The future European power system under a full and a partial nuclear phase-out policy

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(1) Overview

The recent nuclear power policy adopted by the German government in 2011, a full phase out of nuclear power from the German energy mix by 2022, introduce interesting challenges for Europe's collective capacity to mitigate greenhouse gas emissions. Typically, low emissions scenarios for future energy system development analyzed with so-called integrated assessment models (IAMs), see Parson and Fisher-Vanden (1997), include significant shares of nuclear energy in the power sector, (Fischedick et al. 2011). As Germany, the second largest producer of nuclear energy in Europe[1] with about 15 % of the total installed capacity and generation, shut down their plants low carbon scenarios with a high nuclear share in the European energy mix might seem unrealistic. On the other hand, other European countries with a high share of nuclear power, such as for instance France and the UK, have not adopted a phase-out policy. Therefore, nuclear power can potentially still be an important technology for helping reduce carbon emissions in Europe. This paper presents an analysis of the development of European power system where we take into account long-term climate stabilization targets from an integrated assessment model and the current policy on nuclear power in Germany. Two different scenarios are studied, one where nuclear power is available in countries without a phase-out policy and one where all nuclear power capacity in Europe is retired by 2050. The analysis will focus on how the different polices influence optimal investments in generation and transmission capacity in Europe.

(2) Methods

In this paper we apply a modeling framework in which a top-down integrated assessment model, GCAM, is soft-linked with a more detailed power system capacity expansion model. First, a pre-defined policy scenario aimed at limiting CO_2-e concentration to a given level is analyzed using GCAM (Calvin et al. 2009, Clarke et al. 2008). In GCAM, which is a partial equilibrium model, the world is divided into 14 regions and Europe comprises the two regions, Western Europe and Eastern Europe. Results from the policy scenario include annual demand for energy, the energy fuel mix, fuel prices, and a carbon tax in each region. These results are then disaggregated to national levels and used as input parameters in a capacity expansion model of the European power system. The capacity expansion model is formulated as a least cost planning problem where optimal expansions of generation capacity and inter-country transmission capacity are computed given the demand projections and energy fuel mix from GCAM as constraints. This approach allows us to investigate the equilibrium solution provided by GCAM in further detail, and aims at aiding our understanding of where it would be optimal to build new renewable energy production and what transmission capacity reinforcements are necessary. In order to capture variability of intermittent resource production the capacity expansion model is formulated as a two-stage stochastic optimization problem, see Birge and Louveaux (2011), with operational uncertainty in generation from intermittent resources and load. The first stage decisions are the investments in 5 year time steps from 2010 to 2060, while the second stage problem is finding the optimal operation of the system given the investments.

(3) Results and conclusions

The result section will feature an analysis of two GCAM scenarios, both with a targeted 650 ppm CO_2-e concentration stabilization over course of the next century. Assumptions in the two scenarios are the same except for a restriction in technology availability in one where nuclear power is phased-out completely and there is no available CCS technology. In the capacity expansion model Germany's policy of nuclear power phase-out is adopted for both GCAM scenarios. A comparison of the results from the two scenarios will be provided and special attention will be given to how a full nuclear phase-out versus a partial nuclear phase-out in Europe affects optimal investments in renewable energy resources and the transmission system. Figure 1 shows the electricity mix from GCAM for the two policy scenarios and the reference (no policy) scenario.

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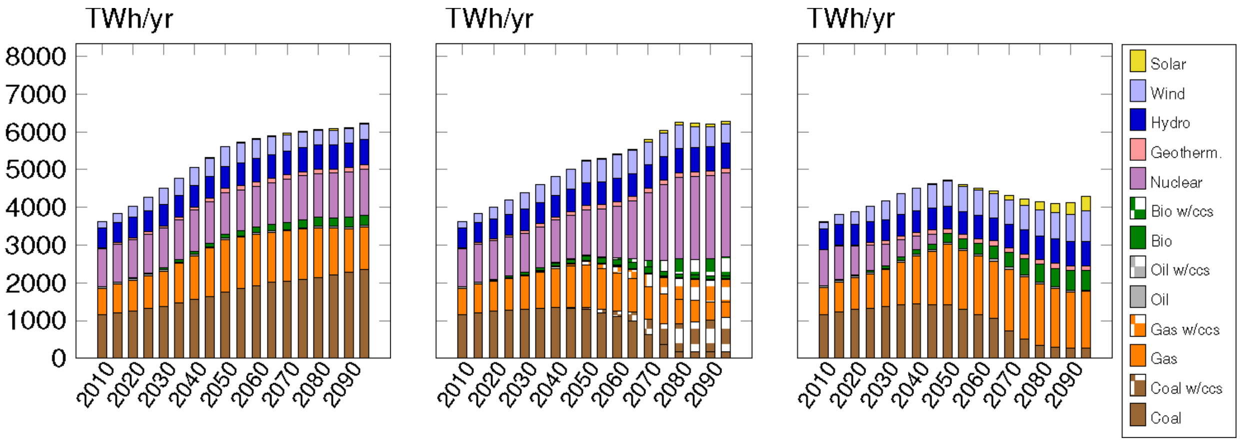
[1] In 2012 Germany had about 20,480 MW installed nuclear power generation capacity which generated 140.56 TWh that year. The total for the EU-27 countries was 132,497 MW installed capacity and a generation of 916.6 TWh in 2012 (European Commission 2012).



a) Electricity mix in Europe in the reference scenario

b) Electricity mix in Europe in 650 ppm scenario

c) Electricity mix in Europe in the 650 ppm scenario without nuclear or CCS technology available

Fig. 1: Electricity mix in Europe (WE+EE) calculated by GCAM for the two different 650 ppm scenarios and for a reference scenario.

References

Birge, J. R., and F. V. Louveaux. 2011. *Introduction to stochastic programming*. 2nd ed. New York, NY: Springer.

Calvin, K., J. Edmonds, B. Bond-Lamberty, L. Clarke, S. H. Kim, P. Kyle, S. J. Smith, A. Thomson, and M. Wise. 2009. "2.6: Limiting, climate change to 450 ppm CO_2 equivalent in the 21st century." *Energy Economics* no. 31:S107-S120.

Clarke, L. , M. Wise, J. Edmonds, M. Placet, P. Kyle, K. Calvin, S. Kim, and S. Smith. 2008. CO_2 Emissions Mitigation and Technological Advance: An Updated Analysis of Advanced Technology Scenarios. Richland, WA: Pacific Northwest National Laboratory.

European Commission. 2012. EU Energy in Figures – Statistical Pocketbook 2012. Luxembourg: Publications Office of the European Union.

Fischedick, M., R. Schaeffer, A. Adedoyin, M. Akai, T. Bruckner, L. Clarke, V. Krey, I. Savolainena, S. Teske, D. Ürge-Vorsatz, and R. Wright. 2011. *Mitigation Potential and Costs*. Edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer and C. von Stechow, *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Parson, E. A., and K. Fisher-Vanden. 1997. "Integrated assessment models of global climate change." *Annual Review of Energy and the Environment* no. 22:589-628.