LARGE-SCALE INTEGRATION OF FLUCTUATING RENEWABLES: THE ROLE OF STORAGE

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Overview

According to the German government's Energy Concept, renewables should account for at least 80% of gross power demand by 2050 (BMWi and BMU, 2010). In a carbon-constrained future, comparable or even higher shares of renewables may be required in many countries as greenhouse gas mitigation options outside the power sector appear to be comparatively expensive (cf. IPCC 2014). Due to limited potentials of dispatchable hydro power and biomass in Germany, achieving such high shares of renewables requires the massive deployment of fluctuating wind and solar power. A cost-efficient future power system largely based on variable renewables not only requires an appropriate mix of different generation technologies, but also the utilization of dedicated flexibility options such as flexible thermal backup capacity or power storage (NREL 2012). In this study, we carry out a model-based long-term analysis to determine cost-minimizing combinations of generation and storage capacities, depending on distinctive assumptions on the future costs and availability of different storage options. Whereas our green-field analysis is parameterized to loosely reflect the German system, our simulation is setup is rather general in nature, such that the findings are also relevant for other countries moving toward high shares of fluctuating renewables.

Methods

We use a linear cost minimization model that simultaneously optimizes capacity investments and dispatch – where we base our analysis on a full year with hourly resolution. The model is implemented in GAMS and solved with the commercial solver CPLEX. The hourly resolution features a detailed treatment of inter-temporal constraints related to the operation of storage facilities. Compared to earlier analyses (e.g., Bussar et al. 2014), we not only include power demand on the wholesale market, but also the provision of operating reserves. This allows us, in contrast to many other studies, to comprise three relevant system values of storage facilities: i) a capacity value, ii) an arbitrage value, and 3) a value related to the provision of reserves. To be more precise, we include both secondary control reserve and minute reserve, capturing distinct temporal dimensions of flexibility required to back up large-scale integration of fluctuating renewables (primary control, in contrast, is assumed less relevant as it may be provided by virtually any generator or dedicated power electronics). Exogenous parameters include power demand and the provision of control reserves, specific investments and operational costs of thermal and renewable generators as well as of storage facilities, and historic time-series of renewable availability. We consider three stylized storage technologies with different specific investments related to both charging/discharging and energy capacity. The deployed capacities of different technologies as well as the hourly dispatch of these capacities are all endogenous model variables. As for storage, also the optimal energy-to-power ratio is determined as model outcome.

Preliminary Results

We compare the outcomes of various scenarios with different shares of renewables (80%, 90%, and 100%) and varying assumptions on the costs and availabilities of the three stylized storage technologies. We compare total system costs, investments, technology shares as well as renewable curtailment and CO_2 emissions. Preliminary results indicate that wind capacities dominate PV capacities in all scenarios. In the 100% renewable scenario, disproportionately high investments are required compared to the 80% and 90% scenarios. In particular, storage capacities are very large in the 100% scenario. Among the different storage technologies, long-term storage generally seems to dominate. We find that higher storage costs and lower storage availabilities have a substantial impact on the capacity mix and on system costs. In particular, low-cost long-term storage options considerably decrease system costs. Interestingly, results change considerably when the provision of control reserves is not included; specifically, less storage is required.

Conclusions

We analyze cost-optimalinvestments in generation and storage for different scenarios of very high shares of fluctuating renewable power generation. Overall system costs of the 100% scenario are relatively high compared to other scenarios with lower shares of renewables; for those, however, overall power system costs are surprisingly low. Both system costs and the optimal capacity mix vary substantially with different assumptions on storage costs and availabilities. The availability of low-cost storage appears to be particularly beneficial in the context of very high renewable shares. Accordingly, policy makers should actively promote R&D for storage at an early stage, even if there is no need for additional storage facilities in the short run. To draw a modeling-related conclusion, we find that the consideration of operating reserves substantially increases optimal storage deployment. Earlier analyses which have only considered other value streams of storage, thus, may have substantially underestimated storage requirements.

References

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