Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

From Vision to Reality: Unlocking the Geothermal Potential

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Keywords: Geothermal, Heat Demand, Oil and Gas Workflow, Crossover, Upscaling, Play-based Exploration

ABSTRACT

The need for cities to transition from fossil fuel-based energy to renewables is a challenging topic at the forefront of modern scientific, engineering and political agendas. The city of Munich together with a number of surrounding communities, located in the favorable geological setting of the South German Molasse Basin, have been realizing geothermal projects as part of an energy transition since the turn of the century. The combination of a significant heat demand, a positive political framework and a strong, trustful and long-term developer – planner partnership are viewed as some of the reasons for success. This has established geothermal know-how and allowed for regional development of the geothermal sector over the last two decades unseen anywhere else in Germany.

The Munich based consultancy ERDWERK has been an active driver and leader in the geothermal sector since the early days of geothermal development in the Molasse basin in 2002 and has become a major player for low to medium enthalpy geothermal developments in Germany and Europe. Skills and technology have been successfully incorporated from E&P and adapted to geothermal projects, making the Greater Munich area a knowledge center of geothermal best practice and know-how.

The general absence of exploration wells for geothermal projects mean there is little opportunity to build exploration data sets for play definition and to test technologies. However, the large number of successful wells drilled in the Molasse Basin have allowed an iterative development of employed technologies and methodologies. Data and knowledge from existing wells act as a valuable exploration dataset for new projects. Today, in order to meet project developer expectations, (minimized exploration risk, cost effective low risk drilling, minimal and managed seismic risk, project realization in urban areas) HSE standards and technology from the E&P sector are implemented.

This paper analyzes the development of the geothermal sector in the Munich region over the last 15+ years. It showcases what many cities and Countries need to be doing in the coming decade in order to successfully develop the geothermal energy sector in their region.

1. INTRODUCTION

Geothermal energy has long been established as a relevant renewable energy, especially in high-enthalpy zones. In recent years low-enthalpy geothermal energy has gained importance as a result of the climate debate and the general expansion of renewable energies. From an ecological and technical point of view, geothermal energy scores highly compared to other renewable energies with low land consumption and emissions and base load capacity. The Paris Basin and South German Molasse (specifically Munich) demonstrate that low-enthalpy geothermal energy can be used in geologically favorable regions in a comprehensive and economically efficient way.

In 2003, the TAB study developed a visionary scenario for geothermal energy in Germany. The realistic scenario assumed in the study was an expansion of annual geothermal electricity generation to 28 TWh or 5% of gross electricity generation. At an efficiency of 10%, about 250 TWh of waste heat would be generated. In the scenario described in the TAB study, the 28 TWh would be generated by 350 plants with a capacity of 10 MWel. We are currently a long way from achieving this in Germany. Although the expansion of geothermal energy in the Molasse basin has progressed. Here an output with an average operating time of approx. 40 years (very rough assumption, from Schulz, 1989) and continuous operation under full load is forecast, this would correspond to a potential of almost 2,000 MWth (and 200 operating years approx. 400 MWth). In the Molasse, this is due to the generally favorable reservoir conditions offered by the Upper Jurassic carbonate deep aquifer (Böhm, 2012; Steiner et al., 2014).

After the experiences of the last few years, a recent study on the eastern molasse (RPV 18 Energy Concept 2018) with an adapted and optimized development approach achieved several times this value; for the eastern molasse alone, 4,000 MWth are forecast here.

Despite the productivity and successful execution of geothermal projects in the Greater Munich and Bavaria region, geothermal energy plays a near insignificant role in the regional and national energy mix, as detailed in Figure 1. The political and social political arguments for geothermal projects will always be problematic, however this is made more difficult due to the current renewables market penetration where geothermal remains a niche in a niche. Despite the overall low percentage of geothermal energy in Germany, Bavaria plays an important role with 58% (14 from 26) of the heat and power geothermal projects in Germany (Agemar et al., 2010). Most recently other regions in Germany, such as the Rhine Graben und the North German Basin, are seeing more and more geothermal exploration activity resulting in a good outlook for the geothermal industry in Germany.

