Infrastructure System Institute

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Decentralized Intelligent Multi-party Competitive Aggregation Framework for Electricity Prosumers

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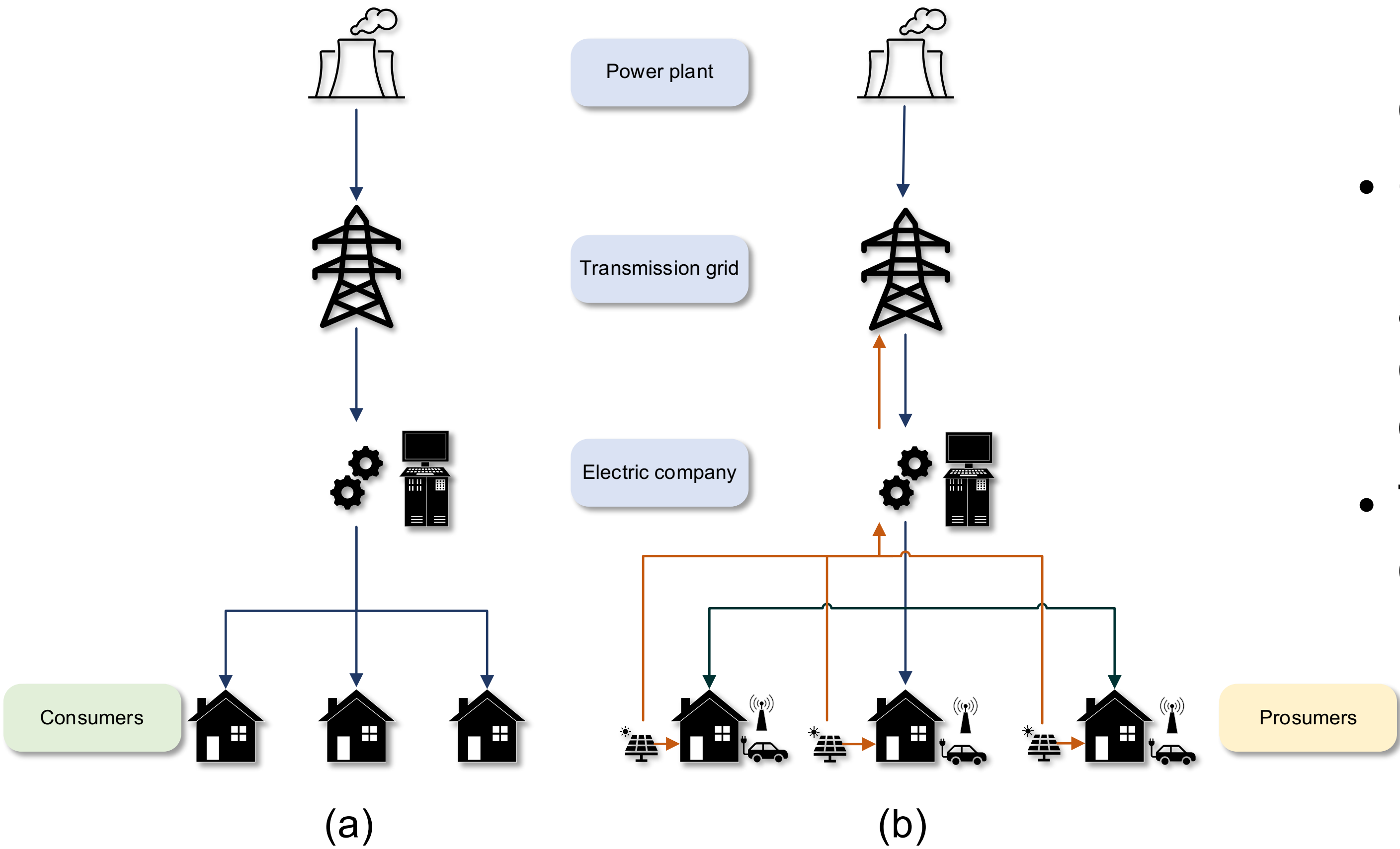
The one-liner

We designed a privacy-preserving market where multiple aggregators and prosumers reach a unique equilibrium, solved decentrally with linear convergent graph-consensus ADMM.

