Chapter 10
Risk Management for CO_2 Geological Storage Projects

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Abstract A number of key challenges relating to potential CO_2 reservoir capacity, injectivity and confinement need to be overcome when validating the performance of a storage system for its lifecycle. In the case of a failure of a storage operation, the environment, investments, and human health and safety, may be at risk. It is therefore important to use risk management methods to ensure that the project will meet its objectives in all aspects. The aims of risk management are both to identify and evaluate all the risks that could impact the project objectives, and to establish treatment, monitoring actions and plans to reduce the impact of risks thereby ensuring the project performance. This Chapter discusses the implementation of risk management for a CO_2 geological storage project.

10.1 Introduction

Deep CO_2 geological storage is one of the most promising solutions to reduce the CO_2 emissions to the atmosphere, and minimize the impact of greenhouse gas effects. Nevertheless, some key challenges relating to capacity, injectivity, and containment need to be addressed in order to ensure the performance of the storage

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system during its lifecycle, for a duration that can range from some years to hundreds of years. This means that we need to understand the risks associated with this technology and devise strategies to manage these risks, which include technological risks to the environment and human health and safety, social risks, policy risks, legal risks and the like.

Risk management for the geological storage of CO_2 is complex due to the

- wide variety of physical phenomena that need to be taken into account (including hydrodynamic, geochemical, geomechanical phenomena) and their inter-dependence,
- limited access to geological data and the associated uncertainties,
- variability between the sites and the time scales involved, ranging from very short term to centuries or a few millennia.

The safety management of the storage projects is one of the key obstacles to the large-scale deployment of the technology, not only for technical reasons, but also for societal reasons, including acceptance of industrial projects of a new type and growing awareness of people. Ensuring the safety of a geological storage project requires mitigating the main technological obstacle, namely that of reliably predicting the behaviour of the storage performance over its lifecycle. This goal is fraught with the inherent uncertainties related to deep geological reservoirs.

Currently, there is no recognized and by the international scientific community commonly accepted standard methodology, for the analysis and management of the risks related to the geological storage of CO_2. The activity of geological storage of CO_2 is still under development. Research over the past ten years proposed approaches for the identification of risk scenarios or tools for their representation (Pawar et al. 2015). However, these studies have not yet produced a generic, comprehensive and commonly accepted methodology to evaluate, in a quantitative way, the risks posed by the geological storage of CO_2.

Risk studies have been carried out in for various sites, such as:

- In-Salah, Algeria (Dodds et al. 2011; Paulley et al. 2011; Oldenburg et al. 2011),
- Weyburn, US (Stenhouse et al. 2005),
- Illinois Basin, US (Hnottavange-Telleen et al. 2009, 2011),
- Fort Nelson Carbon Capture, US (Sorensen et al. 2014),
- The North Sea, Captain Sandstone Aquifer, UK (SCCS 2015).

The aforementioned studies were conducted as part of research projects and had no regulatory framework for the definition of procedures and/or standards (Oldenburg et al. 2008; US EPA 2008). Examples of initiatives in Europe include those by Quintessa, who has developed a database on related FEPs (Features, Events and Processes) (Maul et al. 2005), by DNV (Det Norske Veritas 2009) and by TNO (Wildenborg et al. 2004; Yavuz et al. 2009). The project ANR CRISCO2 (Bouc et al. 2010) proposes a method to determine qualitative and quantitative criteria to ensure the safety of CO_2 storage. This study focuses on aquifer storage. The approach was developed on the basis of the Paris Basin case study and relies on reasonably conservative assumptions and simplified models for quick evaluation of the safety. CO_2-PENS software platform has been developed by the Los Alamos Laboratory (Pawar et al. 2006; Stauffer et al. 2009, 2011) and tests on a few storage cases within National Risk Assessment Partnership (NRAP) projects (Cugini et al. 2010) have been performed.

National Energy Technology Laboratory in the US has in a Best Practices Manual summarized the concepts of risk analysis (risk assessment) and numerical simulation by describing the experience gained by the DOE Regional Carbon Sequestration Partnerships as they implemented multiple field projects (NETL 2011). This manual focuses on the risks arising from unplanned migration of injected CO_2 from the reservoir and on the ways in which numerical codes have been used to model specific processes related to the behavior of injected CO_2 in the subsurface.

Guidelines and standards are needed to delineate best practices for conducting studies of long term predictive failure analysis for elements of geological storage of CO_2, namely:

- reservoirs and geological barriers,
- geological features (faults, fractures),
- wells (former ones or those constructed for the purpose of the storage project).

Potential impact studies concerning the effect of CO_2 geological storage on both surface targets, such as drinking water aquifers and soils as well as subsurface targets and on human health, fauna and flora are also needed. This is needed to provide objective demonstration of the performance of such projects elements. Risk management is the process that aims at identifying all the potential risks related to a project, organizing them in order to define which are the critical ones and outlining actions that may be taken to lower these risks. The different steps of risk management process are the following (Fig. 10.1):

- Communication and consultation;
- Establishment of the context;
- Risk assessment or risk analysis, that includes risk identification, estimation and evaluation;
- Risk treatment;
- Risk monitoring and review.

Management and communication will ensure that the policy is understood, implemented and maintained at all levels of the CO_2 project.

