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A framework for multiple participation in Energy Communities

Ivan Mariuzzo, Bernadette Fina, Stefan Stroemer

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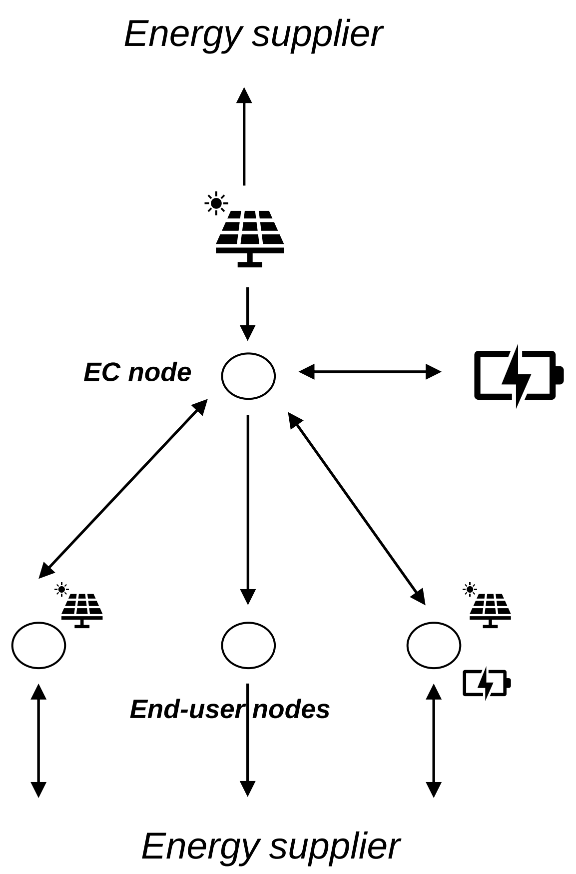
RENEWABLE ENERGY COMMUNITIES

- RECs are legal entities grouping end-users of different sectors **sharing** renewable energy produced locally under **geographical constraints,** as same low-voltage or medium-voltage feeder

- **Virtual** aggregation**:** each participant retains the rights to choose for energy supply conditions and/or leave in case of dissatisfaction.

- RECs can operate **community owned units** and properly allocate benefits amongst the participants



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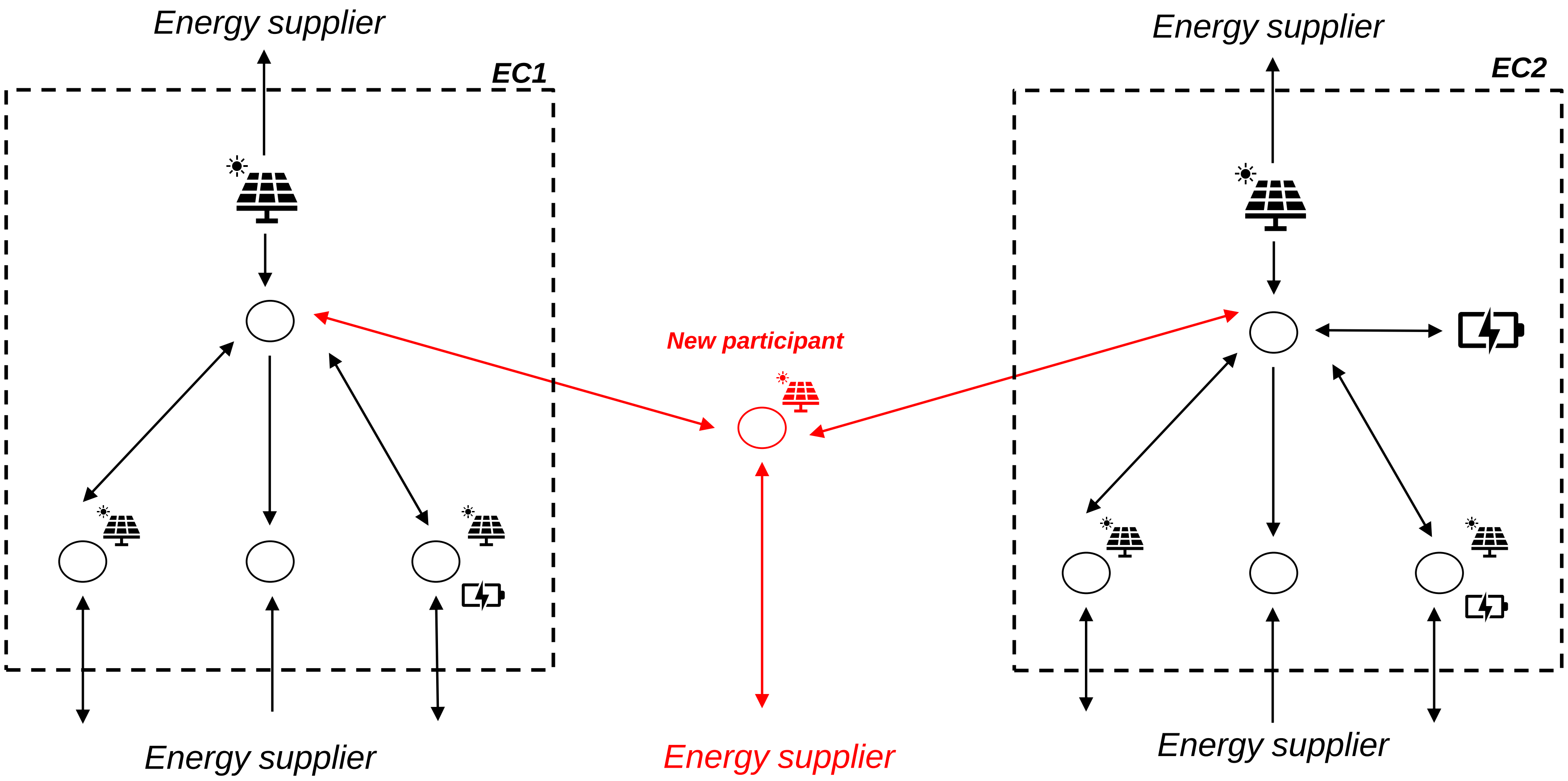
RENEWABLE ENERGY COMMUNITIES

