Coupling Market Incentives to Physical Power Flow: An Agent-Based Approach

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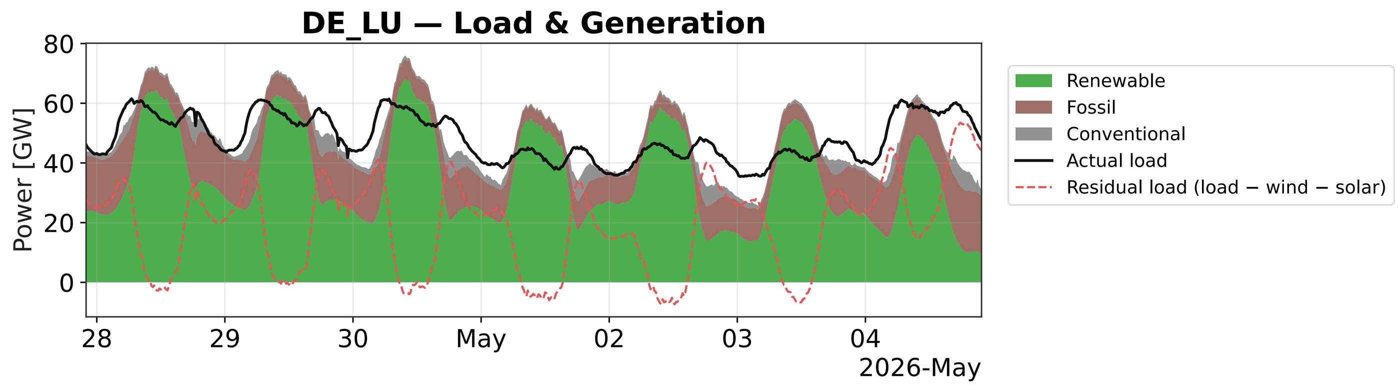
Introduction

