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The impact of carbon capture and storage on a decarbonized German power market

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ABSTRACT

The European energy policy is substantially driven by the target to reduce the CO_2-emissions significantly and to mitigate climate change. Nevertheless European power generation is still widely based on fossil fuels. The carbon capture and storage technology (CCS) could be part of an approach to achieve ambitious CO_2 reduction targets without large scale transformations of the existing energy system. In this context the paper investigates on how far the CCS-technology could play a role in the European and most notably in the German electricity generation sector. To account for all the interdependencies with the European neighboring countries, the embedding of the German electricity system is modeled using a stochastic European electricity market model (E2M2s). After modeling the European side constraints, the German electricity system is considered in detail with the stochastic German Electricity market model (GEM2s). The focus is thereby on the location of CCS plant sites, the structure of the CO_2-pipeline network and the regional distribution of storage sites. Results for three different European energy market scenarios are presented up to the year 2050. Additionally, the use of CCS with use of onshore and offshore sites is investigated.

1. Introduction

In the latest Energy Roadmap (EC, 2011) the EU emphasizes the objective to transform the European energy sector into a low carbon economy. Hence, a reduction of greenhouse gas emissions by 80 to 95% compared to the levels of 1990 is the ambitious goal for 2050. This mitigation target determines efforts in all relevant energy sectors. Simultaneously an affordable, sustainable, competitive and safe energy supply should be guaranteed (EC, 2011). It is a matter of fact that large scale emission cuts and the transformation of a whole economy into a decarbonized system is a mega-project that requires years if not several decades and billions of Euro. Despite the ambitious climate targets of the EU it is very likely that fossil fuels will have a certain share in the European energy sector for the next decades. The IEA projects in the main scenario of the latest World Energy Outlook (IEA, 2012) a 75%-share of fossil fuels in 2035 concerning the world primary energy demand. The energy mix in the EU in 2011 is dominated by about 75% of fossil fuels. Whereas the transport sector is predominantly oil-driven, the electricity generating sector is about 50% based on coal and gas plants (IEA, 2012). The carbon capture and storage-technology (CCS) could be instrumental in cutting global or regional CO_2-emissions significantly without removing fossil fuel plants from the energy system in an overhasty way and jeopardizing the security of electricity supply. CCS provides a technical solution to cut CO_2-emissions from punctual large-scale emissions sources like fossil power plants or large industrial producers. The CCS-technology requires a transport-system (e.g. a pipeline-net) to transport the separated carbon dioxide to geological storage formations like saline aquifers or exploited gas fields on- or offshore (Metz et al., 2005). CCS could therefore facilitate the transformation to a low carbon energy system without massive redeployments in the infrastructure of the electricity generating sector simultaneously providing the advantages of a controllable energy generation backing up the ongoing proliferation of renewable energies.

Germany, the biggest member state in the EU, realized a renewable share of more than 20% of the electricity production in 2011 (AGEB, 2012). Despite the unprecedented advance of the renewable energy sources in Germany, the fossil fuels lignite, hard coal, gas and oil stand up for more than 58% of the gross electricity production (AGEB, 2012). According to the new energy concept that has been announced by the German administration in the middle of 2011, the German nuclear phase out has to be completed till 2022. The loss of roundabout 20 GW installed capacity of the carbon free nuclear technology compared to 1990 makes the CO_2-reduction targets of minus 40% till 2020 and of minus 80% till 2050 (compared to 1990 levels) considerably

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more challenging. Until 2012 already about 10 GW of nuclear have been phased out and energy-related CO2 emissions have decreased by 22% compared to 1990. However most of the emission reduction has been achieved until 2005 (−18%) and between 2011 and 2012 there has been even an increase in emissions by 2.2% (BMWi, 2013). Thus the 2050 target is still ambitious. Notwithstanding the fast diffusion of renewable technologies it is quite likely that fossil fuel plants will continue to play a fundamental role in electricity generation in Germany for the next decades. Therefore, CCS might be an interesting solution for the German electricity market. In accordance with the European Union, the German administration considers the CCS technology as a possible bridge into the forthcoming era of renewable energies (BMWI, 2010).

The implementation of the CCS technology in conventional power producing sectors has been the topic of many modeling approaches. Gough et al. (2006), Fowler (2008) and McFarland and Herzog (2006) presented bottom-up models as well as top-down and integrated assessment model approaches. A variety of linear optimization model approaches can be found in Bakken and von Streng Velken (2008). An interesting approach of a scenario based policy analysis is presented e.g. in Capros et al. (2008). In the context of a mixed integer and nonlinear programming problem, Chen et al. (2010a) integrate the CCS technology as an investment alternative in the electricity sector. Szolgayova et al. (2008) and Chen et al. (2010b) discuss CCS in the frame of the real options method.

