Local Energy Sharing Considering Different Technologies, Individual Preferences, and Contributions

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Agenda

- Introduction and motivation
- Concept of FRESH:COM (Energy community model)
- 3 use-cases: Optimization model and results
  - Maximizing the community‘s self-consumption
  - Including the Prosumer‘s willingness-to-pay
  - Adding a new member to the community
- Conclusion

Introduction and Motivation

- Energy communities and further democratization of the energy system are explicitly mentioned in the **EU‘s Clean Energy Package**
- The 4Ds:
- Decarbonization – Digitalization – Decentralization – Democratization
- Rising awareness of one‘s own carbon footprint
- Shared economy
- Making investments in renewables more profitable

What is an Energy Community?

IEEE 33 Bus Distribution Network:

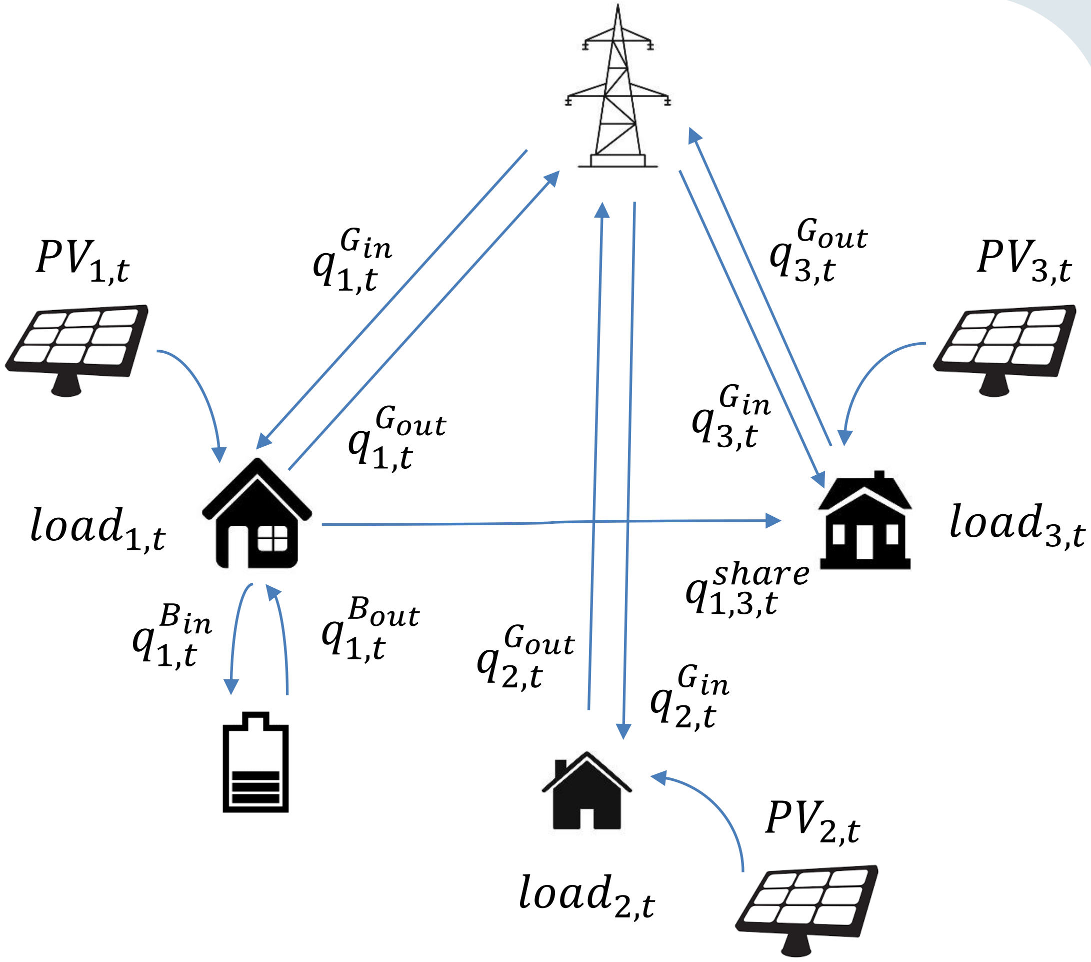
About FRESH:COM

- Model used in this work: **FRESH:COM**
  - “**FaiR E**nergy **SH**aring in Local **COM**munities “
  - Linear optimization model
- Local Energy Community (EC):
  - Participants are *Prosumers* or simply *Consumers*
  - Renewable energy: PV, battery storages, …
  - Participants have different reasons to join an EC (economic reasons, environmental aspects, self-sufficiency)
  - Fully democratic participation: voluntary participation, willingness-to-pay for renewables

Variables and Structure of FRESH:COM

$i \in \{1, \dots, N\}$ … Prosumers
$t \in \{1, \dots, T\}$ … time
$PV_{i,t}$ … PV production of prosumer i at time t
$load_{i,t}$ … load of prosumer i at time t
$wtp_{i,t}$ … willingness−to−pay of prosumer i at time t
p_t^G … Retail price of electricity from the grid at time t
p_t^F … Feed−in tariff at time t

Optimization Variables:
$q_{i,t}^{G_{in}}$ … Prosumer i buys from the grid at time t
$q_{i,t}^{G_{out}}$ … Prosumer i sells to the grid at time t
$q_{i,j,t}^{share}$ … Prosumer j buys from prosumer i at time t
(with $q_{i,i,t}^{share}$ self−consumption of Prosumer i at time t)
$SoC_{i,t}$ … State of charge of prosumer i's battery at time t
$q_{i,t}^{B_{in}}$ … charging of prosumer i's battery at time t
$q_{i,t}^{B_{out}}$ … discharging of prosumer i's battery at time t

