Geothermal Energy in Munich (and Beyond) A Geothermal City Case Study

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ABSTRACT

Between 2008 and 2013 much was written and discussed about the state of the geothermal sector in and around Munich, Germany. The region had experienced the early signs of a prosperous period which looked as to have kick started some momentum with many projects being planned. The subsequent fall off in activity was largely attributed to the global financial crisis, amongst other factors. This paper looks briefly at Munich's geothermal journey and then provides an update on the activities in the region and the prospects for the future.

The Bavarian city of Munich in the south east of Germany benefits from a strong local economy and the ideal geological conditions for direct use geothermal heat schemes. The carbonate Malm reservoir, which is found between 2000m and 3000m depth below the city, is known to have good natural porosity and the geothermal fluid to be low in salinity. This together with its naturally high yield makes the Malm the ideal source for direct use district heating. During the last 15 years Munich has experienced strong growth within the geothermal sector despite regional and global economic uncertainties.

Project experience and collaborative research has assisted in developing robust frameworks and methodologies for executing low enthalpy projects within the Bavarian region. Through this work, the assessment of geological uncertainties in respect to the potential productivity of a geothermal well and approaches to drilling and well design have been optimized.

The prospects for Munich look strong as the Stadwerke München (SWM), in English "Munich City Utilities" pushes geothermal utilization to another level, by setting the goal of making Munich the first European city with a district-heating network supplied 100% from geothermal energy by 2040. This is being made possible through a collaborative research projected called GRAME, which was founded with support from the Bundesministerium für Wirtschaft und Energie (BMWi), in English "Federal Ministry of Economics and Energy".

1. Munich and the Malm

Munich

The Bavarian city of Munich in south east Germany benefits from a strong local economy and ideal geological conditions for geothermal direct use heating schemes. It is this combination, together with a growing population and a national energy policy shift (following the nuclear disaster in Japan), that has led to the development of many successful geothermal projects across the region. Munich has previously experienced a geothermal growth period between 2004 and 2009, however this saw a sharp drop in activity due to a number of factors, including the global financial crisis. However, through recently completed and planned future projects, momentum is being built and the city's confidence in the potential of geothermal energy is starting to grow.

The Malm

Deep beneath Munich, an Upper Jurassic carbonate aquifer (the Malm) can be found up to 600m thick, forming the base of the southern Bavarian Molasses Basin. The Malm comprises remnants of a 150-million-year old reef system, which forms a series of marls and locally dolomitized limestones. The Malm outcrops west of Bavaria in the Schwabian Alb and to the north in the Franconian Alb and dips gently southwards beneath the alpine orogeny, (Bachmann, Muller and Weggen 1987). Figure 1 depicts the aquifer in cross section, the north south dip of the formation beneath Munich can be seen. The measured temperature of the geothermal water, within the Malm reservoir ranges from 60°C north of Munich (at approximately 2500m depth) and up to 150°C to the south (at approximately 5000m depth).

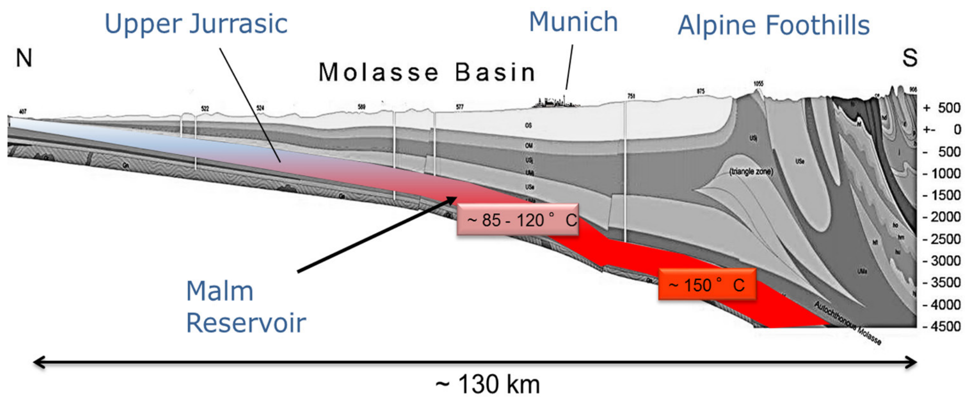

Figure 1. Simplified geological cross section of the Munich region. Adapted from 'Geologische Karte von Bayern 1:500000', Bayerisches Geologisches Landesamt, 1996.

