.

The development and off-take of deep geothermal itself also comes with technical and societal risks that are difficult to handle by unexperienced parties. These risks can further reduce the interest of companies and governments to explore the potential for deep geothermal. An overview of the risks and the way they affect the appetite of investors is given in Deliverable T1.2.2 [1].

Several projects looked into national and regional policies that affect the development of geothermal and the development of renewable district heating. A comprehensive overview of the polies in different member states and of legal barriers in given in deliverables from the IEE GeoDH project and the IEE GeoElec-project. The policies with respect to geothermal vary widely. In some member states or regions, geothermal plays an important role in the energy and climate plans, with the definition of clear targets and support schemes. In others, the potential of geothermal is barely mentioned. A

[1] T. van Melle, F. Strozyk, K; Welkenhuysen, 2021. Investors Profiling: Who might invest in DGE? Interreg North-West Europe DGE-ROLLOUT Deliverable T1.2.2

focused communication towards governments and local councils may help to bring the potential under the attention of policy makers. In all cases, a frank dialogue between the geothermal sector and regulators will help to keep the regulation and policy in line with state of the technology.

Geothermal projects have an impact on their environment and can cause nuisance to the residents. It is essential to communicate the possible impacts in a clear way from the start of a project. It is equally important to be open about any nuisance or damage that may arise when developing the project. Although it goes without saying that open communication is important, organizing transparency in information provision and a sustained stakeholder engagement are not simple tasks. Much can be learned from previous projects. To make this possible, it is essential that the lessons learned from these projects are collected and communicated to interested parties. In addition, research in the field of social sciences and technology transition can help to identify what makes a project successful.

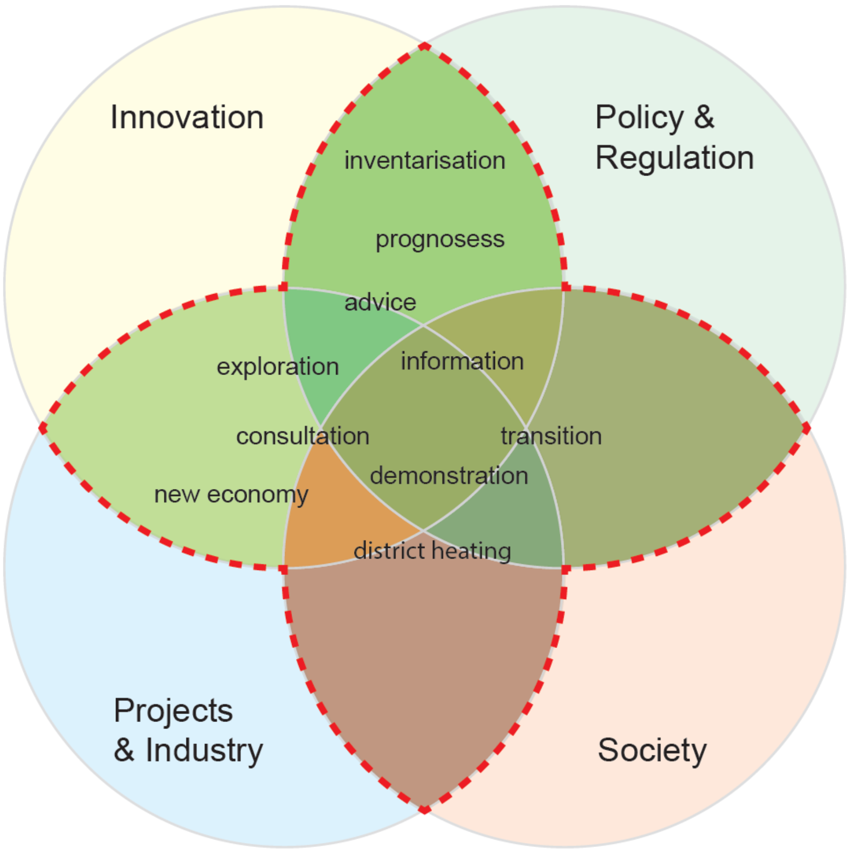


Figure 1: Position of the Guidance network in the quadruple innovation helix framework

To advance the utilisation of deep geothermal in the region, actions are required at all levels of society. An effective guidance and support system should seek interaction with all crucial actors, i.e., policy makers and regulators, the citizen, the industry and the R&D (Figure 1). In dialogue with these actors, it may define the actions that are most relevant to advance geothermal in the region. These actions include communication, sharing of knowledge and information, stakeholder engagement and R&D. The R&D needs are both fundamental, e.g., for exploration of the resources or for the development of new concepts to drill and extract the resources, and of applied nature, e.g., for the integration of geothermal in industrial processes or for a flexible coupling of deep geothermal with district heating. From the reference projects discussed below, it is clear that demonstration and optimization of the geothermal system and system components are essential to build confidence in the viability of geothermal district heating among the stakeholders.

The DGE Guidance network

SWOT analyses

A SWOT matrix for a guidance system that should facilitate the rollout of DGE in the NWE-region is given in Table 1. Input for the SWOT-matrix came from deliverable D1.1 Network concept report and input collected during the partner meetings in Brussels (14/09/2021) and in Lille (24-26/11/2021) (see also Annexes 1 & 2).

Strengths - The transnational exploration carried out during DGE-ROLLOUT confirmed the DGE potential in the NWE region - DGE-ROLLOUT created a close group of supporters for the development of DGE - DGE-ROLLOUT created the basis of a network that is focused on the development of DGE in the NWE-region - An active network in covering the NWE region - Access to demonstration projects for optimize technology and to show the operability to stakeholders	Weaknesses - Activity and continuation of the network asks for a lasting commitment of the members - "Free of charge" may sound like "of no value"; this may faint the impact of the network - Network organisation and involvement in network activities by the members may be hampered because budget is limited or not available - The working of / involvement in the net-work may drop due to staff changes by the members
Opportunities - There is need to green out heating demand and find alternative sources for (district) heating systems with a large, high-temperature (> 60°C) energy demand - Carbon taxes and rising energy prices create new business opportunities for the development of sustainable low-carbon heat sources - Price stability for heating will reduce the risk to push residents in energy poverty - There is growing support from Europe and local governments to invest in deep geothermal, both for R&D and the deve-lopment of new project	Threats - Interest in a new network may be limited as several networks already exist at the local and European level - Bad experiences/problems with existing geothermal plants may result in more reluctance to invest in deep geothermal by the private sector and governments - The trend towards shallower geothermal systems, with lower development risks, may reduce the interest in deep geother-mal - Discussions about induced seismicity and environmental impact my lead to slow down of development of deep geothermal - Confidentiality issues may hamper the exchange of data and experience

- Development of projects benefit from an exchange of data and experience, especially in green fields - Combining efforts in research and technology development results in a more effective use of resources - Sites to test operational solutions and new technologies under real conditions can make market introduction easier	

Table 1: SWOT-matrix for a guidance system to advance the development of deep geothermal in the NWE-region

Objectives

The objectives and organization of the post-project guidance system were discussions among the partners of DGE-ROLLOUT. After a couple of discussions, the development of a DGE guidance network seems the most viable option. The aim of the network is a regular exchange of knowledge, experience and expertise between geological surveys, research institutions and market players in the fields of exploration, networking and energy on regional activities, harmonization and cross-border collaboration regarding deep geothermal for the next 5 to 10 years.

The DGE-Rollout Network will be a platform for exchange of data and experience on special local cases and thereby supports local project developers and stakeholders in realizing geothermal projects by covering the complete value chain for geothermal projects. The network will focus on the NWE-region. It will cover geological, social, legal and financial aspects. The mission and vision of the network is elaborated in deliverable D1.1 Network concept report.

Description of the network activities

The activities of the DGE guidance network will include organizing regular network meetings to bring parties that are actively involved in the development of deep geothermal in the NWE region together. Two types of meeting are envisioned:

- Joint Network Meetings during which network related issues are discussed, the status of DGE development is reviewed and new projects are presented;
- Team Meetings that deal with 1) Geological issues, 2) Research and technology development and 3) Market issues.

Access to the network meetings will be restricted to network partners. In the context of the network meetings, public events may be organised to communicate the potential of deep geothermal to a broader public.

Joint Networking Meetings will be organised each year and Team Meetings every second year. In general, the meetings will last for two days. An example of what the agenda of a Joint Network Meeting might took like is given in Table 2

- Day 1: Workshop with presentations by each partner and Parallel Sessions and Plenary Session with stakeholders combined with a Networking Dinner
- Day 2 – (Geological) Field trip or site visit or a public event.

Day 1		Access
09:00	Welcome	Members only

09:15	Open workshop	Members only
13:00	Lunch	Members only
14:00	Pitch talks (online) with stakeholders and open to public	Public
15:00	World Cafe with stakeholders and open to public	Public
16:00	Presentation of team results and discussion of open questions	Members only
17:00	end	
19:00	Network dinner	Members only
Day 2		
09:00	Field trip or site visit including lunch	Members only
17:00	end	Members only

Table 2: Example of what the agenda of the Joint Network Meeting might look like

Intended results

The DGE network aims to advance deep geothermal in the NWE region. The success of the network will, to some extent, be reflected in the number of deep geothermal plants that are running in the region. The goal is to have at least 14 deep geothermal plants targeting deep fractured limestones running in the region 5 years after the start of the network.

Guidance for project development by the network will be the core for the future: each successful project will lead to more DGE users and more knowledge and experience that can be shared within the network.

Partners

Partners of the DGE guidance network will be the partners of DGE-ROLLOUT and other parties that are currently active in the development of deep geothermal in the NWE region. Potential additional partners include BGS, the geological surveys of Ireland and Luxemburg, Geothermie Nederland, SPW, HITA and Engie.

The partners will be able to assign a specific team:

1) Geological Team: deals with exploration and other geological issues (members: BRGM, GD NRW, GSB and TNO)
2) Research Team: deals with research and technology development to advance deep geothermal, including the integration of deep geothermal in future energy schemes (members: Fh-IEG, TuDa, TNO, VITO)
3) Market Team: deals with non-technical (societal, financial, and legal) issues (members: DMT, EBN, RWE, VITO)

Beneficiaries

The network will create a plenum to discuss issues that impact the development for DGE in a region specific way. The network can formulate common actions to overcome these issues. As the members have close ties with the local authorities and civil society organizations, they are well placed to define coordinated answers to questions and concerns with respect to deep geothermal. The network will also fulfill a role in the communication of the potential, challenges, and status of DGE in the region. In this way the activities of the network may be of value for local policy makers and, competent authorities, civil society groups, citizens and local industry.

Structure of the network

Based on the replies to a questionnaire the choice is to organize the network in a light form. There will be no central organization. The administrative burden will be limited to the development and maintenance of the members database. Members will have the possibility to sign-up for one or more of the thematic teams.

A common view on how to deal with confidential information will be defined before the start of the network.

A preliminary schedule for the Joint Network Meeting and Team Meeting for the first 5 years has been drafted. These meetings will be hosted by DGE-ROLLOUT partners. Organization of the meetings will be coordinated by the host.

Business concept

Participation to the activities of the DGE-Rollout network is free and on a voluntary basis regarding travel and staff costs. For each meeting/event one of the members will act as host. Selection of the host will be on a voluntary basis. The Network Meeting host will cover the costs for rental of the room(s) and refreshment/lunch during the meeting for all participants. Based on the experience of DGE-ROLLOUT, the budget to host a meeting is estimated at 3000 EUR.

This business model is supported by 7 out of 10 partners of DGE-ROLLOUT (see Annex 1). In case the requirements of the Guidance Network changes over time, it can be reevaluated.

For events that are open to non-network members, all participants may be asked to pay a fee, depending on the requirements by the host. A hybrid organization is possible with meetings having a ‘members only’ session and a public session. In that case, a fee could be charged for the ‘public session’.

As an alternative for the fee to be paid for public events, universities could be run as Scientific Advisors. Instead of paying in cash, they provide a scientifically (based) input to be defined in the form of reports / lectures.

The majority of the DGE-ROLLOUT partners is willing to host Network Meetings under these conditions (see Annex 1).

Reference projects

The Balmatt geothermal project (Mol, Belgium)

This section gives an overview of the Balmatt geothermal project in Mol, Belgium. It tells the story as it was perceived by the author, Ben Laenen, a researcher at VITO who was closely involved from the start of the project. In that respect, the story is subjective. It may be told in another way, depending on the perspective of the storyteller and his distance to the project. However, the author tried to stick to verifiable facts to outline the course of the project. The story becomes subjective when he discussed how these facts influenced the course of the project. The author however is convinced that his story contains elements that may help to define a way to guide and support the development of deep geothermal in a region where the technology is largely unknown.

The section starts with a summary of the different phases of the Balmatt geothermal project. It is a sequence of objective and verifiable facts that is supported by the deliverables of Task 3. Next is discussed how the interaction with different stakeholders took place and how this influenced the course of the project.

Objectives and motivation

The Balmatt geothermal project was initiated as a research and exploration project. From the start, it was however the ambition of VITO to use it as a pilot in the Flemish energy transition as well. With the project, VITO wanted to give a new impulse to the development of deep geothermal energy in Belgium. VITO is convinced that deep geothermal energy can make an important contribution in the future to meet the local need for heat and electricity.

With the project, VITO aims to:

- Identify the technical and non-technical challenges for the development of deep geothermal energy in Flanders;
- Examine the technical and economic feasibility of deep geothermal energy in Flanders;
- Evaluate the social and ecological potential of deep geothermal energy in the Flemish energy system;
- Contribute to the international research to remove the technical and non-technical barriers to the development of deep geothermal energy;
- Collect data and fine-tune infrastructure that makes it possible to test new concepts and technologies in an operational geothermal power plant.

Like all regions in Europe, Flanders is facing major challenges in the fields of energy supply and climate. One of the challenges is greening heating and cooling. With the upcoming amendment of the Energy Performance of Buildings Directive, the issue of green and affordable heating and cooling becomes even more urgent [2]. The supply of heat accounts for about 50% of the Flemish primary energy consumption. In the future, this share will decrease due to stricter energy efficiency standards for buildings. However, forecasts by the Renewable Heating and Cooling Platform and the International Energy Agency show that the increasing degree of insulation results in a steady growth

[2] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

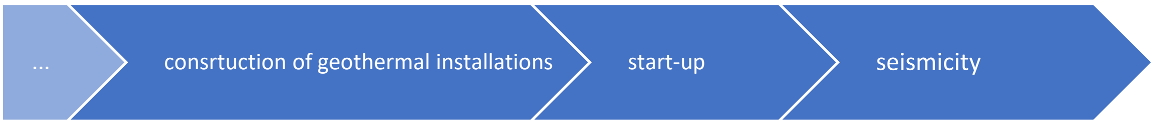
of energy consumption for cooling. At best, energy consumption for heating and cooling in the EU27 will fall by about 25% by 2050.

