Cost-Optimization for Win-Win P2P Energy Systems

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Introduction

Abstract: Peer-to-Peer (P2P) energy sharing helps to make the most of the local energy resources. Optimizing their usage is either directed to reduce costs for the customers or the grid company, and it is hard to make them both win. We develop and analyze here a realistic model to implement P2P energy sharing systems that are attractive both to customers and grid companies.

P2P Energy Sharing Actors considered here:

1. **Prosumers (P)**,
2. **Consumers (C)**,
3. **Utility Company (U)**,
4. **Retail Electricity Provider (E)**,
5. **Aggregator (A)**.

Main Results: We develop a case-study based on concrete scenarios and up-to-date price models used in a real metropolitan area, compare in our study the demand-only and peak-based prices and demonstrate win-win configurations for different settings of P2P energy-sharing communities.

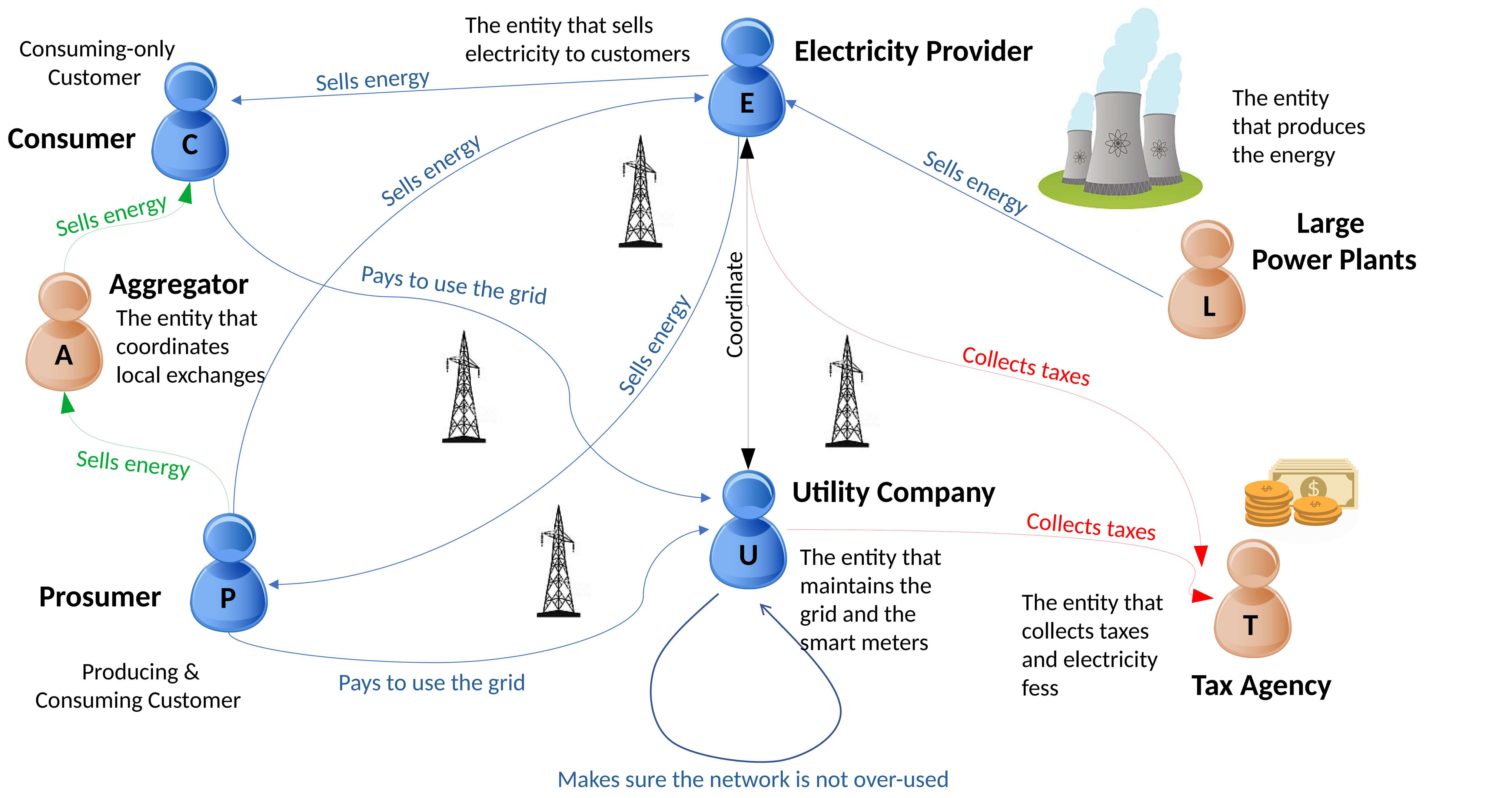

Fig. 1: Illustration of the interactions between the different actors that may be involved in setting P2P energy sharing communities.

Customer Electricity Tariffs

