MEET Project: Toward the spreading of EGS across Europe

Eléonore Dalmais[1], Albert Genter[1], Ghislain Trullenque[2], Eric Leoutre[3], Bernd Leiss[4,5], Bianca Wagner[4,5], André Charles Mintsa[6], Kristian Bär[7], Ivan Rajsl[8]

[1] Électricité de Strasbourg Géothermie, Bat Le Belem, rue de Lisbonne 5, FR-67300 Schiltigheim, France

[2] UniLaSalle, GEOS department, B2R team, 19 rue Pierre Waguet, FR-60000 Beauvais, France

[3] Vermilion REP SAS, 1762 route de Pontenx, FR-40161, Parentis-en-Born, France

[4] Geowissenschaftliches Zentrum der Georg-August-Universität Göttingen, Goldschmidtstr. 3, DE-37077, Göttingen, Germany,

[5] Universitätsenergie Göttingen GmbH, Hospitalstrasse 3, DE-37073 Göttingen, Germany

[6] ENOGIA, 19 avenue Paul Heroult, FR-13015, Marseille, France

[7] Department of Geothermal Science and Technology, Institute for Applied Geosciences, Technische Universität Darmstadt, Schnittspahnstr. 9, DE-64287 Darmstadt, Germany

[8] Sveuciliste u Zagrebu Fakultet Elektrotehnike i Racunarstva, Unska 3, HR-10000, Zagreb, Croatia

eleonore.dalmais@es.fr

Keywords: EGS, ORC, Variscan basement, geothermal – oil coproduction, Europe.

ABSTRACT

The MEET Project aims at boosting the development of EGS across Europe in various geological contexts (sedimentary, volcanic, metamorphic and crystalline) by different approaches. This project, funded under EU Horizon 2020 grant program, has started in May 2018 and will last until October 2021.

In regard to temperature, the MEET consortium will jointly demonstrate the opportunity to use proven low temperature resources (<90°C) from existing deep wells by finding the best material to avoid scaling and corrosion issues, by minimizing thermo-mechanical impacts in the cooled reservoirs (e.g. induced seismicity) as well as by testing innovative mobile ORC (Organic Rankine Cycle) to boost the electricity production.

These low temperature resources will be provided by using oil wells or by lowering the reinjection temperature of operating EGS plants. The use of such existing wells will diminish the upfront investment, thus de-risking EGS and lowering their LCOE.

In regard to mass flow, geological investigation of Variscan metasediment together with outcropping crystalline rocks will help the development of the enhancing strategies in such geological settings which are widely spread across Europe. Enhancement of permeability through the application of soft chemical stimulation concept will be carried out on new geothermal boreholes drilled in late Variscan granites in Cornwall.

To support this program, various demo-sites have been selected to perform studies and experiments. These demo-sites represent various geological settings widely present in Europe: granites in Cornwall (UK) and Soultz-sous-Forêts (France), metamorphic sedimentary rocks in Havelange (Belgium) and Göttingen (Germany), oil field in Paris and Aquitanian sedimentary basins (France) and volcanic rocks in Reykjanes (Iceland). Finally, a map at European scale of all the compiled geological and technical information along with the development of a decision making tool will provide a useful mean to assess where future capacities should be installed.

1. INTRODUCTION

The MEET project or "Multidisciplinary and multi-context demonstration of EGS Exploration and Exploitation Techniques" designed for different geological conditions is aiming to demonstrate the geothermal potential of Europe from real projects in relevant industrial environment for attracting investors. Thus, to enable the development and the market penetration of EGS geothermal energy, several demonstration sites show the feasibility by enhancing the heat use and/or by producing electricity in different geological contexts (Trullenque et al., 2018) and by the upscaling of EGS in different geological conditions at European scale.

The MEET project primarily focuses on sites that already have certain infrastructure (surface facilities, existing wells) and thus mainly avoids large CAPEX. Reservoir types from the Variscan orogenic belt which are largely outcropping through Europe are selected.

