Geothermal ERA-NET

RD&D needs

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Abbreviations

Table legend for all tables:

CH = Switzerland;
DE = Germany;
FR = France;
HU = Hungary;
IS = Iceland;
IT = Italy;
NL = The Netherlands;
SI = Slovenia;
SK = Slovakia;
TR = Turkey
RD&D phase: paper/lab-scale work (R&D);
Field tests and demonstration (DM);
Other (O)
U (Urgency):
Urgent (++),
Mid/ long term issue (+)
I (Importance):
High importance (++),
Important (+),
Less important (-).
Default is + (important).
S (Sector):
Sector(s) that consider this an RD&D need.
Users/Developers/Investors of geothermal projects (U),
Geothermal Industry (I),
Research community (R),
Government/Ministry (M),

Abstract

This report shows research, development and demonstration needs for geothermal development in countries, participating in ERANET Geothermal energy. These RD&D needs have been identified by the participants of ERANET Geothermal energy. They will be an important input in setting up joint activities between the partner countries

Executive summary

Stimulating the use of geothermal energy as a source of renewable energy for heating and/or electricity generation is a priority in all countries in the ERANET Geothermal Energy. Collaboration between the countries, to address common research, development and demonstration issues, can make efforts to further develop geothermal energy more efficient. Countries can learn from work done in other countries, and joint challenges can be taken up together.

In order to get a clear view of common research, development and demonstration needs, the ERANET Geothermal energy conducted a survey amongst its member countries. All countries indicated about ten RD&D needs for the development of geothermal energy. These RD&D needs were discussed and clustered at a workshop.

The ERANET countries have much in common, and there is certainly scope for collaboration. The common clusters of RD&D needs that we have identified at our workshop are the following:

- Reservoirs
  Knowledge on reservoirs, as well as modelling and exploration

- Operation
  Knowledge regarding operational and injection issues as well as pumps and components

- Public relations (PR) and data
  Dissemination, public acceptance and reporting code/statistics

- New concepts
  Opportunities in developing and testing new concepts for the use of geothermal energy including innovative concepts, heat and power cycles.

- Anthropogenic influence
  Reservoir creation and seismicity issues

- Drilling
  innovative and cost-efficient drilling technology

These clusters, together with Barriers & Opportunities clusters identified at a “sister” workshop, will be input for the joint activities of the ERANET Geothermal energy.

1 Methodology

This report shows the research, development and demonstration needs (RD&D) in the field of geothermal energy in countries, participating in ERANET Geothermal.

The "ten main" RD&D needs have been identified by the national representation of the participating countries in autumn 2013. It was up to the participants to decide how: some worked in consultation with relevant parties in their countries, and others worked from their own observation.

The RD&D needs were then analysed and clustered by all participants in a workshop at the 5th project meeting in Gstaad, Switzerland. At the workshop, some countries added additional barriers and opportunities, identified at the meeting itself.

The aim of this report is to help identifying joint interests, as a basis for organising joint activities for forwarding the RD&D and deployment of geothermal energy – a source of sustainable energy that plays a role in the 20-20-20 ambitions of all countries participating in ERANET Geothermal Energy

Figure 1 Impression of a result from the clustering workshop Gstaad, Switzerland

2 Clusters by numbers

The tables below show an overview of the numbers of RD&D needs, identified to be part of the various clusters.

Table 1 Number of RD&D needs per cluster per country

	1 Reservoirs			2 Operation			3 PR & data			4 New concepts			5 Anthropogenic influence		6 Drilling	
	A reservoirs (general)	B reservoir modelling	C reservoir exploration	A operational issues	B injection issues	C pumps and components	A dissemination	B acceptance	C reporting code/statistics	A innovative concepts	B heat	C power cycle	A reservoir creation	B seismicity		
CH		1	1								1		4		1	8
DE	1		3	1		1		1		1			1	1	1	11
FR		1	1			1	1			1		1	1	1	1	9
HU	1	1			1				1				1		1	6
IS		1		1	1			1	1		1		1	1	1	9
IT	1		1	2	1	1				1	1	1	1	1		11
NL	1	1		1	1		1	1		2				1	1	10
SI	1	1		1	1				1							5
SK			2										1		1	4
TR					1						2	1				4

	5	6	8	6	6	3	2	3	3	5	5	3	10	5	7	77

From the table, it shows that the RD&D needs mentioned by the partner countries are well spread over the (sub) clusters. When looking at the numbers, one has to bear in mind that the "weight" and "breadth" of the individually mentioned RD&D needs is not equal in all cases. For example, if country A has combined specific RD&D needs in one issue, and country B describes exactly the same in three separate issues, the conclusion that there are "more" issues in country B will not really help our work. The purpose of this report is to find common ground for collaboration. Analysing the numbers assists this, but then, we must look at the content again. And at the chances for collaboration which this content offers.

Most important conclusion is that many RD&D needs are shared by different countries, and in many (sub) clusters issues are mentioned by at least several countries.

3 Research, Development and Demonstration Needs

This chapter presents the results of the workshop in Gstaad at the 5th project meeting. The answers from all participating countries were consolidated to 6 major clusters, which represent RD&D needs in the same research field

3.1 Reservoirs

A geothermal reservoir is the target area for geothermal drillings characterised by an underground rock formation with relatively high temperatures. Those enable the use of this formation for geothermal energy production. In case of a hydrothermal reservoir, the formation contains an accumulation of natural hot water and shows, in most cases, high porosities and permeabilities. A petrothermal reservoir does not contain any natural water and often shows insufficient porosities and permeabilities. In this case surface water is pumped to an artificially created system of fractures to collect the heat from the reservoir.

Many countries have the demand to improve the knowledge on geothermal reservoirs. This major cluster includes sub clusters about exploration of geothermal reservoirs, reservoir modelling and the understanding of the major processes within the reservoir.

Reservoirs (general)

This sub cluster includes RD&D needs about the sustainable reservoir use and the reservoir behaviour during the development of the resource. In several countries a lack of usable data leads to insufficient knowledge of areas with possible reservoirs. In other countries where interesting areas are identified the enhancement of the knowledge about processes in the individual reservoir may be in focus. Also the sustainable use of a reservoir and, dependent on that, the optimised plant-management are important topics.

Reservoir Modelling

The geometry and the internal structure of a reservoir are important for its eligibility for geothermal use. With data from geophysical exploration a virtual model (2D or 3D) can be created. This model can help to simulate the characteristics of the reservoir prior to the first drilling. After the drillings the model is enhanced by additional data and is used to simulate the reservoir behaviour during the recovery of the heat resource. The focus of the named RD&D needs lies on the enhancement of those models. To render the models more precise, parameters like the internal heat flow, the mechanical behaviour as well as the hydraulic and chemical parameters have to be taken into account.

Reservoir Exploration

Reservoir exploration includes all techniques and methods to gain information about a potential reservoir. The most important technique for geothermal use is the seismic exploration. This method uses artificially created elastic waves to create a model of the subsurface based on different wave velocities in different materials. In high enthalpy regions also electromagnetic methods are common

The RD&D needs in this sub cluster envelope the enhancement of seismic exploration as well as the research of new innovative exploration methods.