Hourly-based customer tariffs are based on:

1. **Grid traditional pricing**: fixed *monthly fee* (U1), *grid fee* based on consumptions per kWh (U2), and energy tax per kWh (U3).
2. **Grid peak-based pricing**: (U1)-(U3) and *peek fee* proportional to the highest consumption hour over the last month (U4).
3. *Grid compensation* for surplus electricity (U5).
4. *Tax level* (T) applied on all fees, except U3.

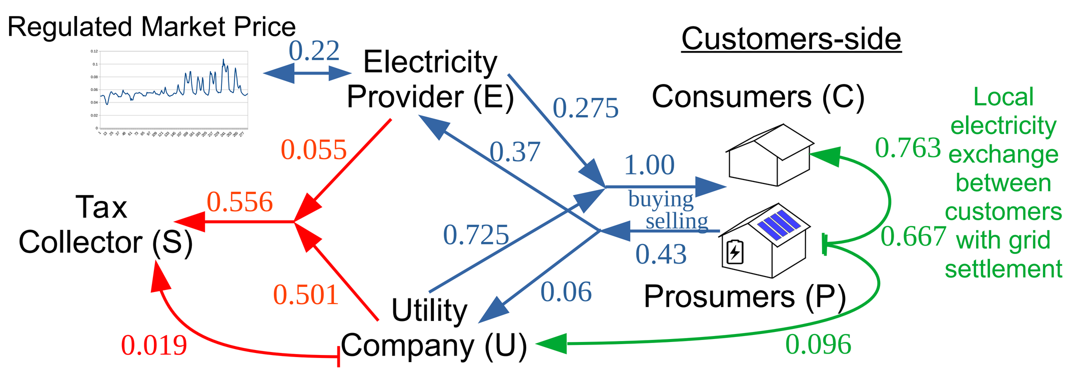

Fig. 2: Example of transactions between different actors.

Proposed Cost-Optimization Scheme

Total Customer Cost: Assuming $\boldsymbol{peak}_{u,M} = \max_{t\in M} \boldsymbol{in}_{u,t}$ is the highest consumption of u over M, the cost for u over period M is given by (with U1-U5 provided by the electricity price model "traditional" or "peak-based"):

$$\boldsymbol{cost}_{u,M} = U1 + U4 \cdot \boldsymbol{peak}_{u,M} + \sum_{t\in M} \left(\boldsymbol{in}_{u,t} \cdot p^{\text{buy}}_{u,t} - \boldsymbol{out}_{u,t} \cdot p^{\text{sell}}_{u,t} \right),$$

with $p^{\text{buy}}_{u,t} = (p_{u,t} + U2) \cdot T + U3$ and $p^{\text{sell}}_{u,t} = p_{u,t} + U5$ with $p_{u,t}$ being the current market electricity price (kr/kWh).

