LIÈGE université
Sciences Appliquées

Local energy communities Benefits, impacts and models

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DENSYS immersive week in Liège

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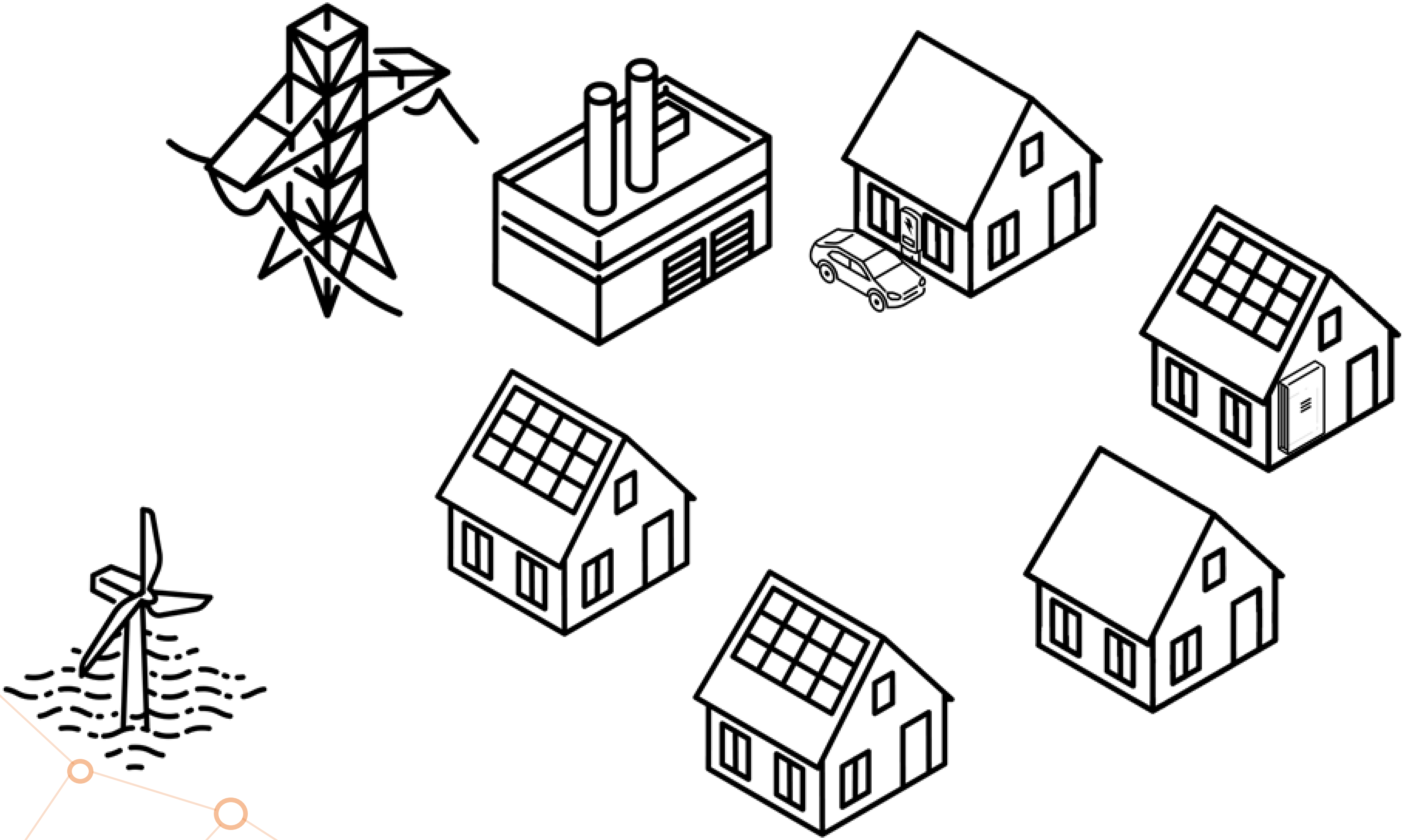
Introduction

What is an energy community ?



Goals of energy communities

- Improve energy independance
- Increase DER penetration
- Participate in electrical network support
- Create a social structure around energy
- Allow users to decrease their energy costs

- Economic impact
- Environmental impact
- Social impact

Improve energy independance

Maximizing self-sufficiency allows for less reliability on retailers.

This can be achieved using distributed energy resources.

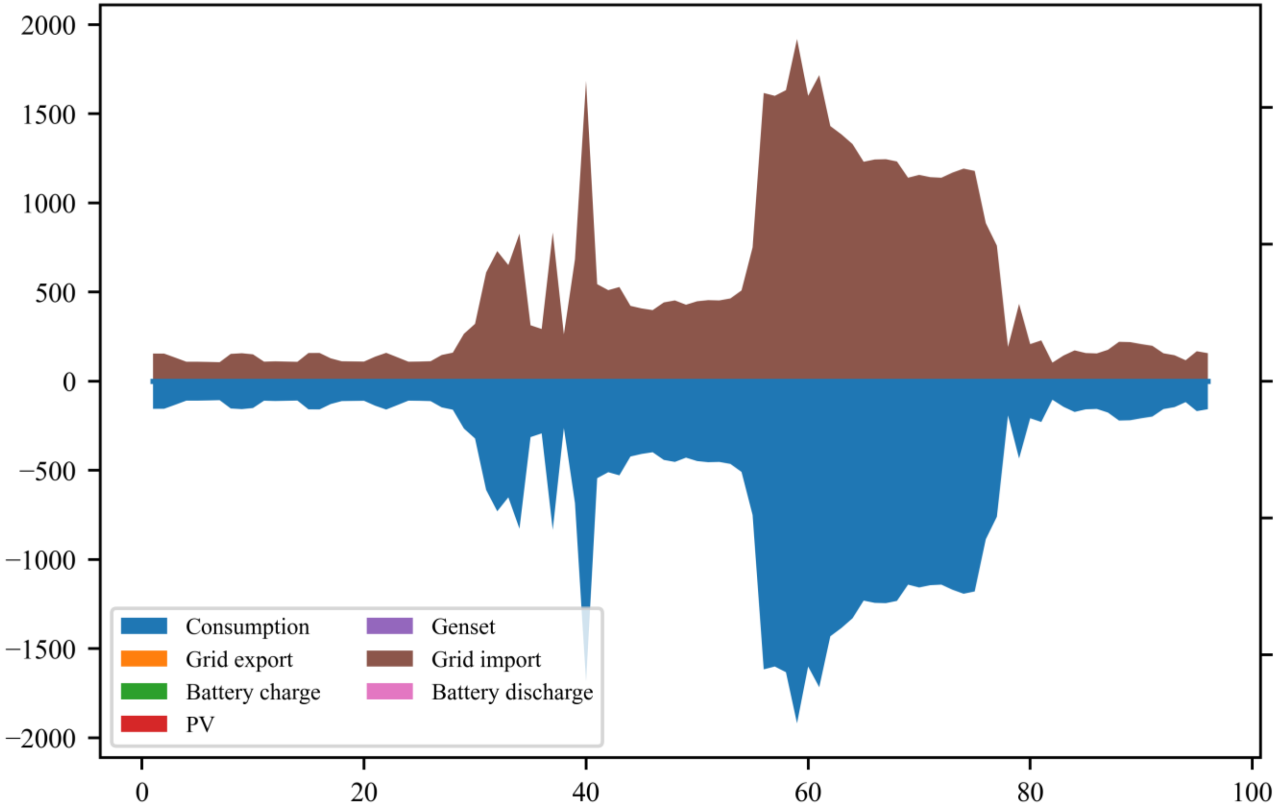
Energy communities improve the usage of existing DER.

