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The Battery Boom: Between Flexibility and Unpredictability for Grid System Operations. A Quantitative Foundation

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Batteries play a pivotal role in complementing electricity generation from renewable energy sources, especially photovoltaics. Currently, investors applied for grid connections of more than 500 GW in Germany alone. However, batteries can change their output on short notice. While this provides needed flexibility to the system, it makes system operations, in particular congestion management and related operational planning processes, more complicated.
The challenge for operational planning is that the processes preventing grid constraints take time: First, the TSO responsible needs to collect all data (i.e. planned nodal consumption and production). Second, the TSO needs to calculate resulting electricity flows and determine overloaded grid components. Third, redispatch measures to elevate these constraints need to be determined. Fourth, they need to be implemented: producers and/or consumers in various nodes need to react. The full integration of European day-ahead and intraday markets through day-ahead and intraday auctions as well as continuous trading also enables more interplay between European energy systems to increase social welfare. At the same time this could lead to more changes in batteries'schedules between day-ahead auction and physical delivery, which makes it more difficult to implement them in a congestion management process without restricting the change of the batteries'schedule.
Our paper provides a quantitative analysis of battery schedule variations in the context of the fully integrated European power market. The analysis is based on a Rolling Horizon optimization model encompassing the four short-term electricity market auctions, starting with the day-ahead auction (at noon on the day before delivery) and ending with the third intraday auction (at 10 am on the day of delivery). The model dispatches a stylized battery system using auction prices from June 2024 to July 2025. By comparing the auction schedules with each other, we quantify differences in the battery operating state and filling level. We find that nearly 50 % of all quarter hours in the intraday auctions deviate from the day-ahead schedule. By investigating days with extreme deviations, typically occurring on weekends, our analysis reveals that renewable forecast errors are a key driver of price formation and consequently battery dispatch. (This demonstrates that batteries react to price signals inflicted by updates in the information space.)

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