PROCEEDINGS, 43rd Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 12-14, 2018
SGP-TR-213

Upscaling of EGS in Different Geological Conditions: a European Perspective

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Keywords: EGS, ORC, Variscan reservoir, oil-well synergies, LCOE

ABSTRACT

In Europe, only a few industrial geothermal plants based on the Enhanced Geothermal System (EGS) technology (Soultz-sous-Forêts and Rittershoffen in Alsace, France and Insheim in Germany) are operating. Most of them are located in the Upper Rhine Graben and are related to the exploitation of natural fluids trapped in deep fractured hard rocks made of clastic tertiary sediments and/or crystalline rocks. The European commission decided to further explore and exploit its EGS potential by supporting the development of innovative techniques in different geological conditions. At European scale, these are deep sedimentary basins (e.g. the Southern Permian Basin area, the Pannonian Basin and the various foreland basins of the Alps and the Pyrenees) and the metamorphic and crystalline rocks of the Variscan orogen, which forms most of the bedrock of central and southern Europe. More than 70% of the overall geothermal potential of Europe is located in low permeable bedrock only exploitable by EGS technology, which allows – theoretically – a permanent heat and electricity production at any place. However, for the implementation of enhanced geothermal energy systems into our future energy supply, distribution infrastructures dealing with EGS are crucial. Only EGS makes geothermal energy - heating or heat storage – exploitable at large scale and in view of a significant market penetration.

Until now, main drawbacks of EGS are related to 1) high costs (drilling, CAPEX) and relative low experience due to only very few operating power or heat plants, 2) only very few exploitations due to the lack of available technical solutions of different reservoir types with unexceptional geothermal conditions, 3) highly aggressive fluids causing corrosion or scaling and thus damaging technical installations, and 4) the lack of a clear integration strategy in existing power or heat networks.

These gaps have to be filled by systematic studies associated with site demonstrations in different geological contexts in order to significantly extend the range of EGS in Europe.

The MEET project (Multidisciplinary and multi-context demonstration of EGS exploration and Exploitation Techniques and potentials) aims to:

(1) apply EGS techniques to a – in Europe - very common but until now nearly unexploited reservoir type, namely the different rock units of the Variscan orogenic belt. Several research and prospection wells have demonstrated the unexpected presence of hot fluids and sufficient rock permeabilities. We will explore sites, where we already have a strong heat demand for such reservoir types from existing district heating systems which have to be converted to sustainable energy systems.

(3) increase the productivity of existing geothermal power plants (Soultz sous Forêts, France) using a fractured granitic basement as reservoir rock. The re-injection of geothermal fluids with a colder temperature in combination with the latest generation of small-scale ORC units will enhance the heat and electricity production. Solutions have to be developed to avoid the scaling problem, which increases by lowering the fluid temperature.

(2) use the hot fluid of mature oil fields, where water is reinjected without using the calories. Such an enhancement through oil barrels and electricity KWh "co-production" of wells could be realized by new low temperature ORC systems, which we aim to test in French oil fields. Ultimately this could lead to a better definition of a value-creating method to assess the conversion of abandoned oil fields.

The proposed different studies clearly aim to enhance the geothermal reservoir types by new exploitation and energy production techniques with the consequence of geographically extending the geothermal heat and electricity production to be supplied to smart energy grids. The large amount of potential production sites together with the reconversion of existing wells will greatly contribute to lower the costs of geothermal energy making it economically competitive in comparison to conventional fossil and nuclear sources.

1. INTRODUCTION

The EU energy development policy is targeting both climate and energy long-term objectives having decarbonising of energy supply as one of main drivers. For convincing geothermal project developers, policy makers need relevant economic quality data for better informing potential investors and make their energy decisions easier. Levelized cost of energy (LCOE) is used for considering energy solutions and in the present case identifying at low risk further geothermal resources.

To extend the range of EGS in Europe, we are considering the three main European continental crust rock types as potential sources: fractured granites, sediments, and non-granitic basement rocks (Variscan low-grade metasedimentary and metavolcanic rocks). All the three represents 70 to 80% of EU surface as potential reservoirs. The main ambition of the initiative is to demonstrate at production scale that power and heat production from these different rock types is technically feasible and economically viable. The MEET project will primarily focus on sites that already have certain infrastructure (surface facilities, existing wells) and thus will mainly avoid large CAPEX and also on reservoirs from the Variscan orogenic belt largely outcropping through Europe.

In the framework of MEET a multi-scale approach using up-to-date maps and spatial datasets will be created in order to estimate the geothermal potential on a large scale and to identify promising areas for further exploration by using decision-support tools (national, regional, local scale).

