A COMPARATIVE ANALYSIS OF CENTRAL AND AGENT-BASED OPTIMIZATION OF LOCAL ENERGY COMMUNITIES

Clara HUBER*[1], Christoph LOSCHAN[2]

Motivation

Energy communities (ECs) are regarded as an essential component in achieving the European Union's energy and climate objectives. Through the Renewable Energy Directive (RED II) [1] and the recast Electricity Market Directive (EMD) [2], adopted as part of the Clean Energy for All Europeans Package, the EU established a legal framework for ECs by introducing two distinct community-based constructs: Citizen Energy Communities (CECs) and Renewable Energy Communities (RECs).

CECs and RECs share similar structural characteristics. They both are voluntary associations promoting environmental and social benefits rather than profit through the joint generation, use, storage, and distribution of energy. While CECs may involve all electricity-related technologies, RECs focus on renewables and are subject to stricter spatial requirements, as their members must be near the renewable energy generation facilities operated by the community [3].

The local energy community (LEC) considered in this analysis thus represents a concrete form of a REC that relies on locally available renewable energy sources. By bringing power generation closer to the point of consumption and increasing the self-consumption of locally generated renewable energy, LECs can contribute to the reduction of photovoltaic (PV) feed-in peaks, the stress on distribution grids, and the need for costly grid reinforcements. This localized approach supports decarbonization and economic efficiency, fostering social cohesion and citizen engagement.

However, realizing these benefits entails substantial design and operational challenges. Although a growing body of research explores optimal LEC configurations, most existing models adopt a centralized perspective in which the community is represented as a single decision-maker pursuing a unified objective [4]. In practice, LECs are composed of heterogeneous actors who differ in their priorities, constraints, and motivations. It is therefore essential to examine how model outcomes change when individual member interests are explicitly represented, rather than subsumed under a single communal objective.
This raises the central question of how the differences between centralized planner optimization and an agent-based approach that accounts for individual objectives influence the outcomes of LEC operation.

Methods

The community optimum is compared with the optimum of individual interests, employing two distinct modeling approaches.

In the first, a model for global demand optimization is developed by formulating a linear mathematical optimization. The Gurobi solver [5] is used to determine the optimal values of the decision variables. The overall linear optimization framework is implemented in Pyomo [6], a Python-based open-source optimization package.

The second approach implements an agent-based simulation to model the individual interests of the members of the energy community using the Python-based open-source MESA library [7]. The optimization does not occur explicitly but rather results indirectly from the actions and interactions of agents in the simulated environment.

The LEC is comprised of three distinct household categories, as illustrated in Figure 1. Households classified as Category 1 are defined as pure consumers with an inflexible demand. Households classified under Category 2 are prosumers, meaning they partially meet their electricity needs through decentral PV generation. Consequently, they function as both consumers and producers. The PV

[1] Technische Universität Wien Energy Economics Group, Gußhausstraße 25/370-01, 1040 Wien, Austria, huber@eeg.tuwien.ac.at, https://eeg.tuwien.ac.at
[2] Technische Universität Wien Energy Economics Group, Gußhausstraße 25/370-01, 1040 Wien, Austria, loschan@eeg.tuwien.ac.at, https://eeg.tuwien.ac.at

electricity that is generated can be sold to other community members or fed into the grid. Households classified as Category 3 are equipped with both PV systems and battery storage, enabling surplus PV electricity to be stored for later use.

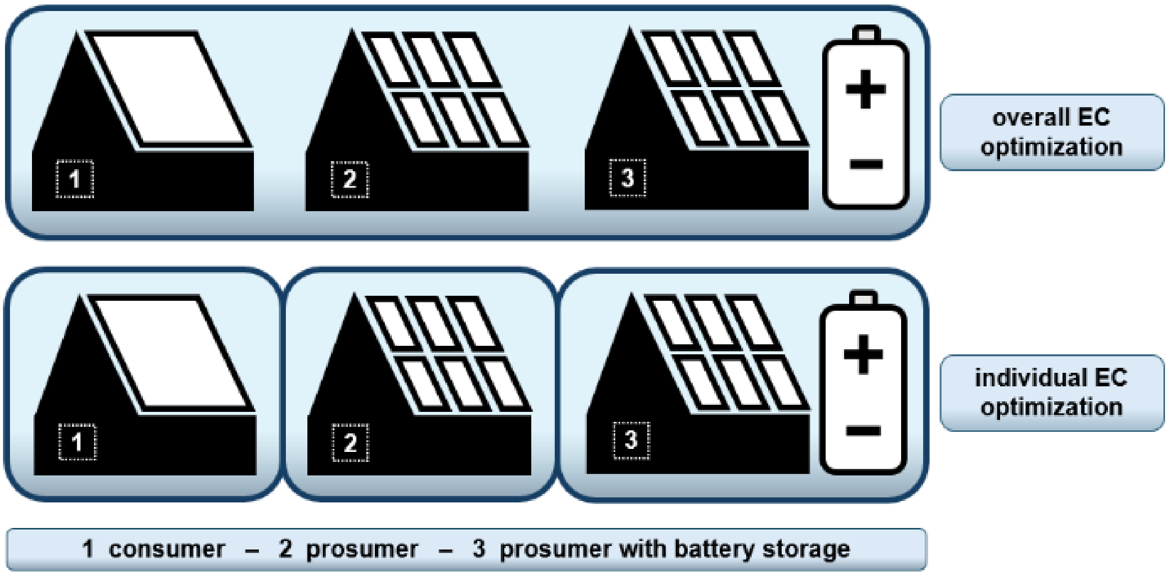

Figure 1 Visualization of the two optimization approaches and different household categories

Results and Conclusions

The previous results of the two modeling approaches indicate that the selected optimization type has a substantial influence on the electricity allocation and the distribution of benefits within LEC. Central optimized LECs result in maximization of the economic benefits for the whole LEC, but the share between the household categories tends to benefit inflexible consumers more than flexibility providers.

Conversely, individual household objectives, such as maximizing self-consumption, change energy flows significantly. The shares of self-consumption, shared battery use, and LEC trading are subject to change as households prioritize their own objectives, resulting in a more balanced distribution of benefits but a reduction in the total benefit at the community level. These findings indicate how critical the choice between global and individual optimization is for balancing fairness and efficiency in LECs.

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