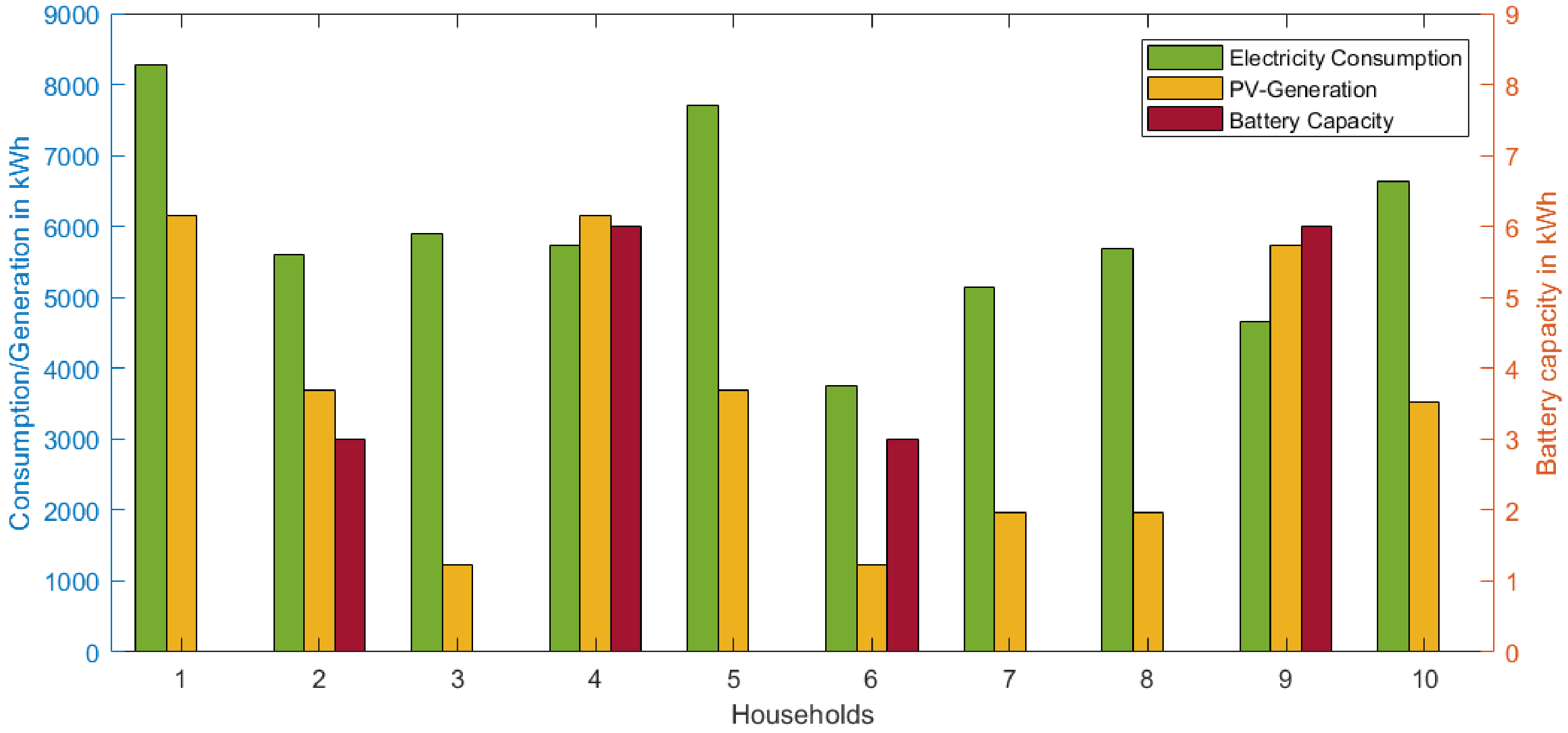


Data and Assumptions

10 *Prosumer*:

Prosumer	PV-Orientation	PV-Peak Output [kWp]	Storage Capacity [kWh]	Willingness-to-Pay [Cent/kg CO2]
1	South	5	0	5
2	South	3	3	8
3	South	1	0	15
4	South	5	6	2
5	South	3	0	6
6	South	1	3	12
7	East-West	2x 1	0	13
8	East-West	2x 1	0	15
9	South West	5	6	0
10	South East	3	0	10

Data and Assumptions



Data and Assumptions

- PV generation data: http://renewables.ninja [1],[2]
  - Hourly data
  - 8760 values
  - Year: 2014
  - Different azimuth and tilt (here: tilt=35°)
- Households:
  - Load quarter-hourly (35040 values)
- Willingness-to-pay: depending on the marginal emissions of the electricity supply and each prosumer‘s preference to avoid emissions
  - Randomly assigned
- Prices:
  - Household electricity price: 15 Cent/kWh
  - Feed-in-Tariff: 3 Cent/kWh

[1] Pfenninger, Stefan and Staffell, Iain (2016). Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 114, pp. 1251-1265. doi: 10.1016/j.energy.2016.08.060

[2] Staffell, Iain and Pfenninger, Stefan (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi: 10.1016/j.energy.2016.08.068

Methodology – Maximizing the EC‘s Self-Consumption

Objective function:

$$\max \underbrace{\sum_{i,t} p_t^F * q_{i,t}^{G_{out}} - \sum_{i,t} p_t^G * q_{i,t}^{G_{in}}}_{\text{Community welfare}} + \underbrace{\sum_{i,t} p_t^G * q_{i,i,t}^{share}}_{\text{Self-consumption}}$$

Subject to:

$$load_{i,t} = q_{i,t}^{G_{in}} + \sum_j q_{j,i,t}^{share}$$

$$PV_{i,t} = q_{i,t}^{G_{out}} + \sum_j q_{i,j,t}^{share}$$

$$q_{i,t}^{G_{in}}, q_{i,t}^{G_{out}}, q_{i,j,t}^{share} \geq 0$$

For all $i \in \{1, \dots, N\}$, $t \in \{1, \dots, T\}$

Subject to (with batteries):

$$load_{i,t} = q_{i,t}^{G_{in}} + q_{i,t}^{B_{out}} + \sum_j q_{j,i,t}^{share}$$

$$PV_{i,t} = q_{i,t}^{G_{out}} + q_{i,t}^{B_{in}} + \sum_j q_{i,j,t}^{share}$$

$$SoC_{i,t} = SoC_{i,t-1} + q_{i,t}^{B_{in}} * \eta_{bat} - q_{i,t}^{B_{out}} / \eta_{bat}$$

