Energy Sharing Concepts in Energy Communities

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About the project „PV Prosumers4Grid“

- **Target countries:** Belgium, Germany, France, Italy, Netherlands, Austria, Portugal & Spain
- **Start:** 01.10.2017
- **Duration:** 30 Months (March 2020)
- 12 Partners
- **Coordinator:** BSW-Solar

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Motivation

- Renewable energy production offers opportunities for the local government and communities (Schoor and Scholtens, 2015)

- Energy Communities (EC) are promoted to transform the energy system.

- The European Commission (2016) defines an EC as

  “Legal entity which is effectively controlled by local shareholders or members … involved in the distributed generation and in performing activities of a distribution system operator, supplier or aggregator at a local level, including across borders”

- Recent changes in the legal framework allow owners and tenants to invest in and operate energy generation and storage devices jointly.

Literature

- Energy communities (ECs) may generate monetary gains by aggregation, mostly due to Economies-of-Scale (Schwabeneder et al. 2019)
- ECs allow the introduction of a multi-energy system (distributed energy resources (DERs) and energy storage systems (ESSs)) on a local level. (Mancarella 2014)

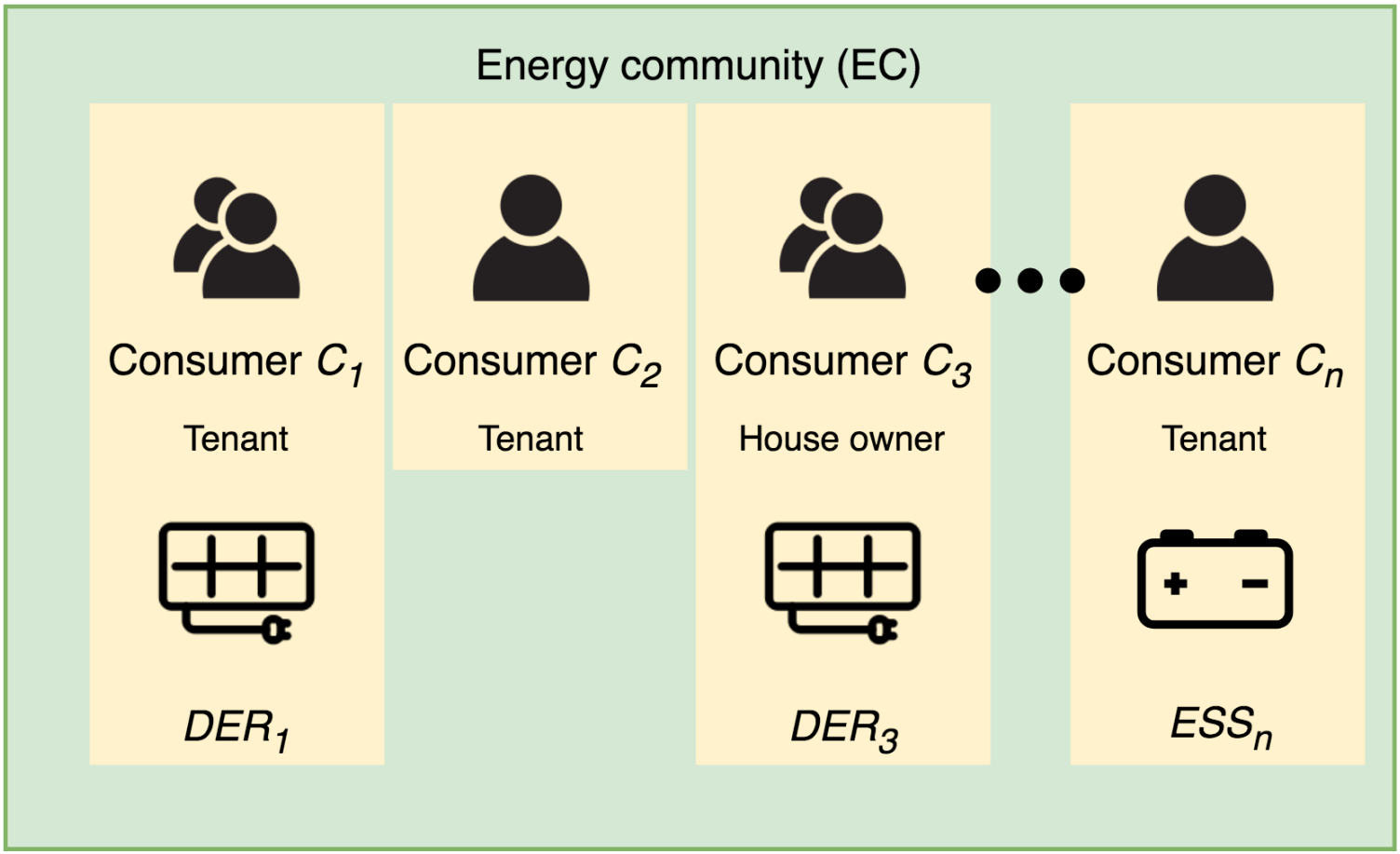
Research question 1: How to allocate energy and monetary gains in an EC.