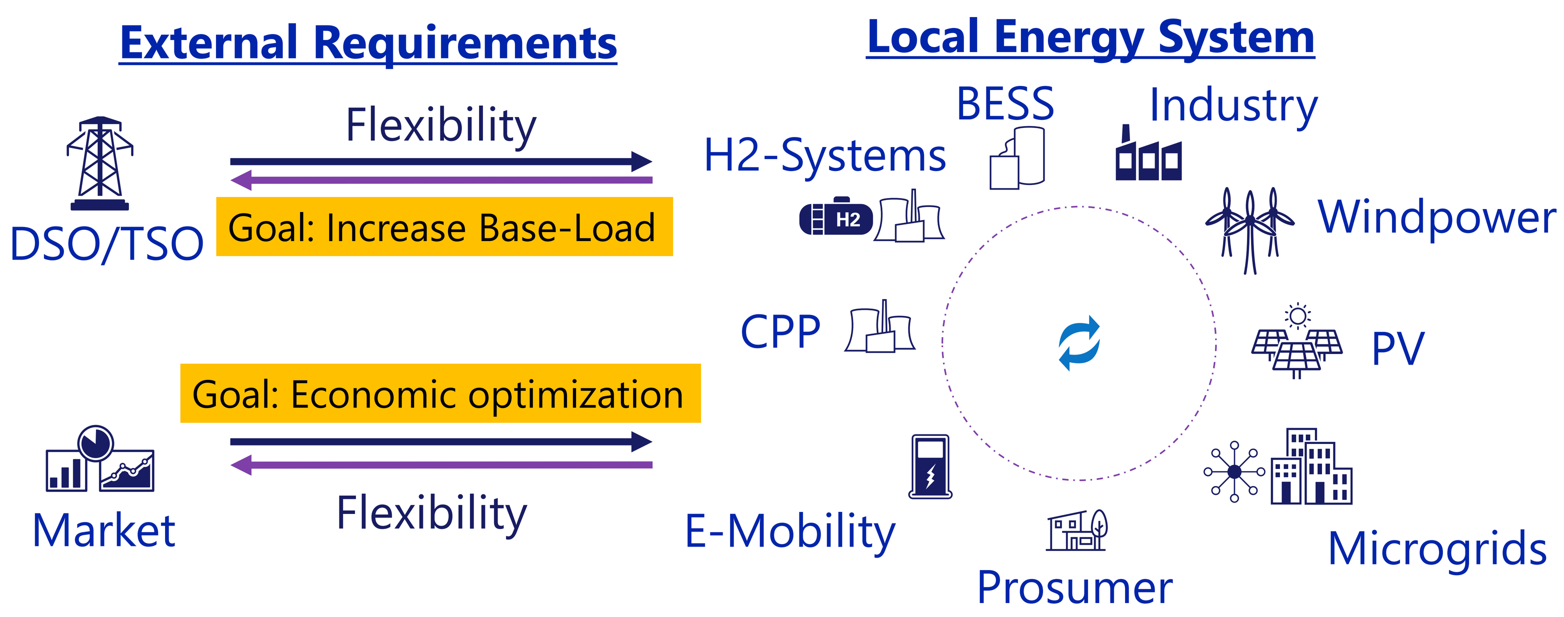


Renewable generation is spatially and temporally limited, producing a growing mismatch between availability and demand, that leads to intermittent grid congestion. Many European regulators respond to this with an expanding set of price and tariff signals. All market participants must interpret these signals individually, with limited foresight, no coordination, and no security against regulatory change. *Price signals exist but their physical impacts on the grid are neither coordinated nor predicted.*