$$SoC_{i,t} \leq SoC_i^{max}$$

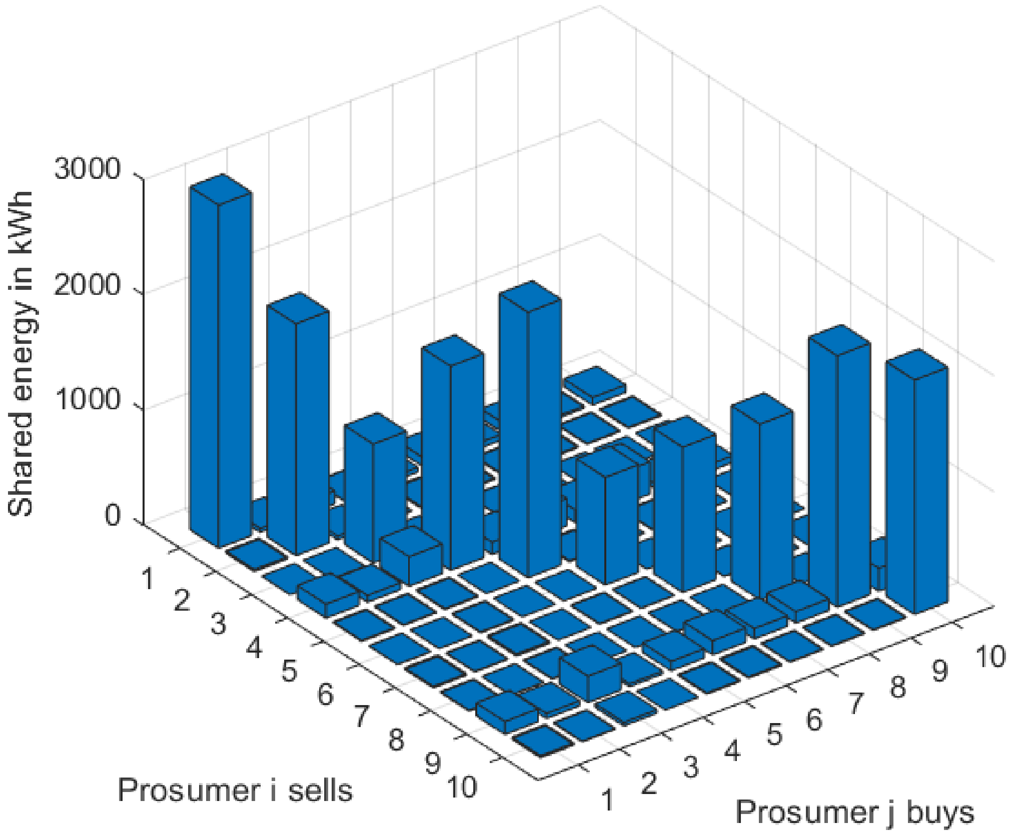
$$q_{i,t}^{B_{in}}, q_{i,t}^{B_{out}} \leq q_i^{B_{max}}$$

$$q_{i,t}^{G_{in}}, q_{i,t}^{G_{out}}, q_{i,j,t}^{share}, SoC_{i,t}, q_{i,t}^{B_{in}}, q_{i,t}^{B_{out}} \geq 0$$

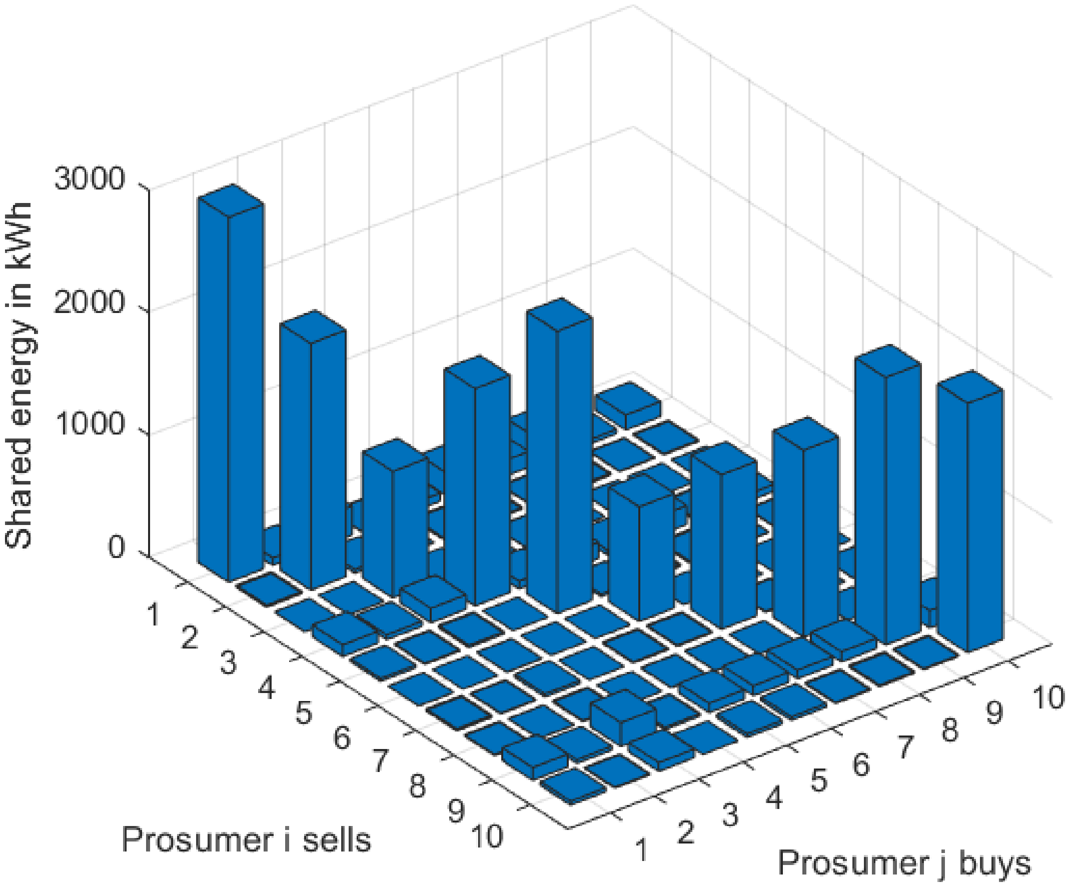
For all $i \in \{1, \dots, N\}$, $t \in \{1, \dots, T\}$

Results – Maximizing the EC's Self-Consumption

Without battery storages:



With battery storages:



Results – Maximizing the EC‘s self-consumption

Comparing scenario with battery and without battery:

- Decreasing consumption from the grid with batteries
- Batteries also decrease the feed-in to the grid

→ Better community welfare (CW)

Methodology – Including Willingness-to-Pay (wtp)

Objective function:

$$\max \underbrace{\sum\nolimits_{i,t} p_t^F * q_{i,t}^{G_{out}} - \sum\nolimits_{i,t} p_t^G * q_{i,t}^{G_{in}}}_{\text{Community welfare}} \underbrace{+ \sum\nolimits_{i,j,t} wtp_{i,t} * q_{i,j,t}^{share}}_{\text{Prosumer welfare}}$$

Subject to:

$$load_{i,t} = q_{i,t}^{G_{in}} + q_{i,t}^{B_{out}} + \sum_{j=1}^{N} q_{j,i,t}^{share}$$

$$PV_{i,t} = q_{i,t}^{G_{out}} + q_{i,t}^{B_{in}} + \sum_{j=1}^{N} q_{i,j,t}^{share}$$

$$SoC_{i,t} = SoC_{i,t-1} + q_{i,t}^{B_{in}} * \eta_{bat} - q_{i,t}^{B_{out}} / \eta_{bat}$$

$$SoC_{i,t} \leq SoC_i^{max}$$

$$q_{i,t}^{B_{in}}, q_{i,t}^{B_{out}} \leq q_i^{B_{max}}$$

$$q_{i,t}^{G_{in}}, q_{i,t}^{G_{out}}, q_{i,j,t}^{share}, SoC_{i,t}, q_{i,t}^{B_{in}}, q_{i,t}^{B_{out}} \geq 0$$

For all $i \in \{1, \ldots, N\}$, $t \in \{1, \ldots, T\}$

- **Community‘s welfare:** selling and buying to/from the grid
- **Prosumers‘ welfare:** from trading within the community

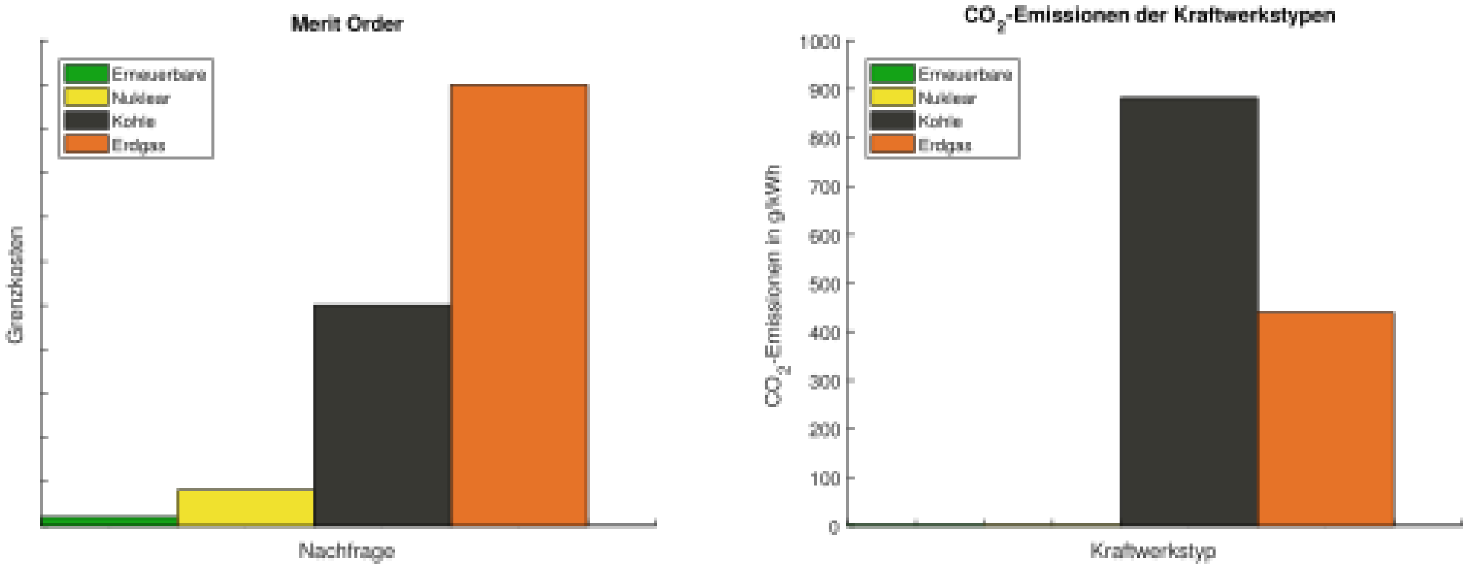
Methodology – Willingness-to-Pay

$$wtp_{i,t} = p_t^F + w_i * e_{i,t}$$

p_t^F … Feed−in Tariff [€/kWh]
w_i … willingness to pay for marginal emissions [€/kgCO$_2$]
$e_{i,t}$ … marginal emissions from the grid [kgCO$_2$/kWh]

	$e_{i,t}\ [\frac{kg\ CO_2}{kWh}]$
Renewables	0
Gas	0.44
Oil	0.645
Coal	0.882

Source: e-control (https://www.e-control.at/konsumenten/oeko-energie/oekostrom-erkennen/stromkennzeichnung)



Source: Wachter, 2018 Peer-to-Peer Stromhandel in einem Verteilnetz mit lokaler Photovoltaik-Stromerzeugung unter Berücksichtigung verschiedener Zahlungsbereitschaften

Revenues of the Prosumer

Trading within the community:

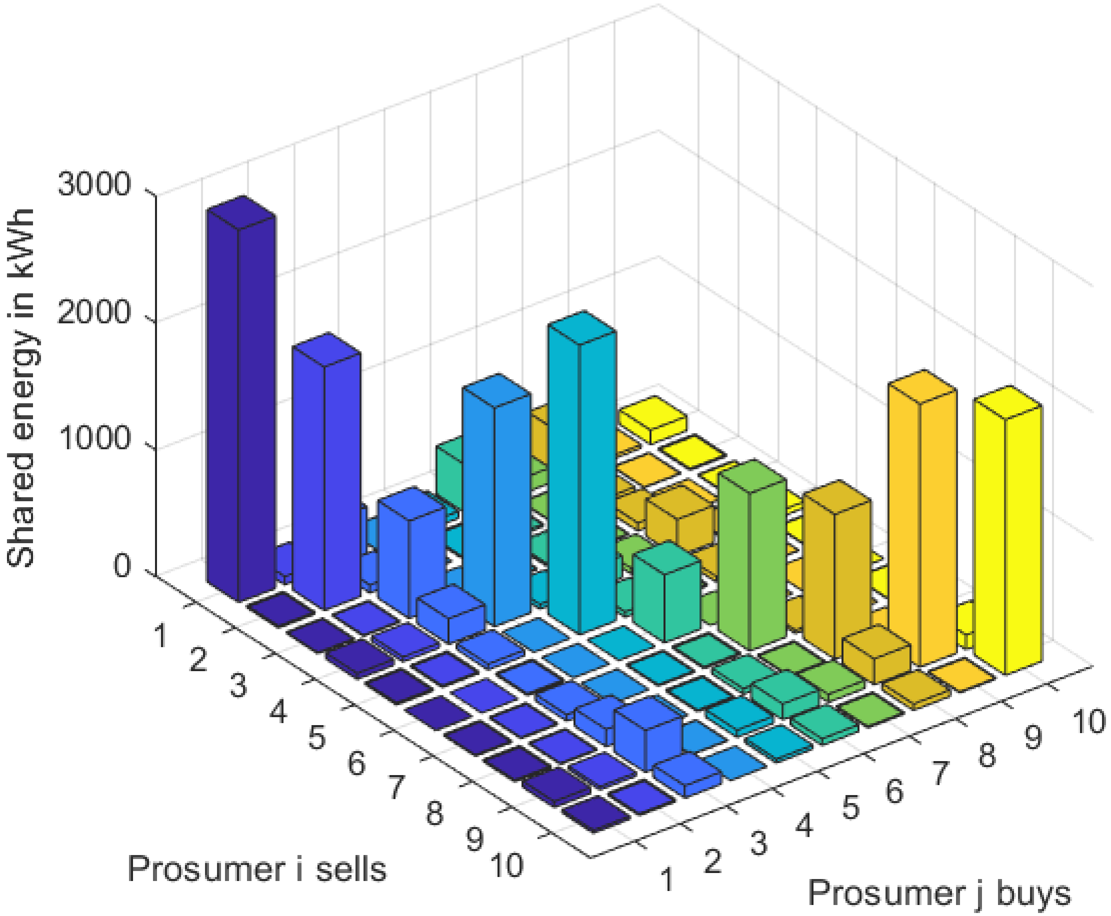
$$Revenues_i = \sum_{t=1}^{T} q_{i,t}^{G_{out}} * p_{i,t}^{F} - \sum_{t=1}^{T} q_{i,t}^{G_{in}} * p_{i,t}^{G} + \sum_{t=1}^{T} q_{i,j,t}^{share} * wtp_{j,t} - \sum_{t=1}^{T} q_{j,i,t}^{share} * wtp_{i,t}$$

Without community trading:

$$Revenues_i = \sum_{t=1}^{T} q_{i,t}^{G_{out}} * p_{i,t}^{F} - \sum_{t=1}^{T} q_{i,t}^{G_{in}} * p_{i,t}^{G}$$