Risk management is an iterative process to be applied over the project lifecycle (Fig. 10.2), from site selection to abandonment stages and should be viewed as an essential component for any CO_2 storage project. Its main principles are to:

- Contribute to the achievement of project objectives regarding, for example, health and safety, environment and investments as well as the improvement of project performance;

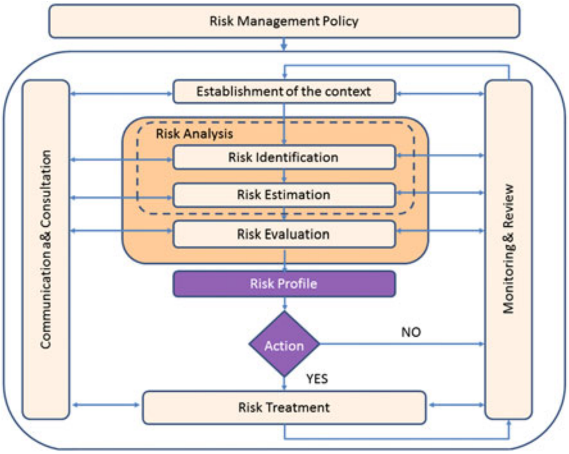


Fig. 10.1 Risk management process according to ISO 31000 (2009)

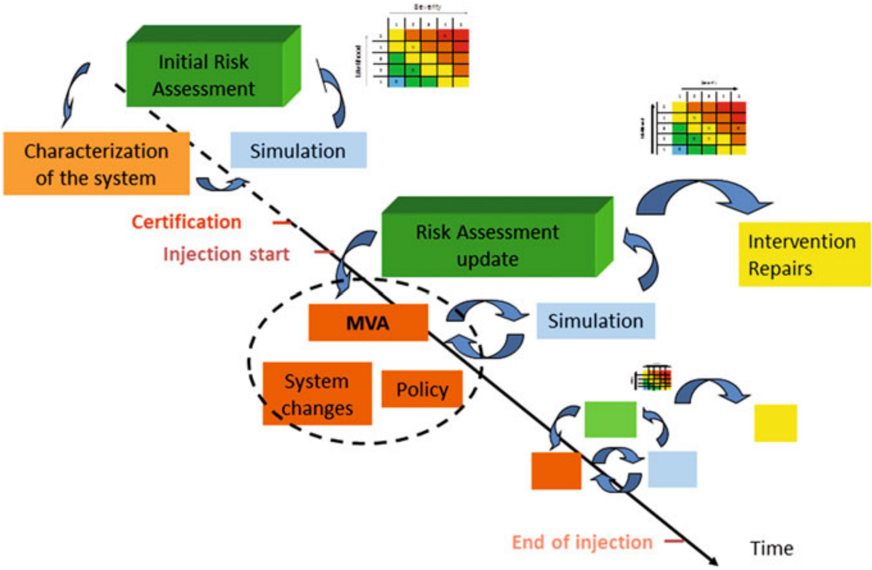


Fig. 10.2 Risk management workflow over CO_2 geological storage project life cycle

- Support the decision making process for risk treatment and definition of any Monitoring, Verification and Accounting (MVA) program, including prioritizing actions and justifying the choices;
- Provide management and/or authorities demonstration of effective and comprehensive management of risks;
- Provide consistent, comparable and reliable results of risk evaluation as a product of a transparent and structured methodology.

10.2 Risk Management Policy

According to the reference process for risk management (ISO 31000 2009), the risk management policy should:

- Clarify the project objectives and commitment for risk management;
- Specify the link between the risk management policy and the project objectives, and rationale for managing risk;
- Specify the processes, methods and tools to be used for managing the risks;
- Identify the roles and responsibilities in the project team for managing risks;
- Describe the way in which risk management performance will be measured and reported;
- Establish the project commitment to the periodic review and verification of the risk management policy.

10.3 Establishment of the Context

The definition of the context of the CO_2 project supports the risk management process, as it defines the contours of the risk management and the elements to be considered in the process. The context of this process will vary according to the needs of the project. It can involve, but is not limited to:

- Defining the scope, as well as the extent of the risk management activities to be carried out, including specific inclusions and exclusions;
- Defining the activity, process, function associated to the project in terms of time and location as well as their goals and objectives;
- Defining the way performance is evaluated in the risk management;
- Identifying and specifying the decision process (who, when, for which purpose and what).

The definition of the context of a project must include the elements listed below, which are described in more details in what follows:

- The scope of the project: environment of the project, storage characteristics and timeline.

- The internal and external entities involved in risk management, including the operators, stakeholders and contractors.
- The risk criteria to evaluate the significance of the risk: the probability and severity levels and the criticality matrix.

It is also important to point out that good quality information is essential in any risk management process. The data collection step is one of the most important steps in the Risk Management process, and must be started early in the process.

10.3.1 Scope of the Study

The first step in the definition of the scope of the risk assessment is the identification of the system under consideration and its breakdown into subsystems. It is also necessary to define the type of risks that will be considered. These risks must be included in the different risk families defined previously in the field of application of the risk management policy.

