Guideline

Risk management during the drilling and testing phase of deep geothermal projects

Status: 12/2025

This is the English translation of the German-language guideline.
For definitive reference please refer to the original.

Bundesverband Erdgas, Erdöl und Geoenergie e.V.
Federal Association of Natural Gas, Oil and Geoenergy

In cooperation with
DGMK e.V.

Table of Contents

List of figures

1. Brief explanation of this guideline

The aim of this guideline is to describe and apply a generally applicable risk management process for deep geothermal projects. The focus is on a systematic approach to identifying, assessing and managing potential risks that may arise during the drilling and testing phase of a deep geothermal project. The guideline is intended to help identify risks at an early stage, document them appropriately and manage them with suitable measures.

Key components of this guideline:

- Technical and organisational sequence of drilling and testing work (Chapter 3)
- Structure and implementation of an effective risk management process (Chapter 4)
- Description and application of common risk analysis tools (Chapter 5)
- Creation and maintenance of a risk register (Chapter 6)
- Options for insuring drilling and exploration risks (Chapter 7)

Distinction from existing guidelines:

- The topic of well integrity is covered comprehensively in the BVEG's well integrity guideline (only available in German), which covers the entire life cycle (design, construction, operation and plugging) of boreholes.
- This guideline is closely linked to the guideline "Economic assessment of geological risks in deep geothermal projects". It is applicable once the decision to implement the project has been made based on preliminary geological exploration.

2. Introduction

Objective of the guidelines

This guideline was developed in collaboration between the DGMK and the BVEG. It is intended for all institutions and individuals involved in deep geothermal energy, such as project developers, investors, insurers, planners, supervisory or licensing authorities, and drilling and service companies commissioned to carry out drilling and testing work.

In terms of content, this guideline deals with the management of potential risks associated with the drilling and testing phase of a deep geothermal project and provides recommendations on how these risks can be identified in advance and controlled if they occur.

This guideline is closely linked to the guideline "Economic assessment of geological risks in deep geothermal projects". It is applied when, based on preliminary geological exploration, the decision has been made to implement a deep geothermal project and is intended to ensure that the practical implementation is done "correctly" and that avoidable mistakes are prevented. Since geological exploration is closely linked to the practical implementation of the project and is sometimes carried out in parallel, the two guidelines overlap.

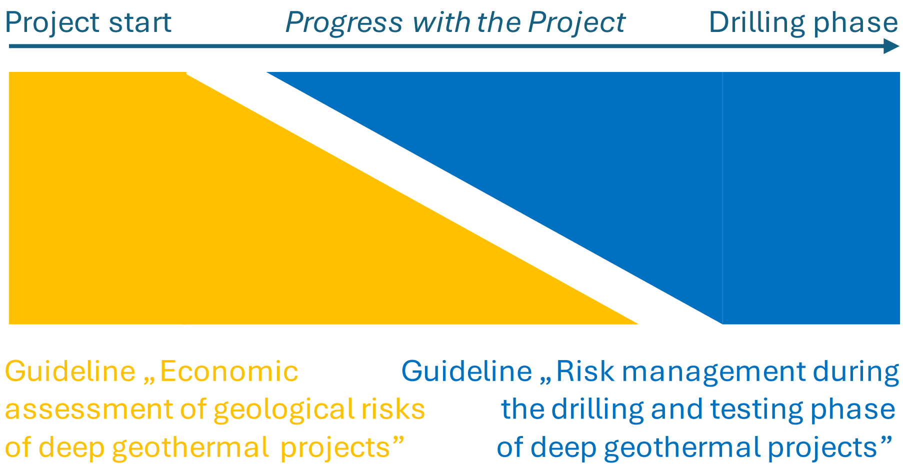


Figure 1 : Temporal relationship and integrative interaction of the two guidelines

This guideline describes a generally applicable risk management process. The technical methods to be used (e.g. various drilling systems or fluid systems) may vary depending on the specific geological and drilling conditions.

The guideline primarily refers to individual projects but may also be applied to a portfolio approach with multiple projects.

Context and scope

This guideline considers all drilling and flow-test activities associated with a deep geothermal project. It covers petrothermal (including closed) and hydrothermal systems that are to be drilled to a depth of more than 400 metres. The focus is on projects such as those found in Germany. This guideline is applicable to both exploration drilling (first wells in a region) and production drilling (subsequent wells in a proven geothermal system).

The guideline only covers the drilling aspects and the subsequent flow test of a geothermal project. It does not cover the risks associated with the subsequent operation of the plant.

3. Risk management during the drilling and testing phase

3.1 General information on the process of deep geothermal drilling

Deep geothermal energy extraction requires the use of deep drilling technology for drilling depths of several kilometres, as is also known from the oil and natural gas industry and differs significantly from geothermal drilling at depths of less than approx. 400 m. Commonly the rotary drilling method is used. In this method a drill bit rotates with significant weight-on-bit towards the bottom of the borehole in conjunction with a drilling fluid. The drilling fluid enables transport of the cuttings drilled by the bit from the bottom of the borehole to the surface, supports the borehole against the collapse and keeps liquids and gases from the rock out of the borehole. To advance to the target depth (known as “TD” in mining terminology), the well is drilled in sections using "telescopic" drilling with well diameters that decrease with depth, depending on the local geology. As part of the drilling plan, the final diameter of the borehole in the reservoir required for the planned production is first determined and the further borehole construction is planned from the bottom up. In case of geothermal production wells, the diameter of the submersible pump to be used must be considered. It thus determines the initial open-hole- and casing-diameter of the deep well.

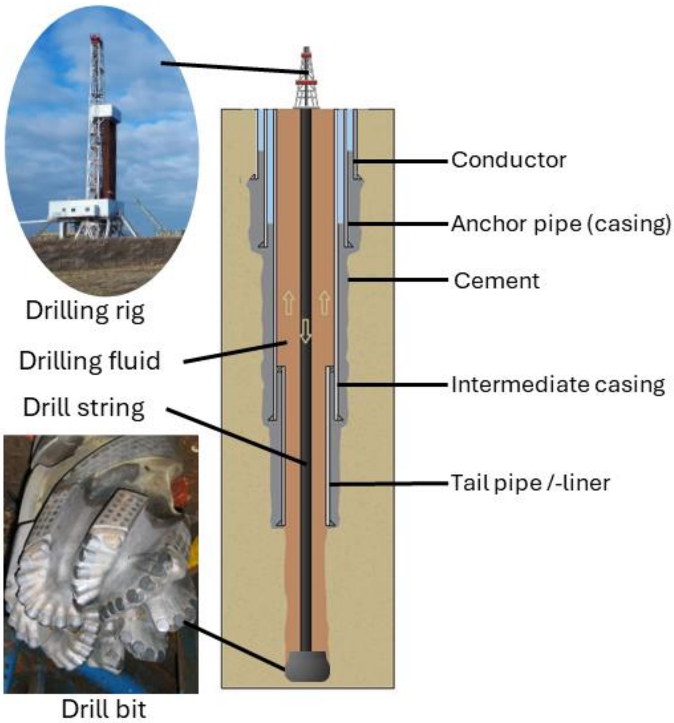


Figure 2 : Drilling rig with schematic representation of the drill string and borehole construction