Base load

Total negative energy (consumption):
- Base consumption: -12 kWh

Total positive energy (production):
- Grid import: 12 kWh

Daily cost: 5€

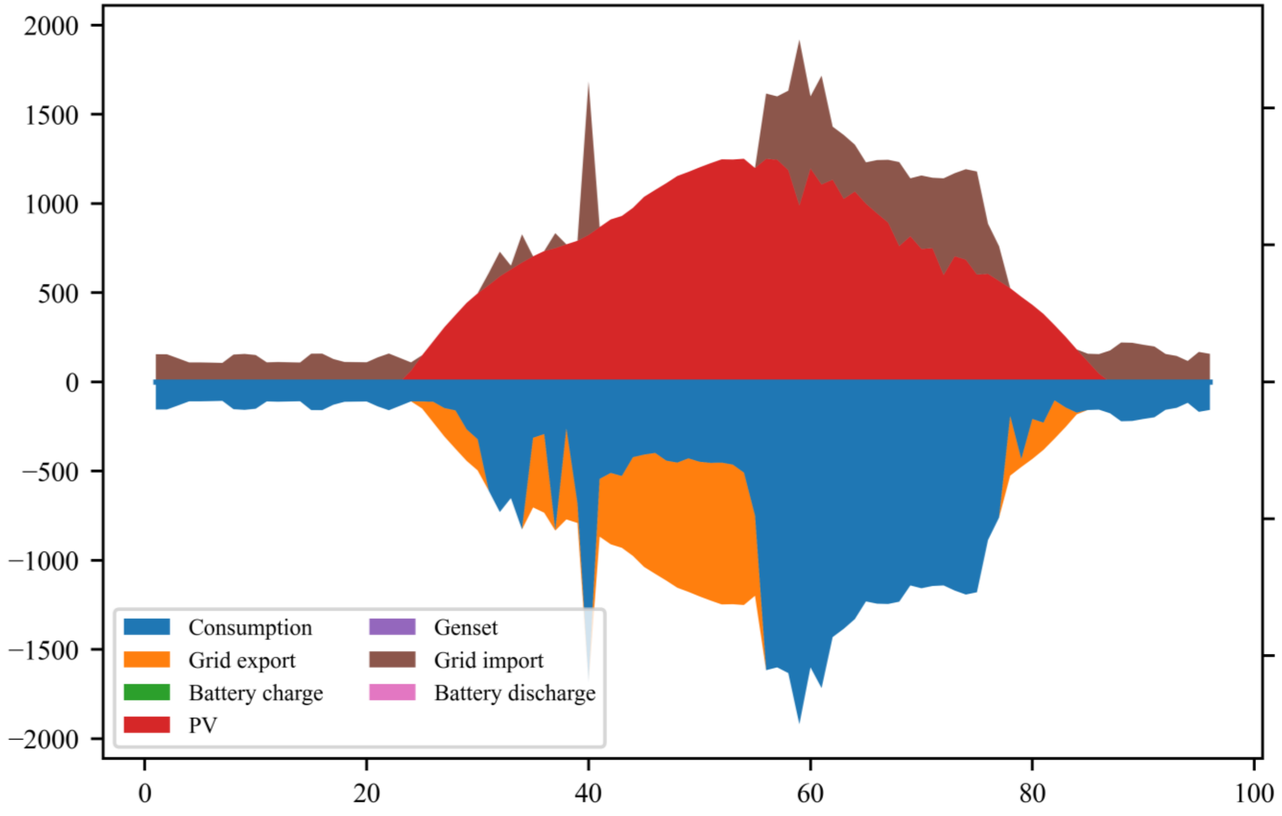


Small PV system

Total negative energy (consumption):
- Base consumption: -12 kWh
- Grid export: -3 kWh

Total positive energy (production):
- PV production: 12 kWh
- Grid import: 3 kWh

Daily cost: 1.4€



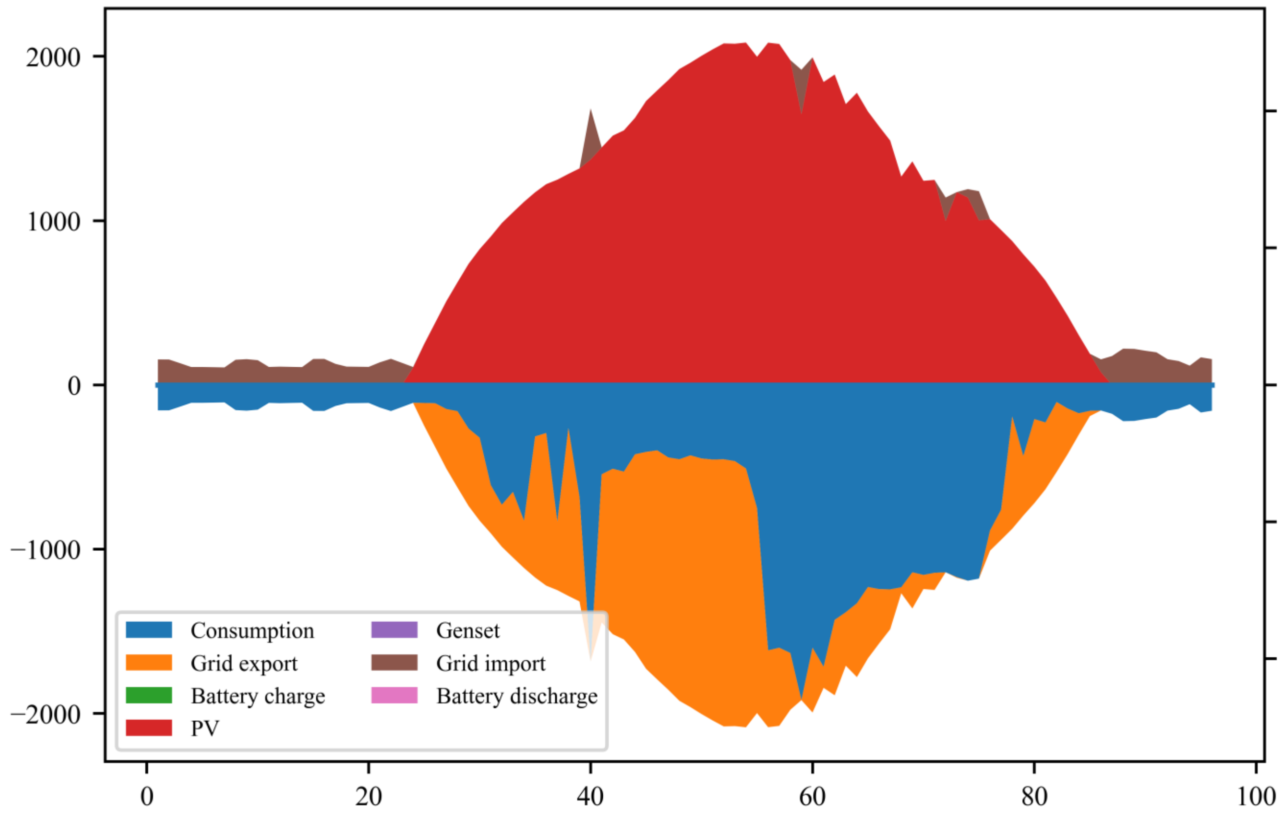
Note that the net import is null

Bigger PV system

Total negative energy (consumption):
- Base consumption: -12 kWh
- Grid export: -8 kWh