The margin to reduce that energy demand even more by means of additional insulation or increasing the energy efficiency of traditional heating and heating installations for individual users seems limited. On the scale of energy landscapes, however, there is still room for more efficient use of energy. Large amounts of heat are being lost in Flemish industry and in the built environment. In many cases, we used the energy once and vent the waste heat or cold to the atmosphere. A large part of the industrial waste heat is released at temperatures of 80°C or more. In theory it can serve perfectly for traditional space heating. A condition is, however, that the residual heat can be fed into a pipeline network that efficiently transfers the heat to the users. Heat networks are therefore a sine qua non for using the residual heat efficiently.

Heat networks also help to maximize the potential of local renewable energy sources. With the current state of the art and costs for drilling deep wells, the development of deep geothermal energy is only feasible if the heat demand is large enough. This either asks for connection of the geothermal system to an application with a large, more or less stable heat demand or its integration into a district heating system with a high base load. After all, heating networks make it possible to efficiently transfer the heat to the end users. This also increases the potential for electricity production based on deep geothermal energy: with the current state of the art and development costs, electricity production based on deep geothermal energy in a temperature range of up to approx. 150°C is only profitable if sufficient heat can be sold.

Development of district heating networks that are operated at low supply temperatures may further increase the applications for deep geothermal. First, a lower supply temperature results in a higher heating capacity of the geothermal source. Second, the temperature of the water after the heat exchanger of a binary cycle typically is 60 to 65°C. This heat can be used for low temperature heating applications without loss of binary cycle output.

Nov. 2009	2011	Sept. 2015	
• Preliminary-study	• Feasibility study	• MOL-GT-01	
• 2D seismic survey	• Permitting	• MOL-GT-02	
	• Due diligence	• MOL-GT-03	



	Jan. 2017	Nov. 2018	July 2019
	• Construction geothermal plant • Connection district heating • 1st phase seismic monitoring network	• Commissioning • Start-up	• Study impact seismicity • 2nd phase seismic monitoring network

Figure 2: Overview of the main phases of the Balmatt project

Technical phases

VITO started the Balmatt geothermal project in November 2009. With the project, VITO wanted to explore the geothermal potential of the Lower Carboniferous Limestone at a depth of 3000 to 4000 m. An overview of the main phases of the Balmatt project is given in Figure 2. An overview of the technical phases is provided in Table 4. Further information about the project and its relationship with earlier geothermal research in Belgium is given by Broothaers et al., 2021 [3].

After a process of preliminary studies and a2D seismic exploration, the first drilling was spudded on 15 September 2015. MOL-GT-01 hit hot water at a depth of 3200 to 3400m in the limestones of the '*Kolenkalk*' Group. In the following years two more deep wells were completed: MOL-GT-02 which serves as an injection well, and MOL-GT-03 which was carried out as a second production well, but ultimately turned out to be 'dry'. The technical specifications of the three deep wells are given in Table 3. The well paths are shown in Figure 3.

		MOL-GT-01(-S1)	MOL-GT-02	MOL-GT-03(-S1)
Total depth (TD, MD)	m	3610	4341	4905
Vertical depth (TVD)	m	3610	3830.2	4235.7
Side track (MD)	m	2700 - 3610		4308 - 4905
Top *Kolenkalk* Grp.	m	3175.5	3787.5	3643
Base *Kolenkalk* Grp.	m	-	-	4747.5
Maximum temperature	°C	139	147	142
Maximum flow during test	m³/h	150 (p)	240 (i)	dry well

Table 3: Technical specifications of the three deep wells drilled at Balmatt (p: production test, i: injection test)

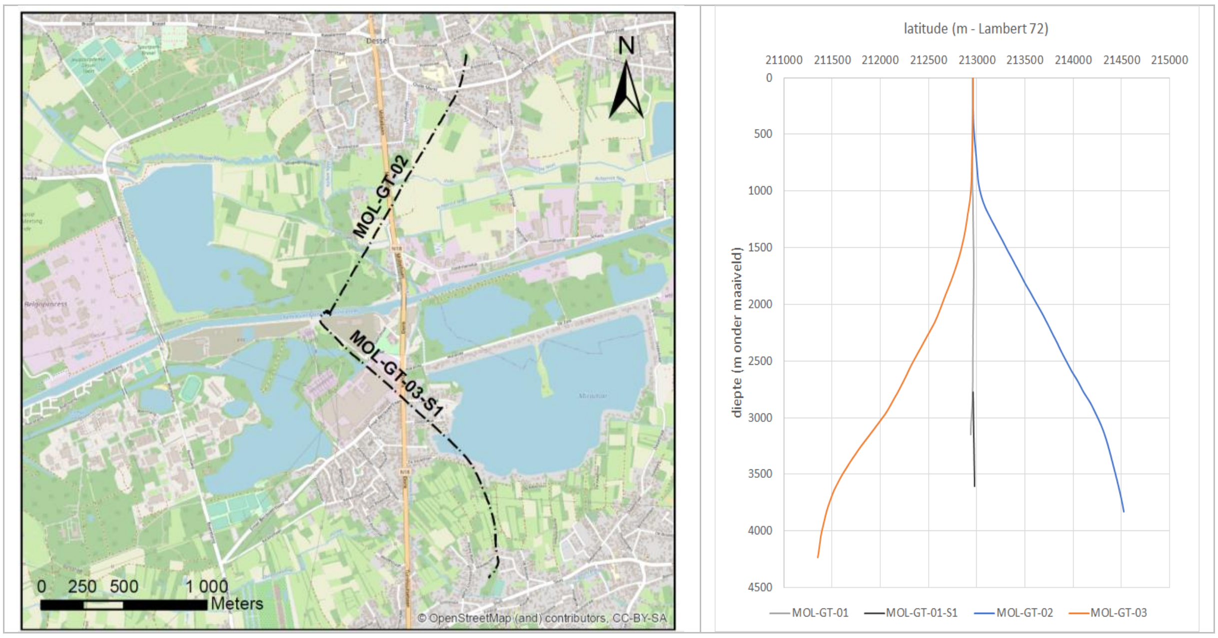


Figure 3: Well paths of the three deep wells drilled at Balmatt

[3] Broothaers, Matsen; Lagrou, David; Laenen, Ben; Harcouët-Menou, Virginie; Vos, Dries, 2021. eep geothermal energy in the Lower Carboniferous carbonates of the Campine Basin, northern Belgium: An overview from the 1950's to 2020. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften. http://dx.doi.org/10.1127/zdgg/2021/0285

In January 2017, VITO started the procedures for the procurement of the construction of the geothermal power plant and the above-ground installations. A connecting pipeline between the Balmatt site and the boiler room of the heat network of VITO – SCK•CEN had to be installed and a geothermal power plant had to be built. The works were divided into 4 blocks: the geothermal power plant, the heat network between the Balmatt site and the VITO boiler room, the connection to the heat network and the installations for the ORC. An overview of the main parts of the surface installations is shown in Figure 4.

The works for the above-ground installations started in the first quarter of 2017. The geothermal plant was completed in November 2018. It includes a connection to the heat network of VITO – SCK•CEN and a prototype of a flexible ORC for the production of electricity. During the construction of the plant, several technical issues arose that needed solving. They caused a delay in the commissioning of the plant and an overspending of the budget for the surface installation by 2/3. Major issues were:

- The presence of Naturally Occurring Radioactive Materials in the brine (NORM) leading to the requirement of defining protocols to replace filters, to remove scalings and to deal with non-injected brine;
- Proper material selection to reduce the impact of corrosion;
- To measure the bubble point and define proper operational pressure to avoid degassing and minimize scaling.

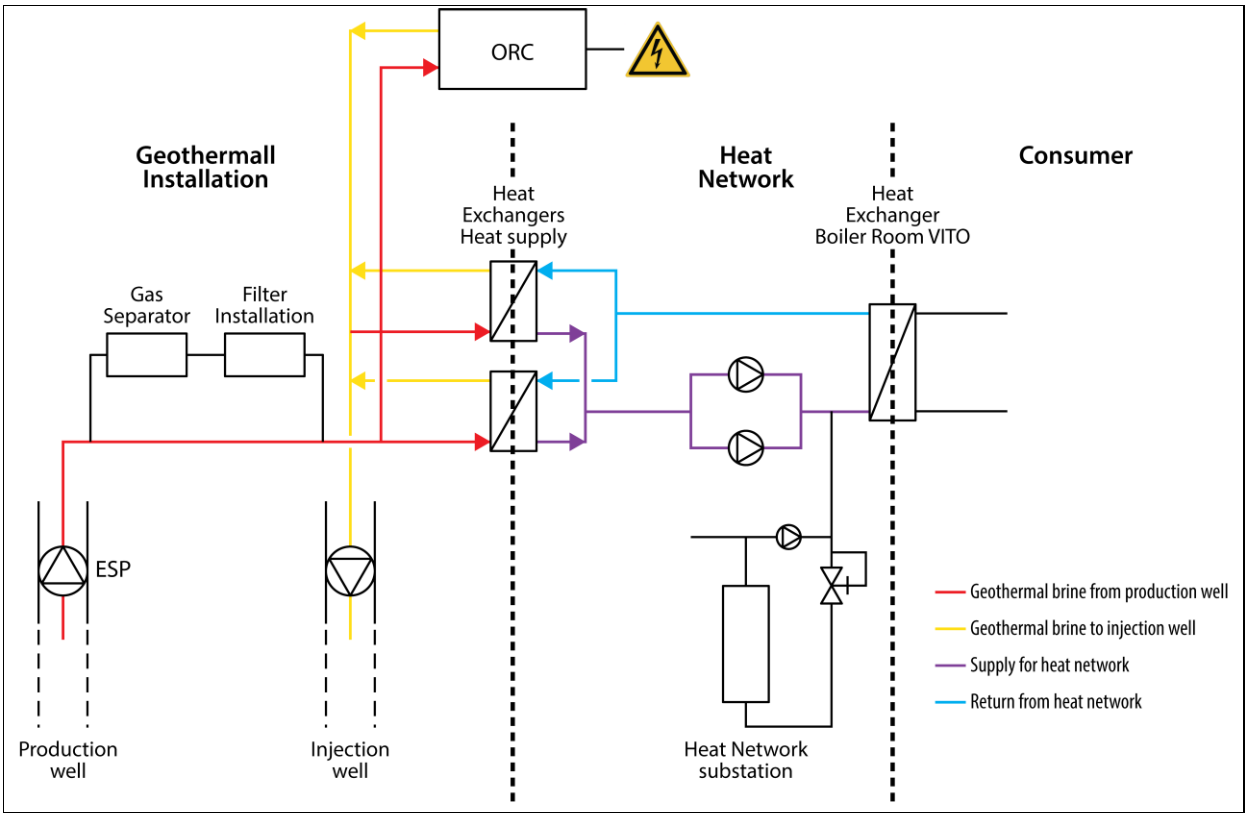


Figure 4: Overview of the main parts of the surface installations of the Balmatt geothermal plant

In the period December 2018 – June 2019, a series of production tests were carried out with the aim to start-up stable heat production. The start-up of the plant proved to be difficult: the main reason for this is the high pressure that is required to inject the pumped water back into the subsurface. Production was restarted in April 2021. Since then, several production cycles were run to investigate the impact of production on the seismic response of the reservoir. The tests are performed at low flow rates (10 – 30 m^3/h). The duration of the production phases varied from a few days up to 63 days. An overview of the system configuration and of the lessons learned during this start-up phase are given in D.T3.1.2-4 [4].

Seismic monitoring

During the testing of the wells, the seismic activity was monitored using four seismometers that were installed as part of the ONDRAF/NIRAS cAt-project and that are monitored by the Royal Observatory of Belgium. Two of the seismometers were located on the surface and two at depths of 600 (DSLB) and 220 m (MOLT) respectively. Several seismic events were recorded during the injection test performed on MOL-GT-02 in the fall of 2016. The strongest event was measured on 3 October 2016, 17 days after the end of the injection test. The event measured M_L 0.9. Analysis of the data suggested a relationship between the seismic activity and the high pressure that is needed to inject the water.

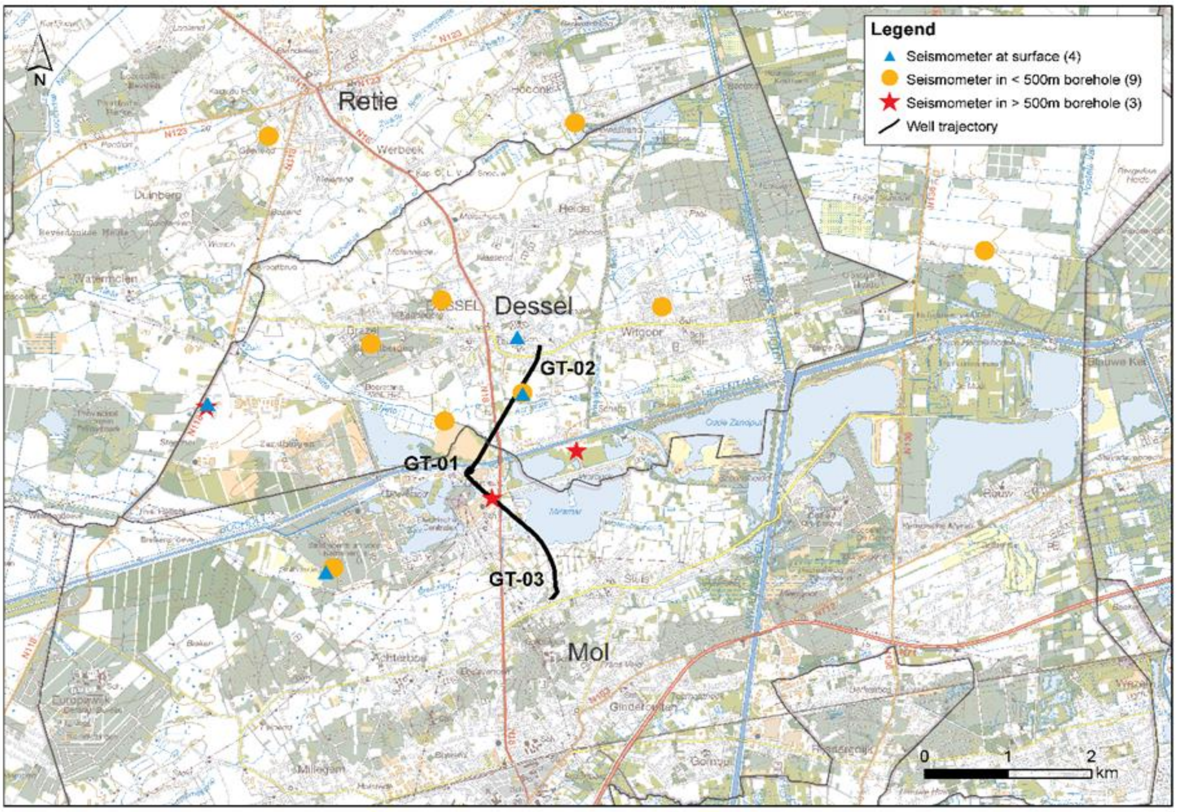


Figure 5: Location of the seismometers installed near the Balmatt geothermal plant

[4] Vos, D., 2020. Evaluation of production strategies and technologies for long-term production optimization for a Carboniferous carbonate reservoir. Interreg North-West Europe DGE-ROLLOUT Deliverable T1.2.2 – 4.