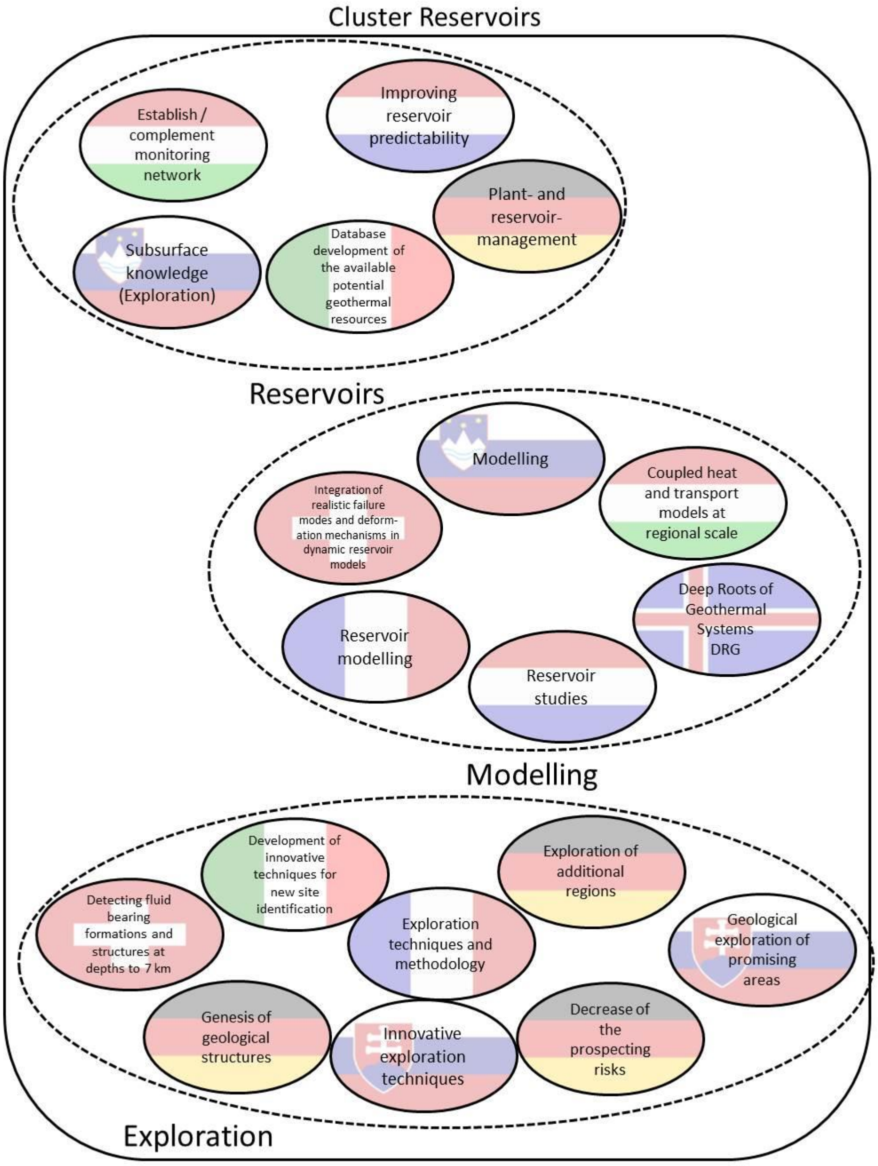

Figure 2 Results of the thematic clustering in the research area "reservoirs"

Table 2 RD&D needs: Reservoirs

Reservoirs (general)		
DE–R&D U:+ I:+ S: U, I, R	Plant- and reservoir-management	Long-term prediction of the reservoir behaviour and the life cycle of the plant.
HU-DM U: + I: + S: U, M	Establish / complement monitoring network	Special network monitoring thermal water production.
IT - DM U: ++ I: ++ S: I, U	Database development of the available potential geothermal resources	Organization and collection of all the available geothermal data, including those public and private from the dismissed mining lease for the calculation of geothermal potential (as VIDEPI Project for hydrocarbon resources).
NL–DM, O U: ++ I: + S: U, I, R, M	Improving reservoir predictability	Alignment of Best Practices and protocols / working methods to reduce differences in forecasts of reservoir behaviour and future production levels.
SI-DM U: + I: ++ S: R	Subsurface knowledge	Except in Slovenian part of Pannonian basin (15% of Slovenian territory) there is a lack of deep structural boreholes (on the rest 85% of Slovenian territory only 10 boreholes are deeper than 1000 m. There is a need for regional exploration of perspective areas for shallow and deep geothermal use by various geophysical methods. New research boreholes are proposed.
Reservoir Modelling		
CH-R&D U: + I: + S:	Integration of realistic failure modes and deformation mechanisms in dynamic reservoir models	No major new insight will be gained by continuing to use established elastic and standard inelastic constitutive equations (e.g. phenomenological friction laws, J2-deformation theory for plastic behaviour, etc.. Modern constitutive theory of reservoir mechanics is expected to allow for predictive modelling of reservoir mechanical behaviour. The interplay between failure of intact and faulted rock is poorly understood mostly due to poor characterization of operative (physical) deformation mechanisms.

FR-R&D, DM U: + I: + S: I	Reservoir modelling	The issue is to link the initial geological modelling to reservoir modelling, taking into account fluid circulations, temperature etc.: this is done in porous sedimentary aquifers but is much more difficult in fractured/faulted reservoirs in magmatic and amagmatic regions. This would allow a better well siting and a more efficient operation of the wells.
HU- R&D U: + I: + S: R, U	Coupled heat and transport models at regional scale	numerical models to study regional (also cross-border) effects at different thermal groundwater abstraction scenarios
IS- R&D, DM U: ++ I: ++ S: U, R, I	Deep Roots of Geothermal Systems	Simulation and modelling, exploration, utilisation Research on magmatic intrusions as heat sources of geothermal systems and the mode of superheated or supercritical heat transfer up to the conventional geothermal systems at subcritical temperatures and pressures. Properties of fluid and rock in the suprastate layer and obstacles in exploitation. The aspect of reservation operation strategies and monitoring as well as equipment monitoring (scaling, condition, structural monitoring of wells) is equally important
NL-R&D U: + I: + S: U, M	Reservoir studies	Reservoir studies in less-known regions as well as work on optimal spatial (sub-soil) well configuration both in horizontal sections as well as interference risks between layers (wells) at different depths.
SI-R&D U: + I: + S: R, M	Modelling	Geothermal modelling for direct use of thermal water is rarely performed. In some areas, the models will be used to grant a concession quantity. There is a need for regional geothermal models of a few sedimentary basin geothermal aquifers in Slovenia, which show indications of overexploitation. Beside, new investors may be asked to show by the use of models, that new applications will not deteriorate the current quantity state of aquifers and to evaluate the geothermal doublet life-time.. Geothermal modelling in carstic areas is yet not performed but is also needed to be enhanced.
Reservoir Exploration		