Why this matters



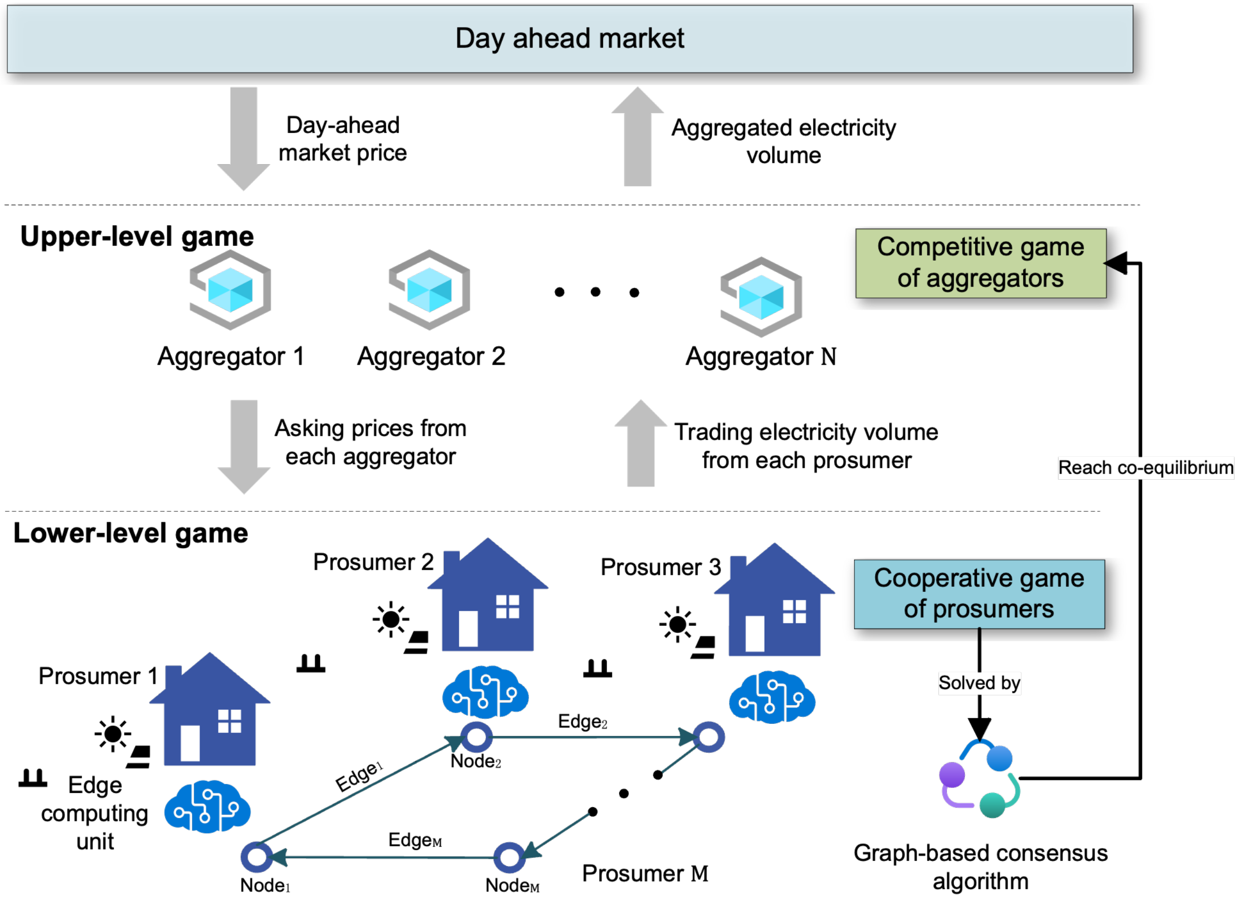
- Distributed energy resources broke the conventional playbook
- Consumers have become prosumers: actively producing, consuming, and trading energy
- This creates additional complexity for gird management

Research question

- Prosumers would like to trade excess electricity, but…
- Electricity market have entry requirement -> aggregator
- Existing literature builds on single aggregator structure, but what if…?
- There are multiple aggregators in a local market?