To monitor the earthquake activity during operation of the geothermal plant, the network of seismometers was extended with 5 stations: two seismometers were installed at a depth of 332 m and 604 m respectively, and 3 in 30 m deep boreholes (Figure 5). The 5 new stations were operational on 10 October 2018 and integration with the existing stations at DSLB and MOLT was ready on 22 November 2018. In addition, a traffic light protocol was also implemented with the aim of adjusting the geothermal operations in response to the observed seismic activity. In this way, VITO tried to avoid perceptible earthquakes.

Several earthquakes were recorded during the testing of the installations and the start-up of production in 2018 - 2019. In total, 226 seismic events were detected between 05/12/2018 and 01/07/2019. The hypocenters of the quakes were located near the injection zone around MOL-GT-02.

The start-up of the plant was suspended after an earthquake that was felt in Dessel and Mol on 23 June 2019. The earthquake resulted in a red-light situation within the traffic light protocol. From July 2019 to December 2020, further studies were conducted into the seismic hazard and risks associated with geothermal energy extraction from the Lower Carboniferous limestones. These studies resulted in a new research program that aims to determine to what extent deep geothermal energy in the Mol – Dessel region is technically and economically feasible from a seismological point of view.

In preparation of this research, the seismic monitoring network has been extended. The extended network should allow us to detect and locate events Ml < 0 and should lower the magnitude of completeness (Mc) to 0.0. Te initial network failed in detecting all events down to Ml 0.0. The network now consists of 16 seismometers: 4 at surface, 9 at a depth of 30 to 500 m and three on the ‘bed rock’ between 600 and 2052 m (Figure 5). Test productions as part of the investigation started in April 2021.

Non-technical aspects of the Balmatt project

The development of the Balmatt geothermal plant started as a research project. The different stages were defined in a linear manner covering pre-feasibility, exploration and development with defined go/no-go decisions. The decision tree of the project is given in Table 4.

	Phase	Success criteria	Results	Decision
November 2009 – May 2011				
1	Preliminary study	Presence of high temperature hydrothermal reservoir is likely Realistic business case	Hydrothermal resource in Lower Carboniferous Limestone Group (LCLG) likely based on G3D.v2 and existing data Link with local district heating can result in viable business case	continue
2a	Seismic exploration	Confirmation of geological model Indications for porosity and permeability enhancing processes	The 2D seismic survey 2D Mol-Herentals 2010 confirms the geological structure of the area. The survey reveals faulted zones with a good chance for enhanced porosity and permeability below Balmatt. The top of the LCLG is estimated at 2700 – 2800 m corresponding to an	continue

			estimated formation temperature of 120°C at the top and 142°C at the base of the limestone.	
September 2011 - April 2014				
2b	Resource mapping	Presence of hydrothermal reservoir for combined heat-and-power is likely: - > 10 MW thermal - $\geq$ 120°C production temperature	New temperature and resource mapping in the context of GEOHEAT.App suggests the presence of a high temperature resource in the region Turnhout – Geel – Mol that meets the criteria.	continue
3a	Technical evaluation	Criteria of success: - Acceptable technical challenges and risks - Feasible business case - Status of permits	The evaluation of the available geological data result in a P90 output of 12.6 MW, with a flow rate of 140 m³/h and a COP of 27.2 at an injection temperature of 60°C (38.5 at 35°C). There is sufficient energy demand in the vicinity to make the business case. The geological risks (geological uncertainty and seismicity) are judged to be acceptable. It seems likely that all necessary permits can be obtained in time;	continue
April 2014 – June 2014				
3b	Due diligence	Criteria of success: - Second opinion with respect to technical challenges and risks - Evaluation of permits - Confirmation of budget estimates - Confirmation of assumptions business model	The due diligence confirms the assumptions made in the technical evaluation. The due diligence confirms that all permits to drill the first two wells are in place. The due diligence formulates a number of recommendations with respect to project management, risks and risk mitigation.	continue
June 2014 – March 2015				
3c	Financial close	Budget to drill exploration well MOL-GT-01 is secured	A total budget of 7.2 M€ is made available. A drilling risk insurance has been taken out.	continue
September 2015 - February 2016				
4a	Drilling of exploration well MOL-GT-01	Reach target (LCLG) Indications for the presence of a geothermal reservoir	Target not reached – lost in hole at 3148 m	project on-hold

4b	Evaluate option to side track	Likelihood to reach target from a technical and budgetary perspective	Side track is technically feasible Costs for side track can be borne Claim for drilling risk insurance	decision to side-track
4c	Drilling of side track MOL-GT-01-S1	Reach target (LCLG) Indications for the presence of a geothermal reservoir	LCLG reached at a depth of 3175 m Total mud losses from 3280 m onward are indicative for permeable zone(s)	continue
4d	Production test	Presence of a geothermal reservoir that meets the pre-defined criteria of success: - Flow rate: 130 m^3/h - Production temperature: 124°C - ΔP: 60 bar	Production test shows presence of a geothermal resource: - Flow rate: 108 m3/h - Production temperature: 126°C - Drawdown: 30 bar	partial success: re-evaluate business case
4e	Re-evaluation business case	For a project lifetime of 20 years: - LCoE < LCoE for gas boiler - IRR > 3%	Estimated economics for a project lifetime of 20 years based on production characteristics of MOL-GT-01-S1: - LCoE: 23 – 33 €/MWh - IRR: 4 – 6% - Proposal to acidize MOL-GT-01-S1	decision to acidize continue
March 2016 – October 2016				
5a	Drilling of injection well MOL-GT-02	Reach target (LCLG) Indications for the presence of a geothermal reservoir	LCLG reached at a depth of 3787 m MD (3298 m TVD) No mud losses	partial success continue
4f	Acidizing MOL-GT-01-S1	Improved productivity; criteria of success: - Flow rate: 130 m^3/h - Production temperature: 124°C - ΔP: 60 bar	A production test after acidizing resulted in a flow of 139 m^3/h at 30 bar drawdown and a temperature up to 131°C. This corresponds with a 29 to 54% improvement due to the acid stimulation.	continue
5b	Well test	Ability to close the geothermal loop: - Flow rate: > 140 m^3/h - COP of the doublet: > 24 at injection temperature of 60°C - Maximal injection pressure: 100 bar	Airlift test did not result in flow	decision to acidize continue
5c	Acidizing well MOL-GT-02	Generate flow to well	Three batches of 15% HCl were injected at well head pressures of 74 – 82 bar.	evaluate injectivity continue

			The acid job did not lead to a productive well.	
5d	Injection test	Ability to close the geothermal loop: - Flow rate: > 140 m^3/h - COP of the doublet: > 24 at injection temperature of 60°C - Maximal injection pressure: 100 bar	Extended injection up to 240 m^3/h: - 90 m^3/h at 60 bar - 120 m^3/h at 75 bar - 180 m^3/h at 80 bar - 240 m^3/h at 100 bar - Seismic activity picked up during injection test	continue
	↳ decision to build geothermal plant and connect to existing district heating ↳ decision of evaluate drilling of a third well to extend heat delivery			
November 2016 – June 2017				
6a	Evaluation of seismic hazard	Evaluate seismic hazard based on registered events Proposal for seismic monitoring	Source mechanism and correlation between well head pressure, injected volume and seismic activity evaluated Suggestion for location of additional seismometers	Implement monitoring and TLS
December 2017 – August 2018				
7a	Drilling well MOL-GT-03	Reach target: Devonian Indications for a geothermal reservoir	Lost in hole at 4480 m	evaluate option to side track
7b	Evaluate option to side track	Likelihood to reach the target from a technical and budgetary perspective	Side track is technically feasible Costs for side track are bearable	decision to side-track continue
7c	Drilling of side track MOL-GT-03-S1	Reach target: Devonian Indications for a geothermal reservoir	Devonian reached at 4747 m MD (4082 m TVD) No mud losses during drilling	partial success continue
7d	Well testing	Confirm geothermal reservoir in the LCLG	Airlift test did not result in flow	decision to acidize
7e	Evaluation acid job	Acid job feasible	An injection test at 14.5 m^3/h resulted in a well head pressure of 72.4 bar and back flow of 50% of the injected volume. Acid injection judged to be impossible.	'Dry' well Well suspended
5e	2nd acid job well MOL-GT-02	Improve injectivity	Acid job did not yield improvement of the injectivity	No action continue
	↳ plan to extend heat delivery suspended			
February 2017 – November 2018				

8	Construction of surface installations	Completion of buildings and surface installation according to plan and timing	Construction of approximately 1.8 km connecting pipes between Balmatt and the boiler house of the district heating network Adaptions of the boiler house Construction of the geothermal building Commissioning of the geothermal installations on 01/05/2019: - Design flow rate: 70 – 150 m3/h - Thermal power: 3,500 – 8,000 kW - Prototype flexible ORC: 350 kW - Adiabatic cooling	Commissioning of geothermal installations with a delay of 7 months
6b	Seismic monitoring – phase 1	Install seismic monitoring to detect seismic events $M_l \geq 0$ Implement TLS	Extended monitoring system operational from 22/11/2018 onward: - 5 additional seismometers installed - TLS based on M_l, peak ground velocity and frequency of events	Decision to start test production
December 2018 – June 2019				
9a	Start-up	Start production to reach the expected output of 7 - 8 MW Keep seismic activity below sensible level	4 production phases at average flow rates of 60 – 70 m3/h Injection pressure higher than expected (96 – 115 bar) Felt seismic event on 23/06/2019 causing red light situation of TLS	Production suspended
	↳ evaluation of seismic activity and update of the seismic hazard and risk evaluation			
July 2019 – May 2020				
6c	Seismic hazard and risk	Evaluate risks related to restart of operations	New insights into source mechanism Correlation between seismic hazard and production Evaluation of seismic risk Identification of data/knowledge gaps Recommendations for further research Recommendations to extend seismic monitoring network and to adapt TLS	Decision to extend seismic monitoring and prepare for further testing
	↳ decision to evaluate support base ↳ decision to elaborate a research plan including test-production to collect additional field data			
9b	Evaluation feasibility test production	Feasible and affordable research & test program with acceptable risk Societal support	Definition of research and test program to evaluate feasibility geothermal production for seismological perspective Identification of interventions to improve the performance of the plant	Decision to prepare for test production

			Design of extended monitoring network and update of TLS Communication and dialogue with stakeholders	
	↳ decision to increase coverage by the insurance ↳ decision to set up communication			
June 2020 – April 2021				
9c	Adaptation geothermal plant	Adapt installation to: - Avoid degassing - Lower injection pressure - Allow for lower flow rates	Maximal system pressure increased to 50 bar. Installation of longer injection tubing Installation of a pressure control system in case of abrupt shutdown Installation of a smaller ESP	
6d	Seismic monitoring – phase 2	Seismic monitoring to detect and locate events $M_l \leq 0$ and lower Mc to 0.0	Installation of seismometers at 6 additional locations around the injection point TLS adapted based on recommendations (6c)	Decision to start test production
April 2021 - ongoing				
9d	Start test-production	Geothermal energy production viable from a seismologic perspective	Test program to evaluate the correlation between geothermal energy production and the seismic response of the LCLG and to define the operational window for the Balmatt geothermal plant started on 20/04/2021	Decision on future operation Balmatt

Table 4: Overview of the technical phases and decision tree of the Balmatt geothermal project

Although more or less clear technical criteria were defined to decide whether or not to continue the project, progress was largely influenced by non-technical aspects and by flanking actions or actions taken by other stakeholders. This is clearly reflected when the progress of the technical actions is set in time (Figure 6). An overview of the non-technical aspects of the project is given in Table 5.

