Emission Pathways towards a Low-Carbon Energy System for Europe: A Model-Based Analysis of Decarbonization Scenarios

Karlo Hainsch,[a] Thorsten Burandt,[b] Konstantin Löffler,[c] Claudia Kemfert,[d] Pao-Yu Oei,[c] and Christian von Hirschhausen[c]

Overview and Motivation

The European Union (EU) has declared several climate goal targets, which should lead to an energy system with almost no greenhouse gas (GHG) emissions until 2050 (European Comission 2018). While the focus of the scientific community in recent years was heavily set on decarbonizing the electricity sector (Gerbaulet et al. 2019; Child et al. 2019), an integrated approach of including all energy sectors (power, heat, and transportation) offers the benefit of capturing interdependencies between them. Therefore, the European Commission (2018) uses the PRIMES framework, an energy system model, to analyze possible pathways for the European energy system. However, the framework shows a substantial lack of transparency with respect to model setup and data, which impedes further analyses and verification. Our work aims to bridge that gap, providing insights from the Global Energy System Model (GENeSYS-MOD) about the European energy system under different climate scenarios.

Methods

This paper presents different scenarios based on the regional distribution of the available CO_2-budget to keep the global mean temperature well below 2° Celsius. To analyze these scenarios, the "Global Energy System Model" (GENeSYS-MOD) by Löffler et al. (2017) is used. GENeSYS-MOD is a full-fledged energy system, originally based on the existing "Open Source Energy Modelling System" (OSeMOSYS) created by Howells et al. (2011). The model uses a system of linear equations of the energy system to search for lowest-cost solutions for a secure energy supply, given externally defined constraints on GHG emissions. In particular, it takes into account increasing interdependencies between traditionally segregated sectors, e.g., electricity, transportation, and heating. For our approach, we aggregated European countries into 17 geographic regions, calculating energy- and resource-flows to meet power, heat, and transport demands. The installed capacities in 2015 serve as a starting point for further investment, production, trade, and salvage decisions which are calculated by the model. Several European limits of emitting CO_2 corresponding to common emission pathways (1.5°C, 2°C, BAU) are analyzed. The BAU case assumes a carbon price, while the climate goal scenarios set carbon budget constraints in line with the respective goal. In these

a Corresponding author. Workgroup for Infrastructure Policy, Technische Universität Berlin. Send correspondence to Workgroup for Infrastructure Policy, Secretariat H33, Straße des 17. Juni 135, 10629 Berlin, Germany. E-mail: kh@wip.tu-berlin.de.

b Workgroup for Infrastructure Policy, Technische Universität Berlin, Department of Energy, Transport, Environment, German Institute for Economic Research (DIW Berlin), and Department of Industrial Economics and Technology Management (IØT), Norwegian University of Science and Technology (NTNU).

c Workgroup for Infrastructure Policy, Technische Universität Berlin and Department of Energy, Transport, Environment, German Institute for Economic Research (DIW Berlin).

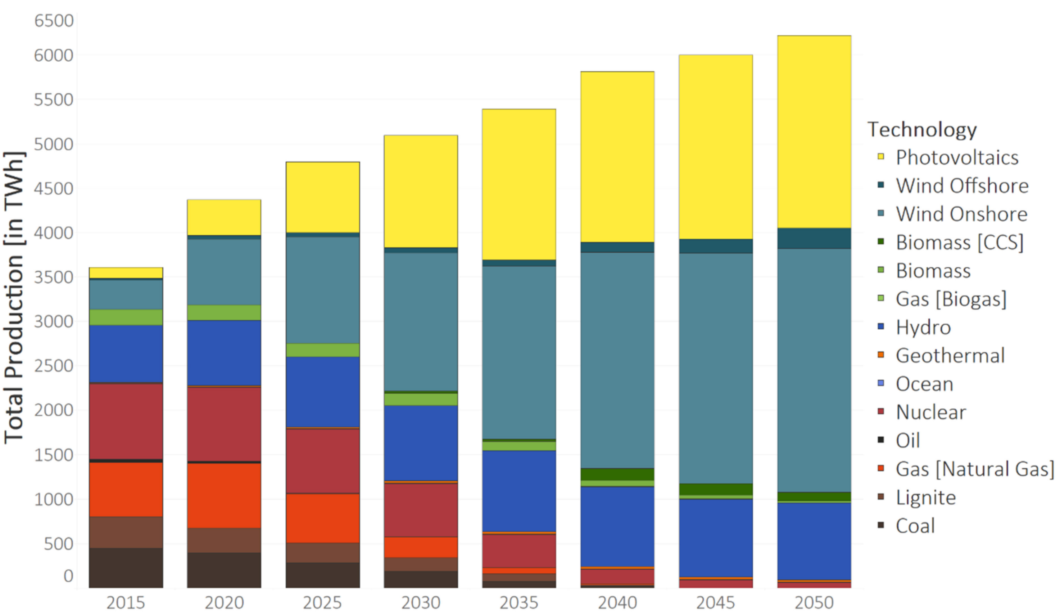
d Energy Economics and Sustainability, Hertie School of Governance, Department of Energy, Transport, Environment, German Institute for Economic Research (DIW Berlin), and German Advisory Council on Environment (SRU).

