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Abandonment of natural gas production and investment in carbon storage☆

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ABSTRACT

Long-term mitigation scenarios rely heavily on Carbon Capture and Storage (CCS) for achieving ambitious climate change targets. The amount of CO_2 storage in these scenarios depends on the CO_2 price and exogenously determined availability and costs of storage capacity. We analyze investment in CCS in more detail by taking the opportunity costs of CO_2 storage into account, assuming that CO_2 injection and resource extraction are mutually exclusive. Using real option valuation, we study the impact of i) correlation between gas and CO_2 prices, ii) volatility of CO_2 prices, and iii) regulatory deadlines on the value of the option to invest in CCS. We find that the value of the option to exchange gas production for CO_2 injection is decreasing in the correlation of gas and CO_2 prices, but increasing in the volatility of CO_2 prices, and in shorter regulatory deadlines for removal of gas production facilities. This implies that next to consistent and high pricing of CO_2, extending the deadline for removal of gas production facilities could increase the incentive to invest in CO_2 storage in mature gas fields. We argue that considering these dynamics in mitigation scenarios could lead to more realistic projections of CCS application.

1. Introduction

Practically all scenarios in the IPCC scenario database with a likely chance (> 66% probability) to limit global average temperature change to less than 2 °C compared to pre-industrial levels, show negative CO_2 emissions by the end of the century (Clarke et al., 2014; Fig. 6.7). The reliance on negative emissions becomes even stronger when mitigation action is delayed until 2020: then all scenarios with less than 50% probability to exceed 2 °C show net negative CO_2 emissions (Clarke et al., 2014; Fig. 6.31). This shows the importance of negative emissions for achieving the international long-term climate goal of the Paris Agreement (UNFCCC, 2015) of keeping global temperature change well below 2 °C compared to pre-industrial levels, and even more so when 1.5 °C is aimed for.

Negative CO_2 emissions can be achieved by applying carbon dioxide removal (CDR) technologies. Apart from reforestation, the most important CDR technology is bio-energy in combination with carbon capture and storage (BECCS), which implies combining bio-energy use with capturing CO_2, transporting it to, and store it in underground geological formations. Most scenario analyses show CCS to be a relatively cheap mitigation option for electricity producers, based on exogenously determined availability and costs of storage capacity (usually taking into account differences in costs between storage sites). Consequently, the IPCC concludes that CDR technologies such as BECCS are fundamental to many scenarios that achieve low CO_2-equivalent concentrations (Clarke et al., 2014). However, the assumption of exogenously determined supply and costs of storage may lead under certain circumstances to a biased estimation of the real value of the CCS option as a mitigation technology.

For example, availability and cost of storage of CO_2 in mature gas fields depend crucially on the value of the remaining reserves in the gas field. Due to technical restrictions on the simultaneous production of gas and injection of CO_2, storage capacity may not become available until resource production has ceased - and once CO_2 injection has started, gas production will be permanently ceased (Hendriks et al., 2004).[1] As the decision to abandon a natural gas field depends on the viability of gas production, the value of the remaining gas reserves should be taken into consideration as opportunity cost of CO_2 storage

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[1] There have been attempts to increase gas production by injecting CO_2 into a field. However, further exploration is needed as the environmental risks are still not clear (Khosrokhavar, 2015).

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when valuing the option of CCS as a climate change mitigation technology.[2]

Even if resource production has ceased due to a lack of viability, the value of the CCS option may depend on the decision to abandon (removal of infrastructure and plugging of injection wells) a resource field. Regulations require that infrastructure and plug production wells have to be abandoned and removed within a certain time period after a field is not used. Since it is very costly to reactivate an abandoned gas field, such regulatory requirements restrict the lifetime of the CCS option and therefore affect its value.

Finally, the option value depends on the costs of abandonment: installations that have been used for gas production and distribution can be reused, after some modification, for CO_2 injection. Therefore, firms do not have to pay abandonment costs until the end of the injection of CO_2 so that abandonment cost can be discounted over the time span of CO_2 injection. Contrary to the devaluating restrictions on the lifetime of the option, higher abandonment costs increase the option value of CCS.

In this study, we analyze to what extent the value of the CCS climate change mitigation option depends on i) the maximum allowed abandonment time of resource production facilities, ii) uncertainty in and correlation between resource and CO_2 prices, and iii) windfall profits due to discounting of abandonment cost. As such, this study goes beyond existing studies in which the value of the option to invest in CCS only depends on uncertainty in CO_2 prices and the costs of CCS.

In order to evaluate the impact of these issues on the value of the CCS option, we develop a case where an electricity producer is facing stochastic emission penalties, and has access to a potential CO_2 storage. We use real option valuation to value the option of investment in CCS for the electricity producer. We focus on storage in a mature gas field because i) the total storage capacity in gas fields is a factor of 2–6 higher than in oil fields (Freund, 2001; Hendriks et al., 2004); ii) the geological properties of such resource fields are well known and the fields are easily accessible via existing infrastructure, which could be reused after modification; iii) gas fields used to contain pressurized gas for several million years without leakage (Loizzo et al., 2009). We expect our results to hold qualitatively for storage in depleted oil fields when CO_2 injection and oil extraction are exclusive, i.e. when enhanced oil recovery is not possible.[3] Finally, onshore saline aquifers seem to be the least realistic storage alternative as many experts predict that these will not become available as CO_2 storage option (Gough, 2008).