Total positive energy (production):
- PV production: 20 kWh
- Grid import: 1 kWh

Daily cost: 0.22€



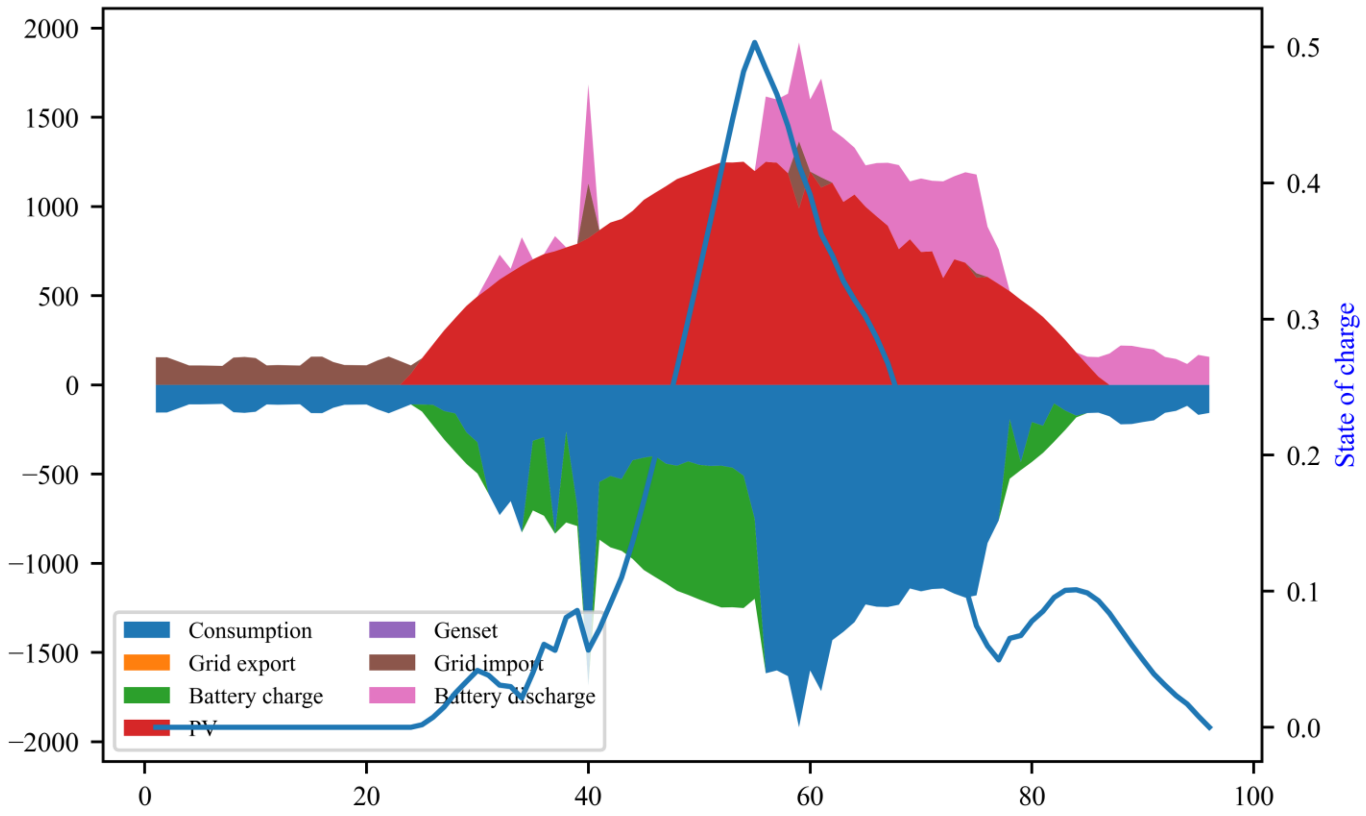
PV system quickly becomes oversized…

Battery storage system

Total negative energy (consumption):
- Base consumption: -12 kWh
- Grid export: 0 kWh
- Battery charge: -3 kWh

Total positive energy (production):
- PV production: 12 kWh
- Grid import: 1 kWh
- Battery discharge: 2 kWh

Daily cost: 0.4 €



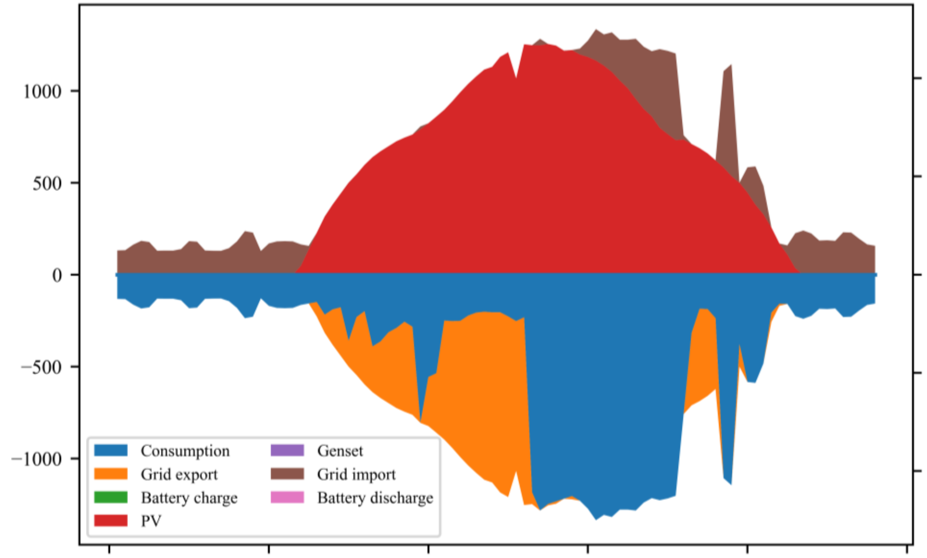
Improved self-consumption

Two separate profiles

Total negative energy (consumption):
- Base consumption: -11 kWh
- Grid export: -3 kWh

Total positive energy (production):
- PV production: 12 kWh
- Grid import: 3 kWh

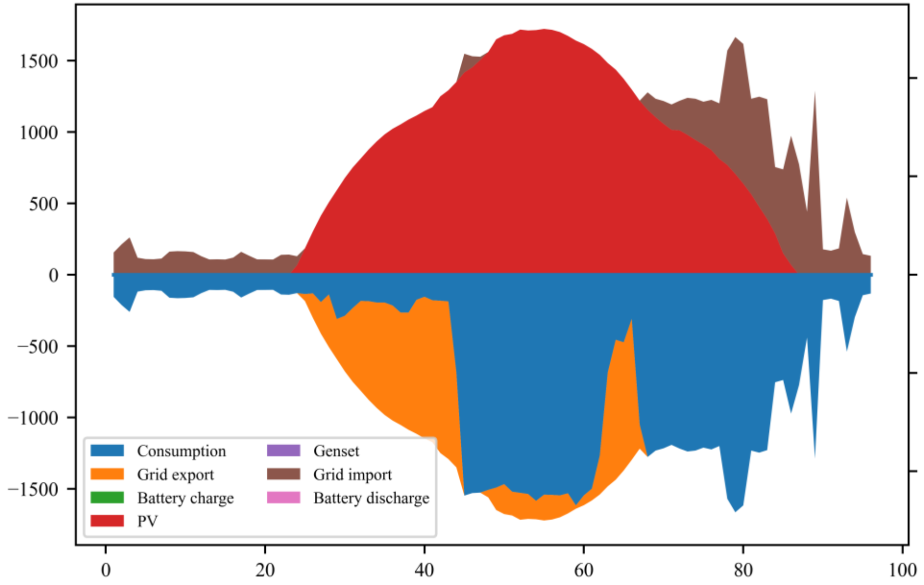
Daily cost: 1€



Total negative energy (consumption):
- Base consumption: -16 kWh
- Grid export: -4 kWh