2. OPTIMIZATING LOW TEMPERATURE RESOURCES

One of the key challenges for usage of low temperature resources is the availability of a local heat user. To overcome this challenge, MEET aims at developing a mobile small scale ORC which will be able to produce electricity from a temperature range of 70 – 90°C which can easily be connected to an existing well.

The idea is to adapt an existing ORC technology to the specificity of geothermal application, especially through the sourcing and testing of adapted, cost-effective, heat exchangers technology. The main challenge consists in the ORC being compatible with geothermal water chemistry variability originating from various geological conditions. To achieve this, experiments are performed on potential material candidates in both laboratory and on-site tests. The on-site tests will be performed at different geothermal environments to obtain a more comprehensive overview of which heat exchanger materials are eligible for a given environment. In order to be able to respond to the different configurations representative of the conditions of the geothermal resources present in Europe, the electricity production is evaluated on three main types of geological settings:

- Granitic: on existing EGS plants,
- Sedimentary: on existing oil fields,
- Volcanic: on existing geothermal power plant.

For each of these three types, one or two sites with different chemical, temperature and flow characteristics will be tested. To cover these sites with the necessary reactivity and flexibility, three mobile and autonomous 40 kW ORC units with integrated air condenser, installed on a truck's trailer will be designed and manufactured. To optimize the operation of the ORCs on each of these sites, their heat exchangers and turbine blades will be adapted.

2.1 ORC operation on existing EGS plants

In the Upper Rhine Graben, existing EGS plants usually exploit temperature ranging from 150-170°C at production to 70°C at reinjection (Figure 1, Baujard et al., 2018). Indeed the very saline brine circulating in deep seated granite induces scaling and corrosion issues in surface equipment (Mouchot et al., 2019). The reinjection temperature is the key factor that controls the scaling formation and decreasing temperature may certainly introduce new scaling such as silica.

The MEET project aims at demonstrating the feasibility of decreasing temperature at reinjection down to 40°C. This will be achieved in two steps:

- A first test has been attempted on 10% of the flow rate. The heat exchanger was designed with several tubes alloy in order to determine the best trade-off between corrosion resistance in Upper Rhine Graben conditions and economical aspect (Figure 2). This alloy selection will also assess the impact of metallurgy corrosion on scales. (Ravier et al., 2019). The scaling and corrosion phenomena will be then investigated in great detail from the microstructural and geochemical point of views in order to understand all interaction processes involved and define adequate way to exploit the geothermal brines at low temperature (Mouchot et al., 2019). The heat exchanger has been commissioned on Soultz site by January 31st 2019and will be running until May 2019 (Ravier et al., 2019).

Figure 1: The Soultz power plant producing electricity (source: GEIE EMC)

Figure 2: Test heat exchanger installed in Soultz power plant on 2019 (Ravier et al., 2019)

- If this proves concluding, a second test at full flow rate will be attempted. The additional calories will be valorised with a mobile ORC that will generate electricity at 70°C.

In parallel to this energy optimization, a specific monitoring network will be deployed to record the effects of cold reinjection in the reservoir. This monitoring will be achieved with a seismological surface network and pressure measurements in peripheric wells together with a fiber optic system in order to evaluate the thermo-mechanical impact in the reservoir. A first fiber optic deployment in an observation geothermal Soultz well has already been done in the framework of MEET (Figure 3).

Figure 3: Deployment of a fiber optic in a Soultz geothermal well by Febus Optics, September 2018

2.2 ORC operation on oil fields wells

A huge number of wells exist in Europe for oil and gas exploitation, where fluid temperature usually ranges between 20°C to 90°C. Given the fact that the oil-water ratio diminishes during reservoir exploitation time and that in mature fields like most of European ones, wells usually produce more than 90% of water, taking advantage of these wells will provide important additional geothermal capacities to Europe at low capital expenditure. In these conditions, well life extension by valorising geothermal energy becomes economically interesting. This last point is of crucial importance in France where a law has been voted in 2017 to plan a progressive stop of oil and gas production by 2040. A conversion of oil fields into geothermal ones is in this case an elegant solution to ensure a long term value of the assets.

