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LONG ABSTRACT

A comparative assessment of national CCS strategies for Northwest Europe and the cost-effectiveness of storing CO_2 at the Utsira formation.

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Carbon dioxide capture, transport and storage (CCS) is increasingly recognized as a key CO_2 mitigation option. A key component of CCS is an efficient and cost-effective CO_2 pipeline, or network of pipelines, connecting CO_2 sources with potential sinks. Several European studies on CCS have pointed out the Utsira formation in the North Sea as a large potential sink that could theoretically supply CO_2 storage capacity for several European countries for a period of several decades (e.g., Odenberg et al, 2008; Gale 2004; van den Broek et al 2009). There are, however, uncertainties on how and at what costs CO_2 storage at Utsira could be cost-effectively tuned to the development of national energy supply systems in the North Sea region. Whether and when storage at Utsira may be used will depend on the potential deployment of CCS in each country, costs and availability of local storage. This project aimed to analyse the contribution of CCS in the national portfolio of mitigation for the countries in the North Sea region (Denmark, Germany, Norway, the Netherlands and the United Kingdom) and assess the role that Utsira may play as a potential storage location.

Methodology

The analysis is done using national bottom-up linear optimization MARKAL models (for Netherlands, Norway and the United Kingdom) and TIMES models (for Denmark and Germany). All models include fossil fuel price projections from the IEA World Energy Outlook (WEO 2008). As these projections encompass recent upwards movements in fuel prices, a sensitivity case was carried out on IEA WEO 2007 which had a lower set of fossil fuel prices. Developments of import-export of electricity for each national model and country specific CO_2 mitigation targets were based on results provided by the PanEU-TIMES model, as this is an EU model covering regional electricity markets. For parameters such as final electricity demand, load curve of electricity, final heat demand, vintage structure of existing electricity generation, no harmonization attempt was made. Hence each model's energy service demands were derived on a national basis. Similarly, national policy and fiscal circumstances were kept model specific. Parameters related with efficiencies, learning rates, costs of mitigation technologies have been harmonized

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among the models. In addition, in all models CO_2 is transported in the supercritical phase. Finally, harmonized aggregated data on the Utsira basin has been incorporated.

Two future policy scenarios have been examined, a 20% reduction of European CO_2 emissions compared to 1990 levels in 2020, which is consistent with the EU's 2020 climate goal (C-20 scenario) and a linear reduction, starting in 2020, of 80% by 2050 (C-80 scenario). Several sensitivity scenarios have been included to assess the robustness of the results.

Results

Results from the national models highlight large differences on the role that CCS and Utsira can play in the national portfolios of CO_2 mitigation. A brief overview of the results by country for 2050 for the C-20 and C-80 scenario follows.

Low mitigation targets (C-20 Scenario, WEO 2008 prices unless otherwise specified):

- *Denmark*: In 2050 electricity demand will increase by 18% reaching a level of 970PJ, there is a significant increase in the use of biomass, mainly for electricity and heat. The very dominant feature is the variation of wind power and electricity export. In this scenario CCS technologies do not play a role
- *Germany*: In 2050 primary energy consumption reaches 10.2 EJ. Fossil fuel remains dominant with a share of two thirds of the total primary energy demand. The electricity supply increases to a level of 2.2 EJ, with 1.1 EJ being produced from renewables. In this scenario CCS technologies play only a moderated role. For carbon storage national saline aquifers and hydrocarbon fields are primary used. A maximum of 25 Mt/year are transported and stored abroad. Direct storage in Utsira does not appear cost-efficient in this scenario.
- *Netherlands*: Total electricity generation reaches 592 PJ in 2050. The Netherlands switches from being a net importing country in 2020 (19 PJ) to a net exporting country of electricity (21 PJ) in 2050. CO2 emissions in 2050 from the power and industrial sector are about 193 Mt. CCS technologies for electricity generation are limited to IGCC-CCS plants. The capacity of power plants with CCS is projected to be 8 GW in 2050 producing about 36% of the electricity. Amount of CO2 stored in 2050 is estimated at 43 Mt. During the first decades (2020-2040) CO_2 is stored in (national) onshore gas fields. Offshore storage becomes cost-effective when capacity of onshore sinks for CO_2 storage is depleted (in 2050). In total in 2050, 14% of the CO_2 is stored offshore including 8% in the Utsira formation and 6% in depleted offshore gas fields in the Dutch platform.
- *Norway*: Primary energy demand in 2050 is estimated at 1033 PJ. Electricity generation is dominated by renewables. The model assumes CO_2 capture to the existing NGCC power plant at Kårstø from 2015. In this scenario is this exogenous investment the only source for CO_2 captured. CO_2 is stored at Utsira, which is assumed to be the most mature Norwegian storage formation