To define the scope of the CO_2 project, all the elements and interactors of the project must be defined. The following paragraphs describe what these elements and interactors could be. Here, we focus only on technical aspects. Note that the elements and the interactors depend on the system or subsystem under consideration.

For any CO_2 storage project, the system elements could be included into two main groups, namely (1) the natural system, i.e. the geology, which defines the target reservoir, the caprock above it, the overburden, the fresh water aquifers, and (2) the anthropogenic influence, i.e. the wells located in the storage area, including any injection wells, oil and gas production wells, water disposal wells, monitoring wells, shutoff wells, plugged and abandoned wells.

10.3.2 Internal and External Entities

The second step for establishing the context is to define the internal and external entities of the CO_2 project. The relationship between the CO_2 project and its environment (both internal and external) must be taken into account when identifying and assessing risks. The identification and definition of internal and external entities will support the identification of stakeholders. To ensure that all stakeholders are taken into account, both internal and external contexts are defined and linked to the subsystems by means on a functional analysis.

There is a wide variety of stakeholders that must be considered in the context of a project. The stakeholders can be considered either internal or external. Internal stakeholders would be departments or teams that interact with the project (several disciplines and groups will be involved, such as geologists, drilling engineers, geophysicists, to mention some), while external stakeholders would consist of entities that interact with the operator and may affect or have an impact on the project, such as regulators, other oil and gas companies, local communities and the

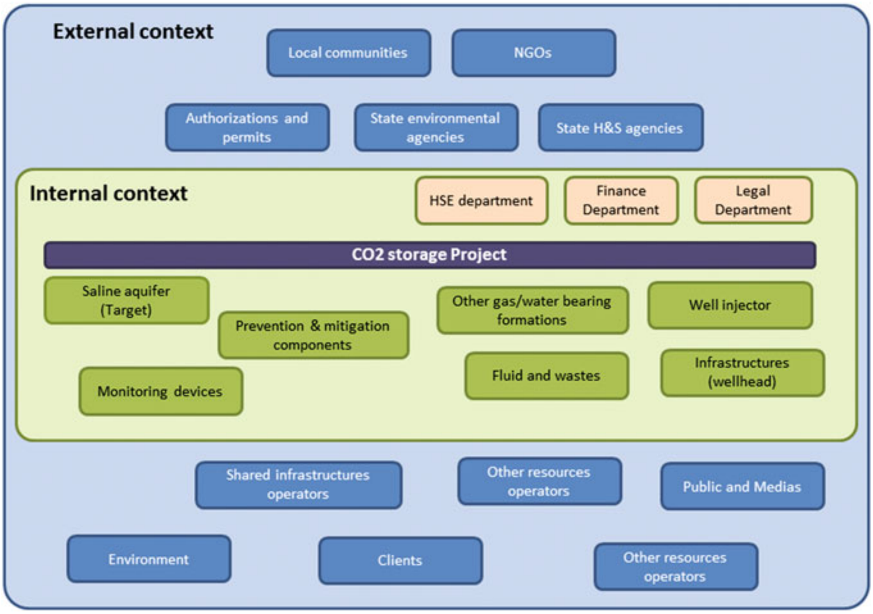


Fig. 10.3 Key actors/activities within in a CO_2 geological storage project

like. Figure 10.3 illustrates a representation of key stakeholders to be considered in a CO_2 geological storage project. The understanding of the internal context can include, for example:

- The capabilities, understood in terms of resources and knowledge (e.g. time, people, processes, systems and technologies);
- Information systems, information flows, and decision making processes (both formal and informal);
- Internal stakeholders;
- Standards and reference models adopted within the project.

External context is the external environment in which the project seeks support to achieve its objectives. The external context can include, but is not limited to:

- The cultural, political, legal, regulatory, financial, technological, economic, natural and competitive environment, whether international, national, regional or local;
- Key drivers and trends having impact on the objectives of the project.

10.3.3 Constraints

The definition of constraints is one of the important steps in the establishment of the project context. The project team needs to identify the activities, the media and the organizations which can be affected by any risk. Examples of constraints for a CO_2 storage project include, but is not limited to:

- Technical aspects, such as capability to safely transport and store CO_2;
- Health and safety aspects, to ensure that the personnel and the local population will not in any way be endangered by the activities related to the project;
- Public outreach and confidence aspects, including demonstrating a reliable leadership of the project as well as the benefits gained from the project, to reach public confidence;
- Financial aspects, including achieving the project within the frame of the agreed budget;
- Policy and strategic aspects: CO_2 storage project is an innovative technology which is involved in global and local climate change and energy strategies;
- Compliance with national and local authorities' requirements.

10.3.4 Risk Criteria

This step uses the project objectives to identify key performance indicators that will be used to estimate, evaluate and treat risks. In this step, the risk criteria will be defined and used to evaluate the importance of risk. The criteria must reflect the project values and objectives and be continuously reviewed. Risk criteria could be defined according to expert opinions, interviews with stakeholders and actors, or by expert elicitation with the project team (Edlmann et al. 2016).

10.3.4.1 Probability Grid

The definition of the probability grid is defined with the knowledge of the project team and eventually based on other expert opinions. When possible, a quantitative estimation has to be used, such as probability of a CO_2 leakage, probability of a mechanical failure for a well component, to mention some. This quantitative estimation is then converted to a probability level on the basis of the probability grid used for the project. An example of such a grid is presented in Table 10.1.