CH-R&D U: ++ I: ++ S: U, I, R, M	Detecting fluid bearing formations and structures at depths to 7 km	Identifying fluid bearing formations and structures using remote and cheap exploration methods remains the holy grail. Significant advances in computational hard- and software, tools and techniques will eventually yield measurements that are sufficiently sensitive to detect such geothermal features. Broad and diversified – and above all sustained R&D in a multitude of fields (geophysical inverse theory, potential field methods, seismic methods etc.) is required.
DE-R&D U: ++ I: ++ S: I,U,R,M	Decrease of the prospecting risks	Including exploration techniques and methods, reservoir modelling and stimulation methods.
DE-DM U: + I: + S:I, U	Exploration of additional regions	Enlarge the areas which are suitable for geothermal use by the improvement of the database with e.g. a national drilling program.
DE-R&D U: + I: + S: R	Genesis of geological structures which are important for the geothermal use	Include the time component and the history of faults in the reservoir analysis.
FR-R&D, DM U: + I: + S: I	Exploration techniques and methodology	Innovative exploration techniques must be developed for geothermal resources. In addition the way to combine these techniques and integrate the various results is crucial, so that an efficient exploration strategy can be put in place.
IT-R&D U: ++ I: ++ S: U, R	Development of innovative techniques for new site identification	Development of new technologies for the identification of high-potential sites.

SK-DM U: + I: + S: U	Geological exploration of promising areas	Detailed exploration of the areas with suitable conditions for district heating and cooling systems
SK-R&D U: + I: ++ S: R, M	Innovative exploration techniques	Development of real-time exploration techniques instead of coring/lab analysis approaches

The research on reservoirs has a relatively high importance and a high urgency in the participating countries. In the field of the general investigation of reservoirs, the need from the developers and the industry is high. One major problem is the lack of information and data. The countries see the main focus on demonstration projects. The modelling cluster shows a medium importance and a medium urgency. Better models can support the approval procedure and can improve the pre-drilling planning of projects. Mostly developers, researchers and the authorities see the need for research on this topic. The sub cluster on exploration shows high urgency and even higher importance, especially from the developers, the research community and the industry. The goal is to gain better exploration data through improved technologies. The focus for the clusters modelling and exploration are mainly R&D projects.

3.2 Operation

Once a reservoir is explored and developed, dependent on the reservoir type and the local geology, several operational issues can affect the regular plant operation. In the cluster Operation, there are three sub-clusters, one related to general operational issues, one related to injection issues, and the last related to pumps and components.

Operational Issues

Brines used for geothermal energy production are often a solution containing significant amounts of gas, corrosive salts or other chemical substances which can produce scaling in a geothermal plant once the parameters (p, T) are changed. These products can affect the operation cycle of the plant and/or lead to environmental issues (NORM waste – Natural occurring radioactive material). The topics in this sub cluster range from the treatment of thermal brines to methods to reduce the impact of these aggressive thermal waters on the components of the plant.

Injection Issues

Once the geothermal brine is extracted from the reservoir and the geothermal heat is extracted, the cooled water has to be reinjected into the reservoir. Due to the cooling of the brine the previously described effects can take place in the surface part of the plant. During the injection itself the interaction with the reservoir can lead to undesirable effects. The different chemical composition can induce effects in the subsurface reservoir as scaling and chemical reactions. Even small earthquakes can be induced due to the temperature difference or due to the injection pressure which is needed in some cases to get the fluid back into the reservoir. The topics of the sub cluster are covering the research on all these problems.

Pumps and Components

The economic viability of a geothermal power plant is strongly dependent on the yearly run-time of the thermal water cycle. The main component to keep the system running is the discharge pump. Pumps which are used for the extraction of thermal water can be electric submersible pumps or line shaft pumps. Most pumps used are adapted from the oil and gas industry but are often not capable to handle the temperature and pressure conditions of geothermal reservoirs or the high production rates which are mandatory especially for the electricity generation. The main focus of the research needs is topics to extend the lifetime of the pumps and to reduce the susceptibility to failure.

