Acceptability of geothermal installations: a geoethical concept for GeoLaB

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Highlights

- GeoLaB is conceived as the first geothermal reservoir simulator dedicated to reservoir technology and borehole safety
- Transparency of research guarantees quality control of the GeoLaB projects, and is an important means of exchange with stakeholders
- GeoLaB forms a platform for education and capacity building, science communication, participation and dialog with stakeholders from industry, politics, administration and society.
- GeoLaB allows for pioneering research, associating fundamental to applied scientific challenges, bridging laboratory to field scale experiments and connecting renewable energy research to social perception.

Keywords

GeoLaB; geoethics; EGS; geothermal; URL; acceptability

Abstract

The growing demand for energy, natural resources and urban expansion during the last two centuries increased human interference with the geosphere far beyond geothermal usage. The increasing number of large-scale projects intervening the area of life of communities raised public concerns related to their environmental and social impact. Integration of public concerns into such projects should therefore go beyond outreach and communication measures. It requires an open approach to inclusive governance structures with respect to designing research and development processes and to modify technological options. Geoethical concepts emphasize that geoscientific knowledge may assist society in decision making as well as in dealing with risks, user conflicts and environmental threats on local, regional and global scale in order to support more sustainable practices at the intersection of human beings and the geosphere.

In the present article, we analyse the social response to recent geothermal development and identify the precondition for public acceptability of geothermal projects. On this basis, the potential contribution of a GeoLaB, a Geothermal Laboratory in the crystalline Basement, to a geoethic approach in geothermal research and technology development is discussed. The underground research laboratory is planned as an infrastructure to answer scientific challenges and to offer the necessary transparency to interact with the public. The GeoLaB approach aims on transparent, tangible science and can serve to enhance mutual understanding of stakeholder groups. It may increase public awareness on geothermal research and potentially enhance the opportunity for public approval of planned activities. As a generic site, GeoLaB can develop scientific-technological solutions for a responsible exploitation of geothermal energy accompanied by sociological studies. The underground research laboratory will serve as a platform for science communication, participation and dialog of stakeholders from industry, politics, administration and society. This complies with the comprehension of responsible research in a geoethical sense.

1 Introduction

Geothermal energy in high-enthalpy regions has been used by societies for centuries, especially where geothermal manifestations occur at the surface (Cataldi et al. 1999; Fridleifsson 2001). With ongoing industrial development, this energy source was considered for use at a commercial scale for electricity generation (Garnish 1976; Grant, Bixley 2011; DiPippo 2012). Since the 1970s, new technologies allowed for tapping geothermal energy even in low-enthalpy regions down to few thousand meters of depth. At that time, first steps towards reservoir generation using hydraulic fracturing were undertaken in the so-called Hot Dry Rock projects (e.g. Brown 2009). The concept of Enhanced Geothermal Systems (EGS) represents an advancement of Hot Dry Rock and focuses on enhancing (or engineering) existing permeable structures in the crystalline basement. EGS was originally introduced at the reference project of Soultz-sous-Forêts, France (Genter et al. 2010). Although still under development, EGS is now considered as a major pillar for the worldwide geothermal energy growth (IEA 2011). The roadmap of the International Energy Agency (IEA) (2011) foresees a worldwide geothermal production of 140-160 GW_{el} in 2050 (from today 12 GW_{el}) with a portion of 60% on EGS. Implementation of geothermal power plants involves high risk investment during the development phases dominated by the prospecting risk. It also implies technical challenges during operation, such as the mitigation of corrosion and scaling. This can impinge the long-term monetary gain of a project, and it may affect the public perception of the technology itself. Issues such as perceptible seismicity during reservoir development and operation, radiotoxic scalings and inflow into drinkable groundwater by corrosion represent possible environmental impacts and are therefore of concern to the public.

EGS development and related public perception are best and most completely documented at Soultz. Here, the concerns about noise and induced seismicity dominate the negative perception of EGS power plants (Lagache et al. 2013). While noise accompanies many developing and existing technologies, the topic of induced seismicity represents a major and technology specific obstacle for up-scaling geothermal heat and power production. During the operational phase at Soultz, induced seismicity has been reduced to a non-perceptible level after 2011 by reducing the well head pressures at the injection wells (Cuenot, Genter 2015). Since at Soultz pressure is linearly related to flow rate (Schill et al. 2017), the reduction of pressure has a direct impact on the economics of the power plant (e.g. Held et al. 2014). First attempts to mitigate seismicity during EGS reservoir development, originating from the experience in Soultz and involving progressive cyclic hydraulic stimulation, were successfully applied at the follow-up projects at Landau, Insheim and Rittershoffen (e.g. Schindler et al. 2010; Baujard et al. 2017). Parallel to this technology, first steps towards understanding of acoustic emissions during hydro-fracturing by cyclic injection were made in meso-scale experiments at the Äspö Hard Rock laboratory (Zang et al. 2017). Despite these first scientific achievements, perceptible seismicity and lately also radioactivity remain major subsurface-related aspects and are perceived as such in the critical public debate on deep geothermal energy (Figure 1). From a social scientific perspective, this may partly relate to the distribution of scientific knowledge in society that itself led to a rising number of knowledge experts and proto-experts (Nowotny 1993). So-called proto-expertise, i.e. scientific and technological knowledge of different kinds and degrees applied in different contexts, is gained among others from being confronted with different projects, institutions, or experts (Chavot, Masseran 2012). Resulting novel configurations of knowledge and knowledge claims need to be addressed.

Figure 1: "No geothermal power plant at Steinweiler"-manifestation of negative impacts related to geothermal energy development on the community as seen by the citizen's action group of Steinweiler (Germany, photo: Horst Geckeis, 4.12.2016).

Past experience revealed differences in the perception of EGS projects by the different stakeholders, in particular operators and local communities. The analysis of concerns that have been raised in the past should be used to propose suitable technological options with reduced environmental impact. It should also be used to establish a proper dialog that is going beyond outreach and communication measures. Furthermore, research and development efforts should be conducted to adapt technological options.

With the intention to develop EGS technology towards an environmentally safe technology, the present paper aims at analysing the social response to recent geothermal development, identifying the precondition for public acceptability of geothermal projects and evaluating the potential contribution of straightforward investigations in underground research laboratories like GeoLaB to a geoethical approach in the discussion on geothermal and EGS technology.

2 Geoethics and Underground Research Laboratories

Ethics is regarded in this contribution as a moral philosophy that is based on concepts of what is right and wrong. If one accepts that a technical installation is neither per se right nor wrong, then for geothermal applications geoethics can be viewed in terms of acceptable, responsible, preferable, or desirable technologies and their antagonisms. Here, we focus on acceptability on the basis of a concept defined by Renn (2015) and Benighaus et al. (2016) (c.f. chapter 3.1): We define technical acceptability for a technology if the risks are a very minor contribution compared to the added value, whereas some risks like those dealing with certain aspects of health, safety, and environment (HSE) have to be eliminated or reduced to a minimum level. We write this paper in the awareness of unknown risks, the knowledge that all work and operation involves risks, and that it is impossible to interact with the subsurface without any hazard.

The awareness of risks is an important factor, which controls acceptance to a certain point. Geothermal installations seem to have a rather low environmental impact, as they need e.g. only a relatively small surface installation, and no severe damage is known from deep geothermal installations – compared to other mining activities or power plants. Even if this is rationalized, the perception might be different.

In the presented geoethical concept we want to focus on acceptability and acceptance, which is more than a rational balancing of chances (e.g. robustness of our energy system) and risks (e.g. HSE) whereas the surplus has to be significantly higher than the possible damage, as it also includes the necessity of felt confidence and perception, as well as aesthetics.