Table 10.1 Example of a probability grid

Description	Probability over CO_2 storage period[a]	Level
Very unlikely: very rare	<0.001 %	A
Unlikely: rare	(0.001 %; 0.01 %)	B
Possible: can be observed, feared	(0.01 %; 0.1 %)	C
Likely: already observed, will probably occur	(0.1 %; 10 %)	D
Very likely: expected to occur (almost certain)	>10 %	E

[a] Provided as an example

Table 10.2 Example of severity grid

Description	Level
Minor	1
Low	2
Medium	3
High	4
Very high	5

10.3.4.2 Severity Grid

The severity levels indicate the magnitude of the impact if an unwanted event, or failure, occurs. The definition of the severity grid is also defined with the knowledge of the project team and with subject matter expert opinions. It is the preliminary step of the consequence grid elaboration. Table 10.2 is an example of a severity grid with 5 levels.

10.3.4.3 Consequence Grid

The consequence grid provides a description of the different severity levels for each project objective identified. The objectives are expressed in using performance indicators to illustrate the different level of impact (severity levels) on the objectives of the project (see Sect. 10.3.3).

This grid is the link between the project objectives impacted and resulting severity level. It must be developed closely with the project stakeholders, and eventually with expert opinions. When the objectives of the project and the key indicators (severity levels) are defined, each project stakeholder defines the minimum and maximum severity levels regarding each objective and then proceeds to complete the intermediate levels.

10.3.4.4 Risk Matrix

The risk matrix shown in Table 10.3 is also named a criticality matrix. The criticality “C” represents a mathematical relation between the severity and probability level. Mostly, criticality is a function of the severity level and the probability level:

$$\mathrm{C}\,(\mathrm{Criticality}) = \mathrm{F}\,(\mathrm{S}(\mathrm{Severity}), \mathrm{P}\,(\mathrm{Probability}))$$

The higher the criticality level, the higher the risk.

Table 10.3 Illustration of a risk matrix

Probability	**E**	Medium	High	High	Extreme	Extreme
	D	Medium	Medium	High	High	Extreme
	C	Medium low	Medium	Medium	High	High
	B	Medium low	Medium low	Medium	Medium	High
	A	Low	Medium low	Medium low	Medium	Medium
		1	**2**	**3**	**4**	**5**
	Severity					

10.3.4.5 Level of Acceptability

The level of acceptability is the level used to decide if treatment actions or monitoring actions are required. The definition of the level of acceptability depends on each objective identified by the project team. This level is defined according to the technical, financial, legal, social and other criteria. It is defined within the project and reflects the appetence or aversion of risks by the company.

Acceptability level of risk delimits 2 zones (Table 10.3): a zone where risks are critical (not acceptable) and a zone where risks are acceptable. For example, if the acceptability level has a criticality level of 6, the critical risks are those located in the orange and red zones in Table 10.3. This enables the definition of an action plan to mitigate risks.

10.4 Risk Assessment

A risk cannot be managed unless it is first identified and its impact assessed. Consequently, after risk management policy and context have been completed, the first process in the iterative Risk Management process aims to identify all the knowable risks to CO_2 project objectives. Risk assessment is the process of systematically and continuously identifying, categorizing, and assessing the initial significance of risks associated with a CO_2 project. Risk identification determines risks that might affect the project and registration of their characteristics.

The assessment should be performed on a regular basis throughout the project timeline. The purpose is to identify risks to the maximum extent that is practicable. The fact that some risks are unknowable or emergent requires the ‘identify risk’ process to be iterative, repeating the ‘identify risks’ process to find new risks which have become knowable since the previous iteration of the process. During the progress of the project through its lifecycle, new risks may appear. The project team should be involved in this process so that they can develop and maintain a sense of ownership of, and responsibility for, the risks and associated risk response actions.

In the following section, we will focus the risk assessment on technological issues for a CO_2 geological storage project to illustrate the approach.

10.4.1 Risk Identification

A comprehensive identification based on a well-structured and systematic process is essential to ensure that all significant risks are considered. Different methodologies can be used for this: FMEA (Failure Mode and Effects Analysis), Fault tree analysis, Event tree analysis, or Features, Events and Processes (FEP) analysis (Wildenborg et al. 2004; Pawar et al. 2006; Oldenburg et al. 2011; Paulley et al. 2011). We propose the use of FMEA. This is a systematic approach that focuses on the function to be fulfilled by the subsystems and components. In this process, the list of risks is based on the failure modes that might prevent, degrade or delay the achievement or performance of the objectives of the CO_2 project; it uses the results of the establishment of the context. For each subsystem and component (Fig. 10.4), the failure modes, their causes and their potential impacts (or consequences) on the objectives are defined (Fig. 10.5). The outcome of the risk identification step is a comprehensive list of risks related to the project compiled in a risk register (Table 10.4). This risk register is the input for the risk estimation step.