LP Cost-optimization Model (sketched): The cost for each end-user u at time-step t is computed as:

$$\boldsymbol{cost}_{u,t} = \boldsymbol{in}_{u,t} \cdot p^{\text{buy}}_{u,t} - \boldsymbol{out}_{u,t} \cdot p^{\text{sell}}_{u,t} + \boldsymbol{imp}_{u,t} \cdot (p^{\text{com}}_{u,t} + p^{\text{grid}}) - \boldsymbol{exp}_{u,t}(p^{\text{com}}_{u,t} - p^{\text{grid}})$$

with $p^{\text{grid}} = \frac{\gamma}{2}$ with γ being a **grid fee on traded electricity** (kr/kWh), and $p^{\text{com}}_{u,t} = (p^{\text{buy}}_{u,t} + p^{\text{sell}}_{u,t})/2$.

Optimization variables: $\boldsymbol{out}_{u,t}$: sold electricity (kWh) to the grid, $\boldsymbol{in}_{u,t}$: bought electricity (kWh) from the grid, $\boldsymbol{imp}_{u,t}$: electricity imported from G (kWh), $\boldsymbol{exp}_{u,t}$: electricity exported to G (kWh) with G being a given community.

Objective: to minimize $\boldsymbol{bill}_G = \sum_{t=t_0}^{t_{max}} \sum_{u\in G} \boldsymbol{cost}_{u,t}$, for timespan $[t_0, t_{max}]$ and initial battery level of b_{u,t_0-1}.

Constraints: (1) battery is capped, (2) battery is balanced, (3) demand is balanced, (4) traded electricity is balanced.