- Saad et al. (2012) conclude that game theoretic methods are a promising tool to share the value, by two concepts:
  - Non-cooperative concepts: players with conflicting interests (see Fleischhacker et al. 2018)
  - Cooperative concepts: players communicate with another and cooperate
    → Two methods **Shapley Value** (Shapley (1953)) and **Coalitional Nash Bargaining** (Nash (1953) and Compte and Jehiel (2008))
- Communities often lacks on stability (Abada et al. 2017)

Research question 2: How to stabilize an EC and prevent them from breaking apart.

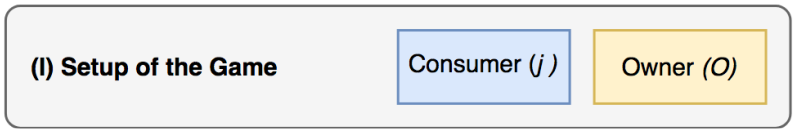
EC … Energy community

The method bases on real life use cases.



DER … Distributed energy resource
EC … Energy community
ESS … Energy storage system

Method of this work



Mixed Integer Linear Program (MILP)

Cooperative Game

◄—	Energy flow	$j \in C$	$d \in \{\text{PV}, \text{HP}, \text{EC}\}$
◄- -	Parameters	$t \in \{1, 2, \ldots, T\}$	$s \in \{\text{BESS}, \text{TESS}\}$
		$c \in \{\text{Elec}, \text{Heat}\}$	

We use the Optimization Problem to formulate a Cooperative Game for Payoff Allocation

Cooperative Game Theory

Energy community with members $i \in I$ with $|I| = n$

Coalition $S \subset I$ generates value $v(S)$ → run the MILP $2^n - 1$ times

Allocation by two concepts of the cooperative game theory:

- **Shapley value** (Algorithm)

$$x_i^{Shapley} = \sum_{i \in S \subset I} (v(S) - v(S/i)) \frac{(n-s)!(s-1)!}{n!}$$

- **Nash Bargaining** (Non-Linear Optimization Model)

$$\max_{x_i^{Nash}} \quad \prod_{i \in I} \left(x_i^{Nash} - d_i\right)$$

$$\text{s.t.} \quad x_i^{Nash} \geq d_i \qquad \forall i \in I$$

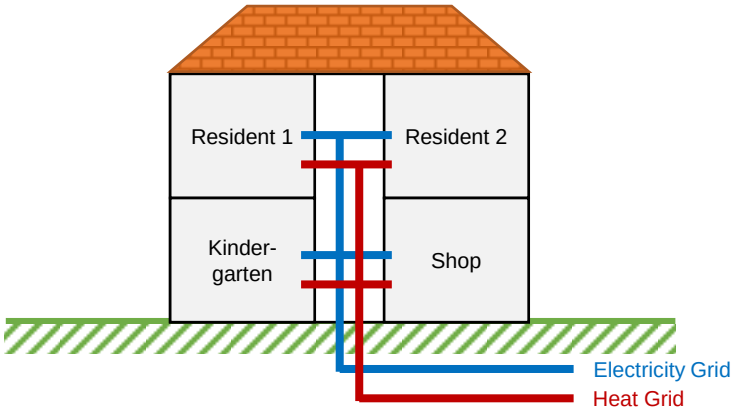
Core of the game:

$$\sum_{i \in S} x_i(v) \geq v(S), \forall S \subset I$$

$$\sum_{i \in I} x_i(v) = v(I)$$

Use Case of an Energy Community in Austria

- Building in Austria
  - Two residential consumers
  - One kindergarten
  - One shop
  - Baseline:



- Retail electricity price 15ct/kWh
- Retail heat price: 7,2ct/kWh

- Characteristics of the time-series data

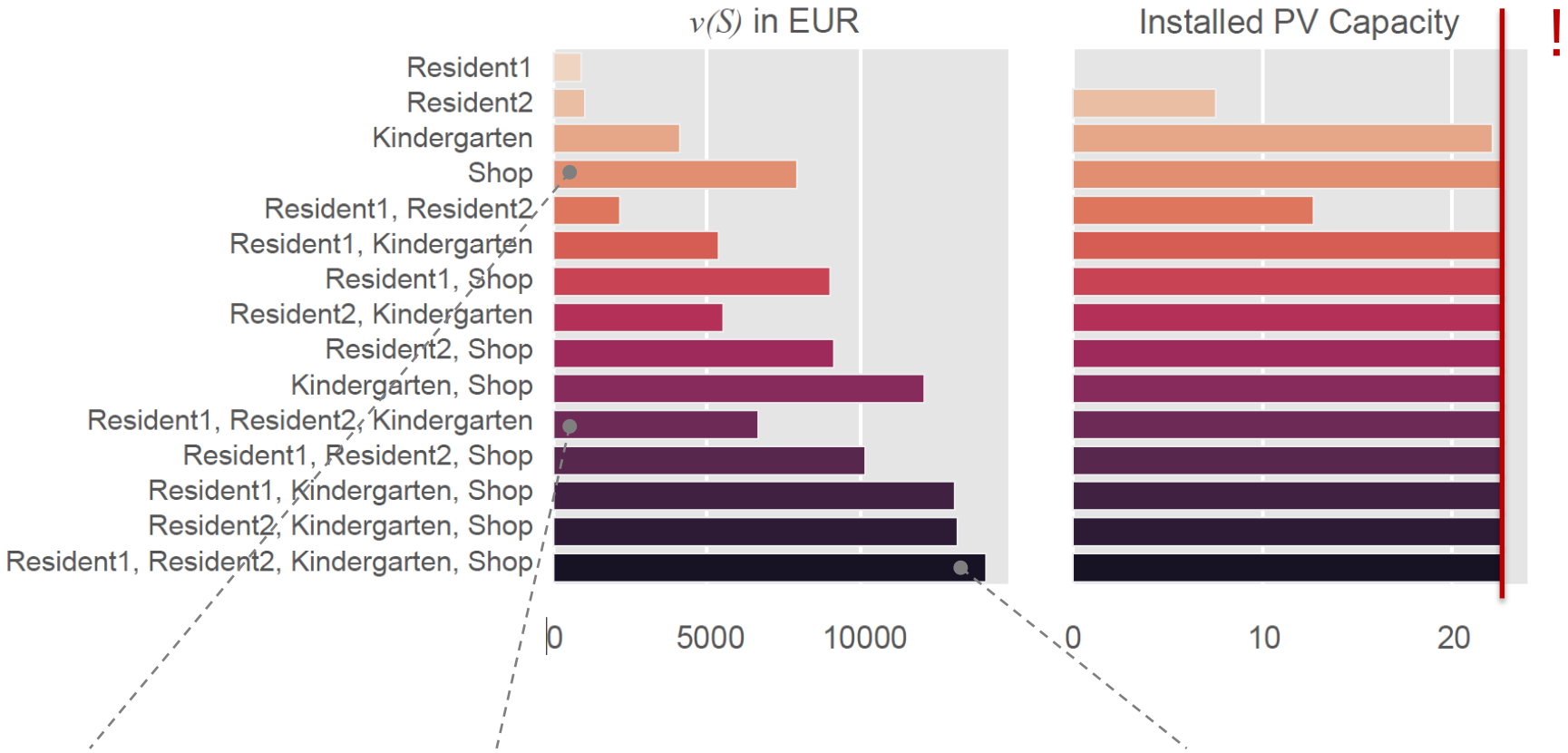
	Electricity demand in kWh	Heat demand in kWh	$\rho_{Elec,PV}$	$\rho_{Heat,PV}$
Resident1	2,742	12,071	0.037	-0.065
Resident2	3,253	12,890	-0.031	-0.064
Kindergarten	3,393	61,190	0.330	-0.263
Shop	90,393	102,852	0.348	0.180

$\rho = 1$	Total positive linear correlation
$\rho = 0$	No linear correlation
$\rho = -1$	Total negative linear correlation
	Highest
	Lowest

Data Sources:
ASUE (2015), Kotzur (2017), Lindberg et al. (2016), Loschan (2017), Teichmann (2012), Tesla (2016), Truong (2016),

Value of all coalitions of game (A)*

* Consumers = owner own the house



$$v(Shop) + v(Resident_1, Resident_2, Kindergarten) = 14\,621$$

Unstable coalition due to a restricted PV capacity.