An example of the risk identification is given in Fig. 10.6. In the figure a structured and comprehensive inventory of leakage pathways and leakage impact factors (risks) through the caprock, which could contribute to CO_2 storage performance, was generated based on information from the literature (e.g. Oldenburg et al. 2011; Vilarrasa et al. 2011; Al-Bazali et al. 2005; Li et al. 2006; Shukla et al. 2008, 2010; Bildstein et al. 2009; Class et al. 2009; Wollenweber et al. 2010; Busch et al. 2010; Amman et al. 2011; Le Guen et al. 2008, 2010; Viswanathan et al. 2008). This is used as the basis for subsequent risk estimation.

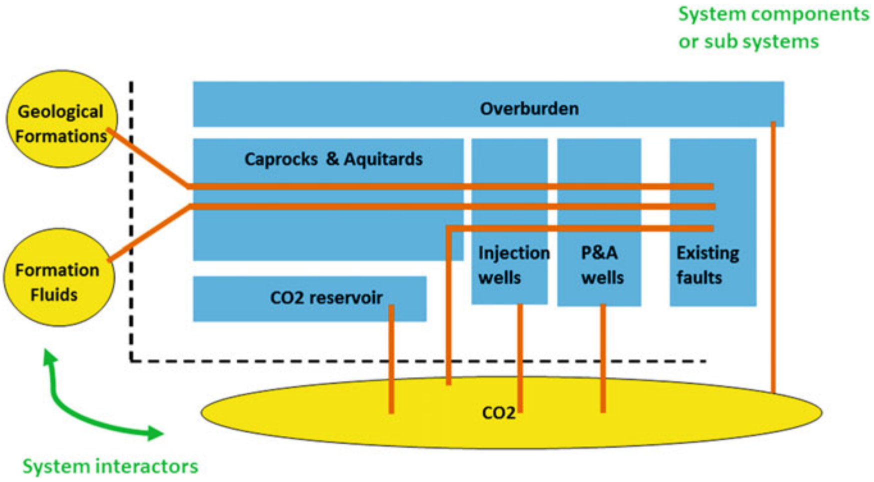


Fig. 10.4 Example of a schematic of a CO_2 geological storage system and possible interactions

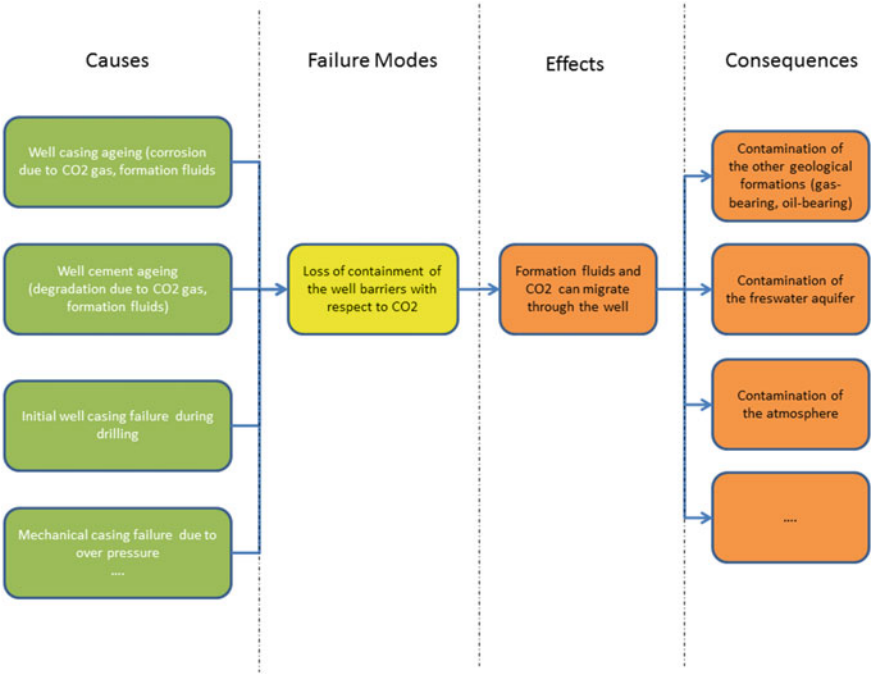


Fig. 10.5 Generic bow-tie illustrating central event ‘loss of containment for an injecting well with respect to CO_2’ and its associated causes and effects

Table 10.4 Example of the components and functions breakdown for a CO_2 geological storage project

Component	Sub-functions	Interactors	Failure mode
CO_2 reservoir	To ensure injectivity into the reservoir	CO_2	Loss of injectivity
	To ensure storage capacity	CO_2	Loss of storage capacity
Caprock	To resist to the formation fluids pressure	Formation fluids	Deformation of the caprock, cracks
	To ensure the sealing with respect to the formation fluids	Formation fluids	Loss of confinement
	To resist to the injected gas pressure	CO_2	Loss of mechanical resistance
	To ensure the sealing with respect to injected gas	CO_2	Loss of confinement
	To resist to geological formations deformation pressure	Geological formation	Deformation of the caprock, cracks
Wells (all types)	To resist to the formation fluid pressure	Formation fluids	Deformation of the caprock, cracks
	To ensure the sealing with respect to the formation fluids	Formation fluids	Loss of confinement
	To resist to the injected gas pressure	CO_2	Loss of mechanical resistance