- *United Kingdom*: Electricity generation in 2050 is estimated at 1585 PJ, 21% of which is generated by renewables. Coal (without CCS) power generation has a share of 58%. With WEO 2008 prices, CCS technologies are not selected by the model. CCS only plays a relatively minor role (18% of the generation capacity) when this scenario is combined with WEO 2007 energy prices. In this case, about 62 Mt CO_2 is stored in 2050. CO_2 is stored for enhanced oil recovery and offshore aquifers in the North Sea (35 Mt). In both cases, a major trade-off is between coal with CCS, nuclear, and large scale wind generation. The marginal cost effectiveness of these electricity technologies within the UK electricity system is close and the model can substitute to any of them. However without CCS, coal electricity is not a viable generation technology in a decarbonised energy system.

Stringent mitigation targets (C-80; WEO 2008 prices unless otherwise specified):

- *Denmark*: in this scenario electricity demand has increased by 14% in 2050 (compared to 2000). CCS plays a role, though relatively minor. CO_2 capture technologies are applied to both gas and coal power plants. Most of the CO_2 is stored in national aquifers. A small amount (about 2Mt/yr) is exported to be stored in the Utsira formation.
- *Germany*: in 2050 the electricity supply increases to about 2808 PJ. The electricity production from renewables energies increases to 1490 PJ. Electricity generation from fossil fuels develops to 1224 PJ in 2050. Electricity from CCS power plants contributes to 40-50% to total electricity supply in 2050. Depending on the fossil fuel prices coal CCS power plants have a share of CCS based electricity generation of 85%. Amount of CO_2 captured amounts to 237 Mt. At lower energy prices (WEO 2007) 159 Mt CO_2 are captured. For carbon storage domestic saline aquifers (243 Mt) and hydrocarbon fields (25 Mt) are primary used. Only minor quantities of CO_2 are transported and stored abroad. In 2050 the next exchange balance is determined by import quantities from Poland (50Mt) and exports to Denmark (20Mt) and the Netherlands (25 Mt). Storage at the Utsira formation is done via a pipeline from the Netherlands. The direct transport of CO_2 to Utsira appears as not cost-effective.
- *Netherlands:* Electricity generation is projected to increase to 1031PJ in 2050, with about 232 PJ being exported. CO_2 emissions in 2050 from the power and industrial sector are about 60 Mt. The share of electricity generation from power plants with CCS is 80% in 2050 (70% coal/biomass and 10% gas). The total capacity of power generation with CCS is estimated at 34GW. Similar to the C-20 scenario, CO_2 is initially stored in onshore gas fields. Due to the rapid increase in CCS, offshore storage of CO_2 in the Utsira formation and in offshore gas fields in the Netherlands starts already in 2030. Storage of CO_2 in the Utsira formation is however still marginal in 2040 (2.4 Mt CO_2/yr), but increases rapidly to 105 Mt in 2050. In 2050, 80% of total CO_2 captured in the Netherlands is projected to be stored in the Utsira formation.
- *Norway*: Primary energy demand in this scenario is estimated at 1040 PJ. In addition to the CO_2 capture unit to the existing NGCC power plant (see C-20

scenario), 2.9 Mt CO_2 are captured from the industrial sector in 2050 (0.82 Mt from cement production and 2.1 Mt from the refineries). All CO_2 is stored at Utsira.

- *United Kingdom:* in this scenario, about 2372 PJ of electricity is generated in 2050. Electricity is mainly produced by nuclear (45%) renewables (39%) and coal with CCS (12%). About 53 Mt CO_2 are captured via CCS in 2050. This CO_2 is stored in national aquifers (no EOR). If lower prices are assumed (WEO 2007), the amount of CO_2 capture increases significantly (210 Mt) with about 24% of this flow being stored at Utsira. The general ordering of costs of CCS transport and storage are: Enhanced Oil Recovery (EOR), the lower portion of the supply curve for UK aquifers, the lower portion of the supply curve for UK oil/gas reservoirs, Utsira, higher cost UK aquifers and finally higher cost oil/gas fields.

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