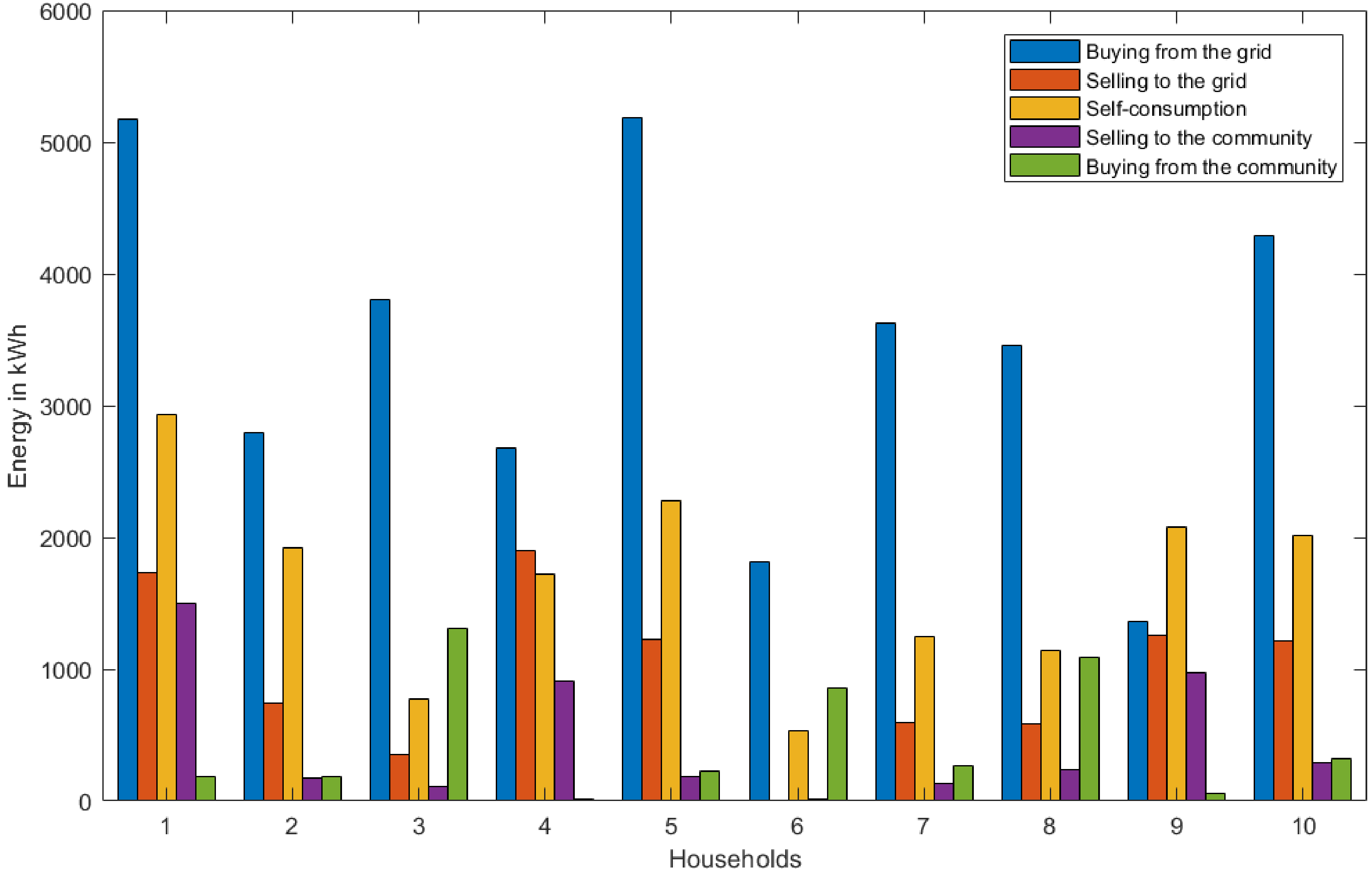
Results – Including Willingness-to-Pay

Energy shared within the community:



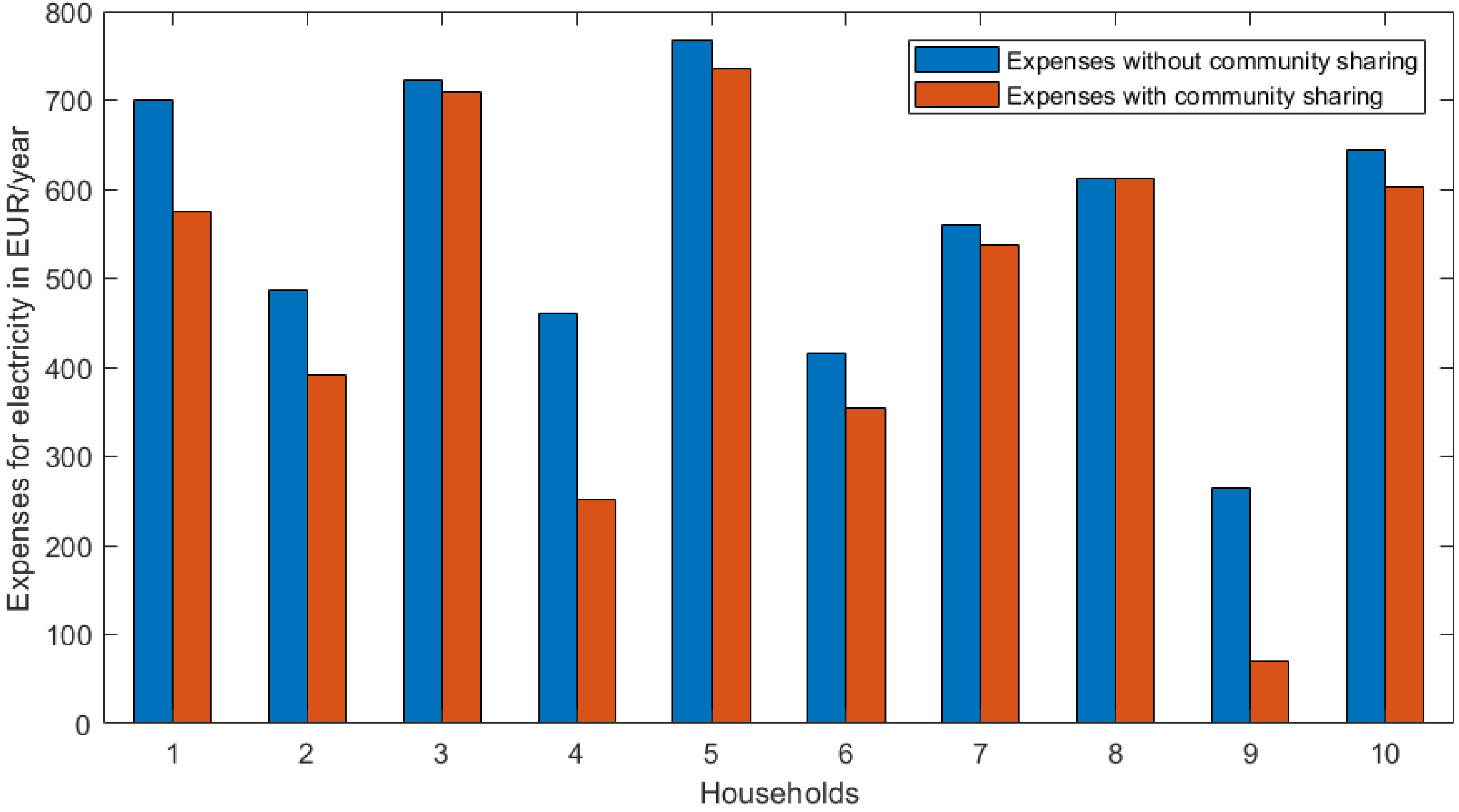
Results – Including Willingness-to-Pay

Energy traded between the grid and the prosumers, and within the community:



Results – Including Willingness-to-Pay

Expenses for electricity of each prosumer with and without sharing:



Methodology – Including a New Member

Objective function:

$$\max \sum_{i,t} p_t^F * q_{i,t}^{G_{out}} - \sum_{i,t} p_t^G * q_{i,t}^{G_{in}} + \sum_{i,j,t} wtp_{i,t} * q_{i,j,t}^{share}$$

… maximizing the community‘s welfare and the prosumer’s welfare

Subject to:

$$load_{i,t} = q_{i,t}^{G_{in}} + q_{i,t}^{B_{out}} + \sum_{j=1}^{N+1} q_{j,i,t}^{share}$$

$$PV_{i,t} = q_{i,t}^{G_{out}} + q_{i,t}^{B_{in}} + \sum_{j=1}^{N+1} q_{i,j,t}^{share}$$

$$SoC_{i,t} = SoC_{i,t-1} + q_{i,t}^{B_{in}} * \eta_{bat} - q_{i,t}^{B_{out}} / \eta_{bat}$$

$$SoC_{i,t} \leq SoC_i^{max}$$

$$q_{i,t}^{B_{in}}, q_{i,t}^{B_{out}} \leq q_i^{B_{max}}$$

$$q_{i,t}^{G_{in}}, q_{i,t}^{G_{out}}, q_{i,j,t}^{share}, SoC_{i,t}, q_{i,t}^{B_{in}}, q_{i,t}^{B_{out}} \geq 0$$

