

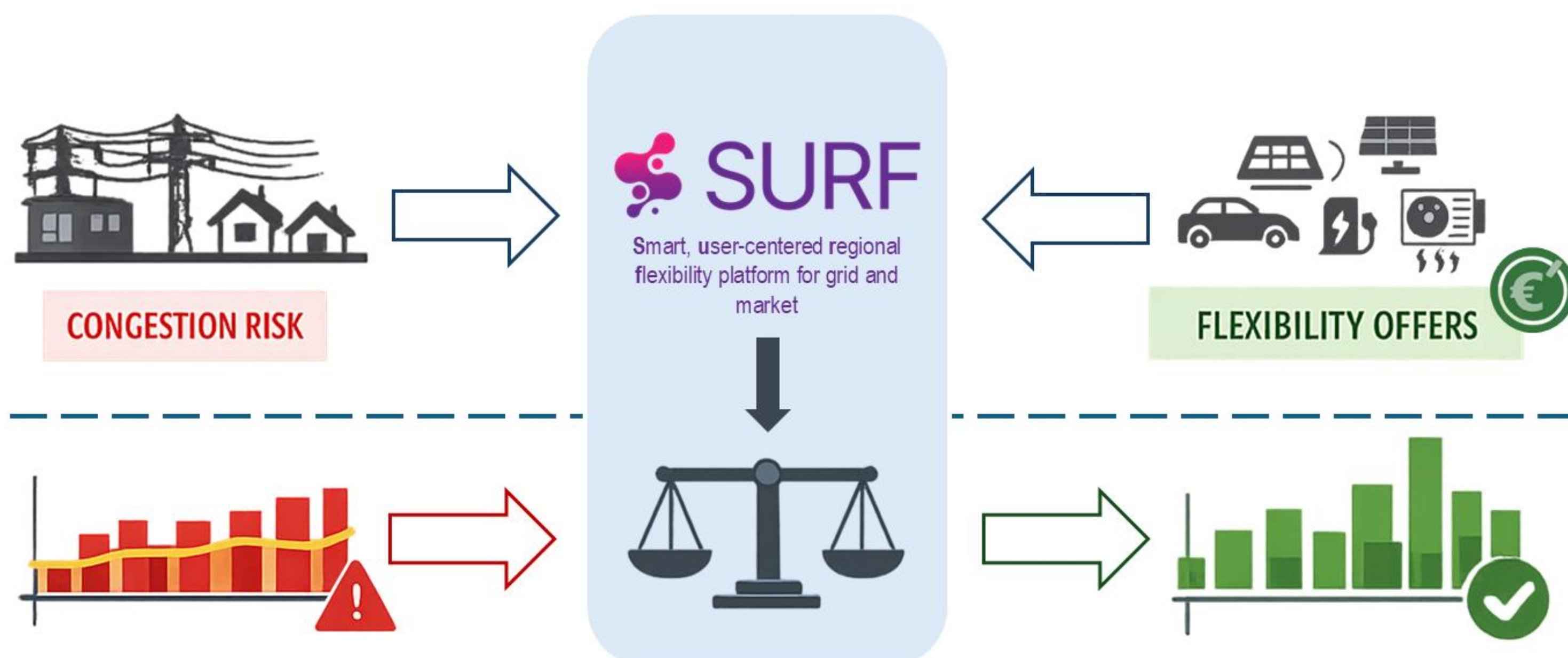
Modeling and Simulation of Local Flexibility Trading to Prevent Congestion in Distribution Networks

Sara Schön | Kim Jost | Saif Ali | Thomas Bleistein
August-Wilhelm Scheer Institute for Digital Products and Processes gGmbH, Saarbrücken, Germany
sara.schoen@aws-institut.de

Introduction

Increasing penetration of controllable household devices (PV systems, EVs, heat pumps, energy storage systems) creates congestion risks in low-voltage grids, while current approaches remain largely reactive and price-driven rather than grid-aware. This work proposes a **proactive, constraint-aware local flexibility market** that embeds grid constraints directly into trading, closing the gap between transmission-level coordination and uncoordinated residential flexibility.

Flexibility Trading Platform



Results

- **2025 baseline:** no congestion under standard capacity limits, which reflects the current situation in German low-voltage distribution grids
- **2025 Stress-tests:** only 37% at ± 30 kW and 44,5% at ± 20 kW can be resolved due to **physical flexibility deficit**, not lack of algorithmic performance
- Low penetration of flexible devices restricts available flexibility

Methods

- **Constraint programming model:** matching prosumer flexibility supply $f_{i,t}$ with grid demand D_t^{req}
- **Optimization objective:**
 - Maximizing demand satisfaction $\delta_t = \left| \sum_{i \in \mathcal{P}} f_{t,i} - D_t^{req} \right|$
 - and participation $\sum_{i \in \mathcal{P}} u_{t,i}$
 - while minimizing total system cost $C_t^{total} = \sum_{i \in \mathcal{P}} (|f_{t,i}| \times \pi_{t,i})$
- **Technical constraints:** flexibility allocation $f_{i,t} \in (F_{t,i}^-, F_{t,i}^+)$, participation status $(u_{t,i})$, bid prices $(\pi_{t,i})$, DSO price limits (π_{dso}^{max}) , and directional grid requirements
- **Input data:** household load and generation profiles with hourly resolution simulated via Load Profile Generator [1]
- **Solver:** iterative time-step optimization of the constraint programming problem using Google OR-Tools CP-SAT [2]
- **Market clearing:** post-optimization merit-order mechanism based on accepted prosumer bids
- **Evaluation:** scenario-based simulation of a 20-household low-voltage grid
- **Scenarios:** **2025 baseline with low controllable-device penetration** vs. **2035 high-electrification scenario**