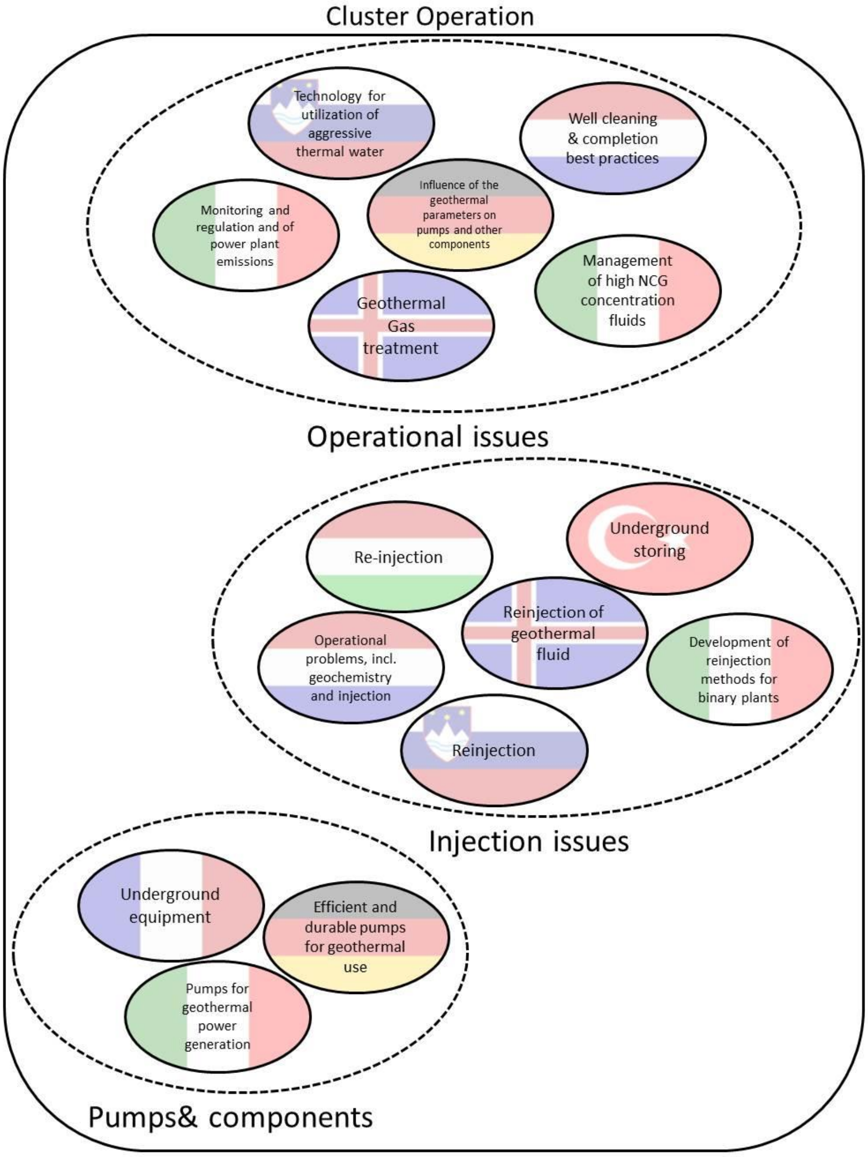

Figure 3 Results of the thematic clustering in the research area "operation

Table 3 RD&D needs: Operation

Operational Issues		
DE-R&D U: + I: + S: I, U	Influence of the geothermal parameters on pumps and other components in the plant-cycle	Gain a better understanding of the chemical processes which limit the life period of components in a geothermal plant. Improve techniques for the monitoring of chemical water-parameters.
IS-R&D, DM U: ++ I: ++ S: U, R, I, M	Geothermal Gas treatment	Gases such as CO2, H2S and H2 accompany the steam and water flowing from geothermal wells in different quantities. They have been considered unwanted, but methods for extracting, abating, sequestering, and/or utilizing them will be investigated in this topic. Utilization can involve CO2 enhancement, algae and bacterial production as well as production of synthetic fuels. Such utilization could reduce environmental effects of these gases, which are commonly let into the atmosphere
IT-R&D, DM U: + I: + S: I, U	Management of high NCG concentration fluids	Identification of reliable technical solutions to ensure a safe treatment of high NCG concentration fluids and with the objective of achieving zero emission.
IT-DM U: + I: ++ S: U, R, M	Monitoring and regulation and of power plant emissions	Development of continuous emission monitoring systems in power plants. Implementation of national regulation on power plant emissions. Today only H_2S, Hg and As emission limits are nationally ruled, while those of Sb, Se, NH_3, CH_4 are not yet defined.
NL-R&D, DM U: ++ I: ++ S: I, U, R	Well cleaning & completion best practises	Prevention of skin damage and remediation methods for injectivity problems; well cleaning & completion best practises; well stimulation.

SI-DM U: + I: + S: U, R	Technology for utilisation of aggressive thermal water	Some waters have high CO_2 or CH_4 content and scaling potential. Problems with degassing and FeS_2 and calcite scaling are not properly managed nor at wells nor at surface systems (in pools, …). Different techniques to avoid degassing and scaling problems need to be developed and demonstrated.
Injection Issues		
HU-R&D, DM U: ++ I: ++ S: I, U	Re-injection	Pilot projects, field tests to study reservoir characteristics in clastic aquifers (see also at technical barriers)
IS-R&D, DM U: ++ I: ++ S:I, R, M	Reinjection of geothermal fluid	Reinjection of the geothermal fluid is a topic of high relevance and great interest of the geothermal industry. No matter whether we are talking about induced seismicity, depth, controlling cooling, tracers and ground water research and monitoring
IT-DM U: ++ I: ++ S: I, R	Development of reinjection methods for binary plants	Development of innovative reinjection methods for binary plants with low/zero induced seismicity.
NL-R&D U: ++ I: ++ S: I, U, R	Operational problems, including geochemistry and injection	Better understanding of subsoil processes and composition/behaviour of geothermal fluids in order to avoid scaling, radioactivity, corrosion and/or decreasing injectivity. Filtering best practises. Influence of injection temperature on thermal stress of casings, effects on injectivity / risks of precipitation.
SI-R&D, DM U: ++ I: ++ S: R, M	Reinjection	One geothermal doublet is active in Slovenia but no public monitoring data is available and therefore other users do not want to set reinjection due to high costs until it is proven to be successful. There is need for reinjection in both, the fissured and porous geothermal aquifers, but no funds for establishing it. Long-term it is expected that reinjection will be demanded for heat exploitation by authorities, but short-term it has to be proved by laboratory and field tests to be effective in sandstones and metamorphic rocks to be seriously thought about by investors.
TR-R&D U: + I: + S: I	Underground storing	All types of relevant studies may be included under the title.

Pumps and Components		
DE-R&D, DM U: ++ I: ++ S: U	Efficient and durable pumps for geothermal use.	Improvement of the long-term stability of pumps. Reduce the amount of energy which is necessary to run the pumps. Promotion of the diversification of the market.
FR-R&D, DM U: + I: + S: I	Underground equipment	The reliability of some devises as pumps still needs to be improved; the scaling and corrosion in the wells must be prevented and precisely assessed. Downhole tools must also resist to high temperature and pressure conditions.
IT-R&D, DM U: ++ I: ++ S: I, U	Pumps for geothermal power generation	In a context of increasing exploitation of pressurized resource by the use of pumps in the production well, R & D efforts should be focused on increasing efficiency and reliability of the equipment.

The cluster "operation" shows research needs on more specialised topics. The general operational issues show a medium urgency for both demonstration and R&D projects and a high importance. This research mainly aims to serve the developers. The focus is on the handling of aggressive thermal waters. The sub cluster "injection" shows the highest urgencies and the highest importance with a focus on R&D projects. In the participating countries mainly the industry could benefit from research in this field. The relatively small cluster on pumps and components shows also a high urgency and a high importance in the countries which have corrosive thermal waters with potential for scaling production. Both demonstration and R&D projects are necessary for further research on this topic

3.3 Public relations (PR) and Data

In some countries, where the use of geothermal energy left the initial phase, data issues and the lack of public acceptance hamper or delay the further development. Also the insufficient collection and the exchange of data leads to higher costs and/or to an unnecessary lower level of information. This cluster is divided into subclusters on dissemination, acceptance and reporting code/statistics.

Dissemination

This topic is mostly on the exchange of already acquired data within the geothermal industry, which may be very limited or not existent. In both cases regulatory authorities can solve the problem with explicit guidelines on data collection and the dissemination of the data. Also the industry has to accept that the advantages of a free data exchange are much higher than the disadvantages through economic competition.

Acceptance

In several countries the lack of public acceptance is one of the key barriers for the development of geothermal energy, on equal footing with other renewables. For future projects in these countries the developers and the industry have to take these social aspects into account, to realise the projects together with the local residents and not against them. Often the knowledge about the technology is insufficient in the public and also in the approving authorities. Research on the marketing of geothermal energy production and the psychology of the potential rejection of the technology can help to solve the problems.

Reporting code/statistics

In addition to the insufficient data exchange within the geothermal industry some countries do not regulate the documentation and the reporting of the development of geothermal reservoirs to the authorities. Standardized reporting codes and guidelines for documentation can help to solve those problems. Also, international standardisation would help international development of the technology.