The carbonate Malm reservoir is known to have good natural porosity and the geothermal fluid to be low in salinity, this, together with its high natural yield, makes the Malm the ideal source for direct use districting heating schemes.

2. Geothermal Evolution

The use of geothermal heat in Bavaria is nothing new. As early as 1938, oil drilling discovered thermal water in Bad Füssing. This was a blessing in disguise for the region, allowing a thermal bath resort to be developed from the resource. However back then, little thought was put into the potential of geothermal as a viable energy source.

As indicated the geology of south Bavaria was known to have potential for fossil fuels and was explored extensively between 1960 and 1980. It is these early exploration wells that provide the basis information for the deep reservoir knowledge of the region. Following the fall in the oil price in the 1990s and uncertainties in the energy sector, the idea of exploring the geothermal potential of the reservoirs beneath Munich was further explored, with projects such as those in Erding and Straubing being completed by 2000.

Over the last 15 years the geothermal sector in Munich has seen one distinctly strong growth period between 2004 and 2009, which was followed by a drop off in activity. This fall in activity can be attributed to the periods of regional and global economic uncertainties resulting from the global financial crisis. However, it is acknowledged that a number of other factors played a role, these include instances where investors and developers were not being able to immediately follow up initial projects with subsequent investments. In many cases the success of a project was not immediately apparent and required a number of years of operational data before this analysis could be undertaken. Further, following 2009, a shift in the exploration strategy was experienced and the exploration risks of the projects were heavily discussed within the sector.

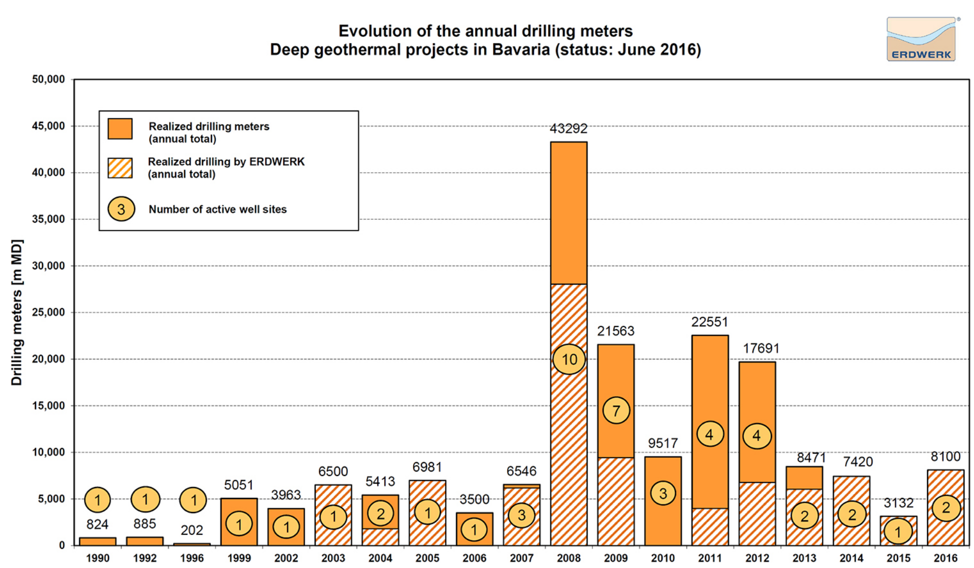

Figure 2. Evolution of the annual drilling meters. Deep geothermal projects in Bavaria (Status: June 2016). Copyright ERDWERK GmbH.

