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Trade-off in emissions of acid gas pollutants and of carbon dioxide in fossil fuel power plants with carbon capture

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Abstract

This paper investigates the impact of capture of carbon dioxide (CO_2) from fossil fuel power plants on the emissions of nitrogen oxides (NO_X) and sulphur oxides (SO_X), which are acid gas pollutants. This was done by estimating the emissions of these chemical compounds from natural gas combined cycle and pulverized coal plants, equipped with post-combustion carbon capture technology for the removal of CO_2 from their flue gases, and comparing them with the emissions of similar plants without CO_2 capture. The capture of CO_2 is not likely to increase the emissions of acid gas pollutants from individual power plants; on the contrary, some NO_X and SO_X will also be removed during the capture of CO_2. The large-scale implementation of carbon capture is however likely to increase the emission levels of NO_X from the power sector due to the reduced efficiency of power plants equipped with capture technologies. Furthermore, SO_X emissions from coal plants should be decreased to avoid significant losses of the chemicals that are used to capture CO_2. The increase in the quantity of NO_X emissions will be however low, estimated at 5% for the natural gas power plant park and 24% for the coal plants, while the emissions of SO_X from coal fired plants will be reduced by as much as 99% when at least 80% of the CO_2 generated will be captured.

Keywords: Acid gas emissions; Carbon capture; Capture ready plant

1. Introduction

Nitrogen oxides (NO_X), sulphur oxides (SO_X) and carbon dioxide (CO_2) are among the gases that are generated during the combustion of fossil fuel for the production of electricity. NO_X and SO_X form acid gases that have a negative impact on the environment, causing acidification, eutrophication of water masses, smog formation, etc. (Tzimas and Peteves, 2001; EEA, 2005; IEA GHG, 2006). CO_2 is a greenhouse gas that contributes to global climate change when discharged to the atmosphere (IPCC, 2005; IEA GHG, 2006).

The emissions of NO_X and SO_X from power plants have decreased significantly since the 1970s as a result of the development and deployment of technologies that can remove them from the flue gases and convert them into inert substances (e.g. nitrogen and gypsum). These technologies include flue gas desulphurization (FGD) and selective catalytic reduction (SCR). Newly built power plants in Europe can now achieve low NO_X and SO_X emission levels in compliance with the Large Combustion Plant (LCP) Directive (2001/80/EC).[1] Furthermore, technologies are currently under development to capture the CO_2 in the flue gases of power plants and store it for long periods of time in suitable geological formations or use it for enhanced oil recovery purposes (IPCC, 2005; Tzimas et al., 2005b).

However, concerns have been raised, for example, in the recent deliberations for the preparation of the second phase of the European Climate Change Programme (DG ENV, 2006), that the application of CO_2-capture technologies may increase the emissions of acid gas pollutants (NO_X and SO_X). This is a customary concern with trade-off issues between emissions upon the adoption of mitigation

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[1] Official Journal of the European Union, L 309, 27/11/2001 P. 0001–0021.

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options. As an example of such a case, a reduction in CO_2 emissions from gas turbines, by increasing the combustion temperature and hence the turbine efficiency, typically results in an increase in the generation of NO_X. The possible increase in emissions of acid gas pollutants due to CO_2 capture may have implications for the compliance of individual plants with the LCP Directive, as well for the compliance of European States with the National Emissions Ceiling Directive (2001/81/EC), and its successors, that sets upper limits for the total annual emissions of acid gas pollutants from each Member State of the European Union.

This paper intends to clarify this issue by estimating the difference in the quantities of acid gas pollutants and CO_2 emitted by fossil fuel fired power plants with and without CO_2 capture. Two power generation options are investigated: natural gas combined cycle plants (NGCC) and pulverized coal (PC) plants. Post-combustion capture of CO_2 using special chemical solvents, such as alkanolamines, is considered in this paper as this technology has been utilized for many years by the chemical and petrochemical industries and is expected to have a major role in forthcoming demonstration projects and early deployment of carbon capture and storage (CCS) technologies.

Finally, the importance of considering an integrated approach for air pollution control for each plant is highlighted in the paper. Such an approach can facilitate the design and assist the selection of the most efficient options to reduce CO_2 emissions from power plants using capture technologies.