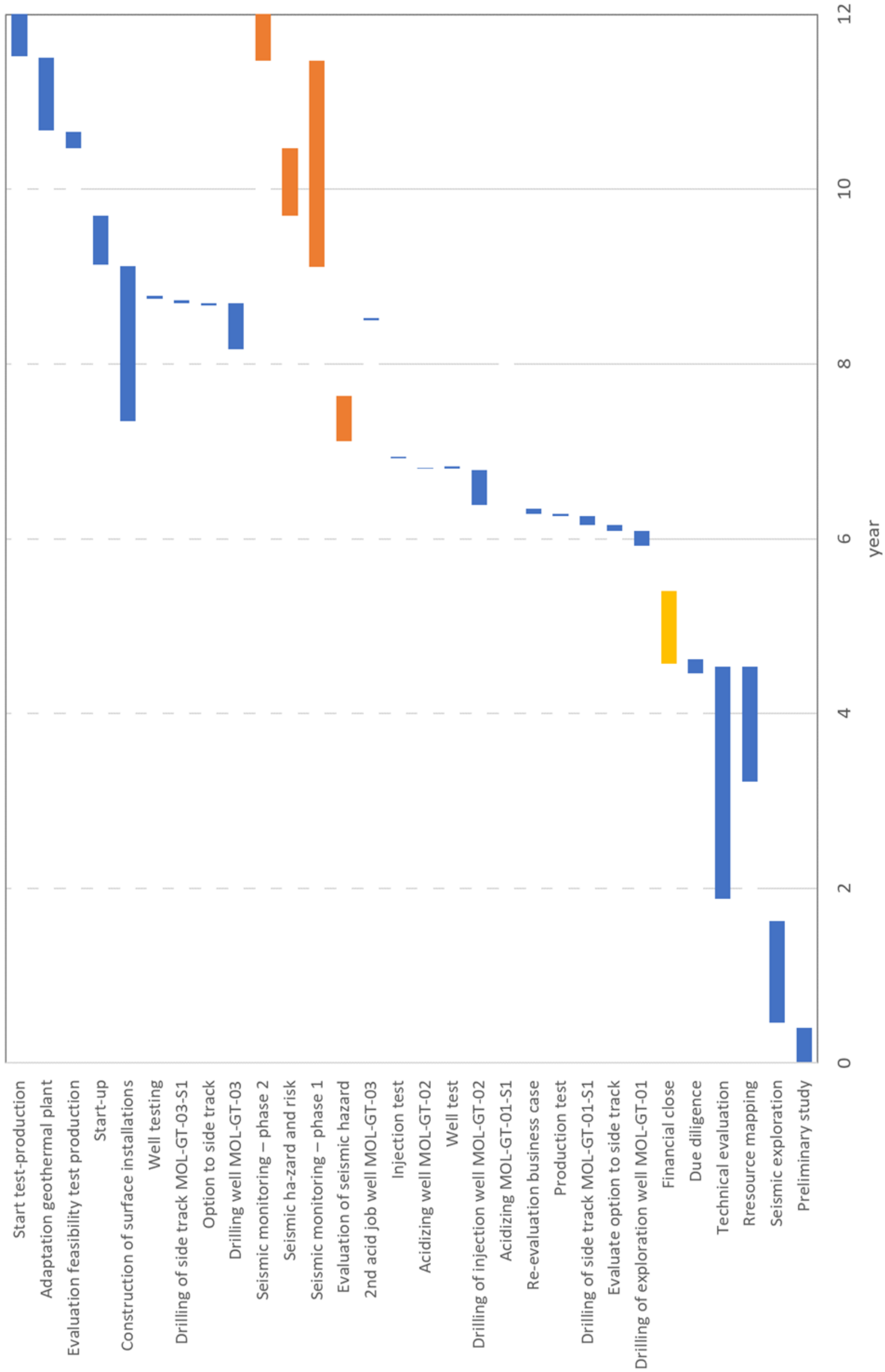


Figure 6: Timeline of the Balmatt geothermal project

	Phase	Permits	Financial aspects	Outreach	Funding
1	Preliminary study		Class 5 cost estimate		Own budget
2a	Seismic exploration	no permits needed for seismic exploration	Refinement of cost estimate (class 5) and business model	Municipalities covered by seismic survey Informing public about aim and set-up of seismic campaign Press releases and interviews	Own budget
2b	Resource mapping		Preliminary business model Application for support from INTERREG VL-NL	Competent authorities, project developers, financers and local companies	INTERREG VL-NL GEOHEAT.App Own budget
3a	Technical evaluation	Evaluation of permit requi-rements and exemptions EIA exemption note for well MOL-GT-01 EIA for Balmatt geothermal project	Refinement of cost estimate (class 3 for drilling operations, class 4 for installation) and business model Search for investors Search for support from local and regional authorities Application for support from ERDF for transition manage-ment and road mapping	Consultation of public and press releases in the context of MER Contacts with provincial and Flemish government Contacts with municipalities Contacts with companies and local Chamber of Commerce Contacts with civil society groups Contacts with possible investors Contact with spatial planners and the Flemish building master VITO-website & Facebook www.diepegeothermie.be	Own budget ERDF GEOTHERMIE 2020
3b	Due diligence	evaluation of status permits	verification of cost estimate	Contacts with financers	Own budget

3c	Financial close			Support from local municipalities, Chamber of commerce and region Presentation of the exploration project for the Flemish gov.	Own budget ERDF GEOTHERMIE 2020
4a-f	Drilling and completion of exploration well MOL-GT-01	Building permit MOL-GT-01 Environmental permit MOL-GT-01	VLAIO subsidy for research aspects of exploration well Collaboration with NIRAS Proposal for support school / youth activities Re-evaluation of business model	Meetings with residents Spud event with high level stakeholders and residents STEM Musical Site visits Information panels VITO-website & Facebook	VLAIO NIRAS Own budget Insurance claim for lost in hole Province of Antwerp (STEM)
5a-d	Drilling and completion of injection well MOL-GT-02	Building permit MOL-GT-02 Environmental permit MOL-GT-02	VEA subsidy for realization geothermal doublet	Negotiation with Fluvius / Warmte@Vlaanderen about district heating STEM Site visits Information panels VITO-website Facebook	Loan & equity VEA Province of Antwerp (STEM)
7a	Drilling and completion of well MOL-GT-03	Environmental permit geothermal plant (up to 5 wells) Construction permit	New proposal for support school / youth activities	STEM Site visits Information panels VITO-website	Loan & equity Province of Antwerp (STEM)

8	Construction surface installations	Environmental permit geothermal plant Construction permit	Call Green Heat (VEA)	STEM Site visits VITO-website	Loan & equity VEA Province of Antwerp (STEM)
9a	Start-up			Press release STEM Site visits VITO-website	Own budget Province of Antwerp (STEM)
6c	Seismic hazard and risk			Information sessions residents Information neighboring companies Information authorities	Own budget
9b-c	Evaluation and preparations test production including adaptations of production process			Information and discussion sessions with residents Meetings with neighboring companies Flemish government and Flemish parliament (Energy Commission) Inquiry public awareness and acceptance www.aardwarmte.be VITO-website	Own budget INTERREG NEW DGE-ROLLOUT
9d	Test-production and evaluation impact adaptations			Press release VITO-website STEM	Own budget INTERREG NWE DGE-ROLLOUT Province of Antwerp (STEM)

Table 5: Overview of the non-technical aspects of the Balmatt-project

A first break in the project occurred after three years. Based on the results of the seismic exploration and a technical and economic evaluation, VITO concluded that the development of a geothermal co-generation plant that would supply heat and electricity to the research campus of VITO – SCK•CEN was feasible. In the beginning of 2014, VITO decided to continue the project by drilling an exploration well at the Balmatt site in Mol-Donk. The drilling was designed to verify the assumptions and to test the geothermal potential of the LCLG in the area. The costs for drilling well MOL-GT-01 were estimated at 7,1 MEuro.

In an attempt to raise the budget for the first well, VITO contracted Verkis Consulting Engineers to evaluate the technical and economic assumptions made in the business plan. Verkis concluded that:

1. The indications for the development of the geothermal project at the Balmatt site are generally positive despite the lack of data on the characteristics of the reservoir and the chemistry of the geothermal fluid. Reservoir characteristics cannot be confirmed until a first well has been drilled and tested. Additional research activities can also be undertaken to support the drilling decision.
2. The Balmatt project is an interesting case to investigate the use of geothermal energy for various applications in the region. The project will undoubtedly contribute to reducing the environmental impact associated with the production of electricity and heat, minimizing the dependence on fossil fuels in Belgium and is likely to benefit the local economy.
3. There may be technical challenges due to the expected characteristics of the geothermal fluid, but none that cannot be overcome with current technology.
4. The available data indicate that the project is likely to be viable from a financial point of view. This should be verified once the first well has been drilled and tested.
5. The technical team preparing the project is knowledgeable and familiar with the (local) challenges associated with project development and with the regional conditions and available data.

Verkis also pointed to the importance of a continuous risk assessment, and advised setting up a risk register.

Despite the due diligence by Verkis, it turned out to be impossible to collect the budget for the exploration well. Up to that point, VITO had communicated the objective and content of the project only to a limited group of stakeholders, most of them potential financers. In January 2013, Grontmij, TNO and VITO started a project to evaluate the geothermal potential in the border region between Flanders and the Netherlands: INTERREG GEOHEAT.App. In the context of this project, VITO discussed its plans with the competent authorities, financers and (geothermal) project developers. That cranked up the momentum for geothermal in Flanders. In parallel, the Flemish administration for land, soil and natural resources prepared an amendment of the Decree on the deep subsurface. The amendment came into force on January 1st, 2017. It created a legal basis for exploration and exploitation of geothermal resources in the deep subsurface of Flanders. It was an important step to raise the confidence of financers and project developers in deep geothermal. With the amended decree in force, Johnson & Johnson (J&J) was able to continue its plans for a geothermal heating grid at their site in Beerse (Diepe geothermie bij Janssen | Janssen België). Besides, a dedicated geothermal development company was founded with the financial support of three local captains of industry (Hita | Home)

Mid 2013, it became clear that the deep geothermal project could only be realized in case it was integrated in the regional energy transition. To initiate the discussion at the regional level, the local Chamber of Commerce, the intercommunal company IOK and VITO started ERDF-project 910 – GEOTHERMIE 2020. With the project, the partners wanted to start a process in which the region resolutely chooses to use its unique geological position to provide itself with affordable and reliable energy in a sustainable way. The aim was to create support for deep geothermal energy through the active participation of a broad group of stakeholders: entrepreneurs, (local) authorities, civil society organizations and citizens. By involving all these parties in the process, the intended local impact of the transition experiment could be enhanced. At the same time, the added value of the efforts to develop deep geothermal in the Campine region could be increased by making the link to a roll-out over a larger area.

The social transition exercise was structured according to the principle of a transition agora. The rationale of the agora stated that: "*If the Campine area wants to become the cradle of geothermal energy in Flanders and part of a larger energy transition story, this must be done in a well-considered, scientifically responsible but open and socially anchored way*." The transition agora became a meeting place to exchange information and talk about transition. It made the transition story explicit: it gave citizens and all groups involved the opportunity to gain insight into the energy transition process and in the technical aspects of deep geothermal. The agora also created a setting where all stakeholders could meet, reflect and discuss how they see the roll-out of geothermal energy in the Campine area and how they want to contribute to making the transition story a '*benefit-for-all*' story.

The interaction with the local stakeholders proved to be crucial to boost the momentum for the project. The agora-approach sparked the interest of the Campine municipalities, the local Chamber of Commerce and the region in geothermal energy and district heating. On 9 May 2014 the Flemish government decided to financially support the drilling of the exploration well at Balmatt (Vlaamse regering geeft diepe geothermie in Vlaanderen bijkomende stimulans | EMIS (vito.be)). Furthermore, geothermal and district heating were included in the local climate and energy plans. An evaluation of the possible macro-economic impact by Idea Consult concluded that geothermal in combination with district heating could generate new opportunities for local companies, bringing new jobs for about 1500 FTE [5]. With the ambition to develop the economic potential and to realize the estimated contribution to the local climate and energy plans, geothermal district heating was also selected as one of the spear points for the development of the Campine region [6].

The support by the local community and the financial support by the Flemish government made it possible to close the budget for MOL-GT-01. The procurement procedure was restarted in the second half of 2014. Preparations for the drilling activities started in the first quarter of 2015. Drilling started in September 2015. The production test on the MOL-GT-01 proved the presence of a geothermal reservoir in the LCLG below the Balmatt site. As the test data confirmed the assumption of the business plan, the budget for drilling the second well was readily raised by combining equity with a bank loan.

Parallel to the ERDF project, the Vlaamse Bouwmeester organized the research project 'Atelier Diepe Geotherme'. The choice for deploying geothermal power plants in Flanders is determined by the potential present in the subsurface, but is also largely related to the spatial configuration of functions

[5] economischeanalyse_rapport_geothermie2020.pdf (vito.be)
[6] RES15-003-dynak publicatie-web.pdf (streekplatformkempen.be)

above ground. Research by design was used to examine how the interaction between deep geothermal energy and landscape can contribute to the energy transition and to the development of a qualitative and sustainable living environment. The Atelier was a follow-up of the design research project 'Energielandschappen'. This project explored layouts of the public space that maximize the use of renewable energy sources in general The design projects pointed to the role of district heating (and cooling) to maximize the potential of renewables in Flanders.

At Flemish level, the interest of the Campine region in geothermal district heating and the ambition of the city of Antwerp to valorize residual heat from the industry provoked a discussion on district heating. The debate was strongly influenced by the role of the operators of the local gas distribution networks in the development of district heating and the interests of the municipalities in these companies. As a response to the debate, the energy distribution companies Fluvius and Infrax decided to establish a new heat company: warmte@vlaanderen. The aim of the collaboration is to combine the strengths of the two network operators in order to maximize the potential of heat networks in Flanders. The collaboration was officially launched on 19 May 2016. In his speech the then Flemish Minister of Energy, Bart Tommelein, stated that "*Green heat and heat networks must become a fully-fledged part of the Flemish energy policy. Today a lot of heat remains unused and residual heat is lost unused. However, more than half of the energy demand does not consist of electricity but of heat. Moreover, green heat is much cheaper than green electricity. Heat networks play a crucial role in achieving greater energy efficiency and contribute to our targets for renewable energy by 2020. That is why we are encouraging the expansion of heat networks together with the Flemish government. The new heat company is a great example of a sustainable energy project for the future.*"

The debate on district heating and geothermal also resulted in an amendment of the Flemish Energy Decree stimulating the regulatory framework for district heating and cooling. In addition, the Flemish government added geothermal as one of the technologies that is eligible for financial support under the Flemish support scheme for strategic ecological investments. Deep geothermal was also added as renewable energy source under the call for Green Heat.

Strengthened by the results of the first two wells and the new support schemes, a plan for geothermal district heating network connected to Balmatt were drawn in the municipalities of Mol and Dessel. In June 2016, VITO started the technical preparations of MOL-GT-03. The drilling had a double objective. Firstly, the well was designed to explore if the Devonian strata below the LCLG have geothermal potential. Secondly, it was considered to be used as a second production well to supply heat to the planned heat network. Besides, the company Kempens Warmtebedrijf was created. The company forms the link between the heat supplier and producer of deep geothermal heat at one side and the customer at the other. As such, it communicates and examines new developments in the field. The heating network would be installed by Fluvius.

With the new financial support schemes, the plan looked viable. Mid 2017, the decision was taken to drill MOL-GT-03. The well was spudded on 13 December 2017. TD was reached on 06 July 2018. The well however proved to the dry and the plan to develop the geothermal district heating was suspended.

The results of MOL-GT-03 were a setback for the Balmatt project and downplayed the role of VITO in the development of deep geothermal district heating in Flanders. It was however not the end to the development of (geothermal) district heating in the Campine region. The initiative was taken over by the intercommunal company IOK and by private players like J&J and HITA. In 2018, IOK started the ERDF project Warmtemakelaar Kempen. The project supported local authorities in the development of heat plans, in creating support and the effective realization of sustainable heat projects. In 2021, a follow-up ERDF project Warmtemakelaar Kempen 2.0 was launched to support an additional 11 Campine municipalities in the development of a heat plan.

A second setback for the Balmatt project was the difficult start-up of the operations in 2019. The injection pressure proved to be higher than expected based on the test performed in 2016. Moreover, the bubble point turned out to be higher than +/- 30 bar that was derived from the downhole samples. The degassing caused instabilities in the surface installations due to hammering effects and (temporary) two-phase flow. The combination of high injection pressure and the presence of free gas makes it difficult to reach a stable production. It was also impossible to reach the anticipated flow rate of +/- 130 m^3/h.

During the testing of the installation in December 2018, the monitoring network detected several seismic events. Seismic activity continued during start-up. The start-up was interrupted abruptly by an earthquake that took place in the evening of 23 June 2019 and that was felt in Mol and Dessel. The event caused a red-light status of the TLS, which means that a restart of the operations is only possible after an in-depth evaluation of the causes and a re-evaluation of the seismic risk. Furthermore, the question was raised whether it is justified to operate a deep geothermal plant in the vicinity of the nuclear (research) installations of SCK•CEN and Belgoprocess.