Coming through those difficult times, the current proposed, planned and recently completed projects in Munich suggest that the period "2016 onwards" has great potential. This is predominantly due to the recognition and acceptance that geothermal direct use is a reliable heat source for district heating projects and does not have a strong reliance on subsidies, such as those required to drive power generation projects.

The number of completed geothermal wells and meters drilled between 1990 and 2016 is presented in figure 2, with the drilling planned by Erdwerk represented by the hashed area. The previously mentioned period of growth and subsequent cooling off is very well depicted in figure 2. 2008 and 2009 were considered record breaking years in Bavaria with over 60,000 drilled meters for deep geothermal projects. Three significant factors were considered a driving force in this period of growth. Firstly, the publication of the Bavarian Geothermal Atlas, which provided a coherent overview of Bavaria's potential, secondly the introduction of increased remuneration for geothermal energy generation projects through the Renewable Energies Act (EEG) in 2004 and thirdly in 2007 the introduction of market incentive programs which included subsidies and low interest loans for geothermal heating projects.

The subsequent drop off can be, at first glance, contributed to the effects of the global financial crisis which took effect over the following years, however as previously mentioned it is acknowledged that investors and developers were not immediately in a position to kick off new projects and this lead to some slowing.

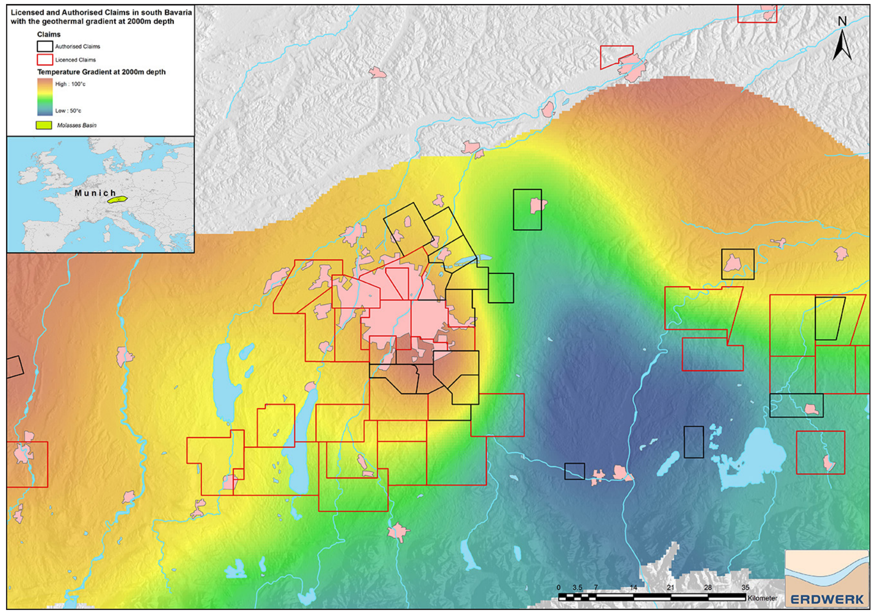

Figure 3. Licensed and Authorized Claims in the southern Bavaria region, with geothermal gradient at 2000m depth. Data courtesy of the Geothermal Atlas 2004. Copyright ERDWERK GmbH.

