Grant Agreement no. *241321-2*

Geothermal Engineering Integrating Mitigation of Induced Seismicity in Reservoirs

Project Acronym: GEISER

GEISER Deliverable6.3: Report summarizing the results of the tasks in form of input and boundary conditions for regulatory guidelines

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Table of Content

1 Introduction

Deliverable 6.3 of Geiser reports the results of Task 6.3 (Real-time tools to monitor the evolution of induced microseismicity) and Task 6.5 (Provide boundary conditions for regulatory guidelines).

Activities in the Geiser project focussed on building a shared conceptual framework for these deliverables in close feedback with other Work package activities providing input. To this end a number of workshops have been organised between WP 5 and WP 6, including a workshop in Utrecht in March 2011 one in Zurich in November 2011 and various work meetings. From a regulatory perspective the boundary conditions need to closely connected to conditions and evaluation criteria for licensing of activities. As an outcome of joint work package meetings during the general assembly in 2011 it became apparent that we needed to further synergize the insights of WP 3 and WP4 into WP 5 and WP6. To this end in Q1 2012 a joint workshop between WP3,4,5,6 has been devoted to the outline of key parameters which control induced seismicity and to discuss strategies how a priori assessment, monitoring and validations of these can be incorporated in a regulatory framework and technical guidelines. As an outcome of the Q1 2012 workshop it has been decided to organize a follow up workshop Q3 2012 for the technical guidelines serving as input for regulatory quidelines

These technical guidelines have been described in detail in the following deliverables of Geiser:.

1) Input Guidelines for best practice for seismic hazard assessment (D5.6)
2) effect of different stimulation techniques on the seismicity and strategies to mitigate induced seismicity (D6.1)
3) Technical best practices for monitoring (D6.2)

In addition a separate deliverable of Geiser deals with Socio-economic best practices(D6.4) [1], which is also of great relevance to providing regulatory guidelines

This document deals with fitting the fore mentioned technical and socio-economic guidelines in existing regulatory frameworks. To this end this document first introduces a conceptual development framework for EGS, identifying main toll-gates for regulatory guidelines. Next this document outlines the main features of various national mining laws and its practical regulatory implementation. For each of these an outline is given how the law and regulatory framework are or could be applied to EGS development. The situation in the Netherlands is first discussed where there is a long track record regarding induced seismicity. Subsequently we deal with countries where EGS exploration and production has been developed (France, Germany, Iceland, Italy, Switzerland). The second chapter summarizes the findings from fore mentioned technical guidelines and socio economic best practices . The last chapter of this document discussed the scope for adaptation of these guidelines into regulatory guidelines that can be accepted by other member states.

[1] Besides a technical-spatial feasibility study, investigating the social-economic characteristics of an EGS-site is needed for designing and planning an EGS-project. A social-economic assessment takes into account 1) the cultural characteristics of the (local) society or community, 2) the actor network involved (including both the actors within the non-formal dynamics and the actors within the formal (regulatory) procedures) and 3) the interests (costs and benefits) that are at stake in the intended project. With the outcomes of this social-economic assessment, the project and communication strategy can be drawn (see figure 2). The objective of both a technical and a socio-economic assessment is to positively influence the potential for public acceptance of an EGS-project.

2 The conceptual development framework for EGS and regulatory tollgates

For EGS five development phases are identified (cf Majer et al., 2011):

Phase I: a) Planning (feasibility, identifying resource, secures rights to resource)
b) pre-drilling exploration (surface exploration).

Phase II: Drilling, Logging, Testing (exploration and/or drilling permits approved, exploration drilling conducted/in progress, transmission feasibility studies underway).

Phase III: Stimulation (securing power purchase agreements and final permits, full-size wells drilled, financing secured for portion of project construction, interconnection feasibility study complete).

Phase IV: Operation (plant permit approved, facility in construction, production and injection drilling underway, interconnection agreement signed).

Phase V: Post operation (abandonment of site)

The transition between phases Ia and Ib, II and III, III and IV, and IV and V correspond to 4 major regulatory tollgates (Fig. 2.1). These are subject of this document.

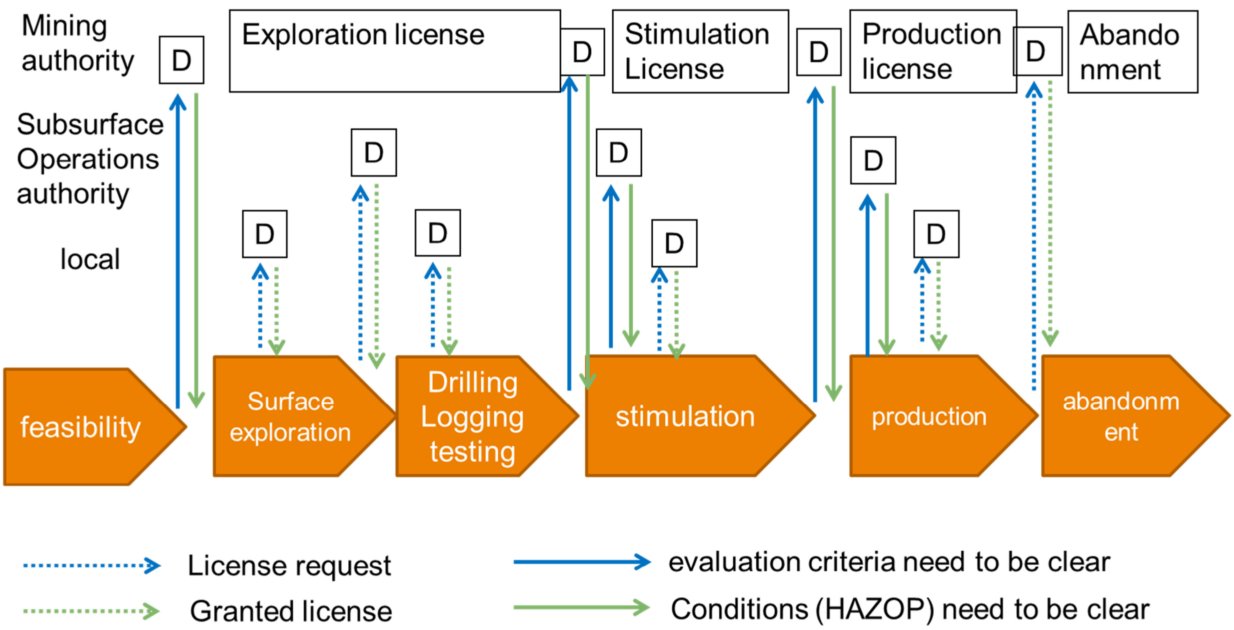
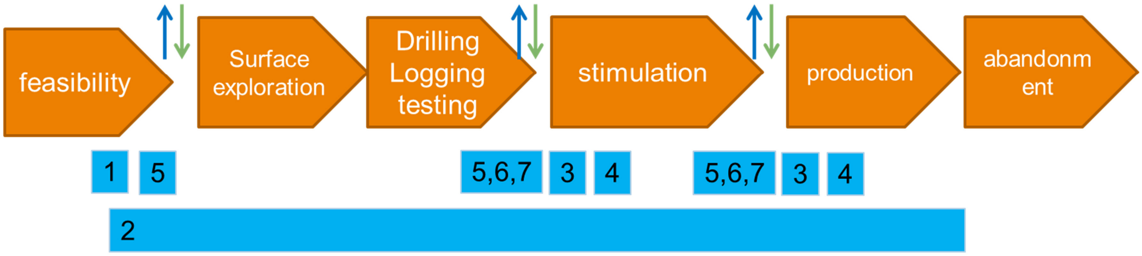


Fig. 2.1 Conditions and criteria for licenses for specific subsurface activities need to be clearified based on technical best practices developed in GEISER. D denotes decision toll gates for national and local authorities. At the bottom a typical EGS project workflow is indicated. Dashed lines indicate clear conditons, whereas solid lines indicate conditions and criteria to be covered by this deliverable



Connect for conditions and criteria to US PROJECT BASED protocol

1) Perform a preliminary screening evaluation
2) Implement an outreach and communication program
3) Identify criteria for ground vibration and noise
4) Establish seismic monitoring
5) Quantify the hazard from natural and induced seismic events
6) Characterize the risk from induced seismic events
7) Develop risk-based mitigation plans

Fig. 2.2: Interconnection of steps in the US protocol for induced seismicity in EGS projects (Majer et al, 2012) and key project development stages for EGS identified in GEISER. The US protocol is primarily intended as best practice for project developers

The proposed attention for social economic best practices (see deliverable 6.4) within the regulatory framework for future EGS-project could likely be integrated in the first phase of an EGS-project (planning phase including the social-economic assessment) and the development of an outreach and communication program (see figure 2.1, phase I and figure 2.2, step 2). Step 5 requires the assessment of parameters and processes beyond human control and interaction with proposed stimulation scenarios (Fig. 2.3).

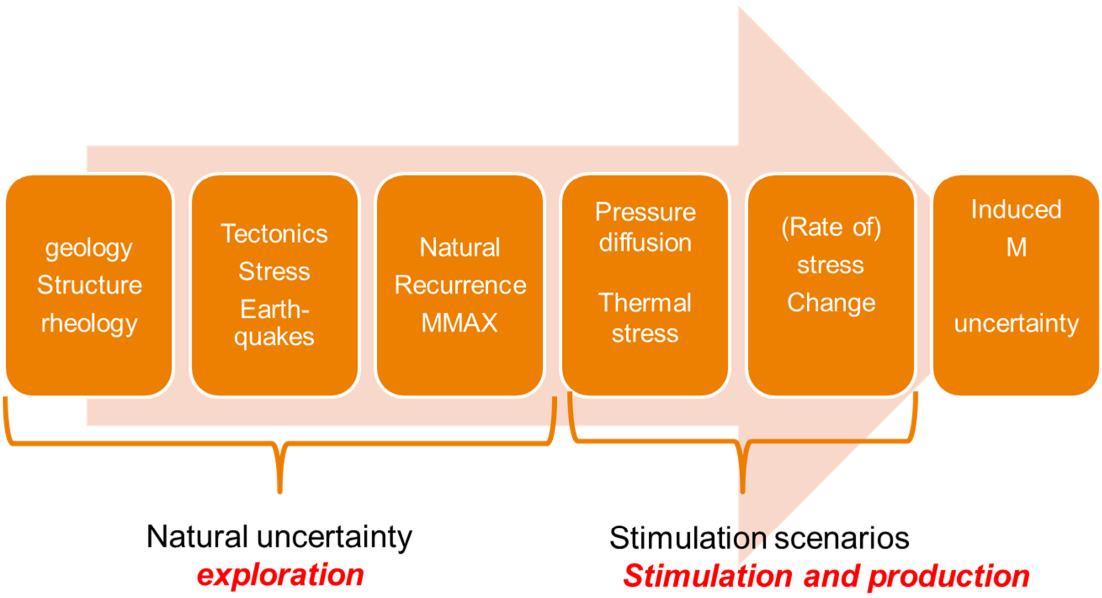


Fig. 2.3. Interaction of key natural parameters and processes beyond human control and options for stimulation and production, affecting jointly maximum magnitudes of induced seismicity.