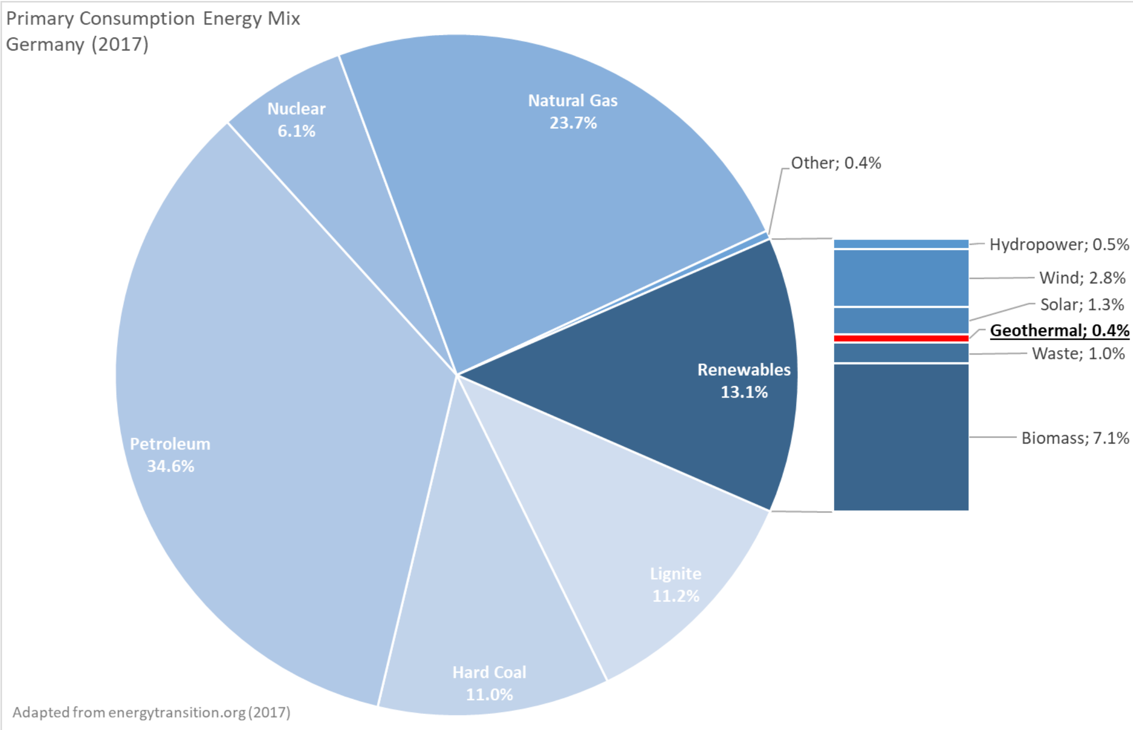

Figure 1: Primary Consumption Energy Mix Germany (2017), adapted from energytransition.org

2. REASONS FOR SUCCESS

Numerous papers ((Farquharson et al., 2016), (Dorsch, 2012)) have provided summaries and explanations of the development of geothermal projects in the Greater Munich region from the early 90s to the present day. Figure 2 provides an updated version of the evolution of deep geothermal projects graphic. Important milestones in the development are indicated, such as the publishing of the Bavarian Geothermal Atlas (StMWIVT, 2012) in 2004, the first dedicated geothermal seismic campaigns (Unterföhring 2006 and Unterhaching 2009) and the impact of the financial crisis in 2008. As detailed in numerous papers (Farquharson et al., 2016) the project planning time from 2004 to 2008 explains the sudden ramp up of projects and the impact of the financial crisis in 2008 together with the region was waiting to evaluate the success of the drilled projects explains the drop off.

In recent years the number of geothermal developments has begun to increase due to planned expansions of existing projects and the systematic exploration campaigns of the largest operator in the area the Stadtwerke München (SWM), in English Munich Municipal Services. SWM plan to utilize geothermal heat to supply all district heating networks within the city with geothermal heat by 2050. The project Schaftlärnstraße, which is currently being drilled in the city center, represents a pinnacle in the reservoir engineering, well engineering and drilling engineering. State of the art 3D thermal and geomechnical and geological modelling and simulation (Farquharson et al., 2016) have been undertaken and advanced multilateral well completions are planned (Lentsch et al., 2020).