3.2 Organisational structure

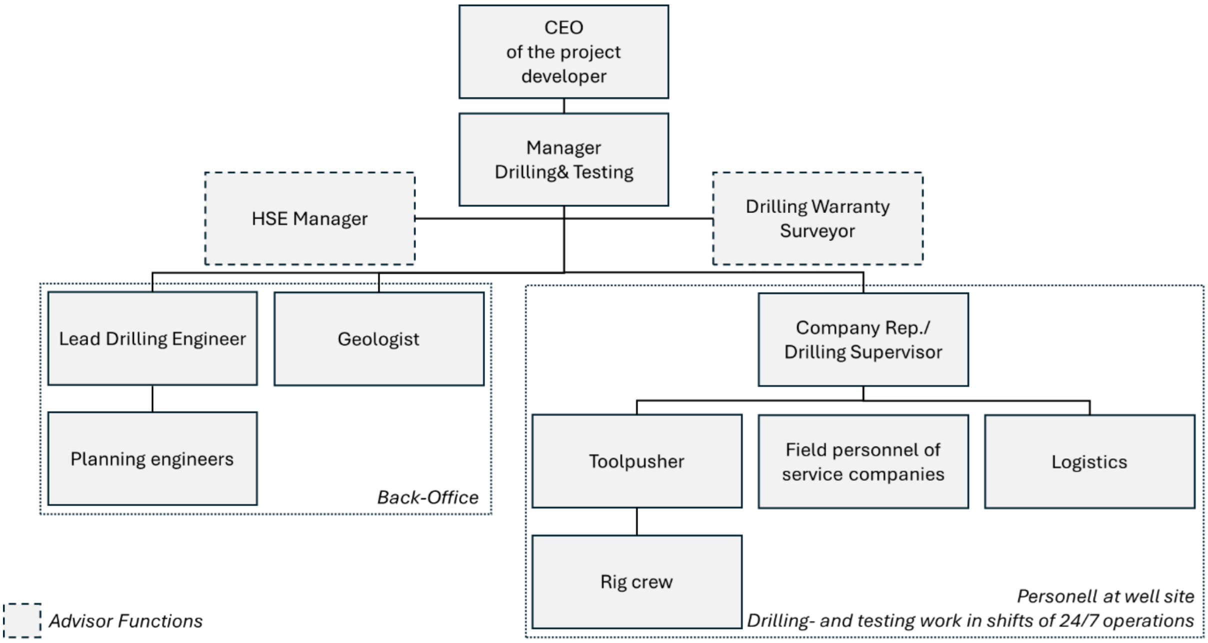


Figure 3 : Typical organisational chart for the execution of deep drilling operations

Drilling operations usually run around the clock and surprises that require a well-founded and immediate response are not uncommon. Hence, a strategy tailored to the respective project and its specific technical requirements must be established by the necessary client representatives (drilling supervisor and specialist planners) who are on site 24/7 during drilling operations. The role of the drilling supervisor (“company man”) carries a special responsibility, as this person is usually responsible for the safety and, to a certain extent, also for on-site financial decisions. Figure 3 shows a typical organisational chart.

Here, it is advisable and usually mandatory to employ appropriately experienced personnel, who are qualified for well control in accordance with international standards (IWCF Level 4 certification) (see [2] Well Control Guideline). In addition, it is important to ensure that there is an adequate support structure with a qualified back-office, as the numerous complex technical issues involved in a multi-trade deep drilling project usually cannot be comprehensively addressed by a single supervisor position.

It is also mandatory to appoint qualified persons responsible for mining law and to formally notify the mining authority of their names.

3.3 The drilling process

After the development and construction of a drilling site (see [14] Guidelines for the design of drilling sites), the procedure for deep drilling typically involves the following steps.

First, the conductors ("standpipes" for the boreholes) are installed to block off the near-surface aquifers. This is done either by drilling or by ramming during the construction of the drilling site. This is followed by the mobilisation and installation of a deep drilling rig and the equipment and systems of the various specialised service providers for solids control, drilling mud, including mud services (measurement of drilling mud properties), mud logging (drilling data acquisition and geological description of the drill cuttings), as well as directional drilling services to ensure proper drill cuttings and mud disposal.

After thorough safety and functional testing of all drilling rig components and equipment as well as systems of the various specialised service providers, approval is given to commence drilling (spud). From this point on, day rates are usually charged for most drilling services, and the client therefore has an amplified cost responsibility that can only be effectively controlled through an effective risk management and monitoring concept.

Unlike in conventional construction projects, it is not customary in the industry for a service provider to pay for any damage caused by the failure of its tools, due to the considerable financial and geological risks involved and the interdisciplinary interaction of numerous specialists. In accordance with the pre-designed borehole construction (see [13] Guideline for Casing Calculation), the borehole is now drilled, logged (measured) and finally cased and cemented section-by-section until the final depth is reached.

An important design parameter here is the geology. The last section is drilled into a production or injection horizon, is often not cased if the rock is stable enough.

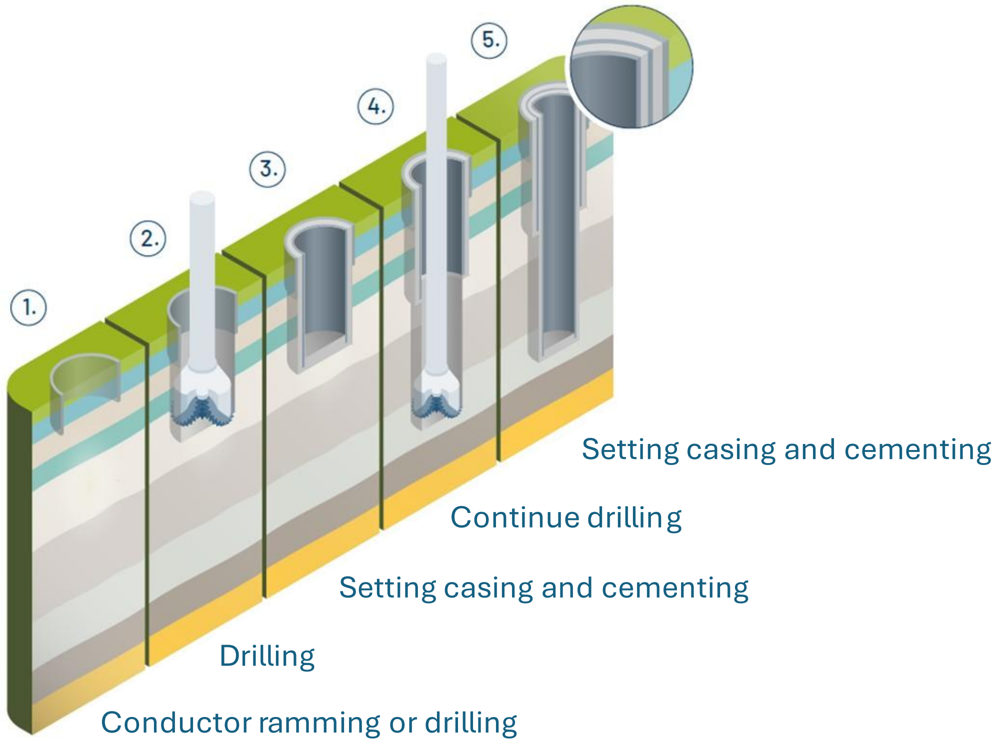


Figure 4 : Schematic sequence of drilling operations: geology and drilling requirements determine the setting depths of the casing

Drilling follows the so-called multi-barrier concept to prevent uncontrolled leakage of fluids such as drilling mud, reservoir fluids or gases. This means that at least two barriers are always required, the first of which is usually pressure control by means of the drilling mud. In addition, a multi-walled borehole structure and blowout preventer contribute to maintaining integrity during the drilling phase. See also [2] BVEG Guideline to Borehole Control.

In addition, integrity monitoring of an internal annular space is also possible and, in some cases, mandatory during subsequent operation, as recommended, for example, in [15] BVEG Guideline on Borehole Integrity. During the drilling phase, however, a sufficiently dense drilling fluid is the first barrier.

For well completion, other drilling service companies are sometimes required, such as casing running, liner hanger service, cementing service, and wireline logging services for geological surveying and quality control of casing and cementing work.

3.4 Production and injection tests

Once the borehole has been completed and the reservoir successfully drilled, deep hydrothermal geothermal projects usually proceed directly to one or more production and injection tests to evaluate the potential of the discovery (temperature, production rate, chemical composition of the thermal water). This serves to determine various reservoir parameters and, in particular, the productivity and injectivity index, which essentially define the economic viability of the project.

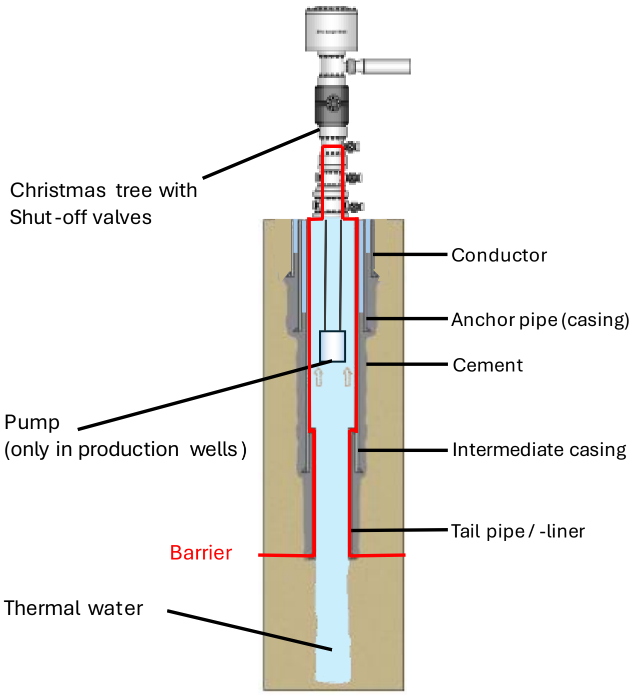


Figure 5 : Barrier concept for deep wells to protect groundwater and ensure safe thermal water extraction during the operational phase

In particular, the injection test can also provide initial insights into the evaluation of the potential seismic risk during later operation of the plant. The results of the test are used to verify the previous seismological hazard studies of a hydrothermal/petrothermal project and the associated traffic light system to ensure that no dangerous seismic events are triggered by the plant. A traffic light system (see [6]-[8] BVG Guideline 1101 Parts 1 to 3 and [9] Recommendations for monitoring induced seismicity – FKPE position paper) provides clear instructions for action (see [5] BVG background paper on induced seismicity in geothermal projects) in order to be able to respond to any induced seismicity that may occur in a timely and effective manner, thereby preventing damage to the surface.