3 The Dutch mining law

Introduction
The current version of the Dutch mining act dates from 2003[2]. The act recognizes two main uses of the deep subsurface: 1) production of resources and 2) storage of substances. In the law it is clearly stated that the provisions regarding exploration and production of resources similarly apply to the exploration for or production of geothermal energy. In order to arrive at actual production of resources three stages are defined, that are described below, including their relevance for EGS.

Exploration license
The first stage is the exploration license. In the application for an exploration license the duration, license area and targeted mineral have to be specified. As soon as an application for an exploration license has been submitted, other parties are given the opportunity to submit a competitive license application within 13 weeks after publication in the Dutch State Gazette (‘Staatscourant’) and the Official Journal of the European Community. The ‘Gedeputeerde Staten (Executive council)’ of a province, to which the application for a license is applicable, may advise on the application. Within 6 months after receipt of the application, the minister will make a decision on the granting of an exploration license, which will then be published in the State Gazette. The exploration license conditions specify the minimum work program to be carried out.

Production license
The next stage is the production license. A production license will only be granted, if the applicant has sufficiently demonstrated, that the resources for which the license will apply, are economically producible in the region of interest. Usually the applicant has extracted that information from activities during the exploration license, but the law allows to use information acquired otherwise as well.The license automatically applies to other resources that are inevitably produced in conjunction with the produced resource.

Refusal
The production license may be refused due to a] insufficient (geo-) technical and/or financial capabilities of the applicant b] inappropriate methods the applicant intends to use or c] lack of efficiency and responsibility of the applicant.

Duration
The validity of a production license has to comply with the duration of the production activities envisaged. Old licenses (e.g. Groningen, 1960’s) used to be granted for an indefinite period of time. Offshore licenses (as from the ‘70’s) and more recent onshore licenses (as from 1984) for oil or gas production expire after 40 years. Extraction of e.g. rock salt or geothermal energy may have a different duration, although 40 years still is a rule of thumb.

Area
The production license is only granted for a specific area, justified from a geological point of view and complies with the work program.
If a license for the production applies to an area in which a reservoir is present which can reasonably be expected to extend beyond the boundary of the license area, the license holder is obliged to co-operate in reaching an agreement with the license holder of the adjacent area.

Production plan
The final stage is the production plan. The production plan needs the approval of the responsible Minister. The production plan describes:
- anticipated volume of resources present and location thereof;
- start and duration of production;
- method of production and related activities;
- volume of resources to be produced annually;
- cost on an annual basis of the production of the resources;

[2] http://www.nlog.nl/resources/Legislation/Engelse%20vertaling%20Mijnbouwwet1.pdf

- soil movement, including subsidence and induced earthquakes, as a result of the production and measures to prevent damages as a result of soil movement

Annually, a licensee has to submit a report (' Jaar-rapport', ex art. 113 Mining Decree) to the license authority on the progress of the execution of the production plan and on any deviations from that plan. In case of significant deviations (e.g. production rates, production method), the licensee is required to submit an update of the production plan, again for approval from the Minister.

The 'Measurement plan'

Measurements of subsidence shall be carried out before the start of production, during production and for up to 30 years after cessation of the production.Forecasts of soil subsidence (and seismicity) are a part of the production plan

For onshore mining projects, the licensee has to submit a regular (annual) update of the plan for measuring soil movement (the 'Meetplan'). This plan contains a.o, the techniques applied, network lay-out and frequency of measuring soil movement. The 'Meetplan' needs approval from the State Supervision of Mines.

Soil movement also includes induced earthquakes. In the production plan the level of earthquake hazard has to be defined. Van Eijs et al., 2004 and 2006, investigated the possibility of a deterministic hazard analysis for induced seismicity in the Netherlands.
Apart from the observation that seismicity only started after a depletion of at least 70 bar, two parameters were identified. The first one is the ratio between the Young's modulus of the overburden and that of the reservoir rock. The second is a measure of the fault density in the reservoir. The estimated seismic hazard is calculated using these parameters. In 2012, van Thienen et al published an update of the deterministic seismic hazard study. One important observation was that induced events (between 2004 and 2010) occurred in gas fields which had medium or high seismic hazard determined from the 2004 study. After the update, fields were divided in three categories; a negligible seismic hazard (0%), a medium one (19%) or a high hazard (42%) . Of course, when a gas field already has shown some activity, the hazard equals to 100%.

A maximum magnitude of Ml=3.9 (Van Eck et al., 2004) is calculated from statistics (Gutenberg-Richter relations), physical properties of the available faults and cumulative energy estimates..

General remarks

The previous holder of a (exploration/production) license must take all steps that are reasonably required to prevent:

- adverse consequences for the environment;
- damage as a result of soil movement;
- jeopardized safety;
- jeopardized interest of an effective management of resources or geothermal energy.

The licensee has to deliver copies of measurement data to the Ministry. A specified set of these data will be publically released after 5 years have elapsed since the date of measurement. Some data types, e.g. production/ injection data per well, are released immediately. On behalf of the Ministry, TNO manages the database and the data release.

How does this work in practice

In practice the ministry of Economic affairs, Agriculture and Innovation (EL&I) is advised on matters regarding the mining law by the State Supervision of Mines (SSM), TNO-AGE and KNMI. Their roles are outlined below.

<u>TNO-AGE</u>

TNO-AGE gives advice on geological, geophysical and geotechnical matters. In addition TNO-AGE evaluates license applications on their technical merits and the adequacy of the proposed work program, evaluates production plans and monitors mining activities and their potential impact on the environment (e.g. subsidence). Since TNO is a commercial company and information provided by the licensees are often confidential, the advisory group to the minister is separated from the rest of the company (TNO-AGE).

KNMI
The seismology section of the KNMI is responsible for monitoring seismicity in the Netherlands, including induced seismicity. Monitoring also includes the calculation of the seismic hazard.

State Supervision of Mines (SSM)
As the name implies, SSM supervises the mining activities in the Netherlands and their compliance with regulations and license conditions.

Soil movement technical commission (Tcbb)
The minister is advised by the **Soil Movement Technical Committee** on the consequences of mining activities for soil movement and damage caused by these activities. In addition the committee gives advice to civilians on damage to their property possibly caused by mining activities and finally the committee will provide advice to civilians, when requested and conditional, on the level of the financial compensation.

In case mining operations cause damage, this can be claimed at the responsible mining company. If there is legal dispute, the claimant can turn to the Soil Movement Technical Committee (Tcbb[3]) for advice. Tcbb is an independent committee and usually settles a disagreement. If the conflict still remains the claimant can still go to court. In addition Tcbb will provide advice to the minister if deemed necessary or if requested.

Mining Council
The mining council advises the minister. Their task is to advice the minister if requested by him and to provide the minister with information necessary for the evaluation of the feasibility of proposed statutory provisions and general policy plans.

Apart from these advisory bodies, a platform was created to discuss issues related to induced seismicity in a group consisting of representatives of above mentioned advisory bodies and representatives of the mining companies. This group is known as the Technical Platform on Earthquakes (TPA) and meets twice a year. Discussion topics are related to the requirements, stated in the mining law, where mining companies are requested to provide a seismic hazard and risk assessment. Research topics are identified and discussed.

Information from government
Formal announcements of license applications and on the granting of exploration and production licenses are published in the State Gazette (‘Staatscourant’).

The status of mining activities, including geothermal, is published in the yearly report ‘*Annual review Natural resources and Geothermal energy in the Netherlands*‘ by the Ministry of Economic Affairs,(EZ), which can be found on the portal www.nlog.nl. This portal also provides information on mining acitivities, resources, regulation, production plans, production data, measurements on soil movement etc and has a special site for Geothermal Energy.

At the level of geotechnical data (well data, core data, seismic data, etc.), www.dinoloket.nl is the central store for access to these data.

In her capacity of adviser to the ministry of EZ, TNO is strongly involved in preparing the above mentioned data sets and reports and in maintaining the portal and related websites.

The State Supervision of Mines has its own website www.sodm.nl, where general information can be found on HSE matters and regulation for supervision on mining activities.

[3] www.tcbb.nl

New developments in mining regulation

The above is a short summary of the current Dutch mining regulations and its implementation.

Relatively new is the policy instrument to declare a certain application in the subsurface as being of national interest. This policy instrument provides for a faster 'one stop shop' license procedure (since it overrides local authorities), but still remains open to objections from stakeholders. A so called Environmental Impact Assessment (IEA) is key in these to evaluate the environmental impact.

Until recently the Dutch subsurface was exploited predominantly for the production of hydrocarbons, coal and rock salt. Over the last decade however, more and more new applications are being developed including geothermal energy production storage of substances and buffering of gas and energy. Many of these applications re-use the space in existing reservoirs and salt caverns at the end of their production .

As described above, the current practice implies that license applications are judged by their technical and economical merits only. Potential alternative uses for the same area are not considered to be a reason for refusing a license except for those that interfere with existing licenses. Neither does the aspect of social acceptance and integration with existing surface planning play a role which often results in many long trials after the licenses are granted.

From the awareness that the amount and variety of subsurface activities ever more lead to conflicting interests (recent examples are: onshore CO_2 storage, gas storage and shale gas exploration) and social rejection (), the ministries of economic affairs and infrastructure have started to develop a new policy (called Structuurvisie Ondergrond) that extends the existing regulations with an encompassing spatial planning for the subsurface, also for geothermal energy production. This new vision on subsurface exploitation is aided by a comprehensive regional study carried out by TNO-AGE that uncovers the entire currently known subsurface potential. Simultaneously the University of Groningen develops a decision-making methodology that systematically weighs all facets for permitting future activities. The new policies regarding subsurface planning are expected to be in effect by the year 2013.

