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Risk assessment of MUSTANG project experimental site – Methodological development

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Abstract

One of the work packages of MUSTANG (MUltiple Space and Time scale Approach for the quaNtification of deep saline formations for CO_2 storaGe) EU project is dedicated to developing a generic methodology for risk assessment related to CO_2 in saline aquifers and applying the methodology to an experimental site. This paper presents the work done by OXAND regarding risk assessment and the application of a risk-based approach to the qualification of the storage site ultimately to provide guidelines for further industrial storage projects.

The risk assessment process is presented, and illustrated with the data of an experimental site. The eight steps of the risk assessment process highlighted in the ISO 31000 are described in this paper: risk management policy, establishment of the context, risk identification, risk estimation, risk evaluation, risk treatment, communication and consultation, and monitoring and review.

Keywords: CO_2 storage, risk assessment, saline aquifer

1. Context: description of the EU FP7 MUSTANG project

The EU FP7 MUSTANG project was launched in June 2009 with the objective to develop methods and models for the characterization of deep saline aquifers for a long term CO_2 storage based on a solid scientific understanding of the underlying critical processes.

Within the framework of the project, a dedicated field-scale CO_2 injection experiment is to be carried out. Based on the analysis of the available geological, geophysical and borehole data from various areas in the studied region, an anticline-structure has been selected as a test site for injection experiment. This site has been extensively investigated for oil exploration (40 wells over an area of about 8 km²) and is therefore well understood.

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In the course of the MUSTANG project it is planned to inject 1000 tones of CO_2 into a three-layer sandstone aquifer. The experiment will consist of the re-entry in an existing well and drilling of a new well for monitoring CO_2 injected into the target formation, the Lower Cretaceous sandstone layer with the total thickness of about 20 m located at a depth of about 1,600 m and overlain by impermeable shales.

One of the work packages (WP9) focuses on the development and application of a risk-based approach for the qualification of CO_2 storage sites to ultimately provide guidelines for further industrial storage projects. An experimental site was selected to apply the risk assessment methodology for the MUSTANG project.

2. Risk assessment for CO_2 storage projects

Risk management must be viewed as essential for CO_2 storage projects and can serve both operator and authorities' needs as its main principles are:

- To contribute to the achievement of the project's global objectives (regarding, for example, health and safety, environment, investments) and the improvement of project performance,
- To support decision making for risk treatment and definition of MVA (monitoring - verification - accounting) program: define priority among treatment actions and justify the choices,
- To provide the authorities with proof of project compliance with regulation, and
- To provide consistent, comparable and reliable results of risk evaluation on the basis of a transparent and structured methodology.

The risk is the combination of (i) the severity (or impact) of a threat to the project objectives and (ii) the likelihood of occurrence of this threat. It is important to note that risk doesn't necessarily have a negative impact, therefore, even if risks are identified, it does not mean that the project is endangered, or that certain actions have to be carried out. Risks can be considered in terms of their potential impacts on project objectives both at the organizational level (e.g. respect delay and cost) and at the technical level (e.g. ensure confinement of the storage complex, ensure integrity of casings).

The risk management process aims at:

- Identifying and evaluating all the risks that could impact project objectives;
- Establishing treatment and monitoring actions or plans to reduce the severity and/or likelihood of risks and strengthen project performance; and
- Ensuring that defined actions are properly carried out, and that risk levels are under control

CO_2 storage remains a new challenge; thus very few results from experience are available to test and strengthen current risk methodology compared to other industrial activities, particularly for saline aquifers that have not been greatly considered by the petroleum industry so far.

Vendrig et al. ([1]) quantified risks associated to CCS project, but focused essentially at the surface transport and injection facilities. Bowden & Rigg ([2]) proposed a methodology elaborated within the GEODISC project. They described a systematic semi-quantitative process based on the judgment of a panel of experts (method entitled RISQUE); it has been used for selection of potential sites in Australia. Wildenborg et al. ([3]) recommend a scenario approach based on a FEP (Feature, Event, Processes) database ([4]). FEP based analysis has been carried out at several pilot sites or in different projects, for example, the long-term behavior of the CO_2 and risks of leakage in Weyburn ([5]), CO2STORE project for the Valleys ([6]), Kalundborg ([7]) or the Schweinrich structure ([8]) case studies. Unfortunately, FEP based approach gives little importance to the risk quantification, in terms of likelihood of scenarios and severity of associated consequence, for a quantitative vision of risk levels.