In open petrothermal systems, this is usually followed by extensive stimulation of the reservoir (e.g. hydraulic or acidification). Closed petrothermal systems, on the other hand, require neither stimulation nor injection testing.

3.5 Reporting and documentation

An important basis for an effective risk management process is also a detailed reporting system during the execution of drilling and testing work. This includes daily reports from the various service companies and the client's representative, presenting all relevant execution parameters (e.g. mud properties, drilling rig parameters, cuttings analysis, etc.), as well as logistical information such as stock levels of drilling fluids, mass balances of materials supplied to and disposed of from the well, drilling tools on site, etc. This information is required for cost-related billing documentation, but also for quality assurance and the preparation of specific technical meetings. The meetings should be held at least on a daily, weekly and section-by-section basis to effectively control drilling operations and respond professionally to deviations from the drilling programme.

If there is state or private insurance coverage for the drilling work or a coverage of discovery, it is usually mandatory to involve an external expert (drilling warranty surveyor) in the daily reporting. It is advisable to involve the external surveyor in the execution planning at an early stage (e.g. Drill-Well-On-Paper-meeting (DWOP): a joint theoretical review of the work steps ahead with all companies involved) to enable them to gain a thorough understanding of the planning and execution work. The task of the external surveyor in the execution phase is essentially to assess the risk of the actual daily work instructions issued by the project owner/operator to confirm insurance cover in the event of deviations from the planned execution programme or, if necessary, to identify uncovered risks/work. Here, too, a risk management system established in the project and a management-of-change process as described here go hand in hand with the external assessment.

In principle, deep drilling work in Germany is subject to mining law and requires extensive approval processes, including an operating plan with a preliminary environmental impact assessment.

3.6 Health, safety and environmental management

Occupational safety is a key issue during the drilling phase, as the work generally involves large masses, quantities and high pressures. However, vibrations, light, noise and gas emissions can also occur.

In addition, there are still geological uncertainties in the forecast, which means that the unexpected encounter and inflow of hydrocarbons (crude oil, natural gas) must always be considered. It is important to systematically identify such hazardous situations at an early stage and to take appropriate measures in good time to keep the drilling under control without causing damage or pollution. The deep drilling rig must be equipped with special equipment for this purpose.

A structured, comprehensive HSE management system (Health, Safety & Environment) which must be integrated with risk management, is therefore necessary and in some cases mandatory. Although, this must be handled much more strictly than is customary in many other construction industries.

4. Risk management process

The process of planning and constructing a deep geothermal borehole should be subject to a strict management process.

This includes compliance with decision points (stage gates, see [3] BVEG guideline on the economic assessment of geological risks in deep geothermal projects), the specification of standards and the definition of individual project phases. This serves to adapt the planning and implementation of the work to the geological findings obtained, while constantly taking the project objectives into account. Only in this way can the process of risk minimisation be implemented systematically and with a focus on the respective critical parameters. This process for creating a borehole is illustrated in Appendix A.

The aim of this process is to create a basic structure for the selection, design, implementation and evaluation of all work involved in well construction, well testing and well commissioning. The goal is to close gaps between the project steps that exist within the project units and to subject the individual phases to rigorous review before the project progresses. This includes the following aspects in particular:

- **Integration** – from decision-making in a specialist department to a multidisciplinary decision-making process involving various drilling trades and geoscientific stakeholders.
- **Learning and technical competence** – from individual competence development to a company-wide learning curve
- **Organisation** – from inefficient duplication due to overlaps to a clear distribution of roles and responsibilities
- **Risk management** – from random, individual risk management to structured risk management focused on the important points

Every company or planning office will have developed its own management process for this. When creating a deep borehole, the management process should chronologically include the following points:

- **Identification** of suitable execution options for creating a borehole.
- **Selection** of the option that generates the least risk and the greatest added value.
- Elaboration of this option with a **detailed design** including contingency planning.
- **Implementation** in strict compliance with laws, regulations, standards, guidelines and requirements.
- **Follow-up** on the work and recording of suggestions to improve subsequent boreholes or projects.

The deep drilling process should continue to be subject to the following principles:

At predefined decision points, key decisions are made in accordance with the stage-gate process in Appendix A, such as concept selection or implementation approval, and only then can the next phase of the project be processed.

Resources are made available within this process framework. This includes not only financial resources, but above all human resources from all relevant disciplines for the structured development of templates for the next decision point, as well as the human resources required to review these templates as part of a peer review process.

A logical workflow must be maintained in all phases of the project – starting with identifying the options and the associated opportunities/risks and following with the development of the best option.

In the case of deep geothermal drilling in particular, it is important to compile and evaluate all available data and information on the subsurface as well as local and regional drilling experience at the start of the planning phase, to check its relevance and to take it into account in the further drilling planning process (see also [5] BVEG guidelines on geological risk assessment for deep geothermal projects).

4.1 Risk management cycle

Care must be taken to ensure that various risk categories, which may be geological, technical, organisational, logistical, ecological, safety-related and contractual in nature, are taken into account and incorporated accordingly in a generic risk cycle.

Figure 6 : General risk management cycle

In general, this cycle consists of the stages of identification, assessment, mitigation and monitoring/reporting.

Ideally, several drilling projects are part of the cycle, so that risk can be minimised through a portfolio approach and a learning process across many wells.

The general illustration in Figure 6 is specified in Figure 7 for deep drilling:

1. Based on a company-specific risk policy, early detection is carried out and risks are identified. One tool for this is the SWOT analysis described below.
2. Tools such as the risk matrices, bow ties and risk registers described below are then used to assess the identified risks.
3. The same tools are then used to identify and select possible mitigation measures (risk control), with priority given to avoidance, reduction and insurance, and finally acceptance of residual risks.

4. During the subsequent monitoring and reporting phases, evidence of results is provided in order to control the risks. Appropriate communication, particularly interdisciplinary communication, is also important.