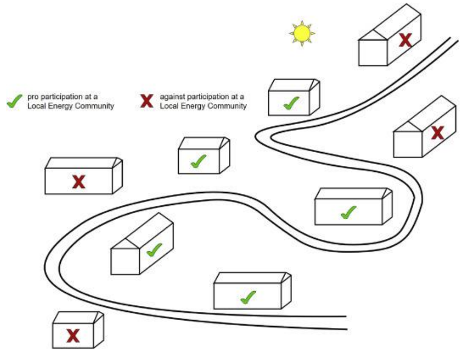
- Energy Communities are entitled to **decide internal purchase/selling prices*** in order to be more competitive with the energy provider, if :
  - Purchase price → lower than provider's
  - Selling price → higher than provider's

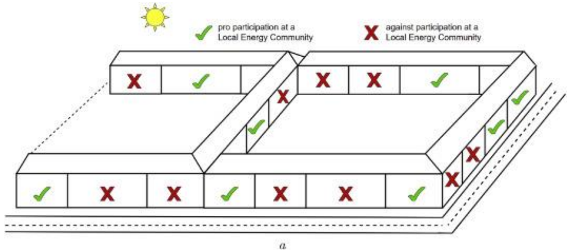
- Austria is about to introduce **multiple participation in ECs** within its own national legislation, starting by 2024:
  - «Split» of the participants and units energy exchanges within more than one EC at the same time
  - Multiple sources o which/from which energy can be sold/purchased by participants and units

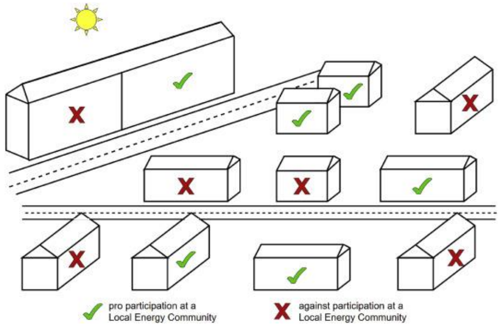
MULTIPLE ENERGY COMMUNITIES



SETTLEMENT PATTERNS







Rural EC(1):

- 5 SFHs* with 2 prosumers
- 3 and 4 kWp PV for prosumers

City EC(2):

- 3 buildings with 5 MABHs** each
- 27 and 28 kWp PV

Mixed EC(3):