The MEET project aims at demonstrating the feasibility of oil and geothermal energy coproduction. This will be assessed in different steps:

- Vermilion company, the first oil producer in France, has reviewed its assets in this country in order to quantify the thermal power of wells. Two wells and one oil depot have been selected for test sites (Paris and Bordeaux areas);

- In order to define the appropriate metallurgy for heat exchanger components, a corrosion experiment based on coupons installed in a pipe close to the wellhead on these demo-sites is running at present. These coupons have been installed and tested in a dedicated rack provided by ICI for 3 months in a Cazaux oil well (Figure 4). Seven different materials have been tested for corrosion issues: stainless steels (5), Nickel alloy (1) and plastic (1).

Figure 4: a set of 7 coupons installed in a dedicated rack for corrosion study installed in a Cazaux oil well (Source: Vermilion)

- a demonstration of heat and power production will be carried out in these demo-sites . At the oil depot site, the heat will be extracted and provided to a local end user. On the two selected wells, a small-scale mobile ORC will be connected to the well heads in order to produce electricity from brines at 90°C. These tests will last 6 months in order to analyse robustness and performance of the system. These pilots will validate the technical concepts and the expected electrical yield at such temperature range. ORC design and pre-installation are in progress for the oil wells demo sites in the Bordeaux and Paris sedimentary basins. ORC will be installed on sites and then tested from summer 2019.

- based on the previous test, an economical analyse will be performed and the profitability of such coproduction will be discussed. It will also serve as case study to set up a Decision Making Support Tool to identify optimum scenario for converting oil fields into geothermal ones.

2.3 On volcanic areas

The chosen demo sites in volcanic area are located in Iceland. The high non condensate gas content of such geothermal brines is challenging and the expertise of Icelandic know-how on corrosion issues will ensure that adequate alloy and design are chosen for the heat exchangers. Whereas one test well is coming from a well-known geothermal field, namely Reykjanes, the other test well is located in a local farm. Showing the potential in electricity generation at this small scale could boost local electricity production with an easy replication in numerous insular locations. The coupons test experiment has already been done at Reykjanes site and corrosion analysis is on-going.

3. APPLYING VARISCAN ROCKS FOR EGS IN EUROPE

Development of EGS at existing infrastructure sites can boost the geothermal energy market penetration on a short term basis. However, improving the knowledge to exploit EGS-reservoirs is mandatory to develop geothermal usage on both long term and large geographical extend.

In that perspective, different MEET subprojects aims at investigating potential reservoirs in the large areas covering Variscan basement of Europe with its granitic, folded and thrusted metasedimentary rocks (Trullenque et al., 2018). To that purpose, a specific approach combining demo sites and outcropping analogues has been developed (Figure 5, Figure 6).

3.1 Geological settings investigated

(1) Variscan metamorphic successions overprinted by younger extensional tectonics: Target horizons consist of meta-greywackes and -sandstones, slates, meta-carbonates, quartzites and diabase. Primarily the Harz-mountains, but also the Rhenish massif serve as outcrop analogue field sites for the demonstration sites located on the Göttingen University campus where the Rhenohercynian fold and thrust belt bedrock is overprinted by the younger Leinetal Graben structure.

a) Fracture zone in a granite at outcrop scale, Noble hills, US

b) Detailed on secondary minerals (quartz, iron oxides) associated to a fractures zone in granite, Noble Hills, US

Figure 5: Structural (a) and fracture hydrothermal alteration (b) investigations in Death Valley, an analogue Soultz site related to granitic fractured reservoir