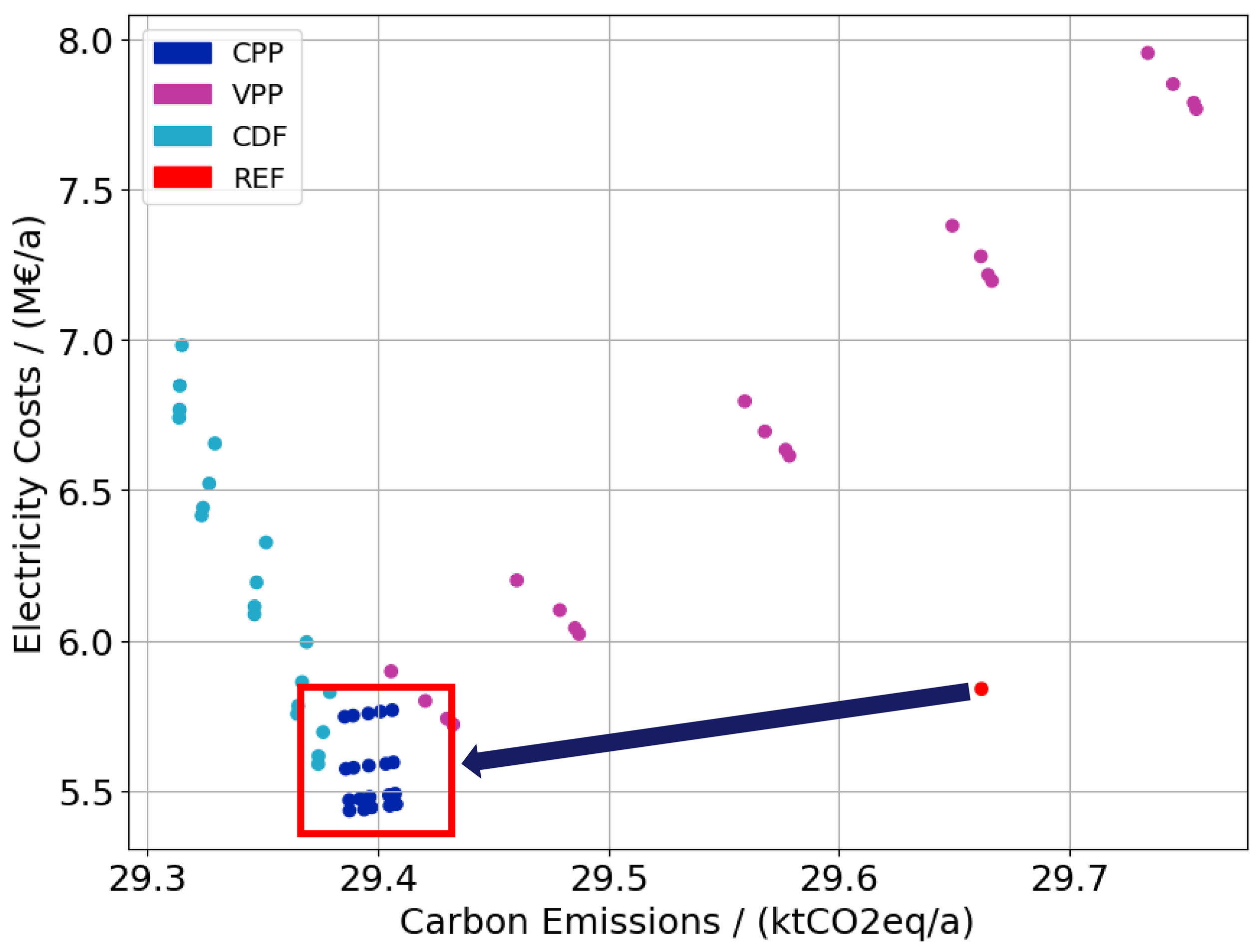
Research Gap

Existing literature shows nodal pricing as the clear efficiency and congestion benchmark, and it documents how specific tariff designs shape industrial and end-user flexibility. However, it does not yet answer whether a single market zone with spatially and temporally differentiated grid tariffs can approximate nodal-level grid relief while preserving market liquidity, especially under bounded-foresight industrial behavior.

Hypothesis: Dynamic grid tariffs within a single bidding zone can reduce grid expansion needs by aligning industrial load with local generation. The success depends on how heterogeneous actors interpret the signal.



Cement Case Study



- **CPP:** Critical Peak Pricing
- **VPP:** Variable Peak Pricing
- **CDF:** Combined Dynamic Grid Fees
- **REF:** Reference Scenario of Germanys regulation

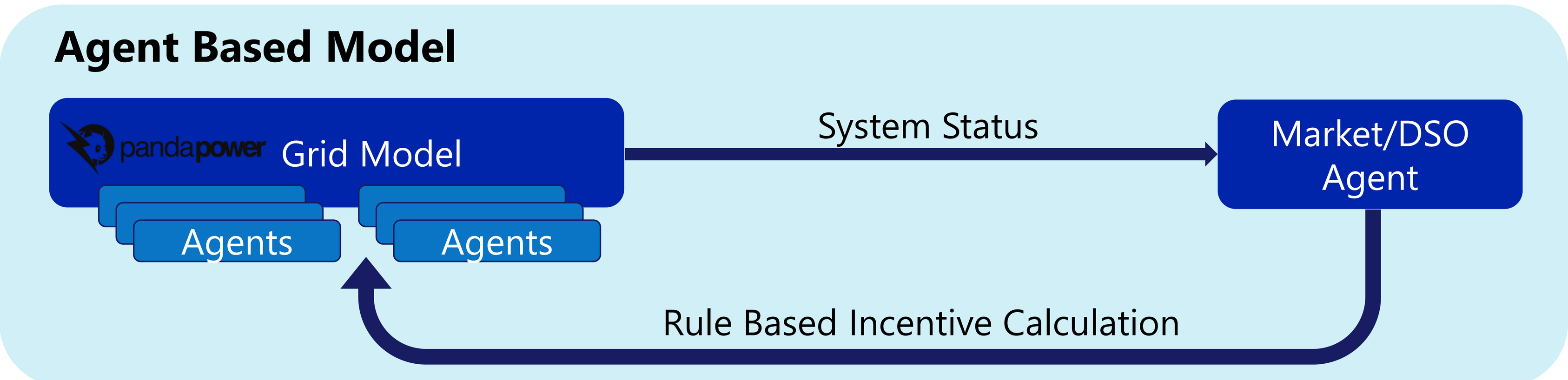
Case Study Results

4.5 to 6.8 % electricity cost savings and 0.80 to 0.92 % grid-related CO_2-emissions reduction under critical peak pricing mechanism