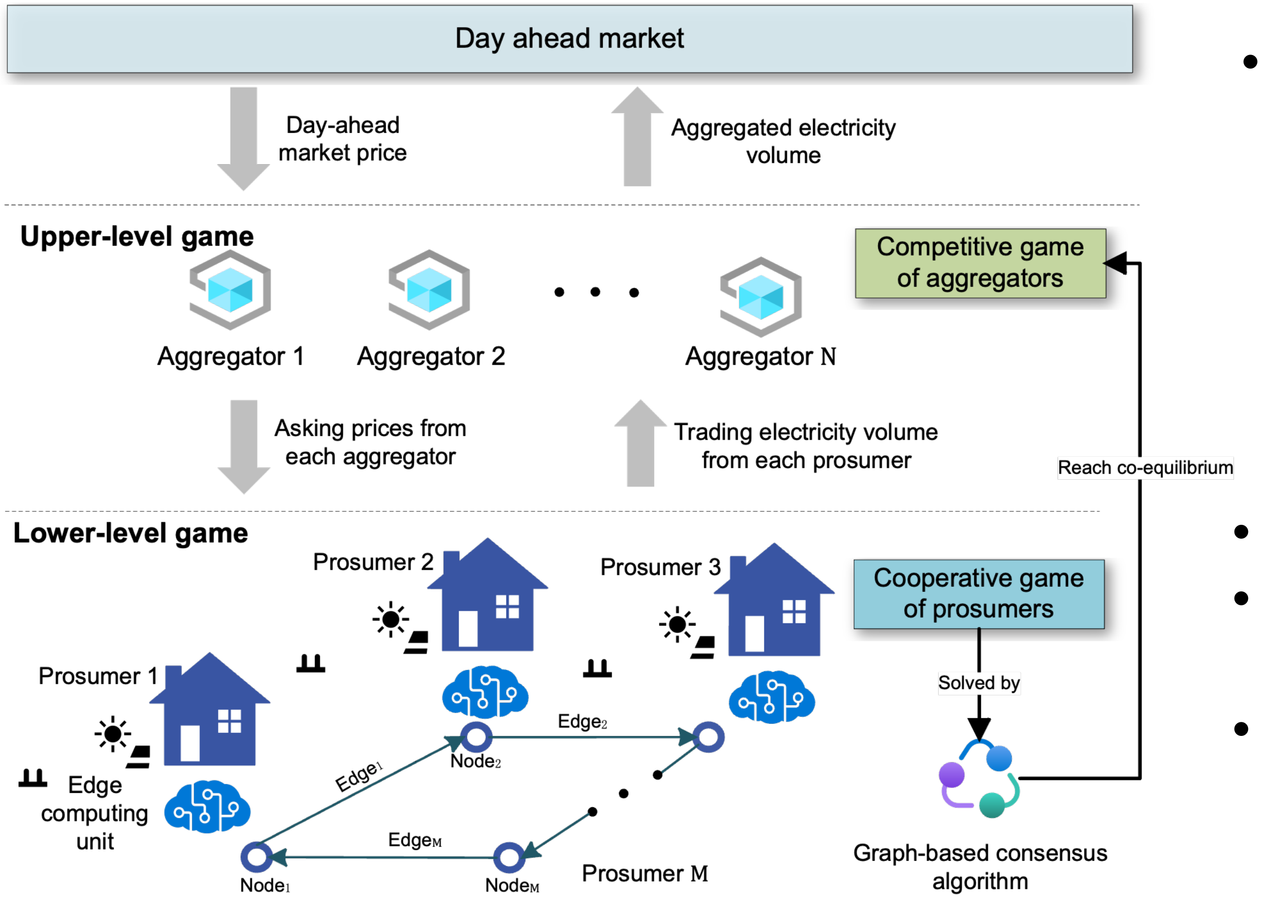
How can we efficiently manage the market competition between many prosumers and multiple aggregators in this new, decentralised landscape?

Bi-level market model



- Market as a game: Multi-leader-multi-follower game
- Multi-party competition of aggregators
- Decentralised architecture

Bi-level market model



- Key challenge on **existence** and **uniqueness** of game solution

Proved through

- Lipschitz gradient continuity
- Tyler expansion of payoff function
- Variational inequality

To solve the equilibrium

- Modified alternating direction method of multipliers

$$\min f(x) + g(z)$$
$$s.t.\ \ Ax + Bz = c$$
$$F_i(x) \leq 0\ \ i = 1, 2, \ldots, p$$
$$G_i(z) \leq 0\ \ i = 1, 2, \ldots, q$$