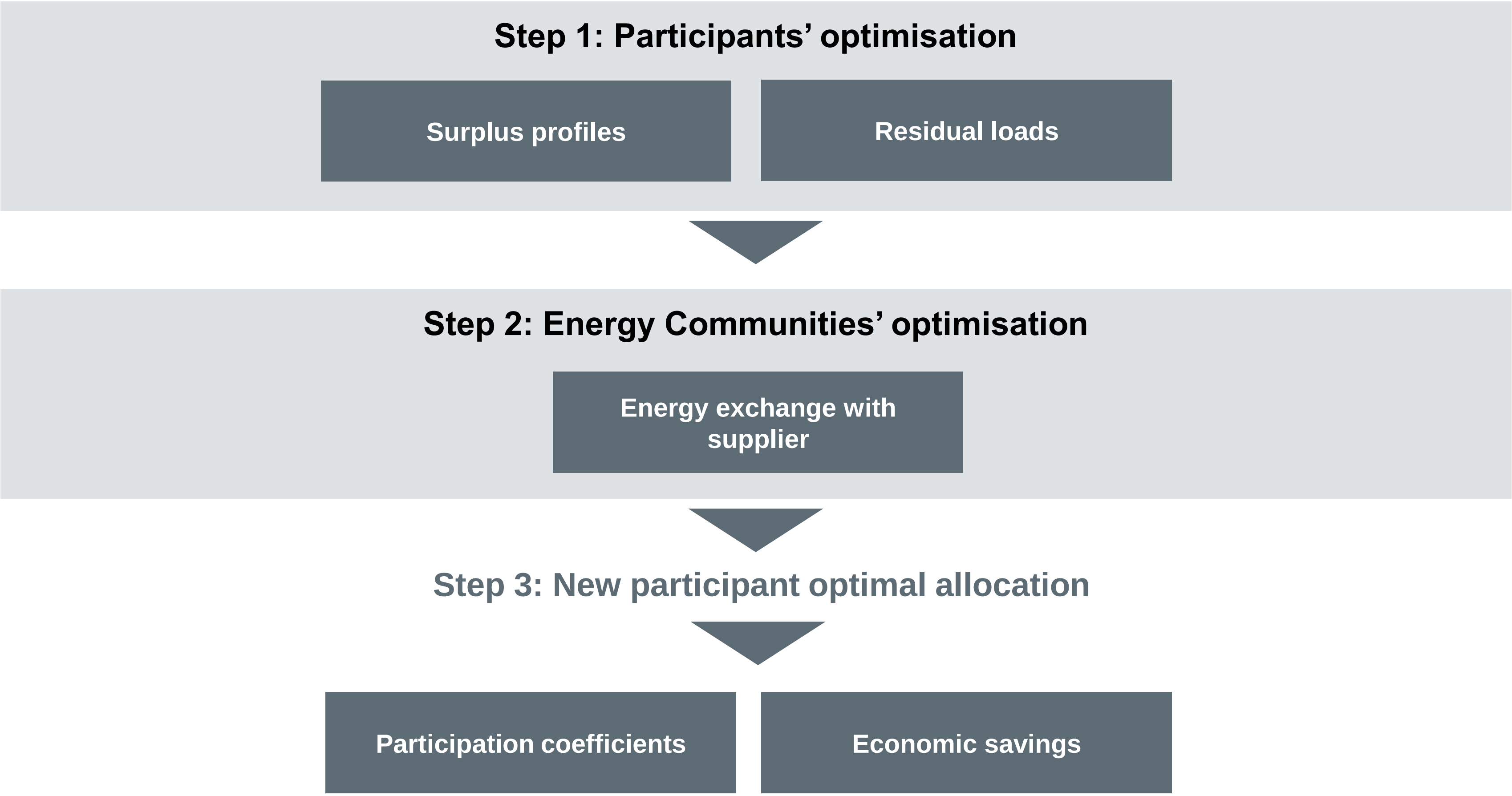
- 1 building with 5 MABHs and 28 kWp PV
- 5 SFHs with 2 prosumer
- 3 and 4 kWp PV for prosumers

***SFH = Single Family Household** - 3000-7000 kWh/year. New participant is assumed to belong to this category

****MABH = Multi-Apartment Building Households** - 1000-4000 kWh/year

Source: B. Fina, H. Auer, W. Friedl, Profitability of PV sharing in energy communities: Use cases for different settlement patterns, Energy 189 (2019) 116148

METHODOLOGY



PROBLEM FORMULATION

The proposed methodology is a formulated as a Mixed Integer Linear Programming (MILP) optimisation problem implemented in **JuMP** and using **Gurobi** as a solver.

