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# Hierarchical Energy Sharing Management for a Renewable Energy Community with Heterogeneous End-users

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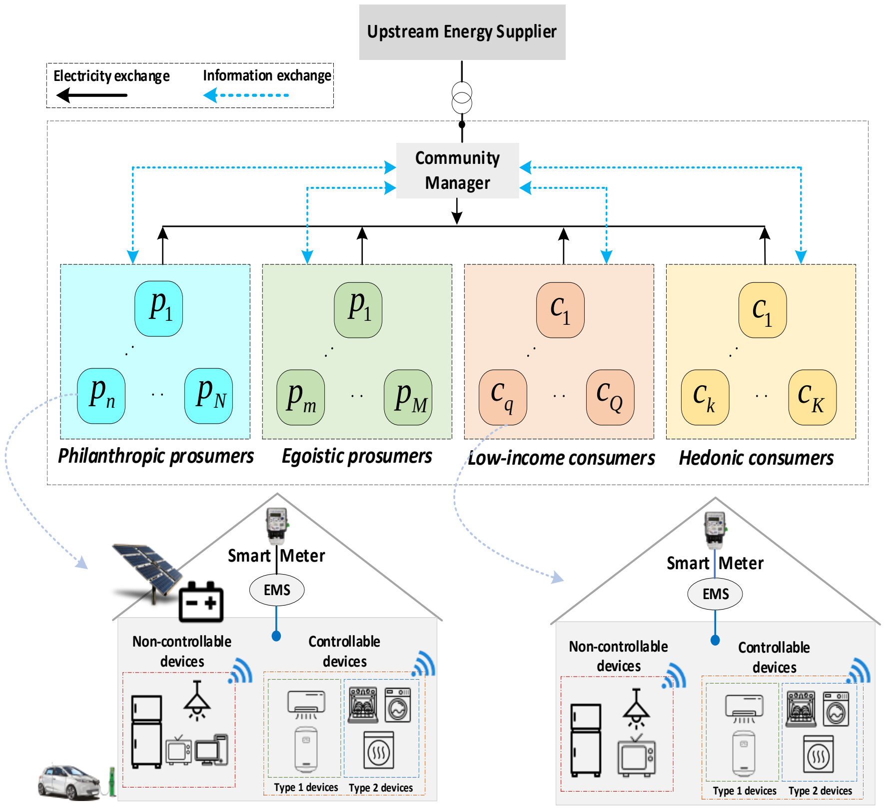
# Introduction

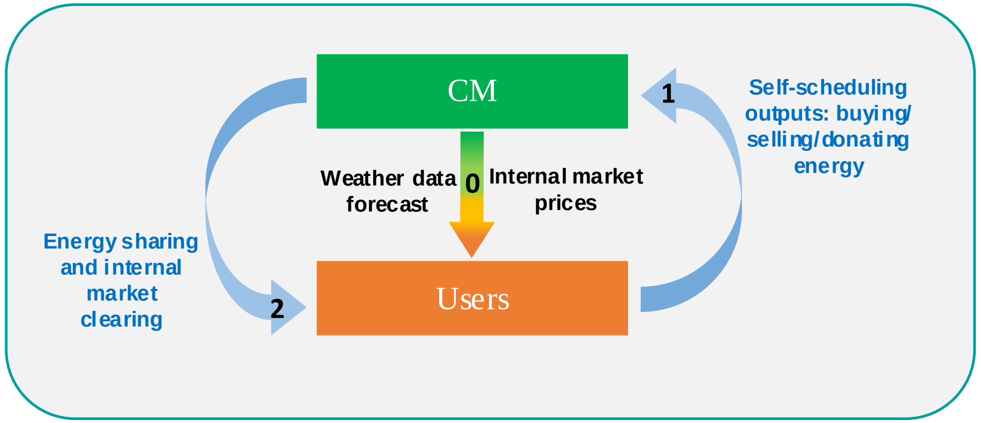
- **Renewable Energy Communities (RECs)** new **facilitating** resources for sustainable **energy transition**.
- The RECs are mainly **composed** by **shareholders and local end-users** (i.e. the community members), who have the right to **generate, store, and distribute energy locally** without resorting to the standard retail market, and own the energy assets individually or collectively.
- REC **members** are **heterogonous** in their **motivations** for participating in energy communities.
- Intrinsic **values** are among **important motivations** for prosumers to join RECs.
- In this paper, we **integrate** the **heterogeneity of preferences** of individuals, which roots in their intrinsic values, **in energy sharing management** of a centralized REC.

