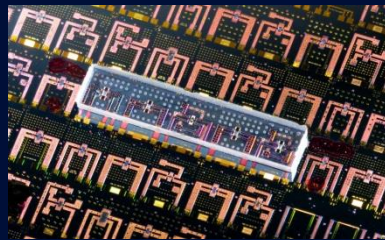


Modelling and Optimization of Power Allocation and Benefit Sharing in A Local Energy Community

UMR CNRS 5269 – Université Grenoble Alpes – CNRS - Grenoble-INP



Alyssa Diva Mustika, Rémy Rigo-Mariani, Vincent Debusschere, Amaury Pachurka

14th International Conference of TC-Electrimacs Committee, 16-19 May 2022 Nancy (France)

1. Context

2. Proposed Methodology: Management of Energy Community

- Energy Management Strategy
- Energy Allocation

3. Case Study, Results & Discussion

4. Conclusion

1. Context

2. Proposed Methodology: Management of Energy Community

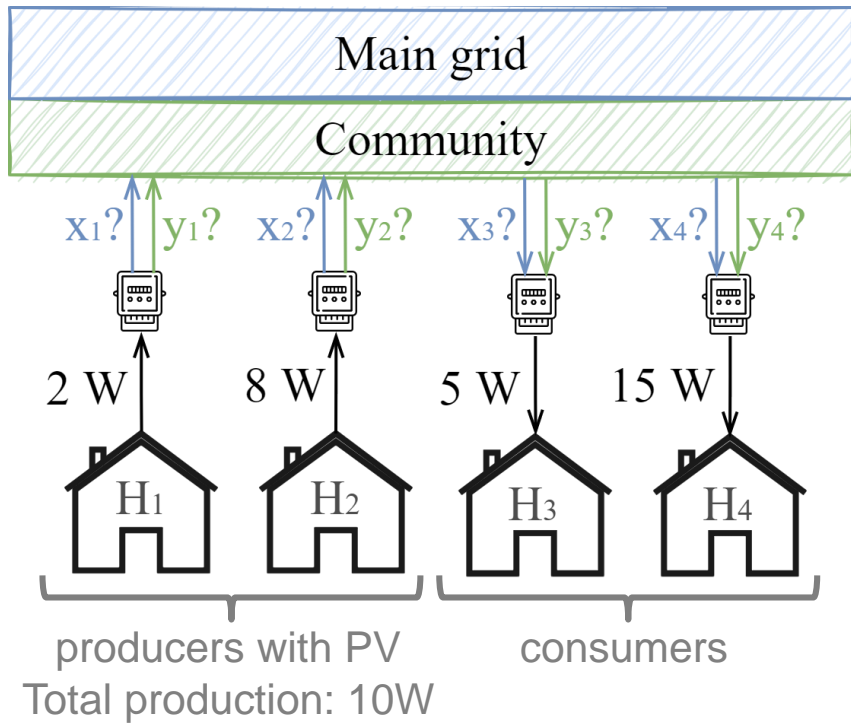
- Energy Management Strategy
- Energy Allocation

3. Case Study, Results & Discussion

4. Conclusion

- **Energy Communities (EC)**
 - **Aggregation** of several end-users (consumers/prosumers)
 - Energy exchanges.
 - Control of distributed energy resources (e.g., storage systems).
 - Concept of **collective self-consumption (CSC)**
 - Heterogeneous energy usages (i.e., load profiles).
 - Potential higher self-consumption & self-sufficiency ratios.
- **Objectives – management of energy community**
 1. Energy management strategy (EMS);
 2. Allocation of community generation to each member (**keys of repartition - KoR**).
- **Contribution**
 - A strategy of **keys of repartition** that considers every members perspective (**introduction of metric: individual energy price**).

Numerical examples of keys of repartition



$$P_{n,t}^{alloc} = \lambda_{n,t} \times P_{coll,t}^{prod}$$

minimum between allocation & consumption

	KoR ($\lambda_{n,t}$ in %)		Community Import (x_3, x_4)		Grid Import (y_3, y_4)	
	H_3	H_4	H_3	H_4	H_3	H_4
1)	50	50	5	5	0	10
2)	40	60	4	6	1	9
3)	80	20	5	2	0	13

etc infinite ways...