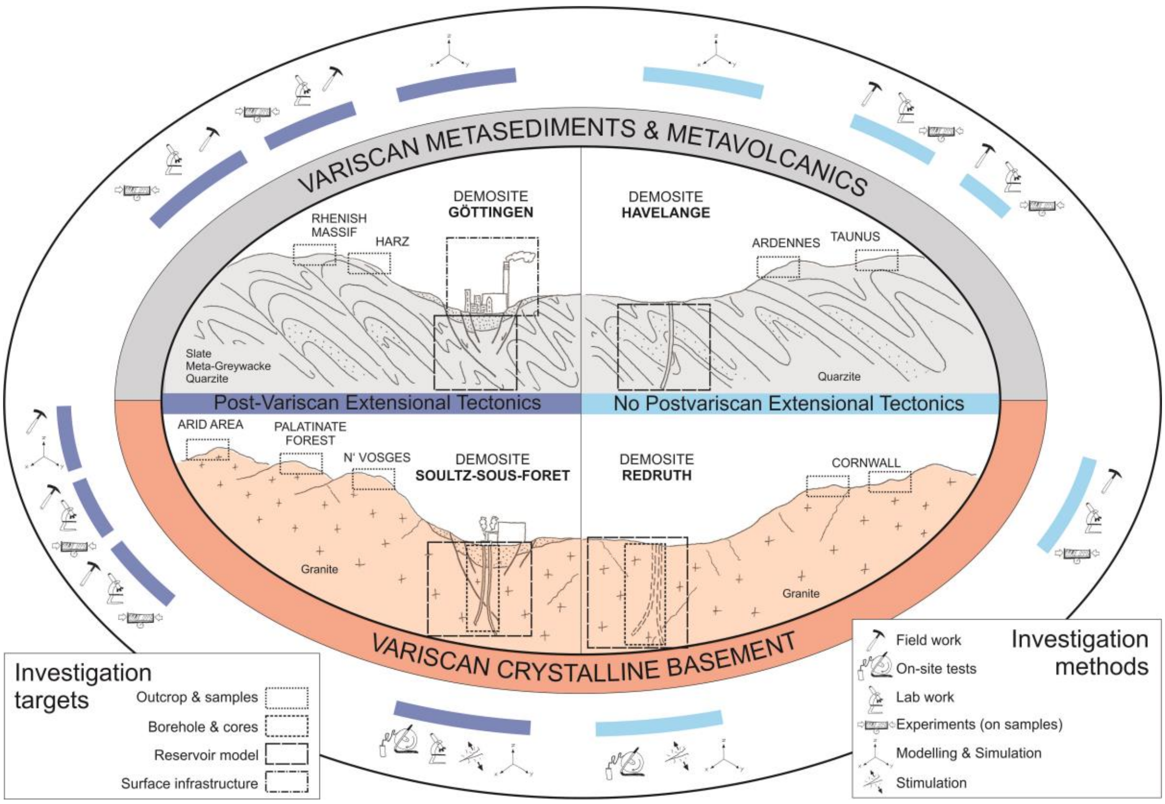


Figure 6: MEET demonstration sites and investigations methods in Variscan crystalline basement, metasediments and metavolcanics

(2) Variscan metamorphic successions not overprinted by younger extensional tectonics: Target horizons are primarily quartzites but also slates, diabase 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 a demonstration site from which drill cores and hydraulic test data are available.

(3) Variscan crystalline basement overprinted by post-variscan extensional faults: Target horizons are fractured granites or granitoids below a post-Paleozoic sedimentary cover. Analogue field sites are the Pfälzer Wald, the northern Vosges and the Odenwald (near field) and Noble hills, Death Valley, California in the USA (far field, Figure 5). The geothermal test site at Soultz, France acts as the demonstration site.

(4) Variscan basement not overprinted by younger extensional faults: Target horizons 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, Figure 7) in Redruth/Cornwall, Britain, which is currently in drilling phase (Law, 2018).

