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Evaluation of two alternative carbon capture and storage technologies: A stochastic model

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ABSTRACT

In this paper we evaluate two alternative CCS technologies at a coal-fired power plant from an investor's point of view. The first technology uses CO_2 for enhanced oil recovery (EOR) paired with storage in deep saline formations (DSF) and the second merely stores CO_2 in DSF. The paper updates and improves on an earlier publication by Tzimas et al. (2005). For projects of this type there are many sources of risk, three of which stand out: the price of electricity, the price of oil and the price of carbon allowances. In this paper we develop a general stochastic model that can be adapted to other projects such as enhanced gas recovery (EGR) or industrial plants that use CO_2 for either EOR or EGR with CCS. The model is calibrated with UK data and applied to help understand the conditions that generate the incentives needed for early investments in these technologies. Additionally, we analyse the risks of these investments. Investments with EOR and secondary DSF storage can only be profitable (NPV > 0) when there is a high long-term equilibrium price for oil of more than $56.38/barrel. When the investment decision can be made at any time, i.e. there is an option value, then the trigger value for optimal investment is significantly higher.

1. Introduction

Carbon dioxide capture and storage (CCS) is frequently seen as an effective means of stabilising the global climate (IPCC, 2005; Luderer et al., 2012; Szulczewski et al., 2012) and as a key technology in the future portfolio of carbon abatement technologies (IEA, 2011). "Achieving substantial reductions in temperatures relative to the coal-based system [...] will depend on rapid and massive deployment of some mix of conservation, wind, solar, and nuclear, and possibly carbon capture and storage" (Myhrvold and Caldeira, 2012: 7–8). Referring specifically to the deployment of CCS in the European Union in the coming decades, de Coninck et al. (2009) point out that "[t]here are no compelling scientific, technical, legal, or economic reasons" against it. CCS could lead to CO_2 reductions of between 5.1 and 10.4 Gt per year by 2050, that is around 14%–19% of the total CO_2 abated globally (IEA, 2007). If the CCS option is not intensively exploited, the cost of a 50% reduction in emissions by 2050 as suggested by the IPCC (2007) would be 71% or USD 1.28 trillion higher (IEA, 2007). However, CCS technologies still need to attain a higher degree of maturity before they can play a significant role in the portfolio of mitigation options, and are broadly expected not to become commercially available in the power sector before 2020 (Haszeldine, 2009). Abadie and Chamorro (2008) analyse the negative effect of uncertainty on CCS investments that could cause a delay in this type of investment. Middleton et al. (2012a) present a model for optimise the capture, transport and storage of CO_2 while another paper by van den Broek et al. (2010) develops a toolbox for the design of CO_2 infrastructures in the Netherlands. Rübbelke and Vögele (2013) and Vögele and Rübbelke (2013) employ load dispatch models in order to investigate the effect of CCS use on the surpluses of electricity suppliers. Other papers that also deal with different sources of uncertainty such as geologic uncertainty (i.e. how rock properties might affect storage performance) include Middleton et al. (2012b, 2012c).

One CCS strategy that offers attractive features is the use of captured carbon in CO_2 Enhanced Oil Recovery (CO_2-EOR). EOR is a method of extracting oil from wells in which conventional techniques are no longer productive. It enables a significant increase to be achieved in the total amount of oil extracted and therefore in the profitability of the wells involved. The geological characteristics of depleted oil and gas fields are well known, which makes the use of these wells for carbon storage quite an attractive prospect. EOR can help to store carbon captured – inter alia – at coal-fired power

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plants, the kind of plant on which we focus in our analysis. This is especially relevant because by 2050 "coal-based generation is forecast to be 252% higher than in 2005, accounting for 52% of all power generation" (IEA, 2008: 31). But carbon emissions captured, for example, from gas-fired power plants (Tzimas et al., 2005),[3] from biomass use[4] and from industrial applications can also fuel EOR processes. In a context of high oil prices and decreasing oil extraction in mature basins, investment in CCS in combination with EOR might become a profitable strategy.

From an investor's point of view the profitability of a CCS installation in combination with EOR is affected by several factors:

a) Costs of CCS in combination with EOR: a significant part of the total cost of CO_2-EOR is accounted for by the electricity needed to compress CO_2, so it is very sensitive to electricity price changes and volatility.[5] The greater the volatility the greater the risk for investors, and the higher the expected price of electricity the lower the expected profitability of investing in CCS.
b) Carbon emission allowances saved if the investing company operates within an emission trading scheme. Here again expected prices of allowances and volatility have an effect.
c) Benefits from the use of CO_2: Carbon dioxide is a productive input in the EOR process. The benefits are related to the price of (the recovered) oil and its volatility.
d) Benefits derived from support from public authorities such as subsidies, fiscal incentives, loans, etc.