Plan



1. Context

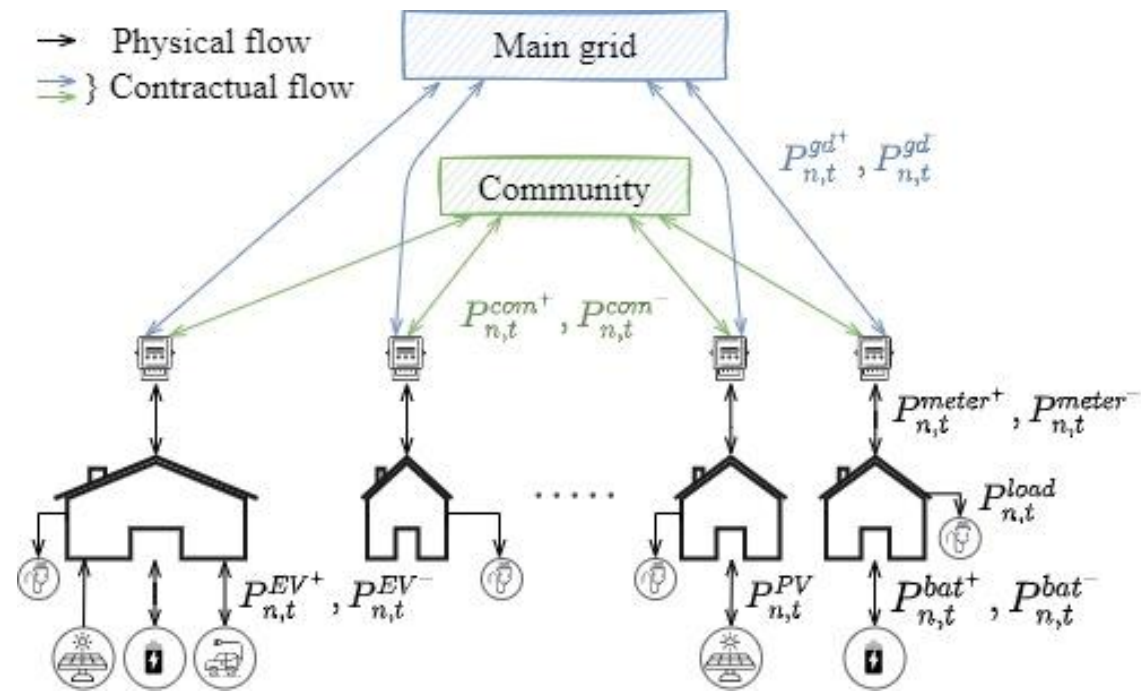
2. Proposed Methodology: Management of Energy Community

- Energy Management Strategy
- Energy Allocation

3. Case Study, Results & Discussion

4. Conclusion

Model of Energy Community



- Each member may own individual energy assets: PV, battery, EV.
- The physical energy flow is measured only in the meter ($P_{n,t}^{meter+}$, $P_{n,t}^{meter-}$), which can be divided into contractual flows of :
 - Community ($P_{n,t}^{com+}$, $P_{n,t}^{com-}$)
 - Grid ($P_{n,t}^{gd+}$, $P_{n,t}^{gd-}$)

Superscript grid, community, meter:
 (+) import energy to the households
 (-) export energy from the households

Superscript storage:
 (+) charge
 (-) discharge

Proposed methodology

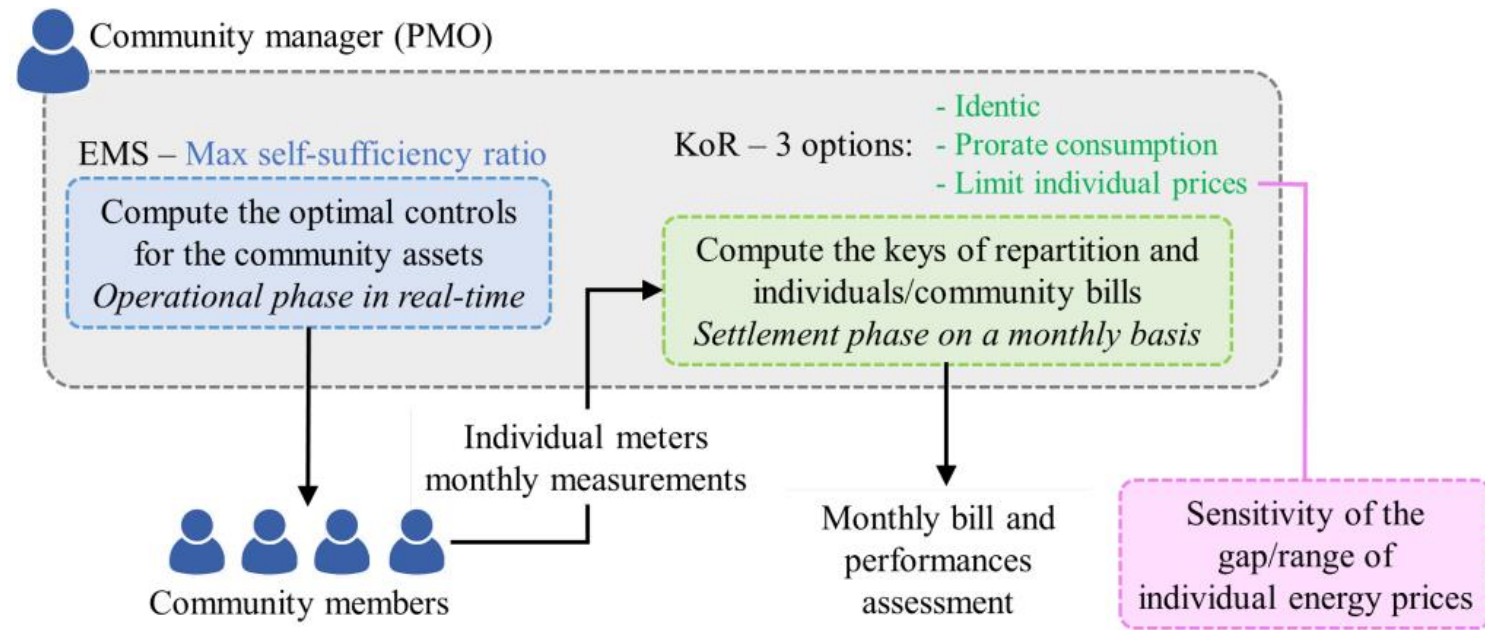
Two-stage management

Stage 1

- System operation through EMS
- At the community level, **coordinate energy system components** to determine the net **physical flow** in the **meter**.

Stage 2

- Settlement through KoR
- **Allocate** the collective production to each member at the **monthly** basis (**30-min resolution**) which affects the **bill**.