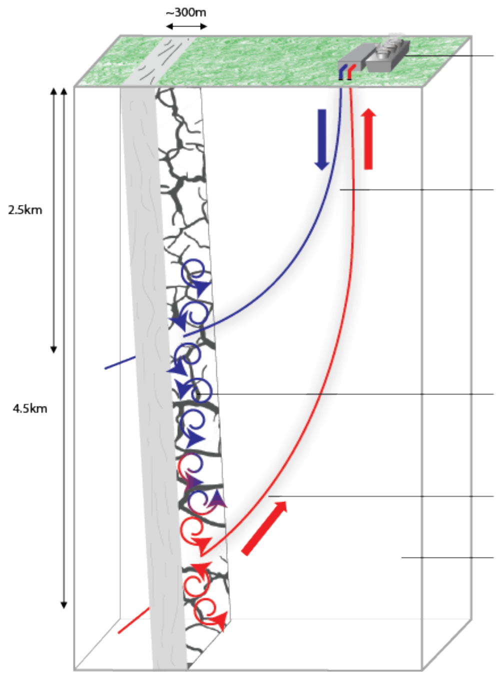


Figure 7: Sketch of the geothermal doublet under drilling operation in a faulted granite at UDDGP site in Cornwall, UK (Law, 2018).

(5) A unique opportunity was offered to MEET consortium to access to the collection of cores from deep down Paris and Aquitanian basins provided by oil companies Vermilion and Total (Sengelen et al., 2019). In consequence, an additional geological setting was added: Variscan basement overlain by sedimentary basins: Target horizons consist of schists, quartzite, micaschists, crystalline schists and gneiss. In that framework, rocks from Triassic reservoirs overlying Variscan basement will also be investigated.

3.2 Methodology developed

Outcrop analogue studies will focus both on the outcrop scale by mapping the folds and faults, the adequate structure-related paleogeothermal and post-Variscan vein systems, fault damage zones, fracture networks and the extent and distribution of different rocks and alteration types (Figure 6, Figure 9). 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. This mapping will be integrated in structural 3D-modelling to cover all fractures network related properties from the micro- to the reservoir-scale.

Besides this detailed fracture characterizations based on analogs, an attempt of imaging in situ fracture/fault zone geometry will be performed using 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. Our final aim is to get a 3D geometry of the fracture/fault network in the granite around the well (Figure 8).

