EXPLORING UNCERTAINTIES IN CCS – DECARBONIZATION OF THE POWER SECTOR & COUNTRYWISE OPPORTUNITIES

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Overview

In 2011, the total CO2 emissions from the EU-27 countries was around 4 Gt CO2, and the electricity (and heat) generation sectors contributed to around 29% of the total CO_2 emissions [1]. The EU energy roadmap foresees a CO2 emissions reduction in the electricity sector of around 95% by 2050 from the 1990 levels [2]. At the same time, several European countries have decided for an early retirement / phase-out of nuclear energy – one of the main low carbon source of electricity generation – thereby making the decarbonisation of the electricity sector a challenging proposition. Besides renewables, carbon capture and storage (CCS) is seen as an alternate source of low carbon electricity. The IPCC sets out that CCS will play a prominent role in decarbonising the energy sector cost effectively, while maintaining security of energy supply [3]. However, large scale deployment of CCS is not yet proven, though extensive number of projects on the research, development and demonstration in this sector are ongoing [4]. Uncertainties also exist in carbon storage potential, with estimates in the range of 1 – 2500 Gt-CO_2 for Europe [5], while annual CO2 emissions from the EU-27 countries' electricity sector is foreseen to be around 0.4 Gt-CO_2 by 2050 for the reference scenario [6], which includes 7% CCS based electricity. Given its uncertainties in technology, social acceptance and storage potential, we explore the role of CCS in decarbonising the electricity sector. We focus on five countries, *viz.* Switzerland, France, Germany, Austria and Italy, which together account for about half of the total electricity generation within the EU-27 [7], and about 40% of the CO2 emissions from the power sector [6]. Under a "what-if" framework, we explore: How can these countries decarbonise their power sectors? What would be the role of CCS? How can countries with higher CCS potentials support the decarbonisation of its neighbouring countries? Several studies address the role of CCS in CO_2 emission reduction [8, 9, 10], but they lack either in representing sufficient intra-annual electricity demand-supply balance [8, 9] and/or ignore electricity trade patterns between neighbouring countries [10].

Methods

To answer the above research questions, a multiregional electricity model of the five countries called CROSSTEM (CROSs border Swiss Times[1] Electricity Model) has been developed. The model optimises to supply for an exogenously given electricity demand over a long time horizon (to account for long term policy goals and investment decisions) while simultaneously representing sufficient intra-annual detail (i.e., seasonal, weekly and hourly) to account for variations in electricity supply and demand. The model encompasses the future electricity demand, a wide range of electricity generation technologies and related electricity and environmental policies of all the five countries. The model also has the possibility to explore the electricity trade between the countries to cost effectively exploit their renewable and CCS potentials.

For this paper, we analyse a *Base* and several low carbon electricity scenarios *(CO2-Base, CO2-CCS-H/L, CO2-NoCCS)*. In the *Base* scenario, existing polices (e.g. nuclear phase out, EU-ETS prices) are included while the low carbon *(CO2-Base)* scenarios are aimed to reduce the CO2 emissions from the electricity sector by 95% of 1990 levels by 2050 – similar to the EU energy Roadmap 2050 [2]. Given the technical uncertainties in CCS technology [11] and its social acceptability [12], we analyse three further variants of the low carbon scenario namely, one without CCS technology (*CO2-NoCCS*) and two variants via high and low carbon storage potentials *(CO2-CCS-H/ CO2-CCS-L)* [13]. The variants on storage potentials are based on a set of assumptions for each of the five countries based on technology adoption rate, realization of theoretical potentials, availability of onshore storage, etc. The CCS potentials are specified at a country level and cross border CO_2 transport is not allowed, implying that the CO_2 captured in one country must also be stored in the same country. The "high CCS" variant *(CO2-CCS-H)* assumes a storage potential of 128 Mt-CO_2 per year by 2050, which is about 25% of the theoretical estimates [13] whereas the "Low CCS variant *(CO2-CCS-L)* assumes a storage potential of 10% of the theoretical storage potential (i.e. 27 Mt-CO_2 per year) [13]. The CCS potential for the low carbon base scenario *(CO2-Base)* is assumed as the average of the high and low potentials.