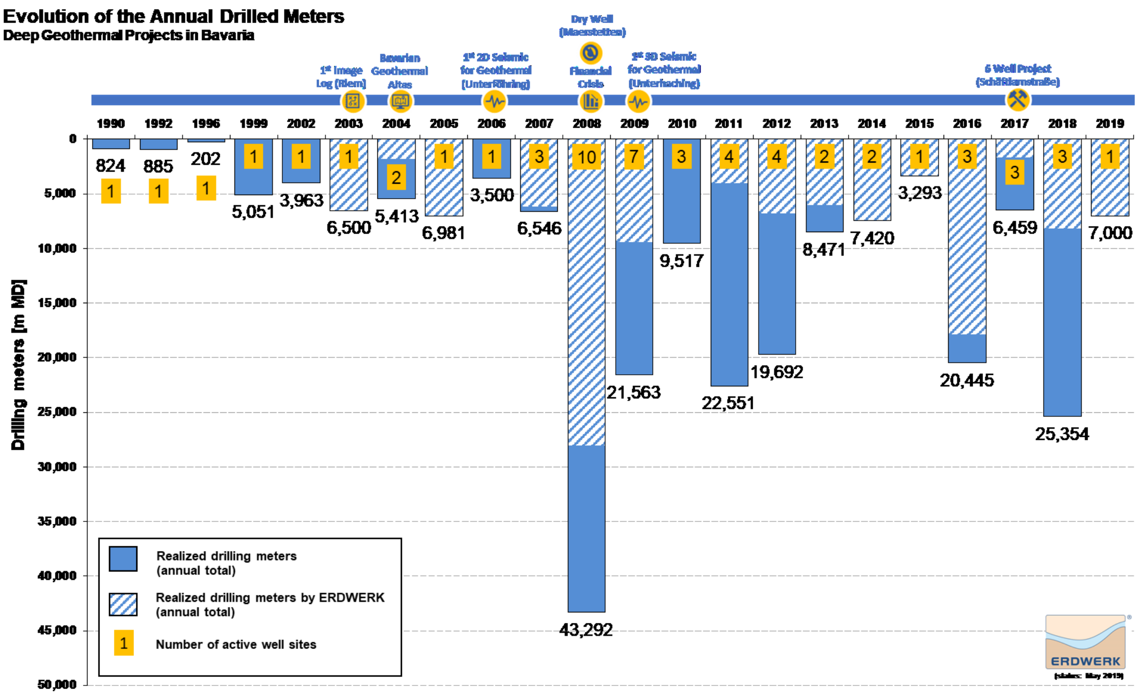

Figure 2: Evolution of the Annual Drilled Meters. Deep Geothermal Projects in Bavaria (May 2019)

The development of the geothermal industry in Bavaria is dependent on the following six main aspects:

1. Favorable geology
2. Economic viability
3. The political framework
4. Strong developer – planner partnership
5. Oil and Gas Exploration and Production Workflows
6. Upscaling

2.1 Favorable geology

One of the main reasons that enabled the geothermal development in Bavaria, is its geological setting. The Upper Jurassic carbonate aquifer (Malm), about 3km deep below Munich and up to 600m thick, represents the most important geothermal reservoir of the southern Bavarian Molasses Basin. The Malm outcrops west of Bavaria in the Swabian Alb and to the north in the Franconian Alb and dips gently southwards beneath the Alps, (Bachmann et al., 1987). In cross section, the formation dips north south beneath Munich. The measured temperature of the thermal water, within the Malm reservoir ranges from 60°C north of Munich (at approximately 2000m depth) up to 150°C to the south (at approximately 5000m depth). The Malm reservoir is formed by a reef (mud-mound), basin system, with the best reservoirs located in the reef complexes. The reservoir is known to have good natural porosity (matrix porosity, fracture porosity and karst porosity) and a good permeability. This makes the Malm the ideal reservoir for districting heating projects.

It is clear then, that without a suitable deep aquifer a region cannot develop hydro-geothermal projects and thus develop a geothermal market. Alternative exists where the geology is not suitable for hydro-geothermal, these include Enhanced (or Engineered) Geothermal Systems (EGS) or closed loop single well systems, however very few examples of these are operating in Europe.

2.2 Economic viability – heat demand

In the Greater Munich and Bavaria Region we find the perfect combination of a geothermal resource and a high (predominantly domestic) heat demand. This combination allows for economically attractive projects to be developed with or without the need to build a district heating network (DHN). In the case of the Schärflarnstraße and Holzkirchen (Lackner et al., 2018) projects the geothermal wells provide heat for existing DHNs and replace (completely or partly) gas or coal fired heat plants.

With the renewable energy sector typically focused on electricity production (eg. From Solar and Wind), the heating and cooling demand of households and industry is often underestimated. One of the main drivers for the focus on electricity is that it is simply more profitable for developers and investors and therefore more attractive because of subsidies. However, taking the energy demand of the 28 members of the European Union (EU28) as an example energy demand for heating and cooling plays a significant role. Figure 3 presents the energy demand data from 2015, heating and cooling was 50% of the total EU28 energy demand, of that 50% space heating (27%) and process heating (16%) dominated the consumption.

