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Energy Procedia 37 (2013) 4757 – 4764

Energy Procedia

GHGT-11

Risk assessment and management associated with CCS

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Abstract

As things stand, there is currently no available commercial insurance for long-term liability of CCS projects. This makes investors shy away from such initiatives, even if the risk of the venture is assessed to be relatively small. A policy review was carried out to assess the risks involved in the CCS industry which identified uncertainties with regards to the risks associated with CCS that make policy making and insuring CCS projects very difficult. This paper presents a coherent understanding of the chain of events that could lead to major failures in a CCS project. This research project has looked into the potential risks involved in CO_2 storage and the ways in which their criticality and importance as well as their probability and likelihood can potentially be calculated using Fault Tree Analysis (FTA) and Analytical Hierarchy Process (AHP) methods.

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Keywords: Carbon capture and storage; Risk assessment; CCS insurance; Long-term liability; Geological storage

1. Introduction

There has clearly been a tangible progress in the technology of carbon dioxide capture and storage. In addition to the increase in renewable energy and promotion of productivity and saving energy, all those who believe fossil fuels should also continue to exist for future generations as for the current one can easily understand the strategy in which storage of CO_2 will have to be carried out.

Although CCS remains a viable option in helping stabilize the atmospheric carbon levels, it still has to demonstrate it is a feasible option in terms of cost and harmlessness to the environment [1]. This means that we have to understand the risks associated with this technology and devise strategies to manage these risks, which include risks to the environment and human health and safety [2].

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1876-6102 © 2013 The Authors. Published by Elsevier Ltd.
Selection and/or peer-review under responsibility of GHGT
doi:10.1016/j.egypro.2013.06.385

In the CCS industry, the public, customers, governments and in-plant personnel require that companies to demonstrate a commitment to control possibilities of incidents and hazards by conducting environmental and health related risks assessments. There are several methods that can be used in analysing the risks involved, such as the Fault Tree Analysis technique (FTA), Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA) and Analytical Hierarchy Process (AHP) among others. Some of these techniques have been used in other industries such as nuclear, chemical and oil and gas industries but have not been incorporated in analysing the risks associated with CCS even though the risks are similar. FTA and AHP are example of these methodologies which have successfully been used in risks assessment in nuclear and chemical industries although it has not been incorporated in CCS.

Storage of carbon dioxide in the deep underground geological reservoirs uses many technologies that have already been developed for use in the nuclear, oil and gas industries. Past experience from oil and gas production, natural gas storage and acid disposal forms a basis from which the risks of geological storage can be evaluated [3]. Benson further explains that industrial use of carbon dioxide in various applications offers guidelines for safe handling of carbon dioxide [3]. Assessment of the risks of CCS is informed by wide knowledge developed over the last century on effects of carbon dioxide on humans, and the occupational safety in handling of CO_2 in industrial settings. In addition, studies on carbon dioxide release in volcanic settings have also enhanced risk assessment in CCS projects [4].

1.1. Risks and insurance

As things stand, there is currently no available commercial insurance for long-term liability of CCS projects [4]. This makes investors shy away from such initiatives, even if the risk of the venture is assessed to be relatively small. Therefore, in order to stimulate investment into such technology, other incentives must be present. One must either address the issue of long-term liability directly, or to find other means of promoting private sector investment.

A specific problem with the European CCS Directive is that the Directive places too much of the financial risk on the private sector, particularly storage site operators and thereby, indirectly onto capture plants as well [4]. Thereby some means of effectively capping or at least limiting long-term liability is needed in order to insure the financial incentive for investment in CCS. Elements such as specific site characteristics and the relative strength of the financial position of firms that are investing in storage sites need to be considered in assigning long-term liability.