2. PROPOSED SYSTEM DEMONSTRATION SITES IN DIFFERENT GEOLOGICAL SETTINGS

2.1 Variscan reservoirs

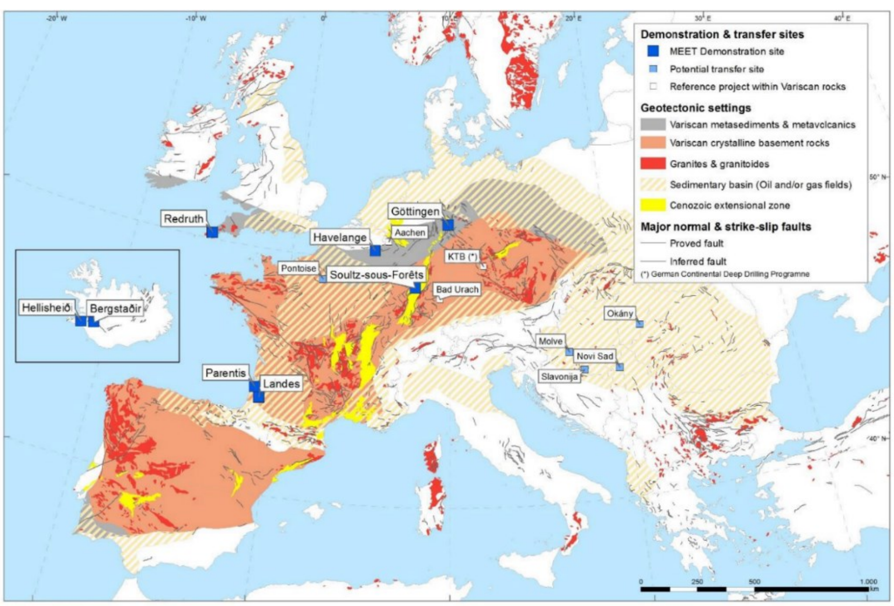
2.1.1 The Variscan orogenic belt in Europe

The Late Paleozoic Variscan orogen stretches backbone-like across the whole expanse of Europe (Figure 1) and is the youngest European orogen before the Alpine one.

The up to 2.000 km long belt is divided into zones of geodynamic significance. These zones can be correlated all over Europe and are from north to south the North-Variscan Foredeep, the Rhenohercynian, the Saxo-Thuringian, the Moldanubian and the southern Fold-and-Thrust Belt.

The assembling of paleogeographic elements by collisional deformation as well as the dismembering by strike slip faults result in a complex structure, complicated by the contrasting response of thin and thick crust to subduction and collision

The internal crystalline part comprises remnants of supra-subduction magmatic and metamorphic rocks as well as high-grade tectonic units. Shelf successions, thick sequences of clastic sediments and volcanosedimentary units were accumulated in the former external basins. Large volumes of granitic material originated in Late Carboniferous times mainly intruded in the central zones, but can be found all over the orogeny (e.g. Franke 2006, Franke et al. 2017).



Sources of geological datasets:
Asch, K. (2005): IGME 5000: 1 : 5 Million International Geological Map of Europe and Adjacent Areas. BGR (Hannover).
U.S. Geological Survey World Petroleum Assessment 2000: U.S. Geological Survey Digital Data Series DDS60: http://greenwood.cr. usgs.gov/energy/WorldEnergy/DDS-60

Figure 1: Simplified overview of the European geotectonic settings targeted by this study. The sketch illustrates the vast distribution of Variscan bedrock and sedimentary basins within Europe. Demonstration sites and potential transfer sites related to the Variscan orogen were selected to represent our four Variscan case study settings: (a) granitoide provinces, (b) sedimentary and volcanic metamorphic rocks and (c, d) overprinted areas of (a) and (b) by post-variscan extensional tectonics.

Variscan metamorphic rocks are usually not classified as potential target horizons for the exploitation of geothermal energy because they show a complex lithological and structural geology. We want to start where the consumer structure already exists, where a high demand for geothermal energy due to economic and environmental pressures exists and where the prognosis for a geothermal system is supposed to be at average. A new approach to plan stimulation actions at such sites will be developed and a new concept to create a reservoir model for economic evaluation.

2.1.2 Selected test sites of Variscan reservoir types

In regard to the development of specific geothermal systems for each of our four defined general Variscan geotectonic settings, we identified four different test sites with adequate analogue outcrop areas: (Figure 2):

(1) Variscan metamorphic (metasedimentary and metavolcanic) successions overprinted by younger (mostly Cenozoic) extensional tectonics (fault and graben systems): Target horizons consist of meta-greywackes and -sandstones, meta-carbonates, slates, meta-basalts and quartzites. Primarily the Harz-mountains, but also the Sauerland and Kellerwald serve as outcrop analogue field site for the demonstration site located on the Göttingen University campus where the Rhenohercynian bedrock (Rhenish massif) is cross-cutted by the younger Leinetal Graben Structure.

(2) Variscan metamorphic (metasedimentary and metavolcanic) successions not overprinted by younger extensional tectonics: Target horizons are primarily quartzites but also meta-basalts and meta-carbonates. Outcrop analogue field sites are the Rhenohercynian Ardennes- and Taunus-mountains of the Rhenish massif. The Havelange borehole in Belgium serves as demonstration site for which drill cores and hydraulic test data are available.

(3) Variscan crystalline basement overprinted by post-variscan extensional faults: Target horizon are fractured granites or granitoids below a post-Paleozoic sedimentary cover. Analogue field sites are the Pfälzer Wald, the northern Vosges and the Odenwald. The geothermal test site at Soultz-sous-Forêts, France acts as demonstration site possibly in comparison with the other deep geothermal sites where hot fluids from the crystalline bedrock are exploited (Landau (Germany), Insheim (Germany), Rittershofen (France) and various projects in development around Strasbourg (France)).