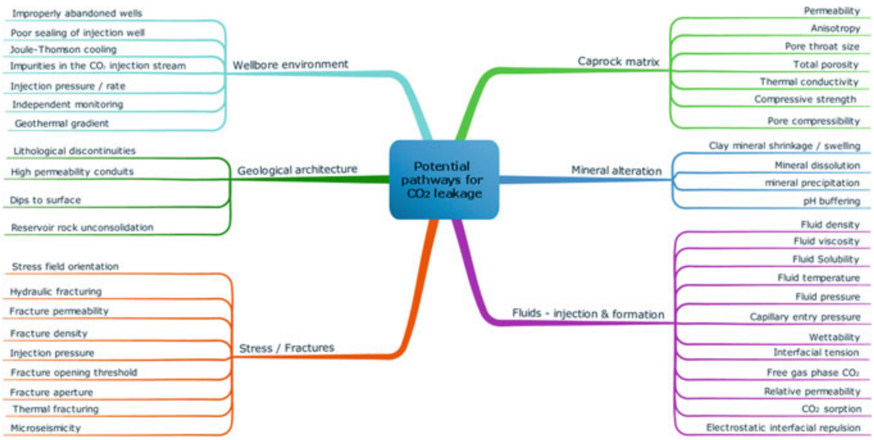


Fig. 10.6 The potential CO_2 leakage pathways and leakage impact factors (risks) influencing caprock leakage grouped by primary category

10.4.2 Risk Estimation

Risk estimation is the second step of risk assessment (Fig. 10.1) where the risk levels are estimated. The input data for this step is the list of risks established by the risk identification process.

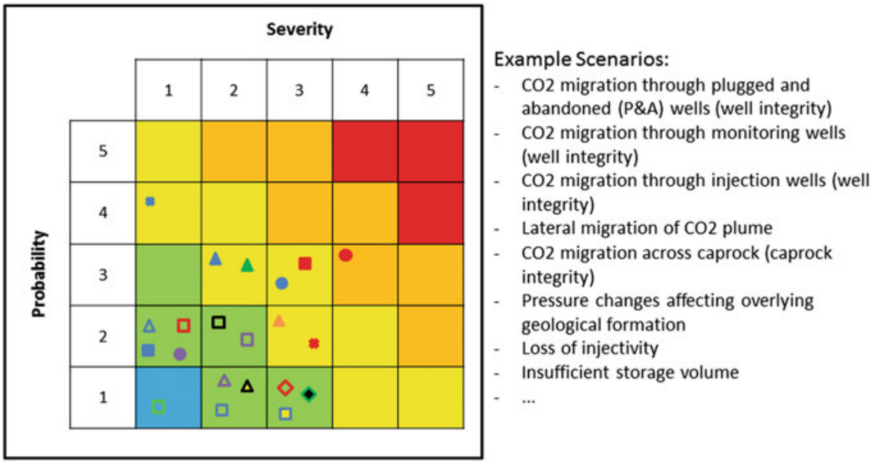
The risk level, i.e. criticality, is a combination of:

- A severity level: the magnitude of the impact of a failure mode on the identified objectives. The definition of the different severity levels is established by defining the consequence grid;
- A probability level: the occurrence of the failure mode. The the different probability levels is established by defining the probability grid.

Estimation can be qualitative or preferentially quantitative estimation of the failure mode and its impacts on the associated performance indicators:

- Quantitatively, using statistical analysis, modeling and simulations;
- Qualitatively, on the basis of past records, experience, subject matter expert's opinions or literature review.

A failure mode can have multiple consequences and can impact various objectives, thus each risk must be estimated for every threatened objective. The resultant outcome of the "risk estimation" step is risk mapping, where each risk is plotted by means of its criticality value, represented by the severity level (y-axis in Fig. 10.7) versus probability level (x-axis in Fig. 10.7) of a failure mode.



Example Scenarios:
- CO2 migration through plugged and abandoned (P&A) wells (well integrity)
- CO2 migration through monitoring wells (well integrity)
- CO2 migration through injection wells (well integrity)
- Lateral migration of CO2 plume
- CO2 migration across caprock (caprock integrity)
- Pressure changes affecting overlying geological formation
- Loss of injectivity
- Insufficient storage volume
- ...

Fig. 10.7 Risk matrix example for a specific CO_2 geological storage project. *Dots* represent various scenarios identified with some examples given in the figure *right* hand panel

10.4.3 Expert Elicitation

Expert elicitation is an approach whereby the reasoned and subjective judgment of experts can be synthesised where there is uncertainty due to insufficient data, making explicit the inherent knowledge based on experience and expertise (Slottje et al. 2008). It is particularly useful in risk assessment when there is very limited “hard” input data. For example, at the beginning of an injection project, early decisions need to be made with regards to data collection, field operation and monitoring strategies. Then, an expert elicitation can be undertaken with the aim to identify, assess and rank potential leakage scenarios, in order to support the assessment and decision making process. The elicitation can be undertaken by a questionnaire where experts are asked for their best estimation of the semi-quantitative scenario uncertainty assessment criteria of severity (i.e. how extensive the leakage could be) and immediacy (i.e. what is the likely time frame of the leakage). Simple mathematical aggregation giving equal weight to all experts can be used for the data analysis and the severity and immediacy be plotted in a probability and impact matrix, assigning an impact rating from low, medium low, medium, high to very high and conclusions made based on the outcome. Such an exercise was carried out for the Heletz pilot injection project (Edlmann et al. 2016), as an demonstration example and the findings were in agreement with more conventional risk assessment studies at existing pilot CO_2 injections sites (Deel et al. 2007; Oldenburg et al. 2011; Watson 2014; Jewel and Senior 2012). Prudent expert elicitation can provide useful insight and guidance and make a valuable contribution to decision making.