Stg1: Energy Management Strategy (EMS)

Variables, Parameters, Objective



- Optimization problem (control of storage power), 30 min resolution for one month horizon.
- Variables (positive semi-definite):

$$\overbrace{P_{n,t}^{st+}, P_{n,t}^{st-}, SOC_{n,t}^{st}}^{\text{storage: battery \& EV}}, P_{n,t}^{gd+}, P_{n,t}^{gd-}, P_{n,t}^{com+}, P_{n,t}^{com-}, P_{n,t}^{indsc}$$

- Parameters:

$$P_{max,n}^{st}, E_{max,n}^{st}, SOC_{min,n}^{st}, SOC_{max,n}^{st}, SOC_{init,n}^{st}, \mu_n^{st}, P_{n,t}^{load}, P_{n,t}^{PV}, P_n^{subs}$$

- Objective: max self-sufficiency ratio (amount of consumption that is supplied by local generation)

$$SSR = 1 - \frac{\sum_{n \in N} \sum_{t \in T} P_{n,t}^{gd+}}{\sum_{n \in N} \sum_{t \in T} P_{n,t}^{load}} \quad \rightarrow \quad f = \min \sum_{n \in N} \sum_{t \in T} P_{n,t}^{gd+}$$

Stg1: Energy Management Strategy (EMS)

Constraints

- Constraints:

$$\begin{aligned}
 & \left. \begin{aligned}
 P_{n,t}^{gd^+} + P_{n,t}^{com^+} &\leq P_n^{subs} \\
 P_{n,t}^{gd^-} + P_{n,t}^{com^-} &\leq P_n^{subs} \\
 \max(P_{n,t}^{gd^+}) &\leq \max(P_{n,t}^{load})
 \end{aligned} \right\} \text{limitation of energy exchanges} \\
 & \left. \begin{aligned}
 P_{n,t}^{st^+}, P_{n,t}^{st^-} &\leq P_{max,n}^{st} \\
 SOC_{n,1}^{st} &= SOC_{init,n}^{st} \\
 SOC_{n,end}^{st} &\geq SOC_{init,n}^{st} \\
 SOC_{min,n}^{st} &\leq SOC_{n,t}^{st} \leq SOC_{max,n}^{st} \\
 SOC_{n,t+1}^{st} &= SOC_{n,t}^{st} + \left[P_{n,t}^{st^+} \times \mu_n^{st} - \frac{P_{n,t}^{st^-}}{\mu_n^{st}} \right] \times \frac{100\Delta t}{E_{max,n}^{st}}
 \end{aligned} \right\} \text{typical storage system boundaries} \\
 & \left. \begin{aligned}
 P_{n,t}^{load} + P_{n,t}^{bat^+} + P_{n,t}^{EV^+} &= P_{n,t}^{indsc} + P_{n,t}^{gd^+} + P_{n,t}^{com^+} \\
 P_{n,t}^{PV} + P_{n,t}^{bat^-} + P_{n,t}^{EV^-} &= P_{n,t}^{indsc} + P_{n,t}^{gd^-} + P_{n,t}^{com^-} \\
 \sum_{n \in N} P_{n,t}^{com^+} &= \sum_{n \in N} P_{n,t}^{com^-}
 \end{aligned} \right\} \begin{array}{l} \text{individual power balance} \\ \text{collective power balance} \end{array}
 \end{aligned}$$

implicit model of KoR
 due to non-linearities
 $(\lambda_{n,t} \times P_{coll,t}^{prod})$

Stg2: Energy allocation through KoR

- Allocate community energy to the different members with three different strategies:

1. *KoR*₁: Identical repartition

- Equal allocation for everyone.

$$\lambda_{n,t} = \frac{1}{|N|}$$

2. *KoR*₂: Prorate consumption (default keys by French DSO)

- Based on the amount of consumption measured at the individual meters.

$$\lambda_{n,t} = \frac{P_{n,t}^{meter+}}{\sum_{n \in N} P_{n,t}^{meter+}}$$

3. *KoR*₃: Limit individual net energy prices

- Optimization to limit the discrepancy between individual net energy prices.

$$\pi_n^{net} = \frac{B_n \rightarrow \text{individual bill}}{\sum_{t \in T} P_{n,t}^{meter+}} \rightarrow \Delta \pi_n^{net} = \max(\pi_n^{net}) - \min(\pi_n^{net})$$

- Objective: minimize total collective bill ($\min \sum_{n \in N} (B_n^{com} + B_n^{gd})$)

Plan



1. Context

2. Proposed Methodology: Management of Energy Community

- Energy Management Strategy
- Energy Allocation

3. Case Study, Results & Discussion

4. Conclusion

Case Study

- Smart Lou Quila: a pilot project of energy community by Beoga located in Le Cailar (near Montpellier), France.
- Seven households with diversity of types & individual assets.
- $\pi_n^{sell,gd}$: 6.5 c€/kWh, $\pi_n^{sell,com}$: 7 c€/kW, $\pi_n^{buy,com}$: 7.5 c€/kWh.