(4) Variscan basement not overprinted by younger extensional faults: Target horizon for the outcrop analogue study are the Carnmenellis granites outcropping in the quarries between Redruth and St. Austell, which were already under investigation in the 1980s for the Camborne project in Cornwall (Great Britain). As geothermal test site serves the United Downs Deep Geothermal Project (UDDGP) in Redruth/Cornwall, Britain, which is currently being prepared for drilling.

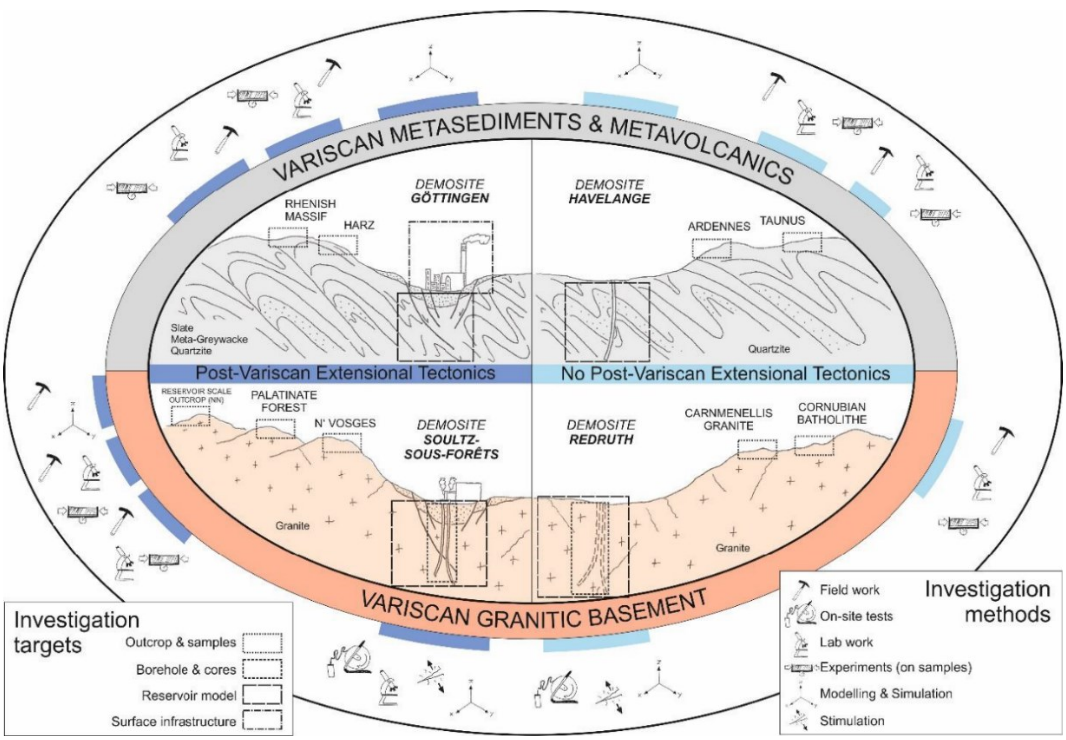


Figure 2: Schematic overview of the four representative European Variscan geotectonic settings including the outcrop analogue areas, the demonstration sites and the necessary site-specific investigation methods.

2.1.3 Methodology

To utilize the Variscan bedrock for geothermal energy production, it becomes necessary to evaluate and demonstrate how the European Variscan basement can be characterized and enhanced for deep geothermal energy production.

Our twin-track approach includes 1) multi-scale site-specific fabric, petrophysical and structural characterizations of reservoir analogues and 2) compilation and extension of all existing information at all demonstration sites.

Outcrop analogue studies need to focus both on the outcrop scale by mapping the folds and faults, the adequate structure-related paleo-geothermal and post-variscan vein systems, fault damage zones, fracture networks and the extent and distribution of different rock and alteration types. Literature, existing maps and, where available, own previous field-work, helps to identify representative geological structures in the field and to complete data during field-campaigns as well as to finally build representative structural 3D-models. Field-surveying is strongly supported by quantitative high resolution photogrammetry, which is also assisted by drones especially in large outcrops or areas of difficult access. Structural 3D-modelling will be performed to cover all fracture network related properties from the micro- to the reservoir-scale

Representative samples of selected rock types from the four representative Variscan analogue settings will be taken for lab investigation of the petrophysical and geomechanical properties both under lab and in situ conditions and will include the evaluation of fluid-rock interaction and mechanical, thermal and chemical effects of fracture healing. This will be accompanied by mineralogical and rock microfabric analysis to understand the processes and influences on the petrophysical properties. Lab investigations of the samples comprise petrophysical measurements (grain and bulk density, porosity, permeability, compressive and shear velocity, thermal conductivity, thermal diffusivity, heat capacity and radiogenic heat production) as well as rock mechanical property characterizations (UCS, tensile strength, shear strength, cohesion, coefficient of friction, poisson ratio, Youngs modulus, bulk modulus, shear modulus, compressibility, Biot-Willis- and Skempton coefficient). These data sets will be completed by fracture investigations and fluid analyses. All the results will be compiled in one comprehensive dataset as demonstrated in Bär et al. (2017).

This data basis will serve as input parameters for advanced thermal, hydrological, mechanical and chemical (THMC) simulations which allow to assess the efficiency of stimulation operations and their sustainability at the different test sites. Based on this THMC-simulation concepts and experiences of in-situ tests at some of the different geological settings, strategies and operational recommendations (guidelines) for stimulation actions of Variscan reservoirs will be developed.