Real option analyses have been conducted previously to value the option of investing in CCS. For example, Reinelt and Keith (2007) valued the CCS option under the assumption that CO_2 prices follow a stochastic process with a jump component, reflecting politically induced uncertainty. They find that political uncertainty raises the social cost of abatement, depending on the technological progress of development of low carbon emitting electricity generation technologies. Fuss et al. (2008) developed a real option model which incorporates various sources of uncertainty and takes the possibility of switching CCS facilities on and off into account. The authors find that policy induced uncertainty makes potential investors in CCS postpone investment, whereas market uncertainty triggers early investment. In all of these studies, the option value of CCS depends mainly on the costs of CCS and (uncertainty in) CO_2 and resource prices. Next to the real option literature, there is a large body of literature employing bottom-up and top-down modeling to evaluate different economic aspects of CCS. Johnson and Keith (2004), for example, analyze the impact of adding CCS to the energy production portfolio consisting of multiple production technologies. In addition to model-based analyses of CCS, survey-based studies have been conducted by Sara et al. (2015) among others. For a more complete overview over the CCS literature see Jepma and Hauck (2010).

The outline of the paper is as follows. Section 2 introduces the general method and assumptions and Section 3 discusses the real option models employed in this study. Section 4 provides the data used to calibrate the models. Results of the calibration of the models can be found in Section 5. The final Section 6 provides a discussion and concludes.

2. Method and assumptions

This study takes the perspective of a single energy producer, who is operating a new carbon capture ready coal-fired power plant as defined by Bohm et al. (2007). The power plant can be retrospectively equipped with a carbon capture facility. The producer is a price taker on the wholesale electricity market. As we are interested in uncertainty in CO_2 and gas prices, we assume that electricity prices are deterministic. The producer operates in a market in which a cap and trade system regulates CO_2 emissions. Hence, the producer has to buy emission allowances on the allowances market where she is a price taker, i.e. prices are independent from her demand for allowances. If emissions are not covered by a sufficient amount of allowances, emitters do have to pay a severe penalty. The evolution of prices on the allowance market is assumed to be given by geometric Brownian Motion (gBM),

$$\frac{dP^I}{P^I} = \alpha_I dt + \sigma_I dz_I, \tag{1}$$

where dz denotes the increment of the Wiener process and $I \in \{A, G\}$. We use $I = A$ when referring to the CO_2 price process, and $I = G$ when referring to the gas price process. Annual growth rate and annual variance of the price processes are given by α_I and σ_I respectively. Modeling emission allowance prices as a geometric Brownian motion process is a frequently used approach in the real option literature (see, for instance, Dixit and Pindyck, 1994; Fuss et al., 2008). We have applied this approach as we are interested in a future in which climate policy gets more stringent over time, and many 2 °C scenarios in the AR5 IPCC scenario database show a more or less linear increase in the CO_2 price over time. The annual growth rate reflects that emission allowances will become more expensive to fulfill long-term climate change mitigation targets. If the producer could sequestrate CO_2 from the coal-fired plant and inject it into a gas field, she could save on buying emission allowances.

The energy producer has the option to store CO_2 emissions from the coal-fired power plant in a proximate mature gas field, which can either be owned by the producer itself or by another actor. The application of real options is appropriate for both cases, because the energy producer has the exclusive right to invest in capture and the gas field operator has exclusive right to sequester. The energy producer will have a de facto exclusive right to sequestration when there are no other producers in the vicinity of the sequestration location and when costs associated with transporting CO_2 over large distances are high. Both players share the common objective of maximizing the payoff of investing in CCS and CO_2 storage (Coase, 1960). The exact distribution of the payoff will be the outcome of negotiations which are not relevant for our discussion.[4]

The capacity of the gas field is sufficiently large to absorb CO_2 emissions from the CCS equipped power plant, and therefore the producer can implement her optimal CO_2 injection policy. In reality, it is well possible that multiple smaller fields must be connected and sequentially filled. This introduces additional frictions in the chain and

[2] With standard production methods, less than 70% of the reserves are recovered, implying that a large share of resources remains in the field.

[3] However, in Europe, there are hardly any oil fields that are large enough to store the CO_2 emissions of a power plant of industrial scale over its entire lifespan. Connecting multiple fields for sequential injection would be very costly.

[4] Under certain circumstances, bargaining may break down and result in inefficient allocation of wealth. This situation is beyond the scope of this article and left for future research. The interested reader is referred to the literature on bargaining games (e.g. Osborne and Rubinstein, 1990).