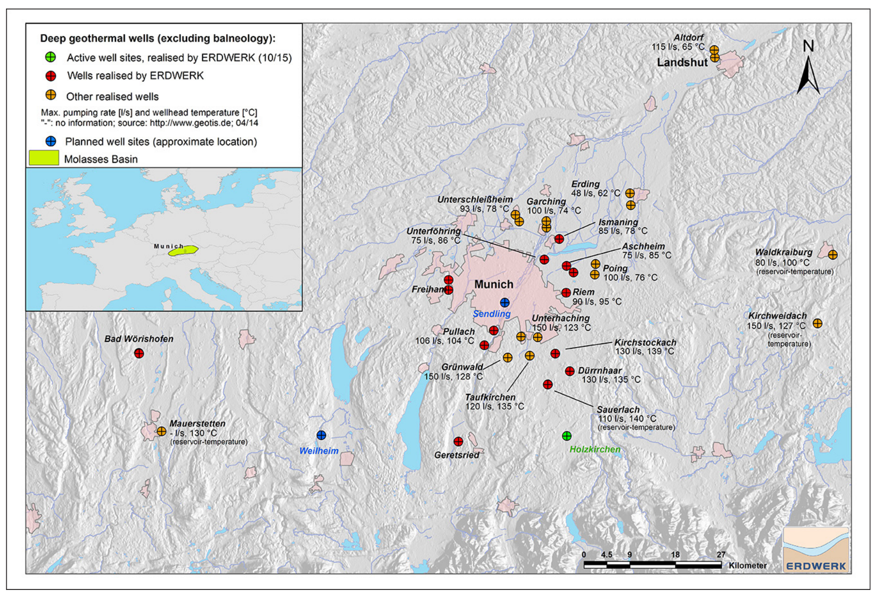

Figure 4. Summary of planned, drilling and completed geothermal wells in the region around Munich, Germany in 2016. Copyright ERDWERK GmbH.

At the time of writing there are approximately 40 geothermal claims in south Bavaria, with an average size of 80 km^2. Figure 3 provides an overview map of all the licenced and authorised claims combined with a heat map showing the temperature at 2000m depth, the geothermal gradient data is courtesy of the Geothermal Atlas (2004). The black-bordered areas represent the authorised claims, within these claims active geothermal projects are producing geothermal water. The orange-boarded areas represent licenced claims which are in the planning, exploration or drilling phase. It can be clearly seen in this figure how the distribution of the claims is influenced by the thermal gradient. The huge potential of the region can be seen by the hot spots depicted by the dark reds. To the south the influence of the cool alpine water is seen, as it filters into the formation cooling the thermal gradient.

Figure 4 presents an overview of the current state of play in Munich, depicting the completed, active (currently drilling) and planned wells as of the beginning of 2016. The projects within and to the north of Munich (pink shaded area) utilize the geothermal water, almost exclusively, for direct use heating purposes. The wells supply existing or newly developed district heating networks and serve communities with sustainable and locally produced non-fossil fuel heat energy. To the south east of the city a small cluster of three projects can be found, all of which produce electricity. Dürrnhaar (5.5MW electrical), Kirchstockach (5.5MW electrical) and Sauerlach (5MW electrical and 4MW thermal). The dominance of direct use heat projects as opposed to electricity across the region demonstrates a number of things. Firstly, that the Malm reservoir temperature is best suited for heating, projects can be completed without an overreliance on subsidies. Secondly that the electricity projects are hugely dependent of subsidies and feed in tariffs (FITs) and therefore the economics of the projects can be very marginal.

In respect to projects undertaken by local authorities, the social economic factors should not be underestimated and in many cases they are the overriding factors to the success or failure of a project. The project economics must match the financial capabilities of a municipality and the demands of the inhabitants. A number of projects in Munich have demonstrated this, such as Pullach and Riem.

Riem is a good example of a successful direct use project in the Munich region. The district of Riem can be found on the east side of the city and is the location of the much acclaimed Munich Exhibition Centre. Riem is home to approximately 16,000 inhabitants and is supplied with heat through a district heating network owned and operated by the Stadwerke München (SWM), in English "Munich City Utilities". In 2003, the SWM commissioned the construction of a classic geothermal doublet to utilize the 94°C heat of the Malm reservoir thermal water. Both wells were drilled from the same well site with a spacing of approximately 15m. The project facts are summarized in Table 1.

Table 1. Riem Geothermal Project Facts.