Besides the detailed fracture characterizations for all the sites the fracture/fault zone geometry will also be studied by multi-offset Vertical-Seismic-Profile (VSP)-data. Based on several existing offset-VSP datasets collected in the Soultz wells, innovative seismic data processing and inversion methods will be applied to image the large scale structures beyond the borehole wall in order to get a 3D geometry of the fracture/fault network in the granite around the well.

Additionally, small scale modeling will be carried out to evaluate parameter changes measured during the lab experiments as for example fracture propagation, permeability and fluid flow development, stress perturbation and induced seismicity. The final reservoir scale 3D-geothermal models of the four different Variscan reservoir types depend on the available information density will be the basis for dynamic simulations of the subsurface response of the different reservoir enhancement methods for each demonstration site. Thus, individual modeling strategies will be defined depending on the geological local conditions and available and generated data background to also model production scenarios.

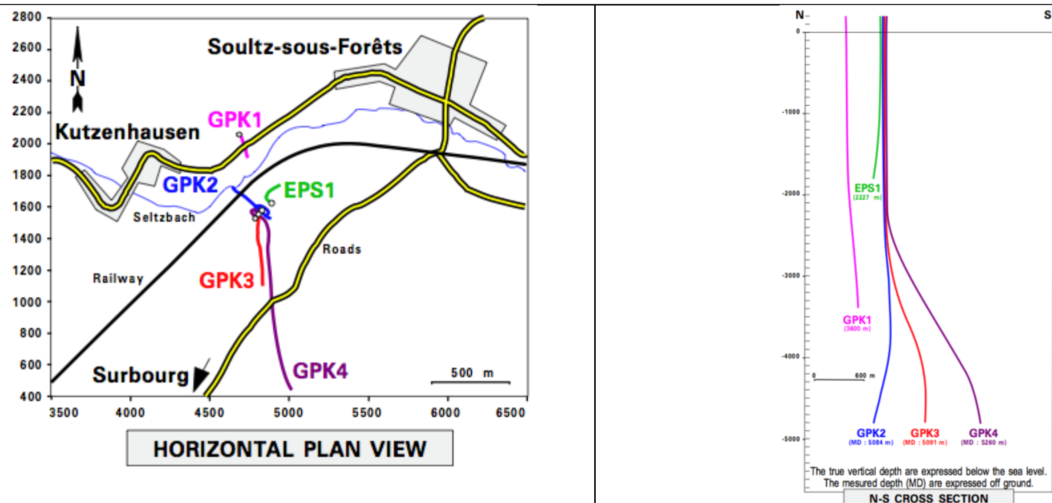
2.1.4 Upscaling of existing power plants: demonstration at the Soultz sous Forêts site

The ambition is to increase the productivity of existing geothermal power plants (Soultz sous Forêts, France) in fractured granitic basement using colder temperature reinjection and stimulation. The objective is to enhance productivity of the EGS running plant by a factor 2 to 3, without requiring hydraulic fracturing.
The reinjection of cold water with 40°C in surface in hot medium with 200°C at 5,000 m deep was never tested during exploitation in crystalline rocks.

We plan to enlarge the geothermal productivity of naturally fractured reservoirs embedded in the deep-seated geology of the Upper Rhine Graben (URG) located in Europe. Several geothermal plants are exploiting the heat carried by the natural geothermal fluids circulating within the fracture/fault system (Genter et al., 2010). They correspond to hidden fractured crystalline basement located in France and Germany (Soultz-sous-Forêts-SsF, Landau-L, Insheim-I, Rittershoffen-R). Those plants produce electricity (SsF, L, I) or heat with temperatures higher than 165°C at surface (R). The general geothermal scheme of such URG geothermal plant is made of deep wells drilled in a Paleozoic variscan granite reservoir at 5 km depth. The current geothermal site of Soultz sous Forêts is made of one production well GPK-2, producing about 30 kg/s of a geothermal fluid at 160°C at surface (Koelbel and Genter, 2017). The Soultz sous Forêts wells have been stimulated by various thermal, chemical and hydraulic stimulations for enhancing its low natural permeability (Schill et al. 2017). During hydraulic stimulation, only some scarce induced seismic events were felt by the local population (Cuenot and Genter, 2015).

The initiative will develop a methodology for an optimized targeting of the borehole trajectory, leading to the ability to reach produced mass flow rates ranging from 60 to 100 kg/s by taking into account the real geological conditions of fractured crystalline rocks and minimizing the possible environmental impacts.

Figure 3: The Soultz-sous-Forêts power plant. On the left, the reinjection well GPK-3 well head, in the middle the GPK-2 production well head with the down-hole pump motor, and on the right the PORC plant. Credit photo ESG.



a b

Figure 4: a) Horizontal map (a) and vertical cross-section (b) showing the well trajectories at the Soultz geothermal site.