A policy review was carried out to assess the risks involved in the CCS industry which identified uncertainties with regards to the risks associated with CCS that make policy making and insuring CCS projects very difficult. The purpose of this paper is to present a coherent understanding of the chain of events that could lead to major failures in a CCS project. This research project has looked into the potential risks involved in carbon dioxide storage and the way in which the probability of them occurring can be potentially calculated. Furthermore, the next step in the development of this project entails the evaluation of the criticality, importance and the probability/likelihood of these risks using different risk assessment methods such as the FTA and AHP methods. An overview of these methods and they ways in which they are going to be used in this research is going to be given in this paper.

The overall aim of this paper is to demonstrate that is possible to quantify the main risks associated with CCS projects using the two methods mentioned before. The results of this risk analysis will be used in order to inform firstly, the insurance industry so that it gives them the ability to calculate/assess the probability of an undesired event, identify safety critical components/functions/phases and measure the effect of the different types of failures that could occur. This will enable them to adjust their current terms and premiums for insuring CCS projects against the risks. Secondly, this paper is aimed at regulators and policy makers in order to help them so that they better tailor legislation to address the risks associated with CCS.

1.2. Specific liability issues

Wilson and Klass note that creating a liability regime for CCS must strike a balance between risks and benefits of technology and this could influence the deployment of CCS [5]. They argue that the certainty, clarity and extent of legal liability could affect technology adoption, or specifically new technology deployment. Companies that may be considering adoption of a new technology may be deterred by uncertain or potentially unlimited liabilities associated with technological problems new to industrial scale [6].

Legal liability is critical for the government and regulatory authorities to promote adoption of the CCS technology as it helps ensure a party with the highest information on the risks and solutions to those risks take the appropriate measures to avoid adverse consequences [6]. In addition, transparent and clear liability system enhances the ability of the public to understand the risks and have confidence that these risks to the human health and the surrounding environment are being actively managed and in case an accident happens, it will be effectively remediated and they will be adequately compensated [6]. Under the CCS directive and ETS, the liabilities associated with carbon exposure deal with the impacts of carbon to climate change in case it leaks to the surface. This therefore calls for the companies to continuously monitor and evaluate the storage site to ensure that they take appropriate actions to prevent leakage of carbon throughout the system [7].

These liabilities deal with the measures that should be adopted by the companies to protect human health and the protection of the environment. Currently, regulations for underground injection only address the operational phase and fail to specify future monitoring and risk management issues [8]. They explain that when the storage site gets to its storage capacity, it is critical to implement to close up the site and monitor the site to ensure that the material injected remains there.

According to Figueredo et al., liability for CCS can be looked from the operational liability and post-injection liability [9]. At the operational stage, liability includes the environmental, health and safety risks associated involved in the capture of carbon dioxide, transportation, and injection. Post-injection liability in CCS refers to the liability that comes up in the storage of carbon dioxide after its injection into the geological reservoir [9]. Carbon capture liability during the storage stage can either be in-situ liability or climate related liability.

In-situ liability results from the potential risks of harm to the environment, human health and property whereas climate related liability on the other hand deals with liability arising from the leakage of carbon dioxide from geological reservoirs and the resulting impacts to the climate [9]. Climate liability is a function of the international and national policies formulated to address greenhouse gas emissions. Post-injection liabilities present unique challenges given that the projected carbon dioxide volumes to be stored in geologic reservoirs are too high; 103-590 GtC between 2000 and the year 2100 [9]. Moreover, the risks of carbon dioxide leakage may take long before manifesting themselves and there are uncertainties in the geophysical system. Given the above challenges, a private liability may not be effective in addressing the risks of CCS [11].

As time passes, the risks of carbon dioxide stored in geological reservoirs could be reduced and as a result increase safety owing to geochemical and geophysical trapping. When liability is fully placed on the private sector, the potential unbounded liability can make deployment of CCS unlikely. On the other hand, when the public sector is made to bear the liability for any future leakage, this can potentially affect the safety measures taken by companies in the near term [12].