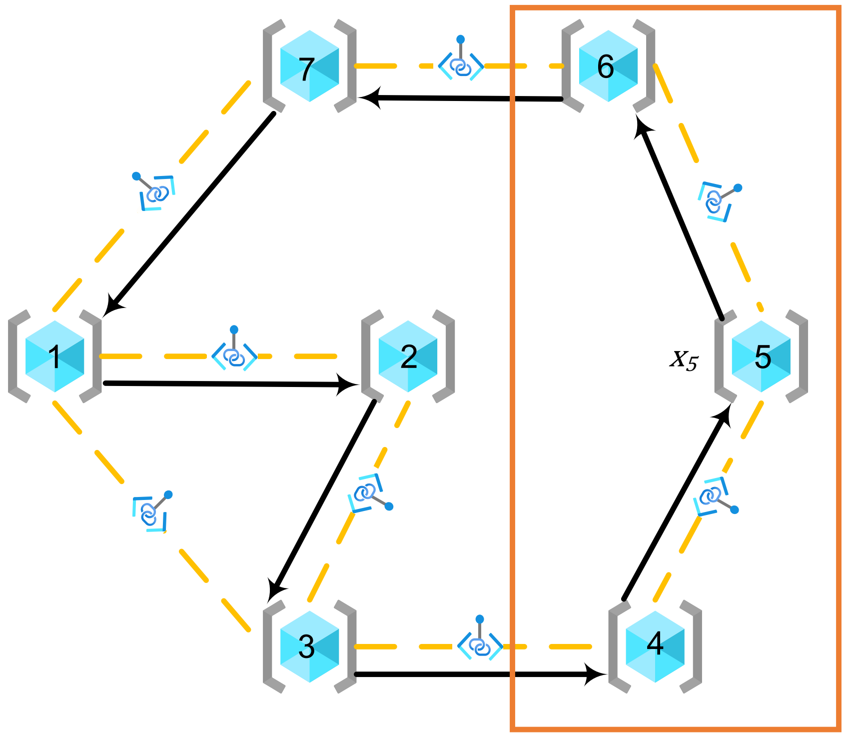
- Augmented Lagrangian functions

- Lyapunov function equivalent

$$V^k = \frac{1}{\rho}\left\|\mu_x^* - \mu_x^k\right\|^2 + \frac{1}{\rho}\left\|\mu_z^* - \mu_z^k\right\|^2 + \frac{1}{\rho}\left\|\lambda^* - \lambda^k\right\|^2 + \rho\left\|Bz^{k+1} - Bz\right\|^2,$$