	Riem Thermal 1	Riem Thermal 2
Depth	3,275 m MD, 3,020 m TVD	3,400 m MD, 2,900 m TVD
Water temperature	94 °C	
Production Rate	75l/s	
Maximum available heat	8 MW	

The project is a good example of utilizing geothermal heat energy to provide a base load to a system. The existing Riem gas fired plant has been retained to provide the heat energy for the peak load periods.

3. An Iterative Process for Optimization: Simulation → Design → Execution → Lessons Learnt → Optimization

The uncertainty of the geology and hydrogeology at depth is responsible for posing risks to many geothermal projects during the planning and drilling phases. The uncertainty can be divided into two distinct categories; geological risks to drilling and hydrogeological output during production.

A thorough understanding of the geological risks to the drilling is brought about by good quality geological and geophysical data and local knowledge of the regional geology. With an understanding of the risks, a drilling program and well design can be optimized to mitigate these risks resulting in optimized and time efficient drilling, which in turn has positive impacts on the project costs.

Further, it should be noted that technological advances in drilling technology has played a huge role in optimizing drilling efficiency. The effectiveness of modern Rotary Steerable Systems (RSS) allows complicated and heavily deviated well paths to be drilled with accuracy. This is a huge benefit when targeting a specific facies within a formation, as in the Malm. Further the increase in the drilling speed limits the amount of open hole time, which reduces the risk of collapse. Further and more specifically, the requirement to drill ultra-deep geothermal wells in Bavaria can increase the risk of casing failures, these risks can be managed by measures such as improved cementing and adapting of the design factors, (Lentsch 2015).

Assessing the geological uncertainties in respect to the potential productivity of a geothermal well is critical when building a sound business case for the project. In simple terms, the greater the certainty of envisaged productivity as a function of water temperature, reservoir permeability and reservoir pressure / static water level the greater the chance a project will succeed at the planning and funding stage. Munich's rich experience in the geothermal sector allows such geological uncertainties to be greatly reduced through the effective and continual advancing of knowledge and methodologies. This is achieved through education, technical innovation and collaborative private and university lead research projects. The extensive geophysical survey data sets, drilling, geological and hydrogeological data obtained from completed wells is continually utilized, analyzed and fed back into the project workflow. This workflow for project optimization is summarized in Figure 5, the 'lessons learnt' feed back into a number of different stages of the project. This means that the experience gained throughout a project can be applied to the next project phase, but also be used for the planning of the next project.

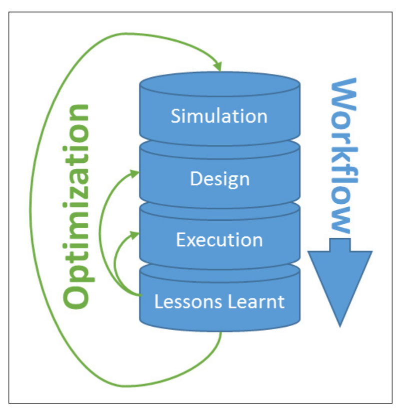

Figure 5. Simulation to lessons learnt and optimization. Copyright ERDWERK GmbH.