Analyses of the collected seismological data by Ineris and DMT gave new insights into the mechanisms that triggered the earthquakes, the characteristics of the seismic sources and the impact on the surface. The analyses also highlighted the principal areas of uncertainty. This led to recommenddations for future research including:

- Quantification on uncertainty of mapped main fault orientation, location, and dip,
- Improvement of the location accuracy,
- Detailing the relationship between geothermal exploitation and the characteristics of seismic activity,
- Investigate the reasons for the apparent absence of seismic events in the immediate vicinity of the injection point,
- Evaluation of the role of aseismic slip in the reservoir.

While point 2 should be achieved with the extended network, and points 3 to 5 are part of ongoing research. VITO has not yet addressed point 1 in detail. Just looking at the uncertainty, yes, but improvement could come at some point with a 3D survey.

A dedicated research project was then defined to investigate the outstanding issues with respect to source location, source characteristics and the relationship between seismicity and geothermal operations at Balmatt. The results of this project will be compared with the outcomes of a side-study by TNO and VITO that includes geo-mechanical modelling of the Balmatt reservoir. This should allow VITO to answer the question whether the Lower Carboniferous Limestone Group (LCLG) near Mol is suitable as a hydrothermal reservoir from a seismologic point of view. The proposed research bears on gathering data on the relationship between seismic activity and operational conditions. To carry out the planned research, the geothermal plant hence must be running. In preparation of the research, the installations were adapted to improve controllability of the operations and to optimize production (see deliverable DT3.1.2-4 [7]). In addition, the seismometer network was extended to reach a lower detection limit and magnitude of completeness, and to allow better positioning of the events (Figure 5).

Besides the scientific and technical aspects, VITO launched a new communication initiative to strengthen the ties with the authorities, the local municipalities and residents and the neighboring nuclear companies. This initiative had the objective of entering into an open dialogue with the main stakeholders to reach a common understanding about the set-up and goals of the planned research and the risks and benefits of geothermal energy production at Balmatt. The initiative was positively welcomed. It proved essential to get support for the seismological research. To cover concerns about possible damage due to the planned production test, the special liability policy was raised. The planned production was restarted in April 2021.

Business case and financing

The initial business model for the Balmatt assumed the development of a geothermal co-generation plant consisting of 5 wells with a combined thermal output up to 45 MW and an electrical output of about 4 MW. The output of the first doublet was estimated at 15.9 MW thermal and 1.3 MW electric. Purchase of a large part of the heat delivered by the first doublet is assured by the heating network at the research campus of VITO – SCK•CEN that is operated by VITO. The generated electricity can be entirely consumed by VITO. Drilling of additional wells would only be justified in case additional customers for the purchase of heat could be connected.

The initial business plan assumed and investment cost for the first doublet of 27.1 MEuro and for the full plant (5 wells) of 46.0 MEuro. The operational costs were estimated at:

- Maintenance 563,000 Euro/year
- Pump costs 568,000 Euro /year
- Consumables (filters, inhibitors) 130,000 Euro /year
- Insurance 40,000 Euro /year
- Personnel 150,000 Euro /year
- Overhead 100,000 Euro /year
- PR 100,000 Euro /year

Actual costs

Actual **investment costs** to build the geothermal plant presented above amount to 48.1 MEuro. This amount includes all costs for:

- Pre-feasibility study 54 kEuro
- Seismic exploration 680 kEuro
- Feasibility study & due diligence 985 kEuro
- Drilling of MOL-GT-01 8.64 MEuro
- Drilling of MOL-GT-02 9.89 MEuro
- Drilling of MOL-GT-03 11.1 MEuro
- Seismic monitoring 926 kEuro

[7] Dries, V., 2020. Evaluation of production strategies and technologies for long-term production optimization for a Carboniferous carbonate reservoir. Study accomplished as part of Interreg NWE project DGE-ROLLOUT, wspeith financial support from Nuhma and Provincie Limburg, VITO-report 2020/RMA/R/2130

- Geothermal plant 13.7 MEuro
- ORC & cooling 2.20 MEuro

Based on the start-up in 2018 – 2019 and the test phase that has been running since April 2021, the annual **operational costs** are calculated at:

- Preventive maintenance (at 8000 operational hours per year) 50,000 Euro/year
- Corrective maintenance 100,000 Euro/year
- Inhibitors (at a flow rate of 140 m^3/h and 8000 operational hours) 90,000 Euro/year
- Filter cartridges 15,000 Euro/year
- Connection to heating network (fixed) 257,000 Euro/year
- Connection to heating network (variable) 43,000 Euro/year
- Seismic monitoring and maintenance seismometer network 115,000 Euro/year
- Insurance 44,000 Euro/year
- Waste disposal 11,000 Euro/year
- Personnel 1 FTE
- COP (kW thermal/kW electric) 13.5 – 16.0

Financing

VITO largely financed the project from its own resources. The financing by VITO itself also includes a bank loan of 10 MEuro. In addition, VITO received 4,687,500 Euro in government support and one-off income for the geothermal project.

Revenues

The revenues currently come from avoided purchase costs for natural gas and heat seals. The heat demand from the network to which the plant is currently connected is approximately 30,000 MWh per year. The network is operated with a supply temperature of 70 – 65°C in summer and 95 – 105°C in winter. The return temperature is around 65 – 70°C in winter and 60°C in summer. Based on the tests performed, the injection temperature appears to be between 57.5 and 71°C, depending on the demand of the heat network.

Lessons learned and recommendations for a guidance system

The Balmatt geothermal project offered a unique situation to create an environment that is supportive to the development of deep geothermal projects in Flanders. It also resulted in an ecosystem of people that believe in the potential of geothermal and district heating.

- The discussion of opportunities and challenges with the competent authorities and policy makers allowed them to create a legal and financial landscape that is supportive for the development of deep geothermal projects. This encompasses a legal basis for the extraction and utilisation of geothermal heat, a legal basis for the distribution of heat and electricity, an adapted regulation with respect to energy efficiency and renewable energy, a scheme to reduce the investment risks, upfront support for investments in capital intensive renewable energy sources, a scheme for operational support to bridge the gap between the costs for the renewable energy relative to conventional sources of heat and electricity.

- The progress line shows the importance to engage with a broad group of (local) stakeholders to create momentum for far-field exploration and to realize a transition in the energy landscape. The agora approach, the design research projects and the incorporation of geothermal in the local energy and climate plans in the spatial planning and design of new (real estate) projects proved to be crucial to build the Balmatt geothermal plant.
- From the Balmatt project and the related INTERREG and ERDF projects an expanding ecosystem emerged that is carrying forward the development of deep geothermal and geothermal district heating the Campine region. Economic actors started to build new business cases that strengthened the momentum for geothermal and district heating (i.e., Beerse geothermal project of J&J, HITA, warmte@vlaanderen and IOK – Warmtemakelaar Kempen). In addition, new research was started that should result in a more efficient development and exploitation of deep geothermal projects, a reduction of the risks and impact of deep geothermal, an effective integration of geothermal (district heating) in the future energy landscape and a socially accepted and justified rollout of deep geothermal and collective heating.

Both the supportive environment and the ecosystem proved to be essential to build the Balmatt geothermal plant. Without the local support, the project most likely would have ended after the exploration phase. Moreover, the ecosystem allows continuing of the development of deep geothermal in Flanders even in case the Balmatt project will be stopped.

To create the local supportive environment and ecosystem, actions must be taken at the local level. However, inter-regional collaboration could help to develop green-field exploration and project development by.

- Sharing of experience with respect to technical issues between project developers / plant operators;
- Sharing practical approaches to engage with (local) stakeholders.
- Combining research efforts to define solutions and develop technologies / materials for technical issues faced by geothermal project
- Combining efforts to develop new technologies and setting up shared infrastructure / sites to test the technologies under relevant conditions.

TRUDI Field Scale Laboratory (Rhine-Ruhr Region, Germany)

Objectives and Motivation

With around ten million inhabitants, the Rhine-Ruhr Region (RRR) is one of the largest conurbations in Europe. Based on the large-scale industrial developments in the mining and energy sector, a globally unique combined heat and power system has emerged in the RRR in recent decades. The largest European district heating network with 6.500 GWh/a, an installed capacity of 3.100 MW_{th} and a length of almost 3.000 km is fed mainly from coal/gas power plants. In order to meet the obligations under international law from the COP21 treaties and the national climate protection targets, replacing these heat sources with low-carbon energy sources is essential in the future. To be able to transform the energy system, the entire chain from low-to-high temperature thermal energy provision, the transformation and extension of district heating systems as well as necessary components to integrate thermal energy into the energy system needs to be demonstrated.

In order to investigate the transformation of the thermal energy provision towards technological solutions with a reduced (and ultimately zero) carbon footprint, different renewable thermal energy sources and storage options will be tested and demonstrated within the TRUDI ("**T**ief **RU**nter unter **DI**e Ruhr") field laboratory in Bochum. TRUDI is the flagship experiment to combine pilot test sites for geothermal energy provision (hydrothermal system), subsurface thermal energy storage (MTES Mine thermal energy storage; BTES borehole thermal energy storage), solar thermal systems, as well as surface technologies to integrate the energy into the current energy system on site. The field laboratory is located in the 50 square kilometer "Future Energy" field under mining law in the south of Bochum where the existing district heating network (115 MW_{th}) is initially to be developed as a pilot location for the entire RRR. Like the energy transition towards low carbon technologies, the TRUDI field laboratory is constantly evolving accounting for technological developments, changing regulatory aspects and societal acceptability. Currently TRUDI consists of the following sites:

- Observatory (seismic, hydraulic, hydrochemical, thermal)
- Fraunhofer IEG – in-situ laboratory and drilling test field (Campus Fraunhofer IEG)
- GeoStar BTES system
- Pilot MTES system beneath the IEG campus
- Access tunnel to the Klosterbusch colliery
- Dannenbaum & Prinz Regent collieries (MARK 51°7).

To illustrate the different implemented components or components that are under construction of the TRUDI field laboratory, individual pilot experiments will be described in the following.

Utilizing artificial transmissivity of the subsurface

Owing to the heritage of the coal mining industry, artificial cavities and fluid pathways have been created in the subsurface and significant subsidence of the land surface is observed in large parts of the RRR. To avoid rising water levels at surface and secure drinking water provision for the RRR, the fluid pathways are presently used to drain the subsurface. Not only can the drainage water be used to provide low temperature thermal energy, the artificial transmissivity in the subsurface can also be used to store thermal energy. Depending on the depth of the mine, thermal energy in a temperature range from 10-60°C might be provided. The estimated potential of thermal energy provision from the abandoned mines in the RRR is in the order of 1.300 GWh/a (LANUV, 2018). Today, thermal energy provision from abandoned coal mines is demonstrated at single collieries in the RRR.

Pilot Experiment 1: Low temperature geothermal energy provision with BTES for district heating – in operation

Project Partners: Hochschule Bochum

Description: 17 Borehole heat exchangers (BHE) were installed on a 6 x 10 m elliptic area in a star-shaped manner with dipping angles of 10° to 13° up to depths of 190 to 200 m. The total effective BHE length is 3.359 m. Prefabricated RAUGEO double-u pipes made of PEXa with DIN 40 x 3.7 mm and factory-made pipes feet were provided by Rehau company. All are equipped with optical fibers for distributed in-situ temperature sensing. Data from logging and analysis of drilling parameters are available (borehole deviations and rock structure (borehole geophysics), thermal conductivity (Enhanced Geothermal Response Tests) and temperature (Fiber Optic Measurement Techniques). Heating and cooling of the IEG campus is performed monovalently with a BHE-coupled heat pump station. The heating load was previously determined to be 140 kW with a heat demand of 252 MWh per year and the cooling load was estimated to 85 kW with a cooling demand of 51 MWh per year. Four electrical brine-water heat pumps (Type: GEO 37) by Rehau with a total heat load of 4 x 34.8 kW (B0/W35) are used for heating and cooling of the buildings. Furthermore, the cooling demand can be also supplied by passive cooling.

Figure 7. Bochum demonstration site. Left: Set-up of the BTES system GeoStar connected to the campus infrastructure at Fraunhofer IEG.

Funding: This project was funded by the Federal Ministry of Education and Research (BMBF).

Pilot Experiment 2: Low temperature thermal energy provision from abandoned mines for integration in low temperature district heating systems – under construction

Project Partners: FUW GmbH

Project Website: https://5gdhc.eu/project-cases/bochum/

Description: Within this pilot project, FUW GmbH as part of the Stadtwerke Bochum group plans to provide the heating and cooling supply for the redeveloped commercial area Mark 51°7 (former Opel plant 1) by using the thermal source of mine water from the abandoned colliery Dannenbaum, that is located below the area. After the closure of the Dannenbaum colliery (1859 - 1958), the shafts were filled and the mine was flooded to above the 4th level, up to approx. -190 m above sea level.

In 2020 and 2021, Fraunhofer IEG who is acting as a technical advisor and supervisor for the drilling and testing operations within this pilot project, continued with the detailed technical planning of two wells, which are targeting the 4th and the 8th level of the mining building. Due to the former mining activities the lithology at the site is well known, however special attention has to be paid to the possible occurrence of mud losses as well as coal bed methane and carbon dioxide. On surface the two wells are 14 m apart. While the first well GT2 will be drilled almost vertically to approximately 340 meters passing alternating layers of sand-, silt- and claystone, the second well GT1 will be directionnally drilled to 806 meters with a vertical section of 270 meters at total depth. To ensure precise wellbore guidance and avoid collisions with the shallower levels of the mining building Gyro While Drilling technology will be applied. The water level at the site is expected at approximately 280 meters depth, which corresponds to the current pumping level at the neighboring coal mine 'Friedlicher Nachbar' located at 7 km distance from the site. Both wells will be completed with 13 3/8" production casing and equipped with pumps allowing production of estimated 19°C mining water from the 4th level for cooling in the summer time, and estimated 36°C mining water from the 8th level for heating purposes in the winter time, at flow rates up to 150 m³/hour.

As part of the project D2Grids, rolling out 5th generation district heating and cooling (5GDHC), the geothermal plant in Bochum will provide base load with a maximum of 6.704 MWh of heating using a heat pump, and 4.735 MWh of cooling using a cooling machine (Bussmann et al. 2019). The two boreholes were spudded in October 2021.

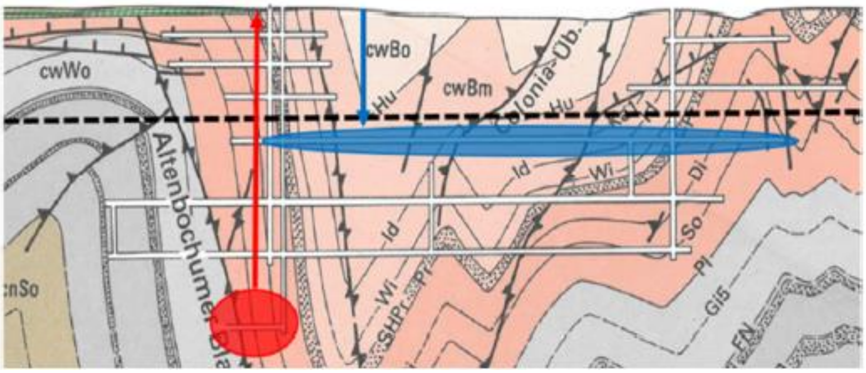


Figure 8. Mine water use in winter (modified according to the Geological Map 4509 Bochum)

Funding: The D2Grids project is supported by INTERREG North-West Europe funds.