Total positive energy (production):
- PV production: 16 kWh
- Grid import: 4 kWh

Daily cost: 1.5€

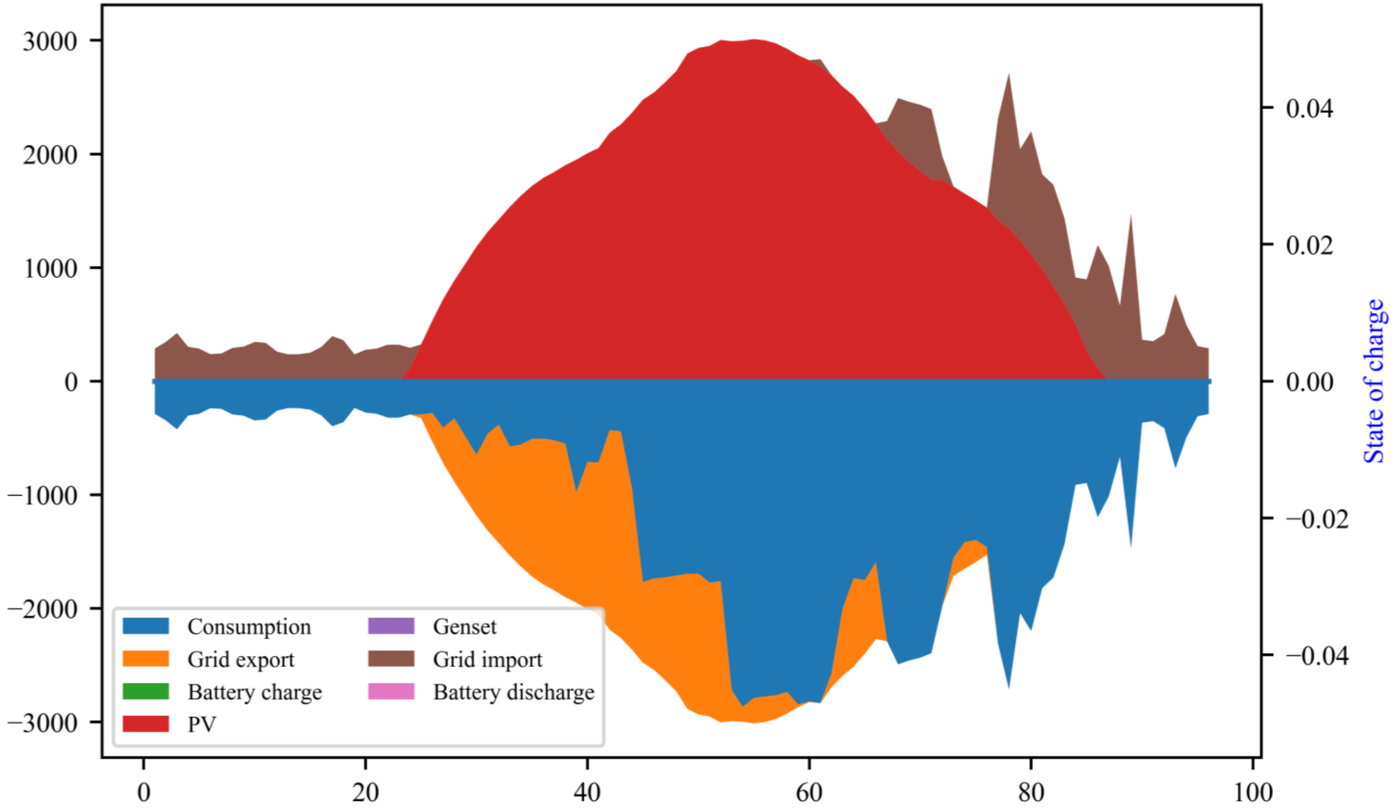


Aggregating the two curves

Total negative energy (consumption):
- Base consumption: -27 kWh
- Grid export: -8 kWh

Total positive energy (production):
- PV production: 29 kWh
- Grid import: 6 kWh

Daily cost: 2.13€ < 2.5€



Better solution for both users

Increase DER penetration

Better use of DER resources allow for more profitability.

Economies of scale provide even bigger incentive for investment.

Community structure also offers opportunity of co-investing.

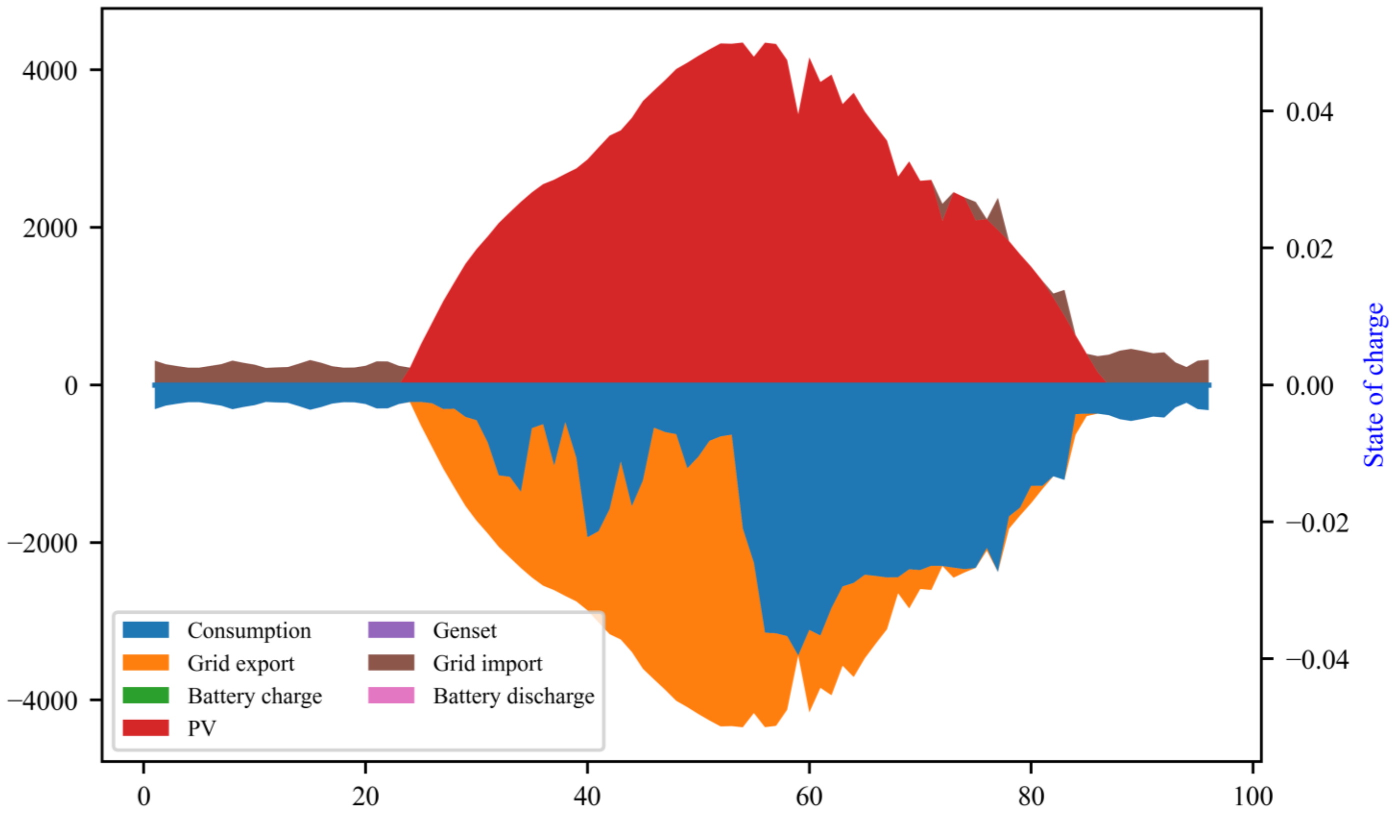
Sizing for a single user

Sizing decisions:
- PV capacity: 2 kWp

Total negative energy (consumption):
- Base consumption: -12 kWh
- Grid export: -11 kWh