2.1 The concept of geoethics

The growing demand for energy, natural resources and urban expansion during the last two centuries increased human interference with the geosphere far beyond geothermal usage. Limited resources, space and the ongoing climate change led to growing consciousness of environmental sustainability with respect to human health and ecological awareness, and the protection from man-made hazards (United Nations 2013). Being experts on issues affecting our planet, geoscientists gain knowledge on systems and processes within the geosphere. Geoethical concepts emphasize that this knowledge may assist society in decision making as well as in dealing with risks, user conflicts and environmental threats on local, regional and global scale in order to support more sustainable practices at the intersection of human beings and the geosphere.

Geoethics deals with the ethical, social, and cultural implications of geoscientific research and practice, forming a bridge between the field of geosciences, economy, sociology and philosophy (Moores 1996; Peppoloni, Di Capua 2012; Peppoloni et al. 2015). Thus, geoethics can provide practical solutions and useful techniques to improve the relationships between the project stakeholders (scientific community, decision-makers, industry and business representatives, mass media, and the public, e.g. Peppoloni, Di Capua 2015; Höppner et al. 2012). Measures to reach the defined geoethical goals, as suggested by Peppoloni, Di Capua (2015), focus on:

- *Research and science:* Establishing codes of ethical conduct for geoscientific research as well as a regulatory framework for geoscientists engaged in activities that have an impact on society; guaranteeing access to data and results of public research; guaranteeing quality control of results.
- *Environmental consciousness:* Setting up guidelines for best practice, and environmentally-friendly and sustainable technologies in different fields; growing attention to the uniqueness of each region and supporting theoretical and practical innovations; attempting to renew the way environmental problems and natural resources are managed.
- *Communication and knowledge transfer:* Capacity building for scholars and relevant stakeholders and definition of action protocols for the proper management of the relationship between geoscientists and decision-makers to guarantee a constant and authoritative mutual support. A central aspect is the engagement of all relevant stakeholders from the first steps of the research and innovation process to stimulate an active approach to scientific learning, and to enable possible direct involvement in activities of social interest.
- *Education:* The development of innovative and diversified education tools to introduce geoethics to the various groups of relevant actors. Educational campaigns should teach an appropriate behaviour in the management of energy and water, and in the area of protection from natural hazards to include the principles of ethics and research integrity in the management and implementation of national and international research projects that have large environmental and social impact.

Infrastructures such as geoscientific research laboratories have the potential to implement the four abovementioned geoethical measures into technological development. They might provide arenas to discuss and design scientific-technical options to minimize environmental harm, enhance quality assurance and long-term safety as well as to embrace societal perspectives on and experience with geothermal energy. Thus, geoscientific *in situ* laboratories can serve to enhance mutual understanding, may increase public awareness on geothermal research and potentially also enhance the opportunity for public approval of the planned activities.

2.2 Geothermal Laboratory in the Crystalline Basement (GeoLaB)

In well-established energy technology sectors, safety is monitored by independent organizations such as the nuclear energy agency (NEA) of the Organization for Economic Co-operation and Development (OECD), whose mission is "to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes" (NEA 2017). In this context, the concept of engineered geologic disposal has been developed for the safe long-term management of long-lived radioactive waste. Throughout the development of a repository, the feasibility, safety and appropriateness of the proposed system must be proven to all stakeholders before a decision can be made and the development process can progress (NEA 2013). Decision making requires practical demonstrations of key technical elements in order to demonstrate the robustness of the proposed design as well as to establish confidence. Concerning the properties of the subsurface, underground research laboratories (URLs) play an important and multi-faceted role in these scientific assessments and demonstrations by providing a realistic environment for characterising and testing the selected technical approaches and materials. In areas such as demonstrating operational safety, acquiring geological information at a repository scale and in constructional and operational feasibility, only URLs can provide reliable in situ data. Moreover, URLs can deliver tangible benefits in enhancing participation by the general scientific community and confidence amongst both technical and non-technical stakeholders.

URLs are categorized into a generic and a site-specific type. Following the definition from NEA (2013), a site-specific location is considered as the continuation of a site characterization program when specific site information or direct access to the relevant parts of the host rock is required. In contrast, the role of a generic URL is primarily aimed at increasing basic understanding; it is commonly located at sites with geological properties that are similar to the target formation. GeoLaB is designed as a generic infrastructure to answer scientific challenges and beyond that, to offer the necessary transparency and interaction with the public (Schill et al. 2016). It is conceived as a reservoir simulator disclosing the long-term challenges in geothermal development. From a technical point of view, the infrastructure GeoLaB is planned as a gallery with individual caverns, from which controlled high-flow experiments can be conducted at a depth of ~400 m. It addresses the objective of observing, describing and understanding in time and space the processes in an analogue of an EGS reservoir in a complex fractured environment. Adapted to the specific requirements of reservoir technology, GeoLaB serves as a scientific platform that supplies a worldwide unique infrastructure in the crystalline basement to the national and international scientific community. The specific scientific objectives of GeoLaB are:

1) The performance of controlled high flow rate experiments in fractured rock,
2) The integration of multi-disciplinary research to solve key questions related to the flow regime under high flow rates, or higher efficiency in reservoir engineering,
3) Risk mitigation by developing and calibrating smart stimulation technologies to reduce the induced seismic hazard, and
4) The development of safe and efficient borehole installations using innovative monitoring concepts.

As a generic site, GeoLaB will serve as an interface between scientists and involved stakeholder groups, by providing a platform, in which an open dialogue on geothermal energy can take place between all stakeholder groups.

3 Analysis of the social response to geothermal development

Social responses to geothermal energy technology, i.e. definition and articulation of societally relevant issues differ according to their spatial context, the social structure and cultural background. In general, direct articulations by societal actors and issues that are translated by scientists or media can be distinguished. Direct articulation can be specified further as invited participation such as focus group discussions on the one hand and uninvited participation, such as citizen's initiatives – a group of actors that critically evaluate geothermal technology on the other hand (Wehling 2012).

Existing research reveals that discourses on geothermal energy are closely related to the local site of the project, thus they are similarto discourses on other emerging technologies (c.f. Hirschberg 2015). Discourse analyses of public debates show more complex relations and semantic links between geothermal energy and other topics such as territorial sovereignty, identification with locality or socio-cultural institutions or power relationships (e.g. Stauffacher et al. 2015; Pellizzone et al. 2017).

Related to geothermal and EGS development, in the following, we first define levels of acceptance, identify relevant stakeholders and the information exchange between them, and finally discuss socially relevant technical challenges in the development that influence the controversial discussion on the technology.

3.1 Levels of acceptance of large infrastructure projects

Generally, three acceptance levels of large infrastructure projects are identified (Renn 2015; Benighaus et al. 2016):

- Level 1: Tolerance of the planned project
- Level 2: Positive attitude towards the planned project
- Level 3: Active commitment to the planned project

Like most large infrastructure projects, EGS plants do not require a positive attitude or commitment of the plant, the tolerance of a planned project is enough to accept it (Renn et al. 2014a; Benighaus et al. 2016; Renn et al. 2014b). If institutions and their activities are highly trusted, people can tolerate infrastructure projects without understanding their necessity. If the level of trust is lower, the following minimum requirements have to be fulfilled, in order to achieve at least the tolerance of an EGS project by the public or local residents (Renn et al. 2013; Schweizer et al. 2016; Benighaus et al. 2015):

Orientation and understanding: The tolerance of a project is contingent on the condition that those affected by the project understand the reasons why it has been proposed. Local residents and public need to be informed about the potential benefits and risks of geothermal projects for themselves, others and the society as a whole. The description of the positive and negative arguments has to be as precise as possible and should address all relevant issues to get the best "orientation and understanding" of the project or planning. The argumentation process should be transparent and comprehensible that the public can take its own decision about the project (Sztompka 2010).

Self-efficacy: Self-efficacy and sovereignty require no restriction on personal freedom of options. In geothermal development, often environmental issues are perceived as personal restrictions. This includes short-term nuisances during installation of the plant such as high traffic around the site location that can restrict the lifestyle habit of near residence enjoying the nature and the silence. Besides temporary impairment of the lifestyle habits, long-term effects such as noise, pollution or micro-seismicity impact the self-efficacy.