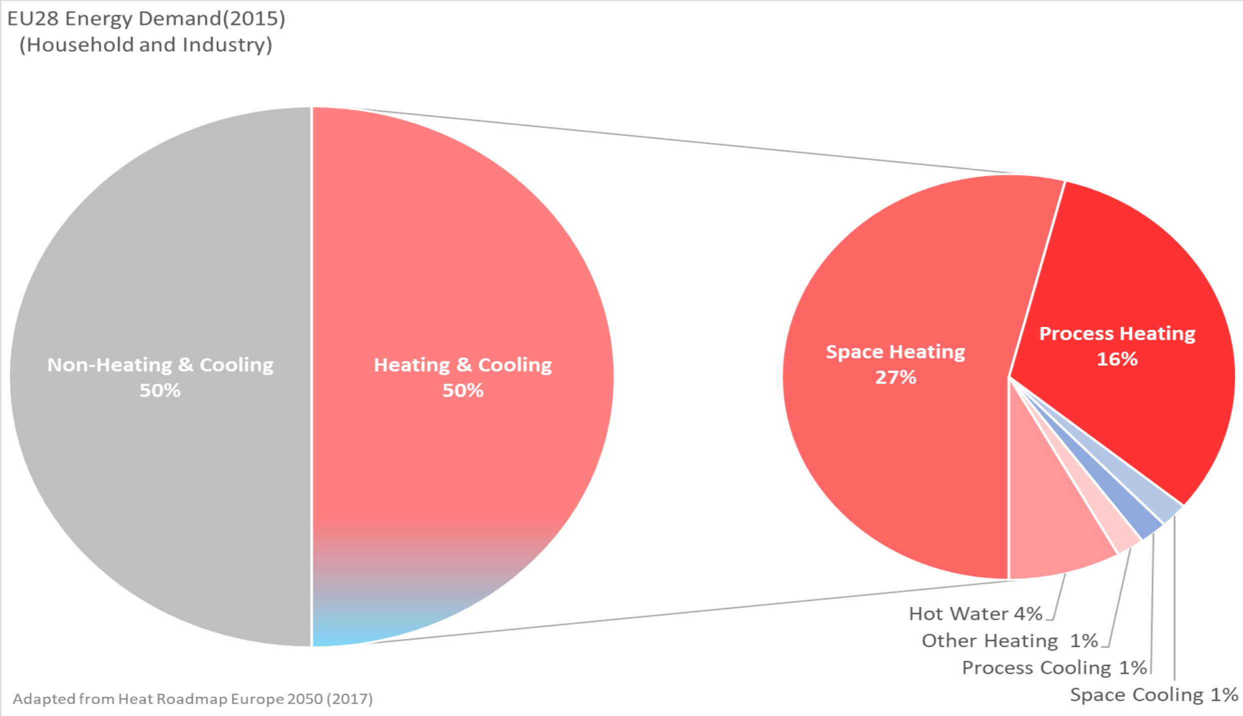

Figure 3: EU28 Energy Demand from Household and Industry, adapted from Heat Roadmap Europe 2050 (2017)

Low enthalpy geothermal resources (60°C to 150°C) are perfectly suited (where the regional geological setting allows) to provide for the 32% of the total regional energy demand (space heating, hot water and other heating). It should be noted that geothermal resources can play a role in providing heat for process heating, however in the data set for Figure 3 process heating is considered as >300°C and therefore not applicable for low enthalpy geothermal resources.

2.3 Political framework

Building on the influence of the heat demand in the German market, the national and regional (Bavarian) subsidy systems allow a proportion of the CAPEX to be obtained (see Table 1). This is particularly important in the cases of a small communities, where the initial drilling and district heating network (DHN) CAPEX could be prohibitive.

Table 1: Geothermal Subsidies Germany - Heat

National Subsidies (Kreditanstalt für Wiederaufbau (KfW))			
Plant Subsidies	200 €/kW(nominal heat output) Max. €2 million		
Deep Geothermal Wells (heat)	400 m to 1,000 m TVD: 375 €/m TVD	1,000 m to 2,500 m TVD: 500 €/m TVD	>2,500 m TVD: 750 €/m TVD
	Max €5 million per doublet Additional work due to unforeseen technical risks, up to 50% of costs, max €1.25 million per well-		
District Heating Network (DHN)	60 €/m (new sections) Max €1.5 million Repayment Subsidies: €1,800 per household connection		
Bavarian Subsidies (LfA Förderbank Bayern)			
District Heating Network (DHN)	Max €0.5 million per project from the LfA Förderbank		
Municipal Infrastructure Projects	loans at reduced interest rates granted by LfA Förderbank		

The available subsidies mean that an example project with a doublet to 2000m depth (TVD) and a thermal output of 5MW would be eligible for approximately €3. Mill for drilling and energy plant construction costs. This amount, although beneficial to the project, would typically only contribute 1/4 to 1/3 of the total CAPEX costs for the wells and energy plant.