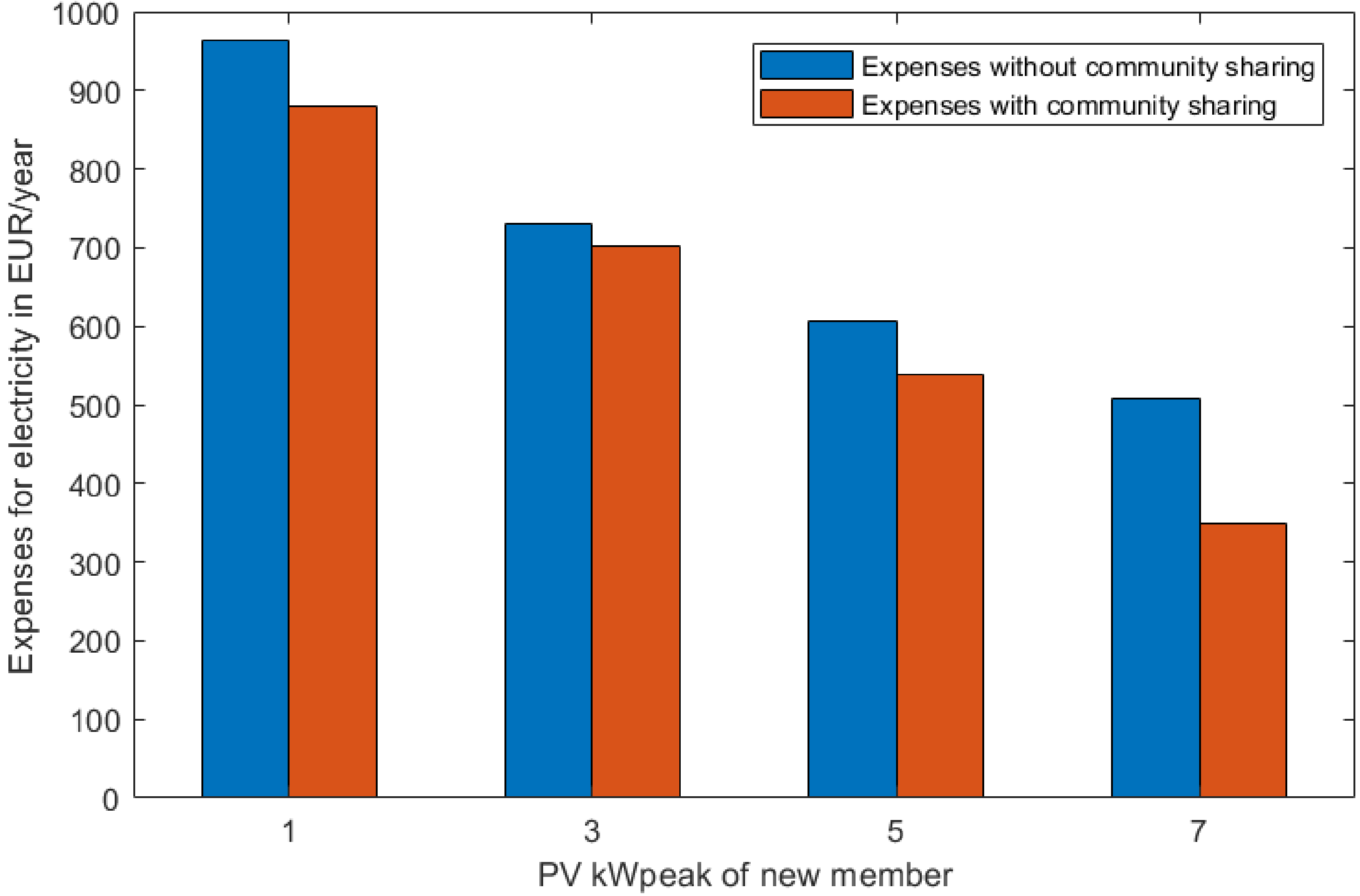
For $i \in \{1, \dots, N+1\}$, $t \in \{1, \dots, T\}$

Data and Assumptions – Including a New Member

- Parameter of existing prosumer remain the same
- New household: fixed load and
- Willingness-to-pay: 10 Cent/kg CO2
- **Different PV dimensions: 1,3,5,7 kWpeak**
- No storage