Since the geothermal water shows high salinity with 100 g/l, the heat of the geothermal water is exploited via heat exchangers by an ORC unit of 1.7 MWe gross power (Figure 3). The brine is reinjected in the granite reservoir at 70°C into two reinjection wells, GPK-3 and GPK-4 (Figure 4a, b). An ORC system (Organic Rankine Cycle) is a technology that converts heat into useful work, here electric power. It uses a thermodynamic cycle, as it is the case for refrigerators or air cooling systems for example. A fluid ("working fluid") is circulated and pressurized thanks to a pump in a closed loop. The fluid is heated up and vaporized in a hot heat exchanger (the "evaporator"), then drives a turbine before being condensed in a cold heat exchanger (the "condenser") and pumped again. The hot source, the geothermal fluid, is circulated on the other end of the evaporator to supply the thermal energy to the system. The turbine turns an electric generator to produce electricity. And finally a cold sink is provided to the condenser to cool down the ORC. It may be done with cold water or with ambient air for example (Figure 5).

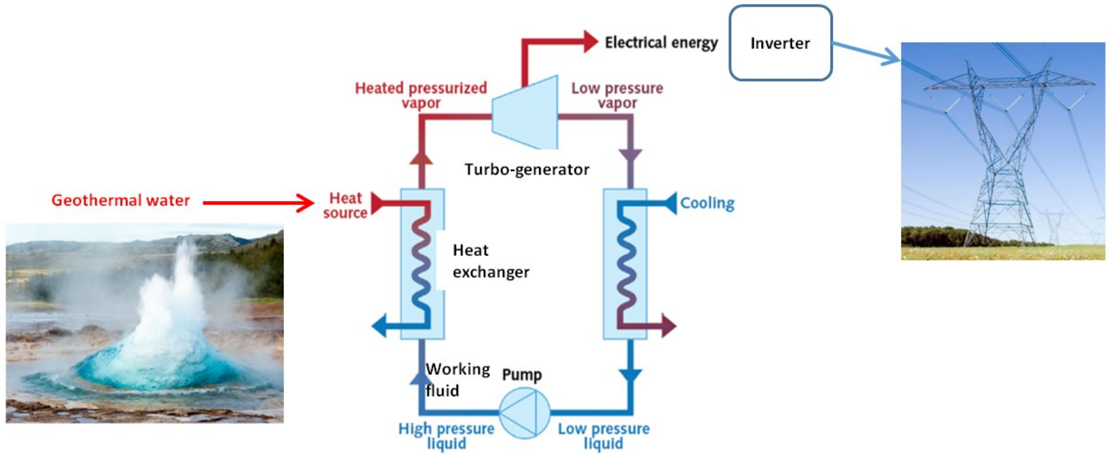


Figure 5: ORC principle and application to geothermal heat source.

We intend to reinject cold water with 40°C in surface in hot medium with 200°C at 5,000 m deep during the geothermal exploitation. This demonstration project starting mid 2018 will allow an increase of heat production from 3.5 to 8 MWth from the existing URG plant like Soultz sous Forêts by using the same geothermal installation, thus with no additional CAPEX. In parallel to enhance geothermal production, we will investigate in-depth all the THMC processes that could occur from various geochemical, geophysical and physical monitoring in order to evaluate the thermal impact of such cold reinjection on the reservoir.

It is anticipated to observe thermal contraction in the casing as well as some mineral precipitations (scaling) due to the reheating of the brine during its reinjection. The main challenges for reinjecting at low temperature geothermal brine into a hot granite reservoir are the possible thermo-mechanical effects that could lead to the development of induced micro-seismicity. It was already observed in the nearby Rittershoffen geothermal site during a thermal stimulation done in 2013 when the native brine has been reinjected at 10°C and lower well-head pressure in a granitic reservoir lying at 170°C (Baujard et al., 2017; Maurer et al., 2015). However, none seismic event was felt on surface by local population. An improvement of the well injectivity index has been shown after this thermal stimulation. Moreover, the reinjection of cold brine at 40°C having a salinity of 100 g/l could be at the origin of several problems encountered like mineral precipitation (scaling) that could plug the fracture system at the borehole wall and then seriously reduced the well injectivity (scaling). Moreover, due to the granitic composition of the reservoir, it has been observed that scaling could concentrate radioelements like radium or lead (Cuenot et al., 2015). In order to reduce scaling, inhibitors will be used as this has been successfully applied already in the EGS plants of the URG (Scheiber et al., 2015). By decreasing the reinjection temperature at industrial flow rates, we could observe a non-expected thermal effect at the production well that could contribute significantly to reduce the overall electrical production of the plant.

2.2 Use of hot fluids from mature oil reservoirs and power production with ORC

The objectives are to produce 15MWth from oil well enhanced by geothermal, validate an LCOE range of 0.07 to 0.2 $/kWh (compared to 0.11-0.3 $/kWh for current EGS running plants) and deliver a report on huge potential of replicability (up to + 1GWth in 2030 and +10 GWth in 2040 in EU).
Regarding heat production with doublets, the main bottleneck is the cost of the wells that typically represent more than 50% of the project costs. The same applies to electricity.

Thousands of onshore wells are present in Europe, typically producing what is called mature fields, meaning that the wells have been on production for a long time. The typical production pattern of most oil producing wells displays an increase of water with time, from 0% initially to 100% of the fluids produced at the end of the well life. In "mature" European oil provinces it is expected that wells are now producing much more water than oil, with an average water / fluid ratio higher than 90%. Oil reservoir depth range is between few hundred meters to a few thousand meters depth; hence the produced fluid temperature at surface can be up to 90°C. This hot water is often reinjected into the reservoir to increase production through pressure support and sweep, therefore the calorific energy of the water is wasted in most cases. On the other hand, mature reservoirs means depleted pressure, hence the need for a method to artificially lift the fluids (oil and <water) up the well: Electrical Submersible pumps and pumping units are installed of most of mature wells that are not naturally flowing. These pumps are using a lot of electricity (power range 100 to 200 kW) and electricity often represents the largest operating cost for these pumped wells, typically 25% of operating cost.