This paper analyses decisions concerning CO_2-EOR investment in the UK, taking into account the three investment criteria a)–c) (price of electricity, cost of allowances and price of oil) which could jeopardise the CO_2-EOR project's profitability. Additionally, it uses sensitivity analysis to understand the effects of higher investment costs and different supporting policies such as subsidies and other fiscal incentives. The methodology presented here can easily be adapted to other CCS projects using different technologies (e.g. enhanced gas recovery), and to other locations. Specifically the model can be adapt/ed to both onshore and offshore investment.

While an earlier publication by Tzimas et al. (2005) uses constant oil prices of $25 per barrel and $35 per barrel, far below actual prices since the price spike in 2007, here we use stochastic processes to model the possible trends in the prices of oil, electricity and CO_2. This is far more realistic and represents a significant improvement with respect to earlier work. Additional enhancements included here and detailed later include analysing the effect of alternative scenarios such as changing the number of barrels of oil that can be extracted per tonne of CO_2, the long term price of oil at future markets and the cost of capturing one tonne of CO_2.

We develop a case study choosing the UK as the location for the CCS/EOR investment for several reasons. The UK has already developed a CCS Roadmap that sets out how commercial deployment of CCS in the UK can be achieved in the 2020s (DECC, 2012). Furthermore, there is abundant carbon storage capacity, assessed at 1.5 times the expected total CO_2 emissions from British large point sources in the next 40 years (Höller and Viebahn, 2011). Finally, social acceptance of CCS in general (Shackley et al., 2009) and of EOR/EGR in particular is relatively high in the UK. As Shackley et al. (2007) find in a survey investigating stakeholder opinions regarding the role of CCS in Europe, "82–3% of respondents in Norway, Denmark and the UK [...] thought that opportunities for EOR/EGR were important or very important for CCS development; 54% of respondents in the Netherlands [...] also responded in this way, whilst the value for France was 43% and 32% for Germany".

From the point of view of a power investor, building coal-fired power plants with CCS or retrofitting existing ones will result in high investment costs, which vary with the technology used. For instance, the cost of a plant with carbon capture may be between 50% and 100% higher (IEA, 2008: 60) than that of a conventional one. The installation of a CCS unit is generally more profitable for big, efficient plants while retrofitting an existing power plant is more costly. The use of CO_2 in EOR can offset part of the cost of CCS.

There are several barriers to the effective implementation of CCS technology, including financial, political, technical and public acceptability barriers (Johnsson et al., 2010). In fact, the number of projects is currently relatively low and some projects have been cancelled due to these barriers. As of mid-2012 there are eight CCS projects currently up and running, capturing 23.2 million tonnes per annum (Mtpa). Another seven projects are under construction with a total additional capacity of 12.0 Mtpa (Global CSS Institute, 2012). None of the existing projects is connected to power generation plants. Among those under construction, there are 2 for power generation and EOR. Therefore, the type of project that this paper is analysing cannot yet be found operating in the market. The methodology focuses on understanding the main financial obstacles to the implementation of the technology.

We address the conditions under which CCS with EOR might become a profitable business activity, accounting for the three sources of uncertainty mentioned above and considering the fixed and variable costs of capture, transport and storage. The sensitivity of business projects to changes in these factors is also studied. Some of these analyses include construction costs which, of course, may vary over time and from place to place. Implementing CCS technologies leads to increases in capital costs and operating expenses and decreases energy efficiency at plants.

A stochastic model of commodity prices is developed that is calibrated with prices (quotes) from futures markets in the UK, with the most appropriate dynamics being selected to represent their behaviour (seasonality and mean reversion or Geometric Brownian Motion). The selection of electricity futures market is based on the proximity of depleted oil and gas fields in the North Sea, while ICE is the most important market on which Brent is quoted.

Our findings illustrate the influence of stochastic prices (with their expected values, volatility and correlations) when deciding whether or not to construct a plant of this type. The impact of non-stochastic fixed and variable costs is also analysed. The results may contribute to the design of efficient policies to support the construction of plants, striking the right balance between profitability and risk.

In addition to investigating investments in CCS with EOR paired with storage in deep saline formations (DSF), we consider an alternative investment option: investment in CCS using DSF only as sinks for CO_2.

Note that the paper assumes that there is coordination between the companies involved in the phases of capture, transport and storage in such a way that they share the total benefits equitably.

The methodology presented in this paper is useful for economic valuation of environmental problems when the market risk is significant and under the hypothesis of complete markets.[6] It can be easily adapted to analyse other environmental problems with up to

[3] However, CO_2 from gas-fired plants is less profitable for CO_2-EOR purposes than that which comes from coal-fired power plants.

[4] We thus disregard the option of combining bioenergy with CCS, which would also constitute an option for the removal of carbon emissions from the atmosphere (see, e.g., Azar et al., 2006).

[5] We refer to the volatility of electricity prices once the deterministic component (i.e. seasonality) and the trend (including the mean reversion) are eliminated.

[6] No opportunities for arbitrage exist in a complete market.