Leakage of carbon dioxide − which is the main risk associated with CCS − can either occur into the surface or subsurface. However, the most probable cause for loss of containment is neglected wells. Well-designed reservoirs have the ability to contain carbon dioxide long after they have been abandoned. Poorly completed reservoirs are more likely to lead to CO_2 escaping into the atmosphere. Another way that CO_2 can be released is leakage via pores of low-permeable caprocks when the injection is done at a high pressure.

Figueredo et al. note that there are five categories of risk resulting from carbon dioxide storage liability. These include toxicological effects, environmental effects, subsurface trespass, induced seismic actions and effects to the climate [9]. Toxicological effects are directly related to the concentrations and period of exposure. Compensation to victims in an event of risk may be difficult given that CO_2 can remain in the ground for too long before it escapes and by that time the companies responsible may have been out of business. Consequently, seeking for compensation for such risks may be difficult given that the afflicted would have to identify defendants. Moreover, even when the defendants are identified, afflicted parties may experience difficulties in demonstrating the particular causation or that the storage site of the defendant is responsible for causing the injuries suffered.

2. Risk assessment

In assessing the risks, the first step is to dissect the whole system into the basic elements and then it is aggregated. The idea behind this approach is that a system's behaviour can be understood more clearly from the basic elements that make up the whole system because of lack of adequate data on the behaviour of a system [13]. Risks from systems to humans and the environment result from external forces acting on the system and resisting the objectives of the system. In a CCS project, external forces such as a leak can act on the system preventing it from containing the CO_2 in the geological reservoir. This calls for the development of methodologies that can be used to respond to the questions of what can go wrong, how likely is it that an event can occur and in case it happens what are the consequences [14]

In risk assessment, two quantitative methods are used to estimate the risks of a constructed structure to man and the environment. These are probabilistic and deterministic approaches as described by. A deterministic system is one which is predictable since they follow a well-known rule. In a deterministic system, the components of the system can be described at any time in the future and the past. A probabilistic system is a system that has some degree of uncertainty in telling how they will behave in future [15].

Probabilistic methods are used to reconstruct the reality in cases where incomplete information on the initial conditions of a flow of events is available. A CCS system is a probabilistic system since the behaviour of the system cannot be clearly described and this can only be predicted through the use of past knowledge or experience [14].

Risk assessment calls for reconstruction of the reality by responding to the three questions described above either by quantitative methods or by qualitative ones. To respond to the question of what can go wrong requires a qualitative analysis, which enhances the ability to identify and rank all the possible failure events, which can result in system failure [16]. In the second and third questions, qualitative and quantitative analyses are employed. Consequently, deterministic and probabilistic methods can be used in risk assessment.

The nature of the risks involved in the storage of carbon dioxide is very similar to the ones involved in the nuclear, oil and gas, chemical and waste management industries. Therefore, one would conclude that the risk analysis methods used in these industries would not only be helpful but more importantly they would be reliable methods to use in order to evaluate and quantify the risks involved in CCS.

Table 1. an example of some the risks involved in CCS and some and their comparable industries

Risk	Type of risk	Comparable industries
Site selection	Technical	Nuclear new build/high level waste storage and wind farm siting
Injection operation	Technical	EOR, EGR and CBM
Closing well	Technical	Oil industry
Stewardship	Technical	Oil industry
Consistency of CO_2 cap	Technical	EOR
Economical profit	Financial/Monetary	All industries
Certainty of investment	Financial/Monetary	All industries
Local/regional hazards	Environmental	Oil and Gas, Nuclear, Landfill, EOR, EGR and CBM etc.
Quantitative estimation of CO_2 emission reduction	Environmental	EOR
System safety	Safety, public/institutional barriers	All industries
Geotechnical safety	Safety, public/institutional barriers	EOR, EGR and CBM
Long-term reliability	Safety, public/institutional barriers	Nuclear and Landfill Oil and Gas, Nuclear,
Legislation/regulations	Safety, public/institutional barriers	All industries
Communication with society	Safety, public/institutional barriers	All industries

The FTA and AHP methods are going to be used in this research in order to quantify the risks associated with the storage phase of CCS. FTA is a well-established technique that has many advantages in comparison with other risk assessment methods such as the fact that it is a visual model, which shows the cause/effect relationships. The technique furthermore models complex systems relationships in an understandable manner, which in turn helps understand the risks associated with the storage of CO_2 in a better manner. This enables insurers and policy makers to observe the interaction of failures and other events within the system by analysing the fault tree.