MEET plans to leverage of the recent success that VERMILION had in France in recovering heat from 2 producing oil fields. On the Parentis oil field in SW France, 60 wells producing a total of 400 m3/h water at 60°C water have been used to heat up 8 Ha of tomato greenhouses since 2008, creating more than 100 jobs. In La Teste in SW France, a single injector well yields 40 m3/h at 70°C which is enough to cover 80% of the heat needed for 450 new flats. These 2 projects demonstrate that recovering heat from produced water creates value and jobs, at any scale (single well or full field).

In parallel with the recovery of this heat for heating, MEET will also demonstrate the possibility of injecting renewable electric energy on a small scale with a robust ORC principle well known for local needs and linked to the network. The advantage beyond the state-of-the-art is the use of a well-known technology dedicated to industry or massive geothermal energy recovery adapted to a small-scale need like a neighborhood.

The capability for running an ORC system using a small water flow and low temperature water represents a differentiating factor of ENOGIA's technology. This explains why the target of MEET project is to adapt the existing small scale ORC technology from ENOGIA to the specificity of the geothermal application. Key point for the adaptation of the ORC range of ENOGIA is the identification and validation of a suitable heat exchanger technology that will be able to resist to geothermal water chemistry in different reservoirs conditions (temperature range, geochemical fluid composition, dissolved gas content, pressure). Thus, ENOGIA and the Innovation Center Island institute will combine their respective expertise for improving heat exchanger technology adequately adapted to different kinds of reservoirs. For example, in granite, it corresponds to very saline brine where corrosion issues are known and must be solved to overcome the deployment of such technology. In sedimentary formations, the exploited fluid is a mixture between a geothermal water and crude oil. In volcanic rocks, the occurrence of non-condensable gases (e.g. CO_2 and H2S) in geothermal fluids is very common and could seriously damage by corrosion steel and alloy materials

ORC will be connected to producing oil wells with high water cuts (>90%BSW). These pilots will validate the technical concepts and the expected electrical yield at such temperature range. It will open new opportunities: possible added revenue from electricity sales or self-consumption benefits during the "co-production" phase. It will also help, together with the heat evaluation, assessing the value of converting an oil field to a geothermal one at the end of its economic (oil) life.

3. DATA BASIS AND GIS-BASED ANALYSIS

For areas suitable for EGS technology, mapping the geothermal resource will be fairly dependent of how the local geological conditions (stress field, temperature field, rock composition, range of existing permeability, reservoir properties) could contribute to provide enough heat by means of stimulated wells but also all the socio-economic needs and various constrain on surface, the environmental and social issues, the regulatory framework, and the geothermal feed-in tariff.

Today, there is no EGS universal map of Europe except the regional or thematic maps done in the framework of EU projects (www.engine.brgm.fr, www.transenergy-eu). Different types of geothermal-related map tools and map viewers were realized over the past 5 years (e.g. Thermomap, GeoElec) showing geothermal capacity at various depths. Some map tools dedicated to geothermal potential make available spatial data about user infrastructure, energy demand, predicted minimum LCOE for geothermal projects and further aspects of geothermal energy use (e.g. GeoDH Europe). One of the major projects of the Geothermal ERA NET was focused on the concept and realisation of the European Geothermal Information Platform (EGIP), providing diverse geospatial data and maps among other records. More advanced users can access such primary spatial data that act as input for estimating the geothermal potential, e.g. data about the recent stress field, heat flow, geothermal gradients, geotectonic zones and structures as well as hydrogeological, geotechnical, geophysical and petrophysical parameters. At the same time, several initiatives (e.g. EuroGeoSurvey) are engaged in the definition of data and metadata standards, the homogenization of heterogeneous national data and the provision of web-based viewers, analysis tools and data platforms (INSPIRE, InGEoCloudS, EGDI, OneGeology) on European level to address the strong needs for data and metadata standardization and documentation in Geosciences all over Europe.

The aforementioned (geo)spatial records at European scale are provided by different European and national institutions, hence they vary in coverage, detail and resolution as well as in availability, data format, coordinate system and documentation. Due to the diverse thematic backgrounds (energy issues, environmental aspects, geoscientific approaches) of these spatial datasets, they might differ in content (categories, parameters, subdivision) and vocabulary. These non-uniform data provenance causes variations in accuracy, completeness and provided (technical) data formats. Therefore, the user/client has to conduct an intensive data search and comparison to find and to select appropriate information. While there are various potential maps at regional and national scale, the number of geothermal potential maps on European scale is still limited. The existing ones are based on differing approaches (number, type, quality and completeness of input data, weights, overlaying procedure), but focus mainly on "traditional" high-enthalpy sites, such as volcanic areas, sedimentary basins and rift zones. Parameters (e.g. the anisotropy of rocks caused by deformation structures as cleavage, folds, etc.) that are relevant for the analysis of "unconventional" low-enthalpy regions were not taken into account.