The **Decision variables** are the following:

- ECs' participants power flows - $P_{h,t}^{EP+/-}$, $P_{h,t}^{EC+/-}$
- New participant's power flows - $P_{0,t}^{EP+/-}$, $P_{0,t}^{EC_r+/-}$, x_t
- New participant's ECs allocation - x_r^-, x_r^+, x_r
- BESS charge/discharge

Dunning, J. Huchette, M. Lubin, JuMP: A modeling language for mathematical optimization, SIAM Review 59 (2) (2017) 295–320.

Gurobi Optimization, LLC, Gurobi Optimizer Reference Manual (2023). URL https://www.gurobi.com

PROBLEM FORMULATION

The **objective** is to minimize the energy Total Costs (TC) of both all ECs and new participant:

$$\min TC = TC^{EP} + TC^{EC}$$

$$TC^{EP} = \underbrace{\sum_{t\in T}\sum_{h\in H} \rho_{EP}^{+} P_{h,t}^{EP+}\,\Delta t}_{\text{HHs purchasing from supplier}} + \underbrace{\sum_{t\in T}\sum_{h\in H} \rho_{EP}^{-} P_{h,t}^{EP-}\,\Delta t}_{\text{HHs selling to supplier}} + \underbrace{\sum_{t\in T}\sum_{r\in R} \rho_{EP}^{+} P_{r,t}^{S}\,\Delta t}_{\text{Units selling to supplier}}$$

HHs purchasing from supplier

HHs selling to supplier

Units selling to supplier

$$TC^{EC} = \underbrace{\sum_{t\in T}\sum_{r\in R} \rho_{r}^{+}\Big(P_{0,t}^{EC_r+} + \sum_{h\in H_r} P_{h,t}^{EC_r+}\Big)\Delta t}_{\text{HHs purchasing from ECs}} + \underbrace{\sum_{t\in T}\sum_{r\in R} \rho_{r}^{-}\Big(P_{0,t}^{EC_r-} + \sum_{h\in H_r} P_{h,t}^{EC_r-}\Big)\Delta t}_{\text{HHs selling to ECs}} + \underbrace{\sum_{t\in T}\sum_{r\in R} \rho_{r}^{+} P_{r,t}^{C}\,\Delta t}_{\text{Units selling to ECs}}$$

HHs purchasing from ECs

HHs selling to ECs

Units selling to ECs

A constraint* is added to not worsen initial ECs' energy exchange with the supplier:

$$\sum_{t\in T}\sum_{h\in H_r} P_{h,t}^{EP-}\,\Delta t + \sum_{t\in T}\sum_{h\in H_r} P_{h,t}^{EP+}\,\Delta t + \sum_{t\in T} P_{r,t}^{S}\Delta t \le E_r^{+} + E_r^{-}$$

*Other constraints that have been used include ECs power balance, BESS management system, etc.

PROBLEM FORMULATION

$$\sum_{r\in R} P_{0,t}^{EC_r+/-} + P_{0,t}^{EP+/-} = P_{0,t,M}^{+/-}, \qquad \forall\, t \in T$$

$$0 \leq P_{0,t}^{EP+/-} \leq P_{0,t,M}^{+/-}, \qquad \forall\, t \in T$$

$$x_r P_{0,t,m}^{+/-} \leq P_{0,t}^{EC_r+/-} \leq x_r P_{0,t,M}^{+/-}, \qquad \forall\, t \in T, \qquad r \in R$$

$$\sum_{r\in R} P_{r,t}^{EC+} + P_t^{EP+} \leq x_t P_{t,max}^{+}, \qquad \forall\, t \in T$$

$$\sum_{r\in R} P_{r,t}^{EC-} + P_t^{EP-} \leq (1 - x_t) P_{t,max}^{-}, \qquad \forall\, t \in T$$

New participant's EMS

$$P_{h,t}^{EC_r+/-} + P_{h,t}^{EP+/-} = P_{h,t,M}^{+/-}, \qquad \forall\, t \in T, \qquad r \in R, \qquad h \in H_r$$

$$0 \leq P_{h,t}^{EP+/-} \leq P_{h,t,M}^{+/-}, \qquad \forall\, t \in T, \qquad r \in R, \qquad h \in H_r$$

$$0 \leq P_{h,t}^{EC_r+/-} \leq P_{h,t,M}^{+/-}, \qquad \forall\, t \in T, \qquad r \in R, \qquad h \in H_r$$