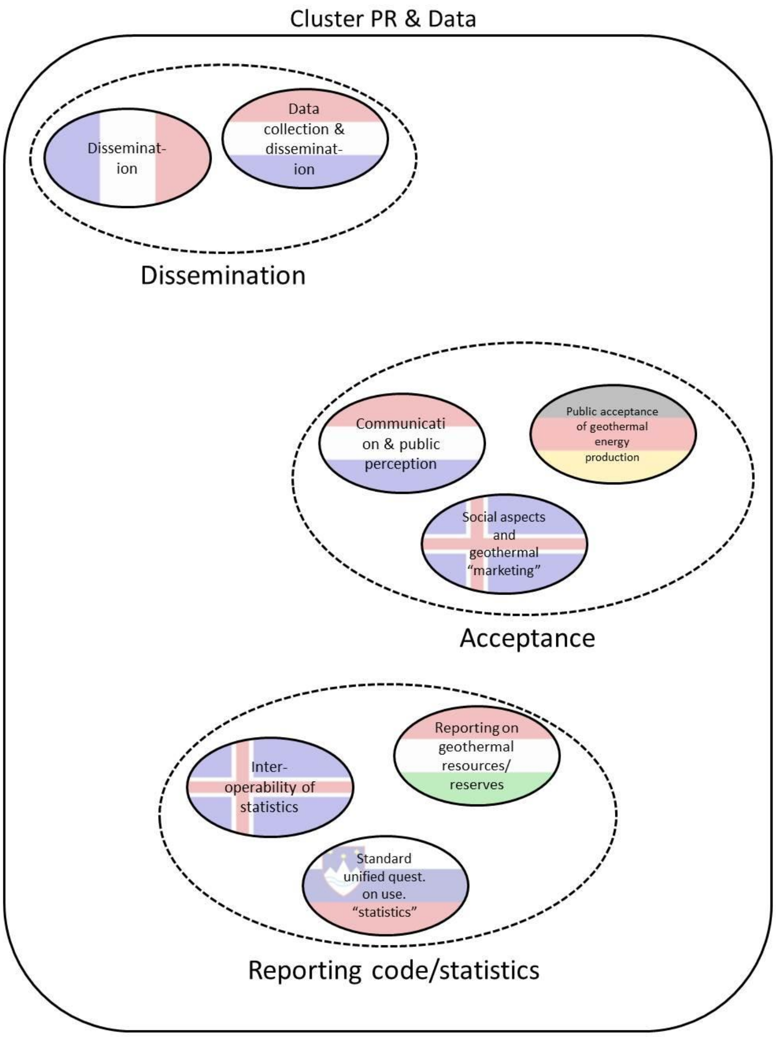

Figure 4 Results of the thematic clustering in the research area "PR and data"

Table 4 RD&D needs: PR & Data

Dissemination		
FR-R&D, DM U: + I: + S: I	Dissemination	The results of exploration projects and the global knowledge about the underground and the geothermal resources must be properly disseminated towards geothermal industry, notably through adequate database.
NL-DM, O U: ++ I: ++ S: I, U, R, M	Data collection & dissemination	Monitoring, analysis of data and practical operational experiences, consolidation and dissemination of results.
Acceptance		
DE-DM U: ++ I: ++ S: U,R	Public acceptance of geothermal energy production	Communicate the advantages of geothermal energy production. Explain negative influences like induced seismicity to the public. Involve the public during the construction of a new site.
IS-O U: + I: + S: M, U ,I	Social aspects and geothermal "marketing"	Increased public acceptance/awareness Cost benefit analysis
NL-DM U: ++ I: ++ S: I, U, R, M	Communication & public perception	Preparation of fact based position papers to be used in public debate in sensitive domains as fracturing & seismic activity, NORM/LSA, (drilling) waste disposal.
Reporting code/statistics		
HU-R&D U: + I: + S: M	Reporting on geothermal resources/reserves	Adaption of internationally accepted (CanGea) reporting codes.
IS-O U: ++ I: ++ S:M	Interoperability of statistics	Geothermal energy statistics: Simplification of geothermal energy statistics gathering for interoperability across countries and associations. Geothermal datasets specification: Defining data tables according to spatial datasets in stage 1 in EGIP feasibility study: Temperature map, surface heat-flow, exploration and production licenses and power, map of education and research institutes and map of geothermal industries. Also definition of common data tables for geothermal areas and wells (according to INSPIRE Technical Guidelines and request for datasets in IRENA Geothermal Strategy for the Global Renewable Energy Atlas) Metadata cataloguing of Geothermal datasets: Each participating country is responsible for completing datasets as defined in 9 and Catalogue the

		metadata for the datasets in the respective official national metadata base and open access to that metadata in the EC INSPIRE Geoportal. This is subject to the finalisation of defining the data tables according to 9 by the end of 2014.
SI-R&D U: + I: + S: M	Standard unified questionnaire on use	One, simple and easy-to-fill-in questionnaire is needed to collect annual data on geothermal use, so that fast and reliable information/outlook will be available to users and authorities. This standard questionnaire should be developed at the EU level for the determining the share of geothermal energy in the RES balance.

The PR and data cluster is divided into relatively small sub clusters with heterogeneous urgencies and importance. The dissemination cluster shows high urgencies for both demonstration and R&D projects. In addition other actions, especially from the approving authorities are required to support a better data exchange. In the countries which have massive problems on the field of public acceptance, the urgency and the importance for a demonstration project are very high. The cluster “reporting code/statistics” shows a low urgency and a low importance; however actions from the approving authorities are required to get unique reporting codes and guidelines for data handling.

3.4 New concepts

A number of countries see the need to develop and promote new concepts for the use of geothermal energy. These innovations are mandatory to consolidate and strengthen the position of geothermal energy in the market. The cluster "New Concepts" is divided into three sub clusters: Innovative concepts, heat and power cycle.

Innovative concepts

This cluster contains new technological concepts which are still on a low TRL (Technology Readiness Level), but might be useful for an application in the field of geothermal energy and therefore should be in focus for future research. For example in the Netherlands, the development of concepts for drilling in depths up to 4000m is a need. In Italy the development of double pipe heat exchangers is a much specified research topic. Parts of these concepts may be already developed in other countries, so the cluster has potential for further joint activities.

Heat

The cluster "Heat" deals with the use of geothermal heat. Iceland draws the attention to the direct use in various new markets. In other countries it is more important to integrate the heat into the existing heating networks or to develop multi-source heating systems. In low enthalpy regions the coupled use of heat during the electricity production is the only way to operate a geothermal plant in an economically successful way.

Power cycle

The sub cluster "Power Cycle" includes the research in the field of electricity generation. Italy sees a need for research into more efficient ORC systems. In Turkey power distribution and transmission is subject of research. France deals with the performance of power cycles. The main goal is to enhance the electricity production per plant.

