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From Model Optimality to Market Reality: Do Electricity Markets Support Renewable Investments?

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The transition to a climate-neutral energy system is one of the most pressing global challenges. It is scientifically well-established that achieving net-zero CO2 emissions is technically feasible and affordable. These studies are largely based on ex-ante fundamental capacity expansion models, where a central planner optimizes cost-minimal (or welfare-maximal) investments (e.g., in power plants) along the decarbonization pathway, assuming market participants will reach long-term equilibria and recover their investment costs.

While optimization models effectively identify cost-minimal transition pathways, they often fail to reflect economic realities. In practice, investment decisions are often made by private actors, relying on undistorted market signals rather than centralized planning. Consequently, optimal investment pathways from a system-cost perspective may not align with actual economic incentives. This study examines whether market signals provide sufficient incentives for investments in renewable technologies—ensuring their levelized costs are covered—or if state intervention (e.g., subsidies or market design adjustments) is necessary.

This research bridges two seemingly contradictory strands of literature: one emphasizing the technical feasibility of deep decarbonization, and the other highlighting the economic challenges posed by high shares of intermittent renewables and near-zero electricity prices. By developing a detailed open-source optimization model of the German wholesale electricity market, this paper assesses whether current electricity markets and policy frameworks provide adequate incentives for renewable energy investments on the path to net zero, and highlights where market design may fall short in ensuring sufficient long-term investment signals.

The wholesale electricity market consists of several trading layers. Long-term contracts are settled in forward and futures markets. Closer to real-time, electricity is traded on the day-ahead (spot) market, which plays a central role in price formation by matching supply and demand for each hour of the next day. In addition, intraday markets allow for balancing closer to delivery and ancillary services markets ensure system stability in real-time.

The spot market is particularly relevant to this study. It reflects the short-run opportunity market for generators, since it is the most liquid and price-relevant trading venue in the wholesale electricity system. Consequently, spot market outcomes serve as key investment signals, and understanding them is essential for assessing the feasibility of market-based decarbonization.

Our findings indicate that future wholesale electricity prices will remain elevated compared to pre-crisis levels, largely due to gas power plants being the marginal generator for over 5000 hours a year. Nevertheless, the economic profitability of renewables faces challenges. Photovoltaics suffer from low capture prices caused by cannibalization effects and frequent infra-marginal pricing due to significant capacity build-up. Conversely, onshore wind demonstrates better capture prices and could achieve financial self-sufficiency with higher carbon and gas prices.

The findings highlight that low capture prices, particularly for photovoltaics, can significantly deter private investment unless proper market interventions are implemented. This conclusion challenges a notion that is widely spread in literature, in asserting that declining market values stem from policy choices rather than a natural property of RES with higher market shares. Moreover, we argue that under the current market design, negative prices will counteract the benefits of a high carbon price. As such, dropping market values in high shares of renewables could be alleviated by market interventions without the need for subsidies. Market design reforms could help stabilize market-based revenues, enabling viable investment in renewables while supporting the planned capacity expansion goals.

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