Positive benefit/risk ratio: Case studies on geothermal energy reveal that the acceptance of a deep geothermal plant is higher, if the community and the individual people enjoy benefits related to economic opportunities, sharing of property rights or lifestyle improvements associated with the realization of the project. Therefore, it is important to design the planning process in a way that a positive cost-benefit ratio for the residents can be accomplished. If the ratio is positive, approval of the project is much more likely to happen, often on the second level of positive attitude rather than mere toleration. One of the major difficulties here lies in the diversity of perceptions for both, benefits and risks. In particular, the assessments and perceptions of risks related to geothermal energy projects differ widely among the public and experts and can cause huge conflicts.

Cultural identity: An identification with a specific project by individuals enhances the probability for the approval of this project. Identification in a spatial context denotes the mental and cultural fitness or matching of the proposed project with the familiar natural and social environment. For example, the city of St. Gallen and its municipal utilities initialized and paid the cost for exploration and amounting to CHF 160 million. The city placed much effort to improve the identification of the citizens with this project (Wiemer 2014). Even when an earthquake was induced during drilling operations, the support for the project remained high.

3.2 Identification of the stakeholders

Besides well-established organizations and administrative bodies, civil society initiatives and individual protests form a complex stakeholder pattern in the surrounding of geothermal activities. Hence, a prerequisite to design an interaction strategy for large-scale projects is to know, who are the relevant stakeholders, what are their concerns, and how communication can take place (VDI-Bereich Beruf und Gesellschaft (BG) 2015). The Association of German Engineers (VDI) developed a guideline for early public participation in industrial and infrastructure projects (VDI-Bereich Beruf und Gesellschaft (BG) 2015). The term and definition of stakeholder groups comprises all public actors that may be able to influence projects or undertakings planned by an organization. Knowledge of the stakeholder structure allows for tailoring the interaction strategy. Depending on the kind and location of a project, potential stakeholders may be competitors, customers, industry and trade associations, media, scientists/experts, private-sector contract partners, non-organized actors, civil society groups, licensing and supervisory authorities, communities, governments, local authorities, or political actors.

With increasing development of the internet over recent years, and the spread of web access for everyone at any time and everywhere, the communication channels shifted and the media landscape changed dramatically. New sources of information evolved and the establishment of social networks significantly increased the information, communication, and mobilisation potential of stakeholder groups. Hence, the German VDI standard 7000 (VDI-Bereich Beruf und Gesellschaft (BG) 2015) suggests the performance of a media analysis in order to identify key external stakeholders and key issues related to the project. A media analysis includes the analysis of the coverage on television, in print media, online media and scientific journals, the analysis and monitoring of communication on the Internet and social networks, and an analysis of previous events and comparable projects. In a following step, it is suggested to carry out an analysis of actors and key issues, i.e. to elaborate the project relevance, conflict potential, and knowledge of the stakeholder groups, and the ways of communication between the respective groups.

For example, Leucht (2012) conducted a stakeholder analysis to identify the relevant actors in the discussion about the two geothermal projects of Landau and Bruchsal in the years 2010 and 2011 (Figure 2). The analysis revealed that the main participants in the discussion about the topics in leading media, journals and regional newspapers came from politics, the geothermal sector and the civil society. It has to be noted, that the proportions of stakeholder groups are subject to fluctuations. For example, the proportion of the civil society rose significantly after the sensible earthquakes in Landau in 2009.

The structure of the stakeholder groups strongly reflects the topics of debate regarding a geothermal project. Politicians and authorities as decision-makers and initiators of surveys or of arbitration procedures are main participators in discussions. People from the geothermal sector such as operators of geothermal power plants play a central role as initiators and beneficiaries of geothermal projects. The civil society represents a group of directly affected stakeholders, which brings forward concerns about e.g. safety, economic, and environmental issues. Scientists are mainly asked for education about risks.

The experience of Landau and Bruchsal showed that the stakeholder groups can be very different depending on the respective project and location of the site and hence, the topics discussed. Moreover, the stakeholder participation can evolve during different project phases. This means that one has to continuously monitor the participating groups in a discourse about a project in order to adapt the communication strategies and used media.

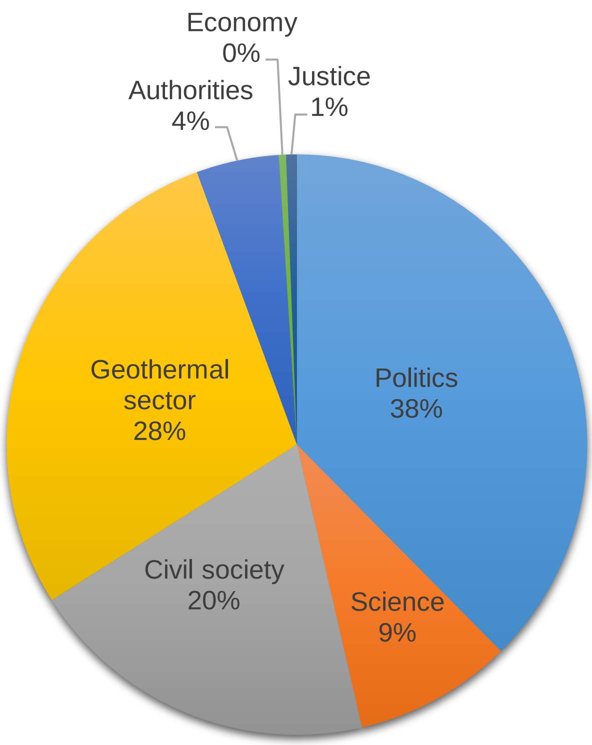

Figure 2: Proportion of stakeholders involved in discussions about the geothermal projects in Landau and Bruchsal, based on 500 total references in local and leading media (Leucht 2012).

3.3 Analysis of information exchange and social responses to geothermal projects

Socially relevant issues concerning geothermal energy technology are taken up in media discourse. Although several studies in the context of energy issues show a close connection between public opinion and this discourse, it is not clear in how far media shape public opinion and vice versa (Stauffacher et al. 2015). Analyses of media discourse on geothermal energy in Germany and Switzerland revealed that relevant issues in media are mainly defined by actors from industry, public authorities, politics, and science (Stauffacher et al. 2015; Leucht 2010). Media articles reporting on local geothermal projects also reflect positions of local citizen's initiatives (Leucht 2014). Interestingly, non-governmental organisations, even when oriented towards environmental protection, do not participate in problem definition in media discourse.

Socially relevant issues are articulated by societal actors in the form of invited but also uninvited participation. Participatory methods in the context of research projects aim primarily at data collection and are often supported, designed or evaluated by social scientists. Thus, they construct a public or micro-public (Capurro et al. 2015) and define the context or frame, in which the public debate takes place. Thus, participatory formats often address publics in regions and places that experienced geothermal energy installations and discuss geothermal energy in the context of energy provision. However, results indicate that issues of public discourse that go beyond the frame set by scientists find their way into these participatory events (Pellizzone et al. 2017). Most visible form of uninvited participation are local citizen's initiatives, in which citizens organize themselves in order to accompany geothermal projects and pose questions relevant for local communities (Kousis 1993; Leucht 2014; Kunze, Hertel 2015).

Critical and positive aspects on geothermal projects observed in public debates are summarized in Table 1. Critical issues often concern environmental, economic and governance aspects. Environmental aspects include induced seismicity, (ground-) water contamination, and air pollution (Moser, Stauffacher 2015). Besides technical issues, such as drilling, exploitation and financial risks, economic aspects are raised, e.g. potential damage on buildings and infrastructures, (Leucht 2014; Kunze, Hertel 2015) as well as governance issues, e.g. unclear responsibilities (e.g. insurances) in case of damages (Popovski 2003; Kunze, Hertel 2015). Governance aspects concern opportunities for local and regional participation in planning geothermal facilities that are rather little (Canan 1986; Moser, Stauffacher 2015), insufficient public communication, and a lack of information on planned projects (Pellizzone et al. 2017). Concerning the interests of industry, the commitment of public institutions is unclear (Pellizzone et al. 2017). Finally, questions are posed on the issue of environmental justice including a fair distribution of benefits and risks (Canan 1986; Kousis 1993; Pellizzone et al. 2017).