- Strictly decreasing

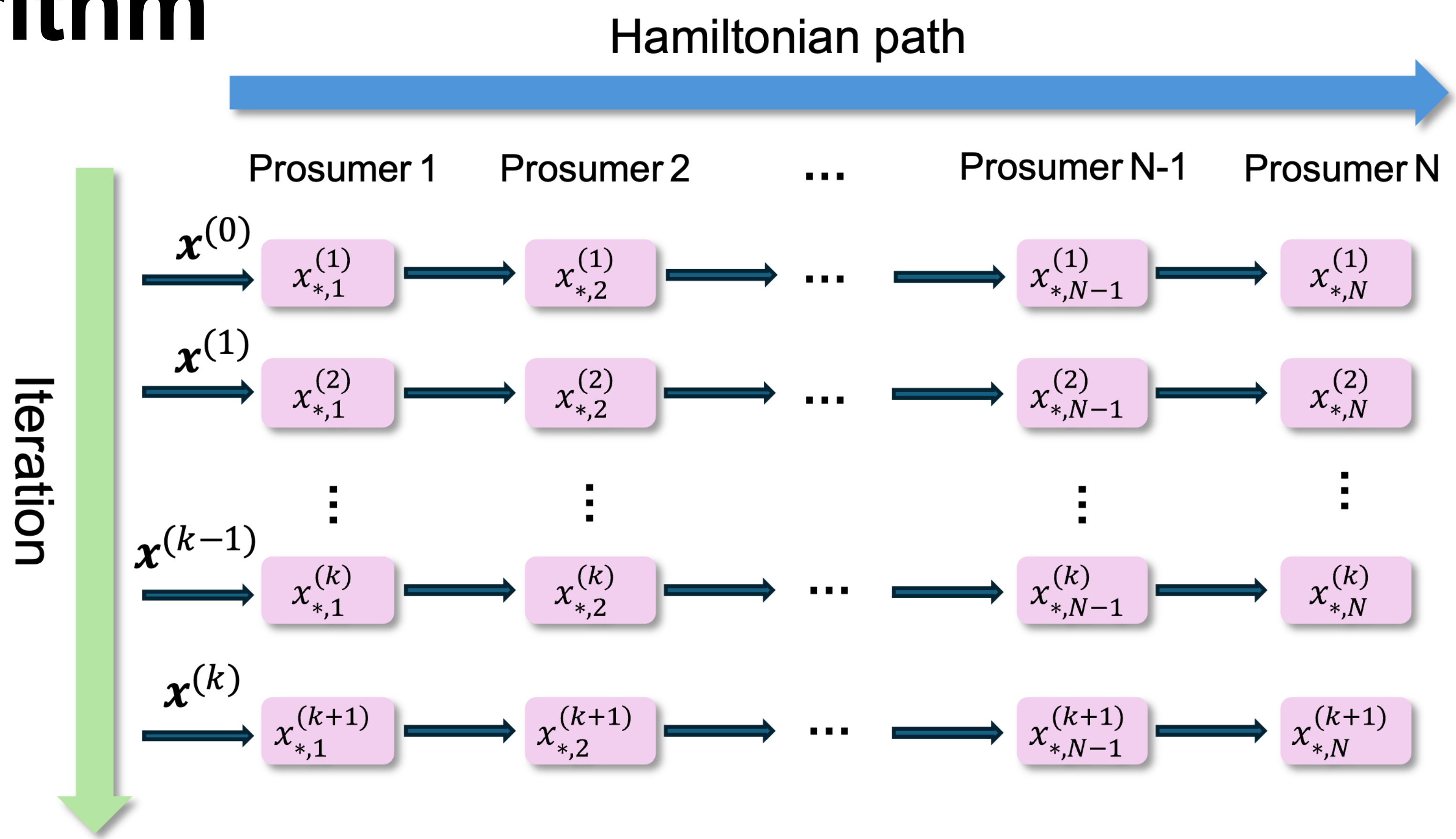
Graph-based consensus algorithm



A sub-graph

- Each agent only communicate with its direct neighbours
- The communication forms a sub-graph that will update the decision matrix
- Hamiltonian path – the shortest path to iterate entire graph