latter cases, we also apply different distribution mechanisms of said budgets to the modeled regions based on economic indicators (free distribution, by GDP, by population, and by current emissions).

Results

As a result, in the base scenario, we were able to model a possible path towards a renewable and almost climate-neutral European energy system in 2050 which would be in line to keep global mean temperature below 2° C. This implies the phase-out of fossil fuels, which happens at different rates for the power, heating, and transportation sectors. The power sector is leading the change to renewables since the electrification of the other sectors is only beneficiary if the required electricity is produced through clean technologies. A significant reduction of fossil-fuel based power generation is required within the next ten years. Both the heating and transportation sectors experience a slower rate of change, depending on the regional configuration of the power sector. 90% of the remaining available emissions are emitted until the year 2035, after which the difficult to decarbonize processes in the high-temperature heating, as well as means of transportation, are tackled. As expected, a stricter carbon budget in line with a 1.5° C target results in a quicker decarbonization of the electricity sector. In contrast, a BAU pathway still shows conventional technologies in 2050, especially in the high-temperature heating sector. While limiting global warming to less than 1.5° C results in a cost increase of roughly 25% compared to 2° C, the BAU scenario barely outperforms said 2° C scenario by 3%, even though the assumed carbon price is rather conservative.

Figure 1: Development of European power generation in the base scenario (2°C without national budgets); Source: Own illustration



Conclusions

The paper provides two major contributions: model-based calculations indicate that decarbonization of the European energy system in line with climate goal targets can be economically and technologically feasible. Second, by contributing a significant piece of modeling to the community, open-access with fully transparent code, data, and results, we contribute to the scientific debate and the transparency of analysis, thus strengthening the political debate with scientific substance.

References

Child, Michael, Claudia Kemfert, Dmitrii Bogdanov, and Christian Breyer. 2019. "Flexible Electricity Generation, Grid Exchange and Storage for the Transition to a 100% Renewable Energy System in Europe." *Renewable Energy* 139 (August): 80–101. https://doi.org/10.1016/j.renene.2019.02.077.

European Comission. 2018. "Clean Planet for All. A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy." Communication from the Commission COM(2018) 773. Brussels, Belgium: EC.

Gerbaulet, Clemens, Christian von Hirschhausen, Claudia Kemfert, Casimir Lorenz, and Pao-Yu Oei. 2019. "European Electricity Sector Decarbonization under Different Levels of Foresight." *Renewable Energy*, March. https://doi.org/10.1016/j.renene.2019.02.099.

Howells, Mark, Holger Rogner, Neil Strachan, Charles Heaps, Hillard Huntington, Socrates Kypreos, Alison Hughes, et al. 2011. "OSeMOSYS: The Open Source Energy Modeling System: An Introduction to Its Ethos, Structure and Development." *Energy Policy*, Sustainability of Biofuels, 39 (10): 5850–70. https://doi.org/10.1016/j.enpol.2011.06.033.

Löffler, Konstantin, Karlo Hainsch, Thorsten Burandt, Pao-Yu Oei, Claudia Kemfert, and Christian von Hirschhausen. 2017. "Designing a Model for the Global Energy System—GENeSYS-MOD: An Application of the Open-Source Energy Modeling System (OSeMOSYS)." *Energies* 10 (10): 1468. https://doi.org/10.3390/en10101468.