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Effects of carbon dioxide capture and storage in Germany on European electricity exchange and welfare

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HIGHLIGHTS

- CCS reduces short-term electricity supply cost and tends to raise suppliers' rents.
- Additional suppliers' surpluses could be used to finance CCS investment costs.
- CCS induces a merit-order effect lowering electricity prices on the spot market.
- This decline in prices raises consumer rents and mitigates political opposition against CCS.
- Effects of CCS in Germany on European electricity exchange and welfare levels are assessed.

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ABSTRACT

In the course of European efforts to mitigate global warming, the application of carbon dioxide capture and storage (CCS) technologies is discussed as a potential option. Some political opposition was raised – inter alia – by uncertainties about the effective cost of such technologies. Because of the cost structure of CCS power plants with high 'flat' investment cost and – in case of high carbon allowance prices – comparable low variable cost, the application of CCS will induce a merit-order effect causing a decline in wholesale electricity prices on the spot market. On the one hand, the reduction of electricity supply cost raises suppliers' rents, while the decline of wholesale electricity prices augments consumers' surpluses. These positive welfare effects tend to mitigate political opposition against CCS. On the other hand, the merit-order effect reduces electricity suppliers' revenues as the wholesale prices decline. This mitigates their scope for additional investments in CCS capacity. In this study, we focus on the influence of CCS in Germany on electricity supplier and consumer surpluses and associated impacts on the scope for investments in additional CCS capacity. By means of the applied model of electricity markets, influences on European electricity exchange and welfare levels are investigated.

1. Introduction

Carbon dioxide capture and storage (CCS) is seen as a major option to mitigate global greenhouse gas emissions. The IEA (2011b) considers it as a key abatement option in the 450-ppm scenario that is expected to be largely consistent with meeting the international '2°C-target'.[2] Though, due to immaturity of CCS technologies, associated risks (unintended leakage or accidental release of carbon dioxide) and negative influence on power plant efficiencies, this technology is controversially discussed.[3] Yet, technological immaturity can be overcome by learning processes in association with the running of demonstration plants and this learning will also help to reduce technological risks.[4] Energy losses (energy penalty) due to the use of CCS are – in turn – not seen as "a major restriction to an extensive application of coal-fired CCS technologies" as there is "abundant availability of coal and potentially also hydrates" (Edenhofer et al., 2011: 88). A fourth problem might however be more serious, which is the restriction of a limited availability of suitable geological disposal opportunities. This is a major constraint for the pursuit of this climate protection

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[2] Yet, Stauffer et al. (2011: 8597) point out that "CCS technology must be deployed at a massive scale to have a meaningful impact on reducing industrial CO_2 emissions to the atmosphere."
[3] Wilson et al. (2007) stress that CCS must be both safe and effective, and they describe associated risks to human and ecological health.
[4] However, uncertainty about large-scale implementation will still remain.

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path such that CCS is largely seen as a transitional technology which might enable a 50-year transition towards renewable energy and away from fossil fuels (Haszeldine, 2009: 1647).

Yet, for CCS to take this transitional-technology role, the 'crucial question' is at what costs CCS technologies can be induced by climate policy (Edenhofer et al., 2011: 89). Viebahn et al. (2007) stress that depending on the growth rates and the market development, the 'mitigation' option in the shape of renewable energy technologies "could develop faster and could be in the long term cheaper than CCS based plants".[5] As Oltra et al. (2010: 698) remark, opposition of non-governmental organizations, experts and other industries to CCS may cause a decreasing social acceptance of these technologies.[6] And rising opposition – in turn – might increase the costs in connection with CCS use.[7] And Praetorius and Schumacher (2009: 5085) point out that environmentalists and renewable-energy lobbyists fear the competition between CCS and renewable-energy technologies for R&D funds and are worried that CCS might raise attractiveness of investments in large centralized power plants which tend to reinforce present supply structures with adverse effects on energy saving efforts, decentralized renewable energies and combined heat and power generation.[8] However, in a survey three-quarters of the participating European energy stakeholders were of the opinion that CCS is 'definitely' or 'probably necessary' to achieve deep reductions in CO_2 emissions between 2006 and 2050 in their home country (Shackley et al. 2007). And after the Fukushima catastrophe negatively influencing the attitude towards nuclear energy technology, CCS as a nearly CO_2-free technique tends to become more attractive.[9]

There are several studies ascertaining the effectiveness of CCS in mitigating CO_2 emissions and the associated cost. According to the IPCC (2005: 4), about 85–95% of the carbon dioxide in a power plant can be captured by available CCS technologies. As a lower bound for the energy penalty for post-combustion CCS from pulverized-coal fired power plants, House et al. (2009) ascertain a level of ~11%, but assess that ~29% would be a decent target value. The IPCC (2005: 4) estimates that the ranges for losses of energy compared to plants not equipped with CCS technology is 24–40% for pulverized coal plants, 11–22% for natural gas combined cycle plants and 14–25% for integrated gasification combined cycle plants. According to the IEA (2009: 23), application of CCS for large coal fired power plants will represent the lowest cost opportunity within the power sector at around USD 35 to USD 50/tCO_2 avoided while capture from gas-fired plants will involve cost within the range of USD 53 to USD 66/tCO_2 avoided.

