

Scaling EV flexibility reveals a trade-off between system value and EV owner incentives

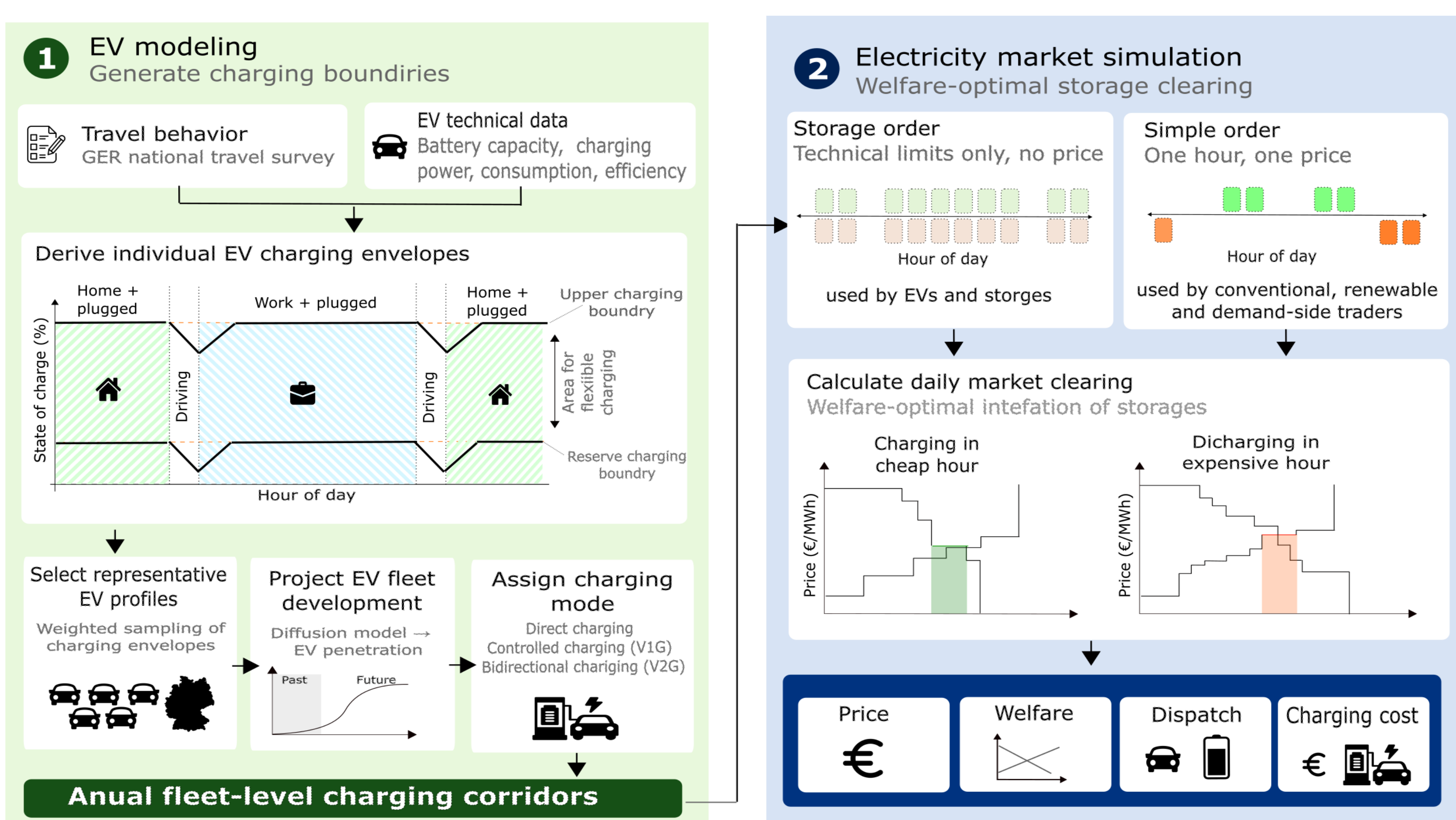
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Electric vehicle batteries already exceed grid-scale storage by roughly an order of magnitude (IEA, 2024), while vehicles remain parked more than 95% of the time (source pending). Smart charging (V1G) and vehicle-to-grid (V2G) could therefore provide short-term flexibility for renewable integration and power system resilience (Du et al., 2025; IEA, 2026). Yet usable flexibility is constrained by mobility, charging behavior, equipment, and regulation (Bucksteeg et al., 2026; Schwarzer, 2025; Signer et al., 2024). As participation scales, EVs also reshape the market prices that reward flexibility, creating saturation effects and weakening individual incentives. We simulate future electricity markets with behaviorally constrained fleets and varying shares of uncontrolled charging (V0), V1G, and V2G.

Hence, we ask: How does scaling EV flexibility affect electricity markets, participation incentives, and short-term system resilience?