Total positive energy (production):
- PV production: 22 kWh
- Grid import: 1 kWh

OPEX = 0.04 €
CAPEX = 1.42 €



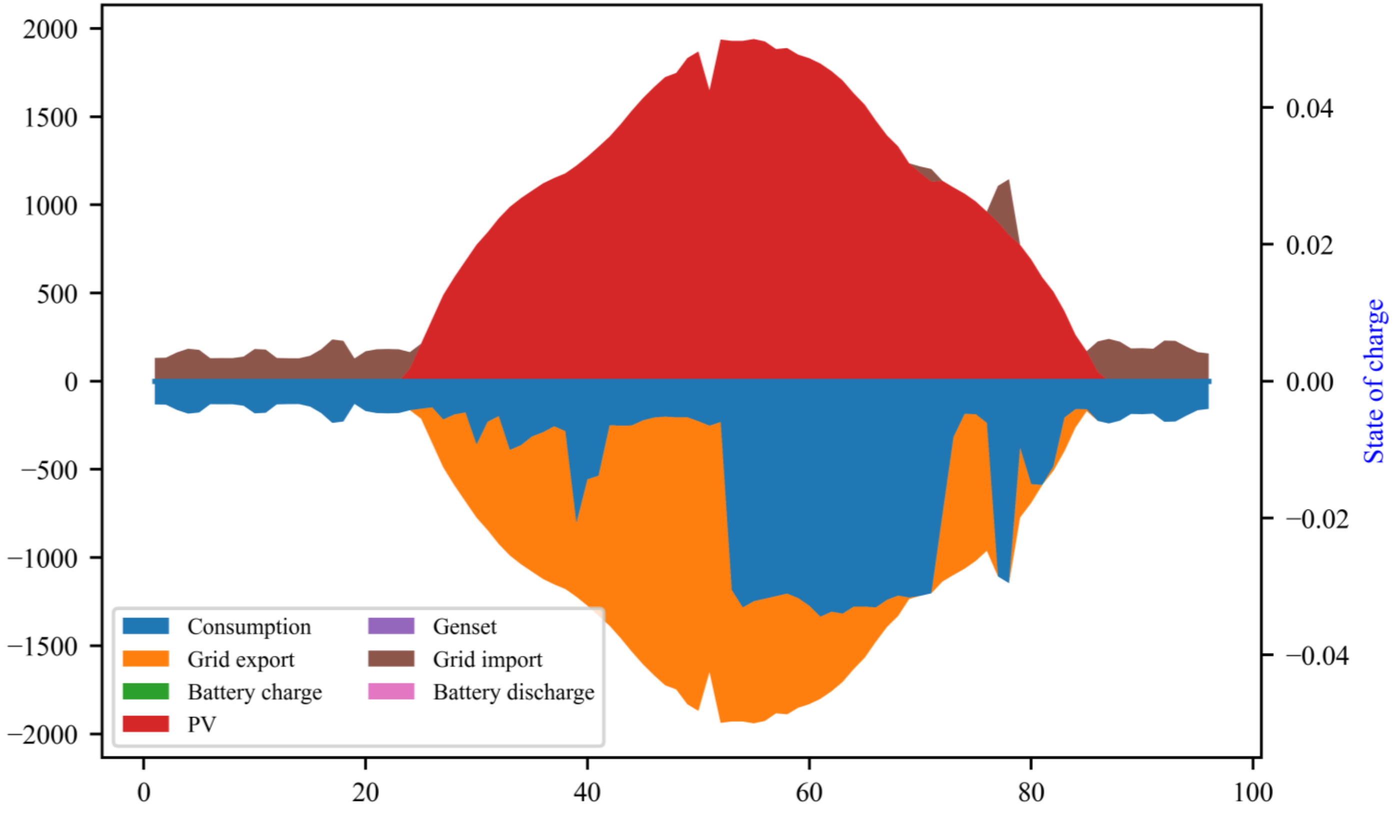
Sizing for a second user

Sizing decisions:
- PV capacity: 2 kWp

Total negative energy (consumption):
- Base consumption: -11 kWh
- Grid export: -9 kWh

Total positive energy (production):
- PV production: 18 kWh
- Grid import: 2 kWh

OPEX = 0.28 €
CAPEX = 1.16€



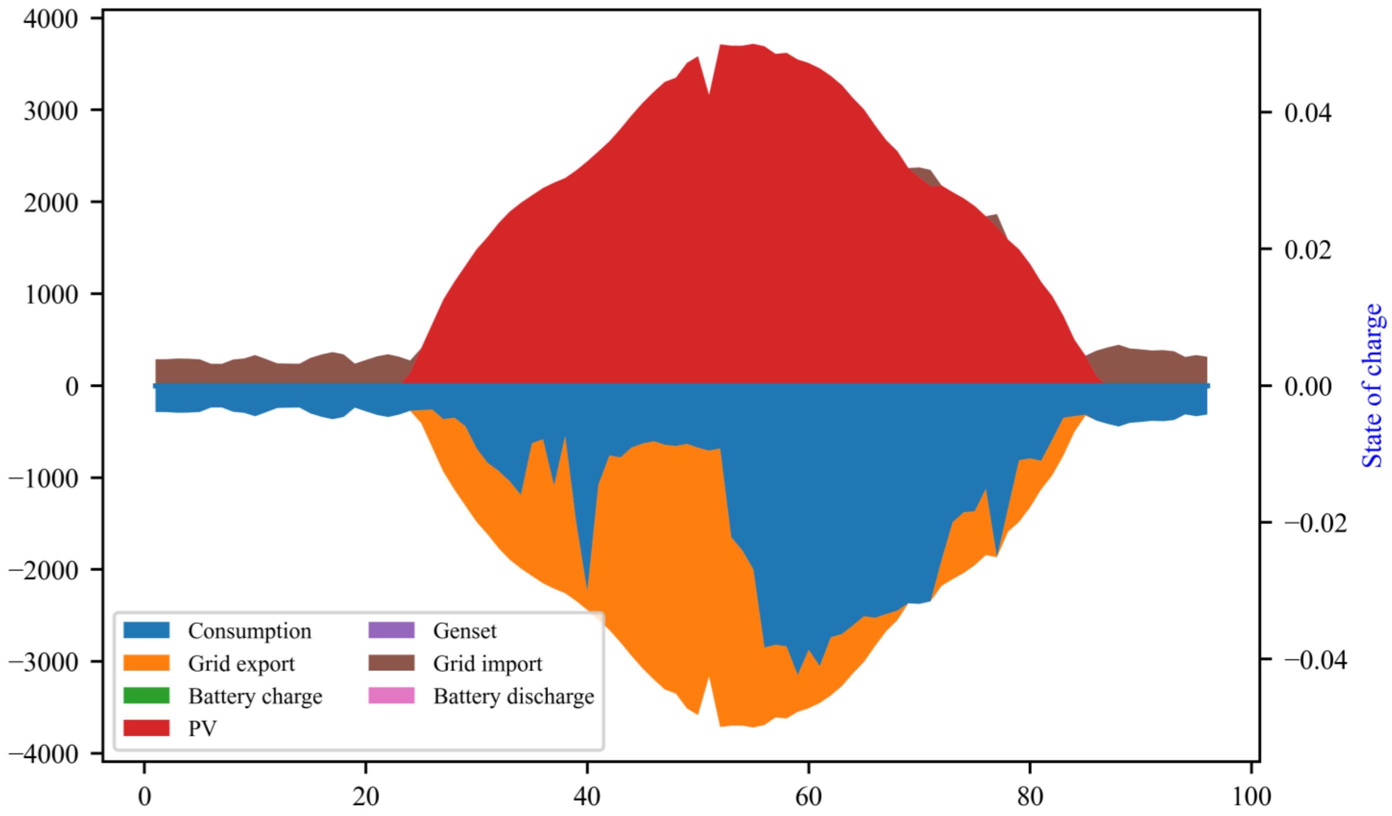
Sizing for two aggregated users

Sizing decisions:
- PV capacity: 4 kWp

Total negative energy (consumption):
- Base consumption: -23 kWh
- Grid export: -15 kWh

Total positive energy (production):
- PV production: 36 kWh
- Grid import: 2.82 kWh

OPEX = 0.52€ > 0.32€
CAPEX = 2.22€ < 2.58€



DER sizes are optimized

1. DER are used to a better potential via agregated load.
2. Investment are more profitable and cheaper with economies of scale
3. Community frameworks permits co-investments.
4. Co-investment also unlocks new type of invesments.

Cheaper and less carbon-intensive energy!

Grid support

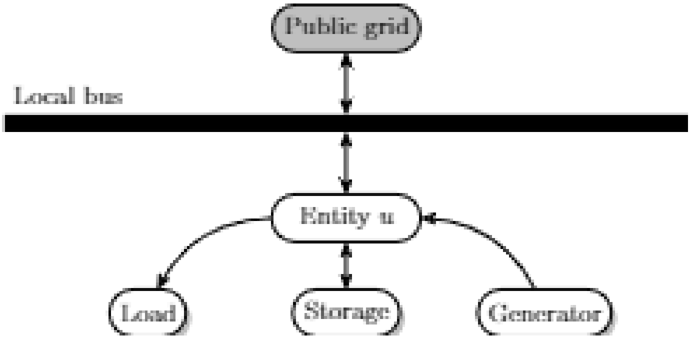
Distribution grids are subject to high stresses due to DERs.

A community could have side goals of operating its own grid.

Additional opportunity of offering flexibility to MV grid.