Positive aspects raised in debates on geothermal energy are the contribution to the renewable energy mix and the reduction of CO_2 emissions (Moser, Stauffacher 2015). Furthermore, the positive impact on regional development is highlighted by the proponents of geothermal energy (Pellizzone et al. 2017). Analyses of geothermal projects show that early information on projects and transparency of communication allows for a debate on and dealing with critical issues (Popovski 2003).

Table 1: Positive and negative aspects brought forward in public debate on deep geothermal energy (Canan 1986; Kousis 1993; Popovski 2003; Krater, Rose 2012; Benighaus et al. 2015; Moser, Stauffacher 2015; Pellizzone et al. 2017).

	Negative perception	**Positive perception**
Environment	induced seismicity, water contamination, air pollution, noise, damage of flora and fauna	contribution to the renewable energy mix, low land consumption local usage robustness of energy system reduction of CO_2 emissions
Economy	damages of infrastructure, financial risks	economic development of regions

Governance	public participation in planning, responsibility in case of damages commitment of public institutions	public participation in planning, early and transparent information, inclusion of public concerns in planning process

Pellizzone et al. (2017) point to the fact that these critical issues can be found in all public debates but their relevance differs between regions and countries, along the time line. The importance of issues also depends on scale and purpose of geothermal installations (Canan 1986; Krater, Rose 2012; Kousis 1993). Existing studies of controversies on geothermal projects reveal six important aspects, on which public perception and responses depend (Canan 1986; Krater, Rose 2012; Kousis 1993). Among these aspects are the experience with geothermal projects, the relevance of local ecological issues, and the potential to establish links to related topics in public debate, the historic-cultural context, local socio-economic conditions, and trust in experts, institutions, and procedures.

Since GeoLaB's focus is on EGS development, in the following, we discuss selected examples of site-specific demonstration projects with respect to their interaction with stakeholders. In this context, site-specific means utilization related demonstration projects such as the EGS reference project of Soultz, in contrast to generic that is related to an analogue site that is used for research and technology development such as GeoLaB.

Identification of societal relevant issues discussed among experts, political decision makers, stakeholders and residents as well as investigations of media content is a crucial step for understanding the debate. Surveys, workshops, focus group discussions, and in-depth interviews are often carried out in order to grasp public opinion and perception of geothermal energy technology (Moser, Stauffacher 2015; Pellizzone et al. 2017). Results are usually published in scientific journals and fed into the scientific debate as well as introduced into the political discourse on this topic. The evaluation of the main topics nominated in leading print media, journals and regional newspapers in the period between 2010 and 2011 for Landau and Bruchsal (Leucht, 2012) is shown in Figure 3. The two projects in the central Upper Rhine Valley represent two extremes in terms of social attention and technology, i.e. strongly discussed EGS at Landau and hydrothermal from fractured reservoir at Bruchsal with little public attention. For Bruchsal, the discussion on seismicity stays behind interest in deep geothermal technology and electric power production.

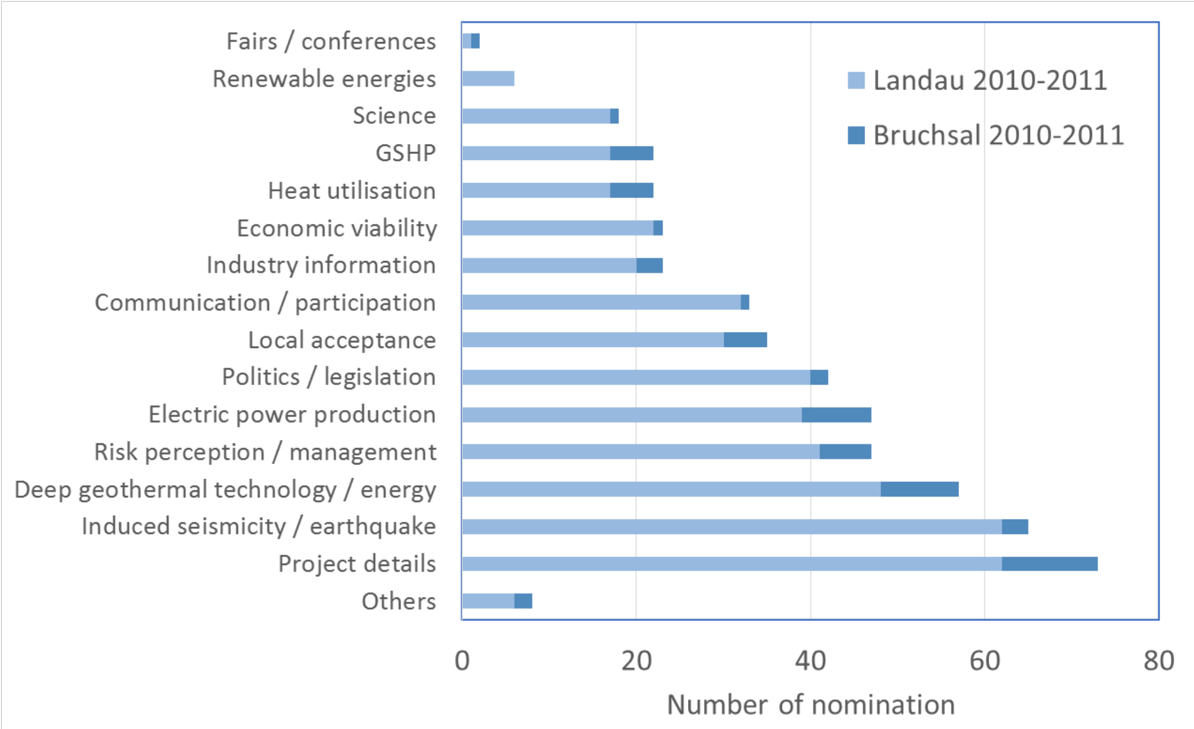

Figure 3: Media coverage of main topics (multiple nomination) for Landau and Bruchsal based on 106 and 14 articles for Landau and Bruchsal in leading media, journals and regional newspapers (after Leucht (2012), GSHP: ground source heat pumps).

At Soultz-sous-Forêts, also located in the Upper Rhine Valley, where an interaction of EGS technology with the local population occurs since 1991, a differentiated shaping of public opinion has taken place over years (Lagache et al. 2013). Within an acceptability study, Lagache et al. (2013) observed that 97% of the 203 respondents knew that geothermal energy is an energy source. However, notwithstanding the 20-years duration of the project, the principle of geothermal energy was only moderately known by the local population. Indeed, only 55% of people who had been living there for less than 5 years (corresponding to the operational phase of the power plant) had some information about the geothermal plant. Regarding the level of awareness of risks associated with exposure to deep geothermal energy, 83% of the people believed that there are no risks originating from the facility that will impact their community. Among the remaining 27%, the main identified risks were induced seismicity and noise (Figure 4). Note, however, that the opinion survey had been carried out in 2012, i.e. five years after termination of reservoir development and two years after the last perceptible seismicity of the operation phase. Finally, despite online information and an average of 2000 visitors per year, the acceptability study showed that the population still felt a lack of information. Thus, it appears that also demonstration projects reach only a limited part of the public. This raises the question, if information given and the channels used are adequate to inform the local population. Thus, future approaches to link demonstration projects with local societies need to be designed differently. A new design might be inspired by generic underground research laboratories.