- **2035 scenario:** higher device penetration leads to higher peak loads in the grid but also enables near-complete congestion resolution
- **Success rates:** 100% at ± 45 kW and 98.9% at ± 40 kW
- CP-SAT remains highly efficient, supporting real-time or near-real-time flexibility trading

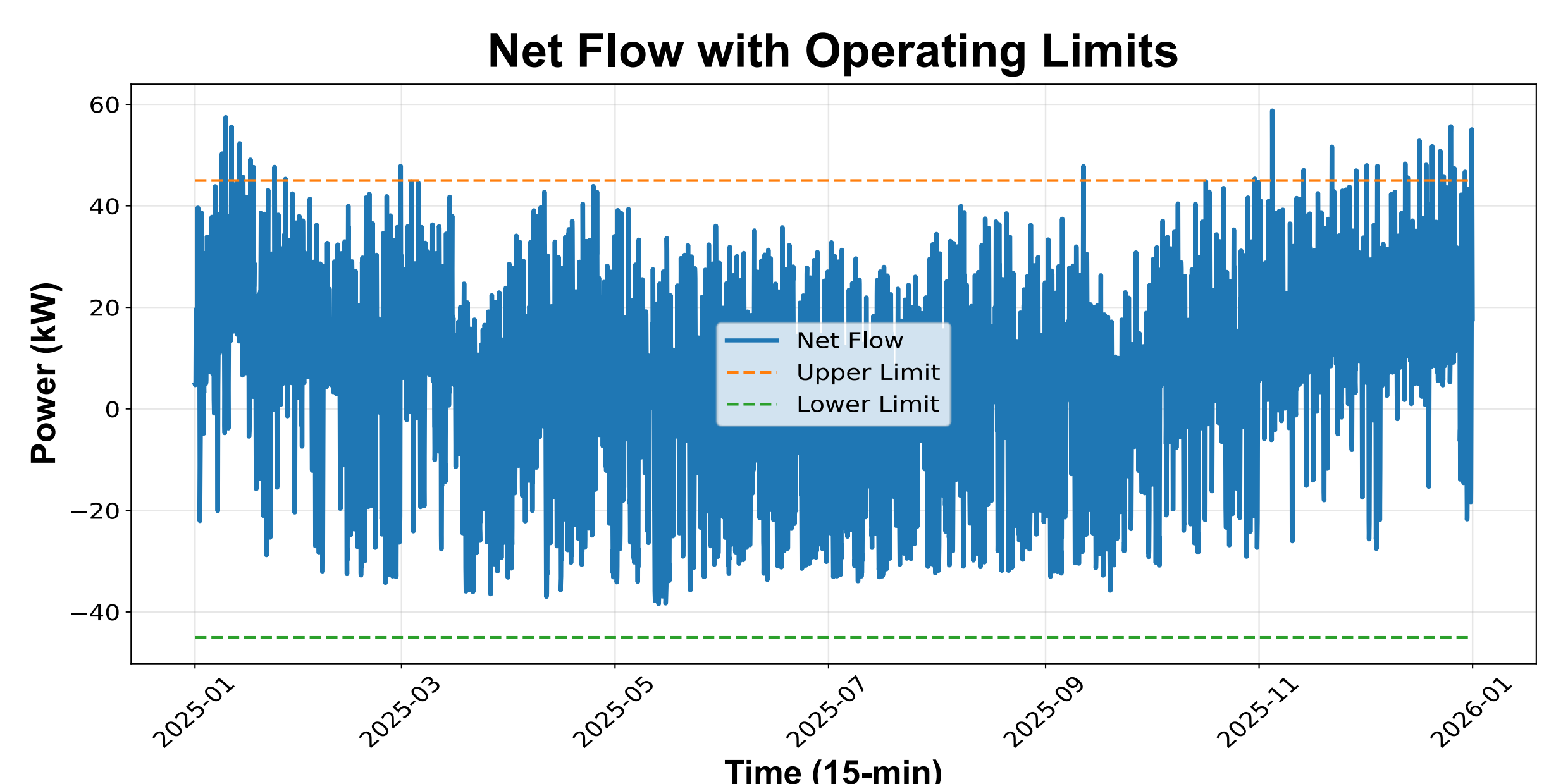


Fig. 1: Load curve for the grid in the 2035 scenario with grid capacity set to 40 kW.

[1] N. Pflugradt, P. Stenzel, L. Kotzur, et al. "LoadProfileGenerator: An Agent-Based Behavior Simulation for Generating Residential Load Profiles". In: *Journal of Open Source Software* 7.71 (Mar. 2022), p. 3574.
[2] L. Perron and F. Didier. *CP-SAT*. Version v9.10. Google, May 7, 2024.
url: https://developers.google.com/optimization/cp/cp_solver/

Conclusion

Proactive flexibility trading is technically effective for congestion mitigation, but its impact is fundamentally constrained by the **availability and diversity of controllable assets** in early-stage markets. Future work must address **flexibility quantification, settlement mechanisms, and system integration** to enable scalable, real-world deployment of local flexibility markets under practical grid conditions.