On the other hand, AHP is a mathematical method that derives ratio scales from paired comparisons. When you combine individual performance indicators to one key performance indicator you can give each one a different weight in order to be able to calculate the importance or criticality of a small risk in with respect to the final failure. In order to derive the weights, AHP derives ratio scales from paired comparisons. It also allows for some small inconsistency in judgment. As an input you can use actual measurements or subjective opinions such as satisfaction feeling or appearance. The output of this method is ratio scales and a consistency index. The method is based on the solution of an Eigen value problem; the ratio scales result from Eigen vectors and the consistency index from the Eigen value.

The process is done in several steps, which are as follows:

1. First the objective has to be defined.
2. Then the elements have to be structured into criteria, sub-criteria and alternatives.
3. In each group a pair wise comparison of elements has to be made and then the weighting and consistency ratio has to be calculated.
4. Then the alternatives can be evaluated using the weightings.
5. The ranking is obtained.

The FTA and AHP techniques have not been widely used to quantify the risks involved in CCS projects whereas they have been used widely in other industries such as the nuclear, oil and gas and chemical industries. For example, in the nuclear industry, FTA has been used in order to calculate the probability of a nuclear power plant safety device being unavailable when needed and to calculate the probability of a nuclear power plant accident [17]. Moreover, in the chemical industry FTA has been used to evaluate a chemical process and determining where to monitor the process and establish safety controls [17]. Furthermore, AHP is used in many fields such as strategic marketing, resource allocation, technology selection, risk analysis/assessment, evaluating engineering projects, production and operations management issues. The advantages of this theory are many and the concept is very easy. Furthermore, this method can be easily applied in order to solve complex problems whether they are multi-objective, multi-variable or multi-time problems. Moreover, AHP can lead one to a detailed understanding of the goal of the problem and stabilize judgments.

3. Risk assessment framework

In order to demonstrate the use of this method, a branch of the tree diagram that has been used in this research was randomly selected. According to the method, the four different criteria now have to be compared pair-wise with respect to the objective. Four semi-expert participants were asked to complete a survey and rank the risk elements within the branch from 1 to 9 according to their importance in comparison to each other (1 being equally preferred and 9 being extremely preferred). Noteworthy that, according to the inverse condition of the AHP method, if the preference of element A to element B is equal to m, then the preference of element B to element A is $1/m$. Table 2 shows the selected branch of the tree diagram of figure 1 in a matrix form. It should be noted that, for example, a_{12} refers to the comparison of the element in row 1 and column 2 of the matrix.