Other risk analyses have been performed for the FutureGen project ([9]) and for formations below the Norwegian continental shelf ([10]). These approaches rely on a comparison with natural and industrial analogues and on expert judgment. Also, OXAND has developed a quantitative Performance and Risk (P&R^{TM}) methodology ([11], [12]) to evaluate the performance and risks associated with well integrity during storage regarding both injection and post-injection phases.

The expected innovation of the MUSTANG project regarding risk assessment is in developing guidelines to apply risk assessment process to CO_2 storage in deep saline aquifers, focusing on the potential technical risks in the subsurface. Also, this project will try to combine the results of models and experts' judgments to build a comprehensive and functional methodology for quantifying risks for CO_2 storage project. For that purpose, the experimental injection site is an important support for the development of specific knowledge and tools, even though a small quantity of CO_2 will be injected.

The risk-based process proposed in this study is in compliance with the international standards ISO 31000 coming from the International Organisation for Standardization ([13]). This process has been adapted and previously applied by OXAND for CO_2 project. The process is presented in Figure 1 and detailed in next sections.

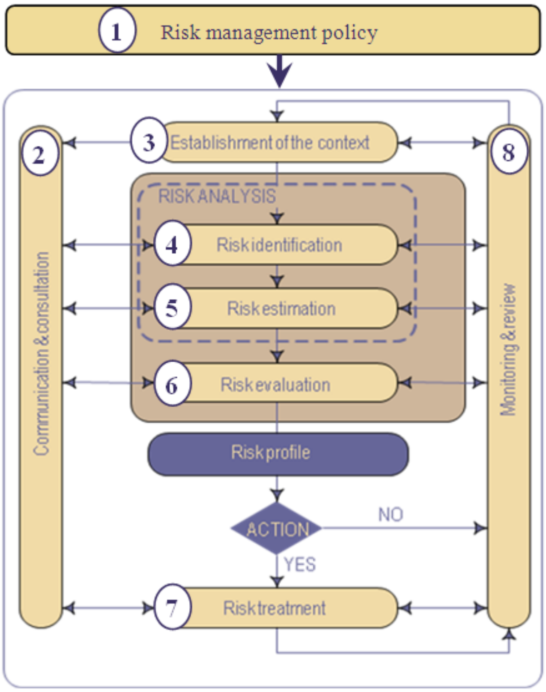

Figure 1: Risk management process according to ISO/FDIS 31000 (adapted from the ISO 31000)

3. Description of the risk assessment methodology

There are 8 major steps in the risk assessment process proposed by ISO 31000: risk management policy, communication and consultation, establishment of the project context, risk identification and estimation (risk analysis), risk evaluation, risk treatment (if some risks require to be treated) and risk monitoring and review.

(1) **Risk management policy**: description of the project objectives and of the commitment of the CO_2 site operator toward risk management, definition of the overall project (process, methods, tools), type of risks to be considered and responsibilities and relation between people involved in the project.

The field of application of the risk management policy must also define the type of risks to be considered in the risk management process. During the MUSTANG project, risk management focuses on subsurface technical risks and their potential consequences on the CO_2 project as well as on internal (i.e. communication support, financial support) and external stakeholders (i.e. regulators, suppliers). Figure 2 presents an example of an organizational chart required to define the roles and responsibilities of a project team. Within the MUSTANG project, the project steering committee is composed of all the work package leaders and the project managers. The Risk manager would be OXAND and the technical team is composed of all MUSTANG partners.

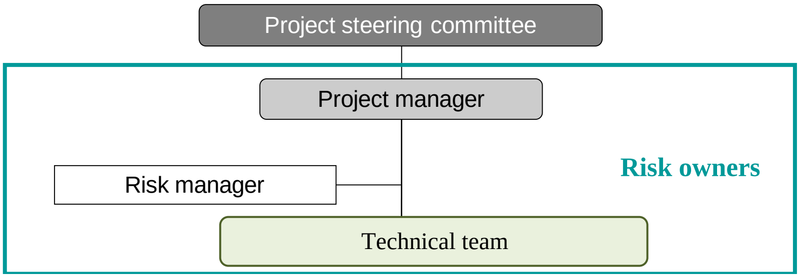

Figure 2: Example of an organizational chart for defining people responsibilities

(2) **Communication and consultation**: description of how the people involved in the risk management process have to communicate and work together at each step of the risk management process.

Management team and communication actions ensure that this policy is understood, implemented and maintained at all levels of the organization. Two MUSTANG project work packages are dedicated to communications: WP1 – "Management", managed by Uppsala University and WP10 – "Impact", managed by AMPHOS 21.