House	PV (kW)	Bat (kW/kWh)	EV (kW/kWh)	Subs (kVA)	$\pi_n^{subs,gd}$ (€/mo)	$\pi_n^{buy,gd}$ (c€/kWh)
1	3.2	5/9.8	11/40	6	8.4	12.97
2	6.12	5/9.8	-	36	24.96	13.31
3	-	5/9.8	-	6	8.4	12.97
4	3.2	-	-	9	10.05	13.31
5	3.2	-	-	9	10.05	13.31
6	3.2	-	-	6	8.4	12.97
7	-	-	-	9	10.05	13.31

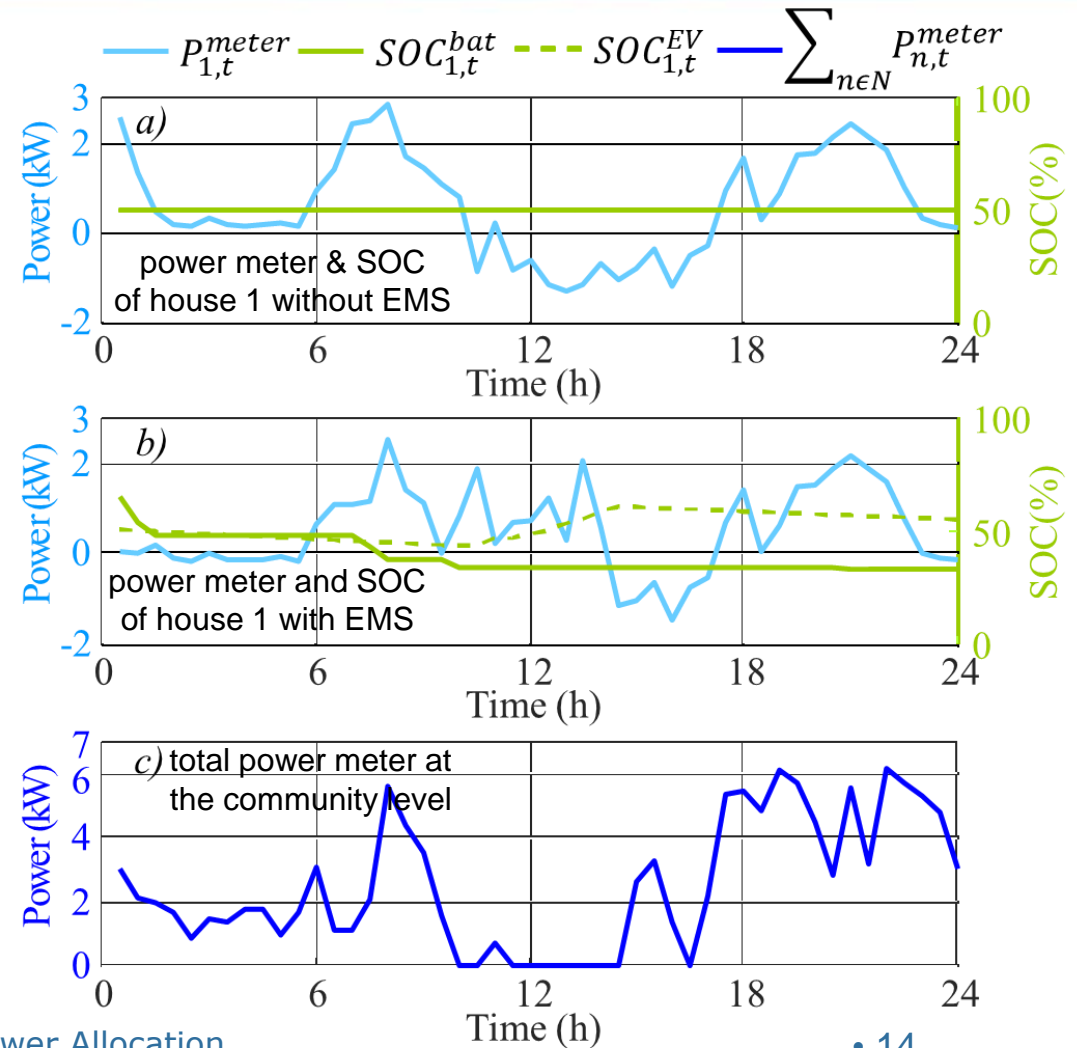


booga
sharing ecosystems

Result of EMS

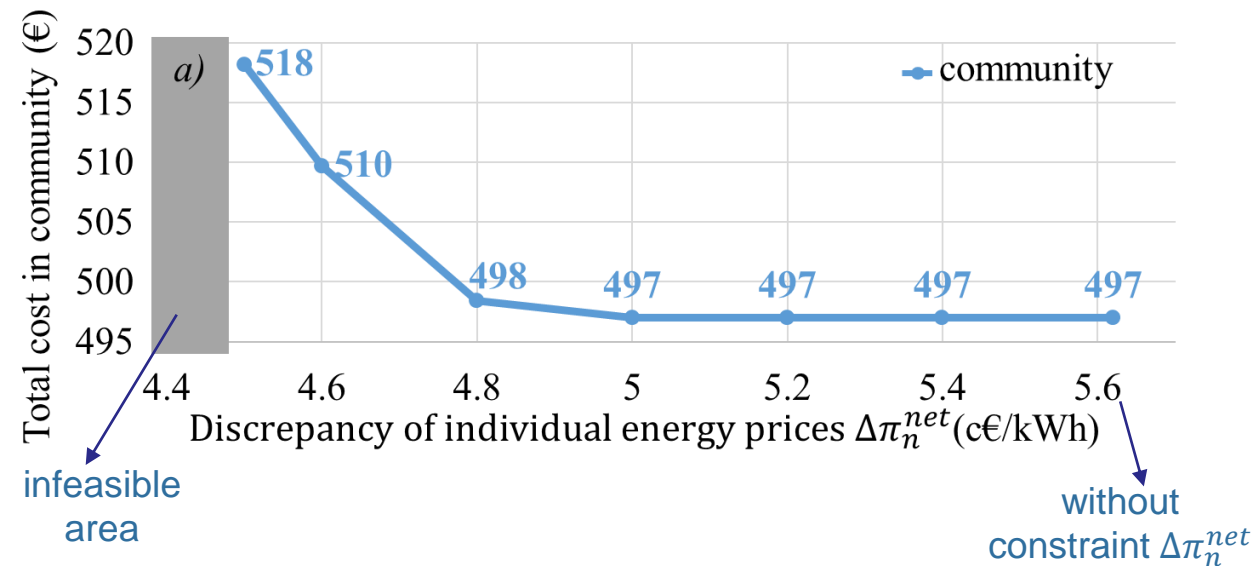
Metrics computed collectively for a month	Individual EMS	Proposed Community EMS
Self-sufficiency ratio (%)	27	42
Self-consumption ratio (%)	64	98.6

