RESIDUAL LOAD, RENEWABLE SURPLUS AND STORAGE REQUIREMENTS FOR RENEWABLE INTEGRATION IN GERMANY

Wolf-Peter SCHILL
DIW Berlin, Department Energy, Transportation, Environment, Mohrenstraße 58, 10117 Berlin
wschill@diw.de

(1) Overview

A key feature of the German „Energiewende“ is a shift towards variable renewable power sources like wind and photovoltaics (PV). According to the medium-term scenario of the network development plan drafted by German TSOs, onshore and offshore wind could account for around 45% of gross power demand by 2032, whereas PV could contribute around 10% (NEP 2012, scenario 2032B). Afterwards, the shares of wind and solar are projected to grow further until 2050 (DLR et al. 2012). The hourly feed in of both wind and PV is only weakly correlated with hourly load profiles. Growing shares of these technologies thus have a strong influence on residual load, for example resulting in temporary situations of power shortage or renewable surplus generation (Consentech and r2b 2010, Denholm and Hand 2011). Integrating growing amounts of wind and PV into the power system increasingly requires the application of dedicated integration measures, for example storage, demand-side measures, network expansion, conventional back-up and renewable curtailment (Dena 2010, Steffen and Weber 2013,VDE 2012a).

In this paper, we focus on renewable surplus generation, storage and curtailment and aim to answer two research questions. First, we are interested in the future development of German residual load under a range of varying assumptions. In particular, we analyze the nature of renewable surplus generation (power, energy, and duration). Second, we determine how much storage of different technologies would be required for taking up temporary renewable surpluses. We specifically explore the interrelation of storage and renewable curtailment: how are storage requirements reduced if increasing levels of renewable curtailment are tolerated? Noticeably, the analysis includes a large number of sensitivities. We consider different renewable expansion scenarios, different developments of load and must-run restrictions, various meteorological wind and PV years, as well as different levels of biomass flexibility.

(2) Methods

We rely on the scenarios of the 2012 German network development plan for renewable and conventional generation capacities (NEP 2012). Load data is retrieved from ENSTO-E and official German statistics. The methodology for determining residual load, renewable surplus and load gradients is straightforward. First, we calculate normalized hourly utilization of installed onshore and offshore wind capacities as well as PV from actual feed-in data for all years for which such data is available (2006-2012 for wind onshore, 2010-2012 for wind offshore, 2011-2012 for PV). We then calculate hourly renewable generation of the given scenario and subtract it from hourly load, considering must-run requirements. As for renewable surplus, we not only determine excess power, but also “connected surpluses”, i.e. total surplus energy of all contiguous excess renewable generation events in a given year.

In order to determine the storage investments required for taking up renewable surplus generation, we use a stylized linear dispatch and investment model (cost minimization). Decision variables include hourly dispatch of conventional technologies and existing pumped storage as well as investment into new storage capacities, their hourly utilization, and renewable curtailment. Storage investments can be made in three stylized technologies: hourly battery storage, daily pumped storage, and seasonal power to gas storage. We do not explicitly model CHP and must-run restrictions, but assume varying levels of must-run. Generation from biomass is either assumed to be perfectly inflexible, or to be flexible, using an energy cap for the whole year. Given the large number of sensitivities, we make the simplifying assumption of Germany as a copper plate. Furthermore, we abstract from cross-border transmission capacities (cp. Heide et al. 2011 for a related European analysis).

(3) Results

The simulation shows that a shift towards variable renewables according to the NEP scenarios decreases residual load substantially compared to the base year 2010, with some variation between different wind and PV years (Fig. 1). At the same time, hourly load gradients increase strongly (not shown here because of space restrictions). While the residual load peak is hardly affected, the right-hand sides of the load duration curves (off-peak) drop substantially with increasing renewables, resulting in noticeable surplus generation in the scenario with the largest renewable capacity expansion (2032B). Load-duration curves of surplus generation generally show high peaks, but very low full-load hours. Surplus increases with both increasing must-run requirements and decreasing load (Fig. 2).Looking not at surplus power, but at surplus

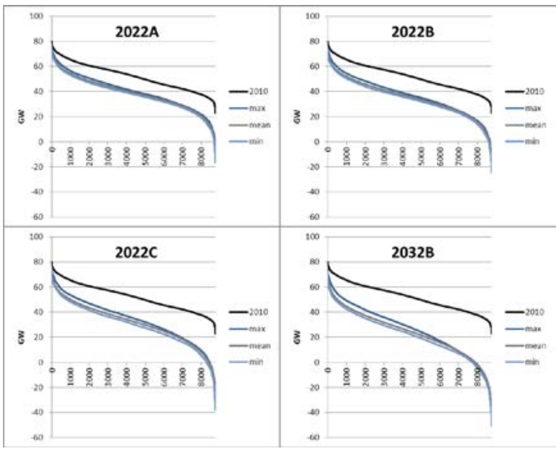

Fig. 1: Residual load for varying wind and PV years

energy ("connected surpluses"), we find that more than 50% of all contiguous surpluses are smaller than the energy capacity of existing German pumped hydro storage (around 40 MWh). This is true for all NEP 2012 scenarios until 2032, assuming non-decreasing load, no must-run requirements, and flexible biomass. Increasing must-run requirements strongly increase maximum surplus energy. Noticeably, extreme values of surplus energy strongly depend on wind years (Fig. 3).

