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Economic incentives for carbon dioxide storage under uncertainty: A real options analysis

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ABSTRACT

Carbon dioxide capture and storage (CCS) is considered to be an important option for reducing carbon dioxide (CO_2) emissions. However, its economic viability remains a question, especially if the risk of leakage in the storage site is taken into account. We use a real options approach for assessing the impact of uncertainty on the timing and the profitability of CO_2 storage projects. We model an investment decision for a storage site under uncertainty about CO_2 leaking from the storage site, about the development of carbon prices, and about the cost of investment. The numerical model results show that investment under these uncertainties requires a much larger price for carbon credits for storage than an investment plan ignoring uncertainty would suggest. We also show under reasonable parameter assumptions that the risk for investing in CO_2 storage is dominated by the uncertain development of carbon prices, whereas the risk of carbon leakage has little influence on the investment decision.

1. Introduction

Carbon dioxide capture and storage (CCS) has gained wide recognition in recent years as a potentially major option for climate change mitigation. Although the CCS technology is in the process of being tested in large scale projects, prospects of its feasibility and costs critically condition the commercial viability of CCS projects and thus strongly influence the long-term paths of global climate policy. For example, recent assessments by both IEA (2014) and IPCC (2014) regard CCS as a critical option to achieve the control of climate change in the long run. In this regard, examination of CCS's technical viability and potential costs offer important implications for the formulation of climate policy options.

CCS has long been subject to research regarding its technological feasibility. Recently the risks in terms of ecologic and climate effects of storing carbon dioxide (CO_2) in sub-seabed formations have been investigated and a best practice guidance for environmental risk assessment for offshore CO_2 geological storage has been developed (Jones et al., 2015; Taylor et al., 2015; ECO2, 2016a,b). Economic assessments of CCS begin to play an essential role for the debate about the role of CCS in future climate policy. Economic dimensions of CCS have been investigated so far mainly by using integrated assessment models (IAMs), and there is already a fairly large accumulation of literature (Ha-Duong and Keith, 2003; Herzog et al., 2003; Riahi et al., 2004; Smekens and van der Zwaan, 2006; Gilotte and Bosetti, 2007; MIT, 2007; Keller et al., 2008; Van der Zwaan and Gerlagh, 2008; Gerlagh and van der Zwaan, 2011). A central issue for economic studies of CCS is risk and uncertainty associated especially with the storage of CO_2. Most of those studies incorporate uncertainty of CCS in the form of long-run CO_2 leakage from the storage reservoirs. By modeling cost-effectiveness of CCS being inclusive of long-run CO_2 release from leakage, they examine the long-term emission reduction pathways at global, regional or national levels as a function of leakage risks and abatement costs.

Those macro-level studies, however, do not address some important aspects of uncertainty and leakage associated with CCS that would become apparent when its operation is seen as a problem of private decision making. It is most likely that large scale CCS activities will need to be conducted by the private sector, both because of its technological knowledge and the sheer scale of the operations.

For the operators of storage sites, profitability of the facility is a fundamental factor. It depends on a number of factors, among which leakage could be one particular risk. Leakage risks can take on multiple forms with diverse economic implications. It could be a loss in carbon credits resulting from a re-entry of stored CO_2 into the atmosphere (European Commission, 2012). It could also be the ecologic damage to the marine environment if the CO_2 is released in

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the vicinity of a sub-seabed storage site. In particular, even the possibility of leakage requires notification of the competent regulatory authority resulting in considerable cost and time commitments even if the eventual release of CO2 into the atmosphere or marine environment are negligible (European Commission, 2012).

Meanwhile, leakage is not the only type of uncertainty that operators of a storage facility face. They decide to start storage by anticipating policy incentives in the future, and uncertainty about those incentives is an integral element for their decision making. Indeed, a prevailing perception in the business community is that uncertainty in net economic benefit of CCS overall discourages or at least delays investment in CCS.

We examine these economic incentive problems of CO_2 storage under uncertainty based on a real options framework. Several studies have conducted real options analysis of CCS highlighting economic returns from CO_2 capture operation without the factor of CO_2 leakage (Abadie and Chamorro, 2008 Fleten and Näsäkkälä, 2010; Abadie et al., 2014; Walsh et al., 2014). Here we focus on the last step of CCS, the storage of the CO_2 which is currently the most controversial step in terms of public acceptance[1] in the whole process of CCS. We also focus on sub-seabed storage since onshore storage is currently unlikely to be implemented in Europe for legal as well as political reasons.[2] In comparison to IAM studies, the advantages of our approach are a consistent representation of potential leakage for individual storage sites with the current scientific understanding and an explicit consideration of uncertain returns to investment in CO_2 storage due to an uncertain future of carbon price levels. Also, our choice of using an analytical model allows for a transparent evaluation of the effects of various parameters.