- **Reduced peak load** thanks to EMS.
- At the community level, **no export to the main grid** as all local generation is used within the community (thanks to the storage control by EMS).



Sensitivity of Individual Energy Prices

KoR₃: Limit the discrepancy of individual energy prices



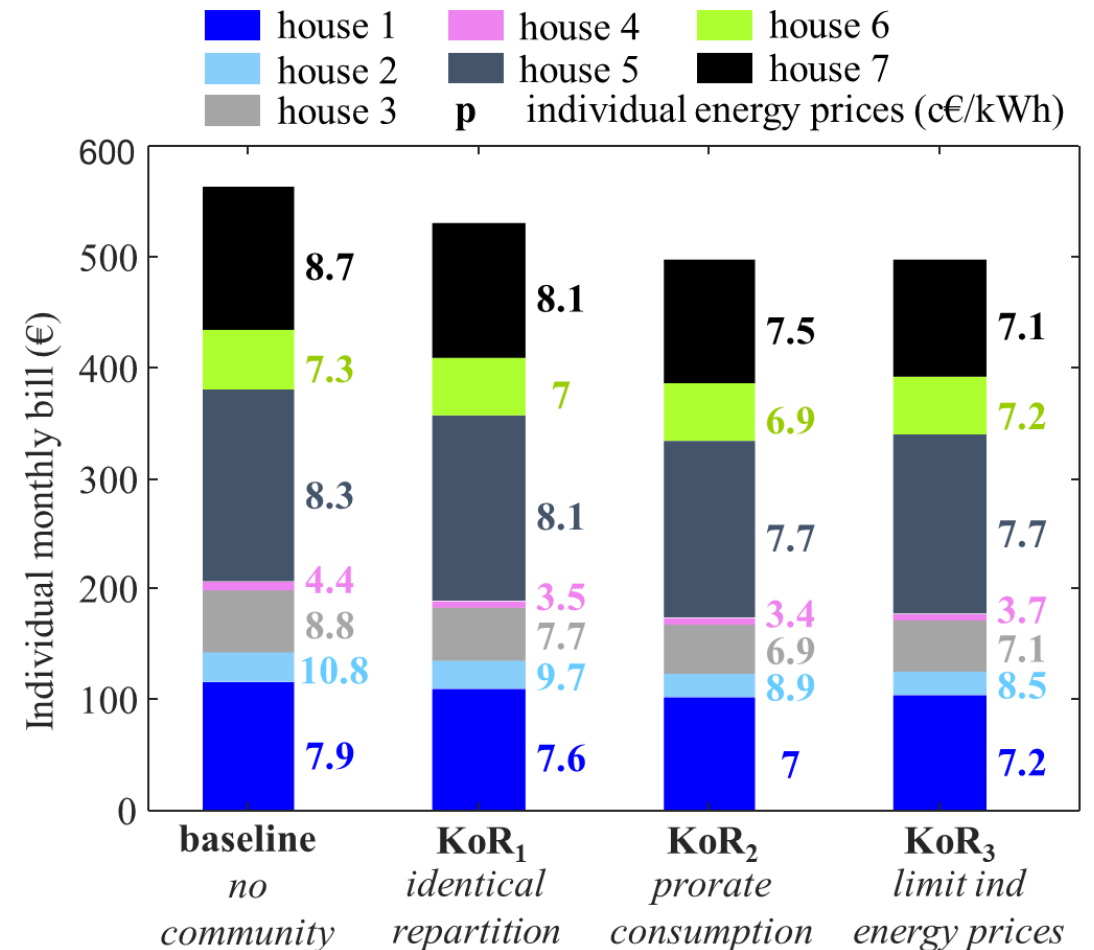
- The total cost increases as the gap $\Delta\pi_n^{net}$ between members decreases.
- **Choose $\Delta\pi_n^{net} = 4.8$ c€/kWh** (small increment of total cost compared to the minimum cost).

Result of different KoR strategies

Collective bill

baseline (no community)	KoR1	KoR2	KoR3
563€	530€	497€	498 €

- The KoR3 returns **11.5% saving** (collective bill).
- The strategy **KoR1** results in wide range of individual energy prices (3.5-9.7 c€/kWh $\rightarrow \Delta\pi_n^{net}$: **6.2c€/kWh**).
- With the lowest cost (**497€**) using **KoR2**, the individual energy prices are still significantly far from each other (3.4-8.9c€/kWh $\rightarrow \Delta\pi_n^{net}$: **5.5c€/kWh**).
- The last keys **KoR3** (which **only higher by 1€** from total community bill) can reach a fairer/narrower gap (3.7-8.5c€/kWh $\rightarrow \Delta\pi_n^{net}$: **4.8c€/kWh**).