Pilot Experiment 3: Solar thermal energy storage in an abandoned coal mine – in commissioning

Project Partners: delta-h Ingenierugesellschaft, Ruhr-Universität Bochum, Geologischer Dienst NRW, DMT GmbH & Co KG, Unique Wärme GmbH & Co KG

Project Website: https://www.heatstore.eu/

Description: In the framework of the Heatstore project, the concept of this demonstration site aims at the reutilization of an abandoned small coal mine, which is directly located under the premises of Fraunhofer IEG in Bochum, as a high temperature MTES. The small and flooded coal mine is at a depth of up to approximately 64 m below ground. Currently, the groundwater level resides at a depth of approximately 21 m below ground. This is constantly monitored in the 5 observation wells R1 and O1-4. Overall, the small coal mine produced 37.043 tons of coal during its life cycle. Based on a calculation with a coal density of 1,35 g/cm³, we can assume a void volume of approximately 27.439 m³. This volume does not include any drifts and shafts. The mine was accessed by 3 vertical wells with a depth of 64, 62 and 29 m, respectively. All wells are cased with a DN 175 casing and equipped with fiber optic cables for continuous temperature monitoring. In a first stage (2021) a 30 kW concentrated solar power system is tested to provide heat for the storage system. In a second step, a heat pump system will be installed and connected to the local district heating system of Bochum.

Figure 9. Extent of the abandoned mine displayed on top of the campus pictures.

Funding: HeatStore (170153-4401) was a project under the GEOTHERMICA – ERA NET Cofund aimed at accelerating the uptake of geothermal energy by 1) advancing and integrating different types of underground thermal energy storage (UTES) in the energy system, 2) providing a means to maximize geothermal heat production and optimize the business case of geothermal heat production doublets, 3) addressing technical, economic, environmental, regulatory and policy aspects that are necessary to support efficient and cost-effective deployment of UTES technologies in Europe. GEOTHERMICA is supported by the European Union's HORIZON 2020 program for research, technological development and demonstration under grant agreement No 731117. The German project is co-funded by Federal Ministry of Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestages (Germany).

Pilot Experiment 4: Subsurface high temperature thermal energy storage below coal bearing formations – exploration phase

Project Partners: Karlsruher Institut für Technologie KIT, Deutsches GeoForschungsZentrum GFZ, Stadtwerke München Services GmbH- SWM

Description: Within the CONTRAST feasibility study, a basic understanding of the geological situation, the tectonic stress field, the required borehole design and the hydraulic regime should be obtained through geophysical deep exploration below the Fraunhofer IEG in Bochum in order to assess its potential for high temperature thermal energy storage below the coal bearing horizons. For this purpose, the massive, folded sandstone horizons of the lower Carboniferous (Kaisberg Formation, Namur B) and their fracture systems from the extension tectonics in the axis area of the Variscan fold mountains as well as the NNW-SSE-trending (mainly saxonic) fault systems examined and characterized with regard to their thermal water flow and storage capacity. The IEG has a suitable location with the geothermal license field "Future Energy". The focus of the feasibility study is the planning, implementation and evaluation of a seismic measurement campaign in order to be able to show exploration depths of up to 1.500 m below the IEG drilling site. In addition to clarifying the structure of the subsoil, seismic data are also used for detailed planning for future deep geothermal drilling projects to assess the Devonian carbonates (see also pilot experiment 6) in the south of Bochum.

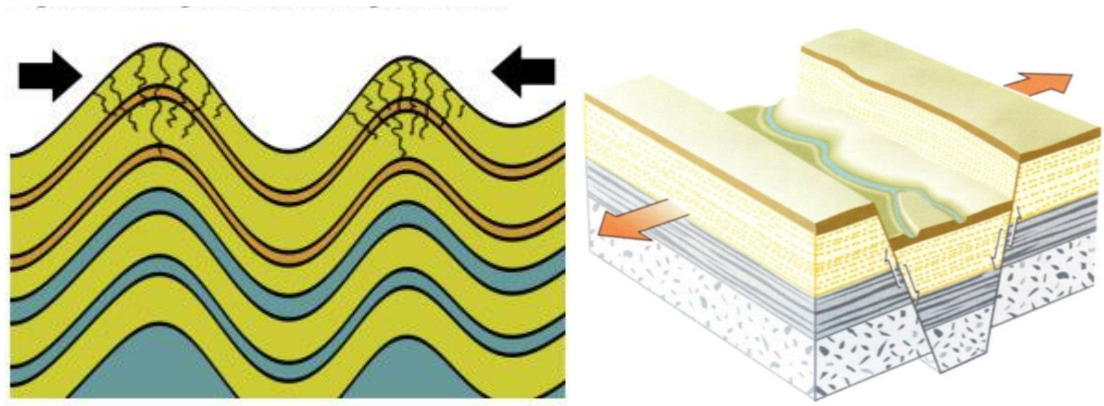


Figure 10. Schematic of the formation of fracture structures in the project space through stretching processes: a) Variscan (left) in the fold axes, and b) saxonic (right) with normal faults occurring transverse to the fold structure (Source: General Geology, Publisher: Spectrum).

Funding: The VESTA – CONTRAST project is nationally funded by the Federal Ministry of Economic Affairs and Energy (BMWi).

Pilot Experiment 5: Integration of mine thermal energy storage systems into existing high temperature district heating networks – under construction

Project Partners: Geologischer Dienst NRW, DMT GmbH & Co KG, VITO - Flemish Institute for Technological Research NV, French geological survey BRGM, TU Darmstadt, Geological Survey of Belgium, EBN, TNO, RWE. Associated partners are Ruhr University Bochum, Unique Wärme GmbH & Co KG and Johnson Controls.

Project website: https://www.nweurope.eu/projects/project-search/dge-rollout-roll-out-of-deep-geothermal-energy-in-nwe/

Description:

<u>Introduction</u>

At the location of the Fraunhofer IEG in Bochum it is planned to install a 500 kW high temperature heat pump (HTHP) that, after a testing phase, will be connected to the district heating grid of the Ruhr University Bochum (RUB). As source, an abandoned mine, situated beneath the campus of Fraunhofer IEG, will be employed (see pilot experiment 3). The mine will be heated during the summer months using concentrated solar power. In winter, the stored thermal energy will be extracted as a source for the heat pump. The general scheme is depicted in Figure 17.

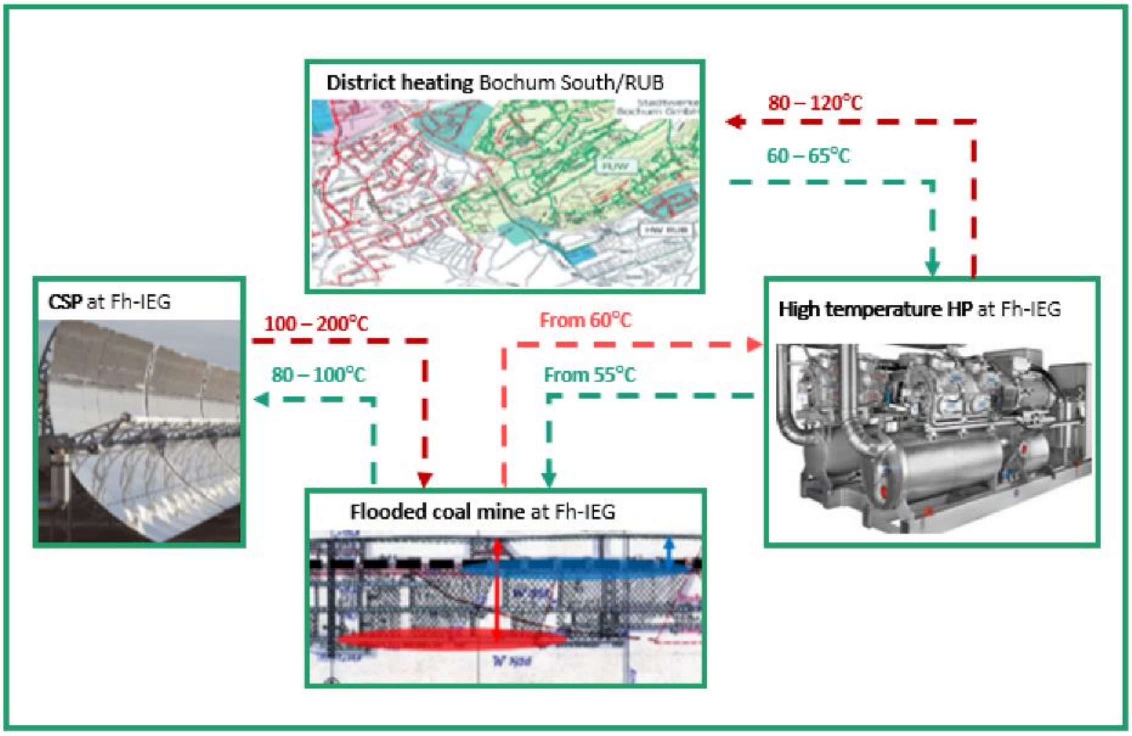


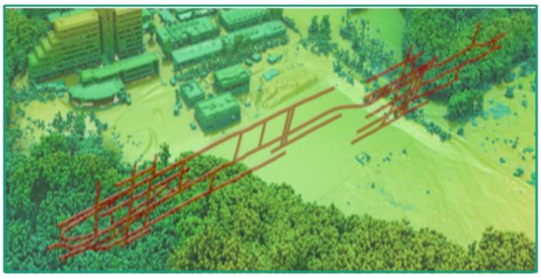
Figure 11. Sketch of the set-up completed in the framework of the DGE Rollout project.

The heat pump will be able to provide pressurized water at temperatures between 120°C and 80°C, varying linearly according to the district heating demand. Furthermore, the heat pump will be able to deal with the temperature difference of the source over the heating season from 60°C to ca. 10°C.

<u>Methodology</u>

The individual components of the pilot site (i.e. HTHP source, CSP, HTHP sink and HTHP technology) were analyzed to enable design and construction of the overall system.

The **HTHP heat source** is made of unemployed shallow flooded coal mine galleries situated below Fraunhofer IEG in Bochum (Figure 12) and utilized also for the HeatStore project (see above). From the recorded mass of coal extracted (Figure 12), the assumed maximum exploitable volume of water is 19.207 m³, considering that 70% of the total volume is flooded, because of water level, shafts, drifts and backfill.



Mine galleries specifications	
Years of production	1954 - 1957
Mine depth [m b.g.l.]	75
Groundwater level [m b.g.l.]	21
Coal extracted [t]	37.043
Coal extracted [m³]	27.439

Figure 12. Mine used as HTHP HT-MTES for the HTHP and Coal mine galleries specifications

To analyse the HT-MTES seasonal behavior due to the temperature fluctuations and therefore to determine the best drilling locations, thanks to the collaboration with *delta h Ingenieurgesellschaft*, stepwise numerical 3D simulations of groundwater flow and heat transport (SPRING software) were performed *(*Figure 13*)*. Finite element approximation was applied to solve groundwater flow and transport equations.

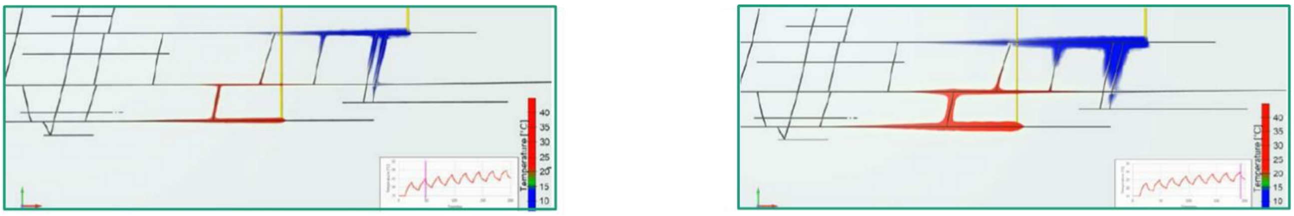


Figure 13. HT-MTES behavior after 2 and 8 years respectively

The groundwater temperature, that is unheated at 12°C, will be increased up to 60°C by the end of the summer season by means of parabolic trough **CSP** technology. For testing purposes in the Heat-Store concept, 12 collectors positioned in 2 rows are employed. Their overall specifications are shown in Figure 14.

CSP specifications	
Collector surface area [m²]	108
Collector mounting area [m²]	220
Tot peak power [kW]	60
Temperature level [°C]	100-200
Concentration factor	43
Heating fluid	Water

Figure 14. CSP technical specifications

The **HTHP heat sink** is the Bochum south district heating grid. The total heating capacity of the grid is of 115 MW. It is characterized by elevated supply temperatures that are function of the external ambient air temperature (Figure 15). The return temperature lays between 60°C and 65°C. After testing the overall system, the HTHP is connected to the grid.

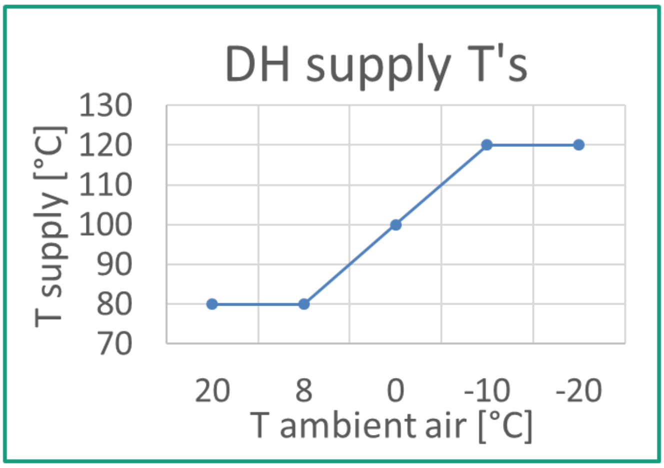


Figure 15. DH supply T vs. ambient air T

As first approximation, considering the source maximum expected water content and its seasonal temperature variation of 50 K, assuming furthermore the heat pump working for the entire heating season and its COP, the needed **HTHP technology** can produce up to 500 kW. It needs to supply pressurized water between 80°C and 120°C and withstand the heat source temperature variability throughout the heating season (from 60°C to 12°C). It also should be flexible in terms of power modulation for experiment purposes on the mine waters. Review of different available technologies was performed, and ideal numerical MATLAB models for the heat pump thermodynamic cycle and performances were developed.