10.4.4 Risk Evaluation

Risk evaluation is the third step of risk assessment. The input data for this step are the outcome of the risk analysis, i.e. the list of the risks with a level of severity, probability and criticality.

The purpose of risk evaluation, based on the outcomes of risk analysis, is to make decisions about which risks require treatment and to define priorities between treatment actions.

The final outcome of a risk evaluation is a prioritized risk register recommending further action. In addition, the risk evaluation yields a risk matrix in which risks are ranked (Fig. 10.7). Risks with the higher criticality levels should be treated with priority.

A detail of the map can be drawn for specific scenarios. An example for caprock integrity is detailed below (Fig. 10.8).

10.4.5 Description of Risk Treatment Process

Risk treatment defines the processes of selection and implementation of measures to modify the risk. Risk treatment is based on the outcomes of the risk evaluation which ranked the risks that have to be treated by priority.

Risk treatment involves:

- Identifying the key parameters driving the critical risks;
- Listing the range of options for treating risk, including (1) selecting a short list of actions among treatment options and applying those options to critical risks and (2) assessing the options;
- Defining the actions in terms of cost, nature, and duration.

Before a risk can be effectively treated, it is necessary to understand its cause, in order to identify and select the appropriate actions. Possible risk treatment actions are defined by the project team during review meetings and the selection of treatment options is made by project managers or those delegated by the project manager. Treatment options can include the following:

- *Avoid the risk* by deciding not to start or to stop any activity that contributes to the risk, in other words terminate the risk.
- *Change the nature and magnitude of probability of a risk* by prevention and/or monitoring, thereby lowering the probability of the risk occurring.
- *Decrease the severity of a risk* by protection and/or mitigation actions, thereby lowering the consequence(s) of the risk.

Other options can also be chosen, such as to tolerate the risk by deciding to start or to stop any activity that contributes to the risk.

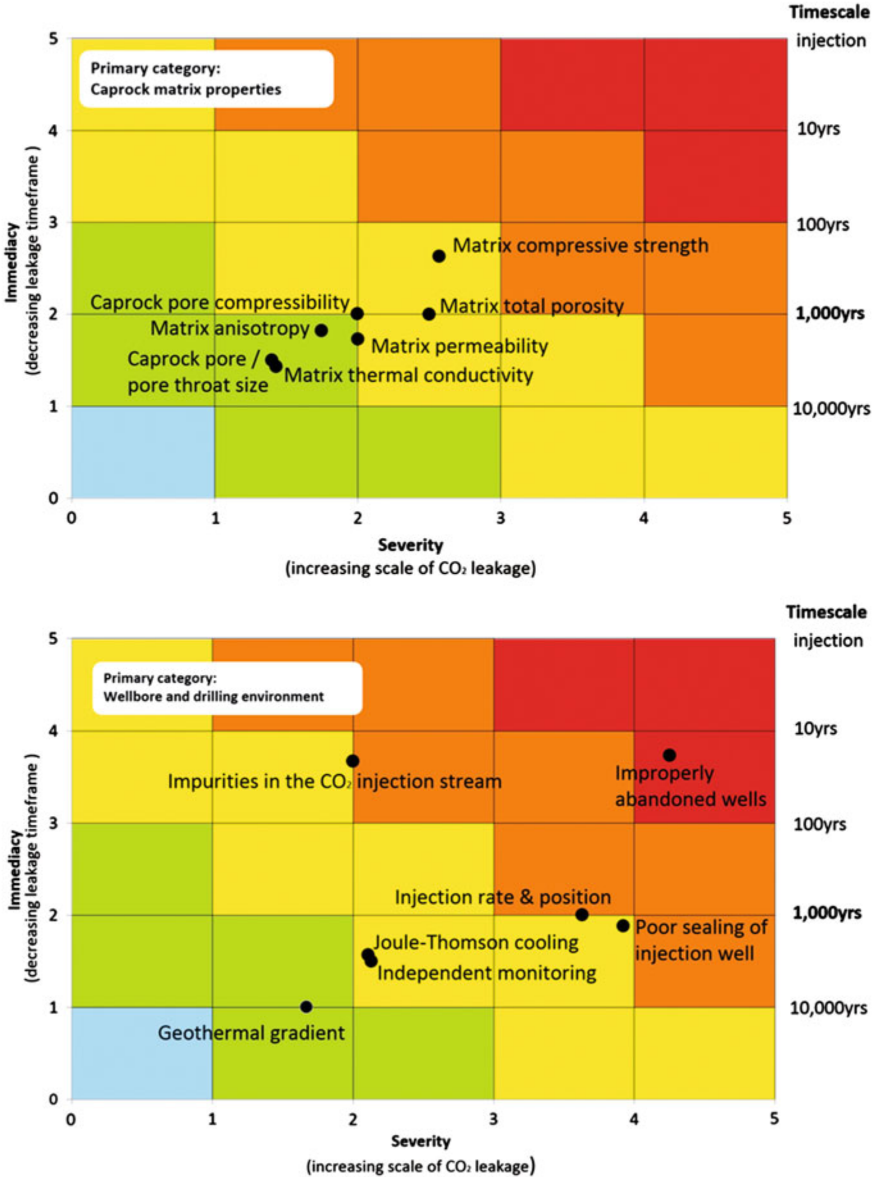


Fig. 10.8 Risk matrix plot for CO_2 leakage scenario. Example for poorly defined input parameters when assessing caprock integrity