# System overview




- **Community manager:** Optimizes energy balance between community and upstream energy supplier. Facilitates energy sharing and internal billing mechanism within the energy community.
- **Philanthropic prosumers:** Follow altruistic behaviors by donating (all or some of) their surplus generation to the community manager.
- **Egoistic prosumers:** Follow self-interest behaviors to maximize their personal (financial) gains by selling their surplus energy to the community manager.
- **Low-income consumers:** They are identified by the community manager. Purchase electricity from the manager. Also, receive free-of-charge donated energy.
- **Hedonic consumers:** Follow pleasure and personal satisfaction behaviours. Purchase electricity from the community manager.

# Energy Sharing Management Problem




Self-scheduling of individuals (prosumers & consumers):

$$\textbf{Min}\ f(X_{j,t})$$

*s.t.*

- Flexible (consecutive & non-consecutive) loads constraints.
- Energy storage constraints.
- EV constraints.
- Boundaries on buying (selling) power from (to) the community manager.
- Constraint on power balance condition.

**Outcomes**

- Donated power by philanthropic prosumers
- Selling power by egoistic prosumers
- Power demand by all the members

**Input**

Energy Management (Manager):

$$\textbf{Min}\ g(Y_t)$$

*s.t.*

- Boundaries on buying (selling) power from (to) the supplier.
- Constraint on power balance condition.

# Energy Sharing Management Problem

Energy Sharing Algorithms:

- Energy Class 1: Supplier energy
- Energy Class 2: Donated energy
- Energy Class 3: Green energy

**Algorithm 1** *Sharing donated energy by altruistic prosumers (class 2) with low-income consumers.*

Collect the first-stage scheduled power quantities from all end-users.
**for** $h = 1{:}H$ **do**
  Calculate $\hat{p}_h^{dnt}$ as in (35); ⟶ $\hat{p}_h^{dnt} = \sum_{m\in\mathcal{M}} p_{m,h}^{dnt}/card(Q)$
  Allocate $\hat{p}_h^{dnt}$ to $q^{th}$ consumer: $\xi_h^b\left[p_{q,h}^b - \hat{p}_h^{dnt}\right]^+$;
  **while** $\hat{p}_h^{dnt} > p_{q,h}^b$ **do**
    Distribute surplus donated energy with hedonic consumers having lower peak consumptions: $\xi_h^b\left(p_{k,h}^b + \left[p_{q,h}^b - \hat{p}_h^{dnt}\right]^-\right)$;
  **end while**
  Revise the billing cost of consumers with allocated donated energy;
**end for**

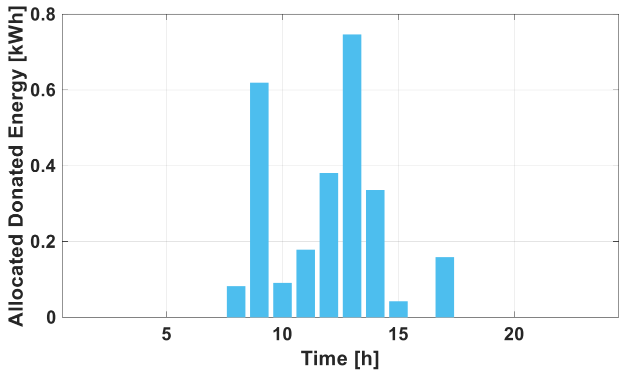
**Algorithm 2** *Sharing green energy by self-interested prosumers (class 3) with REC members.*