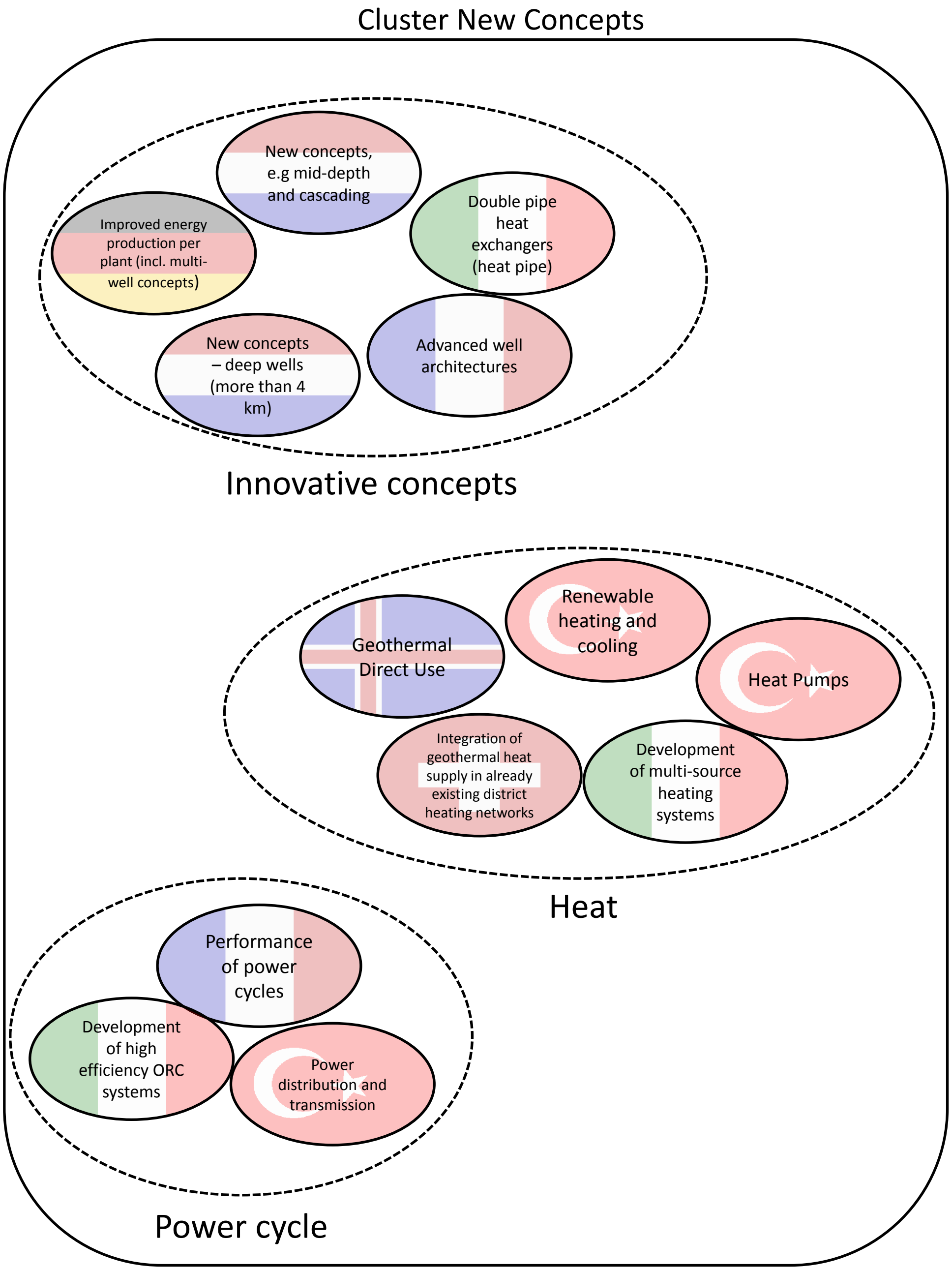

Figure 5 Results of the thematic clustering in the research area "New concepts"

Table 5 RD&D needs: New concepts

Innovative concepts		
FR-R&D, DM U: + I: + S: I	Advanced well architectures	Advanced well architectures (sub-horizontal, multi-drain…) would allow harnessing resources with poor permeability or a limited thickness. Disruptive new concepts can also be developed and assessed.
DE-DM U: + I: + S: U,I	Multi-well arrangements for geothermal use	Improve the amount of energy production per plant
NL-DM U: ++ I: ++ S: I, U, M	New concepts – deep wells (more than 4 km)	Pilot project at depth of ± 4 kilometres. Pilot would result in better insight in costs, reservoir permeability, required enhancement methods, productivity & economics – and indirectly relevant for (estimates of) potential of geothermal energy.
NL-DM U: + I: ++ S: I, U	New concepts, including mid-depth (0,5-1,5 km) geothermal potential and cascading options.	Potential of "mid-depth" wells, integration of wells with high temperature heat storage, cascading applications (cooling, heat pumps) and relation to heat demand in various sectors, especially buildings.
IT-R6D, DM U: + I: ++ S:U, R	Development of double pipe heat exchangers (heat pipe)	Development of double pipe heat exchangers (heat pipe) for geothermal exploitation without the extraction of fluids from the subsurface to the advantage of the efficiency exchange and of the environmental impact.
Heat		
IT-DM U: ++ I: ++ S: I, M	Development of multi-source heating systems	In areas where the characteristics of geothermal resource do not allow its use as the sole source of energy, it is still possible to integrate multi-source systems by using locally available RES
IS-R&D, DM U: ++ I: ++ S:U, R, I, M	Geothermal direct use	The fact is that one of the most under-utilized resources in the entire world is low temperature geothermal energy. Many European countries have large geothermal areas that are not utilized as the temperature is too low for competitive electricity production. However, direct utilization of this renewable energy source for industrial processes is the obvious way forward to a more sustainable future. Focus on cross-sectional innovation and direct use of renewables in industries as well as greening today´s businesses with more environmentally friendly processes, turning waste into value streams. Example of important industries are health and food sectors including aquaculture, horticulture, microalgae, seaweed and other health products and added value processing. As well as tackling societal challenges by

		minimizing pollution and bridging the gap between government, research, businesses and markets. Other aspects of direct use is also of high interest for Iceland, such as central district heating system, alternative gas fired system and possible geothermal cooling.
TR-R6D U: + I: + S:I	Renewable heating and cooling	All types of relevant studies may be included under the title.
TR-R&D U: + I: + S:I	Heat Pumps	All types of relevant studies may be included under the title.
CH-DM U: ++ I: + S:U, I, M, some R	Integration of geothermal heat supply in already existing district heating networks	District heating networks may require additional operational flexibility if geothermal heat supply is to be integrated next to waste heat from industrial processes, waste incineration or combined heat and power plants.
Power Cycle		
FR-R&D, DM U: + I: + S: I	Performance of power cycles	The efficiency of the power cycles (including ORC, possibly with supercritical fluids, Kalina…) must be enhanced, notably for low temperatures.
IT-R6D, DM U: + I: ++ S: U, I, R	Development of high efficiency ORC systems	Development of ORC systems for the exploitation of medium enthalpy resources.
TR-R&D U: + I: + S:I	Power distribution and transmission	All types of relevant studies may be included under the title.

The table above shows the importance to develop and promote new and innovative concepts in geothermal use for the future. Especially innovative concepts are necessary in countries, where the geothermal resource is difficult to use. Here, efficiency of the heat and the electricity production can be enhanced by using multi-well concepts and the development of deep reservoirs. New concepts in heat utilization are an important issue in all countries. In countries where the geothermal heat is already well developed, new direct uses have to be made accessible. The countries, where geothermal energy is covering only a small part of the heat demand, the integration of the geothermal heat and energy in existing networks is in focus. In addition, new concepts in the performance of power plants are necessary to enhance the efficiency of the production (e.g. ORC).

As you can see in the table, the research-cluster of heat has a high urgency and is an important factor especially for the industry.

3.5 Anthropogenic influence

The cluster "Anthropogenic influences" includes topics related to manmade interventions to the natural geothermal system. In geothermal these topics include fracturing or stimulation of the reservoirs. The two sub clusters are divided in reservoir creation and seismicity. Of course induced seismicity can be a result of reservoir creation; however seismicity can also occur during the regular operation.

Reservoir creation

As described before (see chapter 2.1) the geothermal reservoir is the target area for every geothermal drilling. In case of insufficient production rates the reservoir has to be stimulated. This sub cluster includes research on different ways to stimulate reservoirs (chemical, mechanical). Mechanical stimulations are used to create artificial fractures within the reservoir to increase flow rates in the reservoir rock. This can be done by the injection of water under high pressure. Chemical stimulating uses acids to enhance flow rates by the partial dissolution of the rock. Other topics in this sub cluster are the development of EGS demonstration projects or the advanced reservoir creation.

