THE IMPACT OF POLICY MEASURES ON FUTURE POWER GENERATION PORTFOLIO AND INFRASTRUCTURE – A COMBINED ELECTRICITY AND CARBON CAPTURE INVESTMENT AND DISPATCH MODEL

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Overview

This paper presents a general electricity-CO_2 modeling framework that is able to simulate interactions of the energy-only market with different forms of national energy market policy measures. We set up a two sector model where players can invest into various types of generation technologies including renewables, nuclear and Carbon Capture, Transport, and Storage (CCTS). For a detailed representation of CCTS we also include industry players (iron and steel as well as cement), and CO_2 transport and CO_2 storage including the option for CO_2 enhanced oil recovery (CO_2-EOR). The players maximize their expected profits based on variable, fixed and investment costs as well as the price of electricity, CO_2 abatement cost and other incentives, subject to technical and environmental constraints. Demand is inelastic and represented via a selection of type hours. The model framework allows for regional disaggregation and features simplified electricity and CO_2 pipeline networks. The model is balanced via a market clearing for the electricity as well as the CO_2 market. The equilibrium solution is subject to constraints on CO_2 emissions and renewable generation share. We apply the model to a case study of the UK Electricity Market Reform to illustrate the mechanisms and potential results.

Methods

Different kinds of models are used to assess the impact of policy instruments and their ability to achieve climate change policy objectives. Most electricity market models do not put any emphasis on CCTS, and handle the technology like any other conventional generation technology by specifying investment and variable costs and fuel efficiency (Leuthold, Weigt, and von Hirschhausen 2012; Eide et al. 2014; Spiecker and Weber 2014). By contrast, if models focus on CCTS infrastructure development, they often neglect how the technology is driven by decisions in the electricity market (Oei, Herold, and Mendelevitch 2014; Morbee, Serpa, and Tzimas 2012; Middleton and Bielicki 2009; Mendelevitch 2014).

The ELCO model mimics the competition of different conventional electricity generation technologies on the electricity market and their interaction with new technologies that are financed via fixed tariffs (Mendelevitch and Oei 2015a; Mendelevitch and Oei 2015b). Each technology is represented via a stylized player that competes with the others. For a better representation of scarce CO_2 storage resources we also include a detailed representation of the complete CCTS value chain, including potential CO_2 capture from the steel and cement industry. The different CO_2 storage options such as CO_2-EOR, saline aquifers and depleted oil and gas reservoirs compete against one another in the last stage of the CCTS value chain. All players maximize their respective profits subject to their own as well as joint technical and environmental constraints. Other (external) costs as well as further welfare components are not analyzed. Regional disaggregation takes into account geographical characteristics like availability (especially with respect to maximum potential and conditions for renewables as well as CO_2 storage) and specific electricity demand.

We then apply the model to the specific case of the UK. Different policy measures such as a Carbon Price Floor (CPF), an Emissions Performance Standard (EPS) or feed-in tariffs in form of Contracts for Differences (CfD) are included in the modeling framework. The ELCO model analyzes how these policy instruments will influence the construction of new generation capacities. CfD for newly constructed low-carbon technologies can be derived endogenously using shadow variables of constraints. Assuming perfect competition between the different players, equilibrium is reached when overall system costs are minimized subject to all constraints. The developed model is able to assess regionally disaggregated investment in electricity generation, generation dispatch and simplified flows as well as CO_2 transport, storage, and usage for CO_2-EOR. Incorporating CO_2 capture by industrial facilities from the steel, and cement sector enables, on the one hand, the representation of economies of scale along the transport routes while, on the other hand, leading to higher scarcity effects with respect to CO_2 storage options.

Results

The implementation of the various policy measures leads to a diversified electricity portfolio. The share of coal-fired energy production in the UK is sharply reduced from 39% in 2015 to 0% in 2030 due to a phasing-out of the existing capacities. New investments in fossil capacities occur for gas-fired CCGT plants, which are built from 2030 onwards. EPS hinders the construction of any new coal-fired power plant. Sensitivity analysis shows that a change of the EPS from 450 g/kWh to the range of 400-500 g/kWh has only little effect: Gas-fired power plants would still be allowed sufficient run-time hours while coal-fired plants remain strongly constrained. The overall capacity of nuclear power plants is slightly reduced over time. The share of renewables in the system grows continuously from 20% in 2015 to 30% in 2030 and 46% in 2050. Wind off- (41% in 2050) and onshore (25% in 2050) are the main renewable energy sources followed by hydro and biomass (together 27% in 2050). In 2050 with no specific RES target in place, renewables account for 46% of generation, gas (26%), nuclear (15%), and CCTS (13%).

CO_2-EOR creates additional returns for CCTS deployment through oil sales. These profits trigger investments in CCTS regardless of additional incentives from the energy market. The potential for CO_2-EOR is limited and will be used to its full extent until 2050. The maximum share of CCTS in the energy mix is 16% in 2045. The combination of assumed ETS and oil price also triggers CCTS deployment in the industry sector from 2020 onwards. The industrial CO_2 capture rate, contrary to the electricity sector, is constant over all type hours. The storage process requires a constant injection pressure, especially when connected to a CO_2-EOR operation. This shows the need for intermediate CO_2 storage to enable a continuous storage procedure and should be more closely examined in further studies. From 2030 onwards, emissions in the industrial sector are captured with the maximum possible capture rate of 90%. The usage of saline aquifers as well as depleted oil and gas fields is not beneficial assuming a CO_2 certificate price of 80 €/tCO_2 in 2050.

Conclusions

This paper presents a general electricity-CO_2 modeling framework (ELCO model) that is able to simulate interactions of the energy-only market with different forms for national policy measures as well as a full representation of the carbon capture, transport, and storage (CCTS) chain. The model can be used to examine the effects of different envisioned policy measures and evaluate policy trade-offs. The results of the case study on the UK electricity market reform (EMR) present a show case of the model framework. It incorporates the unique combination of a fully represented CCTS infrastructure and a detailed representation of the electricity sector in UK. Therefore, the modeling framework mimics the typical issues encountered in coal-based electricity systems that are now entering into transition to a low-carbon generation base.

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