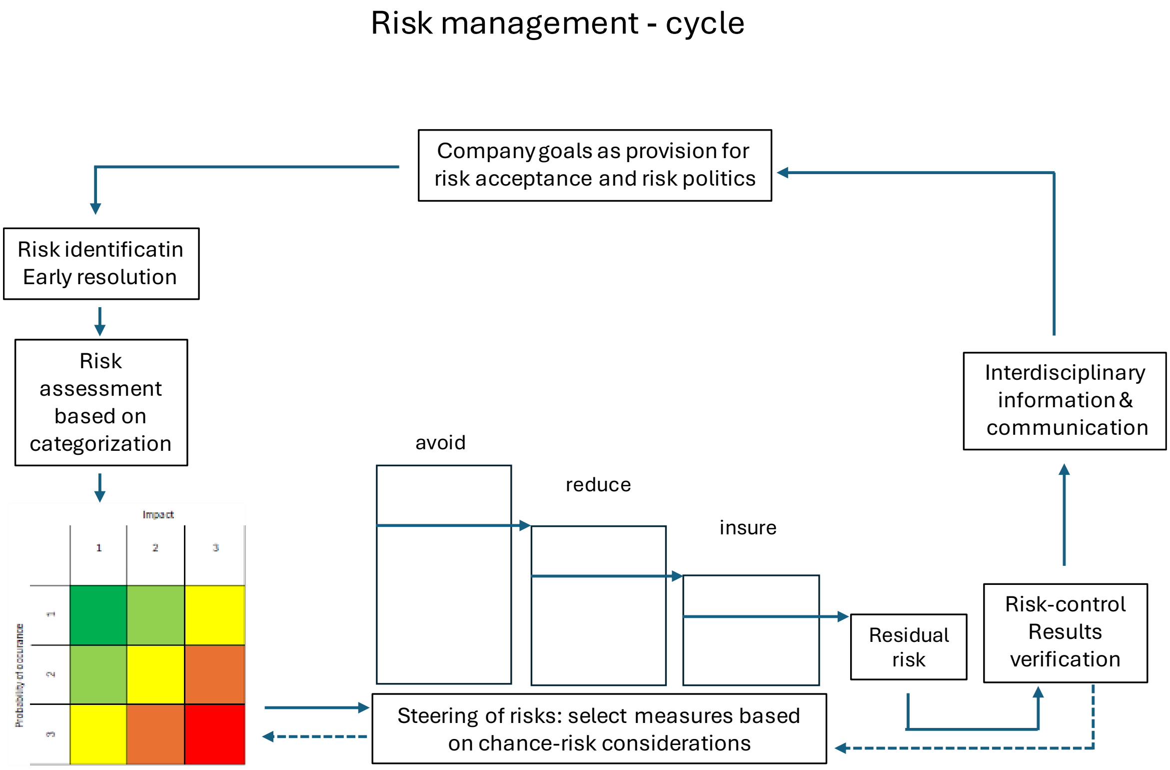


Figure 7: Risk management cycle for deep geothermal projects

The process cycle described in Figure 7 takes place as a sub-process with increasing detail along the phases of the geothermal stage-gate process (see Figure 8), which is described in its entirety in the guideline [3] "Economic assessment of geological risks of deep geothermal projects". The results of risk management and control are important input parameters for the final investment decision (FID),

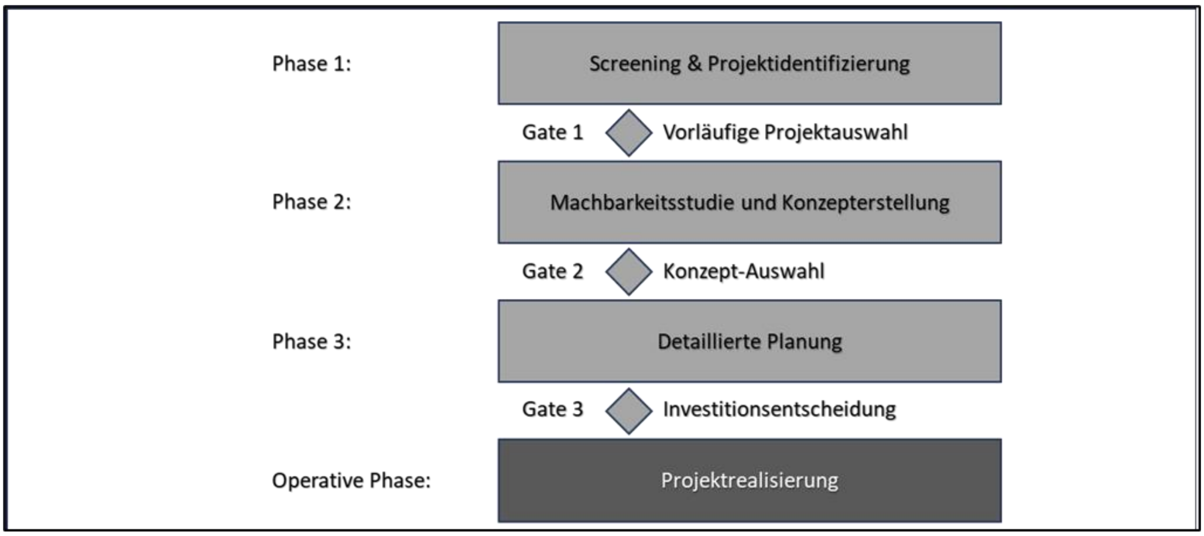


Figure 8: Geothermal stage-gate process

particularly for Gate 3. Drilling and geological aspects must be considered in conjunction with each other.

4.2 Effective risk management

Depending on the size and complexity of the project and the experience of the company, the process of creating a deep borehole can be complex. For example, in the case of repetitive drilling as part of a larger field development and after an extensive exploration phase, it is possible to dispense with an individual creation process and standardise it. In the hydrocarbon industry, which is engaged in large-scale field development, this has a positive impact on processes and results. Examples of such databases include the private global "Rushmore" database and, in the Netherlands, the public solution [11] "NLOG.nl ". In geothermal energy, this is generally still in its infancy.

Many European hydrocarbon regions are located in the lower left quadrant of Figure 9. The same applies, for example, to plant expansions in parts of the Bavarian Molasse. However, many current geothermal projects are in the upper right quadrant and therefore require detailed process support for risk mitigation.

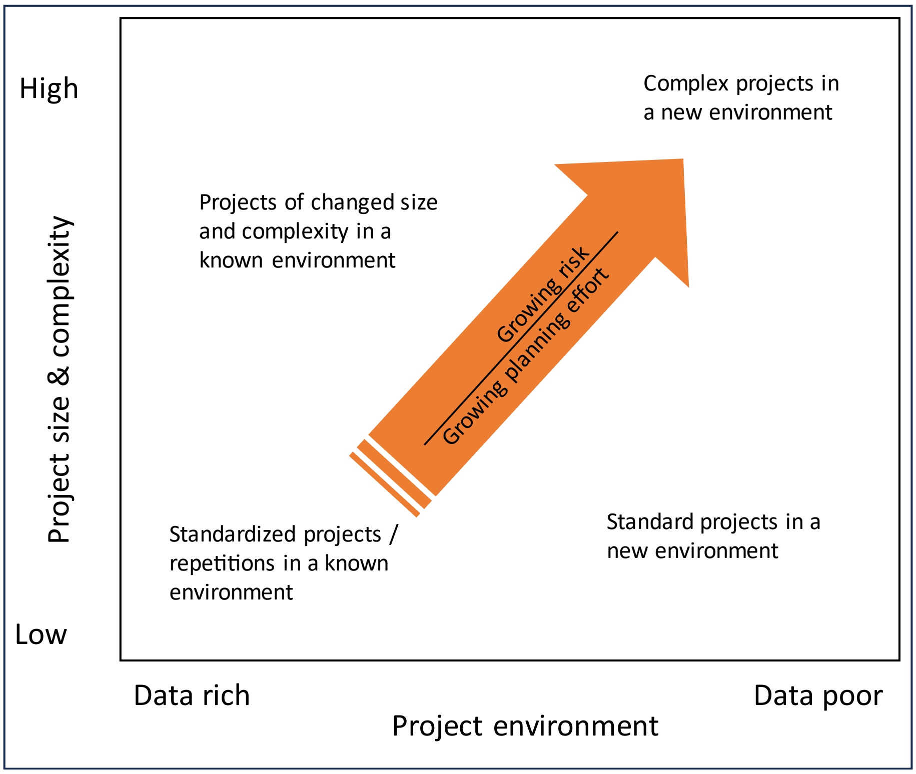


Figure 9: Risk evaluation according to project size/complexity and project environment

4.3 Classification of risks according to probability and impact

The classification of risks according to probability of occurrence and impact (amount of damage) is an essential part of effective risk management. It enables the prioritisation and targeted treatment of risks, improves resource allocation and supports well-founded decision-making. In addition, it promotes transparency and communication within the project and facilitates the continuous monitoring and adjustment of risk management strategies.

4.3.1 Probability of occurrence

The probability of occurrence describes the likelihood of an event to occur. It can be rated on a scale from very unlikely to very likely:

1. Very unlikely: Less than 5% probability of occurrence.
2. Unlikely: 5-20% probability of occurrence.
3. Possible: 21-50% probability of occurrence.
4. Probable: 51-80% probability of occurrence.
5. Very probable: More than 80% probability of occurrence.

4.3.2 Impact (amount of damage)

The amount of damage describes the potential impact of an event on the project. This can also be assessed on a scale from minor to catastrophic, for example:

1. Minor: Minor impact on the project schedule or budget, easy to manage.
2. Moderate: Moderate impact on schedule or budget, requires adjustments to the project plan.
3. Significant: Significant impact on schedule or budget, requires significant adjustments and management attention.
4. Severe: Severe impact on the project, potentially jeopardising the project goal, requires immediate action.
5. Catastrophic: Catastrophic impact, potentially leading to project failure, requires immediate and comprehensive action.

Impacts can be of various kinds, e.g. related to costs, the environment, occupational safety or acceptance.

