ECONOMIC AND GRID IMPACTS OF SMART AND SHARED FLEXIBILITY IN PRIVACY-CONSTRAINED LOCAL ENERGY MARKETS

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Motivation and Research Question

Local Energy Communities (LECs) are expanding across Europe following the EU Clean Energy Package, and participation levels continue to rise. In parallel, digitalisation and automation are enabling prosumers to use flexible consumption and generation in response to market signals or tariff incentives. These developments are associated with potential economic advantages for participants and possible technical benefits for distribution grids. While positive economic effects are well documented, reported grid impacts vary across studies and depend on participation levels, coordination mechanisms, and the activation of flexibility [1].

A combined perspective on LEC participation and prosumer flexibility is required, as both aspects are interdependent in practice. Effective use of flexibility within LECs relies on information exchange and a certain degree of automated responsiveness. At the same time, prosumer actions need to be aggregated and coordinated, for example through Local Energy Markets (LEMs), to maintain manageable operation and ensure compatibility with distribution grid constraints. Current implementations integrate these elements only to a limited extent, and research that examines their combined effects under realistic privacy constraints remains scarce [2]. This paper examines how different levels of participation and smart flexibility affect both the economic outcomes for participants and the impacts on distribution grids in privacy-constrained LEMs.

Methodology

The proposed analysis employs a simulation-based, scenario framework using a multi-agent model of a LEC embedded in a distribution grid. Grid-connected devices are represented as assets. Flexible assets include electric vehicles (EVs), heat pumps, and battery energy storage systems (BESS), while inflexible assets include households, industrial sites, agricultural facilities, and renewable energy systems (RES). Assets located at the same grid node are aggregated into a prosumer unit. Each unit is modeled as an autonomous agent responsible for the operational and market decisions of its constituent assets.

Agents differ in their automation level: smart agents adjust flexible assets automatically in response to market signals, while conventional agents follow predefined or static operational profiles without automated decision support. Agents may either participate in the LEC or procure all electricity individually from an external retailer. Energy coordination within the LEC is implemented through a centralized, double-sided market. The clearing formulation applies reduced grid fees for intra-LEC trades. Smart agents submit price-quantity bidding curves derived from individual optimisation problems. A detailed description is given in a previous work by the authors [3]. Flexibility utilisation in LECs requires information exchange, whereas extensive sharing may raise privacy concerns. To reflect this, the proposed LEM operates under privacy-constrained information sharing. As agents submit only bidding curves, no operational data, device-level information, or peer-to-peer communication is required. The reduced-information setup departs from full-information optimality yet provides a realistic and feasible representation of the LEC operation.

The evaluation covers economic and technical indicators. Economic metrics include total social welfare for LEC and non-LEC agents, individual asset revenues, traded energy volumes (self-supply, intra-LEC trades, and external purchases), and resulting grid fees and levies. Technical metrics include congestion events within the distribution grid and net power exchange with the upstream network. These indicators allow assessments of how participation share and smart flexibility levels influence economic outcomes.

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Scenario Simulation

The simulation setup consists of a reference case and three development pathways. The reference case reflects the current situation and assumes no LEC participation and no smart prosumer units. Scenario A models increased automation and digitalisation, with high responsiveness but no local energy sharing. Scenario B assumes high LEC participation with limited automation and low responsiveness. Scenario C combines both developments through increasing shares of smart and sharing-capable prosumers.

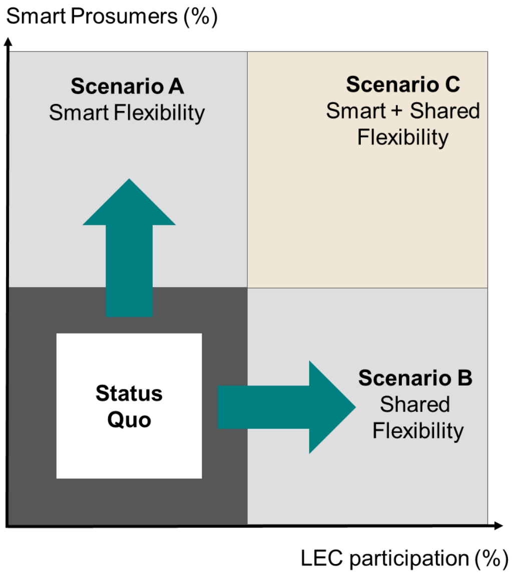

Figure 1: Smart and Shared Flexibility Scenarios

The simulations are based on the synthetic SimBench grid and dataset [4], representing expected grid, load, and generation conditions for 2030. Multiple low-voltage grid types, including rural, urban, and semi-urban grids, are considered. Simulated LECs span a single low-voltage system (grid level 7) or several interconnected systems via the medium-voltage level (grid level 5), with community sizes ranging from approximately 20 to several thousand participants. All scenarios are simulated for one full year using 15-minute time steps. The scenarios are constructed from weather data, day-ahead prices, and weekday-specific patterns. This configuration enables a systematic assessment across different LEC setups and development pathways.

Results

First results show distinct economic and grid impacts for the three scenarios. Increased smart flexibility (Scenario A) leads to higher simultaneity factors and elevated line loadings, which results in more frequent congestion events. Higher self-consumption reduces grid-fee revenues for distribution system operators (DSOs) and decreases energy-sales revenues for retailers, while prosumer units benefit from lower energy costs. High LEC participation without automated responsiveness (Scenario B) produces almost no change in power-flow patterns or congestion, but intra-LEC trading leads to moderate reductions in DSO grid-fee income and retailer energy volumes.

The combined pathway, integrating smart and shared flexibility, reduces congestion relative to Scenario A and increases local trading compared to Scenario B. The results indicate that flexibility gains depend critically on automated responsiveness. They further show that coordinated local trading, enabled by limited market-based information exchange, is crucial for LECs to realise economic and grid-related benefits.

References

[1] J. Urbansky, N. Offermann and V. Knappertbusch, „Zukunftsnetze. Partizipative Transformation durch Energiegemeinschaften," in 14. Internationalen Energiewirtschaftstagung (IEWT), Wien, 2025

[2] T. Capper, A. Gorbatcheva, M. A. Mustafa, M. Bahloul, J. M. Schwidtal, R. Chitchyan, M. Andoni, V. Robu, M. Montakhabi, I. J. Scott, C. Francis, T. Mbavarira, J. M. Espana and L. Kiesling, „Peer-to-peer, community self-consumption, and transactive energy: A systematic literature review of local energy market models," Renewable and Sustainable Energy Review, 2022.

[3] J. Schmeing, R. Jahn and U. Häger, „Smart grid tariffs for preventive congestion management - an impact analysis for a German distribution system," in IEEE PES ISGT Europe, Malta, 2025.

[4] S. Meinecke, D. Sarajlic, S. R. Drauz, A. Klettke, L.-P. Lauven, C. Rehtanz, A. Moser and M. Braun, „SimBench—A Benchmark Dataset of Electric Power Systems to Compare Innovative Solutions Based on Power Flow Analysis," energies, Nr. 13, 2020.