<u>Results</u>

The results are described in terms of the different elements of the system.

Considering the **HTHP heat source**, by means of the numerical model on the groundwater source, it was possible to determine the best drilling sites (Figure 16). Injection, production and monitoring wells were drilled during summer 2020 at the in Bochum with the Fraunhofer IEG self-owned drilling equipment (BO.REX) (Figure 16).

Figure 16. Injection, production, monitoring wells sites (left). Drilling operations with BO.REX ring

The groundwater was sampled from each well. The measured values, despite elevated Fe II of, allow the installation of the planned heat exchangers. Pump tests at constant intervals up to 7 m³/h were also performed. The concentrated solar power plant CSP in the final configuration, is installed on the newly developed buildings that will accommodate the HTHP (Figure 17).

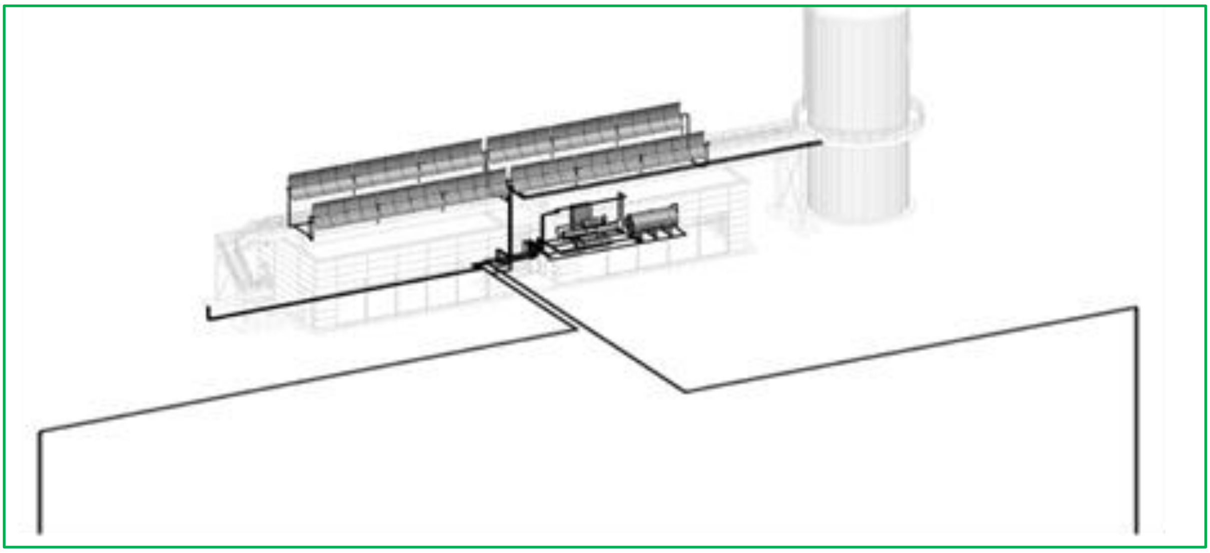


Figure 17. Sketch of the overall system with wells, CSP and HTHP

Particularly challenging for the **HTHP technology** are the required supply temperatures. DH grids are in fact usually fed by heat pump technologies when they require temperatures up to 90°C, since the range of temperatures between 100°C and 140°C is prototype status for the HTHP technology. Currently present on the market are circa 20 models that reach supply temperatures higher than 90°C, and only few are able to exceed 120°C (Figure 18).

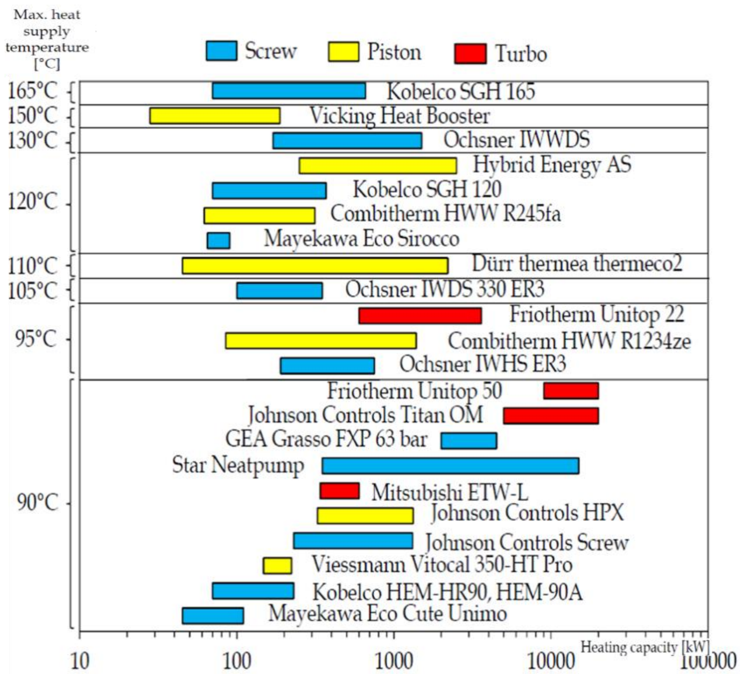


Figure 18. Commercially available HTHP's 2018

The chosen refrigerants play a fundamental role towards the achievement of the needed temperatures. In Figure 19 are reported suitable refrigerants for different technical solutions, i.e. 1-stage, including transcritical cycles, 2-stage, and hybrid absorption and compressor driven solutions.

Analysed possible suitable refrigerants					
Refrigerant	**Tcr (°C)**	**Pcr (kPa)**	**ODP**	**GWP**	**SG**
R134a	101,06	4059	0	1300	A1
R744 (CO2)	31,04	7380	0	1	A1
R717 (NH3)	132,40	11280	0	0	B2L
R718 (H2O)	373,95	22060	0	0,2±0,2	A1
R245fa (ÖKO1)	154,05	3640	0	858	B1
R407c	86,05	4634	0	1774	A1
R1234ze(e)	109,40	36	0	6	A2L
R410a	70,17	4770	0	2088	A1
R600	152,01	3796	0	4	A3
R1336mzzZ (Opteon MZ)	171,30	2900	0	2	A1

Figure 19. Possible suitable refrigerants. Green are favorable elements, red are non-preferred ones

To conclude, with the projects development, it will be possible to prove the exploitation of abandoned mines as heat storage facilities. Coupling them with HP's will enable the energy conversion towards the CO_2 reduction goals.

Funding: This study was supported by the Interreg North-West Europe (Interreg NWE) Programme through the Roll-out of Deep Geothermal Energy in North-West Europe (DGE-ROLLOUT) Project (http://www.nweurope.eu/DGE-Rollout), NWE 892. The Interreg NWE Programme is part of the European Cohesion Policy and is financed by the European Regional Development Fund (ERDF). Activities of Fraunhofer IEG were further supported by the Federal Ministry for Economic Affairs and Energy via the subproject "Roll-out of Deep Geothermal Energy in North-West Europe – German complementary project to Interreg North-West Europe".

Pilot Experiment 6: Deep geothermal energy provision for high temperature/energy intensive industrial applications – in exploration phase

Project Partners: Kabel Premium Pulp & Paper, Fraunhofer UMSICHT

Project website: https://www.kabelpaper.de/kabel-zero/

Description: Within the 'Kabel Zero' project, high temperature geothermal energy provision from Devonian carbonates for the paper drying process of Kabel Premium Pulp & Paper in Hagen is investigated.

The first sub-project (since 02/2020), 'Geothermal Paper Drying' is a feasibility study including an initial geological exploration campaign, technical simulations and model calculations. The project ends in the first quarter of 2023 and is funded by the EU and the state of North Rhine-Westphalia from the European Regional Development Fund ERDF.

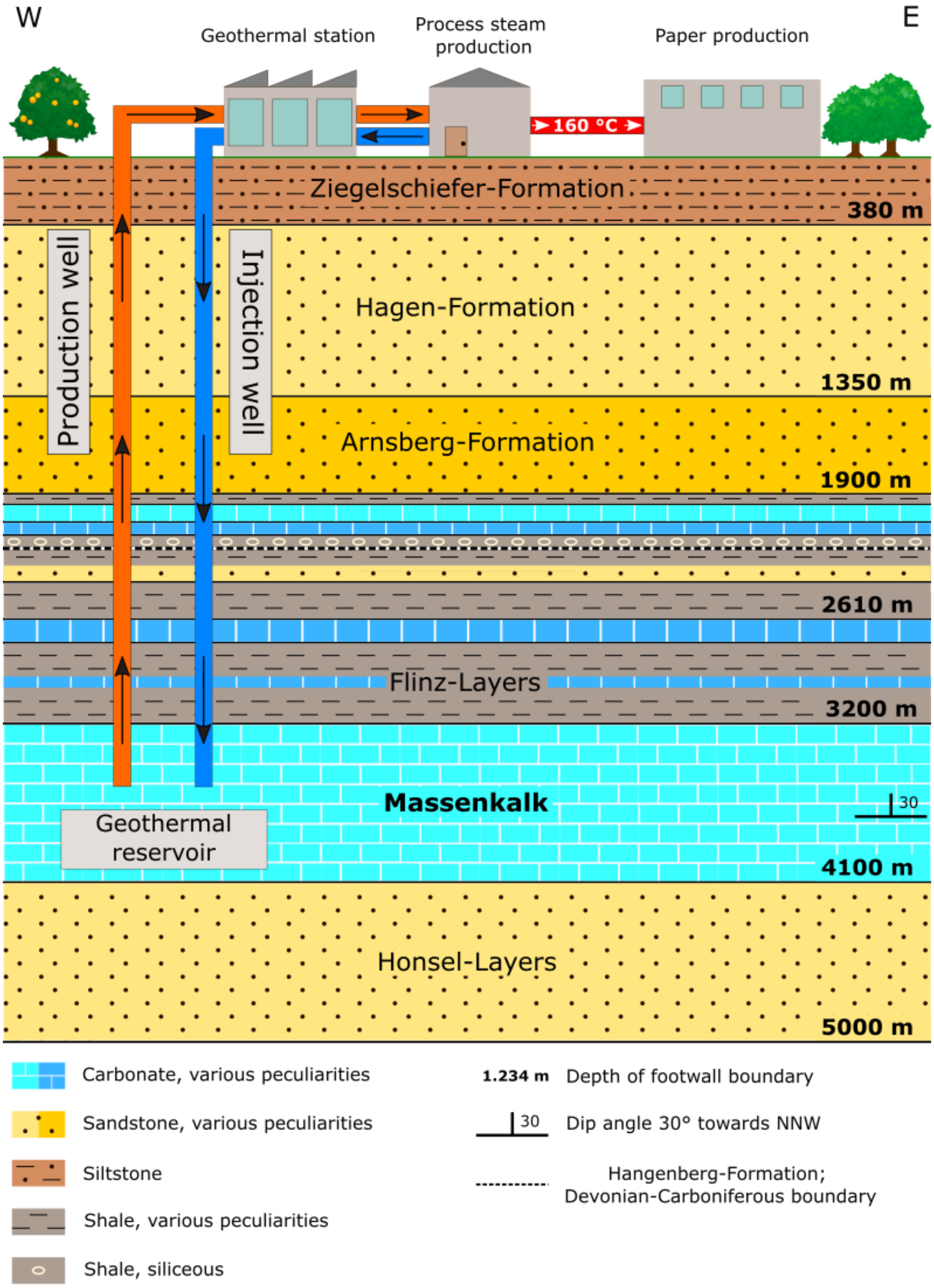


Figure 20. Conceptual model of the Kabel Zero project (modified after Salamon et al., 2020).

In the paper industry, large amounts of industrial process heat in the temperature range of around 160°C are required to dry the paper towards the end of the production cycle. The steam is usually generated in central plants and from fossil fuels such as natural gas. In order to reduce the ecological footprint, i.e. CO_2 emissions, of the paper industry and to save costs in the long term, the 'Kabel Premium Pulp & Paper' (KPPP) paper factory in Hagen launched the 'Kabel Zero' project, which promotes sustainable paper production through the utilization of geothermal heat energy in the drying process. The 'Geothermal Paper Drying' project represents the first step of the overarching 'Kabel Zero' project. It is primarily about exploring the subsoil and designing geoscientific and technical development concepts. The company location of KPPP in Hagen, thereby, shows promising circumstances for the future construction of a hydrothermal doublet system. On the one hand, the Großholthausener Sprung, a normal fault system, runs through the company premises as a regionally important fault zone. Thus, there could be increased rock permeability at depth. In addition, according to the Geological Survey of North Rhine-Westphalia, Devonian carbonate formations are expected at an estimated depth of around 3.200 m to 4.100 m. Carbonate units represent potential deep geothermal reservoirs, as evidenced by experience from district heating in the Munich area.

A seismic campaign around the KPPP company site was carried out in order to be able to unambiguously localize the overlapping of Devonian mass limestones and large-scale fault zones such as the Großholthausener Fault in the subsurface. In the course of this exploration measure, two 2D seismic lines that intersect almost vertically were acquired using the so-called Vibroseis method with special trucks in order to generate an image of the subsoil.

The evaluation of the seismic data forms the basis for further project steps. In the next phase a 300 m exploratory well will be drilled into the Devonian carbonates that are outcropping at a distance of a few km from the paper factory. The goal of this well is to assess the hydraulic properties within the carbonate at greater depth. Based on the data, a 3D reservoir model will be parameterized (geology, geomechanical, thermal and hydraulic properties). A sensitivity analysis will be performed to evaluate the geothermal energy provision at the site with regard to fluctuating input parameters such as reservoir temperature or permeability. Fraunhofer UMSICHT will design the surface components to ensures the steam provision at required conditions such as temperature, pressure, etc. KPPP is the lead partner of the project and coordinates the various tasks.

Funding: This project receives grants from the state of North Rhine-Westphalia using funds from the European Regional Development Fund (ERDF) 2014-2020, "Investments in Innovation and Employment".

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TU-Darmstadt medium deep BTES

Objectives and motivation

The overall objective of the SKEWS project is the successful design, construction and experimental operation of a pilot plant of a medium depth geothermal heat storage system (MD-BTES) in the crystalline basement. Consisting of four 750 m deep borehole heat exchangers at the . SKEWS is the world's first technical implementation and operation of this so far purely theoretical storage concept.