2. Natural gas combined cycle plants

An NGCC plant practically does not emit any SO_X, since natural gas is desulphurized prior to combustion (Kohl and Nielsen, 1997; IPCC, 2005). It generates, though, considerable amounts of NO_X, within the range of 200–700 mg per normal m^3 (mg/N m^3) of flue gases at the gas turbine exit, depending on the gas turbine size and technology (US EPA, 1993; Tzimas and Peteves, 2001; IPPC, 2005). It is noted that NO_X refers to a mixture of nitrogen oxides produced during combustion. Conventionally, NO_X is used to refer to a mixture of nitric oxide (NO), nitrogen dioxide (NO_2) and small quantities of dinitrogen monoxide (N_2O). NO is the primary form in combustion products, as it contributes to over 90% of the total NO_X in most combustion types (IPPC, 2005). Generally, there are three primary routes of NO_X formation in combustion processes: *thermal* NO_X—referred to NO_X formed during high-temperature oxidation of nitrogen found in combustion air, *fuel* NO_X—referred to NO_X formed from fuel-bound nitrogen; and *prompt* NO_X—attributed to the reaction of atmospheric nitrogen with radicals derived from fuel (Perry and Green, 1999).

In the case of NGCC plants, it is assumed that 90% of the NO_X is composed of nitric oxide (NO), the rest being nitrogen dioxide (NO_2). SCR and other NO_X control technologies (e.g. low excess air, air and fuel staging, flue gas recirculation, reduced air preheat) reduce the concentration of NO_X in the flue gases to less than 50–75 mg/N m^3, so that European plants comply with the LCP Directive. This range of values for NO_X emissions is equivalent to approximately 40–60 kg NO_X/TJ of fuel input, based on an evaluation of plant case studies (IPPC, 2005).

New NGCC plants also produce 340–380 kg CO_2 per MWh of net electricity generated (kg/MWh_e). The average reported value for CO_2 emissions cited in the literature is 367 kg CO_2/MWh_e (IPCC, 2005). Post-combustion carbon capture technologies are currently being developed targeting to 'cost effectively' reduce CO_2 emissions by 85–90%. Most of these technologies rely on chemical absorption: CO_2 in the flue gases is captured by special solvents[2] and separated from the flue gases. When the CO_2-loaded solvents are heated to 100–140 °C, CO_2 is released. Following this regeneration step, CO_2 is compressed and transported to a storage site while the CO_2-lean solvent is reused. More details concerning post-combustion capture can be found in the recent special report of the Intergovernmental Panel on Climate Change (IPCC, 2005) and other relevant literature sources (Kohl and Nielsen, 1997; IEA GHG, 2004, 2006).

A significant amount of energy, produced by the plant, is however consumed during the CO_2-capture process, in the form of heat to regenerate the solvent, and electricity to drive pumps and compressors. Hence, the thermal efficiency of an NGCC plant with CO_2 capture is lower than that of an equivalent conventional NGCC plant. According to recent publications (IPCC, 2005; Tzimas and Peteves, 2005a; IEA GHG, 2006), the reduction in efficiency due to CO_2 capture is estimated in the order of 7-percentage points, decreasing from 55%, which is the average efficiency of a typical NGCC plant without CO_2 capture, to 48% LHV[3] when CO_2-capture technology is used in such a plant. It is noted that such efficiency penalties, albeit to a smaller magnitude, have also been imposed to power plants in the past, as a result of the implementation of acid gas removal technologies, such as FGD and SCR. The efficiency in these cases has decreased by 1–3 percentage points.

Due to the decrease in power plant efficiency, an NGCC plant with CO_2 capture will export to the grid 87% (= 48/55) of the power generated by an identical plant without CO_2 capture, when the same amount of natural gas is consumed. The volume of flue gases that have to be treated and the amount of NO_X generated by both plants will

[2]These alkanolamine-based solvents include: monoethanolamine (MEA), diethanolamine (DEA) and methyl-diethanolamine (MDEA).

[3]The efficiency of a plant based on the lower heating value (LHV) of a fuel (i.e. disregarding the heat of condensation of the water vapour formed during combustion) is lower than that quoted based on the higher heating value (HHV) of the fuel by approximately 10% for natural gas plants and 5% for coal plants.