Despite the positive impact of the German subsidies, they only provide a small proportion of the costs. There is no support during the planning phase and no productivity insurance scheme to cover the exploration risk, as seen in the Netherlands, Denmark and Belgium.

As commented in the recent EGEC Market Report (EGEC Geothermal, 2019) the failure of the EU countries to meet the 2020 targets mean that they need to reassessed for 2030. The 2020 targets were not sufficiently robust. The 2030 Policies have a stronger focus on heating and cooling with renewables and it is hoped these can refocus countries to meet their targets and that geothermal can play a significant role in achieving this.

2.4 Strong developer – planner partnership

Regardless of the developer – planner constellation, a long-term partnership is proven to provide the best results. This allows common workflows to develop and the understanding of the geological and drilling engineering challenges to go deeper than just applying the published knowledge. Such a partnership is demonstrated where the SWM together with their select planner successfully developing the Riem geothermal doublet in 2002 and followed with (to date) four projects including the current 6 well Schaftlarnstraße project in the center of Munich city. From each project lessons learnt have been applied to improve the planning and execution of the next.

Within regions where the geothermal market is under-developed the building of a developer – planner partnership can be difficult, inland planners will not necessarily have the experience in executing projects. Here experience from other countries can play a role, either in a full planning capacity, 3rd Party reviews or capacity building. External consultation can help to steer projects through critical decision-making phases. Aside from the technical experience, knowledge of the pros and cons of differing contract forms can be valuable in assisting the project in engaging contractors under the terms best suited to the developer.

2.5 Oil and Gas Exploration and Production Workflow

State of the art technologies and standards in Oil and Gas Exploration and Production (E&P) have been normal practice for a significant period of time. However, in many regions the geothermal sector has evolved out of the hydrogeological sector, where groundwater wells were the standard. Such projects did not have the requirements or budget to employ the sophisticated E&P techniques, thus proceeded with simpler planning and equipment and therefore higher risks.

Technology

Seismic profiling of the subsurface (new or reprocessing) is a typical requirement for all geothermal projects, together with information from reference wells an understanding of the underground can be developed, modelled and simulated prior to drilling. Between 2006 and 2009 the move from 2D to 3D surveys was seen in the Greater Munich region (Figure 2). The exploration benefit of employing the more expensive 3D techniques was demonstrated and today 3D seismic surveys are the norm. The added level of detail obtained by the 3D survey is considered to justify the higher surveying costs. Early geothermal projects were often modelled in 2D GIS software packages (see Figure 4), on the basis of the before mentioned 2D seismic data.