ECs participant's EMS

*+ = power leaving node, - = power entering the node

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PROBLEM FORMULATION

$$x_r^+ \beta_{r,m}^+ \leq \beta_r^+ \leq x_r^+ \beta_{r,M}^+, \qquad \forall\, r \in R$$

$$x_r^- \beta_{r,m}^- \leq \beta_r^- \leq x_r^- \beta_{r,M}^-, \qquad \forall\, r \in R$$

$$x_r^- + x_r^+ \geq x_r, \qquad \forall\, r \in R$$

$$x_m \leq \sum_{r \in R} x_r \leq x_M$$

New participant optimal allocation

- $\beta_r^{+/-} = \dfrac{\sum_{t \in T} P_{0,t}^{EC_r +/-}}{\sum_{t \in T} P_{0,t}^{+/-}}, \ \forall\, r \in R$

- $\beta_{EP}^{+/-} = \dfrac{\sum_{t \in T} P_{0,t}^{EP+/-}}{\sum_{t \in T} P_{0,t}^{+/-}}$

Participation coefficients

RESEARCH QUESTIONS AND ANALYSIS

Investigate the economic viability* of the following scenarios:

1. Case 1: single EC allocation → $0 \leq \sum_{r \epsilon R} x_r \leq 1$
2. Case 2: multiple ECs allocation → $0 \leq \sum_{r \epsilon R} x_r \leq 3$
3. Case 3: → $0 \leq \sum_{r \epsilon R} x_r \leq 3$ and $\beta_{r,m}^{+/-} \geq 5\%$
4. Case 4: → $0 \leq \sum_{r \epsilon R} x_r \leq 3$ and $\beta_{r,m}^{+/-} \geq 10\%$
5. Case 5: → $0 \leq \sum_{r \epsilon R} x_r \leq 3$ and $\beta_{r,m}^{+/-} \geq 20\%$
6. Case 6: → $0 \leq \sum_{r \epsilon R} x_r \leq 3$ and $\beta_{r,m}^{+/-} \geq 30\%$

Analysis are repeated changing:

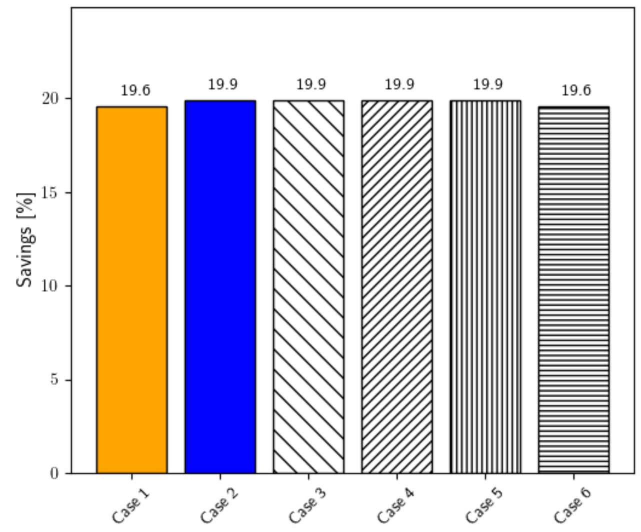
1. The type of the new participant (consumer/prosumer with 4 kWp PV)
2. The local generation** introducing further stand-alone PV and community storage

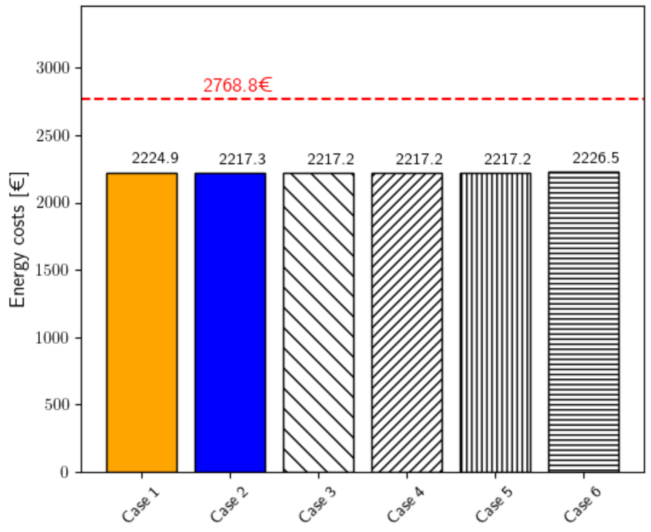
***Supplier's cost**: purchased at 0.64 €/kWh (with levies, grid charges, 20% VAT and 6% user's fees) and assumed to be sold at 0.25 €/kWh