New Research Question

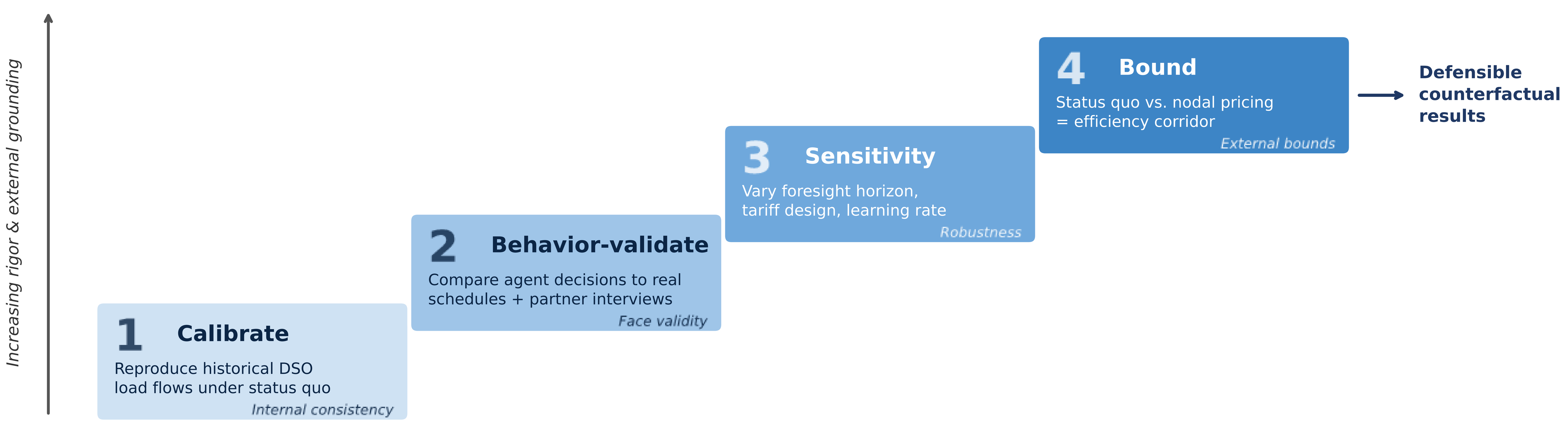
Even under simple time-of-use tariffs, a single industrial site shifts load meaningfully. What happens when many sites do this simultaneously?

Approach & Methodology



Current State (PoC)	Planned (PhD)
Agent MILP with bounded foresight	RL algorithm: open – single vs. MARL
Utilizes Simbench grid	Apply on real DSO data
Rule-based DSO grid tariffs	Same, with strategic design variants
ABM + power flow calculation	Multi-industry simulation

Validation Strategy



Two-track data strategy: real for credibility, public for reproducibility. Real-world calibration on Westfalen Weser Netz operational data under a joint research agreement anchors agent behavior and load flows in observable industrial reality. The same pipeline runs on the openly available Simbench grid for peer review and replication.
Calibration on one, publication on the other.

Open Discussions

1. **When does decentralized response to a shared tariff signal stop relieving congestion and start creating it?** What minimum coordination mechanism prevents herding without collapsing into central dispatch?
2. **When the policy regime being modeled does not yet exist, what validates a counterfactual ABM result?** Is comparison to historical status-quo flows sufficient or is a different epistemological standard required?

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