Storage and balancing synergies in a fully or highly renewable pan-European power system

Through a parametric time-series analysis of 8 years of hourly data, we quantify the storage size and balancing energy needs for highly and fully renewable European power systems for different levels and mixes of wind and solar energy. By applying a dispatch strategy that minimizes the balancing energy needs for a given storage size, the interplay between storage and balancing is quantified, providing a hard upper limit on their synergy. An efficient but relatively small storage reduces balancing energy needs significantly due to its influence on intra-day mismatches. Furthermore, we show that combined with a low-efficiency hydrogen storage and a level of balancing equal to what is today provided by storage lakes, it is sufficient to meet the European electricity demand in a fully renewable power system where the average power generation from combined wind and solar exceeds the demand by only a few percent.