***ECs' cost**: purchased at 0.38 €/kWh, including grid charges, and assumed to be sold at 0.35 €/kWh

** Additional 20 kWp + 12 kWh BESS in rural EC, 33 kWh BESS in city EC, and 20 kWp + 12 kWh BESS in mixed EC

RESULTS: CONSUMER, BASELINE*

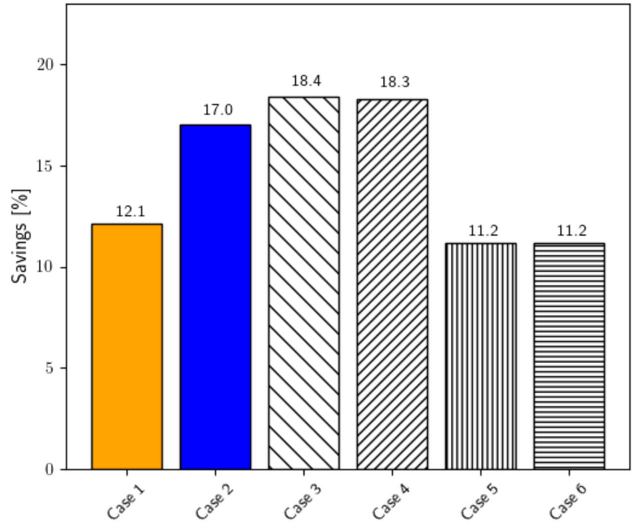


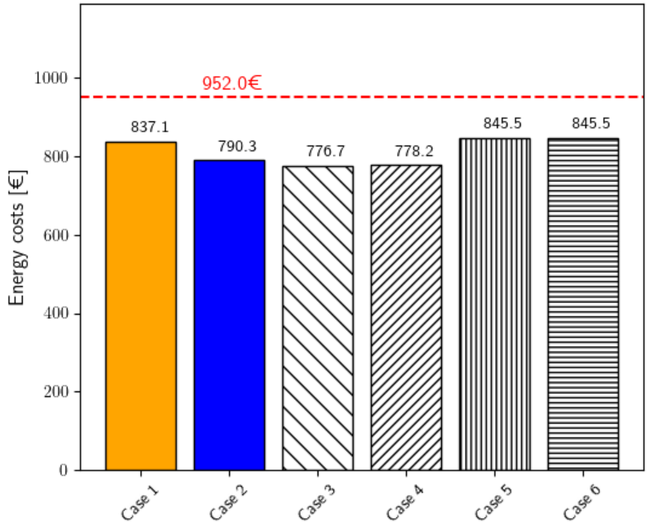


	C1	**C2**	**C3**	**C4**	**C5**	**C6**
$TC[€/y]$	26201.5	26186.8	26186.8	26186.8	26186.8	26201.5
$\bar{\beta}_{rural}$	0	0.15	0.13	0.13	0	0
$\bar{\beta}_{city}$	0.49	0.23	0.22	0.21	0.30	0.49
$\bar{\beta}_{mixed}$	0	0.12	0.14	0.16	0.20	0
$\bar{\beta}_{EP}$	0.51	0.50	0.50	0.50	0.50	0.51
$\sum_{r \in R} x_r$	**1**	**3**	**3**	**3**	**2**	**1**

Mariuzzo Ivan, Bernadette Fina, Stefan Stroemer, Marco Raugi, «Economic Assessment of Multiple Energy Community Participation", Applied Energy, Elsevier, 2023, to be submitted soon