Communication among partners on technical aspects is ensured by two annual meetings where all partners are present, and with semiannual newsletters published by AMPHOS 21. For a constant communication, the website can also be used to share documents about the project (http://www.co2mustang.eu).

(3) **Establishment of the project context**: definition of the stakes and objectives associated with the project (technical, financial, social, etc.), description of the studied system in time and space, internal and external entities involved in the project (project team, suppliers, public, etc.) and finally, definition of the likelihood and consequence grids that will be used for the quantification of risks.

The objectives of a CO2 storage project can for example, be as follows: for technical aspects - capability to transport and safely store CO2 for a long-term period within the storage complex; for health and safety aspects - ensure that the technical staff or the local population will not be endangered by any of the activities related to the CO2 project; for financial aspects - completing the CO2 project within the agreed budget. Other objectives can be defined regarding delays in achieving the project objectives, the environment (atmosphere, aquifers, soil, etc.), the image of the company, etc.

The description of the system aims at collecting and analyzing specific information and data to characterize the site regarding reservoir, aquifers and wells in particular (see Figure 3). The data collection at experimental site is in progress with a strong contribution of GII (Geophysical Institute of Israel) and with the participation of WP2 – "Test sites", managed by Swedish Geological Institute (SGU). The data collected so far include: location of wells (oil producing and others) at the experimental site, characteristics of the wells (position, depth, crossed layers, casings, etc.), description of major geological units in the vicinity of the injection well (age, depth, thickness, etc.), description of the reservoir (depth, thickness, permeability, porosity, etc.), description of the aquifers in the area (position, dimensions, water salinity), description of the surface area (distance from populations, density of population, surface facilities around the site, etc.). The data will be used to define the storage system, which is one of the first steps in the risk assessment process.

The consequence grid provides a description of the different severity levels for each project objective identified. The objectives are expressed using performance indicators to define the different severity levels. It must be developed closely with each stakeholders associated to the project. An example of such grid adapted from another project [14] is given in Figure 4; this grid has to be adapted for each project.

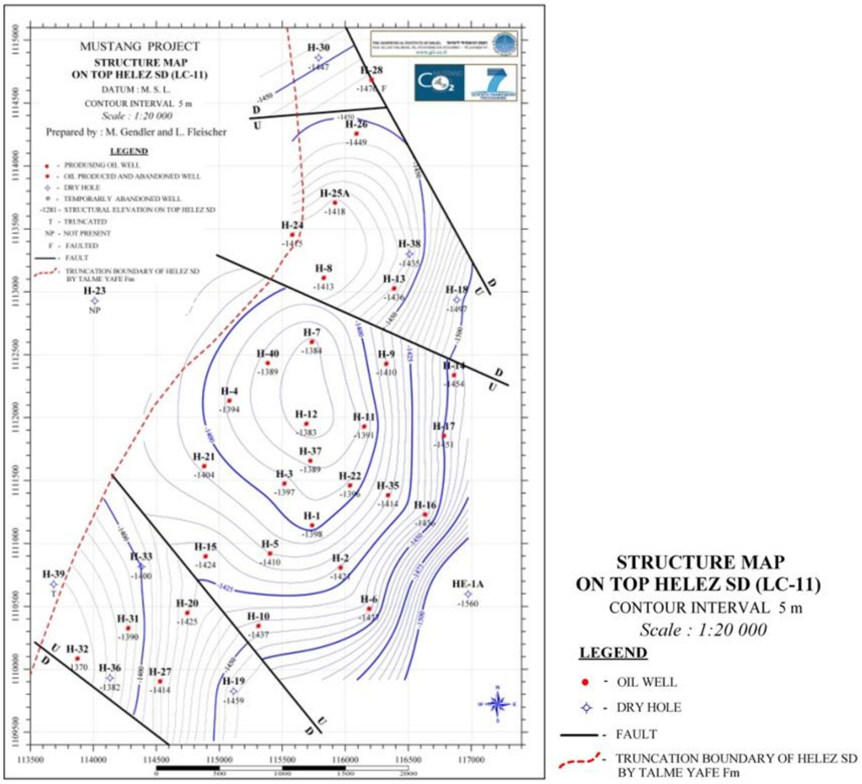

Figure 3: Example of collected data: Structural map on top sandstone

		Stakes			
		Health & Safety	**OPEX - Financial**	**Corporate Perception of know how**	**Environment**
Severity levels	1: Minor	/	< 0.1 M$	no impact	
	2: Low	no impact	[0.1 – 0.5[M$	Technical skill non affected (project is considered as a test)	
	4: Major	Medical treatment	[1 – 5[M$	Lack of confidence from Top Management - Request for a demonstration of technical feasibility	
	5: Critical	Serious personal injury	[5 – 10[M$	Questioning from the Top Management about the technical capability to assume CO_2 storage projects	
	6: Extreme	Serious personal injury, possible permanent injury	>= 10 M$	Stop of the project - Field is not considered as a CO_2 storage field	

Figure 4: Example of a “Consequence grid” (adapted from [14])

(4) **Risk identification**: definition of all risks that could impact the project.