Adaptation of the current regulations in the Netherlands for EGS development phases

EGS would fall under the current Dutch mining regulations. At this moment phases I and II would be covered by the exploration license, while phases III and IV would be covered by the production license. A production plan would also be needed in phases III and IV. For phase V a separate plan for closure is needed which has to be approved by the Ministry.

The criteria and conditions for exploration and production licensing can well be used for regulatory guidelines in EGS, especially for the stimulation phase. The following points are highly relevant:

a) The level of earthquake hazard has to be defined.
b) The previous holder of a (exploration/production) license must take all steps that are reasonably required to prevent:
   - damage as a result of soil movement (including seismicity);
c) In particular measurements of subsidence shall be carried out before the start of production, during production and for up to 30 years after cessation of the production.Forecasts of soil subsidence (and seismicity) are a part of the production plan
d) The licensee has to deliver copies of measurement data to the Ministry (e.g. seismic data, well log data, production data). A specified set of these data will be publically released after 5 years have elapsed since the date of measurement. Some data types, e.g. production/ injection data per well, are released immediately. On behalf of the Ministry, TNO-AGE manages the database and the data release.

Point a) b) c) needs to extended. a) needs *preliminary screening criteria(1[4])* for the exploration stage prior to stimulation, whereas b) and c) for stimulation needs to include measurement of seismicity prior and during stimulation and production, and some time after cessation of the production.

[4] Number refers to items in US protocol (Fig. 2)

Technical guidelines for the measurement plan, can be largely adopted from the US protocol and the development of a dynamic traffic light protocol in Geiser. Aspects included are the *definition of criteria for ground vibration and noise(3), the layout of seismic monitoring(4), the quantification of hazards from natural and induced seismic events (5), and characterization of the risk from induced seismic events(6), and the development of risk-based mitigation (7).*

Point d) is instrumental in providing key data for geothermal project development. In particular mapping of faults from existing seismic data considerably assists in assessment of risks for injecting in fault zones.

In view of induced seismicity communication to the public is important. On national basis we need to have focal points for information to the public. Project developers are responsible to implement an *outreach and communication program(2).*

4 The French mining law

Legal framework

In France, the exploration and production of geothermal resources fall under rules of licensing provided by mining law. The French mining law is scattered throughout the mining code (voted by the Parliament) and several decrees which are made by the government and which precise the way the law must be applied (see infra 'References'). Depending on the targeted geothermal resource being below or above a 150°C threshold, different licensing authorities are competent and different rules of licensing apply. This notably aims at alleviating the regulatory burden for shallow geothermal projects.
To some extent and under certain circumstances, geothermal exploration and production may also have to abide by other legislations than the mining law. This is particularly true when considering drillings over a 100-meter depth or the issue of the prevention of groundwater pollution. In such circumstances, geothermal developers may have to meet requirements from other legislations. However, in order to avoid redundant statements and administrative steps, the mining law provides for some regulatory gateways so that the whole relevant data needed to fulfil all legislative requirements can be submitted to the geothermal licensing authority at once and for all.

General principles

The French mining law distinguishes two steps in every mining project, including geothermal: the first one is exploration and the second one production. Therefore, the rules of licensing consist in two permits: the **exploration license** or the **production license**. The overall objective of these permits is to check that the underground will be explored or harnessed quickly and efficiently. The public authority is looking for ambitious projects to valorise this national wealth that is located in the underground. For this reason, a competition will be organised to identify the best project. The financial and technical capacity of the project developer will be checked. A second objective attached to these permits is to secure the investment made by the project developer so that, for instance, the company which spends money to explore an area is sure to be the one which will exploit the resource that it will have identified during exploration.
In addition to these permits, it is necessary to obtain a specific permit for each operation that is performed in relation to the underground, in order to prevent pollutions and industrial risks. Drillings and stimulation will for instance be strictly controlled. This step consists in the delivery of a **work permit** which can be in relation to an exploration or a production step.

It should be noted at this stage that only rules of licensing for deep geothermal (>150°C) are now laid out. These rules are globally the same as the one for oil & gas or mineral resources.

Rights conferred by the license

The exploration license gives the licensee the exclusivity for exploration of the geothermal resource within the defined area and for the time specified in the license. The term can be set up to 5 years and may be extended twice.
The production license gives the geothermal developer an exclusive right to use geothermal energy within a defined area for the time specified in the license. The term of a production license may be up to 50 years. It may be extended for 25 years.
During the validity period of the exploration license, its holder is the only one who may obtain a production license concerned with the area and geothermal resources provided for in the exploration license.

Application for licences

As far as the application for an **exploration license** is concerned, the application file shall include:

1. The identification of the applicant;
2. The proof of his financial and technical capacity;
3. A technical brief and relevant maps;
4. The programme of contemplated work;
5. An environmental impact statement;
6. A financial commitment specifying the minimum cash amount that the applicant intends to spend for exploration;
7. If need be, the consent of the holder of an existing license;

It can be noted about point 5 that the French Environment Code has recently undergone a deep overhaul paying heed to the need to bring the French environmental legislation into line with the EU requirements dealing with environmental impact assessments. Following this reform, the notion of 'environmental impact statement' (less demanding than the environmental impact assessment) does no longer exist. However, mining decrees do not incorporate this legislative change yet. In practice, the geothermal licensing authority usually requires an environmental impact assessment to be submitted when appropriate.

The application file for a **production license** shall include the same piece of information. It shall however include in addition, and when required, the convention agreed upon by the applicant with the holder of an existing license, let it be a license for mining or for carbon capture and storage, and setting their respective rights and obligations.

The application for an exploration work permit or a production **work permit** shall include:

1. The identification of the applicant;
2. The main characteristics of the contemplated work including all necessary documents and maps;
3. An environmental impact assessment;
4. A brief specifying the methods of exploration or production;
5. A health and safety report;
6. A brief indicating, on a provisional basis, the conditions under which work will be terminated as well as an estimation of the cost of this termination;
7. A report setting out the potential impacts of the contemplated work on water, appropriate measures to compensate such impacts and the compatibility of the project with the regional masterplan for water management and development;

Competent authorities and main steps of the licensing procedure

<u>Exploration</u>
The application is submitted to the Minister of Mines and examined by the local representative of the State ('Préfet').
The Préfet publishes a competition notice in the French Gazette. Counter-applications can be submitted within 1 month from the date of publication.
Competent authorities, including the regional environment directorate (DREAL), are then required to provide their formal opinion on the application.
The Préfet then submits these opinions as well as his own advice to the Minister. He shall do so within 3 months from the date the competition notice is issued.
The Minister of Mines receives the analysis of its technical services (the General Directorate for Energy and Climate), submits its decision to a General Council notably in charge of Mines and eventually decides. When he remains silent for 2 years, the application is rejected; that means that the Minister shall actually comply with a 2-year time limit to provide his decision on an application for an exploration license.

<u>Production (operation and development)</u>
Here again the competent authority to deal with the application is the Minister of Mines. The Préfet deals with the examination of the application.
The application for a production license requires a 1-month public enquiry to take place. An effective press release announces the public enquiry. If no exploration license has been issued previously, competition shall also be allowed. A competition notice is published in the French Gazette and counter-applications can be submitted within 1 month.
Competent authorities, including the DREAL and the geographically concerned mayors shall then provide their opinion on the application.
The Préfet then submits these opinions, the comments raised during the public hearing as well as his own advice to the Minister. These documents are analysed by the General Directorate for Energy and Climate of the Ministry and the draft decision is submitted to the General Council in charge of Mines.
The production license is granted in the form of a decree issued by the Council of State. When the application is rejected, the refusal takes the form of a Ministerial Order. In theory, the Minister has a 3-

year time limit to provide his decision on the application. In practice however, a production license is usually granted between 6 to 9 months from the date of the application.

Permits for exploration/production work

Permit applications for exploration or production work must be sent to the Préfet. The Préfet then organizes a public enquiry.

State services and geographically concerned town councils are required to provide an opinion within 1 month after public enquiry.

On the basis of the application file and the opinions of aforementioned competent authorities, the Préfet decides to deliver the permit or not. This procedural step is quite significant in the overall licensing process as the environmental impact of the geothermal project is usually assessed at this stage ie when considering the application for a work permit. In particular, the environmental impact assessment provided by the developer in his application file shall address potential induced seismicity issues when relevant. The Préfet may then deliver the permit and attach conditions he deems fit to prevent, minimize or compensate the potential environmental impact of the geothermal project. In particular, he may require the developer to measure seismicity on the geothermal field so as to avoid any adverse effect on time. Such conditions are currently in force in relation to some significant projects, such as the Soultz-sous-Forêt site, where seismicity sensors have been installed.

Once the permit has been issued, the Préfet may later dial down or tightened the conditions attached to it as he thinks appropriate.

The developer shall in any case report to the Préfet on the progress of work and shall inform him of any contemplated modification in the ongoing work, existing structures or applied methods.

General rules governing the license

The developer must annually report to the Préfet on the compliance with the work programme, the work already accomplished and forthcoming activities.

The licensee shall always maintain the technical and financial abilities on the basis of which the license has been granted. He shall inform the Minister of Mines of any circumstance likely to compromise the viability of the project.

Where the production license is not granted to the holder of the exploration license, the production licensee shall provide compensation to the exploration licensee, provided results of exploration are technically worthwhile for the production licensee.

In the same way, where exploration or production of the geothermal field is made on private land, the landowner shall receive fair compensation.

The licensee may apply for extension, transfer and farm-out of the exploration or the production license.

Technical requirements

The exploration or production licence gives a general right to explore or harness the underground. In general, it does not add technical requirements to be observed. In fact, the technical requirements which the project developer will have to meet are defined in the work permit.

For each project, the project developer explains the way he will proceed, the techniques he will use and the precautions he will take in the application file for a work permit. In the environmental impact assessment, he demonstrates that he will this way prevent pollutions and environmental risks. In his health and safety report, he explains the precautions taken for the safety of its staff. In any case, the application file will be the first reference which the project developer must respect.