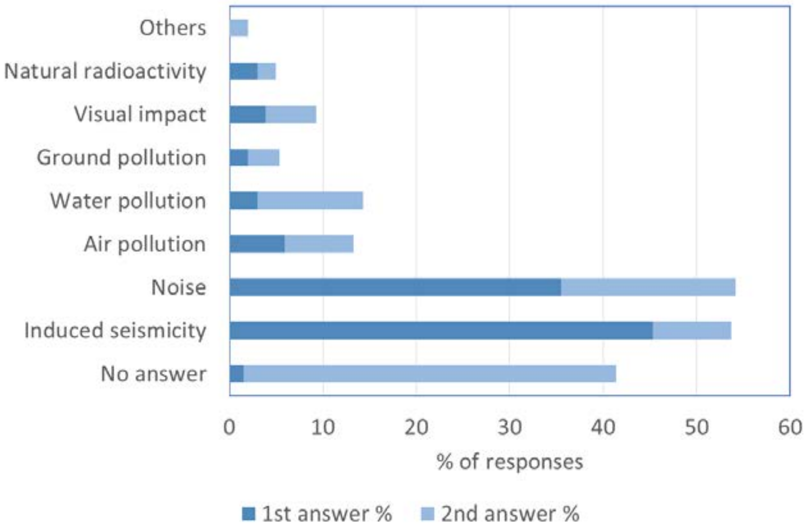

Figure 4: Main nuisances related to deep geothermal energy in percentage of the 27 % of respondents that report nuisance communicated during the social acceptance survey at Soultz in June 2012 (modified after Lagache et al. 2013). Note that 73 % did not report nuisances.

3.4 Socially relevant technical challenges

Advantages of EGS such as CO_2-neutrality, base-load capability and low spatial impact of geothermal energy are thwarted by different technological challenges leading to controversies and public debate about this technology in many countries (e.g. Canan 1986; Krater, Rose 2012; Kousis 1993; Carr-Cornish, Romanach 2014; Pellizzone et al. 2017; Leucht 2010, 2014; Benighaus et al. 2015; Moser, Stauffacher 2015). Issues such as perceptible induced seismicity, borehole integrity, polluting by-products, or groundwater spillovers often raise public awareness and critique. In the following, we discuss the main socially perceived technical challenges. These challenges are addressed by science in order to develop a fundamental understanding of the thermal, hydraulic, mechanical, chemical (THMC) interacting processes in the reservoir to provide generic solutions. These fundamental scientific data may be generated and discussed with a wider society within GeoLaB. In the following, main aspects will be outlined.

3.4.1 Induced seismicity

In general, induced seismicity of geothermal projects is considerably low compared to mining, surface load (dams), injection, fluid removal by hydrocarbon production and others (Grünthal 2014). Nevertheless, as geothermal activities will increase in the future, its induced seismicity needs to be controlled by a full understanding of the processes involved and subsequent risk reduction measures.

Hydraulic stimulation, i.e. enhancement of existing flow paths, and increase of hydraulic yield from ambient conditions is a key aspect in EGS technology. Human activity can influence the effective stress, directly by pore pressure increase, or indirectly by changing the loading conditions on a fault (Ellsworth 2013). Under high differential stress conditions, hydraulic pressures required for stimulation are considerably below the tensile strength of rock. In contrast to stimulation, fracking, i.e. exceeding tensile strength of rock, will create new flow paths. The possibility of inducing seismic events is significantly higher during stimulation since the pre-stressed subsurface rock will release the stored elastic energy by sudden slippage of a fault when the effective stress exceeds the frictional strength of the fault.

Although the conditions of earthquake generation are principally well understood, maximum energy release (maximum magnitude) and how induced seismicity at high flow rates can be controlled remains a matter of debate. Traffic light systems based on local networks have been regarded as most useful for reducing the hazard of induced earthquakes: if a magnitude threshold is exceeded, injection operations will be adjusted to avoid earthquakes of greater consequence (McGarr et al. 2015). Large magnitude events occurring during the shut-in phase are under debate with first concepts that consider the on-going fluid diffusion even after shut-in (Shapiro et al. 2007) and the hydraulic impact on changing the flow paths (Schoenball et al. 2014; Segall, Lu 2015). Therefore, applying controlled, high flow rate experiments (CHFE) in GeoLaB is a prerequisite for the investigation of these effects. The observation of pressure, flow and stress changes in the reservoir under various loading conditions is the key for validating concepts on avoiding large magnitudes in geothermal sites.

3.4.2 Borehole integrity

Apart from induced seismicity, major environmental impacts such as pollution are often an issue of borehole integrity. In crystalline rocks, well integrity is little studied, but certainly linked to brittle behaviour that may lead to an extended damage zone. Boreholes in geothermal applications have to fulfil different important tasks. The well has to securely withstand lithostatic pressures without collapsing. During the exploitation of deep geothermal reservoirs the casing itself, acts as a production and injection liner. This is the consequence of required high flow rates necessitating wide pipe diameters to reduce frictional losses within the casing. Therefore, the cemented casing becomes the only barrier between produced / reinjected fluid and groundwater. The integrity of the borehole is therefore essential to reduce risks of groundwater contamination. Within different groundwater levels, the hydraulic pressure may vary. A secure separation of the hydraulic levels is then a necessity to avoid flow between different groundwater levels. This would otherwise lead to mixture of different groundwater properties and to a possible subsidence or rise of the surface.

The tightness of standard cemented and abandoned wells can be questioned. Experiments show that the surface texture (e.g. roughness) of the drilled well has a significant influence on the formation of mud-channels – for rough surfaces, up to 75 % of the serrations consist of non-displaced mud and only 25 % are well hardened cement, creating possible leakage pathways. Even under idealized cementation conditions using a cement recipe characterized by a very low shrinkage, micro-annuli are formed. These micro-annuli are connected throughout the whole casing in large-scale laboratory experiments (Schilling et al. 2015). In this context the quality of the cemented well-bore is of particular interest. The durability of a hydraulic sealing strongly depends on the success of this displacement. Different cementation flaws may arise in the displacing process, especially sections with remaining mud, e.g. mud channels, may significantly impede the tightness of wells. The effects of interactions between cement and mud during the displacement process are not yet sufficiently understood (Abdu et al. 2012; Nguyen et al. 1992). Micro-annuli, flaws or gaps, can form pathways for migration and emission. Different materials can be used for abandonment (e.g. Kamali et al. 2008). The long-term safe abandonment does not only depend on the long-term resistance of the single materials (rock, cement, steel), but also – and possibly much more pronounced – on the long-term physical, chemical and mechanical interaction of the host rock and different materials of the seal, especially in contact with brine. In geothermal applications, enhanced thermal stresses should be taken into account, which may cause damage of the rock – cement – casing structure.

3.4.3 Corrosion and scaling – incorporation of radioactive isotopes

Related to the thermal water circuit, geothermal projects worldwide are facing scaling and corrosion. The precipitation of solids due to oversaturation or redox reactions in the processed brine occurs with pressure drop, temperature changes, oxygen ingression, and/or corrosion. Carbonates, silica, and sulphur minerals (sulphides and/or sulphates) are the main types of scaling (e.g. Mundhenk et al. 2013). From an environmentally-friendly EGS production perspective, the need to control scaling is related to the incorporation of radioactive isotopes. At Soultz, a general increase of the dose rate values as a function of circulated volume with maximum values on the reinjection line: here the lower fluid temperature (~70°C) tends to induce the precipitation of sulphates (solid solutions between barite, BaSO4, and celestine, SrSO4) and sulphides (Galena, PbS), which are able to trap radionuclides (mainly ^{226}Ra for sulphates and ^{210}Pb for galena) during their formation (Cuenot et al. 2015). An inhibitor system was set up (Scheiber et al. 2012), but so far no process has been established to completely prevent scaling. Corrosion of construction materials is another environmentally relevant concern and generally arises from the combination of elevated temperatures and the presence of corrosive key species in the processed brine (MacDonald et al. 1979). Among those are chloride and carbon dioxide, which are very common in geothermal waters worldwide (DeBerry et al. 1978; Conover et al. 1980). However, it should be noted that not only hydrochemical characteristics, but also other factors (e.g. flow conditions, temperature, and stress) contribute to the harshness of an environment (MacDonald et al. 1979).