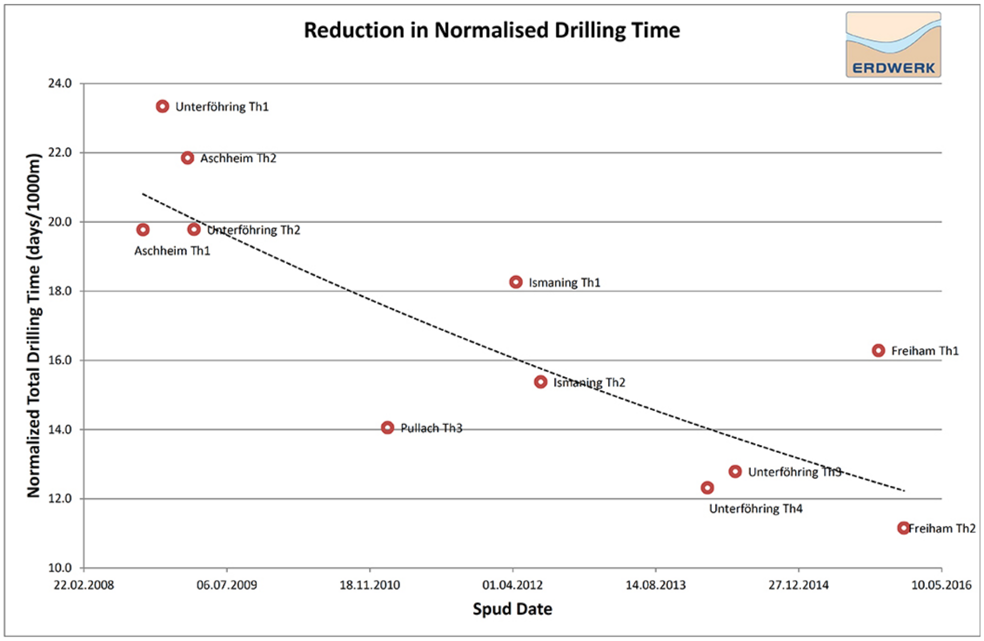

Figure 6. Project optimisation and a reduction in the normalised total drilling time. Copyright ERDWERK GmbH.

Figure 6 demonstrates the learning curve associated with completed projects in the vicinity of Munich. In the majority of cases the second, third and fourth wells drilled for each project show a distinct improvement in the drilling performance. This can be put down to a number of factors, including improvement of the drilling team coordination and improvement of the drilling program through lessons learnt. The obvious impact of reduced drilling time is the reduction to the project drilling costs. The documenting and systematic recording of project performance and costs allows for experience and lessons learnt to be used extensively during the project planning phase. Accurate time and cost simulations can provide project planners and financers with a better understanding of the probability of different scenarios and assist risk assessments, (Lentsch 2013).

It should be noted, however, that many of the processes discussed in this paper are successfully developed within the frame work of completed projects in the Munich region. The datasets and research undertaken relate to projects all with similarities, be it well depth and casing design or thermal water temperature. As soon as a project falls outside of this frame work (for example extreme depths of temperatures) many factors will need to be re-analyzed. What is positive, however, is that the approach, methodologies and recipe for success can be applied globally, hopefully with similar results.

4. SWM: The 2040 Plan

A driving force behind a number of the geothermal projects in Munich is the Stadwerke München (SWM), in English "Munich City Utilities". The SWM is responsible for providing a range of utilities across the city, including power, heat, internet and water. Additionally, the SWM owns and manages a number of swimming pools and sports facilities.

In 2008 the SWM began to diversify their energy portfolio, with a view towards developing more renewable energy sources. Being an early adopter of geothermal in the region, the SWM recognized the potential of geothermal energy for the city of Munich. To date they have executed a number of key, and most importantly successful, projects in Sauerlach, Riem and Freiham (see Figure 4).

However, the SWM is looking to push the geothermal utilization to another level by setting the goal of making Munich the first European city with a district-heating network supplied 100% by geothermal energy by 2040.

In order to supply the entire city with geothermal energy it was clear that a better understanding of the Malm aquifer beneath Munich was required. Previous projects had relied on discrete data sets and locally shot 2D-seismic surveys concentrating on one concession. It was recognized that a universal concept was required to develop an appropriate production strategy.