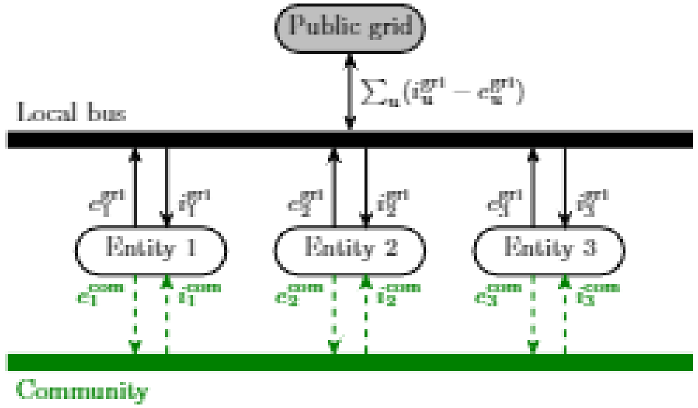
Base of the exchange model

Single user



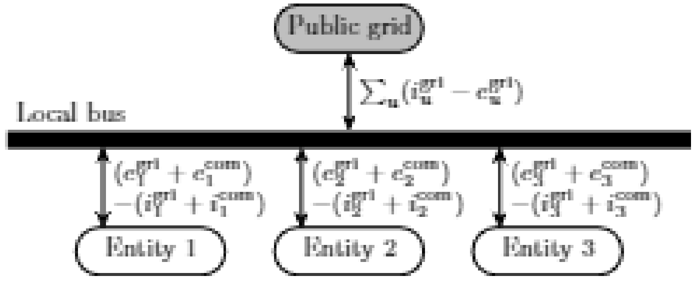
- Single user only exchange power with the grid through its retailer.

Community



- The community allows for more direct exchange between participants.

Physical flows



- The power flows are physically going through the same network.

The grid is necessary to transfer energy

The regular grid has to be modelled to show effects of those fluxes.

Optimal power flow formulation of the model.

This ensures correct operation of the grid regarding physical limits.

Variables like power losses can be dealt with.

DER investment location depends on the real fluxes in the grid.

In this model, the grid is « privatized » by the community.

A single billing can be made at the PCC between community and external grid.

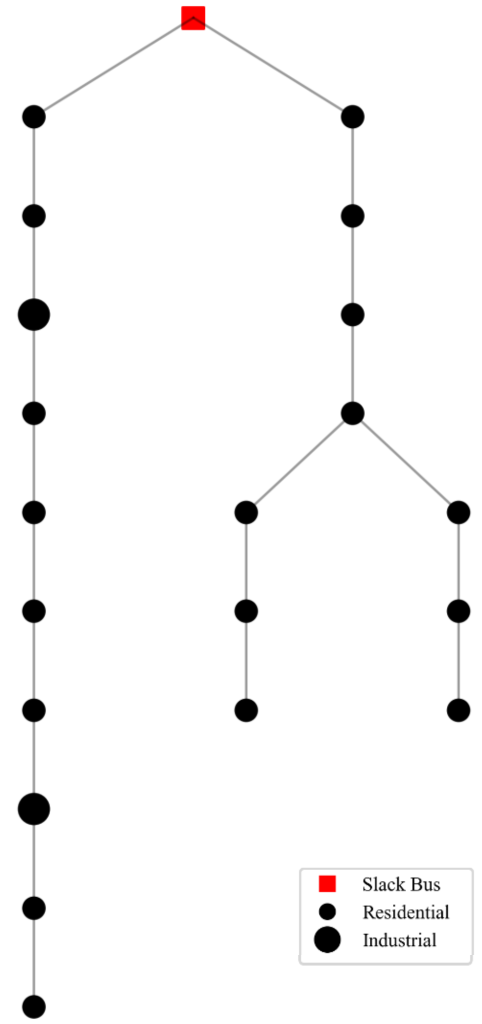
Example of a test case

Community of 10 participants:

- 8 residential users
- 2 industrial consumers
- 1 community operator virtually located at the slack bus
- All grid users are community members

230V distribution network with two feeders

Private grid, operated by the CO



10-node Dickert LV network [3]

How can a house help the grid?

Voltage support using the PV/battery inverters.

Maximized self consumption and local exchanges.

Peak shaving to decrease the maximum current in the lines.

Flexible loads can be aggregated and provide reserve.

Social structure around energy

The community revolves around a social project.

Cooperation should be encouraged by the community framework.

Allocation of resources and benefits needs to be fair.

Energy cooperative

Community framework should encourage cooperation.

To maximize self-consumption and self-sufficiency.

To allow people without capital to benefits from their neighbors investments.

To ensure that said investments are correctly made and used.

To make sure that everyone is wining.

To encourage flexibility aggregating and sharing.

Decrease energy costs

Distribution grids are subject to high stresses due to DERs.

A community could have side goals of operating its own grid.

Additional opportunity of offering flexibility to MV grid.

Price incentive

Despite a lot of other good reasons, money is often the first criteria.

Profitability should be a co-benefit ensured by previous points.

Benefits mostly come from adequate intra-community energy price.

The benefits for the whole community should be shared fairly among participants.

Model

Optimization model

Minimize total costs of operation investment

Subject to:

- Device constraints
- Exchange constraints
- Power flow equations
- Sizing constraints
- CO2 constraints

Operation costs

Grid import costs and export revenues

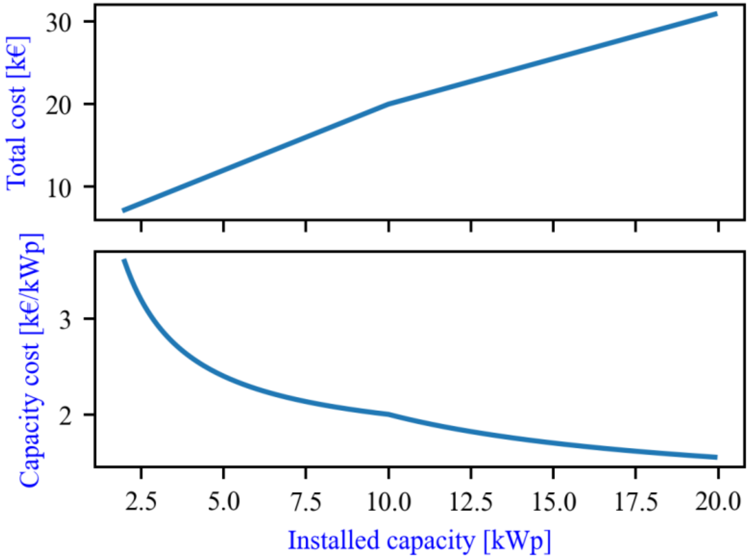
Community exchange fees

Wearing costs for battery usage

Grid losses are penalized at grid import price

Investment costs

- Users can invest in PV capacity (kWp) and/or BSS capacity (kWh).
- The CAPEX is modeled with fixed costs and discounts for big assets
- New capacity bounded up and down
- DER is at one user's location
- Investment horizon is 20 years



Investment costs for a new PV installation

Device constraints

Internal power balance of each user: $P^{inj} = P^{PV} - D^{nfl} + P^{disch} - P^{ch}$

P^{PV}: Injection limited by installation size & PV profile.

P^{disch} & P^{ch}: Battery powers and SoC defined by invested capacity.

SoC evolves through the day with equal starting and ending level.

D^{nfl}: Fixed load profile for each user.

Exchange constraints

Internal energy balance: $P^{inj} = P^{PV} - D^{nfl} + P^{disch} - P^{ch}$

External energy balance: $P^{inj} = e^{grid} - i^{grid} + e^{com} - i^{com}$

Community energy balance: $\sum e^{com} = \sum i^{com}$

- Net injection variables (P^{inj}) are also used in the power flow.

Simulation parameters

- 12 representative days (1/month)
- 24 one-hour periods
- Grid import price 0.4€/kWh – Grid export price 0.05€/kWh
- Com fee = 1ct/kWh Battery fee = 1ct/kWh

Scenarios and objectives

Scenarios

- No REC
  - To compute theoretical individual costs
- REC where members can invest on their own
  - To compare with base case
- REC where members can co-invest optimally
  - Base case

Objectives

1. Price minimization:
   - Operational costs for 1 year
   - Investment costs divided by investment horizon
2. Benefits sharing:
   - The community common bill is less than the sum of individuals
   - The difference between the two needs to be shared fairly