The public authority appraises this file and decides to authorize the operations or not. It can add specific requirements to enforce the precautions that are taken. The public authority will control the points it has added as well as the ones the project developer has presented.

Therefore, the technical requirements are tailor-made for each project. They can secure all types of geothermal projects. Additional requirements can be added at any time by the 'Préfet' if a new risk or impact appears during the works.

In addition, a decree has been taken in 1980 to add a "General Regulation of Extractive Industries", focused on the issue of health and safety of the workers of these industries. It has been updated many times in the past and applies to all these operations. A part of this decree is focused on drilling (for all purposes as oil, gas, geothermal energy…). However, stimulation is not really taken into account for the time being. An update will surely be made soon on this topic, in relation with the stimulation that is performed for geothermal, conventional oil & gas and less surely on unconventional hydrocarbons as their exploration and production has been forbidden by the French law in 2011.

Conclusions and perspectives

The French mining law specifically addresses geothermal licensing. It provides for a two-step process requiring an exploration and a production license. In addition, a work permit must be obtained for each work carried out during any of these two phases that can have an environmental impact (drilling, stimulation, etc.).

In the framework of this licensing and permitting process, room is left for the geothermal licensing authority to consider all the varied issues that may stem from a geothermal project, including the induced seismicity that may be generated. In this respect, the licensing authority may impose conditions upon geothermal developers to mitigate any adverse effect that may occur. This power entrusted to the geothermal licensing authority ensures that the project fulfils legal, environmental and public acceptance requirements. It should be noted that a public inquiry is organised for each work permit.

In this context, the French authorities intend to conduct a reform of mining law. The scope of the reform is not yet known. It is unlikely however that the specific issue of induced seismicity will be of concern, as it is efficiently dealt with in the existing configuration of the licensing system. The reform shall rather deal with better public information (which was, for work permits, lighter for oil & gas than for geothermal and which is not organised for the exploration and production licences); it should also include some further regulatory relief for shallow geothermal projects, qualified as being of 'minimum significance', to be understood as being unlikely to have adverse environmental impacts. For the time being, the regulation of these operations is unclear an not appropriate to develop the geothermal applications for the heating and cooling of buildings.

References

a. The French mining code;
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5 The German mining law[1]

5.1. General Framework

Introduction
In Germany, laws exist both on the federal level (Bund) and on the state level (Länder). Geothermal energy in Germany is governed by the Federal Mining Act (Bundesberggesetz, or BBergG for short). As Germany is a federal republic, a lot of official functions are given to the 16 federal states[2]. All permissions and licences for geothermal devices are tasks of the state authorities. There are two general federal umbrellas

- the Federal Mining Law (Bundesberggesetz)
- the Water Framework Act (Wasserhaushaltsgesetz)

and some laws on federal level which could affect geothermal projects as e. g.

- Groundwater Regulation Ordinance
- Federal Soil Protection Act
- Regulation on the Classification of Substances Hazardous to Waters into Hazard Classes
- Emission Protection Law
- Environmental Impact Assessment Act
- Nature Conservation Act
- Waste Avoidance and Management Act
- Regional Planning Act
- German Statutory Code on Construction and Building
- Directive for Operating Safety

Depending on these federal requirements the federal states developed their own laws, ordinances, directives, regulations, and implementation rules based on different regional, administrative, and political “philosophies”.

The mining authorities of the different federal states are in charge of the licensing procedures for geothermal projects. Shallow geothermal installations with a depth below 100 m are subject to the Water Framework Act. This licensing procedure is task of the lower water authorities connected to the county administrations. It is characterized by a wide variety of partially contradictory implementation rules which are differing from state to state.

5.2 Federal Mining Law[3]

The Federal Mining Law (Bundesberggesetz) is the legal basis for all mining activities and similar operations concerning the utilization of the underground. Therefore geothermal energy is an integral part of this regulation.

The law defines geothermal energy as a “bergfreier Bodenschatz”. That means, geothermal energy is defined as a mineable resource that can be exploited only with the permission of a responsible authority. As there is no federal one, this is the task of the mining authorities of the federal states. A resource considered as “bergfreier Bodenschatz” is not owned by the land owner. Geothermal energy in the mining law is regarded in the line with ore, coal, or hydrocarbons. To use a “bergfreier Bodenschatz” you need an official production license.

-

The approval praxis for deep geothermal projects is also determined by the Federal Mining Law. The law frames the operational plans requested by the mining authorities:

- the long-term general business plan (<= 50 yrs)
- the prospecting / exploration plan to get the allowance for prospecting
- the production plan as the basis for the production approval
- the main operation plan which may cover a period of max. 5 years
- the short-term intermediate operation plans (2 yrs) for seismic, the drillsite, the drilling, and testing

The *general business plan*

- describes the main features of a larger operation.
- is normally valid for a longer period of time.
- includes a general description of:
    - what is intended to achieve within the project
    - how this is to be done (in general terms)
    - research of older paper work (if applicable)
    - seismics
    - drilling
    - testing
    - buildings and construction
    - technical installations
    - financing
    - what will be undertaken to minimize the risks
    - work and health safety
    - protection of the surface
    - protection of mining resources
    - precautions for reutilization
    - what will be undertaken to minimize impacts
    - social impacts
    - legal waste disposal
    - emission impacts
    - security issues and other mining operations
    - financial issues
    - description of applying company

The *main operation plan*

- includes a short summary of the General Business Plan
- gives a detailed description of the technical work that is planned
- contains
    - preliminary geological data
    - a general operation planning on what is done, when and in which sequence
    - a time schedule.

The *intermediate operation plans* (e. g. for seismics, the drilling site, the drilling and completion, and the testing works) include detailed technical descriptions of the work planned. They include detailed information about

- environmental impacts
- safety aspects (e.g. explosion zones)
- laws obeyed
- ground water protection

- waste management plan
- static calculations (e.g. drilling cellar, external sound protection walls).

The *drilling operation plan* has to submit

- job description
- drilling scheme
- well path
- casing scheme
- mud technology
- safety aspects
- borehole safety (BOP)
- work safety
- evidence of education / safety courses
- well head
- rig license
- hookload .wind diagram
- mining authority.s permission
- fire extinguishing plan
- escape plan
- safety & health coordinator

The most relevant articles of the Federeal Mining Law are:

- §3: definition
- §§4 and 69: mining supervision
- §§7 and 11: approval
- §§8 and 12: allowance
- §§9 and 13: ownership
- §10: application
- §16: duration
- §§52 et seqq.: exclusivity, operational plans

5.3 Other federal laws

Water Framework Act 33[4]

The federal Water Framework Act (Wasserhaushaltsgesetz) is the legal basis for all activities concerning the use and the protection of groundwater resources. Therefore geothermal energy is an integral part of this regulation. Especially for the licensing policy of shallow geothermal installations this law plays an important role. Much more than the Federal Mining Law it is influenced by “philosophies” and regulations of the federal state authorities.

Concerning the licensing procedure for shallow geothermal installations it was already mentioned that in cases deeper than 100 m the competent authority is the mining authority. In cases lower than 100 m the competent authority is the water authority. Water authorities are organised as tasks of the federal states. A land or house owner who wants to install a borehole heat exchanger or any other small geothermal systems has to apply for a license at the lower water authority of his hometown or county. A first check has to clarify if the project uses groundwater or not. If groundwater is not used the water authority normally agrees to the project without any additional conditions. If groundwater is used § 3 of the

Water Framework Act demands a licensing according to § 7 of the same act. There is no standardized nationwide licensing procedure.

References

[1]The country information on Germany has been taken from the *Best Practice (BP) Country Report – Germany,* Compiled by: Geothermische Vereinigung – Bundesverband Geothermie e.V., Werner Bussmann, Horst Rüter. We thank the authors for the permission to use this part for the current study.

[2] Baden-Wuerttemberg, Bavaria, Berlin, Brandenburg, Bremen, Hamburg, Hesse, Lower Saxony, Mecklenburg-Western Pomerania, North Rhine-Westphalia, Rhineland-Palatinate, Saarland, Saxony, Saxony-Anhalt, Schleswig-Holstein, Thuringia

[3] The chapter depends mainly on the presentations of Franz, H.: Shallow geothermal energy and mining law and Wundes B., Weiß, E.-G.: Legal framework and regulations for deep geothermal drillings, GTR-H Best Practice Tour Erding, February 26-28, 2008

[4] The chapter depends mainly on the presentations of Büttner, W..: Legal framework of shallow geothermal installations in Germany – The view from public authorities, GTR-H Best Practice Tour Erding, February 26-28, 2008

5.4. Adaptation of the current regulations in Germany for EGS development phases

There are several activities in Germany to change the existing regulations. Some of them are triggered by public concerns and supported by less informed politicians. From the scientific point of view, perspectives for hazard assessment of induced seismicity in a regulatory framework is recommended based on real-time monitoring such as an ongoing intensity report from public. This information has to be compiled with physical measurements such as peak ground accelerations and an assessment of the number and relocation of induced events and the event rate.

6 The Icelandic mining law

Subsurface operations, like mining and tunnelling, have not been extensive in Iceland until recently and then only excavations for road tunnels. Consequently, associated problems like subsidence are not addressed in the present legislation. Subsidence and seismicity has been observed in association with geothermal exploitation. It has not been considered as a problem as background deformation and seismicity is high in the geothermal areas which are mainly located on the plate boundaries of the N-American and Eurasian plates.

Recently, re-injection of water in the geothermal fields has increased. The injection rate has increased and areas bordering the geothermal areas are uses for injection sites. Considerable seismic activity has been observed although well within the limits of the natural long term seismicity.

During the time of the initial use of a new injection site for the Hellisheiði power plant, in SW Iceland operated by Reykjavík Energy, an intense seismic swarm occurred. This caused some concern and fear by the general public. Reykjavík Energy started a workgroup whose goal was to analyse the process and suggest plans on how to carry out re-injections. The workgroup published a report with detailed description which is shown (in English translation) below. This work is to some/large extent based on the recommendations by DOE.Since there are no regulations touching this subject in the Icelandic legislation these suggestions are the closest and will certainly affect the future legislation.