With a rising trend of the carbon prices as implied by the Paris Agreement in COP21 according to the analysis of the IPCC (2014) our results show that an investor for a storage facility generally has an incentive to wait until the carbon price reaches a level well beyond a break-even point of costs and benefits. This is essentially due to the fact that the maximum capacity of a storage facility for which the investment is to be spent limits the income that can be obtained during the time of operation (ZEP, 2014). This creates the incentives – even without uncertainty – to delay the operation since the price increase in the carbon price raises the returns on storage.

In addition to this, uncertainty of the carbon price significantly favors a further delay in the beginning of operation. This feature supports arguments that favor a carbon tax over a cap-and-trade scheme (e.g., Nordhaus, 2008) because a carbon tax scheme is less likely to be subjected to price volatility than a cap-and-trade scheme. Our results show that with realistic levels of parameters for a typical storage operation – in contrast to the uncertainty about carbon prices – the uncertainty about leakage of CO_2 has little influence on the firm's decision to start sub-seabed storage although the possibility of leakage evidently reduces the expected return to the sub-seabed storage project. In addition, uncertainty about future investment costs – in other words, the slope of the learning curve – delays investment decisions even further.

The rest of this paper is organized as follows. Section 2 describes leakage issues that arise in storage operations and thus need to be dealt with by assessment of CCS. Section 3 discusses a real options model. Section 4 presents a simple numerical example by using representative values of parameters and discusses implications of this model for general CCS policy. Section 5 summarizes and concludes the findings.

[1] The relevance of this topic is evident from numerous publications in the International Journal of Greenhouse Gas Control (http://www.journals.elsevier.com/international-journal-of-greenhouse-gas-control/virtual-special-issues/human-choice-and-ccs-deployment/).

[2] A world-wide summary of CCS projects and their current status can be found on: https://sequestration.mit.edu/index.html.

2. General issues in the assessment of leakage from sub-seabed storage

Leakage from storage sites has been an issue for research since quite some time. Various aspects of leakage are discussed in IPCC (2005), supplemented by more recent studies on actual sub-seabed storage operations or natural CO_2 seepage analogues to CO_2 leakage from human-made CO_2 storage reservoirs (e.g., Arts et al., 2008; Chadwick et al., 2009; McGinnis et al., 2011).

The first operations of sub-seabed storage are taking place in a relatively small number of locations.[2] They have shown that geologic storage on land as well as in sub-seabed storage sites is technically feasible. However, the impacts of potential leakage have not been well understood, partly for the very reasons that none of the first storage operations have failed, and therefore that there are no direct observational data about how leakage from a storage reservoir happens. Recent research projects assessing the fate of CO_2 in storage sites and potential leakage have yielded first results (e.g. Phelps et al., 2014). These activities have already identified different types of leakage events that may occur in the course of a CCS activity. Without going into many of the details there seem to be multiple types of leakage that one should be concerned with and which may have different economic impacts.Leakage may occur in the early phase of a sub-seabed storage project, in the period where the injected volume of CO_2 approaches the storage site's capacity, and leakage may occur after the injection operations on a particular site have been completed while a continuing liability for long-term leakage prevails.

The first type of leakage is one which the researchers from the natural and engineering sciences have been most concerned about. Leakage in the early phase is believed to be the more likely. This is due to leakage from fractures in the storage formation that were not identified in the exploratory phase of the project or because of unexpected pressure and phase behavior during injection. The probability of a leakage event can be reduced significantly with proper site assessment and risk management procedures, such as monitoring for containment and implementation of corrective measures when warranted.

Second, it is possible that – near the end, i.e. during the operational phase, or even after the sequestration on a storage site has ended – CO_2 may leak into higher geological layers or even to the surface. Although these two possibilities are not very likely to occur according to current knowledge (ECO2, 2016b), they raise questions with respect to the long-term cost of leakage and their impact on current incentives for performing storage projects. These questions relate to important issues yet to be examined, such as the role of long-term liability of the operator versus societal liability, intergenerational justice with respect to future leakage, or the role of a social discount rate for influencing the societal value of current CCS projects.

The occurrence and timing of a leakage event cannot be known in advance, and thus its threat should be described in a probabilistic fashion. In order to keep the model simple we start with the assumption that there is a positive but most likely very small probability of leakage during the CO_2 storage operation that is constant and independent of the amount CO_2 injected or stored and of the pre-project investment into the exploration of the site. There are several modifications possible. The leakage probability could be influenced by the degree to which the storage site is investigated before the start of the project. Hence, the leakage probability is a function of some initial investment. Also, the leakage probability could be influenced by the amount of injection.