LONG-TERM ELECTRICITY MARKET EQUILIBRIA WITH STOCHASTIC RENEWABLE INFEED AND STORAGE

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Overview

Renewable energy sources (RES) in the electricity system increase the need for flexible balancing of supply-dependent infeed – storage is thereby one important option. We formulate the long-term partial equilibrium model for competitive electricity markets with conventional generation, storage and stochastic infeed represented by a stationary Markov process. We explore the role of precautionary storage both using a stochastic program and using a mixed complimentarity problem formulation. It turns out that storage profitability is enhanced both by deterministic variations of net demand and mean reverting stochastic variations of net demand. Precautionary storage gets particularly relevant with low deterministic and high stochastic fluctuations.

Methods

Optimal storage operation and investment have been addressed in literature using multiple methods. Thereby the perspective of a single operator may be distinguished from an system-oriented analysis. A further distinction is between short-term models with fixed capacities and long-term models with endogenous investment decisions. Methods like stochastic dynamic programming (SDP), stochastic dual dynamic programming (SDDP) and approximate stochastic programming (ASDP) have been successfully implemented to derive optimal storage operation under uncertainy at given capacities – both for single operators and in a system perspective. Yet for long-term modelling with capacity so far deterministic approaches based on linear or mixed integer programs dominate.

The present paper contributes therefore a novel approach that formulates the optimal operation and investment decisions in a partial equilibrium framework (system perspective) including uncertainty notably regarding renewable infeed. It thus avoids the pitfalls of deterministic approaches that provide optimal solutions under an unrealistic assumption of perfect foresight of renewable infeed.

The approach includes modelling the renewable infeed as a stationary Markov process and formulating the optimal operation decisions under uncertainties using the Bellmann principle. In the equilibrium formulation, optimal operation and investment decisions are determined simultaneously with the dual variables that represent the prices and scarcity rents in all system states. Thereby an approach analogous to the Benders decomposition is applied to describe the value function for the storage filling level. This yields a mixed-complimentarity problem.

For the solution of the problem, three methods are explored: a first version simplifies the problem in order to obtain a stochastic linear optimization problem. In the second approach, a problem specific iterative solution approach is implemented including a grid-search approach for determining optimal storage capacities. The third approach finally makes use of standard MCP solvers like PATH to solve the problem in an integral way.

Results

Preliminary results have been obtained sofar for the first two methods with a stylized case study based on German data. They indicate that storage is an important complement to variable renewable energy sources albeit it is competing with other flexibility sources such as conventional peaking units or demand curtailment. Thereby, storage is particularly advantageous if there are predictable fluctuations in the renewable infeed.

The results will be expanded to highlight the role of different infeed patterns and different availability of storage technologies – as both generation of variable renewables like solar and wind and storage potentials for hydro are highly location-dependent.

Conclusions

As it stands, the novel approach allows general insights into the role of storage in the transition to sustainable energy systems. By providing a comprehensive yet reduced problem formulation, the impact of locally varying factors (weather, topography) may be investigated in a coherent framework. The approach may be further extended to include further details like grid restrictions or multiple sources of uncertainty.