Proposal for a general protocol for preparing injection in a geothermal field

In this chapter, an attempt is made to adapt the foreign protocol to conditions in Iceland.
The six following steps are proposed for a general protocol:

1. Communication with local authorities and general public.

2. Preliminary project evaluation.

3. Acquisition of knowledge.

4. Risk, impact and consequences.

5. Decision on injection and its prerequisites.

6. Safe execution of injection.

Each of these steps will be discussed in more detail in the following pages, along with explanations of the general protocol on a flowchart in Figure 6.1.

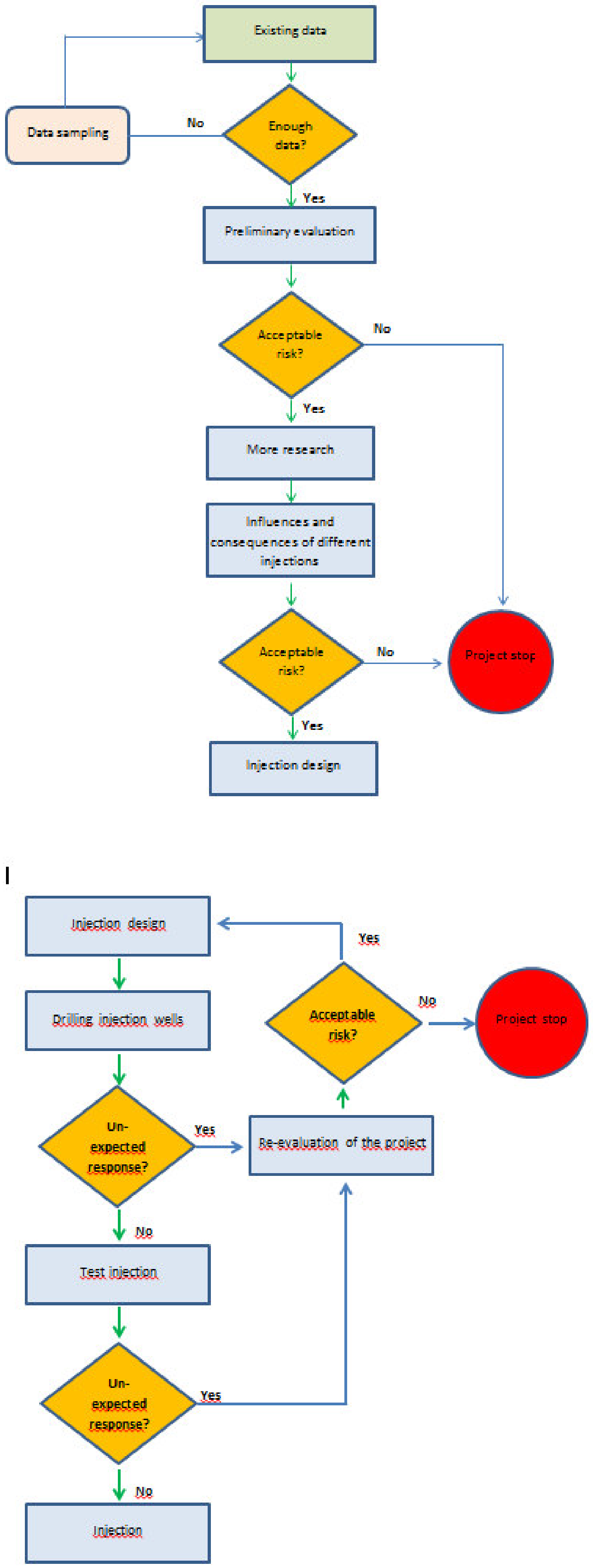

Fig. 6.1 general protocol for preparing injection in a geothermal field

6.1 Communication with local authorities and public

The objective of the cooperation and information program is to engage the community and its representatives in a positive and open manner in advance of onsite activities, and continuously as operations proceed. The first step is to understand the community which the project can possibly affect, and then determine creative ways to inform the community and understand its concerns. It is recommended to have a representative of the community for consultation and to demonstrate the benefits of the project, especially at the local scale. In addition to mutual exchange of information, the objective of the project should be to provide a long-term positive relationship and support from the community. As the project is more distant from settlement, the need for information exchange and consultation reduces. The following points may be taken into consideration:

i. Evaluate communication needs and develop a plan on how this information should be carried out during the project. Identify the people and organizations that would be the outreach targets.

ii. Hold preliminary discussions with the local government, regulators and public safety officials to explain the project and determine their concerns. Explain the benefits of the project, both for the local community and society.

iii. Present the project in an organized way to the media.

iv. Set up a local presentation office, ideally including technical displays for visitors.

v. In advance of onsite activities, hold an initial public meetings that cover the major steps of the project.

vi. As the time for injection approaches hold other meetings to explain the procedures for monitoring the injection and the procedures for modifying the injection with respect to its impact on the community. Set up and announce a call-in line that will be available for reporting felt seismic events or other negative impacts associated with the project. Make known how calls will be handled and how the communication between the developers and public safety officials will be .

vii. Invite representatives of the general public and the local municipalities to the site during a period of active drilling and injection.

viii. After the start of injection, hold another meeting to report on the results. Explain what happens next, and discuss the positive and negative impacts to the community associated with the project.

ix. As the injection continues, inform the community and seek feedback.

Plan continued stream of information with meetings and through media as suitable.

6.2 Preliminary project evaluation

Before considerable time and money is spent on an injection project, a preliminary evaluation of the project should be made and any possible problems that could arise during operation should be evaluated. The risk of abandonment and consequent capital/investment loss must be evaluated. This work should be guided by probability of induced seismicity. The procedures the with lowest risk of induced seismicity should be taken but which nonetheless maintain the level of pressure in the geothermal reservoir.
Since earthquakes can be expected during injection, especially within volcanic areas and seismic zones, the following points should be examined in the evaluation study:

a) Relevant provisions of law, regulations and statutes.

b) Geology and probability of natural seismicity.

c) Distances to structures and densely populated areas.

d) The largest induced seismic events to be expected and their greatest impact.

e) Possible damages, public nuisance, undesirable environmental impacts and sensitive industry disturbances.

f) Rough estimate of potential structural damages due to induced seismicity.

In Iceland it can be expected that sufficient data for a feasibility study exist. Consequently, the process therefore consists primarily of collection and compilation of existing data and information. **The preliminary evaluation result leads to a decision on whether to proceed with the project as planned, stop operations, or collect additional data.**

6.3 Acquisition of knowledge

When the preliminary project evaluation is finished and a decision has been made to proceed with a specific injection plan, the next step is to acquire the necessary knowledge for design and the safest operation of injection. Usually, necessary information depends on local conditions. However, following are some main topics which should be available in all cases:

a) Geological map.

b) Tectonic movements in the area before geothermal production started.

c) Natural seismicity.

d) Map showing fractures and fissures, stress field and largest earthquakes to be expected.

e) Velocity and acceleration in earthquakes.

These five topics are discussed in the following pages.

6.3.1 Geological map

A decent geological map, where visible fractures, faults and eruptive magma conduits have been mapped with care, is a required fundamental document.
Result: The map should contain necessary information on tectonic movements in the area along with an analysis of the tectonic evolution, including the age or relative age of fractures and faults. The results will be used for a further analysis of fractures and the tectonic stress field in the area.

6.3.2 Tectonic movements

Iceland is located at the diverging boundaries of the North American and Eurasian plates, where volcanic and earthquake activity occur when the crust moves apart or fractures due to plate tectonic movements. High temperature geothermal fields are associated with active volcanic systems, and thus it can generally be expected that rock deformation will occur in these areas, possibly varying with time. Both production of geothermal fluid and injection affects the natural background process. Therefore, it is important to measure tectonic movements in geothermal areas, preferably before the start of production, but at least before the start of injection. This is generally carried out with GPS and gravity measurements.
The preliminary project evaluation is to examine whether sufficient information is available on tectonic movements in the area, and whether adequate measurements are in progress. If not, additional measurements, and, where appropriate, installation of continuous GPS-stations should be carried out for improvement. Tectonic movements due to injection are generally small, and therefore it is important that sufficient time series of measurements exists, before the start of injection. As a result, continuous GPS measurements need to be carried out at least 12 months in advance of the injection, to be able to evaluate seasonal natural movements for example.

Result: Report on previous and existing tectonic movements before injection, including geological data on previous tectonic movements. The results would be used to assess the actual impact of the injection on tectonic movements and the tectonic stress field.

6.3.3 Natural seismicity

Exploration of natural seismicity provides information on the frequency and magnitude of natural earthquakes in the area, in advance of operations at the site. It also provides information on active fractures, displacements on faults and the principal stress field.

The exploration includes an analysis of available data on earthquakes, and the installation of a local seismic network.

Seismic monitoring should be commenced as soon as an injection site is selected. It should be comprehensive enough to allow complete spatial coverage of seismicity over an area that is at least twice the radius of the anticipated stimulated reservoir volume. The regional seismic monitoring network of the Icelandic Meteorological Office (SIL) provides information on large-magnitude events and a historical background, but a more sensitive array of seismic instruments is needed to be able to detect small-magnitude events (preferably magnitudes -1.0 to 0.0), and to improve location and depth accuracies. Current experience indicates that such a local seismic networks records up to ten times the number of earthquakes compared to the regional network. The duration of seismic monitoring of the injection area can be short, but it is generally recommended to be at least six months. Moreover, it is recommended that at least six seismic stations collect data in the area. While data is collected by the local seismic network, available data on earthquakes and focal mechanisms in the area should be analysed, both available measurements and evaluation of historical data.

Result: Report containing information on natural seismicity, stating frequency of events, periodic behaviour, magnitude distribution of earthquakes, analysis of seismically active fractures, their direction and dip, and a calculation of the tectonic stress field that creates earthquakes. The report would be the basis for a fracture map, the choice of injection site and an estimation of the probability of induced seismicity and its consequences.

6.3.4 Fracture map, stress field and maximum earthquakes to be expected

Results from geological mapping, and measurements and interpretation of tectonic movements will be used to create a comprehensive fracture map of the area, and to assess the tectonic stress field inside the anticipated injection site. A proposal for an injection site based on this information should then be made, by taking into account the tectonic stress field, probable permeability and the probability of induced seismicity. Moreover, an evaluation would be made on the maximum earthquakes to occur inside the injection site, based on the fracture map and measurements of natural seismicity.