For the purpose of developing the universal concept for Munich the research project GRAME was founded with support from the Bundesministerium für Wirtschaft und Energie (BMWi), in English "Federal Ministry of Economics and Energy." The project is planned to last 3 years (from 2015 to 2017) with a budget of approximately €8 million, 50% coming directly from the BMWi. The GRAME research project comprises a number of companies and institutions in partnership with the SWM. These include the Leibnitz-Institute for Applied Geophysics (LIAG), Erdwerk GmbH, the Chair for Energy Systems at the Technical University of Munich and GGL Geophysics and Geotechnics Leipzig GmbH. The research project is responsible for investigating and developing a basis for optimized and long lasting production from the Malm aquifer and identifying possible locations for new geothermal wells in Munich. For the purpose of supplying the entire city with geothermal heat it is anticipated that approximately 400 MWth will be required, which equates to approximately 25 doublets (50 wells). Clearly to achieve this a thorough understanding of the hydrogeology is required here to avoid hydraulic shortcutting between the wells. Additionally, a number of city planning issues need to be solved, as in order to drill this magnitude of wells it is anticipated that approximately 6000m^3 will need to be identified in what is already a densely populated city. The project results will form a technical, environmental and economical concept for the development of the Malm aquifer and the integration of the geothermal heat into the existing SWM infrastructure in the city.

One of the key activities of the GRAME project is data acquisition. As previously noted in this paper, good quality data along with experience is key to accurate and cost effective planning of projects. From November 2015 to March 2016, the SWM commissioned a 3D-Seismic survey to be undertaken collecting data across south, south western and north western districts of the city (see Figure 8). This data, together with existing 2D geophysical data, provides a comprehensive data set covering approximately 50% of the city.

The survey was undertaken by DMT GmbH (based in Essen, Germany) and was considered to be one of the largest inner-city seismic surveys undertaken globally. Between November 2015 and March 2016 approximately 170m^3 was surveyed using 26t vibroseis trucks (see Figure 8). The signals from the trucks were recorded at almost 8000 points by applying 12 geophones at each survey location. Undertaking such a survey within an urban environment posed a number of challenges to the project. The use of the 26t vibroseis trucks was considered the most appropriate for the city as the signal sources are controlled and do not cause significantly strong vibrations, which avoided damaging buried services such as gas and water and property. The traffic issues posed by working in a city were overcome by restricting working hours to outside of peak travel times. Noise restrictions meant also that the work could not be carried out in the evening and in the early mornings.

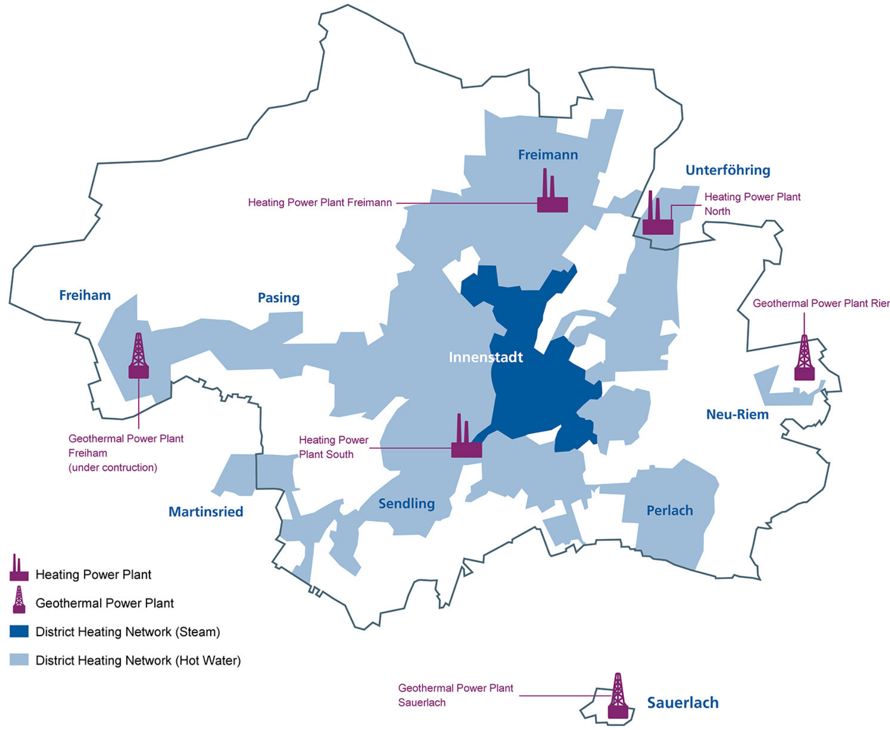

Figure 7. Overview of SWM operated power plants in relation to district heating networks. Adapted from SWM original in German. Copyright SWM GmbH.