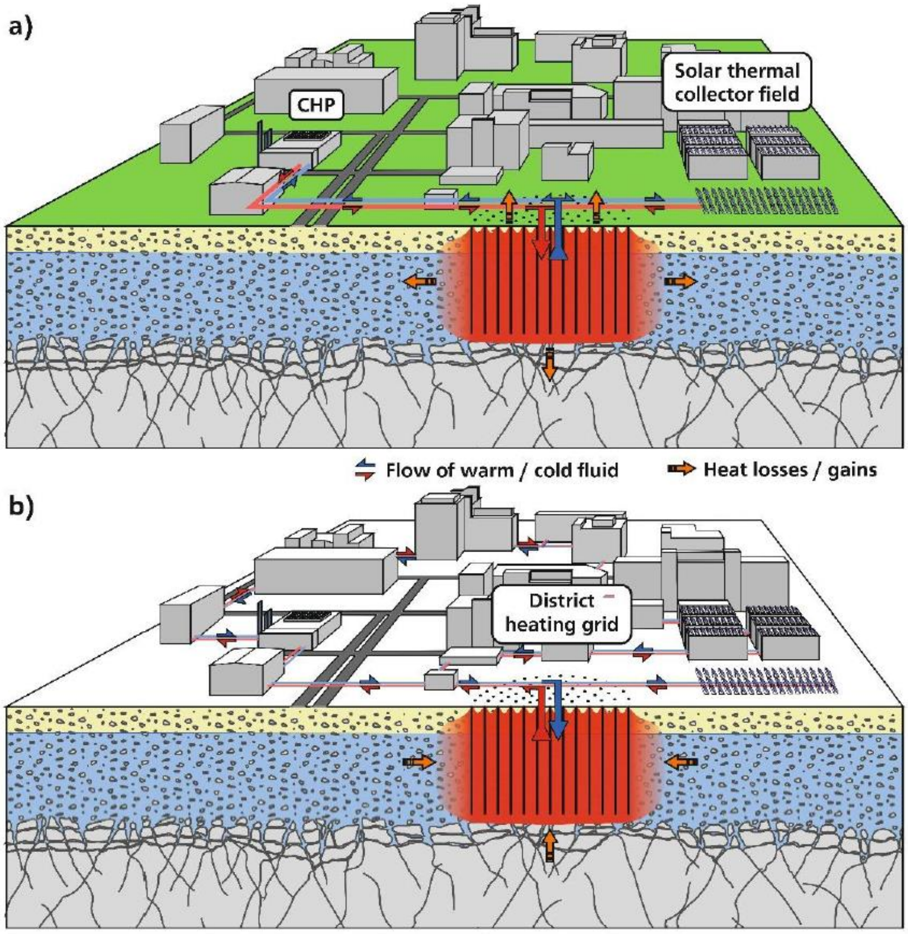

Figure 21. Schematic representation of a saisonal BTES during summer (a) and winter (b). CHP=Combined Heat and Power

In a geoscientific-technical investigation program accompanying the project a large amount of data and characteristic values will be determined. These include hydrochemical data and temperature measurement series from three groundwater monitoring wells set up in the vicinity of the BTES. In addition, during construction, data and characteristic values on e.g., construction costs and ecology (e.g., energy requirements for drilling the boreholes) will be gathered. Additionally, the subsurface structure at the project site as well as thermophysical parameters will be determined in an extensive geoscientific and geophysical investigation program. Finally, the thermodynamic operating behavior of the BTES will be investigated by detailed monitoring during the experimental operation of the reservoir.

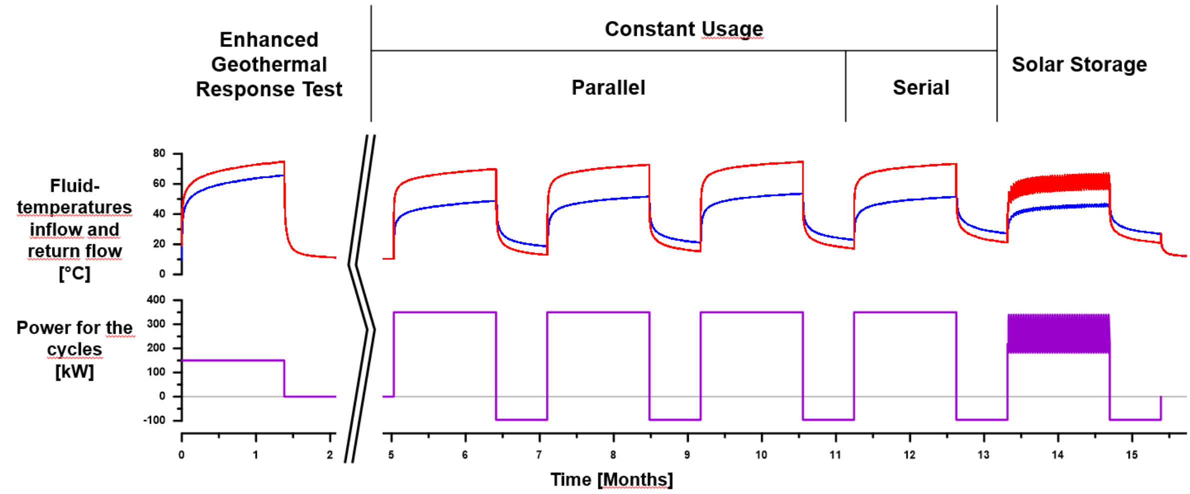

Figure 22. Plan for the test operation cycles.

With the help of this data, the existing theoretical knowledge and experience on thermodynamic as well as the economic and ecological characteristics of this novel storage system will be verified and further developed. This includes validation and adaptation of existing numerical thermodynamic and economic-ecological models. as well as economic-ecological model approaches, which have been developed by TU Darmstadt in the past years. For the validation of these models, the data obtained in SKEWS is indispensable.

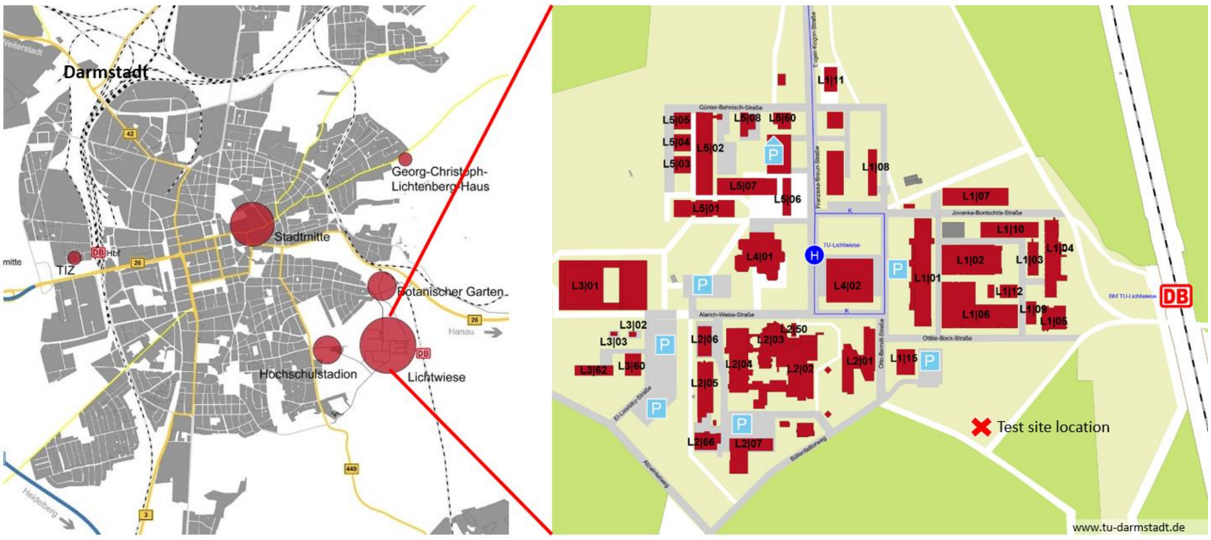

Figure 23. Location of the Test site at campus Lichtwiese in Darmstadt.

The modeling approaches aim to include both the underground part of such a storage system and the aboveground operating facilities (e.g. heat sources and heat consumers) and their interactions. The validation of the models will ensure that a detailed, efficient, and above all, precise simulation of such systems are guaranteed in the future. Due to the reduced number of heat exchangers in the research project in comparison to a theoretically optimal configuration, this BTES demonstration system can only be used for an economic operation after a later extension. The planning of this extension is one of the goals of the project. Therefore, a major research goal in SKEWS is to scale up the thermodynamic, economic and ecological results to technically and economically efficient sizes of the storage with the previously validated simulation tools and evaluation models. This also includes the evaluation of a possible expansion of the demonstration storage at the Campus Lichtwiese to a technically and economically efficient system size.

The integration of the scaled-up BTES into the local heating network at the Campus Lichtwiese of the TU Darmstadt is systemically investigated. Also with regard to the long-term goal of an optimized operation of the heating supply as well as a more efficient and economic operation of the university's own CHP units and other heat sources. This includes the economic and ecological evaluation of a conversion of the heat-led operation of the CHP unit to an electricity-led operation and the integration of a solar thermal collector field and the waste heat from high-performance computers generated on the campus. The investigations into the integration of a medium-depth BTES at the Lichtwiese campus are being carried out in direct connection to the ongoing project "EnEff:Stadt: Campus Lichtwiese_" *at the TU Darmstadt. II: Further development of an energy system at the neighborhood level*" (FKZ: 03ET1638).

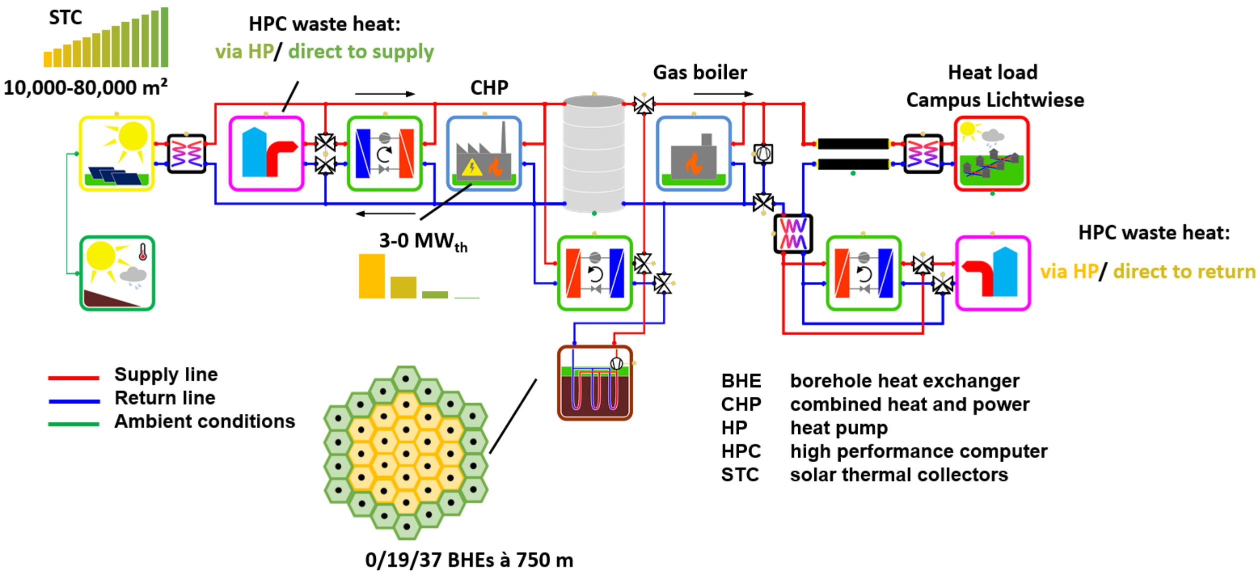

Figure 24. Modelica representation of Lichtwiese Campus district heating grid.

The knowledge gained in the SKEWS project on planning, expansion, operation and monitoring of medium-deep EWSS will be transferable to other heating networks and will significantly reduce the costs of such systems. This will lay the foundations for an economical implementation of the concept on a large scale, e.g. for heat storage in urban neighborhoods or for an entire university campus. The experience gained in the project with regard to the approval process and the as well as the determined parameters relevant for the approval, such as the thermal impact of such systems on shallow aquifers, future permitting procedures for projects of this type will be significantly accelerated.

The large-scale geophysical campaign, which is part of this subproject, is significantly supported by the associated project partners of the Leibniz Institute for Applied Geophysics. by the associated project partners of the Leibniz Institute for Applied Geophysics (LIAG) and the Hessian State Agency for Nature Conservation, Environment and Geology (HLNUG). supported. The four medium-depth boreholes drilled in SKEWS together with the surrounding groundwater monitoring wells offer a worldwide unique opportunity to investigate the crystalline basement by means of surface and borehole geophysics. and borehole geophysical measurement methods to record the crystalline basement three-dimensionally in such a confined space. In addition to extensive borehole logging, a 3D seismic tomography including all boreholes drilled in the project will be carried out. This will result in a unique data set for the crystalline basement. The dataset will be used in the scientific community for model parameterization. This can improve exploratory work or make it more precise and thus improve the economy of the systems. SKEWS can thus make a major contribution to the technical as well as the economic planning of all conceivable geothermal systems in comparable lithologies.

Time plan

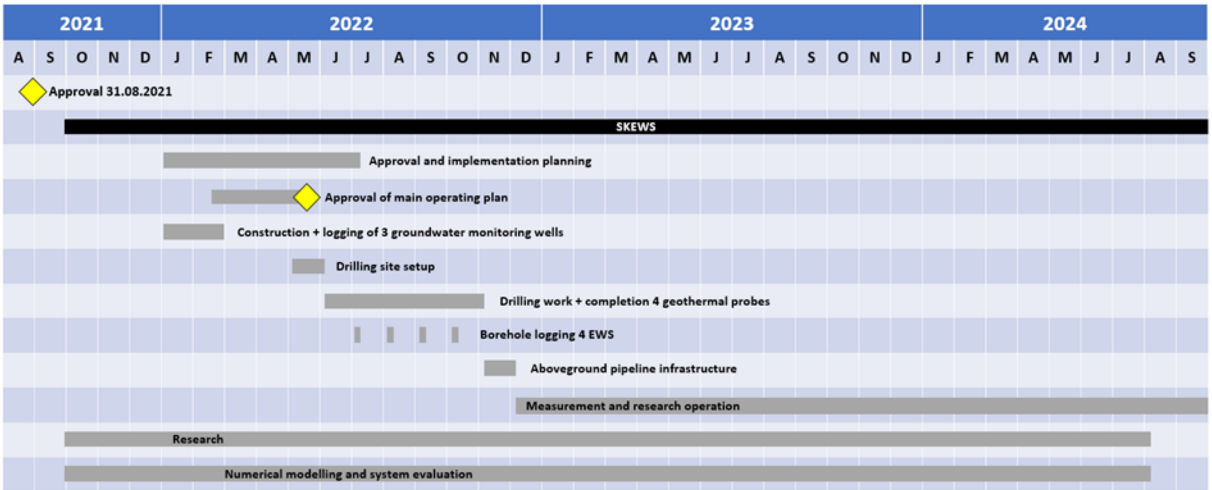

Figure 25. SKEWS project time schedule.

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ebn

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