Results: Recommendations on several potential injection sites, where the advantages and disadvantages of each site selection are explained, such as probable permeability, probability of induced seismicity and corresponding magnitudes, and an evaluation on the maximum possible induced earthquake.

6.3.5 Ground velocity and acceleration

Geological conditions in populated areas, possibly affected by induced seismicity, need to be mapped. Sedimentary thicknesses and shear wave velocities are particularly interesting. Appropriate prediction model has to be made on peak ground acceleration (PGA) and peak ground velocity (PGV) for tectonic earthquakes, considering the earthquake source, magnitude and decay of impact with distance, besides assessing the earthquake impact on people, equipment and structures. If needed, an accelerometer should be installed in the affected community to explore ground vibrations and tremor in advance of operations.

Results: Report on possible impact of different magnitude earthquakes on structures and people in the affected communities.

6.4 Risk, impact and consequences

6.4.1 Probability of induced seismicity

From the information obtained as described in section 6.3, the next thing on hand is to estimate the probability of seismicity based on the different injection alternatives. In that context, the already acquired experience on seismic activity during drilling and injection in Iceland can be useful. It is desirable to take the conceptual model of the geothermal reservoir into account.

Predictive models of maximum induced seismic events, based on injection data, could be considered. Such models use data on flow, pressure, volume and depth of aquifers during injection, as well as stress conditions around aquifers, stratification of rock, fractures, rock temperature, permeability and porosity. It should be noted that most of these models are incomplete and still in the experimental stages, so they would first and foremost be taken into account during the evaluation process.

The conclusion of this section is an assessment of the probability of induced seismicity and the potential magnitude distribution, based on a specific injection plan in a specific injection site, along with information on wave acceleration and wave frequency spectra. It should be noted that large uncertainties can be expected in this estimate, as this theory is rather undeveloped.

6.4.2 Risk and impact of induced and triggered earthquakes on people, equipment and structures

General standards and norms for seismicity and earthquake tremor, used in rules and building standards, impact assessment and measures to mitigate risk, should be examined. These standards and norms concern structural damage, human disturbance, economic activity interference and impact on animals.

The standard method of characterizing seismic risk concentrates on the impact of moderate-to-large earthquakes that have greater magnitudes than those generally observed in injection-induced seismicity. The maximum observed induced earthquakes have been magnitude M_l 5.0 but the vast majority of events are less than magnitude M_l 3.0. Therefore, the dominant risk is associated with events that have low magnitudes and rather cause nuisance than severe damage. The fundamentals of the risk estimation method, however, do not apply for small-magnitude events. Small cracks and other minor architectural damages, along with human perception of small vibrations and the associated nuisance are most common.

The basic elements of a risk analysis are as follows:

a) Characterize the predicted ground motion at each location within the area potentially impacted.

b) Identify the society and assets that could be adversely affected and that could contribute to the total risk. The main categories are:

    i. Physical damage to residential housing and community facilities.

    ii. Physical damage to the infrastructure of industrial facilities.

    iii. Human condition interference.

    iv. Socioeconomic impact from damaged infrastructure, and operation interference in businesses and industrial facilities.

c) Characterize the damage potential from the risk contributors, relative to the level of ground motion at a particular location.

d) Estimate the total risk by summing the elemental risks for all possible ground-motion levels. The result for all points within the impacted area are presented on a risk map. Usually, results of modern probabilistic risk analyses are presented as an estimate of the probability that a certain level of risk will be exceeded.

e) Present the results of the risk analysis to demonstrate that the probable future negative impact of the injection operations are within a range that will be tolerated by the regulators and the community, with consideration of the overall benefits of the project.The results should be separated into structural damage, public nuisance, and economic losses. The results should preferably be presented on maps and tables.

Results: Report on impact and risk assessment of induced and triggered earthquakes.

6.4.3 Responsibility for possible damages

It is necessary to know who has the responsibility for possible damages caused by injection-induced earthquakes. It has appeared in the media that the Natural Hazard Insurance in Iceland does not think it should compensate for the damage of man-made earthquakes, for example by explosions or injection. These are two different things. The total energy contained in explosion-induced earthquakes comes directly from the energy of the explosive used. On the other hand, the pressure applied during injection in Iceland is normally too low to fracture rock. However, the injected fluid can reduce the resistance on a fault surface and trigger large earthquakes that were impending anyway. In this case the resulting damage is caused by a natural event which was triggered or hastened by a human act. This can be compared to an impending avalanche triggered by a skier or even aircraft noise. Would the Natural Hazard Insurance refuse to compensate for avalanche damage under such circumstances, and would the claimant have to take the compensation claims to the skier or the airline?

It is neither acceptable for the possible claimants of triggered earthquake damages, nor the power company responsible for injection, that no clear regulations concerning the responsibility for possible damages exist. That applies even though the probability of damages are minor.

Results: It is proposed that Orkuveita Reykjavíkur, in cooperation with other power companies and stakeholders, initiates discussions with Natural Hazard Insurance **and local authorities to sort these things out.**

6.5 Decision on injection and its prerequisites

At this stage, the best information on potential injection sites exists, based on scientific research, and several reinjection options are available. An assessment of the probability of maximum earthquakes and the potential magnitude distribution is also available, along with an assessment of the impact and consequences of an earthquake of a given magnitude originating in an injection site in a nearby community. The above information is used to estimate the hazard from induced seismicity and whether it is viable to proceed with the injection project or not.

6.6 Safe execution of injection

This chapter contains recommendations for the execution of injection, when a decision has been made on a specific injection alternative. The chapter is divided into five subsections:

a) Injection project design.

b) Drilling of injection boreholes.

c) Test injection.

d) Permanent injection.

e) Parameters and exchange of data.

6.6.1 Injection project design

When a decision has been made to start injecting at a specific site, the next normal step is to fully design the injection project. Numerous factors, dependent on local conditions, have to be taken into account. Still, the following factors should always be taken into account:

i. Injection planning. The injection must be well organized from the beginning. The volume of injection, the injection pressure, the number of injection boreholes, and the acceptable level of seismicity with respect to both natural seismicity and distances to nearby communities and structures must be known. The faults and strata targeted for injection must be defined. Design of the injection boreholes is necessary, as well as the planning of the drilling and the test injection.

ii. Data to be collected during injection. It is necessary to decide what sort of data to collect during the injection and its preparation. It is fundamental to establish a local seismic network, to be able to display precise earthquake locations and available information on the internet in real time. The array, selection and number of seismic instruments should be according to recommended international methods. Continuous recordings of injection volume in every borehole must be carried out, together with measurements of fluid temperatures and wellhead pressures. It is also necessary to organize ways to measure the pressure response of the operation site to injection, and how to carry out tracer-tests to track the injected fluid. It is desirable to establish a dense array of half-continuous GPS-instruments (i.e. continuous GPS measurements for a specific time period) to closely monitor any crustal movements that may occur while the geothermal system is establishing a new level of pressure balance.

iii. Reaction to seismicity. It is necessary to organize the reaction to induced seismicity that exceeds the acceptable level of seismicity. Internationally, a control system called the "traffic light" system has been used to control the injection. Fundamentally, it is a system to mitigate or stop injection if seismicity exceeds a certain level. Still, a quite general opinion of foreign experts is that this method has not been particularly successful where it has been practiced. However, in the light of experience, people generally agree on that the most suitable way of injecting fluid is to start out slowly and avoid any sudden changes in injection.

iv. Communications program. It is necessary to create a communications program, based on identifying the involved people and organizations, and establishf organized ways to inform the community on everything concerning the injection. It is important that local inhabitants agree on the proposed project, have access to information and get a hearing for any comments and suggestions during the operation of the project. For communications and information exchange to go smoothly, everything should work according to an organized communications program from the beginning, and it should be reviewed as operations proceed and comments are received. Discussions need to be informative, comprehensive and clear to anyone.

6.6.2 Drilling of injection boreholes

During the drilling of injection boreholes, collecting useful data to estimate the hazard of induced seismic events is necessary.

i. Accurate recording of drill operations. Installation of a continuous registration system at the drill site is proposed, if not already present. The system should register all the key parameters in connection to the drill operations, especially information on the circulation fluid, i.e. the volume and temperature of injected fluid and the volume of returned fluid.

ii. Microseismic monitoring. Installation of a temporary seismic network around the drill site to monitor possible seismic activity associated with the drilling. In fact, this should be a standard procedure for all high temperature drill operations. A real time display of data is not necessary, but rather that data is collected for later processing.

iii. Mapping of fractures in boreholes. Mapping of fractures in boreholes is important, both permeable ones and the ones that might open up during pumping. This is ideally accomplished using a borehole viewer, either a televiewer or a formation micro-scanner (FMI). In this way, information can be obtained on the dip and strike orientation of targeted faults. It is not adequate to guess the fault direction by connecting locations of circulation losses in boreholes to known faults at the surface, as demonstrated in Húsmúli in Iceland.

iv. Stress measurements in boreholes. If possible, tectonic stress measurements should be carried out in boreholes. Several methods are available. The simplest one is probably using a borehole viewer that measures break-out in boreholes to measure the directionmaxium horizontal stress.

6.6.3 Test injection

A test injection is the most important final test on whether an injection at a specific injection site is acceptable with regard to seismic activity and the flow paths of the injected fluid. A large-scale injection should never be carried out without a prior test injection. During the test injection, the following measurements and observations are a minimum requirement:

i. Continuous recordings of injection, i.e. volume, temperature and pressure.

ii. Microseismic monitoring using a local seismic network, specifically designed and installed to detect micro-earthquakes, i.e. earthquakes of magnitudes as low as M_l -1.0. The best methods according to international standards should be used. The seismic monitoring program must be automatic and provide real time earthquake locations, in order to control the injection test with respect to seismicity.

iii. Tracer tests should be carried out in order to obtain information on the flow paths of injected fluid, i.e. the return of fluid inside the production site, into other boreholes or even into the groundwater system.

iv. Pressure changes in the area should be monitored as possible with borehole measurements inside the production site.

v. Tectonic movements measured in a rather dense network inside the injection site.

Previous to a test injection, a plan must be on hand for information dissemination to the public and stakeholders, along with a reaction plan for unexpected events that might occur during the test.
After the test injection, the best obtainable information should be available on what to expect when full-time injection begins. The results will be used to improve the injection arrangement, and to make a final decision on whether to inject, and the rate of injection at a particular injection site.