Collect first-stage scheduled power quantities from all end-users.
**for** $h = 1{:}H$ **do**
  Calculate the total production of self-interested prosumers $\left(\sum p_{m,h}^s\right)$ and the total demand of end-users $\left(\sum p_{i,h}^b\right)$;
  Equally share renewable energy with end-users who require electricity $\left(p_{i,h}^b \leftarrow \sum p_{m,h}^s\right)$;
  **if** $\sum\left(p_{m,h}^s \le \sum p_{i,h}^b\right)$ **then**
    Purchase deficit power from the supplier (class 1);
  **else**
    Sell surplus power to the supplier (class 1);
  **end if**
**end for**

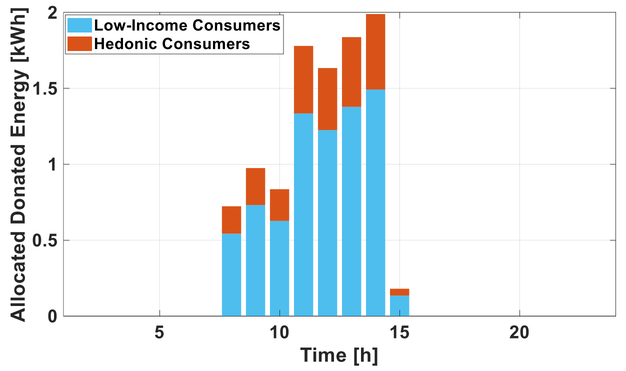
# Simulation Results

- The community consists of 6 prosumers and 6 consumers.
- Simulations are performed for two different days (high & lower PV generation days).

1) Donated energy assigned to each consumer for a (a) winter day; and (b) summer day:

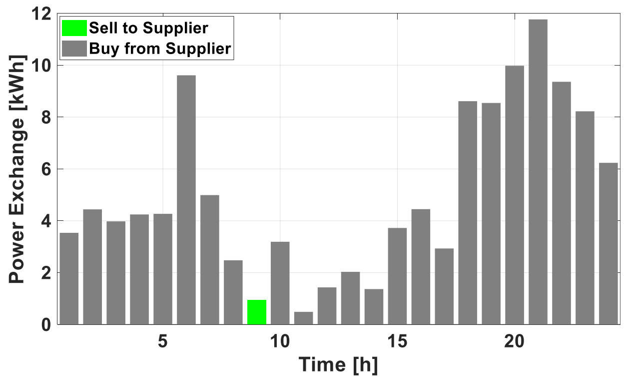



(a)

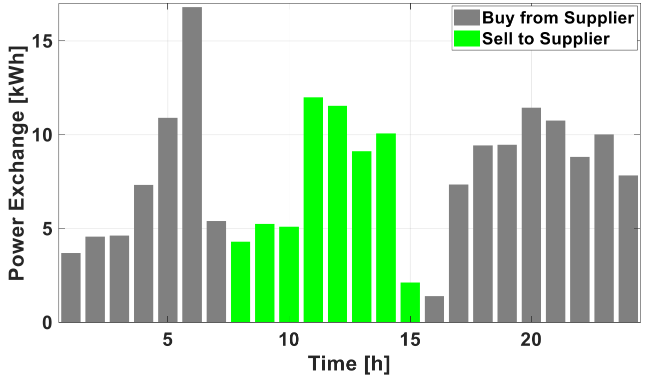



(b)

2) Exchanged power with the upstream supplier for a (a) winter day; and (b) summer day:




(a)




(b)