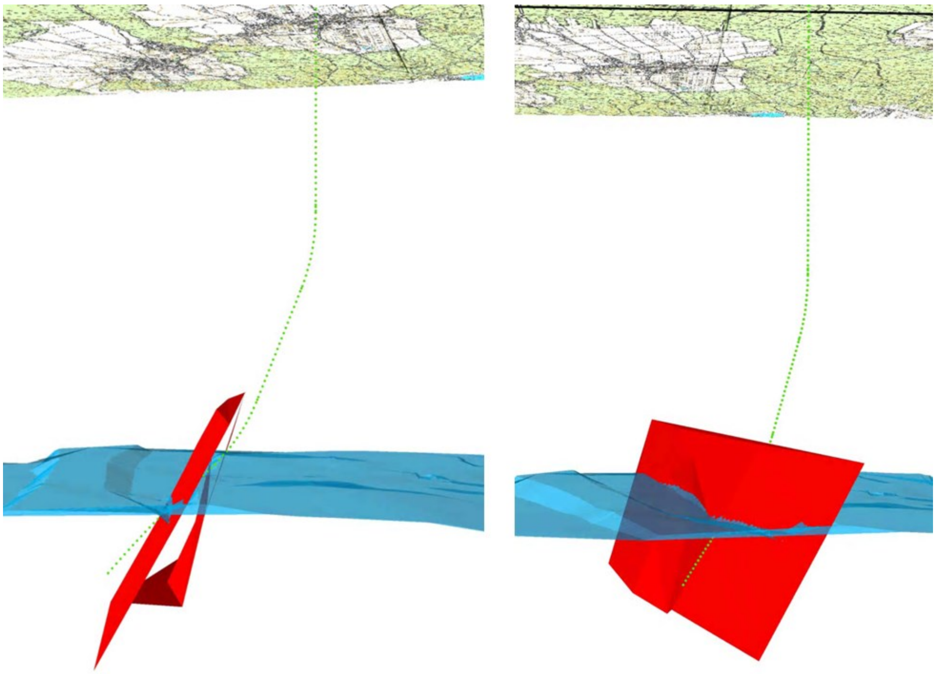

Figure 4: Early 3D Reservoir Modelling in GIS Software

Nowadays more abundant acquisition of 3D seismic datasets and the use of software packages like Petrel and Eclipse established a 3D workflow that is comparable to the standard in the Oil and Gas sector (see Figure 5).

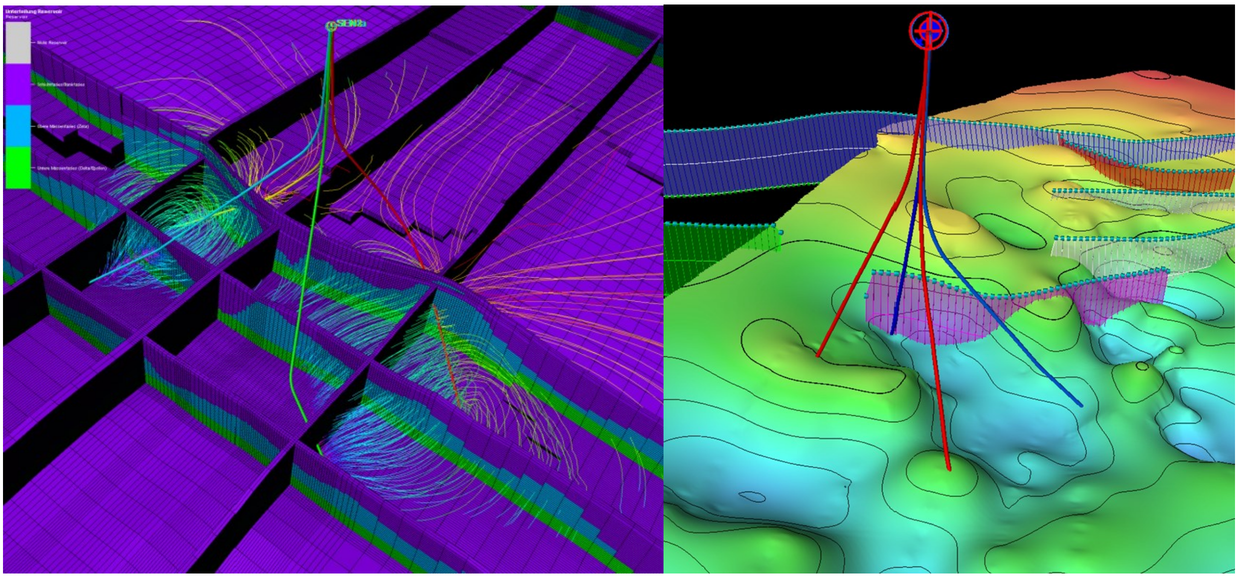

Figure 5: Modern 3D Reservoir Modelling

The now near standard implementation of Rotary Steerable Systems (RSS) for drilling geothermal wells in the Greater Munich region has enabled projects to drill multiple wells from one site (anti-collision measures), increase drilling efficiency and subsequently reduce costs (Lentsch, 2013; Lentsch et al., 2012). Early projects often opted for separate sites for the production and injection wells (Asscheim and Pullach for example), later projects such as Unterföhring executed two doublets on the same site and now project Schäftlarnstraße is undertaking 6 wells (3 doublets) from one site.

Steps are currently being made for the Schäftlarnstraße project to implement multilateral completion on a chosen well to optimize the output by reducing pressure losses. This approach is detailed further in the paper by David Lentsch (Lentsch et al., 2020).

HSE

The geothermal sector is also slowly coming into line with the oil industry in respect to on site HSE: The HSE legacies from the early water well drilling roots are slowly being shaken off, with most drill sites operating at the high HSE standard that is the norm for oil and gas projects.

Human resources

In addition to passionate and pioneering geoscientists and engineers who have led the way in developing the geothermal sector and adopting the oil and gas approaches, industry crossovers have also played a significant role. This has taken place in the form of experienced petro-geoscientists and drilling engineers moving in to the geothermal sector and association and society workshops (such as those organized by the AAPG) addressing the common workspace of the two sectors (Bendias et al., 2019).