Some results

From a 10-user system

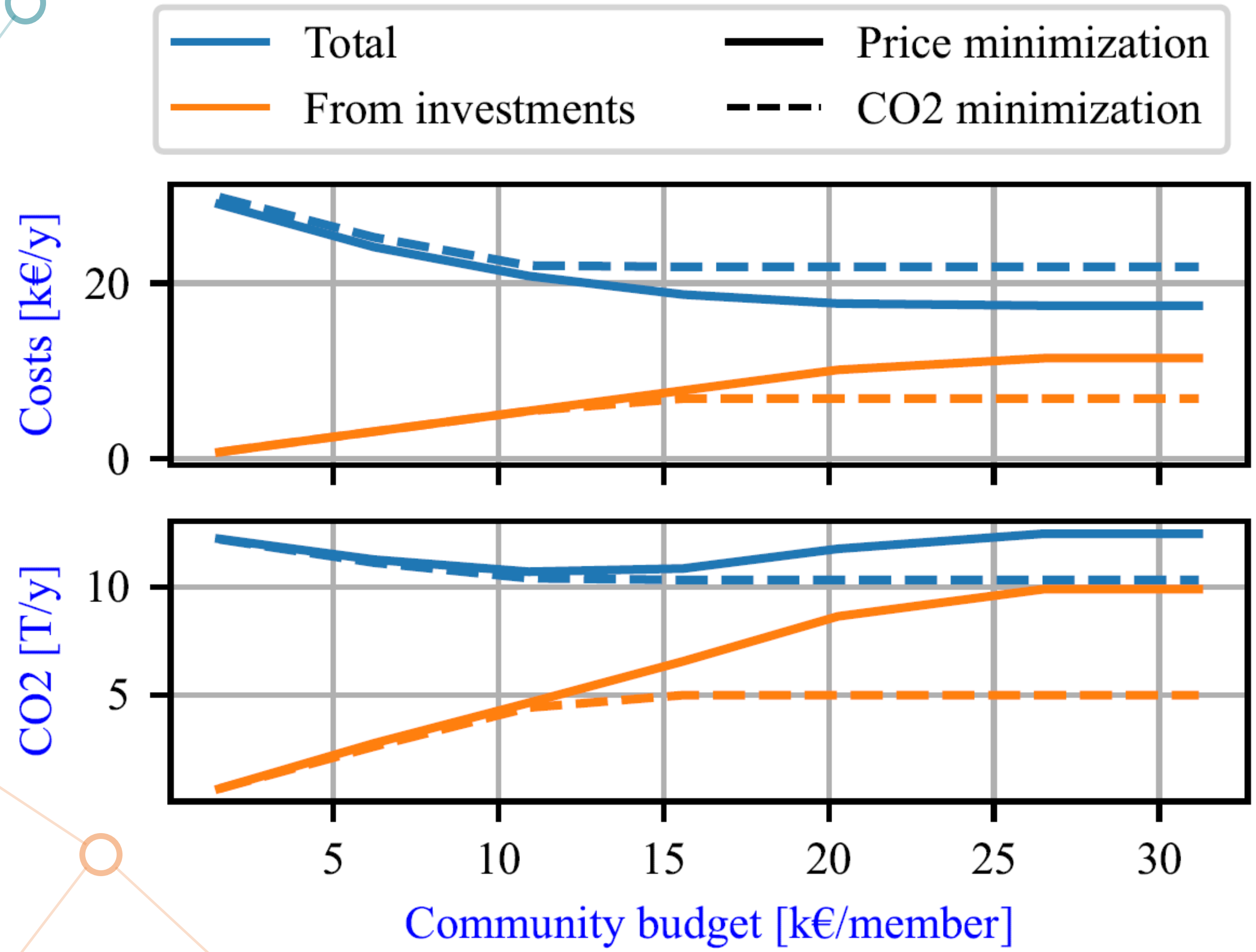
10 users in test case shown previously

The main goal of this model is to compare CO_2 optimum with price optimum.

Results of 2 objectives through 3 scenarios

Scenario:	Solo		EC		Co-inv	
Objective:	**Price**	**CO2**	**Price**	**CO2**	**Price**	**CO2**
Cost [k€/y]	23.8	25.3	20.0	22.5	18.7	21.9
OPEX [k€/y]	16.6	19.9	12.1	14.8	10.8	14
CAPEX [k€]	144.6	107.8	156.0	134.1	156.0	137.4
CO2 [T/y]	12.3	11.4	10.9	10.4	10.8	10.3
CO2 use [T/y]	7.1	8.1	4.7	5.7	4.3	5.3
CO2 inv. [T]	104.1	65.4	123.9	95.6	131.2	99.9
PV [kWp]	53.1	32.1	62.5	46.7	66.1	49.2
BSS [kWh]	32.7	34.0	46.7	52.1	50.4	51.3

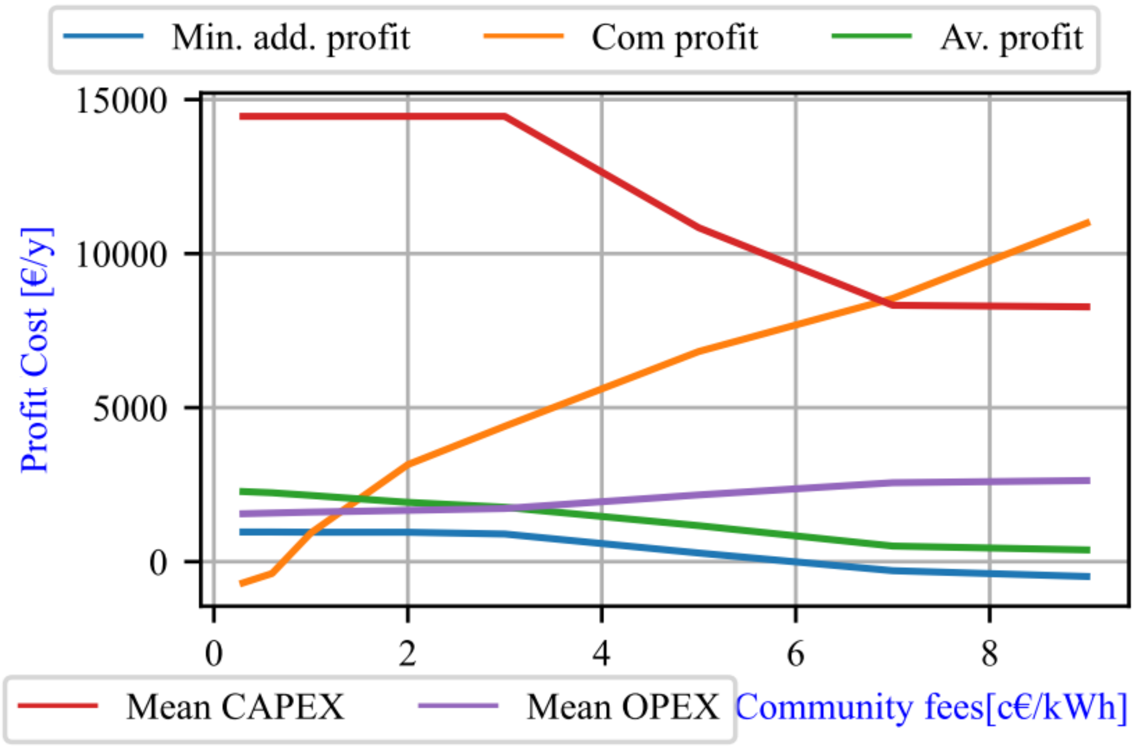
Evolving investment budgets



- There is a maximum on budget use
- Investments stop being profitable for CO2 before stop generating profit
- At low budgets, results are very similar, with maximized investments

Evolving community tariff

- Community profitability starting at €1c/kWh
- Users stop profit at 7 c€/kWh
- DER investment has a plateau
- Community fees should be adequately