Evaluation, Conclusion and Future Work

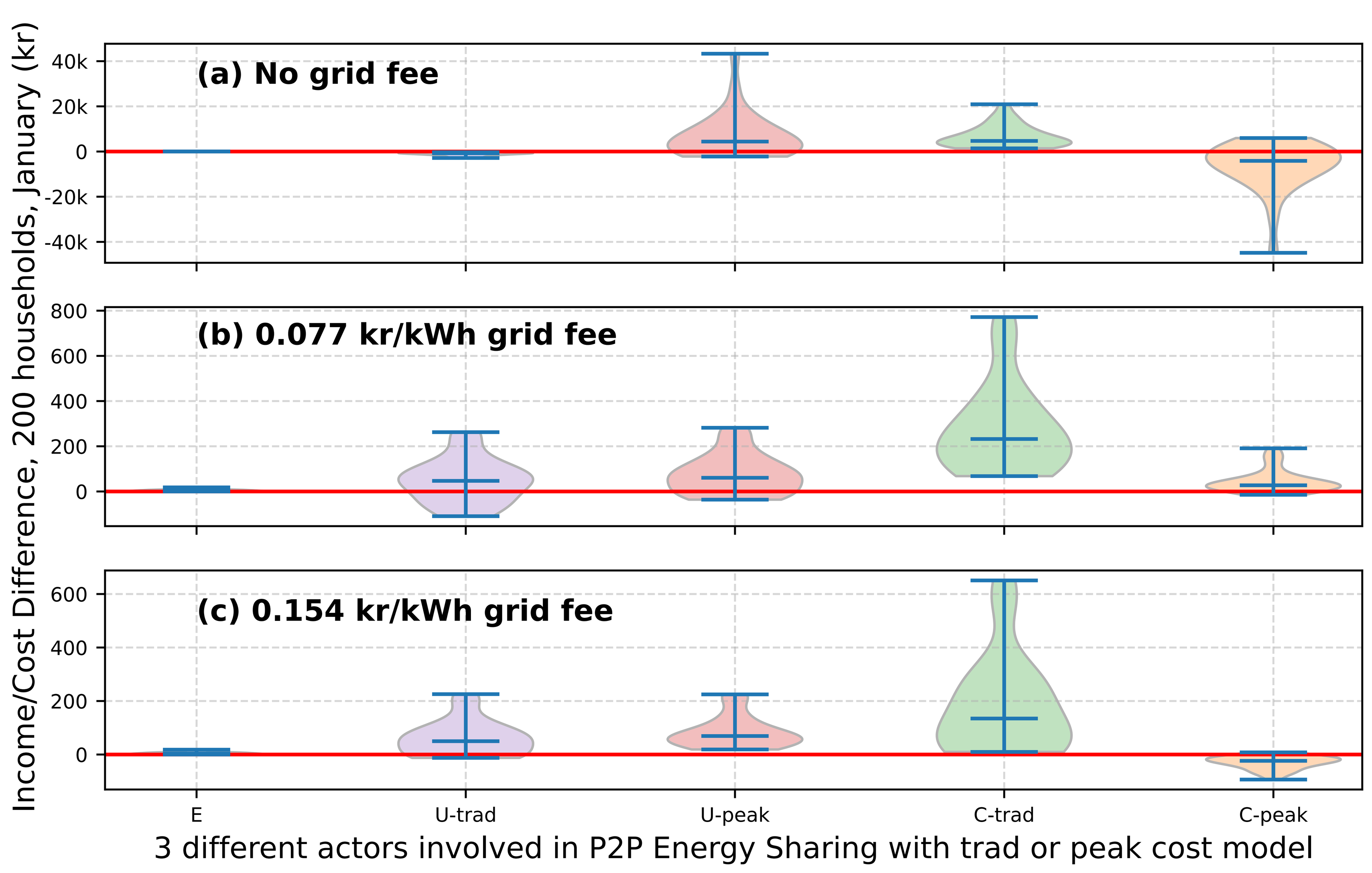

Fig. 3: Income gain (or cost reduction) due to P2P energy sharing for the 3 actors (all end-users C, electricity provider E and grid company U), the two considered price models "trad" (traditional) and "peak" (peak-based) and 3 different grid fees: (a) none, (b) $\gamma = 0.077$, (c) $\gamma = 0.154$.

Case-Study: We use electricity consumption profiles of 2221 real households and assume the prosumers are equipped with roof-top solar PV panels and possibly a local battery. We scale the resources into 3 realistic levels: small, medium, and large with respective average of 5.7 kWp, 7.3 kWp and 10.4 kWp of installed PV capacity and use electricity prices in place in Gothenburg as provided in Table 1.

Results: The total income for 2221 households (M kr) of each actor under our price models considering 1% of battery-users with medium installations is:

Scenario (PV % capacity)	Electricity Provider	Grid Income (trad)	Grid Income (peak)	Customer Cost (trad)	Customer Cost (peak)
10% medium	0.676	11.164	12.110	31.538	32.712
20% medium	0.666	10.865	11.772	30.567	31.694
40% medium	0.633	10.404	11.387	29.170	30.391

Fig. 3 (a) presents the difference in income between the community-based energy sharing system and the one where all end-users do not cooperate, without grid fees on locally traded electricity. Customers are favored by the traditional prices but for peak-based prices, they are slightly losing money and it is the opposite for the grid! Fig. 3 (b) provides a good balance figure where all actors can be "winners" on average, regardless of the cost-model that is being used. A too high grid fee as shown in Fig. 3 (c) results in a net loss for customers with peak-based prices.

Conclusion: Showing that all interested actors can be winners, even when dealing with peak-based price models, is a novel result and may lead to further deployment of P2P energy sharing.

Future Work: To investigate adaptations to better target peak-based pricing.

Table 1: Summary of fees and taxes for the traditional and peak-based price models (* Subject to VAT) used in our case-study (Gothenburg metropolitan area):

Price Model	Tax Level (T, %)	E Sub. Fee* (E1, kr/month)	E Surplus (E2, kr/kWh)	U Sub. Fee* (U1, kr/month)	U Fee* (U2, kr/kWh)	Elec. Tax (U3, kr/kWh)	U Peak Fee* (U4, kr/kWh of peak)	U Surplus (U5, kr/kWh)
Trad	25%	26	-0.05 to -0.15	139	0.224	0.445	0	-0.06
Peak	25%	26	-0.05 to -0.15	89	0.154	0.445	26.8	-0.06