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Flexible strategies to facilitate carbon capture deployment at pulverised coal power plants

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ABSTRACT

This paper assesses operational strategies for deploying flexible CO_2 capture at three generic black coal fired power plants with distinct dispatch profiles. Flexible operating modes involving constant partial CO_2 capture, part-time capture, and variable capture are examined in conjunction with seasonal effects of summer and winter. The three generic dispatch profiles are selected to represent typical black coal base load power plants in Australia and black coal power plants in Germany and perhaps future UK base load power plants in 2011. The results show that for a generic 700 MW subcritical power plant, operating under variable capture mode results in the highest amount of CO_2 captured and avoided and thus the lowest cost. The estimated cost of CO_2 avoided ranges from about \$70 to \$150 per tonne of CO_2 avoided using variable capture, increasing to \$186 to \$226 per tonne of CO_2 avoided for constant partial capture. The flexible capture modes investigated can reduce the overall CO_2 emissions of a power plant by up to 50%.

1. Introduction

1.1. Background

One option to address the increasing levels of global atmospheric CO_2 emissions is to implement Carbon Capture and Storage (CCS) at large stationary emission sources. However, an obstacle faced by wide scale deployment of CCS is the cost of capturing CO_2 from relatively dilute flue gas streams, such as those from coal fired power plants. The research shows that CCS is expensive due to capital and operating costs where the energy required for operating the CCS facilities is a major drawback. Studies show that applying capture at a coal-fired power plant could increase the generation costs by 40–290% (IPCC, 2005; IEA-GHG, 2011).

To ensure that consumer demands are met, the deployment of CCS at power plants requires either that the power plant increases its generation to make up for the CCS energy penalty or that other electricity generation sources are available to provide the additional output to the grid. In either case, there is a trade-off between generators being able to make a profit in the electricity market while at the same time mitigating CO_2 emissions. In enabling CCS to be deployed at power plants, a number of strategies have been proposed. This could include using excess available energy at the power plant, in a portfolio of power plants of one owner or in the market to provide the energy needed for capture and storage while meeting demand or using flexible capture strategies to either minimise the cost of electricity (COE) or increase the profitability of power plants.

Flexible capture can be achieved in a range of ways. At the individual power plant level, flexible operation can be achieved using measures such as adding a solvent storage tank, bypassing the capture facility for certain time periods or operating the capture facility at different capture rates according to electricity output requirements (Chalmers and Gibbins, 2007; IEA-GHG, 2008; Haines and Davison, 2009; Lucquiaud et al., 2009; Ziaii et al., 2009; Chalmers et al., 2011; Cohen et al., 2011; Wiley et al., 2011; IEA-GHG, 2012; Veersteg et al., 2013; Saint-Pierre and Mancarella, 2014). Studies have shown that using flexible capture during periods of high electricity demand can make CCS more cost effective because generators may be able to sell more electricity and achieve a higher operating profit. However, the profitability is highly dependent on the ratio of the capture cost (or carbon price available in the market) to the electricity price (Nimtz and Krautz, 2013, Patino-Echeverri and Hoppock 2012). According to Delarue et al. (2012), it has been suggested that flexible capture may be more beneficial in electricity markets with high penetration of variable energy sources such as solar and wind than those with lower

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levels. This is because these markets are likely to have higher electricity prices. However, the study of the Dutch electricity market by van der Wijk et al. (2014) showed that using flexible capture does not necessarily equate to higher revenues if flexible capture is not utilised for long periods of time. Rather, they suggested that the main benefit of flexible CCS for power plant operators is that it enables the operator to increase their reserve capacity.

In this paper, the potential for application of partial, part-time and variable capture at generic black coal power plants is examined. First, the dispatch pattern for three coal-based power plants is examined. Then generic plant data is presented based on typical base load power plants representative of Australian and German black coal power plants and perhaps future UK base load power plants, amongst others. To analyse the impact of flexible operation on the cost of electricity (COE) and performance of capture, it is assumed that capture is retrofitted to existing power plants without the provision of extra power generation to accommodate for parasitic losses. The results in this paper therefore do not include the impacts of additional 'peaking revenue' that might be obtained by shutting down capture operations during high pricing periods as performed in a profit/loss analysis. Because we are only interested in scoping level estimates of the COE and the emissions avoided, the results also do not show an optimised capture operating pattern and/or mode which will be dependent on the regional dispatch, pricing profiles and the regional operational structure of the market.