Operator Approach

Figure 6 provides an overview of the different operators currently in Europe for Geothermal heating and cooling (EGEC Geothermal, 2019). The distribution is, at the time of writing, very even, and represents the diverse mix of operators. It also demonstrates that large private operators are yet to make significant advances into the market. This could change should larger scale play-based projects become the norm.

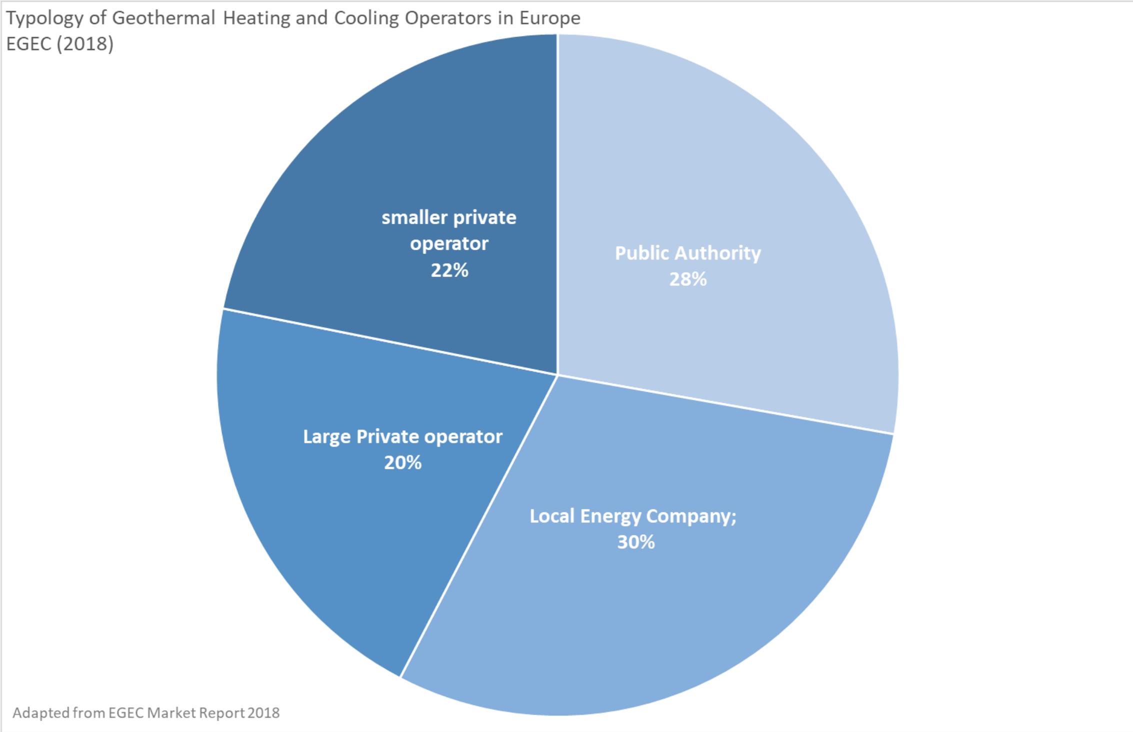

Figure 6: Typology of Geothermal Heating and Cooling Operators in Europe

2.6. -Upscaling

Exploration without Exploration

The typical approach of exploring a new prospect or play, in the oil and gas sector, is to undertake an exploration campaign. Here appraisal wells are drilled to prove the resource and to better understand the reservoir geology. The cost of the wells is offset by the potential revenue from a highly productive resource. The exploration campaign looks to deliver all drilling and reservoir engineering information required for the accurate and cost-effective planning and drilling of production wells. For a typical hydro geothermal project in Europe (and globally) pure exploration wells are not drilled as operators/projects are often small and do not have the finances for these wells. As a result the first wells drilled for geothermal projects are both exploration and production wells.

With the majority of the projects in the Greater Munich region going through one planning office, the project information held therein is significant. Geological and drilling data from over 120,000+ drilled meters has been collected. This dataset acts as an exploration dataset for planning future projects. This allows for the calibration of detailed drilling time and cost estimates (Lentsch, 2013), accurate identification of reservoir targets (Steiner et al., 2014), and identification of drilling risks (Lentsch et al., 2012). However, it is acknowledged that this situation does not allow for a level playing field in terms of market development and in a perfect world all information would be held centrally by the government as in the Netherlands, France and Denmark.