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[1] **T**he **I**ntegrated **M**ARKAL/**E**FOM **S**ystem framework [9]

Results

The model outputs are the electricity generation mix, installed capacity, generation costs and marginal costs of electricity for each country, over the entire modelling time horizon. The analysed results demonstrate how different countries adapt their technology choices to meet the proposed CO_2 emission reduction target of 95% (of 1990 levels) by 2050. Figure 1 gives the aggregated electricity generation mix of the five countries for the 5 scenarios by the year 2050. While the differences between the *Base* scenario and the low carbon scenarios *(CO2-*)* are obvious, the impacts of different CCS potentials on technology choice are highlighted between the various low carbon scenarios. Hence while the *CO2-Base* scenario uses a combination of coal CCS, gas and renewable technologies (besides the nuclear and hydro technologies common to all the scenarios) to meet the demand, the "High-CCS" *(CO2-CCS-H)* scenario is able to provide more base load generation in the form of coal CCS and reduce the share intermittent renewables such as solar. The "low-CCS" *(CO2-CCS-L)* scenario on the other hand sees a switch from coal CCS to gas CCS as base load, due to the lower emissions from gas. Finally, the "No-CCS" (*CO2-NoCCS*) scenario indicates that the five countries would not be able to meet their demands domestically, and would need imports from surrounding countries.

The changes in country wise generation mixes are also apparent between the scenarios (not shown here). The model generates demand load profiles and optimal operational patterns of various renewable and non-renewable generation technologies, as well as import/export profiles between countries, under various external constraints. An example is provided in figure 2, which shows the supply-demand profile for Germany on a summer weekday in 2050, for the *CO2-Base* scenario. The results show how Germany relies on a large share of renewables (65% of total generation) as well as a considerable amount of imports (21%) to meet its demand. This is because, in the *(CO2-Base)* scenario, most of the CCS potential is attributed to Italy, with France and Germany having low CCS potential, resulting in Germany having an increased dependence on base-load generation from Italy and/or France. In the *(CO2-CCS-H)* scenario (not shown), both France and Germany also have considerable CCS potential, thereby reducing the dependence on imports from Italy.

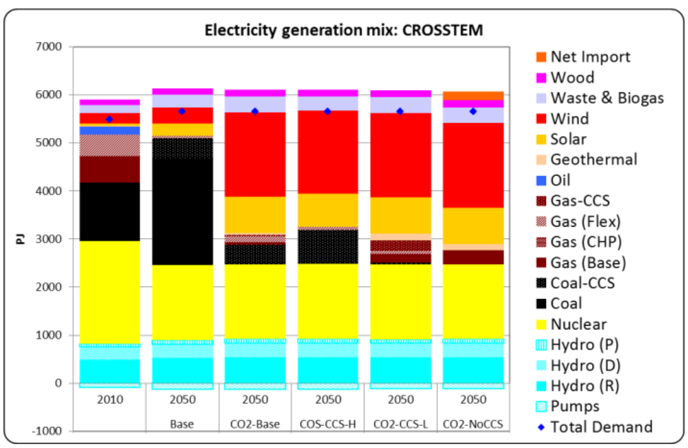

Fig. 1: CROSSTEM Electricity generation mix

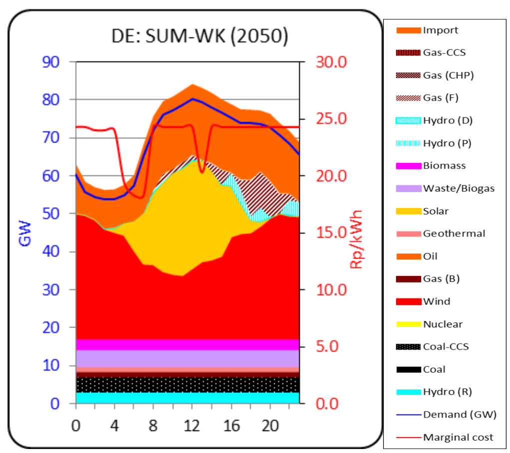

Fig. 2: Germany – load balance profile *(CO2-Base)*

Conclusions

The multiregional electricity model generated insights on the future technology mix and their load balancing mechanism for the five countries. Preliminary results illustrate the different low carbon electricity pathways under different CCS potentials, and how the presence of CCS is vital in achieving the CO_2 emission reduction targets. Differences in potentials result in differing deployments of CCS in various countries, but with higher market liberalisation and optimal import/export patterns, opportunities in one country can be exploited for the benefit of the entire system.

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