Impact categories can be further specified, if necessary, e.g. from X euro costs or according to emission quantity.

4.4 Risk matrix

A risk matrix, e.g. with the above definitions as a 5x5 matrix, is a visual tool used in risk management to assess and prioritise risks based on their probability of occurrence and their impact. The matrix consists of a grid, with the columns representing the probability of occurrence and the rows representing the impact.

4.4.1 Structure of the matrix

The 5x5 risk matrix is formed by crossing the five probability levels with the five impact levels, resulting in a total of 25 fields. In practice, 3x3 to 7x7 matrices are also used, depending on the complexity requirements of the organisation. Each field in the matrix represents a combination of probability of occurrence and impact. The fields in the matrix are often colour-coded to make the risk classification visible immediately.

- Green: Low risk (not critical, low priority)
- Yellow: Medium risk (moderate priority, regular monitoring required)
- Red: High risk (critical, high priority, immediate action required)

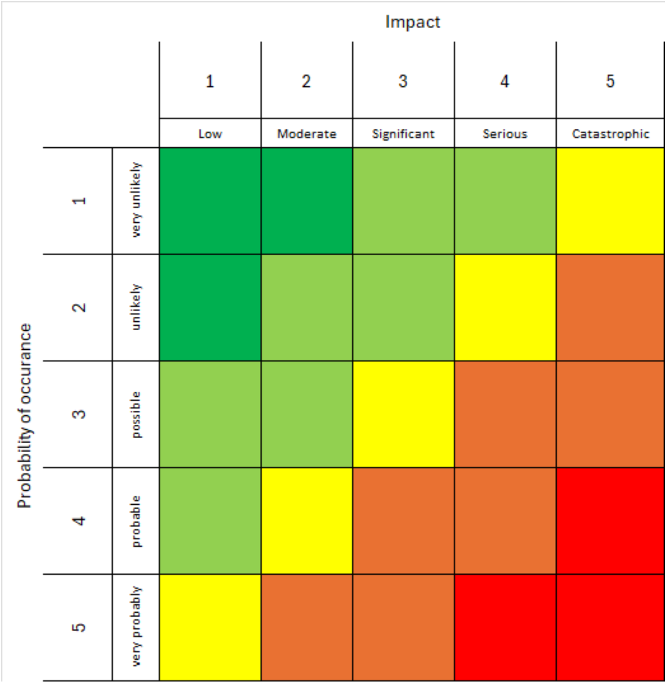


Figure 10: 5x5 risk matrix

In addition to colour coding, the risk itself is often represented as a prioritised category, e.g. as a product of the categories damage level (e.g. "2") and probability of occurrence (e.g. "4") as prioritisation category 8 (= 2 x 4).

4.4.2 Recording risk control

Once the initially identified risks have been assessed and control measures for risk management have been proposed, an additional risk assessment must be carried out after risk management. This is also entered into the risk matrix so that it is clear how the risk assessment has shifted there.

4.4.3 Use of the risk matrix

Risk matrices are used as follows:

1. Risk assessment: Each identified risk is assessed based on its probability of occurrence and its impact and entered in the corresponding field of the matrix.
2. Prioritisation of measures: Risks that end up in the red fields (high risk) are given the highest priority for risk management measures and should be analysed further, e.g. with a bow-tie analysis. Risks in the yellow fields are monitored regularly and addressed as necessary. Risks in the green fields usually do not require immediate action.
3. Communication: The matrix provides a visual and understandable representation of a project's risk landscape, which facilitates communication with stakeholders.

In the risk management process described above, as shown in Figure 7, the first step is to identify measures that completely avoid the respective risk (e.g. brines as drilling fluid can prevent the wash out of salt layers drilled through). If this is not possible, measures to reduce the risk are sought (e.g. lowering a measuring tool on coiled tubing rather than on a cable). Alternatively, or in addition, insurance against the occurrence of the risk should be considered and, if necessary, obtained.

5. Risk analysis tools

Risk analysis is an essential part of risk management in projects. It helps to systematically identify and assess potential risks and to plan appropriate risk control measures. Various risk analysis tools offer structured approaches to understanding and managing risks. These tools enable project managers and teams to make informed decisions and minimise the probability of negative impacts on the project. Common risk analysis tools include bow-tie analysis, SWOT analysis and risk registers, each of which offers specific advantages and applications.

As a rule, a SWOT analysis or alternative risk identification method is first carried out, the results of which are then incorporated into a risk register. Subsequently, a bow-tie analysis should be carried out for each of the high risks.

5.1 SWOT analysis

SWOT analysis (Strengths/Weaknesses/Opportunities/Threats) is another useful risk analysis tool. It helps to identify internal strengths and weaknesses as well as external opportunities and risks that could influence the project.

1. Strengths (S): Internal factors that have a positive influence on the project.
2. Weaknesses (W): Internal factors that negatively influence the project.
3. Opportunities (O): External factors that have a positive impact on the project.
4. Threats (T): External factors that have a negative impact on the project.

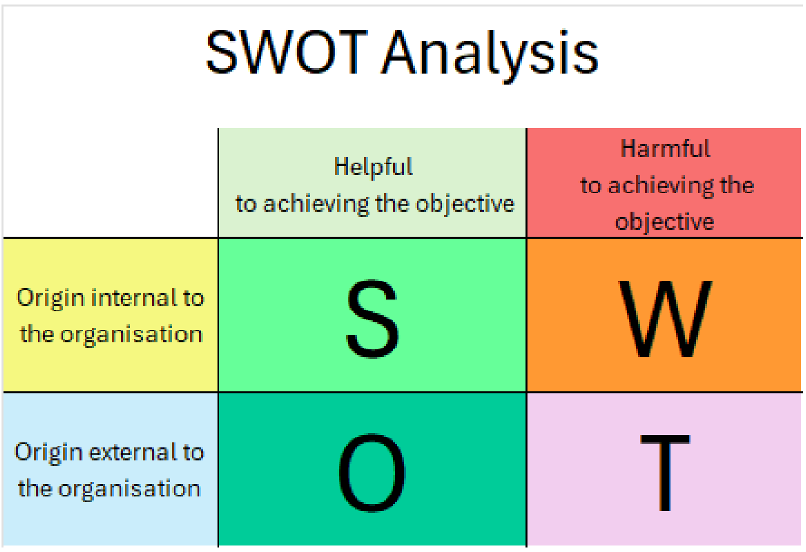


Figure 11: Quadrants of a SWOT analysis

This representation can then be used to identify targeted measures that, on the one hand, further strengthen strengths and make opportunities more likely and, on the other hand, reduce weaknesses and make risks less likely. The results can then serve as input variables for a risk register.

Typical hazards in deep geothermal drilling projects include the possibility of induced seismicity, the occurrence of unexpected geological formations, pressure drops or increases in the boreholes, potential environmental impacts, and inadequate organisational structures and the subsequent shortcomings.

5.2 Risk register

A risk register is a key risk analysis tool that serves to document all identified risks of a project in one place. An example of this is listed in the risk register at *(10) www.georisk-project.eu*.

It provides a structured overview of the events, their assessment in terms of probability of occurrence and impact, and the planned risk management measures. By regularly updating and monitoring the risk register, project managers can ensure that risks are dealt with proactively and that the project team is always informed about the current risk status.

5.3 Bow-tie analysis

Bow-tie analysis is a visual tool for presenting and analysing risks. It combines elements of fault tree analysis and event tree analysis to identify the causes and effects of a risk as well as the control measures for risk reduction. Bow-tie analysis is usually only performed for the highest ranked risks identified in the risk matrix and is event-centred.

The following steps are implemented:

1. Risk management:
   - The central event is shown in the middle of the diagram.
2. Cause analysis:
   - The causes of a possible event are identified and displayed on the left side of the bow-tie diagram.
3. Consequence analysis:
   - The potential consequences or effects of the event are shown on the right-hand side of the diagram.
4. Control measures:
   a. Measures ("barriers") to reduce the probability of the event occurring are inserted on the left.
   b. Measures ("barriers") to limit the consequences (reactive measures) are shown on the right.