2. Methodology

2.1. Capture scenarios

General assessments of CO_2 capture often assume that CO_2 is continuously captured in a single operating mode with a constant full capture rate of 85% or higher coupled with a constant energy penalty. However, it is possible for the capture facilities at the power plant to be turned down and even switched off, so that CO_2 is captured over some time periods and released to the atmosphere at other times. In addition to the ability to switch-off the capture plant, CO_2 capture technology could function in different modes, thus providing flexibility of operation. In this paper, we define flexible capture as follows:

1. Partial CO_2 capture – capturing CO_2 at a low recovery of less than 85% on a constant basis. In this way, a proportion of CO_2 is captured from the flue gas and the remainder is emitted to the atmosphere.
2. Part-time CO_2 capture – capturing CO_2 for a defined time period (such as several hours per day) by running the capture plant during this time. At other times, the capture facilities may be switched off and the CO_2 vented to the atmosphere along with the other flue gases.
3. Variable CO_2 capture – operating the capture plant at several different capture rates over defined time periods for each rate. For example, the capture plant may operate at a 90% capture rate for 8 h of the day, 40% capture rate for 9 h of the day and 10% capture for the remainder of the day.

We assess the potential of these three capture modes for three scenarios based on three generic power plants. It is assumed that all the plants are existing black pulverised coal power plants with a thermal efficiency of 38% HHV, net output of 700 MW (gross output of 730 MW) and a load factor are 85%. The CO_2 emission intensity is 0.88 t/MWh (before capture) which corresponds to an annual emission rate of 4.57 million tonnes of CO_2. The generic plants were selected to cover a range of dispatch patterns observed internationally for both summer and winter. Further details of the methodology for creating generic dispatch curves can be found in Wiley et al. (2011) and Zhang et al. (2013).

2.2. Processing assumptions

2.2.1. Capture plant

The capture plant is sized using the in-house program ICCSEM developed by UNSW for the CO2CRC, which relies on short-cut methods and rules of thumb and has been verified against a range of data available from the literature. Details of the absorption model are provided in Raksajati et al. (2013). The size of the capture plant depends on the fuel, efficiency and emission intensity of the power plant, the amount of generated electricity, and the capture rate. The capture plant includes the flue gas pre-treatment (FGD and SCR), CO_2 separation and compression. It does not include the costs of transport and storage or decommissioning. The capture process is assumed to be a retrofitted post-combustion capture system without heat integration that uses an advanced amine solvent. The CO_2 is assumed to be compressed to 100 bar following separation. The amount of CO_2 captured varies from plant to plant, from 0% recovery rate up to 90%, depending on the available energy at the power plant.

2.2.2. Energy for capture

The energy required for capture (that is, the steam required for solvent regeneration and the electricity for compression and pumping) is assumed to be parasitically derived from the power plant. The total energy penalty is assumed to be 1.2 MJ of electrical equivalent per kg of CO_2 captured.

From the generic dispatch curve, the available energy for partial (constant) capture is estimated as the difference between the maximum generator capacity and the peak dispatch rate. For part-time and variable capture, the amount of energy required for a particular capture rate is firstly determined based on the energy penalty. Then, using the generic dispatch profiles, the time periods that correspond to when that energy is available are determined. For example, to capture at a rate of 90%, the energy required is estimated as 185 MW. Using the generic dispatch graph, the time periods over which capture at a 90% rate can occur is where the difference between the registered capacity and the dispatch are more than 185 MW.

We did not assess full baseline capture with a 90% capture rate as there is insufficient energy available. If full capture was applied, then energy from an external source would be required.

2.3. Economic assumptions

The general economic assumptions are:

- This study is presented in US dollars (US$ 2012).
- Residual capital of existing black coal power plants is assumed to be zero as most plants in Australia, UK and Germany were built in the 1980s. Assuming a capitalisation period of 25–30 years, the amortisation of these plants is now zero.
- Fuel costs are taken as 2.7 $/GJ HHV for coal (IEA, 2011).
- Power plants will remain operational over the next 25 years without upgrading.
- The real discount rate is 10% with a project life of 25 years.

The cost of capture in $ per tonne CO_2 avoided is determined using:

$$\frac{\$}{CO_2\ avoided} = \frac{\mathrm{LCOE}_{capture} - \mathrm{LCOE}_0}{CO_{20} - CO_{2cap}} \quad (1)$$