Graph-based consensus algorithm



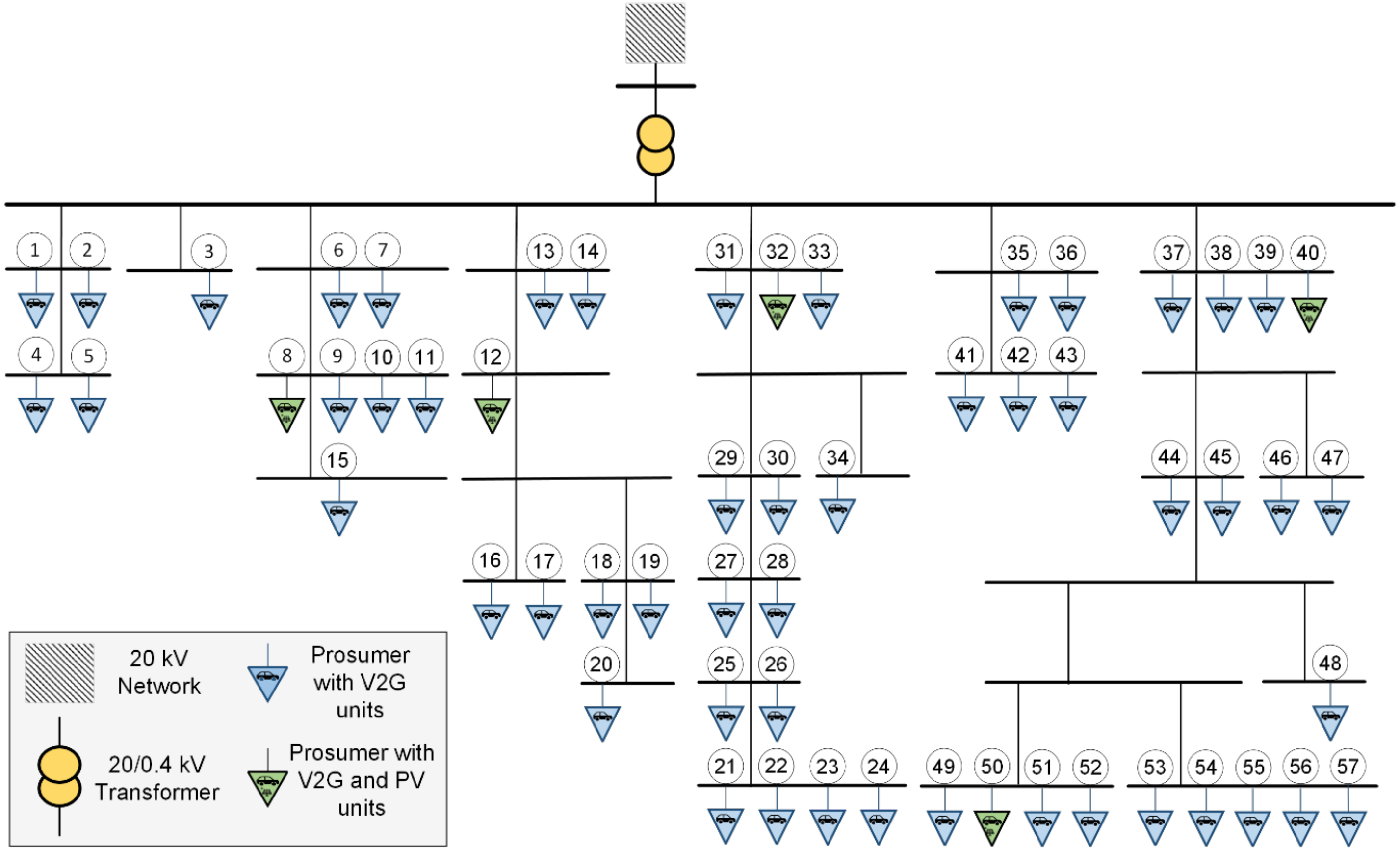
Theoretical guarantee

✓ **Unique Market Equilibrium**: We proved that there is one single, unique solution that the market will converge to, ensuring predictability and stability.