A comprehensive identification based on a well-structured and systematic process is essential to ensure that all risks are considered. Different methodologies can be used to identify risks: FMEA (Failure Mode and Effects Analysis), fault tree analysis, event tree analysis, or FEP (Features, Events and Processes) analysis. We propose to use the F.M.E.A., a systemic approach that focuses on the function to be fulfilled by the systems components to reach project objectives.

Within the MUSTANG project, the functional analysis of the system is in progress. An example of a functional model is shown in Figure 5; it constitutes the basis of the functional analysis leading to the **risk identification**. The functions identified in the scheme are for example, to ensure CO_2 injectivity (F1) or to ensure CO_2 storage capacity (F2).

Bow-ties will then be created to define the risks, their causes and consequences on the project. Figure 6 gives a non-exhaustive example of a bow-tie regarding the risk of "insufficient capacity of the target formation." Although the examples in Figure 5 and 6 may look simple, the F.M.E.A methodology becomes more and more specific while delving in the details of risks, their causes and consequences.

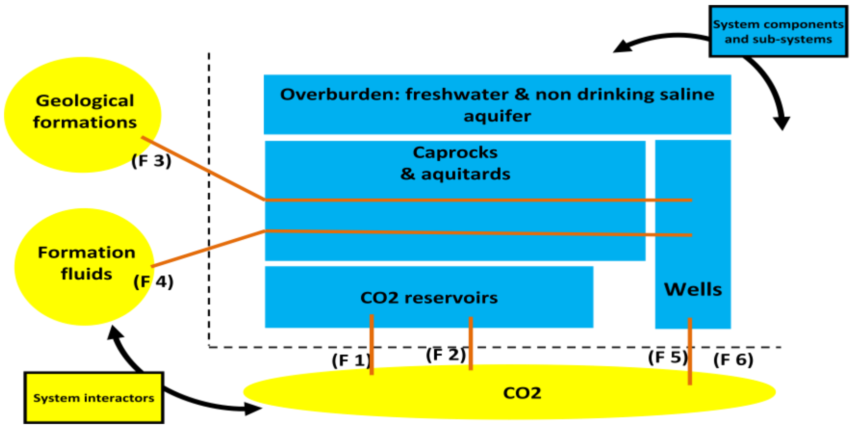

Figure 5: Example of functional representation

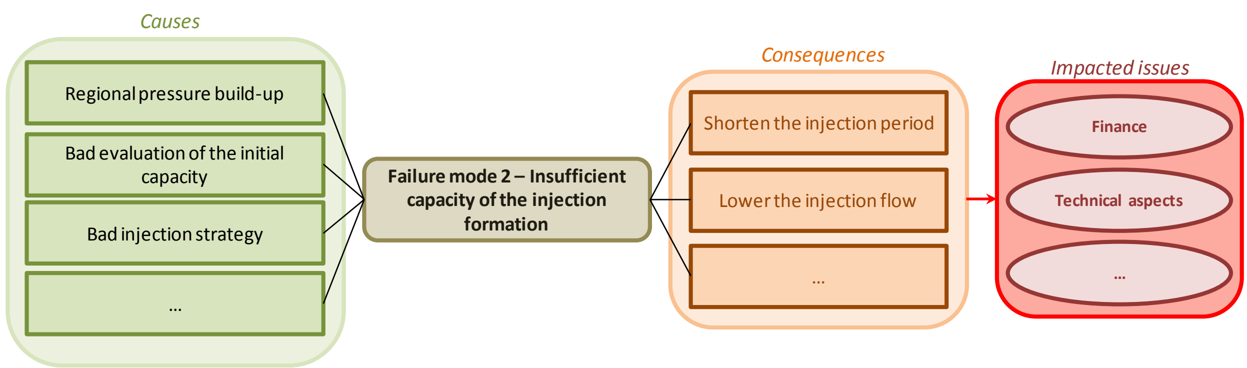

Figure 6: Example of a bow-tie diagram

This part of the process will use the results of WP5 – "Processes", managed by the Israel Institute of Technology, which will give a comprehensive description of all processes involved in a CO_2 storage and an evaluation of their effects.