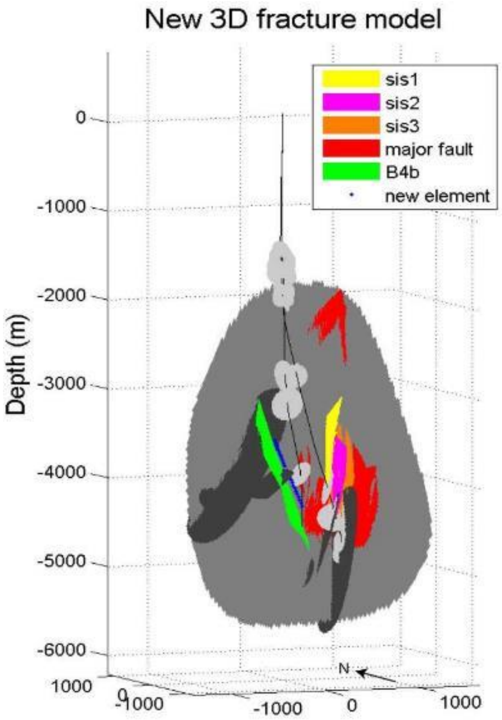
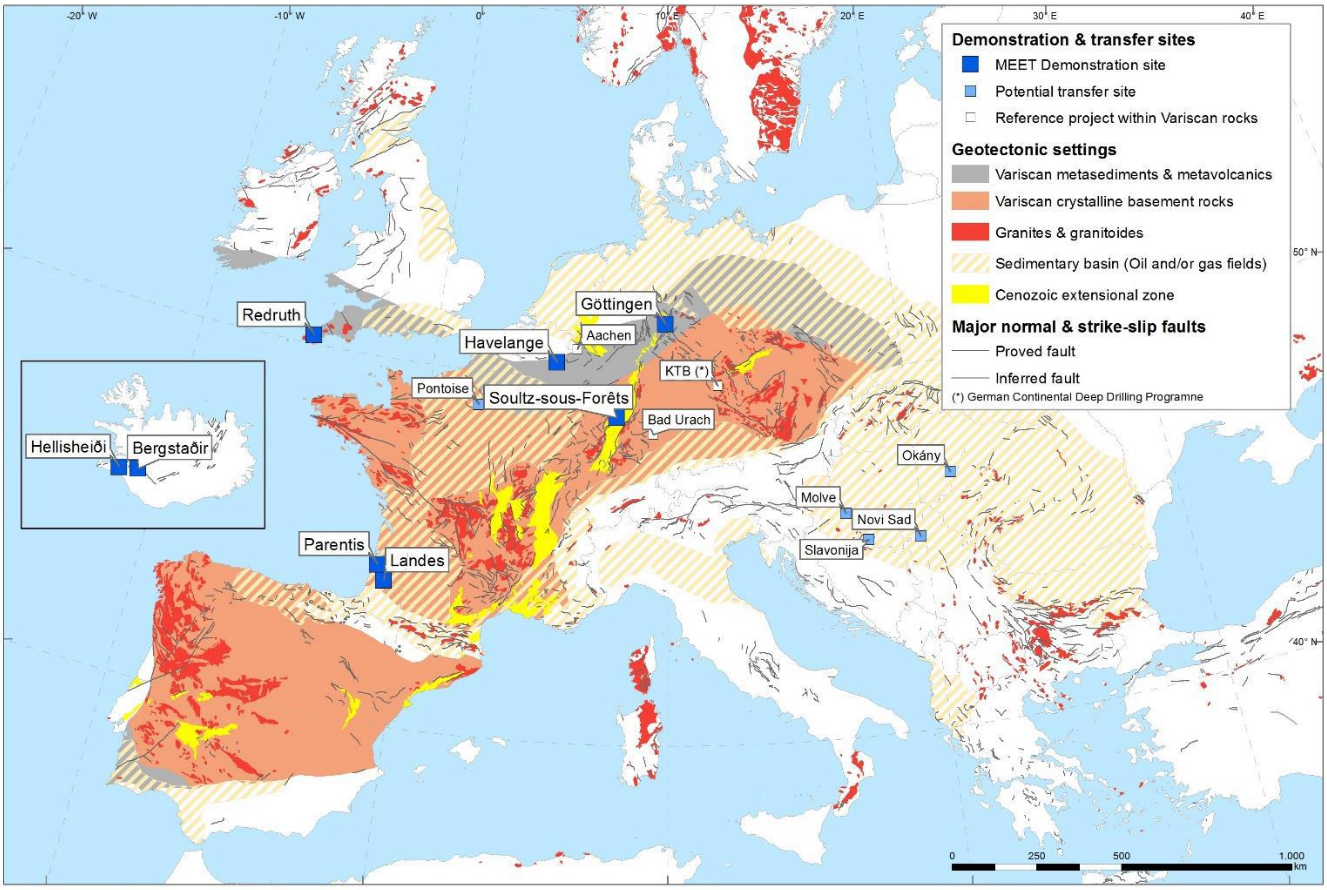


Figure 8: 3D model of the main fracture zone/fault in the Soultz granite derived from VSP and geophysical data (micro seismicity, image logs) (Sausse et al., 2010, Lubrano, 2013)



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 9: MEET demonstration sites and potential transfer site during project duration next to EU geotectonic settings. Variscan environment, granite/granitoid and sedimentary basin illustrate the new terrains where MEET concept will enable the production of heat and/or power

Representative samples of selected rock types from analogues will be taken for lab investigation of the petrophysical and geomechanical properties both under lab and in situ conditions (Figure 9). The study includes 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 that influence rock petrophysical properties. These data sets will be completed by fracture investigations and fluid analyses. This approach aims to minimize the uncertainty by providing high quality datasets measured on field analogues of potential reservoir rocks accompanied by developed numerical models and to minimize the drilling costs by focusing on the sites that already have certain infrastructure.