✓ **Convergence Guarantee**: The algorithm is mathematically proven to always reach a stable solution.

✓ **Linear Convergence Rate**: It finds this solution quickly and efficiently.

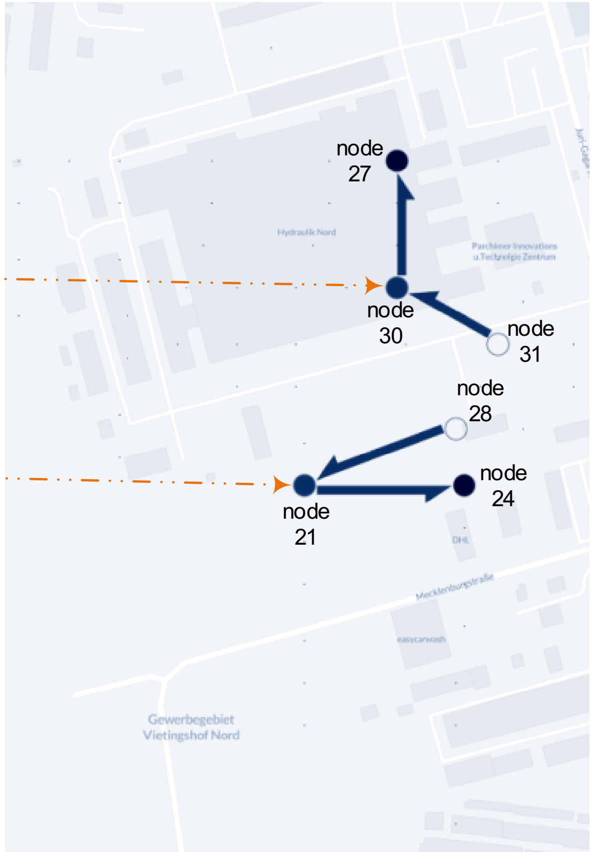
Case study set up



- EU distribution grid dataset
- V2G from EV batteries

Results

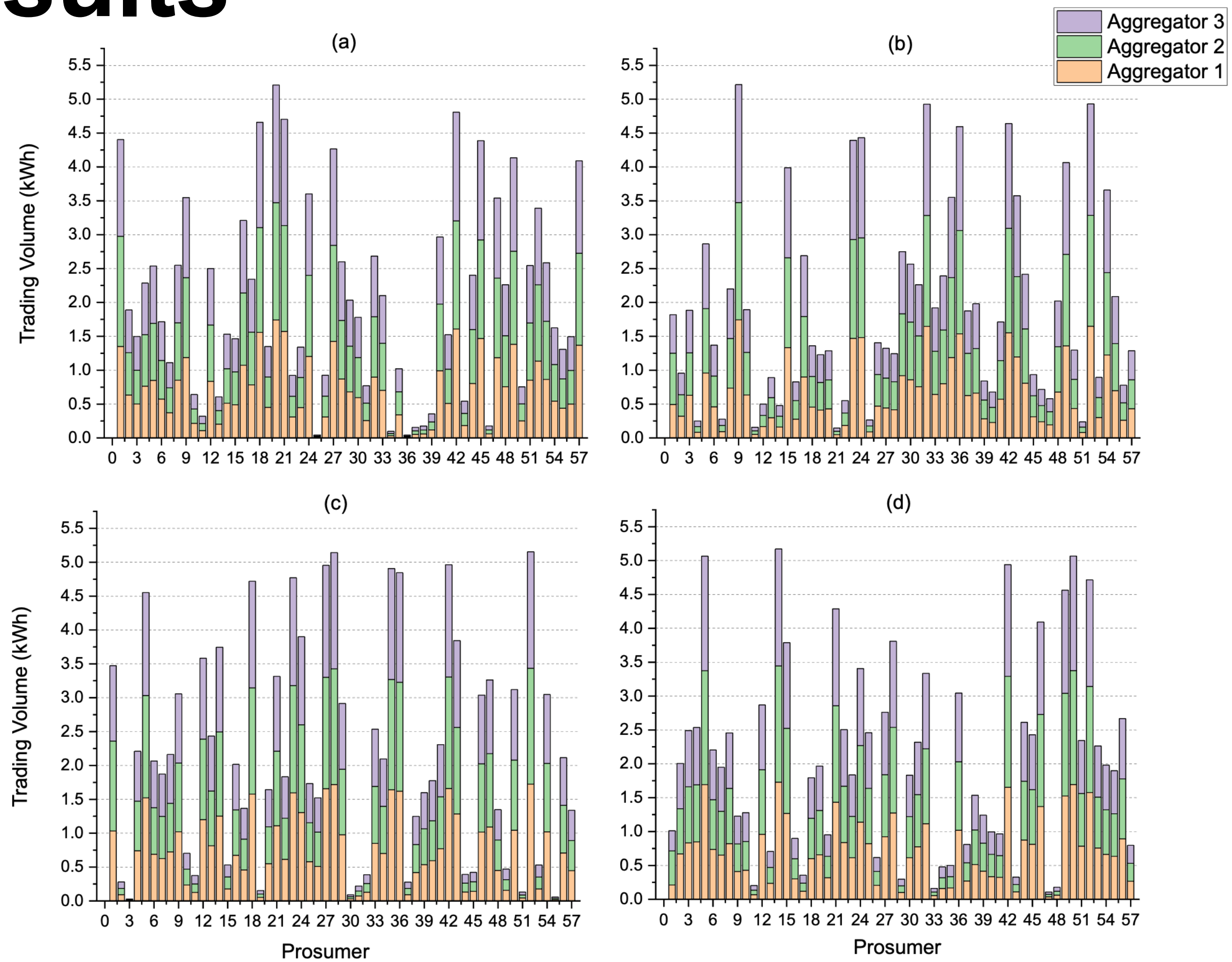
(a)