(5) **Risk estimation**: assessment of the severity and likelihood levels of all identified risks (Figure 7).

The risk estimation could be assessed with expert opinions or simulations results. In the MUSTANG project, WP7 – "Numerical model development and modeling", managed by Nottingham University, is dedicated to modeling. The results of this work package will be used to assess the severity levels of the identified risks.

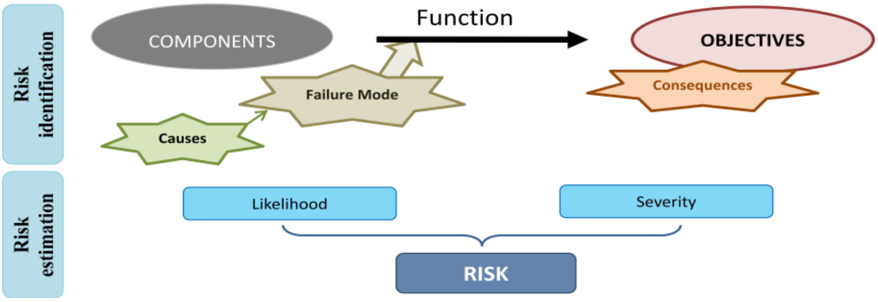

Figure 7 : Pattern of risk identification and estimation

(6) **Risk evaluation**: comparison of the criticality level of each risk to the acceptability level in order to define relevant treatment action plans. The acceptability level is defined by the project team for each project objective. Unacceptable risks are those above the level of acceptability, they will have to be treated first.

The purpose of risk evaluation, based on the outcome of risk analysis, is to make decisions about which risks require treatment or not, and to define priorities between treatment actions.

(7) **Risk treatment**: description of the process of identifying relevant treatment options (i.e. that decrease risk likelihood, severity or both) for the unacceptable risks, and establishing a risk treatment plan to mitigate these risks with the selected options.

Possible risk treatment actions are defined by the project team during risk review meetings and the selection of treatment actions is made by project managers. Treatment actions can include for example: avoid the risk by deciding not to start or to stop any activity that contributes to the risk, change the nature and magnitude of likelihood (prevention, monitoring) or decrease the severity of the risk (protection, curative actions).

(8) **Risk monitoring and review**: description of the process to ensure that risk exposure is well known and controlled and that treatment actions are undertaken in an efficient manner.

Risk monitoring allows risk evolution to be tracked over time. In an operational way, risk monitoring is focused on processes and causes of risks. The purpose is to ensure that risk is known and controlled. Risk 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, it takes place throughout the risk management process (see Figure 1).

The WP6 of MUSTANG project called “Validation”, managed by EWRE (Environmental & Water Resources Engineering Ltd.), will demonstrate the MMV (Measurement Monitoring Verification) process and test novel monitoring and measurements. These pieces of information will be integrated in the risk management process. Also, WP3 – “Field quantification techniques”, managed by the University of Göttingen Geosciences Center, will recommend suitable and cost-effectives technologies that could be applied for the MMV process and provide technologies for monitoring the fate of CO_2 during injection and migration phases in a saline aquifer.

4. Conclusion

CO_2 geological storage is one of the most promising solutions to mitigate CO_2 emissions into the atmosphere, and to minimize the impact of greenhouse gas effects. Nevertheless, some key challenges regarding risk quantification and control need to be overcome in order to validate the performance of the storage system during its lifecycle (from a few years to several hundred years). It is important to use risk management methods to ensure that these projects will meet their objectives, as highlighted in the EU directive regarding CO_2 geological storage ([15]).

This paper proposes a methodology and tools compliant with ISO 31000 Risk Management guideline. It is currently being applied to one of the seven experimental sites of the MUSTANG project with the support of all MUSTANG work packages. The outlook of the next months is to follow-up the risk assessment process by identifying and quantifying the risks related to CO_2 injection at an experimental site.

Risk management must be applied to CO_2 project since the preliminary phases of a project (design phase), up to the permit demand as requested by authorities. However, risk management also has to be applied over the entire project lifecycle (construction and operation phases). Dedicated software exist (such as Simeo™ ERM) to ensure traceability over time, efficient risk treatment of critical risks, follow up of risk levels, and finally to facilitate communication and reporting of risks between people involved (project manager, risk manager, top management).

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