LOCAL ENERGY COMMUNITIES: VALUING FLEXIBILITY FOR POWER MARKET DESIGN AND GRID INVESTMENT PLANNING

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Overview

The liberalization of the electricity market and the increase in renewables have led to significant changes in the electricity market in terms of pricing, market segmentation, governance and investment in transmission and distribution infrastructures. New challenges are emerging with regard to redistribution of costs and benefits of new systems based on cooperation between stakeholders and decentralization of planning decisions.

This paper seeks to analyze the costs and benefits of a local coordination between electricity producers and consumers organized as community, and the opportunity cost of investing in grid network extension to face new power loads from increased renewables and new electricity usages. This new organization is studied through secondary research question related to centralized and decentralized market designs, by evaluating the impact of the community on the rest of the power system. More precisely, this paper aims to value local flexibility relative to new investments in the power system, based on the intuition that local flexibility has the potential, to some extent, to substitute to the grid investment for network extension and to centrally-dispatched power generation. In this way, locally optimizing the power consumption behavior is the key-step prior to the grid investment planning such as to reduce public expenditure, material flows for cables and devices, pick-load units and greenhouse gas emissions, and ultimately the consumer bill.

The case study is the French power system where local power markets are at an early stage of development and can operate only as a local adjustment mechanism in very constraining cases, thus their complexity gives few long-term signals to players (French Energy Regulatory Commission, CRE (2017)). Alternatively, mechanisms based on peer-to-peer energy sharing community represent a potential substitute while relying on viable transparent institutional rules. Javadi and al. (2022) demonstrate the role of local energy communities in reducing the participants' electricity bill, which should however be considered against the economic impact the community has on the whole power system. As this mechanism requires the cooperation among community members, it is also implicitly based on the overall synchronization with consumers outside the community (Wang et al., 2021); hence the question of the community impact on the national power system remains open.

Methods

We build a model of local electricity generation and distribution, where the duality of objective function combines the maximization of collective welfare with the minimization of the costs of the power system made of generators and power distribution, including grid operation and extension. Within this system, we simulate an energy community which is supplied with local resources in priority, and from the national grid for load adjustment only. The objective of the community is to maximize its utility, next integrated into the global objective function to minimize the costs of the local system connected to the national power system. The problem is formulated as mathematical program under partial equilibrium constraints, using GAMS software, well suited for technical-economic optimization models using complex databases. Societal changes are included for the demand projection with concern to sobriety, technological choices and new usages such as electrical mobility and heat with electricity.

We follow two steps (Figure 1). The first step simulates the operation at the level of a physical node of the electricity distribution network, and compares the costs of locally reinforcing the distribution network, with the cost of operation of energy community, including flexibility provision. The second stage assesses the impact of the local flexibility on the central market dispatching. The mathematical principles are as follows:

1) This first step minimizes the cost of operation of the power system, made of generation with multiple sources of wind and solar input, and reinforcement and operation of the electricity network. The local energy community maximizes its welfare under the double constraint of the local power availability and of tariff equalization of network fees among all consumers. We formulate the relationship between the profits of community members and the network tariffs payed by the members outside the community. The goal is to estimate the value of the local

flexibility provided by the community, including the avoided costs with grid extension, and the costs paid by all consumers to cover the network fees.
2) The second step rebuilds the power consumption and generation profiles, at aggregated level of the national power system with heterogeneous customers and power sources. This stage is based on the assessment of spot price signal that triggers centralized flexibility, and on the profusion effect of both demand and supply from renewable sources.

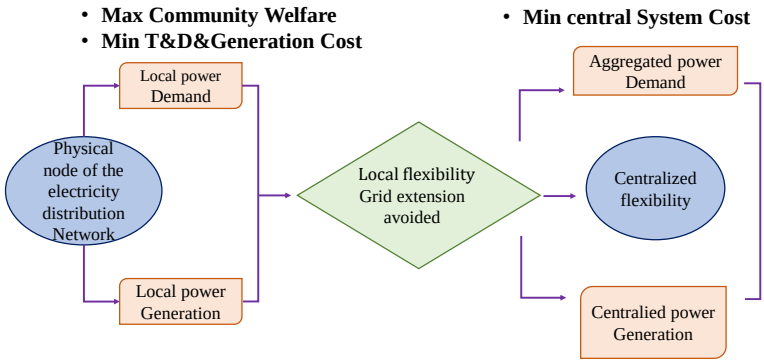

Figure 1. Methodology flow chart

Results

The outcomes of this research estimate the effects of local coordination between electricity producers and consumers in two local communities in the French region, Pays de la Loire, one located in rural area and one in urban area. Numerical applications show that both communities, despite their lack of economies of scale, have the advantage of increasing the share of renewables and the demand response initiatives. Flexibility provided as demand management makes increasing the community profits, from the supply side in rural area and from the demand side in urban area. Rural areas benefit of large potential of wind and solar power installation, while economies of density in urban areas have larger demand flexibility potential. We show that a mix of urban and rural profiles organised as local communities optimizes the community welfare and further contributes to flexibility provision and grid extension avoiding. At centralized level, central flexibility is improved with local communities only for a certain threshold of renewables that overtakes the existing grid sizing. The model shows that local communities could punctually decrease the market price signals rewarding the central flexibility due to increased supply for flexibility, while absent wind and solar power in local communities, the demand for flexible supply could make spot prices increase. The net effect depends on the number of communities, their size and profusion effect, and on their behavior in terms of demand response and power generation potential.

Conclusions

This paper studies the balance between penetration thresholds of renewable energies, costs of distribution network reinforcement and demand-side management. It analyzes architectural alternatives such as the global proliferation of local electricity supply and demand, by pooling long circuit assets, versus the decentralization of supply and demand through the creation of local flexibilities markets, by short circuit. Recommendations, at the attention of energy operators, allow the analysis of the solutions resulting from the investment and allocation models of the limited energy resources, and the characterization of energy community solutions and the benefit functions of community members and non-member actors.

References

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