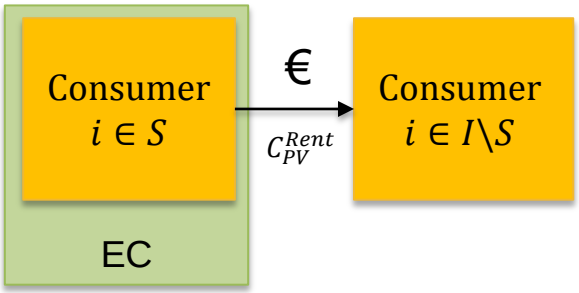
Restricted PV capacity is factor of instability

(A)

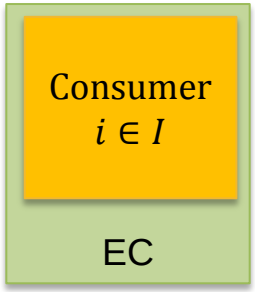
(A) Consumers = owners of the house and the roof (25% per consumer)

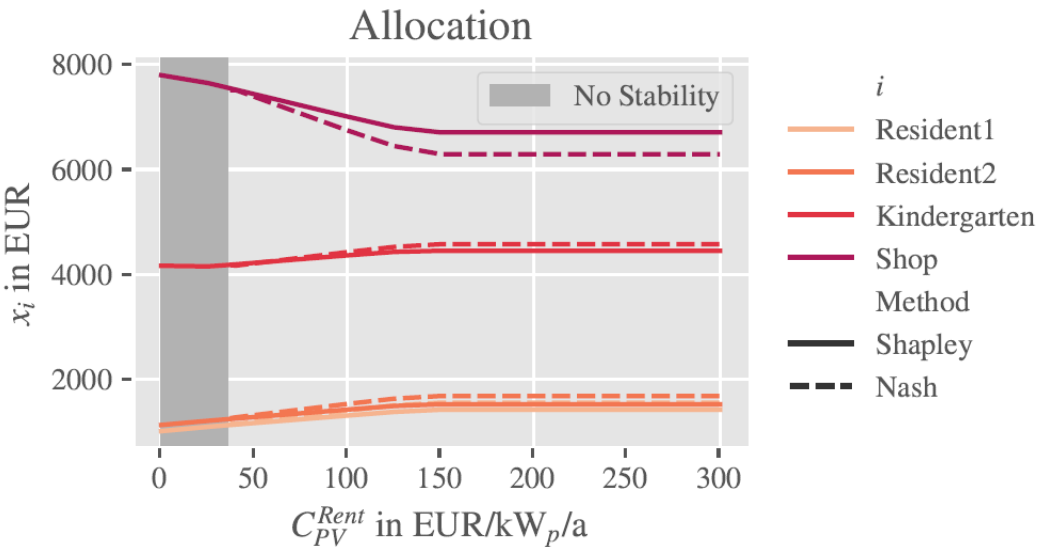
Consumers inside the coalition pays consumers outside the coalition → Stabilization by internal payments

$S \neq I$



$S = I$





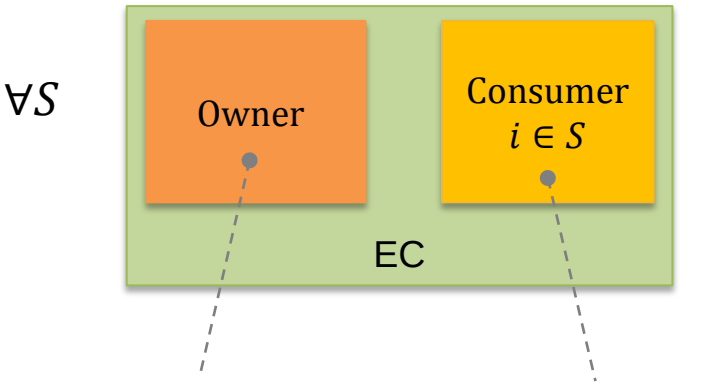
EC … Energy community

Restricted PV capacity is factor of instability

(B)

(B) Consumer = tenants | owner = landlord

Introduction of a superior player → Without the owner no investment is possible.