1. Context
2. **Proposed Methodology: Management of Energy Community**
 - Energy Management Strategy
 - Energy Allocation
3. Case Study, Results & Discussion
4. **Conclusion**

Conclusion

- Management of energy community in two-stage strategy: 1) EMS and 2) KoR.
- Introduce a new metric of individual energy price.
- Proposed strategy: optimization-based KoR that utilizes the metric as an additional constraint (limit the discrepancy between members).
- Collective bill saving reaches 11.5%.
- This work provides an alternative of KoR for a better share of the community energy.
- Future work: ancillary services from energy community, sizing of assets.

Appendix

Numerical examples of keys of repartition

Allocation		Community Import (x_3, x_4)		Grid Import (y_3, y_4)	
H_3	H_4	H_3	H_4	H_3	H_4
5	5	5	5	0	10
4	6	4	6	1	9
8	2	5	2	0	13

producers with PV
Total production: 10W

consumers

$$P_{n,t}^{alloc} = \lambda_{n,t} \times P_{coll,t}^{prod}$$

KoR ($\lambda_{n,t}$ in %)	
H_3	H_4
50	50
40	60
80	20

etc infinite ways...

Total production – Total community import

minimum between allocation & consumption

Allocation		Community Import (x_3, x_4)		Grid Import (y_3, y_4)	
H_3	H_4	H_3	H_4	H_3	H_4
5	5	5	5	0	10
4	6	4	6	1	9
8	2	5	2	0	13

Total Surplus	Grid Export (y_1, y_2)		Community Export (x_1, x_2)	
	H_1	H_2	H_1	H_2
0	0	0	2	8
0	0	0	2	8
3	0.6	2.4	1.4	5.6

prorate production

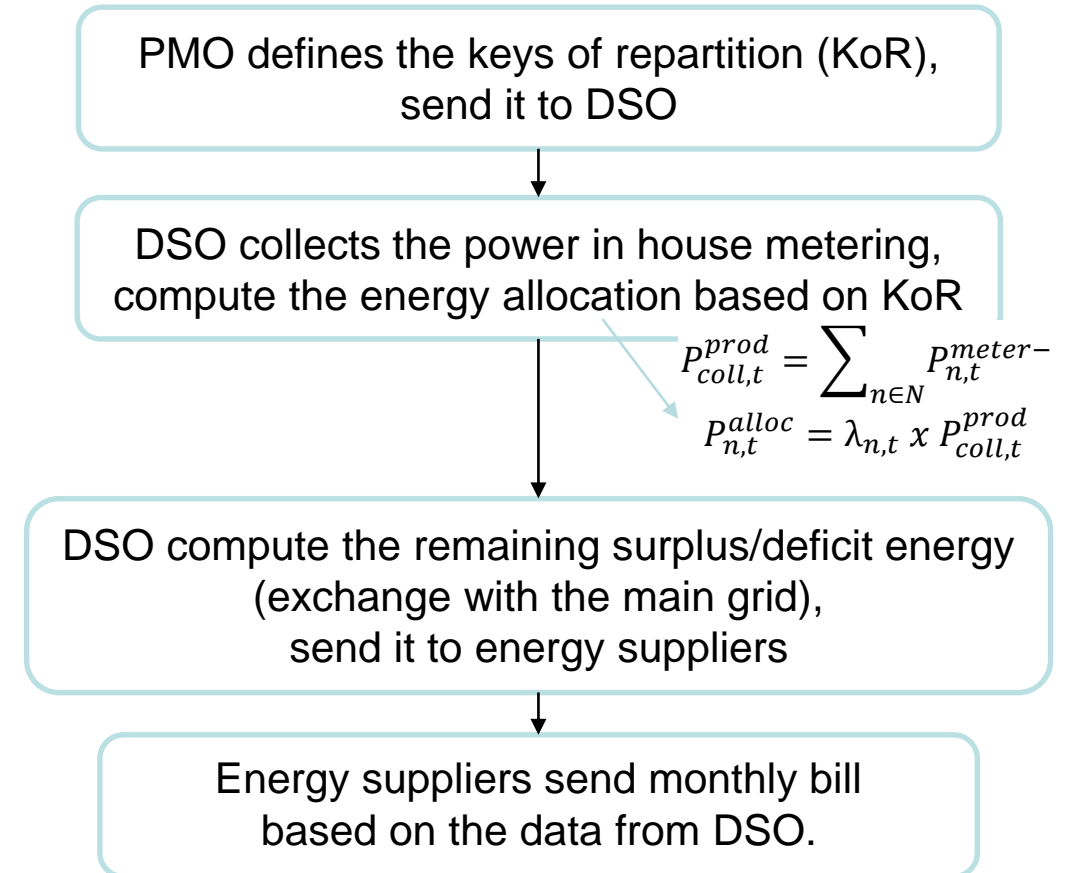
Organization of Energy Community

French Context



- **Maximum distance: 2 km.**
- **Maximum cumulative generation: 3 MW.**
- **Stakeholders:**
 1. **Community members**
 2. **A community manager (PMO - personne morale organisatrice / moral organizing entity)**
 - Legal entity that arranges the internal community organization & external parties.
 3. **Distribution System Operator (DSO)**
 - Manages the physical electrical distribution grid.
 4. **Energy suppliers**
 - Sell/purchase any deficit/surplus of local energy community.

How the KoR works?