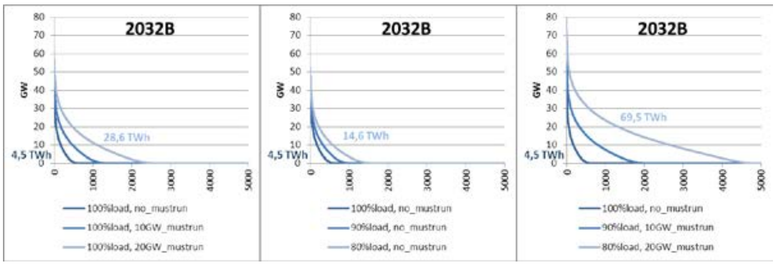

Fig. 2: Renewable surplus for varying assumptions on must-run and load

As for storage investments required for taking up renewable surplus generation, we find substantial daily storage requirements in all NEP scenarios if no curtailment is tolerated. However, allowing curtailment of up to 1% of yearly variable renewable generation already reduces the demand for storage to zero in most scenarios, assuming flexible biomass generation and no must-run requirements. Increasing assumptions on must-run strongly increase storage demand and also lead to a shift towards seasonal storage. Again, we find a strong influence of different wind years. Finally, we relate storage investment costs to avoided energy curtailment. Avoiding renewable curtailment by means of storage results in extremely high specific costs (in €/MWh). These costs exceed base power prices by 1-3 orders of magnitude.

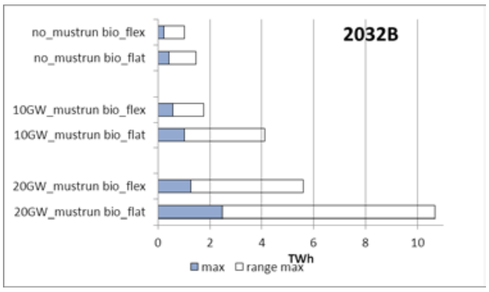

Fig. 3: Extreme values of "connected surpluses"

(4) Conclusions

We analyze residual load, renewable surplus generation and storage capacities required for taking up renewable surpluses for the scenarios of the 2012 German network development plan, considering numerous sensitivity analyses. The expansion of variable renewable sources like wind and PV hardly decreases peak residual load, but substantially reduces full-load hours of remaining conventional power plants and at the same time increases load gradients. Renewable surpluses are negligible in terms of yearly energy in most cases, but hourly excess power can become very high by 2032. Storage investments for taking up renewable surpluses are largely obsolete if some curtailment is tolerated. If storage is used as the only mean to take up renewable surplus generation, specific "curtailment avoidance" costs become prohibitively high. Renewables' shares of total power generation are hardly affected by curtailment, while system costs decrease substantially.

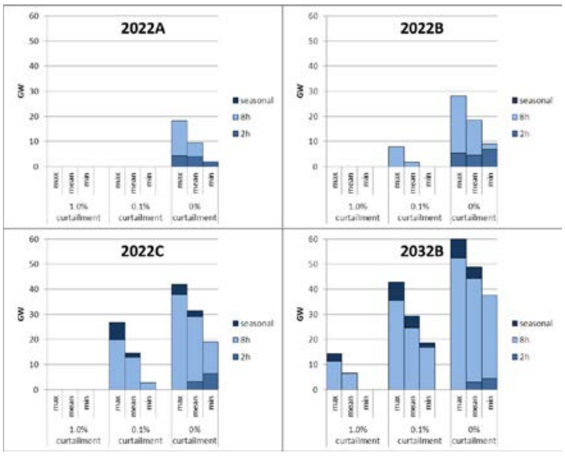

Fig. 4: Storage investments for different curtailment levels

We conclude that additional power storage capacities for taking up renewable surpluses are not necessary in Germany in the medium term. This is even more true if additional options for taking up surpluses like heat storage or exports are considered. Accordingly, there is currently no need to promote large-scale power storage deployment. While this analysis focuses on Germany, the findings are also relevant for other countries shifting towards variable renewables.

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