Petrophysical measurements (grain and bulk density, porosity,permeability, compressive and shear velocity, thermal conductivity, thermal diffusivity, heat capacity and radiogenic heat production) and rock mechanical property characterizations (uniaxial compressive strength, tensile strength, shear strength, cohesion, coefficient of friction, Poisson's ratio, Young's modulus, bulk modulus, shear modulus, compressibility, Biot and Skempton coefficients) will be done on the representative samples in the laboratory of Applied Geoscience Institute in Technical University of Darmstadt in collaboration with project partners. 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 assessing the efficiency of stimulation operations and their sustainability at the different test sites. Based on these simulations and experiences of in-situ operations at some of the different geological settings, strategies and operational recommendations (guidelines) for stimulation actions of Variscan reservoirs will be developed.

Based on this approach, an operational chemical stimulation will be performed on UDDGP site in Cornwall to enhance well productivity with a sustainable innovative chemical treatment.

4. FROM DEMO-SITE TO GENERALIZATION AT EUROPEAN SCALE

In order to attract investors for a long term development of EGS in Europe, the results gathered on MEET demo sites need to be upscaled in a comprehensive manner for non-scientific community. To achieve this objective, the development of two user-friendly tools is planned in the framework of MEET project: a Decision Making Support Tool (DMT) and a Geographical Information System (GIS) database (Raos et al., 2019).

4.1 Decision Making Support Tool for Optimal Usage of Geothermal Energy (DMS-TOUGE)

The DMS-TOUGE will help decision makers assessing the optimal integration of EGS into energy systems. It will analyze and quantify influencing factors regarding investment in EGS.

The DMS-TOUGE will be capable of site-specific environmental and economic analysis with the focus on low-enthalpy energy from co-produced hot water and it will consider: existing infrastructure or future facilities, extension or upgrade, co-use/re-use of existing boreholes, different geological settings and potential geothermal wells. Furthermore, the developed DMS-TOUGE will be useful for the decision makers involved in projects associated with: applications of EGS techniques to nearly unexploited reservoir types (Variscan orogenic belt) by means of geothermal doublets, increasing the thermal capacity of existing power plants by reinjection of geothermal fluids with a colder temperature combined with the power generation from the small-scale ORC units, and usage of hot fluids from mature and abandoned oil fields for electricity or heat production (Raos et al., 2019).

Decision making support tool will be verified and validated based on comparison between tool output and real life expert analyses on exiting operating demonstration sites. Indeed optimization model will be developed for different configurations: EGS power plant extension, oil coproduction/conversion, new projects in Variscan metasediments (Bilić et al., 2018).

4.2 GIS-analysis at European scale to locate and initiate promising EGS projects

In order to better inform decision makers and European citizens, large-scale spatial datasets of Europe will be elaborated using GIS methods.

A geothermal potential map at European scale aiming at a transfer of previous achievements to wider regions and to locate further promising EGS sites will be developed. The GIS-based data compilation and analysis will consider maps or datasets representing the deep geothermal potential, presence of non-geothermal wells, district heating data, existing geothermal infrastructure, main geothermal provinces in Europe (Tertiary grabens, Variscan zones, sedimentary basins, etc...) and relevant geoscientific information. Separate analyses will be made considering different geologic conditions: abandoned boreholes, granitic and non-granitic basement.

The DMS-TOUGE will be applied in order to evaluate and calculate LCOE (Levelized Cost Of Energy) of each perspective new ESG project site. Finally, a list of EU wide perspective EGS projects with associated guidelines and recommendations for future efficient use will be deduced, whereby market viable future projects ranked according to their feasibility.

Based on the results of the previous activities, a detailed list of relevant spatial datasets that act as important ibase for spatial analyses on smaller scales will be elaborated. These guidelines will support the local groups (geological surveys, administrations) to look for and select the right datasets on national, regional and local level to investigate promising targets within "unconventional" geothermal areas in detail.