(b)

- Front-end web
- Information flow in the network graph

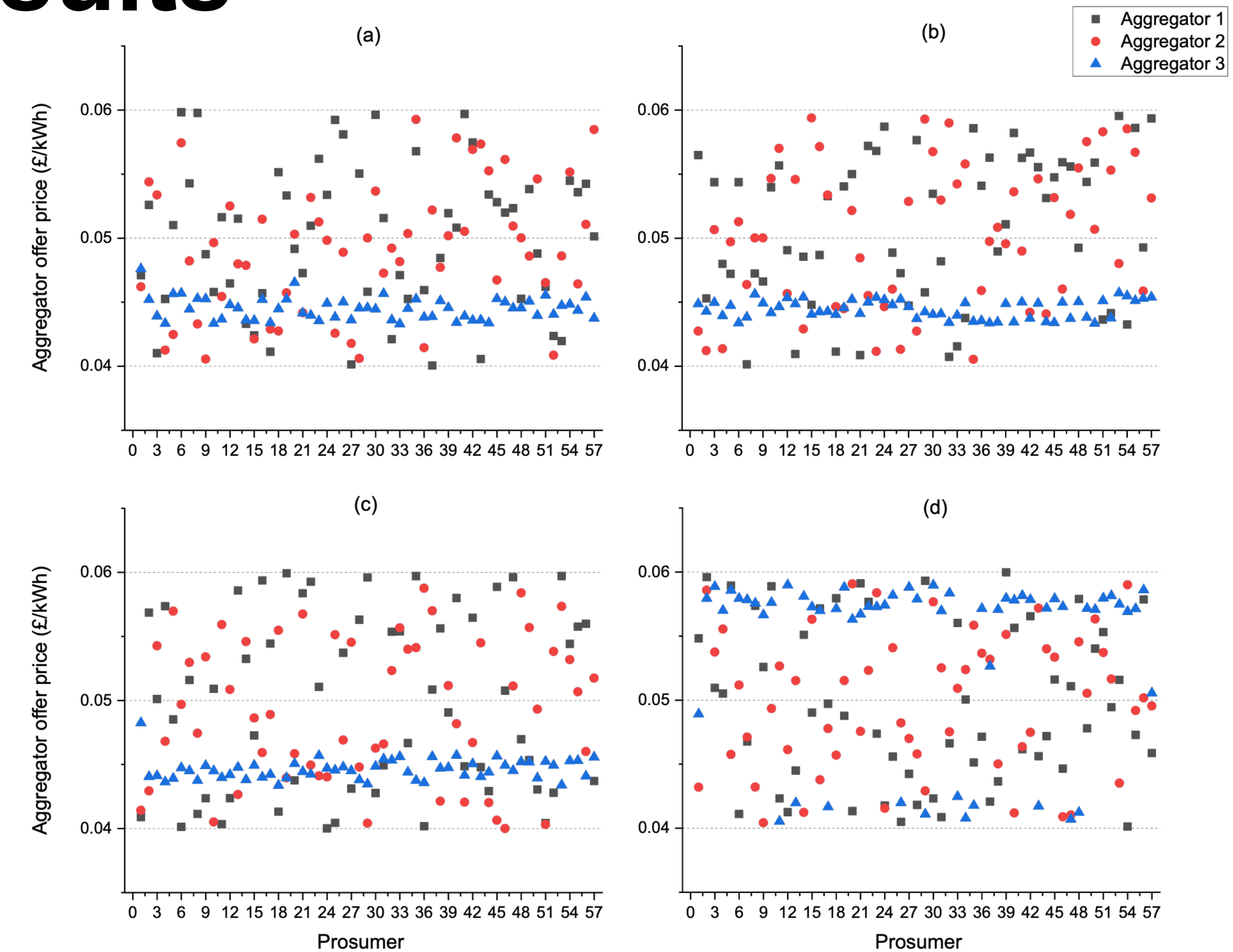
Results



- Aggregated volume of prosumers – results of lower level game

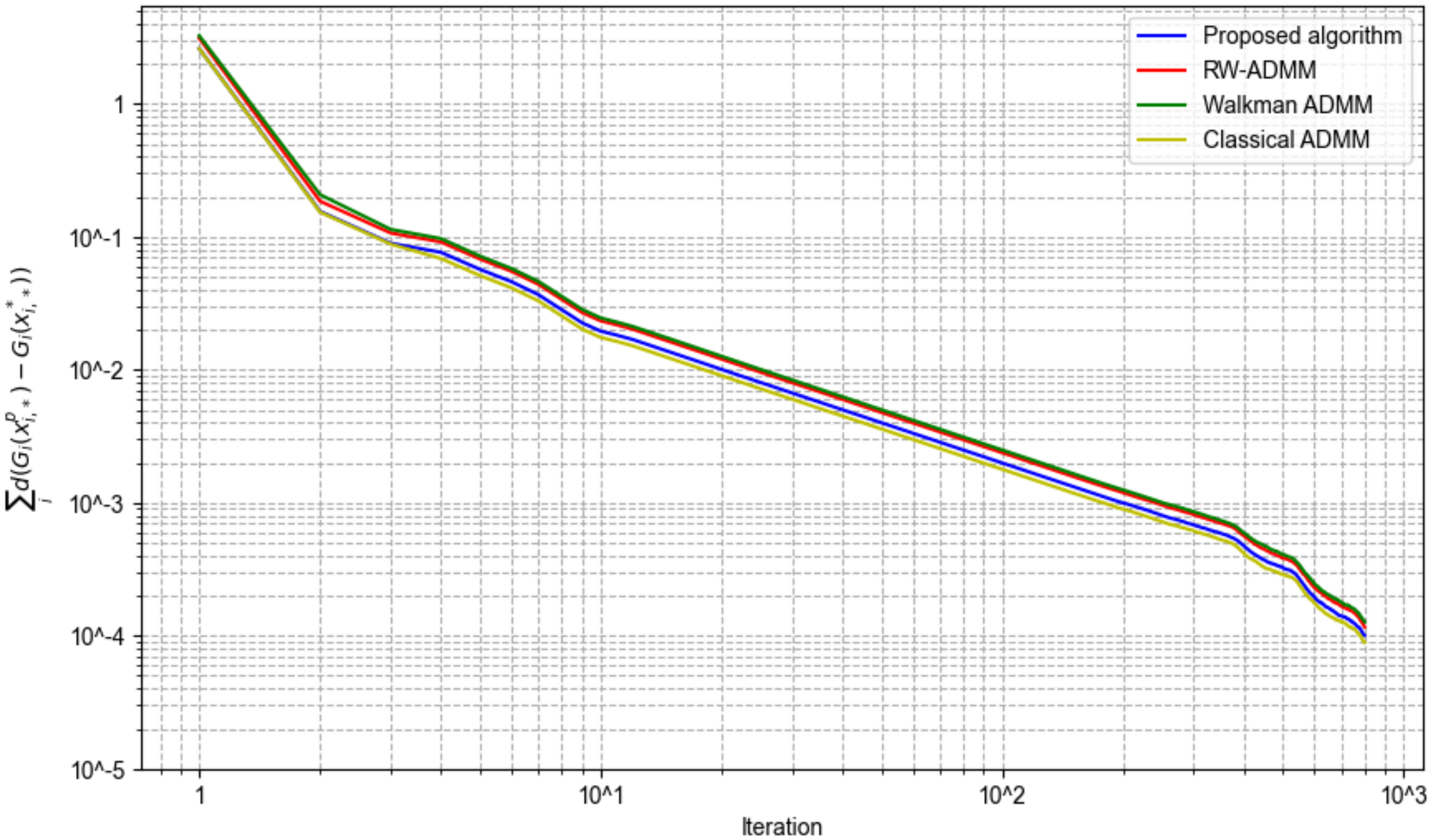
- Volume variation

Results



- Upper-level game results
- Profits made for aggregators

Benchmarking



Conclusion

- We proposed a decentralised multi-part competitive framework for aggregator – prosumer market
- Developed a graph-based consensus algorithm with linear convergence rate
- Validates the proposed framework and algorithm with EU distribution grid dataset

Thank you