4 Towards transparency and tangible science

Science so far takes up societal concerns with geothermal energy and responds by carrying out projects on both, technical solutions to socially relevant issues, and on social acceptance that shall reveal public opinion. The latter often aim on improvement of unidirectional communication strategies and information flow (van Douwe, Kluge 2014). A geoethical approach that takes seriously into account social responsibility needs to develop approaches that integrate the question of responsibility in processes and institutions of geothermal development and to establish a dialogue rather than unidirectional communication. The next sections will discuss concrete examples from Germany, Italy, and France on how responsible processes can be developed.

4.1 Case studies Italy

Explorative engagement can work as a first step for assessing social perception of geothermal energy, engaging the society in the innovation process, and collecting information in order to build further communication and participative activities.

Two case studies assessing the geothermal potential of central and southern Italy, the VIGOR (Manzella et al. 2013) and the Atlante Geotermico del Mezzogiorno projects (Donato et al. 2014), included investigations on social acceptance of geothermal energy in order to understand how public and relevant stakeholders would have responded to eventual geothermal developments. Social acceptance was investigated from the first stages employing a mix of qualitative and quantitative methods in the form of focus groups and surveys. Surveys allowed to reach a large number of people and the focus groups gave the opportunity to go deeper into the discussion on geothermal technologies.

The survey was conducted engaging 400 people from two selected areas, the Provinces of Viterbo and Palermo, and calibrated by a series of variables including gender, age, education, place of residence, and job. The focus groups, composed of 8 to 10 people, were homogeneous and were headed by a moderator and an observer. In both case studies, the local experiences and values were considered. At Viterbo, where a long history of water contamination by arsenic exists, a group of environmental activists that is sensitive to the issue was involved in the discussion. In Termini Imerese, Palermo province, which has a very high rate of unemployed people, a group of ex-FIAT workers were engaged. Further focus groups involved students, local decision makers, politicians and general citizens and all of them were very useful in order to describe the local community attitude towards geothermal energy and also understand their demand of knowledge.

The results of these studies are described by Manzella et al. (this issue). They highlight the concerns and needs of all relevant stakeholders. At a general level, the study revealed a considerable openness towards new energy technologies, however the distrust towards the elite of decision makers can undermine the support for new developments. More specific, geothermal heat pumps are seen as a good opportunity, whereas for geothermal power plants some concerns for the risk of water contamination have been raised by environmentalist groups. People strongly ask for more information in order to participate in the innovation process with awareness, showing a considerable trust for scientists and independent researchers as sources of information.

4.2 Case study Alsace (France)

For the implementation of the climate plan of the Urban Community of Strasbourg (UCS), located in Alsace (France) close to the German border, the realisation of 20-30% of renewable energies is envisaged. In this context, In this context, geothermal possibilities started to be discussed in 2007 in relation with the city of Illkirch-Graffenstaden in the south part of UCS to provide geothermal heat for housing and industries. In summer 2013, following the French mining law, four project proposals were submitted to the Bas-Rhin prefecture, which is responsible for the examination of the case-files and the organization of public inquiries as dialogue spaces. They are part of legal procedures, where citizens may express their point of view regarding major projects related to urban planning or to environmentally sensitive facilities. Dialogue as multidirectional activity in the frame of legal procedures is rather limited (e.g. Köck 2016). However, in a public inquiry, the French law provides investigating commissioners who gather citizens' contributions, valorise some of the arguments and questions, solicit answers from the operators and, in a final report, consider the validity of citizens' and operators' arguments and deliver a personal judgement. The investigating commissioners are mandated by the administrative court. Although advisory, commissioners can influence the decision-making processes himself.

Operators and institutions got engaged in the communication plan in autumn 2014.The controversy on the proposed geothermal projects, however, started already in summer 2014, when the local residents' associations of NE-Strasbourg were alerted by German neighbours associated to German citizens' initiatives about risks linked to geothermal projects. Thus, at the beginning of the controversy, local residents formed their own proto-expertise (Nowotny 1993) on deep geothermal technologies independently from the industrial stakeholders using various sources, such as web sites, but also discussions with experts, scientists, or German neighbours. First critics on geothermal projects were rather technical, enlightening the associated risks and the limits of the measures taken to reduce them. The controversy became multi-form with the release of the projects' case-files in the run-up to the public inquiries that were scheduled for April-May 2015.

Responses to the public inquiries in spring 2015 included simple “no” or “yes”, but also well supported contributions. Most feedback came from French residents and German neighbours, but also from organized groups, such as associations of residents neighbouring communities, environmental protection associations, political groups or town councils. Only one industrialist delivered an opinion. The controversy related to five interconnected issues:

1. Sensitive and densely populated location and choice of the drilling sites according to solely geological and economic interests without consultation of the residents.
2. The delay in information and its focus on strong technical issues, as well as its limited distribution to the village or urban area hosting the projects.
3. Different perception of risks and the capability of risk management of the operators.
4. The lack of a clear political framework for responsibilities, in particular for compensation in case of incidents.
5. Economic issues such as insurance guarantees and financial counterparty to the cities hosting the projects.

Based on the main issues of the controversy, in their conclusions, commissioners put forward the precautionary principle. Finally, the commissioners of the projects except the Illkirch-Grafenstaden one plead for postponing the projects to avoid socially relevant technological risks.

Interestingly, local print media played a secondary role in the development of the controversy. Although reporting on events and stakeholders’ standpoints, they did not propose in-depth information nor an oriented reading of the controversy. This role was taken over by local and engaged blogs, association newsletters and municipal bulletins. In addition, residents’ associations organised several public meetings that attracted each several hundred participants.

At the end of the public inquiry process, the prefecture chose to grant two projects, the Illkirch-Grafenstaden and despite the precautionary opinion of the commissioners, one located at Eckbolsheim (west of UCS). In the decrees authorizing the opening of mining operations, the prefecture will impose the creation of an information committee that will permit regular dialogue between operators and stakeholders. Furthermore, companies have promised to re-examine the possibility of redistributing part of the royalties linked to the projects. In the end, the prefecture and industrialists’ actors took up the concerns related to information demands and financial distribution. More intricate notions such as urban, economic, political and ethical issues that had been addressed during the controversy were raised but did not shape the solution-oriented part of the structured discourse. This outcome may shed a light on the selective functions of structured discourses and the relationships between science, economics, politics, and the diverse publics.

4.3 Case study Carbon Capture and Storage (CCS) in Ketzin (Germany)

For the acceptance of underground installations one might also include the derived knowledge of CO_2-underground storage sites. In Germany, different attempts have been made to get acceptance for a geological storage of CO_2. Besides the accepted and implemented research-project CO_2SINK (www.co2sink.org), several attempts of other storage sites did not receive the same acceptance such as the Vattenfall project in Beeskow (Dütschke 2011), the research project in the Altmark natural gas field (Kühn et al. 2013; Martens et al. 2012) or the RWE-project in Schleswig-Holstein (e.g. Gründinger 2016). Several authors describe communication and outreach as a crucial element for the perception and acceptance (e.g. Szizybalski et al. 2014; Haug, Stigson 2016). Similar to geothermal test sites, the local awareness and acceptance of the different projects seemed to be strongly affected by the local history and experience of the local society (Dütschke 2011). Projects such as in Decature (USA), Weyburn (Canada) or offshore (Sleipner project - Norway) seem to encounter less resistance than the projects in Altmark or Schleswig Holstein. Similar to geothermal, the regional aspect seems to affect the awareness and fears of the society.

Additionally, the successfully implemented research driven CO_2SINK test site close to Ketzin followed a different communication approach by the project leader during permission and implementation of the test site. In all public hearings and discussions with the local community, journalists, and politicians, probable risks and the derived risk mitigation strategies where discussed right at the beginning of presentations. While marking the main identified risks, additional concerns of local residents could be compared.

Similar to hearings in the context of geothermal installations, the main concern in CCS seems to be related to the value of the private property and the security of associated adjustments in the case of damage. The Ketzin communication strategy could also be tested for research driven projects such as GeoLaB. As a resulting aspect, the public confidence and reliability in the operating entity seem to be of importance both in geothermal and CCS.