Seismicity

Seismicity includes all earthquake-phenomena of an area. An important topic is the induced seismicity. Induced seismicity refers to typically minor earthquakes and tremors that are caused by human activity that alters the stresses and strains on the Earth's crust. Most induced seismicity is of an extremely low magnitude.

The research needs in this scientific field include the gathering of knowledge about the basic principles and operation methods to reduce or avoid induced seismicity.

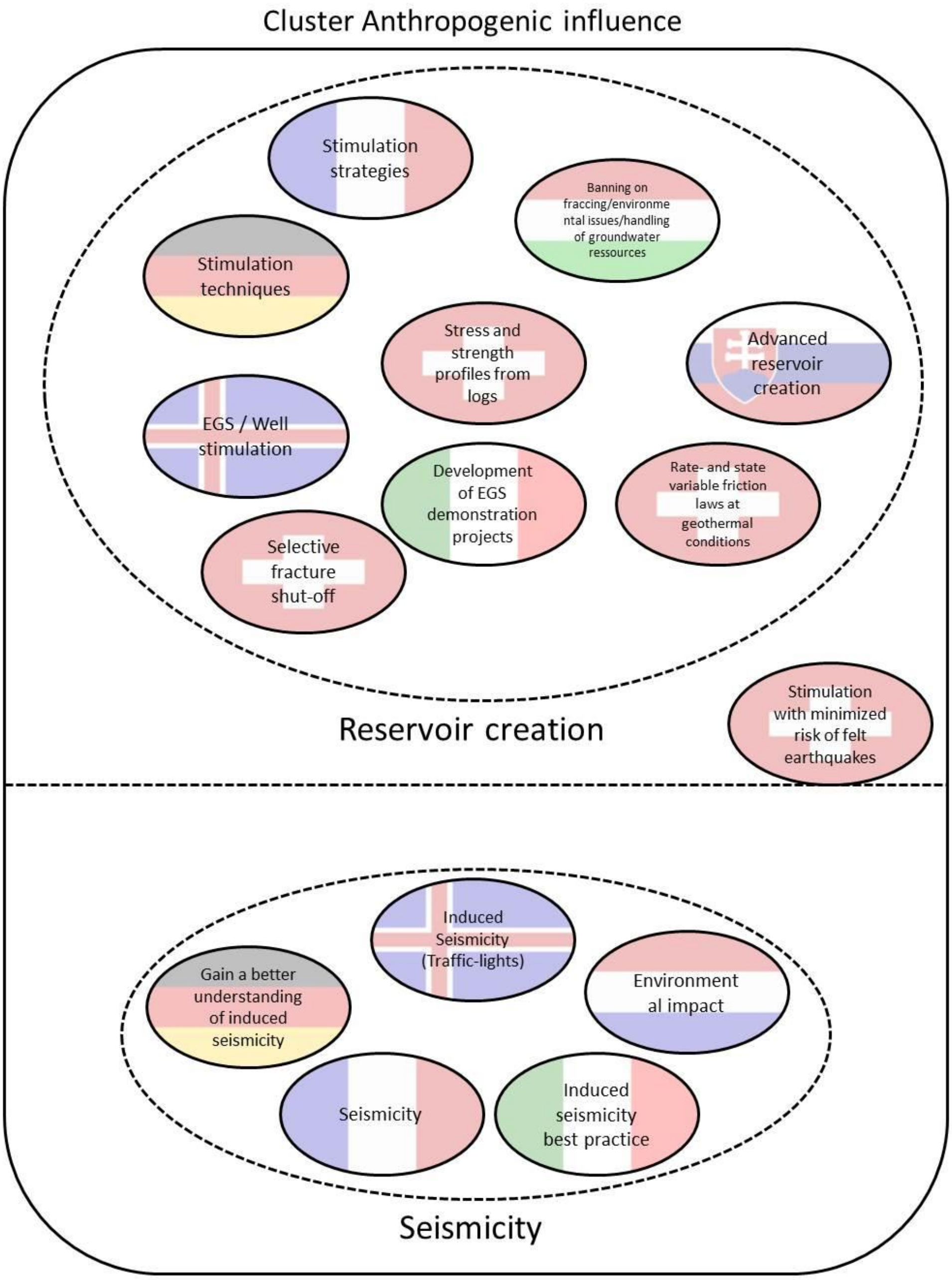

Figure 6 Results of the thematic clustering in the research area “Anthropogenic influence”

Table 6 RD&D needs: Anthropogenic influence

Reservoir creation		
FR-R&D, DM U: + I: + S: I	Stimulation strategies	Several types of stimulation exist: hydraulic, chemical, thermal stimulation… The global objective should be to set up a whole portfolio of stimulation techniques and strategies that can be adapted to the situation of each well that must be enhanced
DE-R&D U: + I: + S: R	Stimulation techniques	Improve stimulation techniques (chemical and mechanical) to reduce the prospecting risks. Find ways to predict and minimize induced seismicity due to hydraulic stimulation
HU- U: + I: ++ S: U, I	Banning on fracking/environmental issues/handling of groundwater resources	More local studies and international examples and analyses are necessary to demonstrate that geothermal fraccing does not threaten deep-seated groundwater resources (pollution), furthermore make evident differences between geothermal (EGS) and shale gas fraccing (procedures, technology, environmental impacts).
SK-R&D U: ++ I: + S: R, M	Advanced reservoir creation	Development of technologies for reservoir creation
IT-DM U: + I: ++ S:U	Development of EGS demonstration projects	To increase the number of demonstration projects based on EGS technology in order to facilitate the dissemination and to raise public awareness.
CH-R&D U: ++ I: ++ S:U, R, M	Stress and strength profiles from logs	Geothermal reservoir engineers perceive of stress and strength as smoothly varying tensor fields or material properties. Detailed analysis on very few boreholes has demonstrated this not to be the case at all.
CH-R&D U: + I: + S:U. R, M	Selective fracture shut-off	Optimizing EGS reservoir performance comprising both, natural and engineered fracture networks will not only require skill and competence of creating such reservoirs, but also subsequent modifications, alterations and management by active interference. One such field will centre on selective fracture shut-off – using chemicals to induce or accelerate solution-precipitation reactions to modify fracture zone permeability.
CH-R&D U: + I: + S:R	Rate- and state variable friction laws at geothermal conditions	Currently research into hydraulic stimulation and induced seismicity, and reservoir management via “THMC” coupled models is severely constrained by a lack of application of modern rock mechanics research – it is mostly fluid flow modellers and seismologists who are active in the field and are unaware of the applicability of modern research into rate- and state-variable friction laws and thermal fracture mechanics.