Most of the existing web-based map viewers or map tools related to geothermal issues on European scale have to be rated as "monothematic" tools because of their limitations in terms of information content. Some were just developed for very shallow applications (Thermomap), others show the geothermal potential at greater depths, but whether geological nor infrastructural datasets or just geothermal infrastructure (Plant Map). Some of the more complex solutions were designed for a wide range of topics, however contain just a few entries provided by single projects or individual countries (EGDI). Since none of the existing tools has given the user a high degree of flexibility to configure the representation of the data (colours, categories), to combine spatial data from different sources independently (e.g. subsurface characteristics, user infrastructure and environmental issues) or to access and query associated databases, the above mentioned EGIP was started as a pilot study. Though the ongoing development and operation of the platform upon the completion of the project might be covered just partly within the lifetime of the subsequent GeoERA activities.

We will create a Web GIS, based on state of the art, open source technologies, that allows the visualization and explorative analysis of small-scale data from our demo sites (e.g. user infrastructure) in combination with major large-scale spatial information relevant for geothermal activities. Further, links to web-based viewer related to geothermal records on national or smaller level will be provided. The application aims to enable users to explore the characteristics of meaningful input data and GIS analysis strategies of our demo sites and to transfer the concepts to promising targets in similar geotectonic settings. Implementing this application, we will analyse existing open source technologies for data management, query, visualization, and dissemination tasks and rely on open standards e.g. from OGC and W3C.

Results will be provided to the community by publishing software created under open source license. The developed potential map and links to web-based viewer related to geothermal records on national or smaller level will be included. Finally, we will work out recommendations for the future operation and implementation of the web application into existing European spatial data infrastructure.

4. DECISION MAKING SUPPORT TOOL

For economic and environmental assessment of EGS integration into energy systems the Decision-Making Support Tool for Optimal Usage of Geothermal Energy (DMS-TOUGE) will be developed. The DMS-TOUGE will among others, ensure knowledge transfer and cooperation between users, industry and science community. The DMS-TOUGE will analyse and quantify influencing factors on decision making regarding investment in EGS. The DMS-TOUGE among many, accounts for: different possible scenarios and accordingly uses forecasted data which can occur during the operation lifetime of EGS technology, proximity of nearest suitable power system grid where EGS could be integrated in, proximity of nearest suitable district heat system where EGS could be integrated in, proximity and availability of cooling water, possibility for usage of geothermal energy for agricultural and touristic needs, geopolitical and legislative environment, possibility of usage of waste communal water from near cities as working fluid in EGS and also possibility for underground heat storage on borehole sites. Other factors not anticipated at this time will be also investigated and accordingly implemented into the DMS-TOUGE. Generally, the main core of DMS-TOUGE, a mathematical program, will be convex and will provide global optimum (strong duality and integrity of the results will be of high importance (Rockafellar, 1974). The main features of DMS-TOUGE are shown in figure 6.