4.4 Need for novel approaches in geothermal research

Similar incidents like the abovementioned case studies of Italy, France, and Germany show that there are fundamental shortcomings in communication and integration of societal perspectives already in the planning phase of geothermal projects, although first concepts already exist. Currently, the social component of projects is often dominated by a passive analysis of stakeholders and opinions although measures to form an open dialogue and discussion would be needed. A deficient and asymmetric communication between project initiators and relevant stakeholders leads to time-delay in information and knowledge generation resulting in unmanageable self-reinforcing tendencies of proto-expertise and opinion formation partly on the basis of questionable unsubstantiated sources of information. Such self-reinforcing tendencies can only be prevented by novel approaches following a geoethical concept.

4.4.1 Interaction with stakeholders and the public

A central aspect of acceptability is seen in the early involvement of and consultation with the local actors in the planning phase as foreseen by law (VDI-Bereich Beruf und Gesellschaft (BG) 2015). With the construction and operation phase, the communication must extend to the larger public, scientific and educational institutions, and industry representatives. Furthermore, it could be useful to install an advisory council involving stakeholders and an ombudsperson independent from project developers. During all project phases, the interaction with stakeholders and public has to be collected and evaluated as regards transparency and fairness. The results then have to be incorporated in the further planning of implementation and operation. An integrated analysis of the interaction with the public has to be conducted as a coherent system in order to identify all lines of conflict of the project. This includes both, the relational social positions of the local public, but also the positions of the project leaders and designers (Bleicher, David 2015; Gross 2009). In this context, the attitude of the local public towards the project cannot be reduced to rational information, i.e. knowing. Cultural and social factors may be of major importance. They can be addressed by an integrated interaction concept (Gross, Bleicher 2013). It must be assumed that all actors are in a state of not knowing with respect to uncertainty, i.e. all uncertainties related to the project can never be completely transformed to certainty, part of the knowledge remains stochastic and occasional deviations will occur (Gross 2010). Public concerns cannot be exclusively addressed on the basis of technical or natural scientific knowledge alone (Benighaus et al. 2016). The transparency of planning and dealing with an emerging technology and large-scale infrastructure projects allows the public to assess the knowledge and uncertainty of the technology. A scientific approach in a laboratory open to actors of a wider society allows an openness of research processes and evaluation of research results that is recommended in the case of emerging technologies (Benighaus et al. 2016).

4.4.2 Real World Experiments and Responsible Research & Innovation

As a basis for quality control within the sociological analyses, the concept of "Real World Experiments" and "Responsible Research & Innovation", RRI, should be applied during the project. Real World Experiments and RRI are concepts for analysing and designing societal processes with experimental character (Gross et al. 2005) and are based on the four quality criteria: 1) Anticipation, 2) Reflexivity, 3) Inclusion and 4) Responsiveness (Stilgoe et al. 2013). These criteria refer to the anticipation of potentially unknown advantages, disadvantages, and knowledge gaps of a new technology, the reflection on the role(s) and interests of natural and social scientists involved into the project, an active consideration and inclusion of concerns of the local population, and the open communication of the possibility to stop the project.

5 GeoLaB – a novel geoethical approach

The need for new communication strategies and dialogue between project developers, researchers, and stakeholder groups in a geoethical sense can be best implemented in a large-scale geoscientific project like the underground research laboratory GeoLaB, which at the same time can serve as a platform for social science. In the following, we will discuss the contribution of GeoLaB to the goal of geoethics to provide geoscientists with practical solutions and useful techniques in their contact with society (Peppoloni, Di Capua 2015). The role of GeoLaB concerns the establishment of an ethical framework and a guarantee for access to data and results of public research including quality control for major debated issues in geothermal development. GeoLaB's core goal is related to setting up environmentally friendly and sustainable technologies with attention to the uniqueness of each region and supporting theoretical and practical innovations. Furthermore, the concept of open platform for the engagement of all relevant stakeholders by exchange of knowledge and experience between the worlds of professionals, researchers, industry, authorities and the public will be detailed. This goes along with the development of education tools based on exchange of experience among educators and users, to stimulate an active approach to scientific learning and a possible direct involvement in activities of social interest.

In the following, we relate activities in GeoLaB to the main concepts of geoethics, research and science, environmental consciousness, and communication and knowledge transfer. A basic geoethical education in creating ethical consciousness towards natural resources is an integral part of the education of young researchers.

5.1 Research and science

As commonly accepted among scientists, research and science benefit from the establishment of an ethical framework and a guarantee for access to data and results of public research including quality control. Interestingly, this is also requested by stakeholders with respect to geothermal energy development. For example, participants of focus groups in Germany and Switzerland demand scientific research to get a more detailed understanding of an emerging technology in an open, transparent process (Benighaus et al. 2015).

GeoLaB is conceived as an open multidisciplinary research platform accessible for national and international research groups interlinking physical sciences and engineering, environmental, geo- and social sciences. The worldwide uniqueness of the infrastructure is supposed to attract international research to ensure research diversity and generate synergies necessary for the complex issues associated with the development of a sustainable new technology. A long-term establishment of competences in specific socially relevant research topics might be achieved. Furthermore, the research infrastructure is planned to be owned by research institutes and/or governmental institutions to ensure that the operation is not associated with monetary gains.

GeoLaB will be accompanied by a virtual reality project. This “Virtual GeoLaB” will implement the recommendation by the National Science Foundation to build adequate long-term data infrastructures for large and complex scientific projects. A virtual reality concept for a complex scientific project such as GeoLaB is novel, but it can be supported by the long-term experience in virtual reality projects (Bilke et al. 2014).

The scientific program of GeoLaB is defined by a number of key experiments in particular controlled high flowrate experiments. During these tests the “Virtual GeoLaB” can provide on-line access to experimental data and will serve as a persistent data repository of the key experiments. Due to the expected large amount of experimental data a visual support in a time-spatial context, where data are linked to their geometric position and duration (e.g. Jahn et al. 2017), will guarantee both, fast and long-term data access. Furthermore, “Virtual GeoLaB” will include experiment related conceptual and numerical model information. In this respect, data availability from one platform is needed for model calibration and validation purposes. In addition to geometric information, “Virtual GeoLaB” will also incorporate possible parameterizations including statistical information. In summary, the “Virtual GeoLaB” concept will provide a permanent visual documentation of the real GeoLaB implementation as well as supporting experimental design and analysis.

5.2 Environmental consciousness

With respect to the environmental consciousness, the advantages of geothermal energy are evident, since geothermal is capable of supplying base load from a huge potential that can be operated in a sustainable and decentralized manner. Requiring only little space at surface it is optimally suited for densely populated areas as a nearly emission free energy source that provides security of supply for both, electricity and heating power. In central Europe, the largest geothermal potential resides in the crystalline basement rock with important hotspots in tectonically stressed areas.

The implementation of this generally environmentally friendly and sustainable technologies with attention to the uniqueness of each region and supporting theoretical and practical innovations is in line with the development of EGS technology towards non-perceptible seismicity, borehole integrity and minimization of scaling. Among these fundamental challenges, GeoLaB will address mainly reservoir technology and borehole safety. The specific objectives of GeoLaB are 1) to perform CHFEs in fractured rock, 2) to integrate multi-disciplinary research to solve key questions related to flow regime under high flow rates, or higher efficiency in reservoir engineering, 3) risk mitigation by developing and calibrating smart stimulation technologies without creating seismic hazard, and 4) to develop save and efficient borehole installations using innovative monitoring concepts. Planned experiments will significantly contribute to our understanding of processes associated with increased flow rates in crystalline rock.

The experiments in GeoLaB will be continuously monitored from multiple wells, drilled from the underground laboratory or from the surface. The application and development of cutting-edge tools for monitoring and analysing will yield fundamental findings, which are of major importance for safe and ecologically-sustainable usage of geothermal energy and further subsurface resources.