For a region or country to mitigate this risk of planning without an exploration campaign, all regional information needs to be made available for the project planner. The Paris region has been successfully developing the Dogger Formation since the 1970s, where it overcame many setbacks and managed to come through the 'Teenage Years', maturing in the 2000s and now looking towards sustainable development (Antics, 2019). In 2001 the step was made by the BRGM (The French Geological Society) to setup the Paris Dogger Database (BRGM, 2001) to store all data from the geothermal projects in the Paris region. This supports the long-term monitoring of the aquifer and extraction operations and ensures optimum conditions for future drilling (BRGM, 2001). Similarly, but on a national scale, the Dutch Ministry of Economic Affairs instigated the development of the NLOG database (TNO, n.d.) to provide information on oil, gas and geothermal energy exploration and production in the Netherlands and the Dutch sector of the North Sea continental shelf. The database is managed by TNO (Geological Survey of the Netherlands) and continually updated. All projects in the Netherlands are required to submit the data to the database in accordance with the mining act after completion. The data submission should be inside a particular time frame dependent on the type of data (for example well data must be supplied 12 weeks after drilling and geophysical data within 10 years).

Playbased Exploration

The TNO and EBN report addressing the Play-based portfolio approach (TNO and EBN, 2018), demonstrated and quantified the benefits of a portfolio approach for geothermal projects. As of today no basin wide coordinated portfolio approach has been utilized for geothermal exploration in Europe. The examples of Paris and Munich come close, but there was no one common developer. The recent work by the SWM (Farquharson et al., 2016) is the beginning of series of projects where in total 25 doubles are anticipated.

The main advantages of the basin wide portfolio approach:

- Geological risk reduction
- Optimal development strategy for the basin
- Continuous improvement through integral project development
- Cost reduction through synergy, efficiency and standardization
- Optimization of above-ground infrastructure
- Financing advantages

It is therefore recognized that larger scale regional developments have significant cost and performance benefits given the project developer has the financial resources. The examples of Munich and Paris demonstrate (to some extent) how regions can be developed either through a principal planner playing a role in the majority of projects or a centrally held and regularly update database available for all projects independent of planner or developer.

5.TEMPLATE FOR FURTHER REGION AND CITIES

This paper has discussed many of the primary problems, drivers and solutions that need to be considered for the successful further develop of the geothermal market in Europe (and globally). These are the key items which should be part of any framework to support geothermal developments in any city, region or country. Table 2 below provides a summary of these key items. An overwhelming majority of the solutions must be centrally and (most probably) governmentally instigated and funded.

Table 2: Geothermal - Problems - Drivers - Solutions

Problems	Drivers	Solutions
o High geological, drilling and exploration risk. o CAPEX, OPEX often too high, projects fail at planning stage. o High cost of single project approach, little scope for optimization. o Private developers not willing to share knowledge and experience (protect IP). o Professionalism of industry only just reaching the levels of E&P. o Investment returns can be slow. Especially for heat projects.	o An industry striving for development. Hugely passionate and motivated people. o Political Change and Climate Targets (Horizon 2020) o Social Political demand for change, 93% of German citizens support the development of green energy (Agentur für Erneubare Energien, 2018). o Market for Geothermal: Heat Demand is near 50% total energy demand. o Subsidies (MWth & MWel) to make geothermal competitive.	o Opensource geothermal information and planning Software to reduce costs. o Funding for research and innovation. o Centralized risk minimization, through exploration Insurance as in Netherlands, Belgium and Denmark. o Seismic Monitoring legislated and funded by government. o Regional initiatives such as Joint Ventures or Consortiums between all stakeholder (private and public) o Portfolio Approach.

The knowledge and experience exists within the geothermal community to implement all the required solutions. However, an open approach is required. Success breeds success and one project not sharing information could lead to the failure of a neighboring project, which can in turn have negative effects on the geothermal market of the region. Investors can loose confidence and communities can become skeptical. The geothermal market is currently too sensitive and requires a cohesive approach.

6. CONCLUSIONS

The geothermal market of the Greater Munich region provides a multitude of insights into main factors controlling the development and relative success. However, when compared to the predicted figures from the TAB report in 2003 the region cannot be classified as successful and is a long way from the 2000 MWth potential. However, despite all the setbacks which have been encountered the region continues to develop and this is due to the main factors identified in this paper.

1. Favorable geology
2. Economic viability
3. The political framework
4. Strong developer – planner partnership
5. Oil and Gas Exploration and Production Workflow
6. Upscaling

With the correct drivers and solutions in place a region can take advantage of favorable geology, to have a competitive, productive, safe and green geothermal market and unlocking the Geothermal Potential.

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