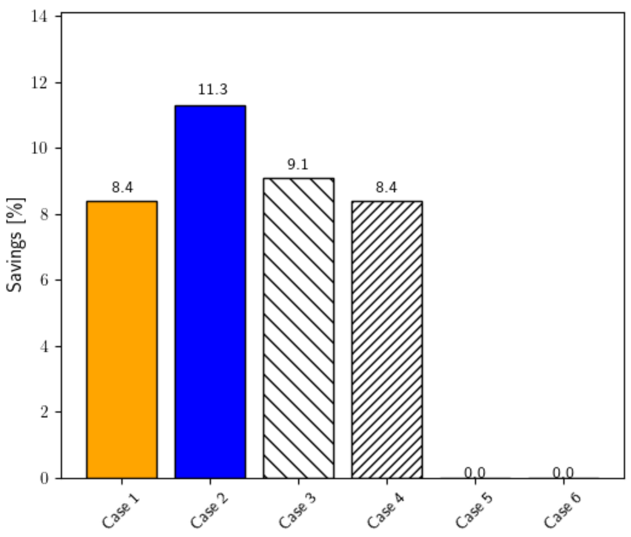
RESULTS: PROSUMER, BASELINE

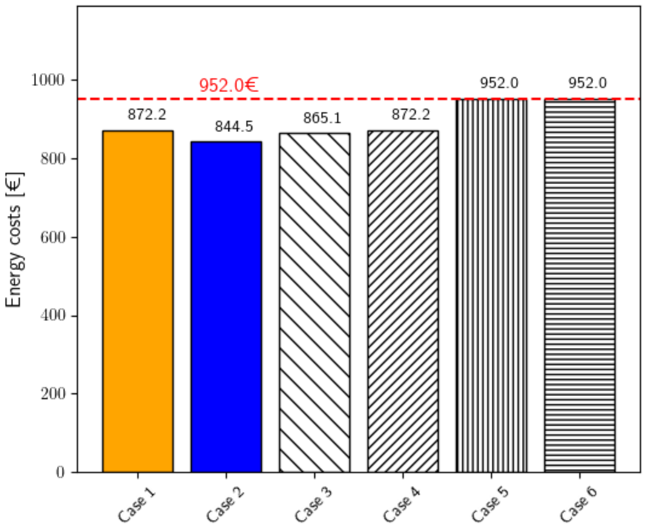




	C1	**C2**	**C3**	**C4**	**C5**	**C6**
$TC[€/y]$	24715.3	24669.5	24670.2	24682.4	24719.5	24719.5
β^{+}_{rural}	0.32	0.31	0.32	0.32	0.33	0.33
β^{+}_{city}	0	0.02	0	0	0	0
β^{+}_{mixed}	0	0.03	0	0	0	0
β^{+}_{EP}	0.68	0.64	0.68	0.68	0.67	0.67
β^{-}_{rural}	0.01	0	0	0	0	0
β^{-}_{city}	0	0.03	0.05	0.10	0	0
β^{-}_{mixed}	0	0.03	0.05	0	0	0
β^{-}_{EP}	0.99	0.94	0.90	0.90	1	1
$\sum_{r \in R} x_r$	**1**	**3**	**3**	**2**	**1**	**1**

RESULTS: PROSUMER, ASSETS





	C1	C2	C3	C4	C5	C6
$TC[€/y]$	6729.7	6707.4	6715.2	6733.8	6790.3	6790.3
β^{+}_{rural}	0	0.01	0	0	0	0
β^{+}_{city}	0	0.01	0.05	0	0	0
β^{+}_{mixed}	0.01	0	0	0	0	0
β^{+}_{EP}	0.99	0.98	0.95	1	1	1
β^{-}_{rural}	0	0.03	0	0	0	0
β^{-}_{city}	0	0.07	0.05	0	0	0
β^{-}_{mixed}	0.11	0.04	0.05	0.11	0	0
β^{-}_{EP}	0.89	0.86	0.90	0.89	1	1
$\sum_{r \in R} x_r$	**1**	**3**	**2**	**1**	**0**	**0**

OUTCOMES

Results

- **Consumer** dependency from provider is reduced up to 50%, but multiple participation only provides benefits as increased flexibility in energy supply.
- **Prosumer** will sell more energy towards provider (>60%) and energy-demanding EC1. MEC incremental savings are up to 6.3% and mainly due to higher flexibility while purchasing from more ECs at lower cost.
- In more self-sufficient communities**, prosumer** revenues will be lower and most of the energy is sold to the provider.
- **Participation coefficients** can be used to reduce number of ECs and avoid small new participant's contribution, but could slightly worsen ECs' units and end-users' savings.
- Results are strongly dependent on energy costs and each ECs participants and units' compositions

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THANK YOU FOR THE ATTENTION!

Ivan Mariuzzo: ivan.mariuzzo@phd.unipi.it
Bernadette Fina: bernadette.fina@ait.ac.at
Stefan Stroemer: stefan.stroemer@ait.ac.at