IS-R&D, DM U: ++ I: + S: I, R	EGS / Well stimulation	Joint activity and research on well stimulation to enhance the output of wells either by improving near-well permeability reduced by the drilling operation itself (i.e. clogging by drilling-mud or drill cuttings) or to open up hydrological connections to permeable zones not intersected by the wells. The stimulation methods are also used for larger-scale reservoir stimulation during enhanced geothermal system (EGS) operations. This topic aims at improving understanding of the physical and chemical processes involved through; (1) Theoretical work, and; (2) Comprehensive and accurate measurements during stimulation operations. As a result current methods can be improved and new methods developed. This applies e.g. to the thermal shocking method, which has been successfully applied in high-temperature wells in Iceland, but is not well understood and needs further development.
CH-DM U: ++ I: ++ S:U, I, M, R	Stimulation with minimized risk of felt earthquakes	Felt earthquakes are today the principal impediment to obtaining a social License-to-Operate; at the same time, only the most direct observations of induced seismicity are used in a technical context (monitoring growth of fracture systems) while attribute analysis is hardly used
Seismicity		
IT-R&D U: ++ I: ++ S: I, M, R, U	Induced seismicity best practice	A synthesis of different experiences in the world about the seismicity induced by injection/extraction of fluids into/from the underground should be done, with the aim of creating a technical guide for operators and as a guarantee for Administrations and Communities.
IS	Induced Seismicity (traffic-lights)	[Added during working meeting – no description available]
NL-R&D U: + I: ++ S: I, U, M	Environmental impact	Seismic events in Groningen are at the centre of the public’s concern these days (originating from natural gas production). Understanding induced seismicity is a must. Preventing or minimising impact of well stimulation.
DE-R&D U: ++ I: + S: R,I	Gain a better understanding of induced seismicity	Triggering vs. fracture creation: Enhanced estimation of the maximum magnitude which may occur. General mechanisms.
FR-R&D, DM U: + I: + S: I	Seismicity	Induced seismicity must be properly managed, both during stimulation and operation phases, to prevent surface damages and manage public acceptance.

The table illustrates that there is a high priority for working on topics related to anthropogenic influences (stimulation / fracking). The understanding on how humans can influence the naturally given parameters is important in the individual countries. Especially in the field of stimulation, knowledge gaps need to be closed. The cluster „Seismicity" shows that research into this topic is very important for the geothermal industry, which has an important role in promoting the technology. This work is also related to the work on public acceptance in section 3.3: in order to communicate that geothermal energy is a clean alternative, further research especially on the social aspects of e.g. public acceptance has great importance.

3.6 Drilling

Geological drilling is the process of creating boreholes in the earth to reach the geothermal reservoir. The drilling costs are the major aspect in the calculation of a geothermal project. Therefore the essential goal is to develop a deep geothermal drilling technology, which is more cost efficient than the existing technologies. With current drilling technologies, borehole price rises exponentially with depth. Thus, finding a drilling technology with which the borehole price rise would be approximately linear with increasing bore depth is an important challenge.

This cluster includes the research for technologies to reduce the drilling costs, to test new drilling ways and the improvement of drilling technologies and techniques.

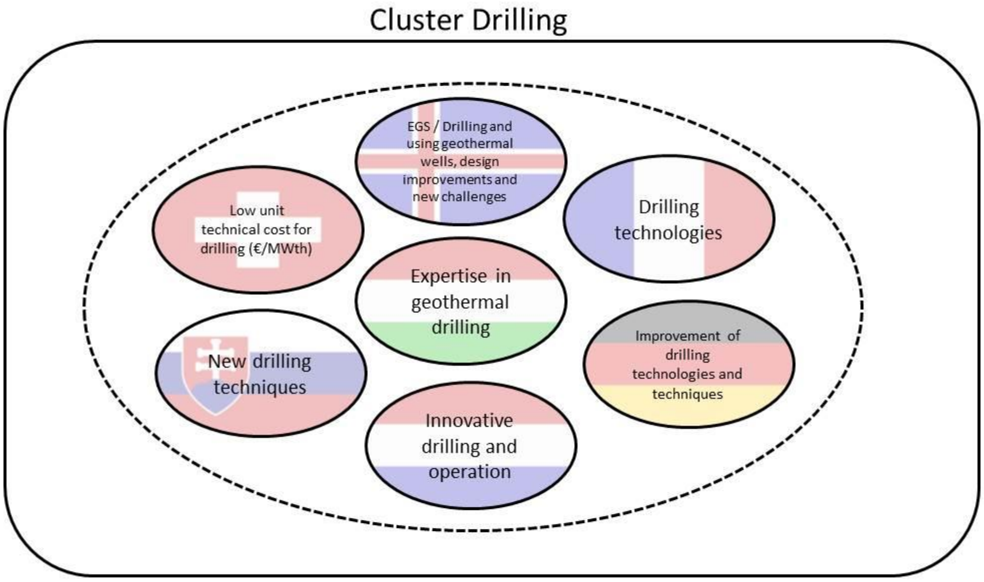

Figure 7 Results of the thematic clustering in the research area "Drilling"

Table 7 RD&D needs: Drilling

Cluster Drilling		
FR-R&D, DM U: + I: + S: I	Drilling technologies	There are two issues on drilling: the adaptation of existing drilling techniques from oil & gas to geothermal (large diameter, basement/volcanic rocks…) and the development of disruptive technologies. The environmental impacts must also be diminished.
DE-R&D U: + I: ++ S: U, I	Improvement of drilling technologies and techniques	The aim is to reduce drilling-costs and -risks (e.g. borehole stability)
HU-DM U: + I: + S:I	expertise in geothermal drilling	lack of reliable and professional drilling companies equipped for high T drilling and field tests
SK-R&D U: ++ I: ++ S: R, M	New drilling techniques	Development of emerging / non-conventional drilling technologies
NL-DM U: + I: + S:U, R, I	Innovative drilling and operation	Techniques to improve drilling performance, save cost, reduce footprint, and minimise operational problems, for example application of composite plastic casings or horizontal drilling.
CH-R&D; DM U: ++ I: ++ S:U. Some R, M, I	Low unit technical cost for drilling (€/MWth)	Advanced drilling technologies while at low Technology Readiness Levels need to be pursued to lower the unit technical cost of wells. At the same time, completions and optimized production systems (artificial lift systems) will also result in a lower unit technical cost (€ per MWh produced) – PSO are at higher TRL and hence more suitable for DM
IS-R&D U: ++ I: + S:U, R, I	EGS / Drilling and using geothermal wells, design improvements and new challenges	Drilling geothermal wells is a complex and costly task and the risk of failure in the whole process of making a well is quite high. This risk involves the drilling itself, inclusion of steel pipes and cementing of the wells as well as corrosion problems during operation. These aspects are particularly important when considering deep drilling, since cemented pipes will have to be much longer and geological conditions may vary considerably between geothermal areas. Drilling and exploration needs to become more economical, potentially with partial automated drilling and on-board measuring devices (MWD) for fast path to target optimization. Drill bit life needs to be extended, primarily with better torque control. Also, corrosion and pressure load could be much higher, making it necessary to use alternative materials and coatings in the pipes.

		Because of high cost and high risk of well drilling, there is much to gain in better understanding the design process and finding new procedures for deep, high energy wells.

The cluster “drilling” shows the need of more field testing and demonstrations of new drilling technologies. New technologies have both a high urgency and a high importance. Especially for investors of geothermal projects, as well as for the existing geothermal industry, innovations and improvements have a high priority.

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