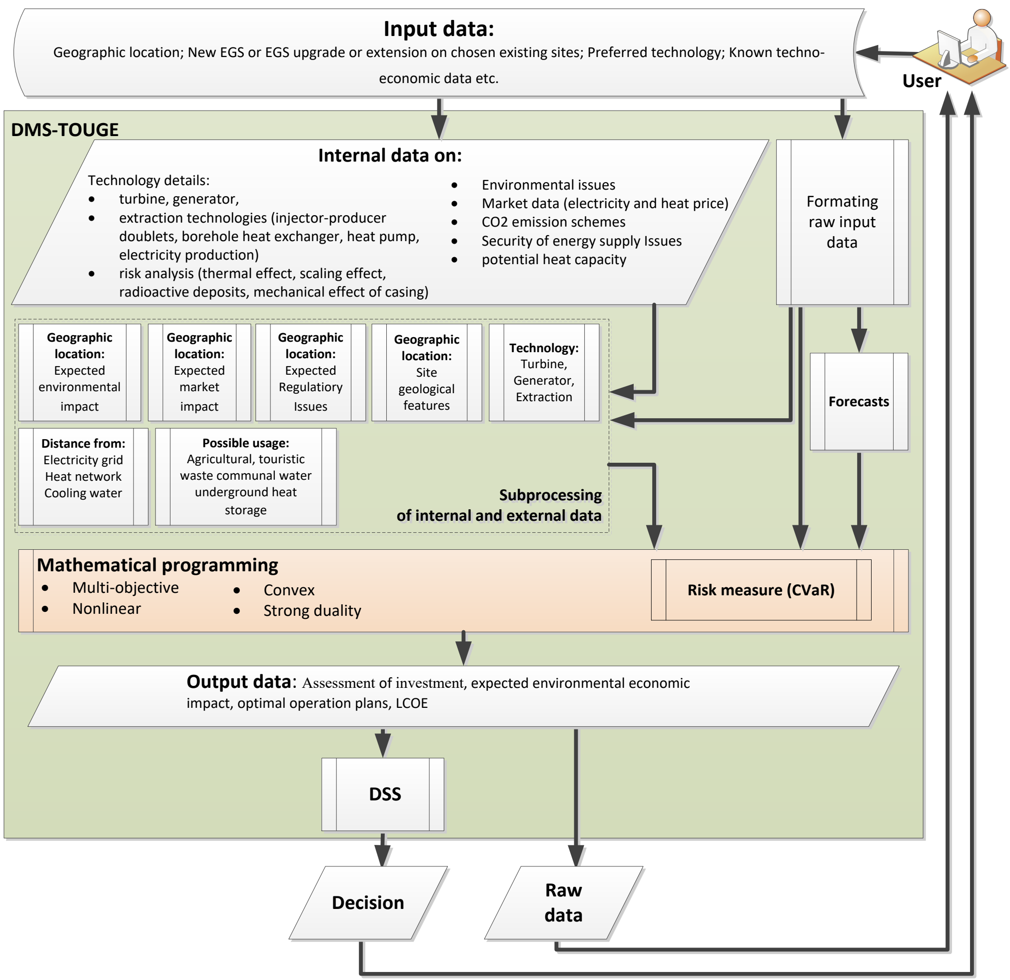


Figure 6: Sketch of the main features of Decision Making Support tool DMS-TOUGE.

DMS-TOUGE will be capable of site specific environmental and economic analysis of: existing infrastructure or future facilities, extension or upgrade, co-use/re-use of existing boreholes, different geological features such as sedimentary rocks, granitic rocks, volcanics and potential geothermal wells. The DMS-TOUGE will use optimisation techniques (such as linear, mixed integer linear or nonlinear programming) and heuristic techniques (such as genetic algorithms or neural networks) which will be also considered. DMS-TOUGE will be capable to use both external data and internal data, depending on amount of data entered by user, such as: heat capacity, electricity and heat price, injection water flow rate values, technology details such on turbine, generator type, extraction technologies (injector-producer doublets, borehole heat exchanger, heat pump, electricity production) risk analysis (thermal effect, scaling effect, radioactive deposits, mechanical effect of casing) or environmental data (CO_2 emission schemes, security of energy supply issues, potential heat capacity). The DMS-TOUGE main core, a mathematical program, will use method published (Soldo and Alimonti, 2017) which will be improved further by quantifying different extraction technology results (injector-producer doublets, borehole heat exchanger, heat pump, electricity production).

The main environmental issues related to the reinjection of cold water into deep hot granite generate some impacts for the geothermal exploitation and thus could influence negatively the whole economy of a geothermal project. These issues will be accounted for and modelled with special care. DMS-TOUGE will be capable to tell if the costs of environmental issues are counter balanced by the positive thermal exploitation of the plant that will produce more energy than expected. All those environmental costly issues will be accounted for by the DMS-TOUGE by its internal subprocessing in terms of cost and benefits due to the additional power production recovered at low temperatures.

In parallel, and as an integral part of the DMS-TOUGE core, any possible risks will be analysed such as market (price) risks and technical issues: thermal effects, scaling effect, radioactive deposits and mechanical effect of casing through the CVaR risk measure which will be subprocesses of main core. Technical issues and risk of escalating costs needs to be managed and limited since of the potential damages likely to take place on an operational plant by reinjecting at low temperature.

Finally, DMS-TOUGE will provide the optimal dispatch, recommendations or optimal projections over the course of EGS lifetime.

DMS-TOUGE will be verified and validated based on comparison between tool output and real life expert analyses on exiting operating EGS sites. Output data of DMS-TOUGE will be available as raw data or in a form of a decisions suitable for decision makers. The raw data will be processed by a special subprocess, a separate decision support system (DSS), into a decision (see Figure 6).

DMS-TOUGE will be used to generate several layers for mapping (of the main promising European sites where EGS can or should be implemented in a near future) in different resolutions: EU wide layer, layer considering different geologic features and pilot site layer and provide the valuable information on economic and environmental assessment of EGS sites considering site specific environmental, techno-economic, geological and other risks (see Fig. 1).

5. CONCLUSIONS

The MEET project aims at an important cost competitiveness of geothermal energy and a drastic financial risk reduction for potential investors.

The approach is primarily based on using existing infrastructures avoiding the necessary drilling phase, which represents more than 40% of the CAPEX in geothermal power generation.

The proposed techniques and methods allow exploitation of geothermal resources in a variety of geological contexts like Variscan orogenic belt, intracratonic basins, granitic massifs affected or not by polyphase tectonic deformation. Altogether, the terrains investigated cover an area larger than 70% of the European territory. This last point demonstrates the drastic market penetration compared to the number of existing power plants installed at present on areas with very specific geological settings.

MEET will evaluate the technical and economic feasibility of new reservoir types as well as the enhancement of the productivity of existing EGS-power plants and will disseminate the results to decision makers by a variety of tools like a multiscale mapping tool for future exploitation sites as well as decision maker tools for future investors.

It is expected that the associated market growth will significantly speed up the current annual 2-4%. The total amount of jobs created at the end of MEET, comprising the enhancement of energy production for local needs, technology development, services, and the co-production methods in mature oil fields is expected to range between 140 and 260 jobs. Beyond MEET, just by taking into account the co-production of energy from mature oil fields on a basis of a hundred jobs per demonstration site and a total of several hundred of reusable oil wells shows already a serious market potential and great perspectives in terms of CO_2-production savings.

ACKNOWLEDGEMENTS

This work was done in the framework of the MEET EU project which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 792037. The Hauts de France region and the Universitätsenergie Göttingen GmbH are kindly acknowledged for financial support during elaboration of the MEET proposal.

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