# Simulation Results

Operation costs of end-users in the community:

| User type and No. | | Operation Cost [€] | | | | | |
|---|---|---|---|---|---|---|---|
| | | Winter Day | | | Summer Day | | |
| | | Comm | Indv [14] | Diff | Comm | Indv [14] | Diff |
| Prosumers | P1 | 3.34 | 4.11 | 0.77 | 3.58 | 4.22 | 0.64 |
| | P2 | 2.75 | 3.23 | 0.48 | 2.52 | 2.96 | 0.44 |
| | P3 | 2.73 | 4.18 | 1.45 | 2.48 | 2.86 | 0.38 |
| | P4 | 1.12 | 1.57 | 0.45 | 0.23 | 0.27 | 0.04 |
| | P5 | 2.44 | 2.87 | 0.43 | 2.37 | 2.80 | 0.43 |
| | P6 | 2.75 | 3.24 | 0.49 | 2.72 | 3.20 | 0.48 |
| | P7 | 0.18 | 1.01 | 0.83 | -2.19 | -1.09 | 1.10 |
| | P8 | 0.02 | 0.60 | 0.58 | -1.71 | -0.89 | 0.82 |
| | P9 | -1.83 | -1.10 | 0.73 | -3.41 | -2.43 | 0.98 |
| | P10 | -0.58 | -0.08 | 0.50 | -1.02 | -0.30 | 0.72 |
| | P11 | -1.45 | -0.74 | 0.71 | -4.67 | -3.55 | 1.12 |
| | P12 | 2.15 | 2.66 | 0.51 | 0.43 | 1.116 | 0.68 |
| Consumers | C1 | 3.83 | 4.49 | 0.66 | 3.08 | 5.57 | 2.49 |
| | C2 | 3.40 | 3.64 | 0.24 | 2.46 | 4.85 | 2.39 |
| | C3 | 4.74 | 5.47 | 0.73 | 3.97 | 6.92 | 2.95 |
| | C4 | 5.60 | 6.67 | 1.07 | 4.69 | 6.75 | 2.06 |
| | C5 | 2.57 | 3.04 | 0.47 | 2.36 | 3.34 | 0.98 |
| | C6 | 3.90 | 4.55 | 0.65 | 3.15 | 4.62 | 1.47 |
| **Total** | | **37.66** | **49.41** | **11.75** | **21.04** | **41.21** | **20.17** |

Acronyms: Comm=Community-based, Indv=Individual-based, Diff=Difference

Low-income consumers' cost savings:

| Day | Consumer No. | Operation cost [€] | | Saving |
|---|---|---|---|---|
| | | *Before receiving donated energy* | *After receiving donated energy* | |
| Winter day | C1 | 4.76 | 3.83 | 0.93 |
| | C2 | 4.17 | 3.40 | 0.77 |
| | C3 | 5.77 | 4.74 | 1.03 |
| | **Total** | **14.70** | **11.97** | **2.73** |
| Summer day | C1 | 4.79 | 3.08 | 1.71 |
| | C2 | 4.27 | 2.46 | 1.81 |
| | C3 | 6.02 | 3.97 | 2.05 |
| | C4 | 4.79 | 4.69 | 0.10 |
| | C5 | 2.81 | 2.36 | 0.45 |
| | C6 | 3.97 | 3.15 | 0.82 |
| | **Total** | **26.65** | **19.71** | **6.94** |

- ✓ Monetary **benefits** from participating in **community-based** energy exchanges for **all members**.
- ✓ Additional **cost reduction** for **low-income (& hedonic) consumers**, enjoying **donated energy**.

# Conclusion

- All members financially benefited from participating in the REC.
- Low-income (& hedonic) consumers received additional cost reduction from donated energy by philanthropic prosumers.
- Recognizing the contributions of philanthropic prosumers towards the savings of anonymous low-income (& hedonic) consumers (Promotes the social and environmental values that underlie the community energy concept).
- Decreases reliance on external energy suppliers, particularly during peak hours.

# THANK YOU FOR YOUR ATTENTION!

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