The high-criticality risks evaluated in the risk assessment are analyzed and broken down into causes, failure modes and consequences. This process results in a list of parameters that may provide direct or indirect indication of the occurrence of the risks, thus requiring monitoring. This list will drive the ensuing selection of applicable MVA technologies. Relevant MVA techniques are proposed to deal with the parameters previously identified. The technical applicability of each solution for the CCS project has to be discussed, as well as its cost level. This results in a list of relevant MVA technologies recommended for the monitoring of the deep subsurface. Frequencies of data acquisition are then defined for each MVA technology, as well as the action plan stemming from the detection of any deviation from the base case scenario. Two types of MVA plan are recommended in CO_2 geological storage projects:

- **A "regular" monitoring plan**: continuous monitoring shows the system behaviour in accordance with the models. Regular additional surveys are performed to confirm this "normal" behaviour;
- **An "in case" monitoring plan**: continuous monitoring detects a system deviation. A risk-based decision-tree will have to be implemented. This decision tree will define the response plan for a proper mitigation of the risk as early as possible through complementary measurements or modification of the injection strategy.

10.4.6 Preparing and Implementing Risk Treatment Plans

In implementing a risk treatment plan, a strategy is formulated using for example: the description of the proposed actions to treat the risk, benefit expected to be gained (i.e. estimate the residual risk after action), cost and man resource required, and schedule.

The outcomes of the risk treatment are:

- A list of treatment actions associated to each risk, including the actions, resources and planning, in other words, a risk treatment plan;
- A new risk matrix, which takes into account the effect of the treatment actions. In this risk matrix the risks are plotted after the treatment actions (for actions which needed to be treated) with new severity and/or probability levels.

The inclusion of new data in a second-round assessment will support the development of a project-specific MVA plan to monitor the critical risks in the most efficient and cost-effective manner.

10.5 Risk Monitoring, Review and Reporting

10.5.1 Objectives

Risk monitoring allows risk evolution to be tracked over time. In an operational way, risk monitoring is focused on processes and causes of the risks. The purpose is to ensure that risk is known and controlled. Monitoring will also ensure that risk treatment actions are effective. Monitoring, review and reporting is an essential and integral step in the risk management process and it takes place throughout the risk management process (see Fig. 10.1).

10.5.2 Risk Monitoring

Risks need to be monitored to ensure that changing circumstances are recorded and duly reported and analysed. Monitoring actions must be continuous and need to be reinforced during particular actions or phenomena. The periodicity of risk monitoring has to be defined in the risk management policy. Very few risks will remain static. Therefore, the risk management process needs to be regularly repeated so that identified risks are up-to-date and the new risks are captured in the process.

10.5.3 Risk Review

Risk review establishes continuity and improvement of the whole risk management process. This stage helps to identify possible deviation from the objectives defined by the risk management policy (i.e., change of injection conditions). It also evaluates the benefits of the risk treatment actions implemented. Periodical re-assessment of the risks must be performed to control risk changes and residual risk levels. After treatment actions, the risks must be re-assessed to identify if the objectives of the treatment action have been achieved.

10.5.4 Risk Reporting

Risk reporting constitutes a necessary support for monitoring and reviewing risks. It relies on a functional risk management tool that provides risk reports. Risk reporting is important to ensure an efficient communication and traceability between all persons involved in the CO_2 project.

10.6 Conclusion

Geologic CO_2 storage project risk management provides a more accurate understanding of the relevant, project-specific technical risks while establishing a robust framework designed to mitigate subsurface risk through the life cycle of the project. By identifying knowledge gaps in current data, risk assessment activities can provide direction for future studies and characterization work. Additionally, geologic storage risk assessment supports the development of a project-specific, risk-based MVA plan.

As a project progresses, the risks can change. The risks that were once estimated to be high can diminish, becoming negligible, and conversely, risks that were once not relevant can become critical. As a result, the risks must be monitored to ensure they are successfully controlled throughout the lifetime of the project. Because risk management is an iterative process, as the details of a project change, the risk management plan may need to evolve to fit its needs. The risk management plan can be reviewed to ensure that it is still effectively controlling the risks for the project and can be modified if necessary.

The successful application of a risk management framework to CCS feasibility projects provide a step forward for the development of CCS. It supports the idea that a risk management framework, including technical risk assessment, can be effectively implemented for large-scale CCS projects. The risk management framework also provides an invaluable decision-making and communication tool that can validate project planning, educate stakeholders, and demonstrate project safety and reliability—all essential for the success of CCS.

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