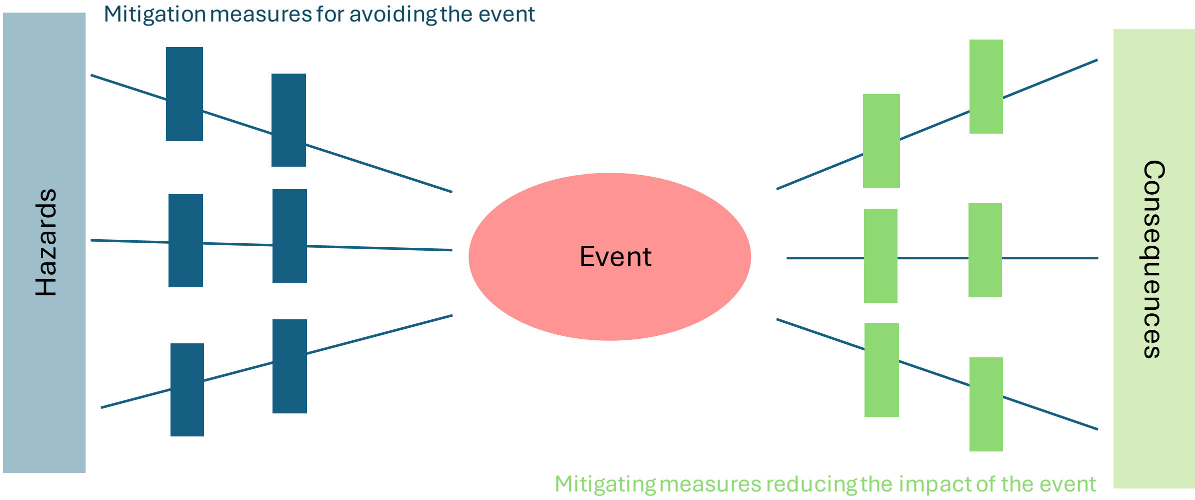


Figure 12: Generic bow tie diagram

The basic idea behind the bow tie diagram is to reduce risk by implementing as many effective risk control measures as possible, which work in series. No measure is assumed to be perfect; it is the sum (or, more precisely, the product) that makes the difference.

Appendix B shows an example of a bow-tie diagram – on the left are the causes and corresponding preventive measures for the event, and on the right are the mitigating measures and possible consequences.

5.4 Decision tree planning

A decision tree is a graphical representation of decisions and their possible consequences, including random events, resource costs and benefits. In well planning, it helps engineers and managers evaluate different drilling strategies under uncertainty – for example, whether a well should be deviated, redrilled or completed – based on expected performance and costs.

Decision trees are defined before spud to determine the correct decisions during the drilling phase a priori. This saves costs and optimises results. The more accurately the probabilities of possible events are determined, the more effectively the tool works.

Decision trees can operate at different levels. At the highest level, decision trees are used, for example, to respond to different injectivity or productivity results. The pre-created decision tree then specifies the best possible responses to the results encountered (see Figure 13). But even at lower levels, decision trees can contribute greatly to the quality of the drilling, for example when determining casing depths or drilling mud weights, etc.

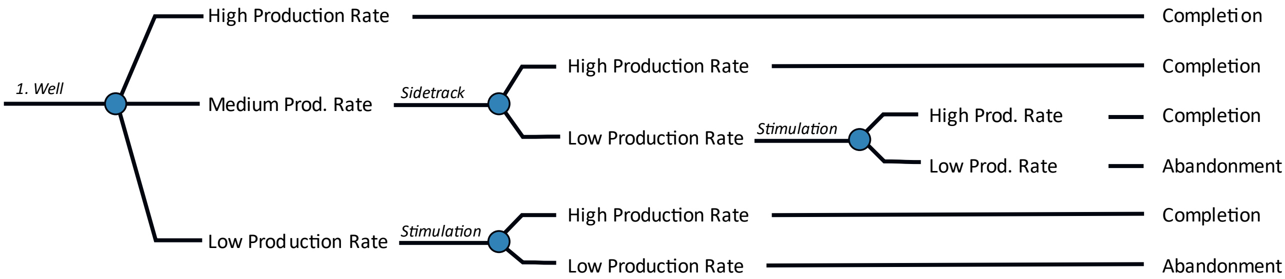


Figure 13: Typical decision tree for a geothermal drilling project (1st well)

Figure 13 shows a typical decision tree for responding to low and high production rates in a geothermal well. The blue dots represent geological drilling results. The more accurately the probabilities for the possible outcomes are determined in advance, the more effectively the well can be planned and the more effectively responses can be made during the drilling phase. For details, see also [19].

6. Creation of risk registers

The importance of a risk register lies in its ability to proactively prepare a project team for potential problems. Through the structured documentation and evaluation of risks, risk management measures can be planned and implemented at an early stage, which increases the probability of project success.

A risk register is a tool for project managers, team members and relevant stakeholders such as insurers and investors. It usually covers the following aspects (for further information, see also [16]):

- identified hazards,
- existing safeguards, mitigation and control measures,
- initial risk description in absence of control measures
- plan for implementing control measures
- description of the risk after the control measures

Chronologically, the procedure is usually as follows:

6.1 Risk identification and description

The first and fundamental component of a risk register is risk identification.

There are various methods for identifying risks, including:

- Brainstorming: A group activity to generate ideas and possible risks.
- Interviews: Discussions with experts and stakeholders to identify specific risks, e.g. through a consultation with the mining authority.
- SWOT analysis: Analysis of the strengths, weaknesses, opportunities and threats of a project, whereby the risks are taken as entries and strengths, opportunities and weaknesses are used as evaluation parameters
- Generic risk lists such as those in [10] www.georisk-project.eu , from [1] bgrm in France or [12] KEM-06 in the Netherlands.
- Research into similar drilling projects that have already been carried out and their available documentation.

Risks can originate from various sources, including:

- Internal sources: Organisational changes, technical problems, lack of resources.

- External sources: Market changes, regulations, environmental factors.

Risks that are not only relevant to drilling projects, e.g. falling objects or accidents caused by untidy work areas, must also be identified and mitigated. The identified risks are then described in the risk register, which usually specifies the event, the trigger and the consequence (see Figure 14).

6.2 Categorisation of risks

Effective categorisation of risks helps to maintain an overview and plan targeted measures. Here are some of the most common categorisations:

- Strategic risks: Risks that affect strategic goals and the business model. (e.g. results of local municipal heating planning, availability of critical resources)
- Operational risks: Risks that affect operations and internal processes. These include drilling risks and occupational safety risks. (e.g. drill string twist-off or a sidetrack)
- Financial risks: Risks that influence economic results. (e.g. interest rate developments or funding commitments)
- Legal risks: Risks arising from legal and regulatory requirements. (e.g. new requirements regarding 'state of the art' or the need for additional permits)
- Technological risks: Risks related to technology and IT systems. (e.g. dependence on fixed partners due to technology selection or drilling rig availability)
- Environmental risks: Risks that affect the environment or are caused by natural events. (e.g. drilling integrity risks or flooding)
- Geological risks: Risks arising from uncertainties in geological forecasts. See also [3] "BVEG Guideline on Economic assessment of geological risks of deep geothermal projects ". (e.g. missing or insufficiently permeable reservoir)
- Market risks: Risks arising from changes in the market environment and competition. This also includes acceptance risks. (e.g. energy price developments or the speed of the connected heat network expansion)

These risks should always be considered in geothermal projects and can be comprehensively presented using risk registers. A narrower range of risks can also be mapped (e.g. only operational risks); however, all risk categories must be considered for a project-wide analysis.

6.3 Risk assessment

Once risks have been identified, they must be assessed. Risk assessment often takes place at the same time as or immediately after risk identification. It is important that this is done by an experienced interdisciplinary group of experts, usually in the context of a workshop. The following are the assessment parameters:

1. Assessment of probability of occurrence: This can be assessed using qualitative (low, medium, high) or quantitative (percentage probability of occurrence) methods. A risk matrix is often used for this purpose.
2. Assessment of impact: The impact of a risk describes the potential damage that an event can cause. This is also assessed qualitatively or quantitatively and often recorded in a risk matrix.

For details on risk assessment using risk matrices, see Chapter 4.4.

Description of Risk			Risk assessment before mitigation		
Precursor	Event	Consequence	Probability of occurance	Extent of damage	Impact

Figure 14: Columns for risk description and risk assessment in a risk register

6.4 Prioritisation of risks

After assessment, the risks must be prioritised. This can be clearly illustrated in a risk matrix (see Figure 16).

Criteria for prioritisation include the probability of occurrence and the impact of the event.

Risks are classified based on their assessment in order to manage the highest risks first and in the most detail. The product of the qualitative levels of probability of occurrence and consequence is often used for this purpose.

6.5 Planning the risk response

Response strategies must be developed for the most important risks.