Application of CCS and related cost will not only provoke allocative shifts by changing the level and structure of climate change mitigation activity, but it will also have distributional effects. Recently, Lüken et al. (2011) investigated distributive impacts of climate change mitigation policy among different world regions taking into account the influence of CCS application also. They find that the unavailability of CCS will raise wealth redistributions among world regions (Lüken et al. 2011: 6037).

We are also interested in the distributional consequences of CCS use, but in contrast to the study by Lüken et al. (2011), we employ an electricity model focusing on pan-European distributional consequences of CCS application in Germany. We ascertain impacts on international electricity exchanges in Europe as well as on consumer and producer surpluses by using this model in combination with a merit-order approach[10] . While positive effects on consumer and supplier surpluses are important for weakening political opposition to CCS, a rise in suppliers' revenues would also be a crucial factor in gaining sufficient funding for additional investments in CCS capacity.

In detail, we proceed as follows. In Section 2, we present approach and model employed in our analysis, and we introduce the scenarios we investigate. Section 3 gathers the results of our model and a discussion of these. Section 4 concludes.

2. Methodology and Scenarios

2.1. Producer and consumer surplus

In our analysis of potential CCS development paths, we employ a producer surplus approach measuring changes in electricity producers' profits. This approach has – in comparison to standard comparative cost methods – the advantage that it captures both changes in prices and in electricity sales. This is much alike fundamental models of power markets, but our approach allows for a more explicit consideration of the rents of consumers of electricity also.

Let us regard the producer surplus and its changes for illustrative purposes in a stylized example. In Fig. 1, we assume that a linear electricity supply curve $c_A(e)$ drops due to an exogenous change in generation costs per unit of electricity e and the new curve is now depicted by $c_B(e)$. Given the linear energy demand function as displayed in Fig. 1, the initial market equilibrium is determined by the intersection of this demand function and the initial supply curve $c_A(e)$ in A. After the exogenous cost decrease, the new equilibrium is at B. As can be observed, the market price per unit of e drops from p_A to p_B.

The suppliers obtain additional profits due to the decrease in the cost of supplying energy and the expansion of sales by the amount S. These additional rents are depicted by the trapezium BCDE minus trapezium AEFG. The gains from declining cost and rising sales are diminished by the falling market price for electricity. Yet, net gains remain positive.

The consumers also benefit as the market price falls and the electricity consumption level increases. Consumer rents rise by the trapezium ABFG.

A cost decline could be induced on the electricity market by the application of technologies reducing carbon emissions. Due to the mitigation of emissions, lower cost for meeting emission caps and for related trading arise for electricity producers. One way to obtain such carbon emission mitigation and potentially a cost-saving effect is the application of CCS.

Yet, electricity is generated by different technologies and by using different inputs. CCS is not applicable to all of them and cost of CCS application – where possible – differs among technologies. Therefore, the heterogeneity of power generation plants has to be taken into account in the subsequent analysis.

2.2. Description of the EU-electricity model

2.2.1. Methodology

To assess the impacts of a use of CCS in Germany on electricity production, wholesale electricity prices and electricity exchanges

[5] However, Hoel and Jensen (2010) describe circumstances under which the support of the development of CCS technologies is preferable to supporting renewable energy technologies.

[6] Fischedick et al. (2009) stress the role of social acceptance of CCS.

[7] Hake et al., 2009: (3923) observe: "On the one hand, CCS can be perceived as a solution for the climate-friendly use of coal. […] On the other hand, CCS itself may suffer from the negative image of coal in certain sections of the population."

[8] There are also other environmental concerns which may mitigate acceptance of CCS, e.g. the application of CCS tends to raise emissions of other pollutants (Markewitz et al. 2009).

[9] Subsequently, we disregard the option of combining bioenergy with CCS which would even constitute an option removing CO_2 emissions from the atmosphere (see, e.g., Azar et al. 2006 and Ricci 2012 for this option).

[10] See Sensfu, Ragwitz and Genoese (2008) and Schaber, Steinke and Hamacher (2012) for examples of studies using merit-order approaches.