Optimal Allocation of Variable Renewable Energy Considering Contributions to Security of Supply

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Recent cost reductions suggest that the cost-optimal decarbonization of the electricity sector will to a substantial part be based on variable renewable energy sources (VRE). Electricity generation from VRE differs from dispatchable power generation in its pronounced dependency on weather conditions. These weather-induced variations show spatial dependencies and are not perfectly predictable. Accordingly, there arise important implications for reliability of supply in power systems as electricity is only storable at comparatively high cost and the supply-demand balance has to be maintained at all times in order to prevent outages.

Reliability of supply has always been a major concern in electricity systems as outages incur high economic losses. With increasing shares of VRE, reliability issues gain further importance due to the variability, spatial dependency and imperfect predictability of electricity generation based on VRE and the resulting risk of unavailability during times of stress. VRE resources are typically less correlated on a wider geographical scope, which reduces fluctuations because of imperfectly correlated generation patterns at different locations (balancing effects). Hence, markets can benefit from these balancing effects via interconnections and cross-border cooperation. Envisaged reliability levels can thereby be reached at lower costs compared to reliability measures restricted to national borders. Against this background, the following research question arises: What is the optimal mix and allocation of VRE capacity in order to benefit from balancing effects both in generation and contribution to security of supply to reach an envisaged reliability target?

Typically, generation patterns of wind and solar power plants at different locations are positively correlated. Therefore, the ability of one unit of VRE generation capacity to substitute firm capacity, which is referred to as its capacity value (or capacity credit), declines as the share of VRE in total generation increases. Nevertheless, economic long-term simulation models for electricity markets, which are widely used in scientific and political practice, often assign fixed exogenous capacity values to wind and solar generation and neglect cross-border effects for reasons of simplification and computational tractability.

Against the described backdrop, this paper develops a new methodology to endogenously determine the contribution of VRE to security of supply in a long-term partial equilibrium model for electricity markets. The proposed methodology builds on an iterative approach, which captures the non-linear dependency of the capacity value of VRE on installed capacity and its spatial distribution considering cross-border cooperation via interconnectors. The methodology therefore determines cost-minimal investment into power plants taking into account electricity generation as well as provision of security of supply of VRE, while keeping computational tractability in a large-scale application. After introducing our methodology, we apply it in a first step to a simple two-country example. Building on that, we extend it to the European electricity system to determine an optimal decarbonization pathway until the year 2050, starting from the existing power plant fleet. Our analysis focuses on wind power, however the presented approach can be applied to all VRE technologies. We build the analysis on a new dataset, which is based on meteorological reanalysis data featuring

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a high spatial and temporal resolution. The data is therefore well suited to optimally capture the stochastic properties of wind generation and the resulting contribution to security of supply.

We show that the proposed methodology is capable to endogenously determine the capacity value of wind power in large-scale investment and dispatch models for electricity markets. The results of the large-scale application imply that wind power can substantially contribute to security of supply in a decarbonized European electricity system cooperating with respect to reliability, with an average wind power capacity value of 13% in 2050. Additionally the results show that the capacity value of wind power is heterogeneous across different regions and years, which is a result of varying wind conditions as well as increasing total installed capacities and technological innovation over time. Existing modeling approaches, which typically assign constant exogenous capacity values for wind power, therefore result in inefficient levels of dispatchable capacities, which are required to guarantee security of supply in electricity systems with high shares of VRE. In our application for the European electricity system, the additional yearly costs for firm capacity provision when applying exogenous fixed wind power capacity values of 5% compared to endogenous capacity values amount to 1.5 and 3.8 bn EUR in 2030 and 2050, respectively, which represents additional costs of 3% and 7%. Finally our results suggest that European market integration can substantially improve the contribution of wind power to security of supply due to cross-border balancing effects.