Methodology



1 Flexibility from travel diaries

Each observed vehicle-day becomes a charging corridor, bounded above by full-power charging and below by the reserve required for the next trip. V0, V1G and V2G are successively wider subsets of this corridor.

2 Day-ahead clearing with storage orders

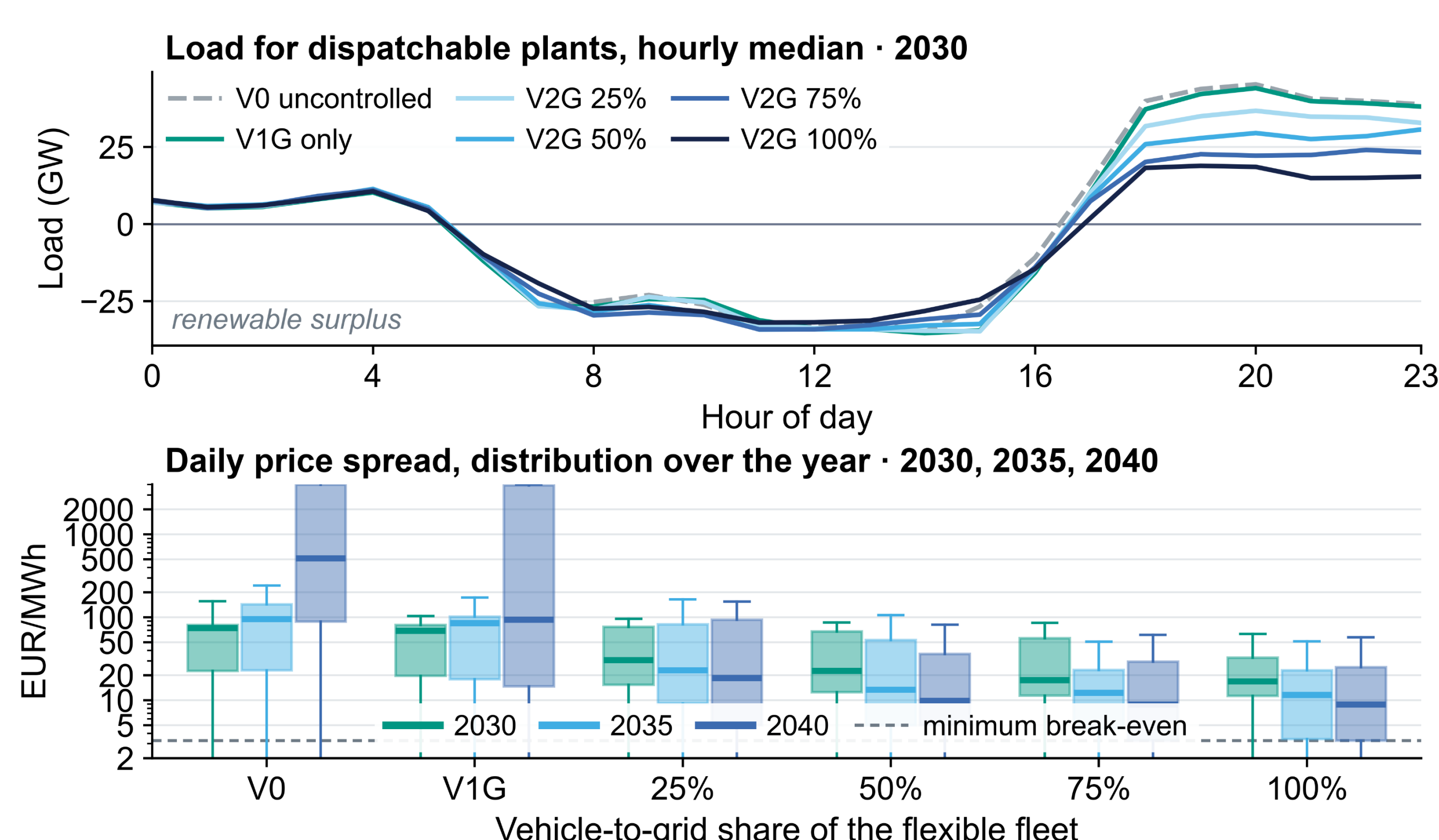
In the agent-based model PowerACE each corridor enters the coupled European auction as one price-free storage order covering the day.

3 Annual cost per charging mode

Market clearing yields electricity prices and welfare effects, which can subsequently be translated into user charging costs.