These are risk response strategies (see also Figure 7), whereby the following order is desirable:

1. Priority: Avoidance (measures to avoid the risk).
2. Priority: Mitigation (measures to reduce the probability or impact)
3. Priority: Transfer (transfer of the risk to a third party (e.g. insurance))
4. Priority: Acceptance (conscious decision to accept the risk).

Strategies are specified in detailed action plans, which define the responsibilities and resources for risk management. A responsible person or group is then appointed to implement these measures.

Risk category	Risk-mitigating measures	Risk owner	Risk assessment after mitigation		
			Probability of occurance	Extent of damage	Impact

Figure 15: Section of a risk register describing risk control measures

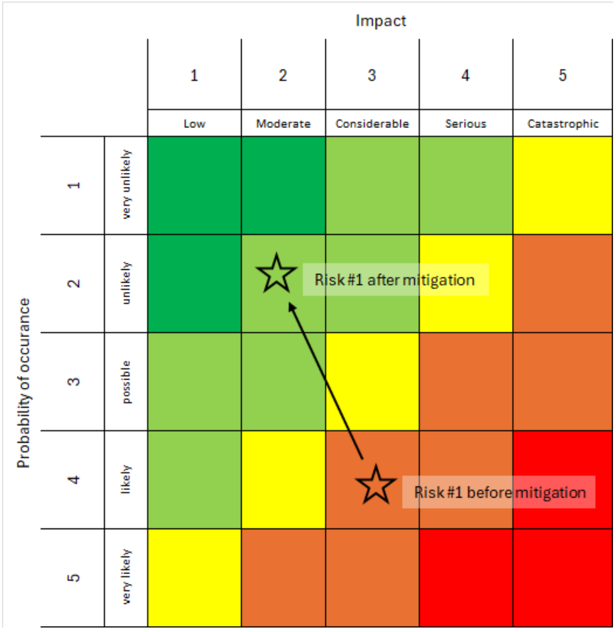


Figure 16: Risk matrix with example risk before and after mitigation

6.6 Monitoring and controlling risks

Risks must be continuously monitored and controlled. This is important to ensure accuracy and relevance. This can be done as part of project status meetings or special risk assessments.

The monitoring process includes constantly observing the identified risks and the effectiveness of the risk management measures. The risk register should be seamlessly integrated into existing project management processes to ensure consistent and effective risk management.

The risk register is updated regularly to record new risks and revise existing entries.

This enables regular reporting to stakeholders on the status of risks, documents the measures taken and thus allows an overview to be maintained and the traceability of response plans to be ensured.

When using and creating the risk register, it is advisable to involve a safety specialist. A functioning HSE- and quality management system is necessary and mandatory under mining law.

A culture of continuous improvement should be promoted by learning from past experiences and developing risk management processes accordingly.

For key risks and mitigation methods, it often makes sense to carry out decision tree planning in advance as part of a management of change process for developments that deviate from the plan. This allows for a quick and appropriate response to surprises.

In principle, a clear distribution of responsibilities (and their limits) with clear job descriptions in all areas of planning and execution, from management to roughneck, is crucial for smooth and safe drilling operations. This is reflected in the management systems described here. It is also important to understand that, due to 24/7 drilling operations, these processes must allow for far reaching decisions to be made on weekends, public holidays and even at night. In addition, structured information management is important due to the interdisciplinary nature of the work.

7. Drilling- and exploration-risk insurance

Comprehensive risk management in the planning and execution phases can already reduce or avoid numerous technical and geological risks. However, there are residual risks. These are associated with the uncertainties of the only partially known subsurface and the selected execution options. In order to partially transfer the residual risks of the project developer, there are various insurance solutions on the market to cover this risk.

7.1 Drilling risk and lost-in-hole insurance

Drilling risks can be covered by specific drilling risk and lost-in-hole insurances. A detailed technical analysis of the drilling programme and the contractors involved is a key component of the insurer's initial assessment.

This is particularly important because, in the case of deep drilling, the drilling risks are not usually covered by the contractors. Drilling risk insurance typically covers physical damage to the borehole during the drilling, completion and testing process, whereby project-specific constraints can be defined.

One component of drilling risk insurance can be a lost-in-hole (LiH) insurance, which covers the fishing work to retrieve the tools or drill string up to a predetermined sum insured in the event of drilling tools becoming stuck or replaces the value of the tools used if recovery is unsuccessful. Complex drilling tools are usually rented from service providers. Lost-in-hole insurance can be part of an insurance concept that should preferably be commissioned by the client. In the event of unsuccessful fishing, the sidetrack drilling that must then follow to bypass the stuck section is covered by the drilling risk insurance.

An unlikely but very serious scenario is a blowout of the well (uncontrolled escape of large quantities of reservoir fluids or gases from the well), which can be covered as a further component ("control of well") of drilling risk insurance.

7.2 Dry-hole insurance

In addition, the exploration risk of discovery can also be insured at different conditions depending on the region. In this case, the insurer's evaluation focuses on geoscientific data and resource assessment. Geothermal projects located in regions with already successful projects or numerous old hydrocarbon wells have an advantage here over so-called greenfields, i.e. regions with little subsurface or drilling data.

One possibility of insuring the discovery of deep geothermal projects in Germany will likely be KfW's Programme 572. The aim here is to enable financing supported by borrower’s banks for the initial well, which would otherwise only be possible from own funds, before the discovery is confirmed.

7.3 Liability insurance including mining damage coverage

The relevant mining authorities very often require insurance cover for potential mining-related damage of neighbors. In most cases, the authorities focus on potential environmentally relevant technical consequences, such as the leakage of liquids or micro-seismicity (minor earthquakes). There are also specific liability insurance policies available on the insurance market that include mining damage in addition to the normal liability insurance conditions. Furthermore, it may be advisable for project developers to join the Bergschadenausfallkasse e.V. (BSAK, Mining Damage Compensation

Fund). This is an association of all key players in the mining sector in Germany who are potentially impacted by mining damage. The BSAK provides access to an additional safeguard mechanism that would come into effect in extreme cases if the liability insurance sum is insufficient to cover the actual mining-damage incurred. It should be noted that this extreme case has never had to be applied since the BSAK was established, as the upstream insurance solutions are sufficient in terms of their liability limits (usually high 7- to 8-digit amounts) and, in addition, no damages amounting to millions have yet been incurred in geothermal energy in Germany, nor are any to be expected in the future.

7.4 Commercial aspects

The usual insurance premiums and deductibles for such insurance solutions are based on the total drilling costs or, in the case of LiH insurance, on the most expensive drilling tool or logging string, and are usually in the six to seven-figure range, so that for an individual project (typically a doublette) or a portfolio approach with several wells, the economic assessment and usefulness of such a concept may vary. It is advisable, especially in the case of a portfolio approach, to evaluate various worst-case scenarios and premium models.

Private insurance solutions are usually offered by a consortium of different insurance companies that share the risk at internally negotiated percentages. As a rule, however, the project developer only has one point of contact at the insurer, who takes over the management of the consortium and informs the affiliated insurers internally. As a rule, a "warranty surveyor", i.e. a specialist insurance assessor as described above, must be involved throughout the project.

List of references

[1] BRGM Bureau de Recherches Géologiques et Minières, "Good practice guide for lessons learned from deep geothermal drilling", *Geothermies*, 2021. https://www.geothermies.fr/good-practice-guide-lessons-learned-deep-geothermal-drilling (accessed 3 February 2025).