Differences in the regional observation occur beside different methodology approaches. Labriet et al. (2012) analyze the impact of technology and climate uncertainties on the future global energy system which may also include CCS power plants. A European perspective can be found in Lohwasser and Madlener (2012). They show the impact of techno-economic assumptions on the diffusion of the CCS technology in Europe using a bottom-up electricity sector model. Cremer (2007) formulates a modeling approach with special focus on the German power market. The presented bottom-up and multiperiodic linear optimization modeling approach contains a coupling with a geographical information system (GIS) based model for location decision support. That approach includes the opportunity to analyze the influence and importance of different geographical parameters e.g. the distance between the CO_2-source and the CO_2-storage site.

Further single country analyses especially for European and Asian countries exist which analyze the future potential of the CCS technology (i.a. Gerbelová et al., 2013; Lund and Mathiesen, 2012). A crucial point in all these analyses is the cost assumptions for the CCS technology. This is further stressed by Voll et al. (2012) and Rubin (2012).

But social acceptance and policy support have also to be taken into consideration when it comes to the introduction of new technologies into the market. The social acceptance of CCS and the willingness to pay have been investigated by Kraeusel and Möst (2012). They found out that CCS technologies fall behind renewable technologies in public opinion. This makes policy support even more important if the CCS technology should obtain market maturity (cf. Nykvist, 2013). A decision framework to answer the question whether at all CCS technology should be supported is presented by Torvanger and Meadowcroft (2011) while Lohwasser and Madlener (2013) analyze the effectiveness of different policy measures in order to promote the CCS technology.

Yet so far an approach is missing which combines a consideration of the interdependencies in the European electricity market with a detailed analysis of location and transportation issues inside Germany. Indeed, a carbon capture, transport and storage network model can be found in Mendelevitch et al. (2010), but they set CO_2 prices exogenously and operational details are only roughly approximated.

The fast proliferation of intermittent renewable energies in Germany plus the nuclear phase out have a deep impact on the German electricity exchange with neighboring countries. Moreover, the local availability of CO_2 storage sites must be considered as well as the challenging climate targets that have been announced by the German administration. These different market developments are considered in three scenarios. In addition to that, the political opposition of some German federal states and the local resistance against storing CO_2 close to inhabited areas is another issue that has to be taken into consideration. Due to this, two variations for each of the three scenarios are introduced: A variation with no restrictions for the transport and storage of CO_2 (all storage case) and an offshore-variation that implies the strict requirement to store CO_2 only in offshore sites in the North Sea (offshore storage case). A model based approach is used to analyze the influence of a CCS deployment together with the expanding fluctuating production of renewable energies on future electricity markets. Thereby an intertemporal optimization model is chosen to ensure a lifetime assessment of the storage sites and capacities as well as to guarantee sufficient storage space for the captured CO_2 from new CCS power plants.

The paper is organized as follows: The second section deals with the applied model framework and enhanced methodology to assure a detailed assessment of the CCS options. Section 3 explains the investigated system and the three main scenarios. Furthermore model results are shown and their implications are discussed. A brief conclusion on the obtained results is finally presented in Section 4.

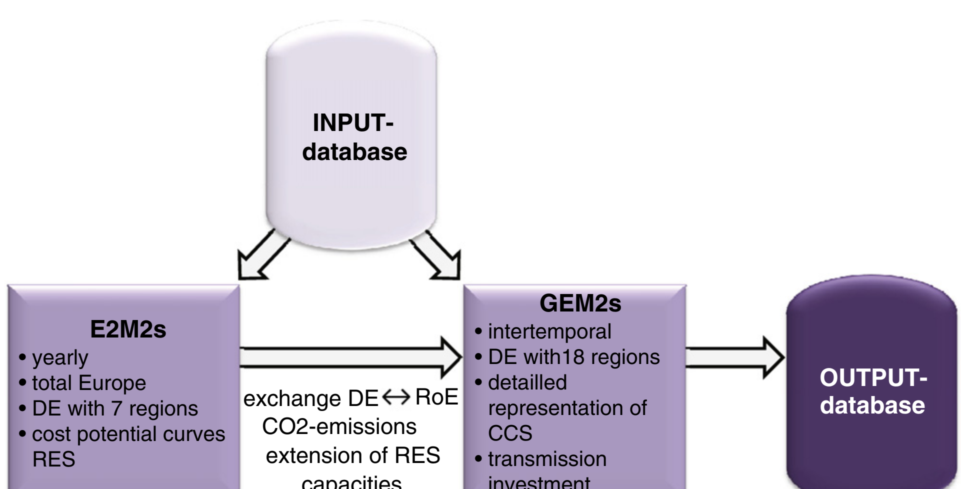

Fig. 1. Model framework.