Owner invests and operates the plant

Consumer is needed or consumption.

	$x^{Shapley}$ in EUR	x^{Nash} in EUR
Resident1	511	961
Resident2	565	1,050
Kindergarten	2,065	3,961
Shop	3,851	4,069
Owner	7,117	4,069

Value allocation according to the "**position**" of each player.

Value allocation according to the "**negotiation power**" of each player.

EC … Energy community

Conclusions

- Our work shows that energy communities provide monetary value to the participants.
- The question of the allocation could be answered by game theoretical concepts (e.g., Nash or Shapley).
- The results show that a limited area for PV generation is a factor of instability.
- By the introduction of external and internal payments or a central owner, it is possible to stabilize the energy community.
- The solutions suggest a "fair" and transparent allocation to all players and help to decrease the negotiation effort necessary to found an EC.
- One setback is that the problem is computationally hard and the effort raises with the size of the EC. Therefore future research may focus on increasing the performance of the model, or test methods of reducing the problem.

→ Follow up the working paper!

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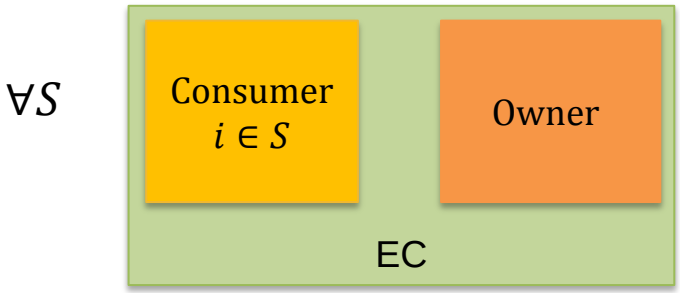
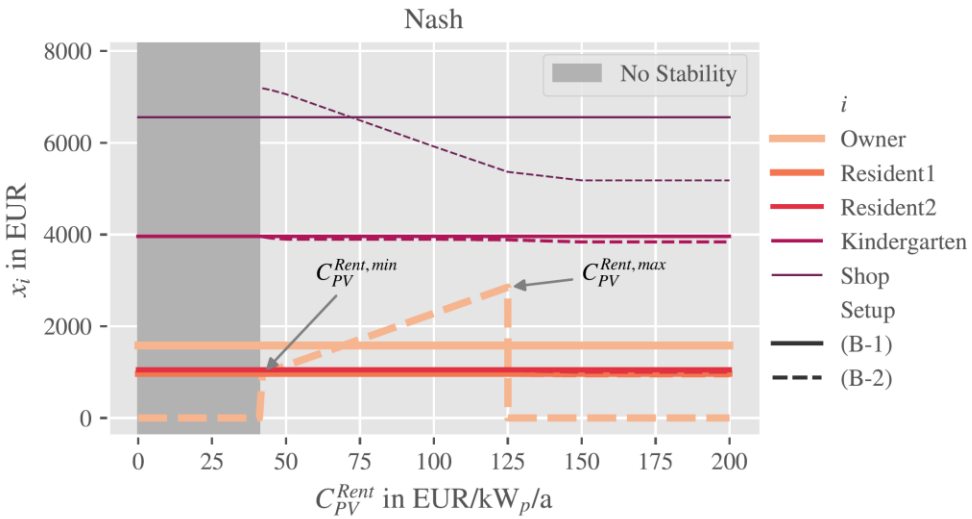
Restricted PV capacity is factor of instability
→ Introduction of rent costs for PV capacity to an external party

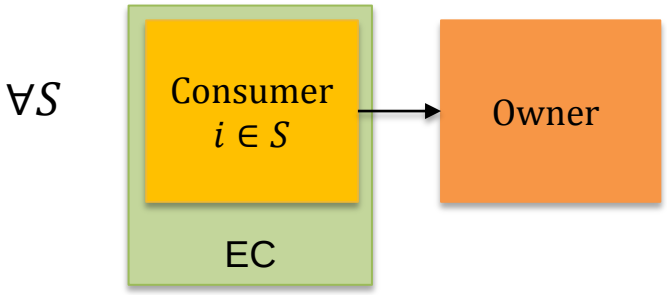
(B) Consumer = owners of the house | External party (owner) owns area for the PV plant

(B-1) Owner joins the EC





(B-2) Consumers are the EC and pays the rent to the owner → External payments



EC … Energy community