[2] BVEG Bundesverband Erdgas, Erdöl und Geoenergie e.V, "Bohrlochkontrolle. Bohren, Workover, Well Intervention" (Well control. Drilling, workover, well intervention), 2015. Accessed: 3 February 2025. [Online]. Available at: https://www.bveg.de/wp-content/uploads/2021/09/BVEG-Technische-Regel-Bohrlochkontrolle.pdf

[3] BVEG Bundesverband Erdgas, Erdöl und Geoenergie e.V, "Economic assessment of geological risks of deep geothermal projects", 2024. Accessed: 3 February 2025. [Online]. Available at: https://www.bveg.de/umwelt-sicherheit/technische-regeln/leitfaden-wirtschaftliche-bewertung-geologischer-risiken-von-tiefengeothermischen-projekten/

[4] BVEG Bundesverband Erdgas, Erdöl und Geoenergie e.V., „BVEG-Leistungsspektrum für Geothermieprojekte V1.0.4“, 2024. Accessed: 3 February 2025. [Online]. Available at: https://www.bveg.de/die-branche/tiefe-geothermie-in-deutschland/das-leistungsspektrum-geothermie/leistungsspektrum-geothermie/

[5] BVG Bundesverband Geothermie e.V., „Induzierte Seismizität bei Geothermieprojekten“, 2023. Accessed: 3 February 2025. [Online]. Available at: https://www.geothermie.de/fileadmin/user_upload/Bibliothek/Downloads/20231201_Hintergrundpapier_Seismizitaet.pdf

[6] BVG Bundesverband Geothermie e.V., „Seismizität bei Geothermieprojekten Teil 1: Seismische Überwachung (Messnetze)“, 2023. Accessed: 3 February 2025. [Online]. Available at: https://www.geothermie.de/bibliothek/lexikon-der-geothermie/r/richtlinie-gtv-1101

[7] BVG Bundesverband Geothermie e.V., „Seismizität bei Geothermieprojekten Teil 2: Reaktionsschema (Ampel)“, 2023. Accessed: 3 February 2025. [Online]. Available at: https://www.geothermie.de/bibliothek/lexikon-der-geothermie/r/richtlinie-gtv-1101

[8] BVG Bundesverband Geothermie e.V., „Seismizität bei Geothermieprojekten Teil 3: Seismologisches Basisgutachten“, 2023. Accessed: 3 February 2025. [Online]. Available at: https://www.geothermie.de/bibliothek/lexikon-der-geothermie/r/richtlinie-gtv-1101

[9] FKPE Forschungskollegium Physik des Erdkörpers e. V., „Position des FKPE e.V. zur Induzierten Seismizität“, 2012. Accessed: 3 February 2025. [Online]. Available at: https://www.fkpe.org/fileadmin/user_upload/Microsite_FKPE/dokumente/Induzierte_Seismizitaet/fkpe_ind_seis_monitor_120709_final.pdf

[10] GEORISK, "Georisk Tool," *Georisk*, 2019. https://www.georisk-project.eu/georisk-tool/ (accessed 3 February 2025).

[11] NLOG Nederlandse Olie- en Gasportaal Hoofdnavigatie, "NLOG Nederlandse Olie- en Gasportaal Hoofdnavigatie," *NLOG Nederlandse Olie- En Gasportaal Hoofdnavigatie*. https://www.nlog.nl/geothermie (accessed 3 February 2025).

[12] Ritsema, "KEM-06 Hazard and risk assessment for Ultra Deep Geothermal Energy (UDG) and inventory of preventive and mitigation measures (finished)," *KEM Programma*, 2018. https://kemprogramma.nl/blog/view/21db9ade-3ffd-4d1f-97f0-2e7716583e08/kem-06-hazard-and-risk-assessment-for-ultra-deep-geothermal-energy-udg-and-inventory-of-preventive-and-mitigation-measures-finished (accessed 3 February 2025).

[13] WEG Wirtschaftsverband Erdöl- und Erdgasgewinnung e.V., "Leitfaden Futterohrberechnung," 2006. https://www.bveg.de/umwelt-sicherheit/technische-regeln/weg-leitfaden-futterrohrberechnung/ (accessed 3 February 2025).

[14] WEG Wirtschaftsverband Erdöl- und Erdgasgewinnung e.V., "Gestaltung des Bohrplatzes," 2006. https://www.bveg.de/umwelt-sicherheit/technische-regeln/weg-leitfaden-gestaltung-des-bohrplatzes/ (accessed 3 February 2025).

[15] BVEG Bundesverband Erdgas, Erdöl und Geoenergie e.V., „Leitfaden Bohrungsintegrität“, 2022. Accessed: 3 February 2025. [Online]. Available at: https://www.bveg.de/wp-content/uploads/2021/09/BVEG-Leitfaden-Bohrungsintegritaet_Technische-Regel.pdf

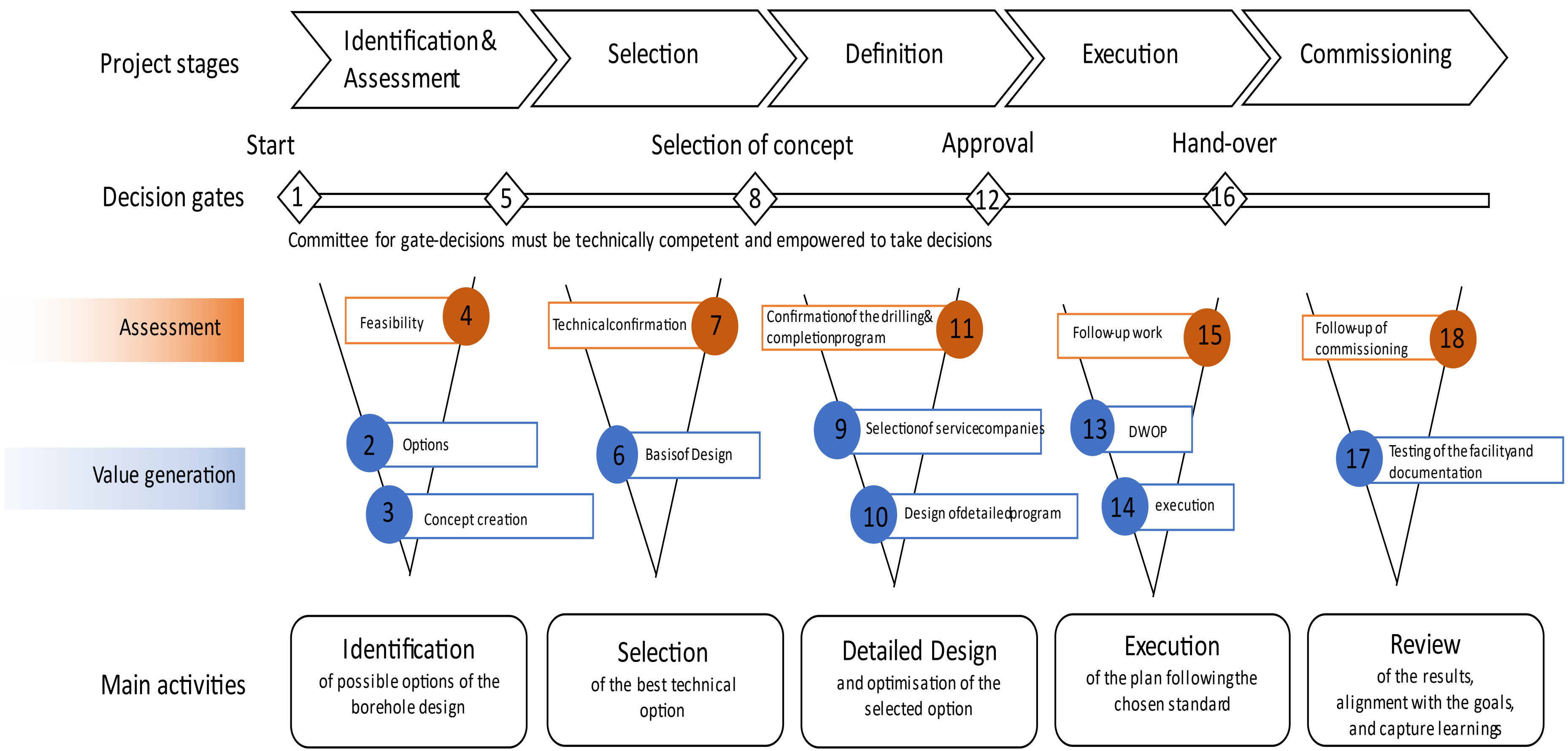
[16] DIN EN ISO 16530-1:2017-11 Petroleum and natural gas industries – Well integrity – Part 1: Life cycle management https://www.dinmedia.de/de/norm/din-en-iso-16530-1/265410798

[17] BVG Bundesverband Geothermie e.V. "Lexikon der Geothermie" https://www.geothermie.de/bibliothek/lexikon-der-geothermie (accessed 21 July 2025)

[18] BVEG Bundesverband Erdgas, Erdöl und Geoenergie e.V., „Wörterbuch der Bohr-, Förder- und Offshore-Technik, Englisch-Deutsch /Deutsch-Englisch“, 2018

[19] Grant, M. A. "Decision Tree Analysis of Possible Drilling Outcomes to Optimise Drilling Decisions." Proceedings of the Thirty-Third Workshop on Geothermal Reservoir Engineering, Stanford University, 2008. https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2008/grant.pdf

Appendix A: Stage-gate process for deep well drilling



Appendix B: Example of a bow-tie diagram