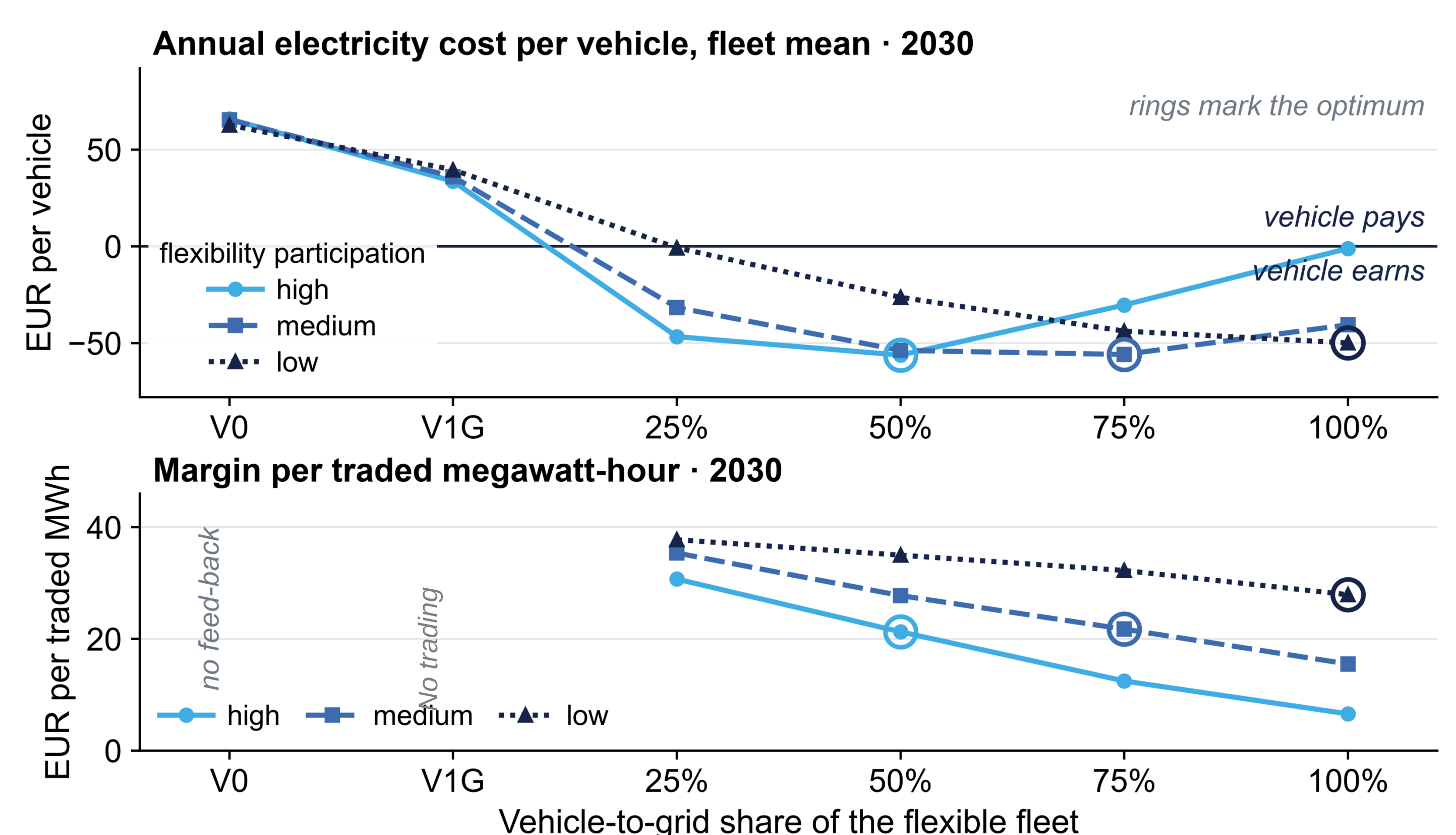
Results: System level

*Simulations are based on TYNDP2024 National Trends Scenario (ENTSO-E, 2024)



- Only V2G materially reshapes the evening peak: V1G cuts it by 1 GW in 2030, while V2G reduces it from 45 to 19 GW.
- Midday flexibility lacks a price signal: By 2040, the fleet absorbs 40% of solar surplus, yet 7 to 8 zero-price hours limit targeted charging.
- Returns saturate quickly: 25% of plugged-in vehicles deliver 76% of spread compression in 2030 and 98% by 2040.

Results: EV owner level



- Smart charging cuts annual charging costs from 66 to 36 EUR per vehicle in 2030 and by 75% by 2040, despite vanishing system effects.
- V2G value saturates quickly: gains peak at 56 EUR per year at 50% participation, but fall to 1 EUR at full participation.
- The privately ideal participation share falls from 75% in 2030 to 25% by 2035.

Conclusions

- V2G delivers the strongest system benefit**, substantially reducing critical evening peaks while smart charging mainly shifts demand.
- Flexibility value saturates quickly**: as participation grows, EVs flatten the price spreads that reward further flexibility.
- Economics and regulation become the binding constraints**, determining how much of the technically available battery flexibility is actually deployed.

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