Infrastructure Requirements for Regional and Inter-Temporal Integration of Fluctuating Renewable Generation in Germany

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In recent years, Germany has experienced substantial growth in renewable energy. According to the National Renewable Energy Action Plan, variable renewable electricity generation from wind and solar power will continue to increase significantly over the next decade. Integrating these variable renewables into the electricity grid is a major challenge. Several strategies are currently being discussed. These include power storage, transmission grid expansion, demand-side measures (DSM), conventional backup power plants, and feed-in management of variable renewables. In this study, we employ a technical-economic analysis to determine a cost-minimizing combination of investments into such integration measures. We focus on the year 2023, in which the remaining nuclear capacity in Germany will be phased out.

We use a combined dispatch and network model with a DC load flow approach. The German high voltage transmission network is represented with over 300 nodes and more than 500 lines. We use an hourly time resolution, covering all subsequent hours of the year 2023. Exogenous model parameters include nodal power demand, thermal and renewable generation capacity, renewable feed-in patterns, variable generation costs and baseline transmission capacity. As for these parameters, changes compared to the status quo are estimated according to governmental and semi-official projections.

In a first model run, we determine nodal market outcomes for all hours of the year 2023 (scenario B of the German network development plan) under the assumption that no additional investments into renewable integration measures have taken place. We are particularly interested in the frequency, duration, and location of (i) renewable surplus generation and (ii) critical shortages of power supply. In a second model run, we allow endogenous investments into storage, and transmission expansion, and determine a cost-minimizing combination of these investments. In addition, wind and solar power may be curtailed.

Importantly, the modeled integration measures “compete” for dispatch in periods of shortage and/or excess renewable supply. We are interested in analyzing their interrelation on a regional level for different capacities of renewables in the German electricity market.