From a 44-user system

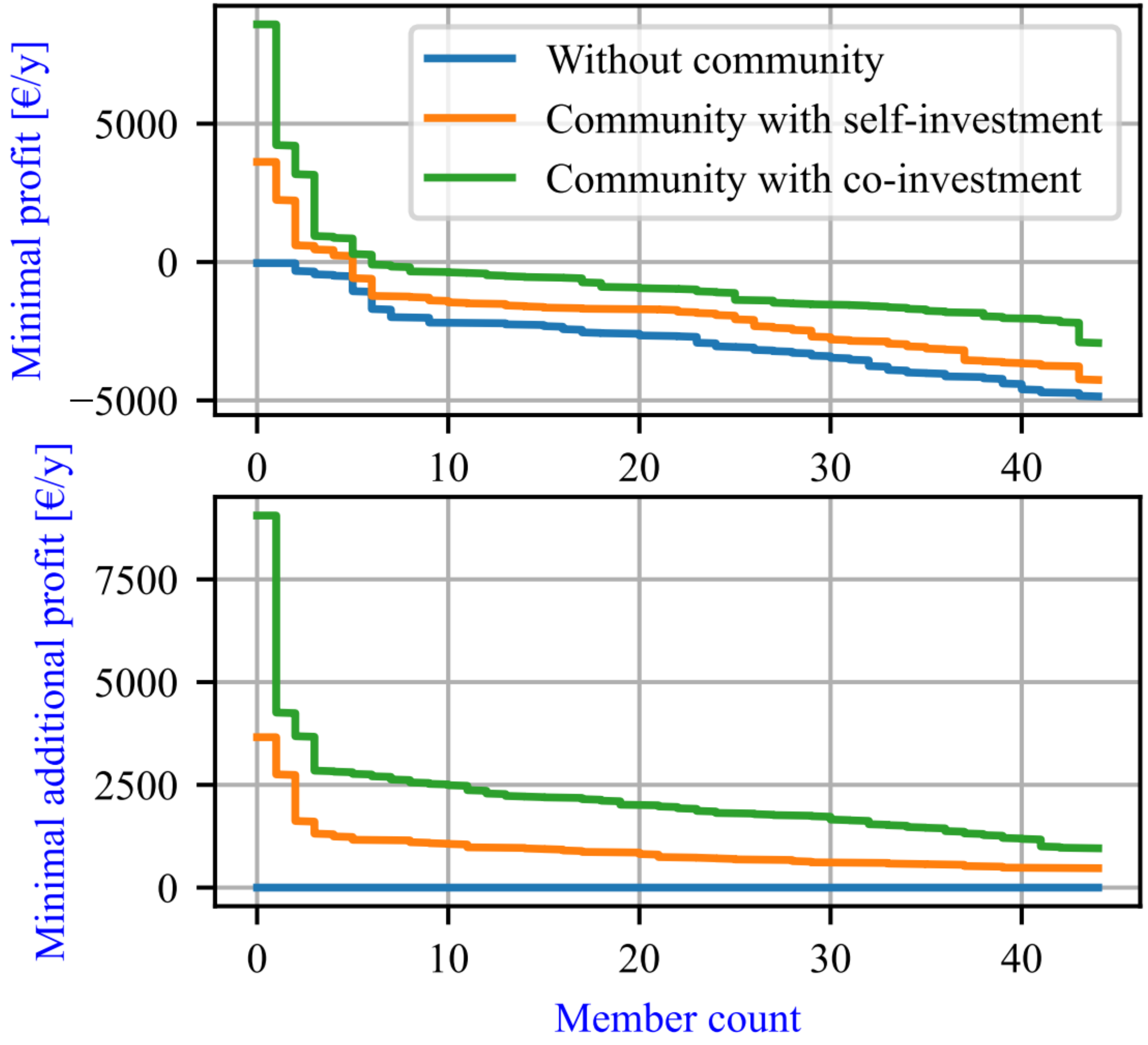
44 users in a bigger network

The main goal of this model is to show effects on the electrical network and what are the optimal investments and their location.

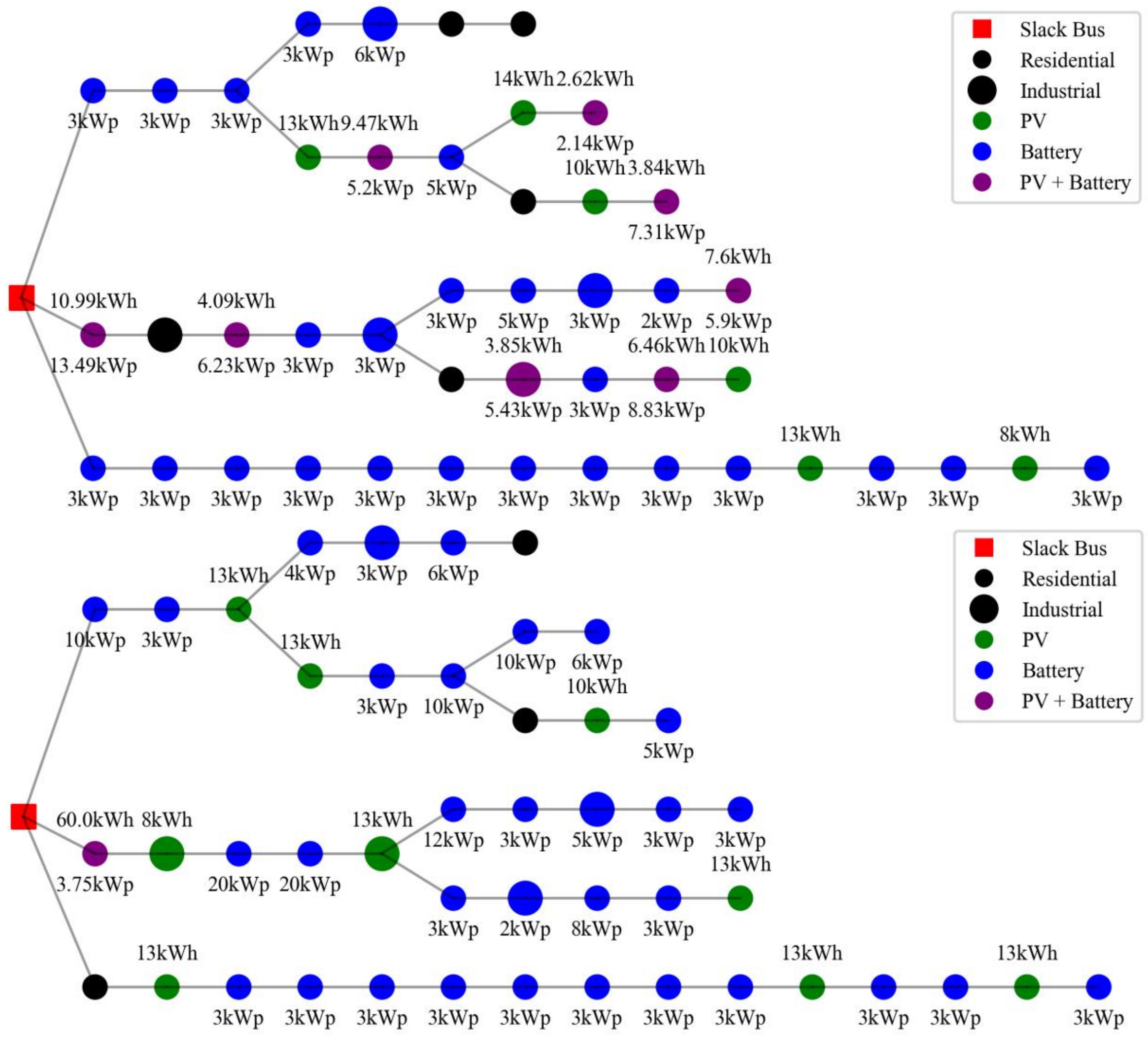
Profit sharing is also considered now.

Profit sharing

- The end of the curve is the minimal member profit
- The beginning is the maximum profit
- x=20 means that 20 members get at least this profit



DER investments



Solo model:

- Every member optimize its investment for its own energy usage.
- A lot of small investments.
- Mostly PV

EC model w/o co-inv:

- Participant will oversize their DER
- Bigger investments.
- Some participants invest for the comunity

Conclusions

Recap. of the goals

- Improve energy independance
- Increase DER penetration
- Participate in electrical network support
- Create a social structure around energy
- Allow users to decrease their energy costs

- Economic impact
- Environmental impact
- Social impact

Key findings

1 A community framework encourages DER investment

2 Both members and operator can have economic benefits

3 Co-investment allows to efficiently use capital, but would be hard in practice

4 Price minimization also decreases CO_2 emissions

These results are highly dependant on hypothesis & parameters

Going further

- Model additional flexibility (EV and HVAC)
- Discuss fairness of sharing mechanisms
- Quantify grid support capabilities
- Ensure privacy of participant behaviors
- Account for forecasts of members profiles

References

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2. Cornélusse, B., Savelli, I., Paoletti, S., Giannitrapani, A., & Vicino, A. (2019). **A Community Microgrid Architecture with an Internal Local Market**

3. Dickert J., Domagk M. & Schegner P. (2013) **Benchmark low voltage distribution networks based on cluster analysis of actual grid properties**