Bill computation

- $B_n^{com} = \left(\pi_n^{buy,com} \sum_{t \in T} P_{n,t}^{com+} - \pi_n^{sell,com} \sum_{t \in T} P_{n,t}^{com-} \right) \Delta t$
- $B_n^{gd} = \Pi_n^{subs,gd} + \left(\pi_n^{buy,gd} \sum_{t \in T} P_{n,t}^{gd+} - \pi_n^{sell,gd} \sum_{t \in T} P_{n,t}^{gd-} \right) \Delta t$
- $B_n^{coll} = \sum_{n \in N} \left(B_n^{com} + B_n^{gd} \right)$

Optimization formulation in KoR3

- Variables (positive semi-definite): $P_{n,t}^{gd^+}$, $P_{n,t}^{gd^-}$, $P_{n,t}^{com^+}$, $P_{n,t}^{com^-}$, $P_{n,t}^{alloc}$, $\lambda_{n,t}$
- Parameters: $P_{n,t}^{meter^+}$, $P_{n,t}^{meter^-}$
- Objective: minimize total bill in the community ($\min B_{coll} = \sum_{n \in N} B_n^{gd} + \sum_{n \in N} B_n^{com}$)
- Constraints:

$$0 \leq \lambda_{n,t} \leq 100\%$$

$$\sum_{n \in N} \lambda_{n,t} \leq 100\%$$

$$P_{n,t}^{meter^+} = P_{n,t}^{gd^+} + P_{n,t}^{com^+}$$

$$P_{n,t}^{meter^-} = P_{n,t}^{gd^-} + P_{n,t}^{com^-}$$

$$P_{n,t}^{alloc} = \lambda_{n,t} \times \sum_{n \in N} P_{n,t}^{meter^-}$$

$$P_{n,t}^{com^+} = \min(P_{n,t}^{alloc}, P_{n,t}^{meter^+})$$

$$P_{n,t}^{gd^-} = \frac{P_{n,t}^{meter^-}}{\sum_{n \in N} P_{n,t}^{meter^-}} \times \left(\sum_{n \in N} P_{n,t}^{meter^-} - \sum_{n \in N} P_{n,t}^{com^+} \right)$$

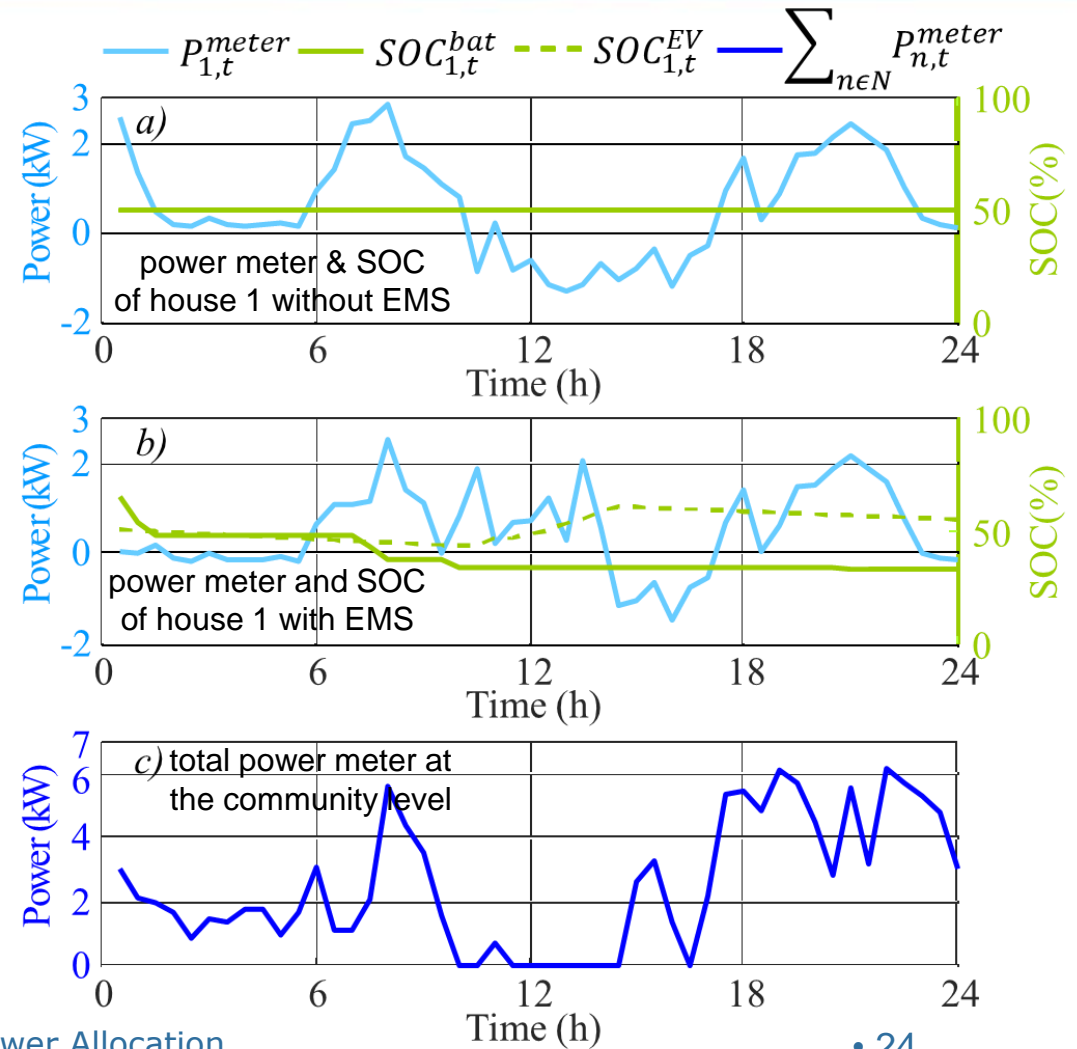
$$\pi_n^{net} = \frac{B_n}{\sum_{t \in T} P_{n,t}^{meter^+}}$$

$$\Delta \pi_n^{net} = \max(\pi_n^{net}) - \min(\pi_n^{net}) \leq 4.8 \text{ c€/kWh}$$