5. CONCLUSION AND PERSPECTIVES

The MEET European project done in the framework of Horizon 2020 has been starting Mid 2018 and aims at an important cost competitiveness of geothermal energy for potential investors. The approach is primarily based on using existing infrastructures such as the Soultz power plant, some oil wells, existing or new geothermal wells in Iceland and UK respectively or the district heating of the Gottingen University campus. Therefore, the proposed methodology allows 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.

REFERENCES

Bär K., Reinsch T., Sippel S., Strom A., Mielke P., Sass I., 2017. P³ - International PetroPhysical Property Database. Proceedings, 42nd Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2017), 1-6.

Baujard C., Genter A., Cuenot N., Mouchot J., Maurer V., Hehn R., Ravier G., Seibel O., Vidal J.: Experience from a successful soft stimulation and operational feedback after 2 years of geothermal power and heat production in Rittershoffen and Soultz-sous-Forêts plants (Alsace, France), Geothermal Resource Council, GRC2018, October 14-17, Reno, Nevada, USA.

Bilić T., Rajšl I., Ilak P., Raos S., Šadek S., Krajcar S., Debrecin N., Genter A., Leoutre E., (2018). Overview of techno-economic issues of enhanced geothermal systems implementation and integration, Conference MEDPOWER 2018, Mediterranean conference on Power Generation, Transmission, Distribution and Energy Conversion, Dubrovnik, Croatia, 12-15 November 2018.

Law R.,: The United Down Deep Goethermal Power, Royal Society, BGS Geoenergy, 25th June 2018, UK.

Lubrano P.: Traitement des données de sismique de puits acquises en 2007 sur le site de Soultz-sous-Forêts pour la caractérisation de la fracturation du réservoir géothermique, PhD thesis Université of Strasbourg, EOST, 2013.

Mouchot J., Ravier G., Seibel O., Pratiwi A.: Deep Geothermal Plants Operation in Upper Rhine Graben: Lessons Learned. European Geothermal Congress 2019, The Hague, 11-14 June 2019.

Mouchot J., Scheiber J., Florencio J., Seibt A., Jähnichen S.: Scale and Corrosion control program, Example of two geothermal plants in Operation in the Upper Rhine Graben, European Geothermal Congress 2019, The Hague, 11-14 June 2019.

Raos S., Ilak P., Rajšl I., Bilić T., Trullenque G.: Assessment of enhanced geothermal projects and their optimal long-term usage plans by using the DMS-TOUGE decision-making support tool, European Geothermal Congress, EGC 2019, 11-14 June 2019, The Hague, The Netherlands.

Ravier G., Seibel O., Pratiwi A., Mouchot J., Genter A., Ragna Ragnarsdóttir K., Sengelen X.: Towards an optimized operation of the egs Soultz-sous-Forêts power plant (Upper Rhine Graben, France), European Geothermal Congress, EGC 2019, 11-14 June 2019, The Hague, The Netherlands.

Sausse, J., Dezayes C., Dorbath L., Genter A., Place J.; 3D model of fracture zones at Soultz-sous-Forêts based on geological data, image logs, induced microseismicity and vertical seismic profiles, Comptes Rendus Geoscience, 342(7-8), 531-545, 2010.

Sengelen X., Robion P., Ledésert B., Hébert R., Regnet J.-B., Bourquin S., Gasparrini M., Margueret S., Barnes Ch.: Petrophysical characterization of the interface between basement and Triassic detrital cover for geothermal purpose in the Paris Basin: from sub-surface data to a reservoir outcrop analogue,), European Geothermal Congress, EGC 2019, 11-14 June 2019, The Hague, The Netherlands.

Trullenque, G., Genter, A., Leiss, B., Wagner, B., Bouchet, R., Leoutre, E., Malnar, B., Bär, K., Rajšl, I.: Upscaling of EGS systems in different geological conditions: a European perspective, Stanford Geothermal Workshop 2018, Stanford, California, USA, 12-14 February 2018.

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 authors are grateful to GEIE EMC and HS ORKA for giving access and using data from the Soultz-sous-Forêts and Reykjanes geothermal plants respectively.