6.6.4 Permanent injection

When all of the above mentioned preparation are completed and the conclusion is that it is safe to start injecting permanently, the final planning, monitoring, control and information exchange needs to be considered. The following things must be considered:

i. Microseismicity. It is necessary to define the array of seismic instruments and accelerometers to monitor the area. It is also necessary to evaluate the need for a specific local seismic network or whether it is sufficient to make use of the existing regional seismic network, perhaps with a few additional instruments. In any case, make sure that the original seismic data is correctly imported to the power company’s database, besides that information on earthquakes and local impact is displayed in real time on the project’s information website. The possession of data on earthquake impacts is important if damage claims are received.

ii. Continuous recordings of injection. The key parameters of injection, i.e. volume, temperature and pressure of the injected fluid, should be continuously recorded at every injection borehole, then imported to the database and available in real time on the project’s information website.

iii. Pressure changes inside boreholes in the area should be recorded to monitor the impact of injection on the production field. Pressure data (water table or wellhead pressure) should be continuously recorded where possible, andavailable in real time on the project's information website. Other pressure data should be imported as soon as they are acquired.

iv. Gravity and tectonic variations. Systematic monitoring is needed to record tectonic movements and gravity variations because of mass changes in the Earth. A mixture of continuous recordings and repeated surveys at specified intervals should be considered. Continuous recordings should be available in real time on the project's information website. Other data should be imported as soon as they are acquired.

v. Response to unexpected events. Various kinds of unexpected events or development may occur after the start of injection, as a result of injection or natural reasons. For example increased seismicity, unexpected tectonic movements, signs of volcanic activity, precipitations in, or close to injection boreholes, unexpected flow paths of the injected fluid, equipment failure and various operating disturbances. It is necessary to define who is responsible, and how to react to any unexpected events.

vi. Communication and outreach program. A well-defined process of communication and outreach between the energy company, its consultants, government bodies, local communities and the public must be followed. Such a program must be in place and approved by the concerned parties, although the injection runs smoothly.

6.6.3 Parameters and exchange of data

The main factors necessary to monitor and measure during injection preparation and full-time operation have been described above. Experience shows, especially abroad, that it is essential to conduct measurements in a systematic and well-defined way, but a shortage of such actions is commonly found in high temperature fields in Iceland, where injection is carried out. The following points must be observed in particular:

1) All measurements should be carried out with approved instruments by qualified persons.

2) All instruments should be calibrated in an approved manner in accordance with quality standards.

3) All data, especially seismic and acceleration data, should be stored in internationally approved formats and preserved in internationally approved databases.

4) A database with metadata should be established, that provides an overview and basic information on all gathered injection data and other specific data related to the injection.

5) All data should be accessible in the same place. This is to prevent any need for searching at institutions or behind the internal structure of power companies to view and download data.

6) Rules should be established on accessibility to data and under what conditions data is accessible.

7) Public access to all data relating to public interest should be ensured simply through the internet.

7 The Italian mining law

In Italy there is no specific regulation for EGS. There is a new Geothermal law, issued on February 2010, which is general (but rather oriented on natural hydrothermal systems).
The basic issues of the new law are:

1) Low and Medium Enthalpy resources (defined in terms of temperature lower or equal to 150°C) are property of the Region which contains them. High Enthalpy resources are property of the National State. However, all resources are managed by Regional Governments to be assigned to private companies to exploit them.
2) Normally, private companies must ask a permission for Geothermal exploration to the involved Regional Government. After each request, the Government publish it on its official Bullettin and give two months of time to other investors requiring the same area. After 60 days, if there is only the first request, the Regional Government issues a meeting with all the public bodies to decide if the environmental impact of the project is reasonnable, and hence the permission can be given. If there are more than one request, the meeting must also evaluate, on the basis of some parameters (i.e. the economic capacity, the geothermal skill, the power of the project, the minimization of environmental impact, etc.) who actually has the permission. The permission for exploration last for maximum 4 years; in this period, the company can at anytime declare that a useful resource has been found, with technical/scientific documents demonstrating that. From the date the resource has been declared, the company can ask the permission for exploitation, which can be given only to such company if the environmental impact of the exploitation plan is favourably evaluated. In case that the company who made the exploration doesn't want to exploit the found resource, the Region issues an auction to assign the permission to another company which offers the best conditions.
3) There is, however, an alternative procedure, which can be used in cases where the resource is already effectively know, due to past explorations (by ENEL and ENI). In such case, a company can ask directly the permission to build a pilot plant, which must be zero emission and with total re-injection, at a site in the area where the known resource is. Such permissions for 'pilot plants' of innovative technology must be requested to the Ministry of Production and Development, which helds a procedure to evaluate, using the National Mine Office technical personnel together with recognized leading experts from Universities, if the project is sound, technocally feasible and with minimum impact. In such case, the Ministry approve and inform the involved Region which must held the evaluation of environmental impact. Pilot plants permissions can be requested, in the limit of 50 MW on all the Italian territory.
4) All the producing plants pay a small percentage of the income to the involved Region/s, except plants with power less than 3 MW with total re-injection. There are not precise specifications for the monitoring activities to perform in geothermal areas. The only 'external' monitoring which is compelling is the emission control by the Regional bodies for environmental control (ARPA).

8 The Swiss mining law

The description below is largely taken from the Swiss Geology portal (http://www.geologieportal.ch/internet/geologieportal/en/home/topics/resources/miniglaw/shortdesc.html)

In swiss law, the Bergregal (principles of mining law) regulates the property rights for mineral resources. In Switzerland, it is mostly determined by the cantons. Energy and ore resources as well as salt are usually included therein. The Bergregal is the right of ownership of unexploited mineral resources. The term is derived from the word “regalia” i.e. the rights of the king (mining sovereignty). Today in Switzerland, the mineral rights are held by the cantons. Only in Graubünden has the canton transferred the mineral rights to the municipalities.

Mining law fundamentals
According to the Swiss civil code (Art. 664 ZGB) the federal government entrusts the disposal and legislative rights over public and unclaimed property, which includes underground mineral resources, to the cantons. It waives a right to it. The cantons can claim their mineral rights or re-establish them. They can also forego thereon and attribute the mineral rights to the ownership of the land.
Thus, the mining law and the list of mineral resource rights differ strongly from canton to canton.
Mineral resources, which are excluded from the property ownership, are designated as sovereign or free-from-mining-law mineral resources. They are exclusively enumerated in the law.
In contrast, the property mineral resources are the property of the landowner. Today, land ownership is usually limited by mining law.

With a license for exploration and exploitation of mineral resources, the planning and building regulations, environmental impact assessments and safety regulations must be observed, in addition to the regulations controlled by the mining law. As for each Canton regulations are different, we refrain from a more detailed description of Swiss mining law

9 findings from fore mentioned technical guidelines and socio economic best practices

Various deliverables of Geiser deal with technical guidelines which are highly relevant for regulatory guidelines

- Input Guidelines for best practice for seismic hazard assessment (D5.6)
- Effect of different stimulation techniques on the seismicity and strategies to mitigate induced seismicity (D6.1)
- Technical best practices for monitoring (D6.2)

In addition a separate deliverable of Geiser deals with Socio-economic best practices(D6.4) [5], which is also of great relevance to providing regulatory guidelines

In this section we summarize the key findings of these deliverables in terms of relevance for regulatory guidelines.

As a first step in Seismic hazard assessment a level need to be set for the maximum tolerable magnitude (Mtol) and associated probability during stimulation/production (Ptol).

These are based on

- Tolerable ground motion at Ptol: this depends on population density , sensitivity of infrastructure, background natural seismicity, public acceptance.
- Relationship between ground motion and magnitude at depth

One can disitinguish

- Earthquakes inside or close to the reservoir caused by pressure difussion
- Earthquakes triggered on distant faults by static coulomb stress changes

The distinction is marked by a significant difference in the increase in seismicity rates relative to background rates. The first deals with earthquake rates which are significantly higher (typically 100-1000x) than natural (e.g. Bachmann et al., 2011). The project is therefore primarily responsible to the damage caused by these earthquakes in and close to the reservoir. Please note that the expected actual reservoir seismicity is likely not to be bounded by Mtol. Predicted Gutenberger-Richter (GR) characteristics of induced seismicity may yield M*P(M)>>Mtol*Ptol at M>Mtol[6].. This should be taken into account in setting Ptol, and to evaluate project-costs for ensurance funds capable to compensate for damages.

Earthquakes triggered on seismically active faults deals with a slight increase of natural seismic rates (typically <<10%) on distant faults marked by M>>Mtol, which may be triggered due to coulomb stress changes. Here a societally accepted slight increase in

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[5] Besides a technical-spatial feasibility study, investigating the social-economic characteristics of an EGS-site is needed for designing and planning an EGS-project. A social-economic assessment takes into account 1) the cultural characteristics of the (local) society or community, 2) the actor network involved (including both the actors within the non-formal dynamics and the actors within the formal (regulatory) procedures) and 3) the interests (costs and benefits) that are at stake in the intended project. With the outcomes of this social-economic assessment, the project and communication strategy can be drawn (see figure 2). The objective of both a technical and a socio-economic assessment is to positively influence the potential for public acceptance of an EGS-project.

[6] In order to ensure that the seismic energy of the GR curve (M>Mtol) is relatively low, the expected reservoir GR curve should be truncated in Magnitude and/or dominated by b>1.5 at M=Mtol

background seismicity may apply, for which the project-developer will not be held liable, if such an event would occur.

The assessment of expected probability of Mtol can be performed prior to stimulation and as part of an advanced traffic light system to safeguard that the expected probability remains lower than Ptol. For more details see boxed text below and deliverable 5.6 of GEISER.

