PRICING MECHANISMS FOR DECENTRALIZED COORDINATION IN ENERGY COMMUNITIES

Nathalie FRIEß (*)[1], Andreas DARMANN[1], Ulrich PFERSCHY[1], Joachim SCHAUER[2]

Motivation

With the passing of the EU Renewable Energy Directive 2018/2001, a new field for active participation in the energy transition has been opened through the introduction of Renewable Energy Communities (RECs). A REC is an alliance of private individuals, local authorities or small- and medium-sized enterprises in close proximity, who join together in a legal entity to share renewable, locally produced energy. The overall goal of such a community is to achieve a more efficient local energy use and to reduce its' members electricity bills. From a more general perspective, the intention behind RECs is to raise awareness for the challenges of renewable-based energy systems, to support collective, citizen-driven energy actions and to attract additional private investments in renewable energy and storage systems.

As reaching full autarky is usually not an objective of RECs, members keep their individual electricity providers, which makes financial settlements much more complicated than in traditional 1:1 contractual relations. The amount of electricity distributed within the community is specified by one of two possible allocation keys (static or dynamic), which define the portion of produced electricity to be assigned to each community member in one discrete time step (15-minute resolution). The allocation key is chosen during the founding phase of the community and reported to the distribution system operator for further settlements with the electricity providers. While there are clear rules for the allocation of electricity quantities, prices for electricity exchanged within the community are not regulated. As pricing policies present an interesting mechanism for incentivizing demand shifts and thereby increasing a community's performance, we investigate different tariff models and their influence on individual and community outcomes.

Methodology

The performance of a REC (measured by indicators such as self-sufficiency, self-supply or financial outcome) depends on the members' individual decisions. Ideally, the timing for charging and discharging batteries, electric vehicles or starting times of energy-intensive loads are coordinated. To understand the system-wide optimum of a community, we formulated a Mixed Integer Linear Program (see [1] for details). The model takes an arbitrary community configuration and short-term forecasts of production and consumption profiles as input and calculates coordinated optimal decisions for the upcoming hours. A major limitation, however, is that central decision-making is not likely to be accepted in a real-world context. Therefore, we aim to explore strategies that incentivize members to replicate this system-optimal behavior and benchmark them with results of our central optimization model.

Empirical evidence shows that for electricity consumer's responses to price changes, i.e., the price elasticity of demand (see, e.g., [2]), historically has been (moderately) inelastic in the short-run, while it has been more elastic in the long-run (see, e.g., [3]). This result can, to a certain degree, be explained by the lack of pricing signals in commonly used electricity tariffs. In recent years, demand side management, i.e., the use of monetary incentives to shift consumer demand, has received increasing attention, though the potential of such mechanisms is still believed to be underutilized, especially in the residential sector (see, e.g. [4]). In this context, we aim to develop an internal pricing scheme for RECs that incentivizes consumption behavior that is beneficial for the communities' electricity balance.

[1] Department of Operations and Information Systems, University of Graz, Universitätsstraße 15 (E3), 8010 Graz, {nathalie.friess@uni-graz.at, andreas.darmann@uni-graz.at, ulrich.pferschy@uni-graz.at}
[2] Department of Software Design and Security, FH Joanneum, Werk-VI-Straße 46, 8605 Kapfenberg, joachim.schauer@fh-joanneum.at

In our proposed tariff model, prices are based on the community's forecasted energy balance. In each discrete time step *t* there is either an over- or underproduction in the community (balance = sum of production - sum of consumption). When the expected electricity imbalance is relatively small, no major price signals are required (especially in consideration of forecasting uncertainties). In contrast, when the community imbalance is expected to be high, a significant price increase or decrease can be used to signal the required decrease or increase in demand, respectively. The proposed pricing function is based on a logarithmic function, as formulated in (1) and demonstrated by the curves in Figure 1 (tariff 2,3 and 4 compared to a standard fixed price tariff 1).

$$f(x) = a * \ln\left(\frac{c - bx}{c + bx}\right) + m \tag{1}$$

Parameter *c* defines the domain of our pricing function and describes the maximum over- or underproduction in a discrete time step. Parameter *m* sets the reference price for the exchange of energy in a balanced community state. The parameter *a* is used to configure the slope of the suggested function, with $b = \frac{\exp\left(\frac{M-m}{a}\right) - 1}{\exp\left(\frac{M-m}{a}\right) + 1}$, whereas *M* sets the maximum price that should be realized in the community.

Figure 1: A dynamic community tariff model based on a logarithmic pricing function

In general, a tariff model for RECs should fulfill a number of different properties, including the following:

- encourage participation in RECs (for prosumers and consumers)
- initiate further investments in renewable energy and storage systems
- allow for changes in the original production/consumption ratio (new members, investments)
- be transparent and comprehensible for participants

In order to comply with the latter requirement, we suggest that forecasts of the electricity balance and prices derived thereof are generated for every 15 minutes time slot and communicated once per day, such that stable day-ahead prices are available. Moreover, the timely resolution of 15 minutes can be extended to 1 hour for reasons of simplicity, although this might reduce the steering effects of pricing signals during peak times.

Outlook

Another possible decentralized approach to coordinate decisions taken in a community is to use reinforcement learning for automated decision-making at individual member nodes using a joint reward function reflecting the goals of the community. This idea is investigated in a parallel study.

References

[1] N. Frieß, E. Feiner, U. Pferschy, J. Schauer and T. Strametz: „Optimization and Simulation for the Daily Operation of Renewable Energy Communities", *Optimization in Green Sustainability and Ecological Transition, AIRO Springer Series 12*, https://doi.org/10.1007/978-3-031-47686-0_10.

[2] R.S. Pindyck D. and Rubinfeld: *Microeconomics*, 9th edition, Pearson, 2017.

[3] T. Jin and J. Kim, "The elasticity of residential electricity demand and the rebound effect in 18 European Union countries", *Energy Sources, Part B: Economics, Planning, and Policy*,17:1, 2022.

[4] C. Eid, E. Koliou, M. Valles, J. Reneses, R. Hakvoort (2016): "Time-based pricing and electricity demand response: Existing barriers and next steps", *Utilities Policy, Volume 40*, 2016, https://doi.org/10.1016/j.jup.2016.04.001.