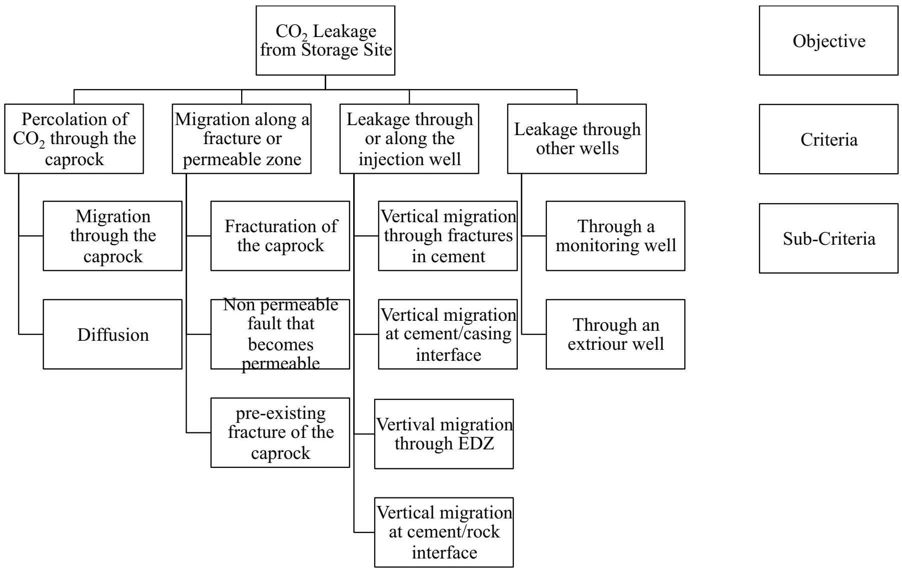

Fig. 1. a branch of the tree diagram used in this research [2]

Table 2. shows the matrix that the participants will be asked to fill in by comparing the element in a pair-wise manner

	Percolation of CO_2 through the caprock	Migration along fracture or permeable zone	Leakage through or along the injection well	Leakage through other wells
Percolation of CO_2 through the caprock	**a11**	a12	a13	a14
Migration along fracture or permeable zone	a21	**a22**	a23	a24
Leakage through or along the injection well	a13	a32	**a33**	a34
Leakage through other wells	a41	a42	a43	**a44**

The four risk elements shown in this table were subsequently ranked according to their importance and criticality. The "migration of CO_2 along a fracture or permeable zone" was ranked first with 32.07%, "percolation of CO_2 through the caprock" was ranked second with 29.94%, the "leakage through or along the injection well" was ranked third with 29.73% and "leakage through other wells" was ranked fourth as the least important element that could contribute to a leakage of CO_2 from the storage site with 8.24%.

4. Future work and difficulties

Sensitivity analysis is going to be carried out in future research in order to evaluate the sensitivity of the overall probability of the main risk (leakage of CO_2) to the sub-criteria. This will enable us to merely quantify the risks that are actually significant enough to make a difference to policy makers and insurance companies. Using the FTA method, we will be able to inspect the effects of altering different elements within the tree diagram to the overall failure probability by combining a range of failure distributions obtained from the sub-criteria in order to obtain a final failure probability distribution. For example, the probability of a pre-existing fracture within the caprock is very low because in most cases these fractures will have been reported by geologists in many resources that will have to be studied by storage site operators before injection occurs. Therefore, we can conclude that, the overall risk of storage is not sensitive to this particular risk element. The difficulty of using this method is that in some cases, there is not enough knowledge available with regards to some risks. Therefore, certain assumptions have to be made according to the risks involved in other similar industries. This will be address in future research.

The AHP method is also going to be used for a larger number of expert participants within the field (around 50 experts).

5. Conclusion

At the moment there is no interest from insurance companies to provide commercial insurance simply because of the fact that they are uncertain about the long-term liability of CCS projects. This makes investors shy away from such initiatives, even if the risk of the venture is assessed to be relatively small.

A policy review was carried out to assess the risks involved in the CCS industry which identified uncertainties with regards to the risks associated with CCS that make policy making and insuring CCS very difficult. This paper has presented an understanding of the chain of events that could lead to major failures in a CCS project. This research project has looked into the potential risks involved in CO_2 storage and the way in which the probability of them occurring can be potentially calculated. Furthermore, has demonstrated the ways in which these risks can potentially be prioritised in terms of their criticality, importance and the probability/likelihood of them using the FTA and AHP methods. By doing this, we can instruct the insurers as to which risks they have to take into account more so that they can minimise the financial risks by tying them down. An overview of these methods and the way in which they can be used has been given in this paper.

The overall aim of this research is to demonstrate that is possible to quantify the main risks associated with CCS projects using quantitative risk assessment methods. The results of this risk analysis can be used to inform the insurance industry so that it gives them the ability to calculate the probability of different types of failures that could occur. This enables them to adjust their current terms and premiums for insuring CCS projects against the risks. Secondly, this paper is aimed at regulators and policy makers in order to help them better tailor the legislation to address the risks associated with CCS.

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