Mitigating induced seismicity through soft stimulation (GEISER 6.1), can take benefit from targeting at tensile fracking, instead of shear stimulation. Tensile fracking can be effectively adopted in settings where the subsurface is not critically stressed and the formation is marked by moderate natural permeability. It has been successfully demonstrated in Gross Schonebeck (Zimmerman et al., 2010) and may provide an effective way to unlock EGS potential of low permeable formations in seismically quiescent regions (Pluymaekers et al., 2013)

Monitoring seismicity is key both for monitoring induced seismicity, as well as seismogenic imaging of the stimulation process. Guidelines have been described in deliverable 6.2 of GEISER, and are aimed at both regulators and operators to address two import aspects of seismic monitoring: (1) *monitoring requirements*, which can be defined in terms of data quality, temporal/spatial coverage, resolution, etc., and (2) *monitoring network design and optimization.*

In order to obtain public acceptance is recommended to project developers to build from a strategy creating 'societal business cases', taking into account the societal context of their specific locations (see D6.4 of Geiser for more details). The strategy entails the following steps (Figure 9.3)

- **Preparation and context analysis:** To identify different interests and (perceived) risks regarding a specific EGS project. This entails a cost-benefit balance for the stakeholders throughout the entire exploration and production workflow. This balance requires to take into account both technical-spatial and social-economic aspects in order to define the project strategies for creating public acceptance of EGS at a specific location (Figure 9.4).
- **Process design:** The different interests and (perceived) risks allows to characterize the policy challenge(Figure 9.4). The policy challenge needs to be proper addressed through the project strategy, including a communication strategy and process definition of involvement of actors and associated actions.
- the **execution of the preparation, context analysis and process design** are recommended to **overlap with the common planning phase of EGS projects**
- **Implementation and evaluation:** The next phases of developing an EGS project (drilling, logging and testing; stimulation; operation; post-operation) should correlate to the implementation phase of the project strategy. During the implementation of the project strategy (cq. stages of development of the EGS-project) the progress of the process will be constantly monitored and evaluated. If needed, the project strategy will be changed and adopted to the process dynamics.

Guidelines for Physics based assessment of the probability of maximum acceptable magnitude

Mtol: maximum acceptable magnitude
Ptol: accepted probability of occurance of Mtol
Mobs(t_{stim}): observed maximum magnitude at time t_{stim} after start of stimulation
M(t> t_{stim}): predicted earthquake magnitudes (as GR) at time>tstim
Pexp(t_{stim}): expected probability of M(t> t_{stim})≥Mtol
Pexp(0): expected probability of M(t> 0) ≥Mtol

It is recommended *to Authorities* to request the project developer for an assessment of Pexp(0) and the set-up of a advanced traffic light system to safeguard Pexp(t_{stim}) <Ptol, in which the prediction of Pexp(t_{stim}) is consistent with a physics based approach.

It is recommended *to project developers* that the assessment of Pexp(t_{stim}) is based on:

a. non-stationary GR characteristics, resulting from b-d, calibrated to observations
b. Reservoir engineering scenarios addressing fluid pressure/stress changes
c. Prediction of induced seismicity of fracture and fault structures in and outside the reservoir based on b, and consistent with natural stress and seismicity catalogues
d. Effects of spatial variation and uncertainties in structure, natural stress, stress and fluid pressure changes and rupture dynamics

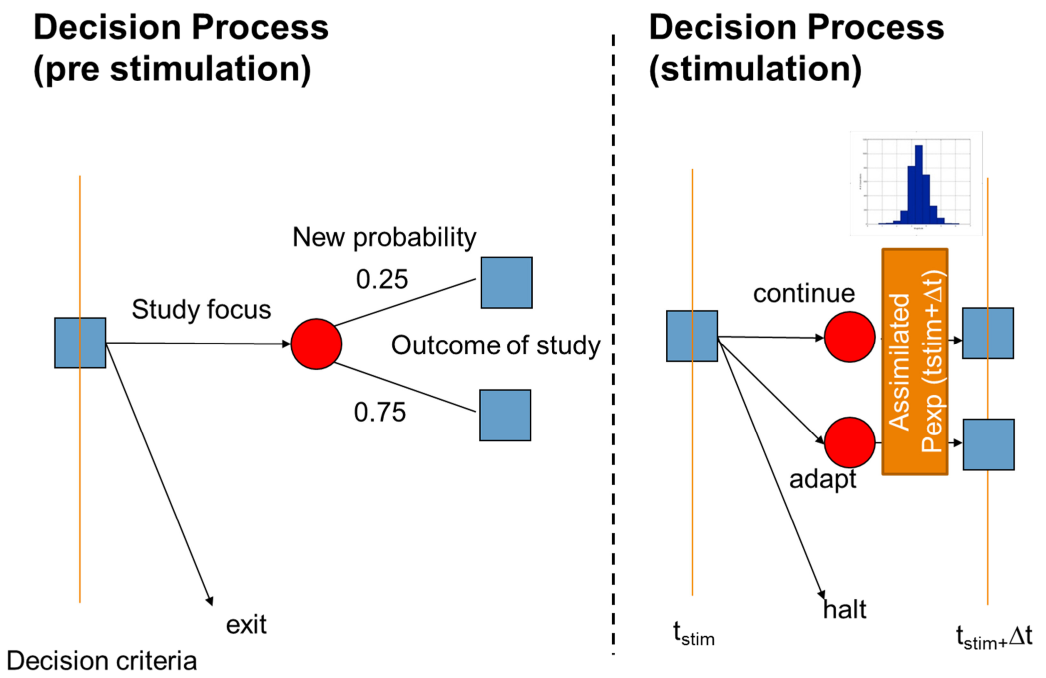

Fig. 9.1 evaluation of Pexp(t) should occur throughout all stages of the exploration, stimulation and production workflow and should be embedded in the decision toll-gates of the project developer and regulators (marked by blue squares). During exploration and stimulation different outcomes of the workflow progress are possible (indicated by red circles)

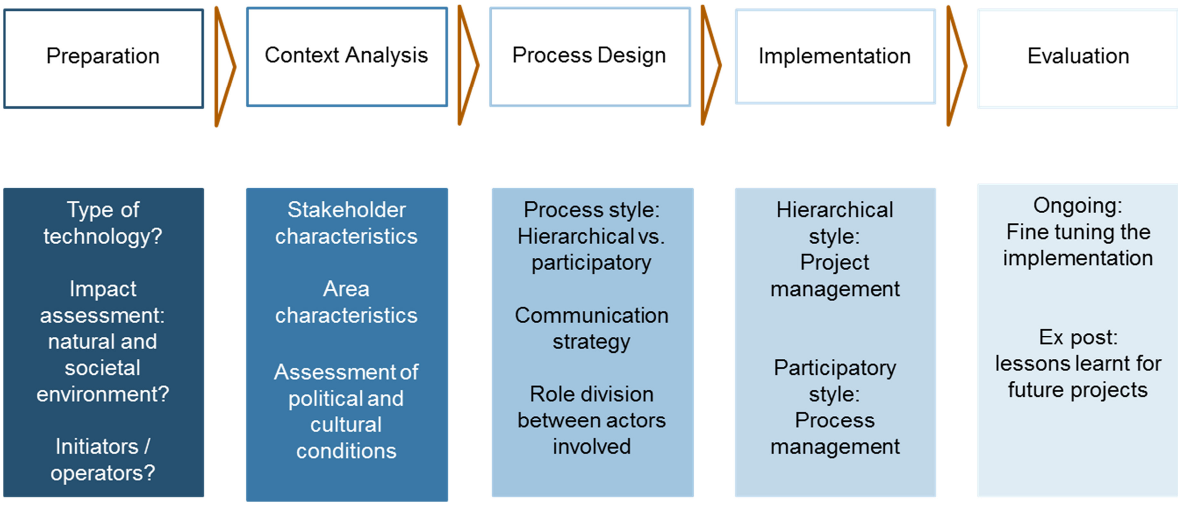

Figure 9.2: project development steps in the decision making process of creating acceptance for EGS (GEISER, deliverable 6.4)

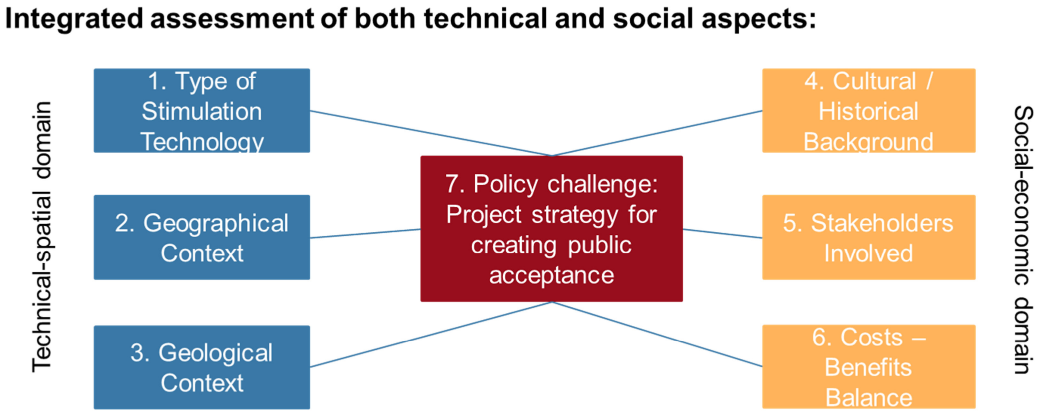

Figure 9.3: integrated assessment of both technical-spatial and social-economic aspects in order to define the project strategies for creating public acceptance of EGS at a specific location (GEISER, deliverable 6.4)

10 Recommendation for European guidelines for EGS

EGS projects are subject to a high likelihood of induced seismicity, with magnitudes which may be felt by the public and can cause nuisance, may cause slight damages and can in exceptional cases result in significant damage and casualties. The following recommendations for European regulatory guidelines are proposed to prevent unsolicited effects of induced seismicity:

1. to set a maximum level of acceptable magnitude (Mtol), and associated treshold probability (Ptol) for earthquakes caused by stimulation and production. The project should be halted if the expected probability of Mtol is higher than Ptol and no operational adjustment can lower this probability.
2. to request the project developer for an assessment of expected probability of Mtol prior to stimulation and to set-up an advanced traffic light system to safeguard that the expected probability remains lower than Ptol, based on a physics based approach (see deliverable 5.6 of GEISER).
3. to request the project developer to set-up a seismic monitoring network which follows GEISER recommendations (deliverable 6.2)
4. to provide incentives for project strategies promoting public acceptance (cf deliverable 6.4 of GEISER). One such incentive can be a differentiation in exploration licensing, allowing for a desk study phase, prior to the drilling and stimulation license. The desk study phase allows to build an outreach program.

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