GeoLaB is an analogue site representative of the world‘s most widespread geothermal reservoir rock, the crystalline basement. It is designed as a generic URL adjacent to the Upper Rhine Graben. Its advantageous geothermal conditions with about 10 geothermal projects in operation or development are well-known. Temperatures in the central part range from 75 °C to nearly 150 °C at a depth of 2000 m. Hydrothermal circulation along faults accounts for 75-85% of the temperature anomalies (Baillieux et al. 2013) and allows for EGS development. Its most prominent geothermal hotspot in Germany represents the uniqueness of this region.

5.3 Communication, capacity building and knowledge transfer

Public engagement aims at eliminating the asymmetry in terms of knowledge and communication between the organisations on the one hand, and the stakeholder groups on the other. In the context of increasing plurality of interest groups with competing interests, e.g. when environmental issues compete with economic interests and individual concerns (VDI-Bereich Beruf und Gesellschaft (BG) 2015), clear, transparent and comprehensible information is needed. Therefore, early involvement of stakeholders with different roles in the innovation process may prevent proto-expertise from acquiring a life of its own. In this respect, geoethics employs concepts of open platforms for the engagement of all relevant stakeholders by exchange of knowledge and experience between the worlds of professionals, researchers, industry, authorities and the public. According to our analyses, such a platform needs to offer the possibility for open discussion on technical aspects such as site selection and risks, but also on related aspects such as regulatory and economic issues.

Tools of knowledge transfer of the GeoLaB laboratory are an integral part of the communication strategy. Knowledge transfer in the broadest sense can be seen as a way of capacity building not only for scholars but for all relevant stakeholders. Capacity building can be described as the process of helping local actors to acquire and use information relevant to a project (OECD 2012). Access to information and understanding how to use information are defined as “knowledge” (Burns, Fazekas 2012). The goal of capacity building is to find better and more efficient ways for different actors to access and use knowledge in local educational contexts in order to achieve desired outcomes. The education concept must increasingly respond to new societal, economic and individual needs. Stakeholder analyses reveal a major proportion of civic stakeholders to discourse about large-scale projects. Hence, it is the local level that is most challenged by these developments. Educational and social activities may include: summer schools, guided tours, blogs in the social media, open access publication, public relations, documentation, brochures, and material for visits of school classes, etc. In line with the “Virtual GeoLaB”, the Earth-Systems-Knowledge-Platform (ESKP) is an example for communication of context and background on a variety of geoscientific questions and challenges such as natural hazards, climate change, pollutants in the environment and renewable energies resources. The web-platform (http://www.eskp.de/) provides information prepared by scientists who are experts in the field and therefore stands as an independent objective source of information. GeoLaB will be integrated in this established platform.

Due to the complexity of data and information on manifold environmental processes and systems - we are developing novel methods and technologies for knowledge building and transfer. In addition to more and more automated procedures – experts' knowledge and experience should be supported at maximum by information technology. Scientific visualization is an example for facilitating the perception of experts (Figure 5). Visual analytics is a key to the comprehension of complex systems. This applies for both, scientists and non-scientists. It is not only a tool for researchers to gain better understanding of complex systems behaviour (Bilke et al. 2014), it particularly supports public understanding and acceptance of geothermal energy exploitation. Visual methods are particular important for geoscientific applications as they are "hidden" in the subsurface.

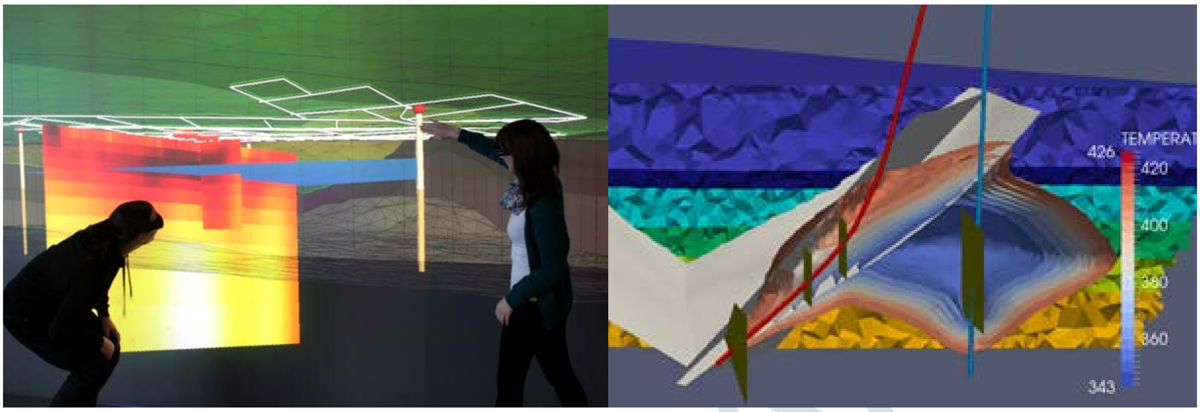

Figure 5: Visualization of a shallow geothermal installation (Borehole Heat Exchanger – BHE elements) in real context of an urban quartier planning (left), Computer simulation of a deep geothermal system including the complexity of physical processes during heat transfer and able to predictions (right) (Source: VISLAB www.ufz.de/vislab)

With its connection between fundamental and applied science combined with its international, multidisciplinary approach, GeoLaB might offer ideal conditions for a high quality, comprehensive education of scientists. This will result in higher competence of scientists in societal highly discussed questions. The platform character can train them in "system thinking" and to interact with the public, stakeholders and decision makers. It might build awareness for the social impact of their scientific work and for their responsibility within their community and society. Hand in hand with the sensitization of geoscientists for societal issues, the active exchange of experience between scientists and project owners and relevant stakeholder groups can stimulate an active dialogue and create a shared level of communication.

6 Conclusion

The G7's declaration at the Elmau Summit on June 8th 2016 committed to a decarbonized world economy by the end of this century. The build-up of an economy based on renewable energies and sustainable development in the light of COP21 requires a concerted action and convergence on subjects in science and public. In this context, the forecasted savings of CO_2 emissions by nearly 70% from heating of building represents a major challenge in Germany.

In a low oil price environment, interest in geothermal development complementing other renewable energy forms and sustainability cannot prevail if solely driven by economic concerns. Political will, social acceptance and consciousness motivated by a concern for environmental consequences would have to be a major driving factor for the implementation of COP21. Decision making on the necessary techniques relies broadly on public opinion spread through media and internet that will be taken up in politics and authorities. Hence, an overall expertise among all stakeholders is required for scientific reasons and public insights. Research on central topics of the energetic transition have to be strengthened in the scientific community by multidisciplinary approaches. Transferring long-term experience from established industrial branches like oil and gas to central issues of geothermal development can be used as a starting point for new pioneering projects.

In this context, GeoLaB is aimed as the first reservoir simulator for geothermal reservoir technology and borehole safety. Real scale experiments and cutting-edge research in crystalline rock next to thermal hotspots will contribute to the environmentally safe development of geothermal energy as renewable energy source. Although being representative for EGS reservoirs in the crystalline basement, results gained in GeoLaB experiments are to a certain extent transferable to other potential EGS sites, hence fostering progress in world-wide safe EGS development. With its unique geothermal laboratory setting, GeoLaB allows for pioneering research, associating fundamental to applied scientific challenges, bridging laboratory to field scale experiments and connecting renewable energy research to social perception.

GeoLaB is conceived as an integrative project: It aims at the development of scientific-technological solutions for a responsible exploitation of geothermal energy accompanied by sociological studies. Providing open access to data and results using different scientific and non-scientific platforms, GeoLaB is seen a central part of transparent communication. This concept guarantees quality control of the GeoLaB projects, but it is also an important means of exchange with stakeholders. Beyond the scientific and technological orientation of the infrastructure, GeoLaB forms a platform for science communication, participation and dialog of stakeholders from industry, politics, administration and society. This complies with the comprehension of responsible research in a geoethical sense.

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