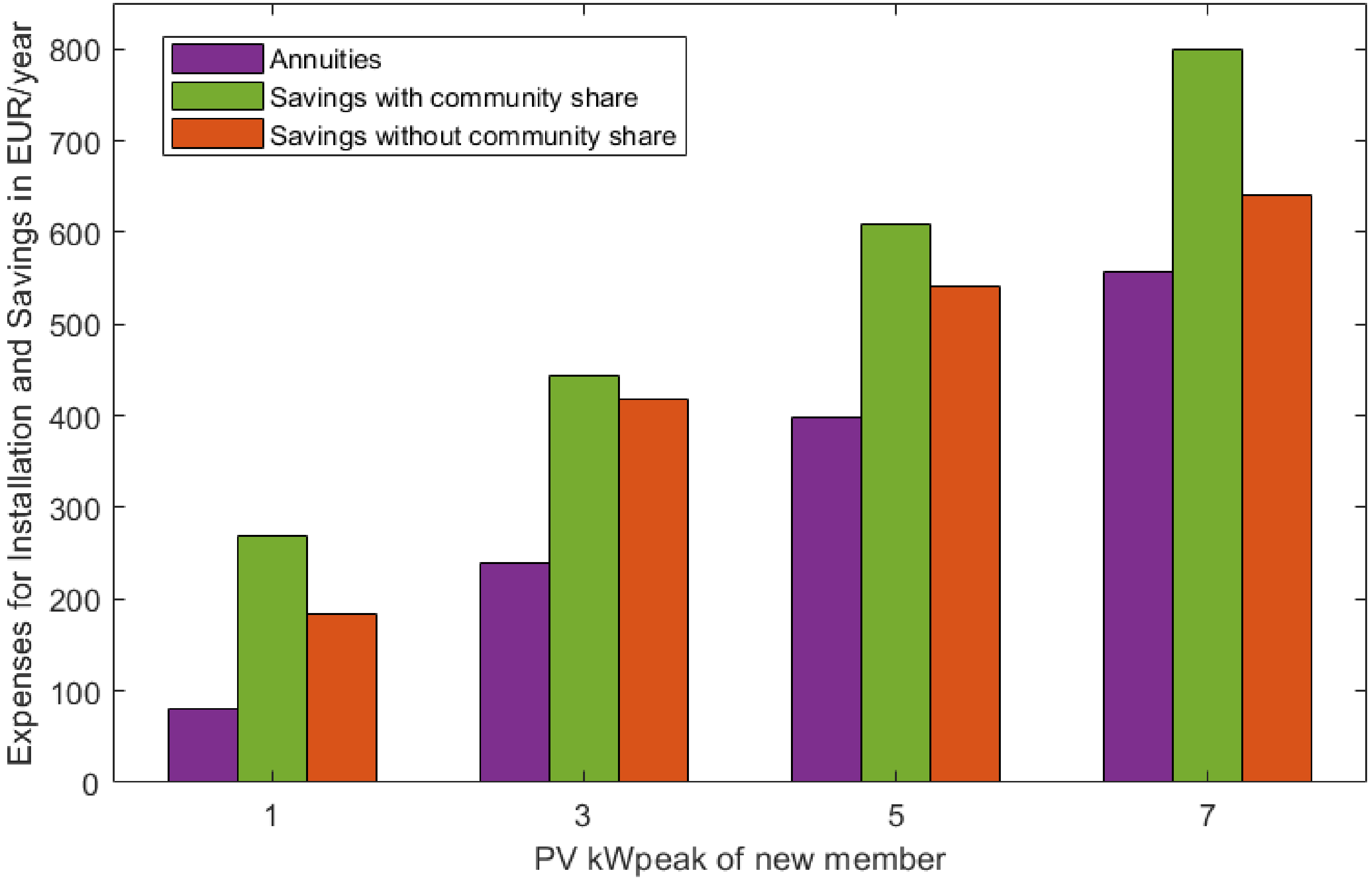
Results – Including a New Member

Yearly expenses for electricity of the new member with different PV dimensions:



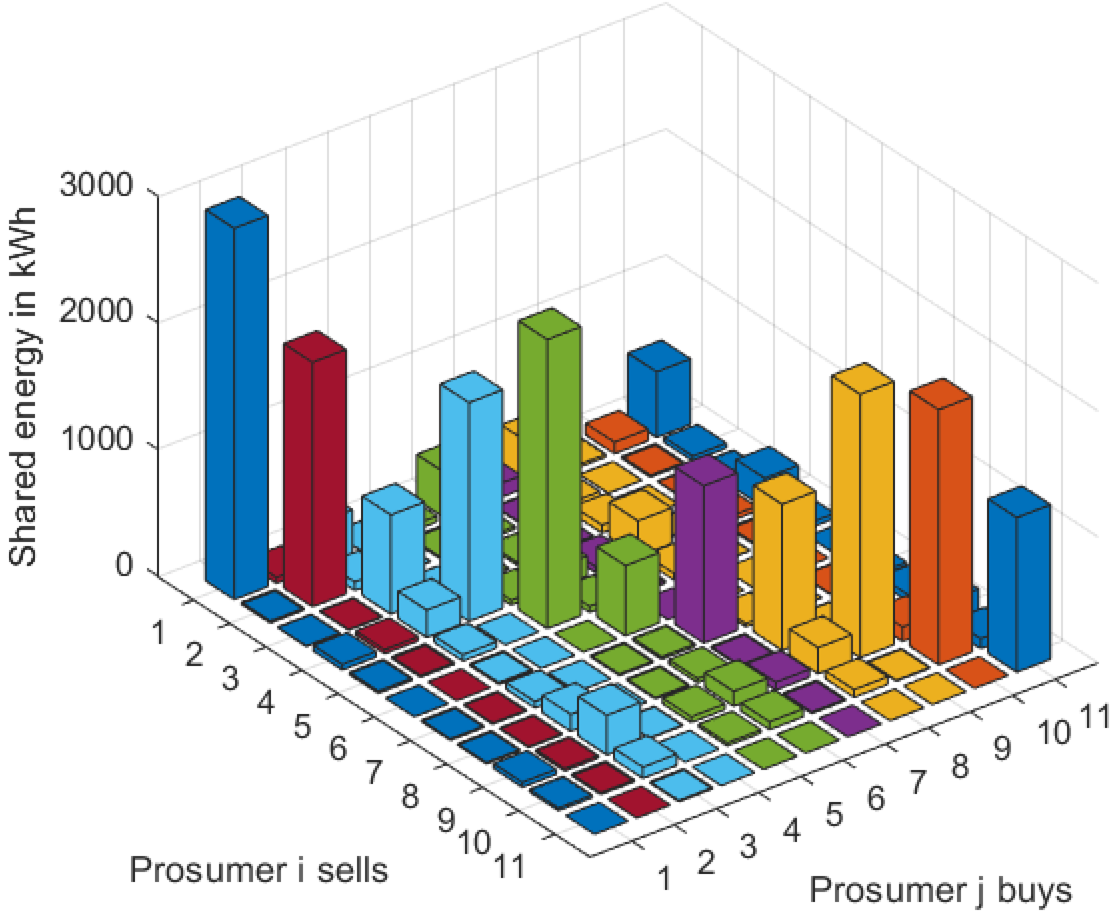
Results – Including a New Member

Yearly profits from sharing vs. the annuities of the PV-module ($r = 0.02, I_0 = \frac{1300EUR}{kW_{peak}}$, $\mathrm{n} = 20$ years):



Results – Including a New Member

Annual shared energy including the new member with 1 kWpeak:



Conclusions and Outlook

- Sharing within the community leads to better profitability of PV
- Prosumers (or consumers) can easily join or leave the community or change their willingness-to-pay
- Up-scaling of the model: Including more than one distribution network section
  - Willingness-to-pay dependent on the distribution network section
- Including other types of renewables:
  - Small wind power plant
  - Small hydro power plant

Thank you for your attention!

Feedback or questions?