Result of EMS

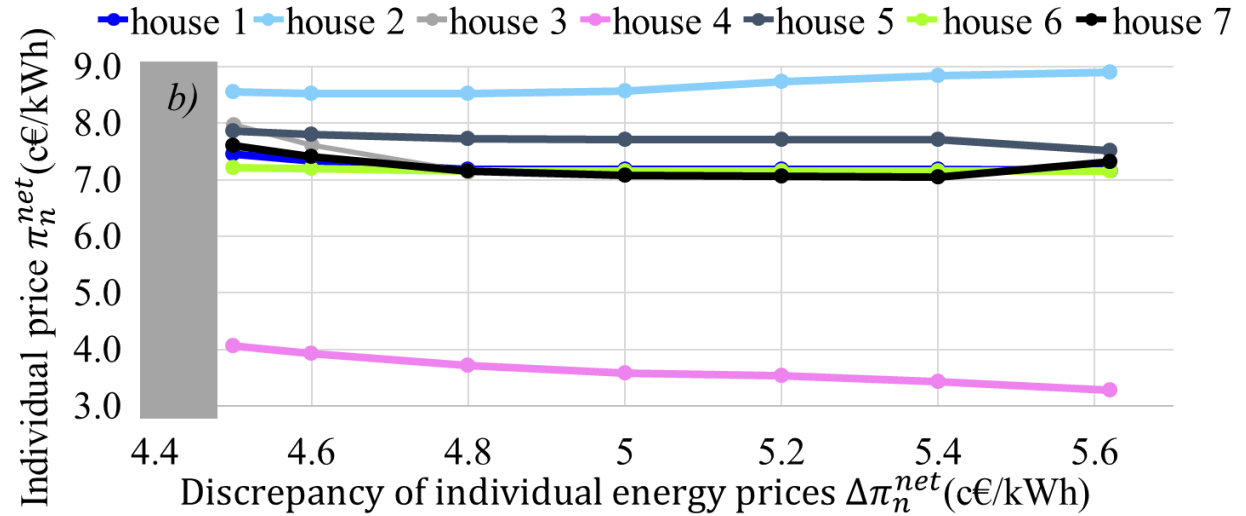
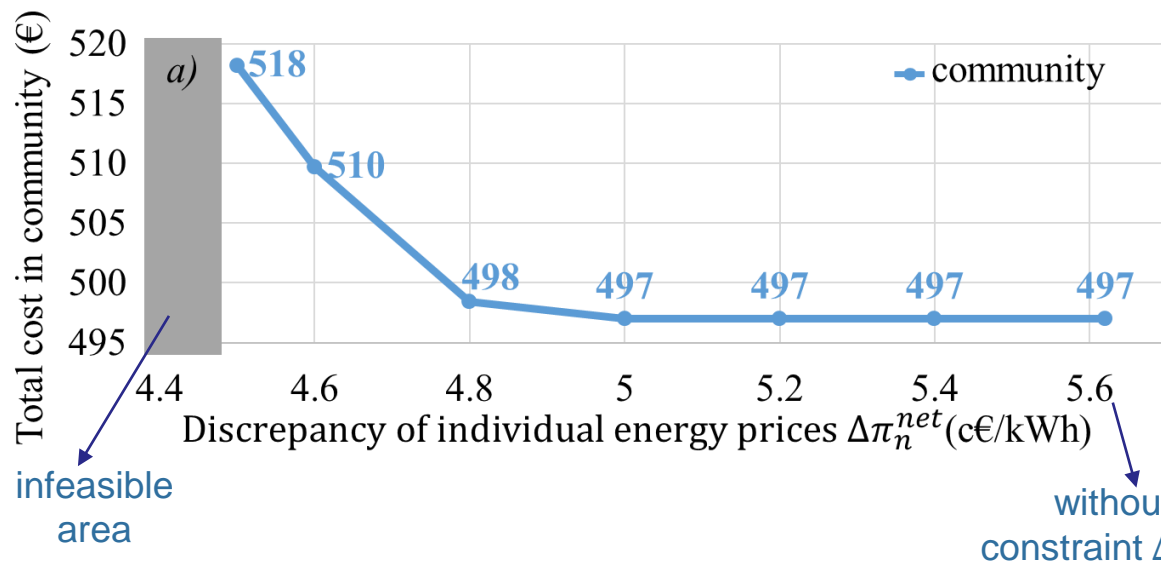
Metrics computed collectively for a month	Individual EMS	Proposed Community EMS
Self-sufficiency ratio (%)	27	42
Self-consumption ratio (%)	64	98.6

- **Reduced peak load** thanks to EMS.
- To lower import from grid, the battery is discharged during the time of high consumption & low PV production.
- EV charge occurs during high PV production and discharge at night.
- At the community level, **no export to the main grid** as all local generation is used within the community (thanks to the storage control by EMS).



Sensitivity of Individual Energy Prices

KoR₃: Limit the discrepancy of individual energy prices



- The total cost increases as the gap $\Delta\pi_n^{net}$ between members decreases.
- Discrepancy in the community: difference between house 2 and house 4 (lowest consumption with same PV capacity).
- **Choose $\Delta\pi_n^{net} = 4.8$ c€/kWh** (small increment of total cost compared to the minimum cost).

Figures