Figure 8. Overview of 3D Seismic survey area and existing 2D Seismic lines in relation to Munich city districts. Adapted from SWM original in German. Copyright SWM GmbH.

In addition to the seismic survey two additional work packages were undertaken. The first was an innovative shear wave experiment, carried out as part of a research project in collaboration with the Leibniz Institute for Applied Geophysics (LIAG). Vibrations were generated using a special technique (SHOVER method) at approximately 20 locations and registered with 3-component geophones. The second additional work package comprised two VSP (Vertical Seismic Profiling) measurements undertaken in the existing geothermal boreholes at Freiham & Reim.

The next major geothermal project in Munich is already in the advanced stages of planning and soon to begin the tendering process. This project is planned for the city district of Sendling, where the largest district-heating network in Munich is currently served by a gas fired power plant ('Heating Power Plant South' in Figure 7). Four wells are planned (double doublet) to be completed from the site of the existing power plant by 2018. The wells are looking to exploit the anticipated temperature of 95°C of the Malm reservoir. This project is set to be the largest in Munich to date and its success will further demonstrate the potential of geothermal within an urban environment. Challenges such as additional traffic due to well site deliveries and 24-hour drilling in an urban setting will be addressed with the upmost sensitivity. Following on from Sendling the city district of Perlach to the south is in the SWM's sights. By 2025 it is anticipated that in total seven geothermal power plants will be operating in Munich.

5. And Beyond…

At the time of writing, the prospects for Munich and the surrounding region are strong and it is important that the momentum built in recent years is not lost. The European Geothermal Energy Council (EGEC) has published a number of market reports since 2011 addressing the state of play in the geothermal sector. The 2014 EGEC report notes importantly that a more stable political and regulatory framework is required to achieve the EU energy targets set for 2030. Further ideas such as a Pan-European geological risk insurance scheme, a market design promoting dispatchable renewable energy technologies and changing the norm so that geothermal heat becomes a standard practice in building renovation and construction, EGEC (2014) are considered viable and important ideas to develop the geothermal market further.

Beyond Munich the potential of geothermal direct use is also being explored. The local authority of Holzkirchen has embarked on a bold plan to utilize the potential 150°C thermal water at approximately 5000m depth for direct use district heating. The drilling of the first well commenced in early 2016 with the anticipated completion of the doublet within 2 years. The district-heating network within the town has already been ambitiously constructed in anticipation of the completion of the wells.

Projects, such as those in Holzkirchen, demonstrate the possibilities for smaller communities to utilize the Malm aquifer. This is typically difficult due to the limited or non-existent district heating infrastructure and social economic factors such as the limited potential uptake due to the small number of inhabitants.

6. Summary

As detailed in this paper, Munich and the south Bavarian region have a rich history and a bright future of utilizing the Malm aquifer. It has been seen and proven that project experience, the quality of project data and collaborative research projects help to educate the developers and planners and minimalize risk during the planning and drilling phase. This leads to significant cost savings, which improve the overall economics of projects, in turn making them more attractive for investors.

Further, the strength of the SWM's 2040 plan can act as a catalyst to stimulate geothermal use within the region and can act as an example for other local authorities or industry to explore the geothermal potential. However, this cannot happen relying on the work of the SWM alone, the correct regional, country and EU wide policies are required to support and promote geothermal energy.

Low Enthalpy is a viable option for district heating purposes now and in the future. The knowledge and methodologies developed within the Munich region can be transferred globally. Sedimentary basins with deep carbonate aquifers such as the Alberta Basin (Canada), the Pannonian Basin (Hungary/Romania/Bulgaria) or the Guadalquivir Basin (Spain) all have great hydrothermal potential and could be the next regions to adopt this technology.

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