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Ex-post allocation of electricity and real-time control strategy for renewable energy communities

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Renewable energy communities.

Technological advances push for a revolution in the electricity retailing sector:

- Empowering consumers thanks to **inexpensive electricity generation installations** (e.g. solar photovoltaic).
- Fostering **decentralized** electricity trading.
- Moving toward **consumer-centric electricity markets**.

It is now essential to properly define the rules governing these new electricity markets:

- how can **different prosumers share** their generation assets **with other consumers/prosumers**?

The European Directive of December 2018 introduced the term Renewable Energy Community (REC) to provide a framework for these markets.

Allocating local electricity.

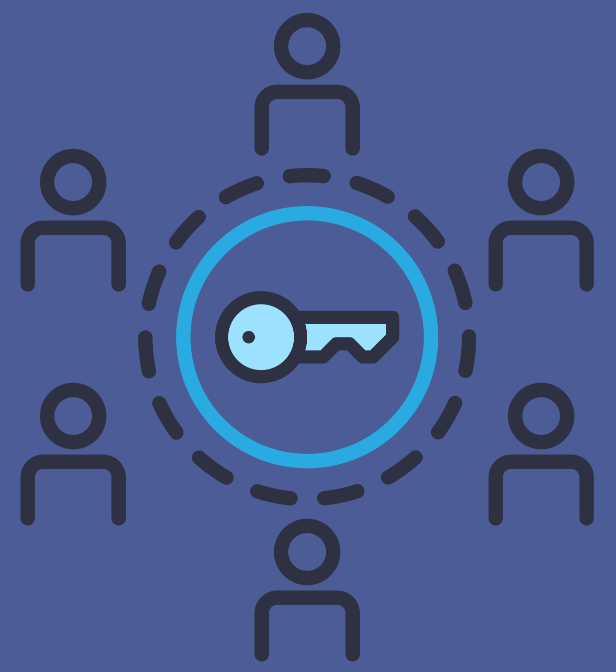
- Any final customer (consumer or prosumer) may participate in an REC.
- RECs can **produce**, **consume**, **store**, and **sell** renewable energy.
- RECs allow for **sharing local generation assets** among their members.
- The manager of RECs is the energy community manager (ECM).

How to share these assets –or, in fact, the local electricity generated with them– is not clear yet:

- There is, to date, **no regulation** detailing this (different countries/regions have their own ideas on how to transpose European law).

A methodology based on an ex-post allocation of local electricity is proposed:

- Using real measurements of consumption and production (time-series) of the REC’s members.
- Dispatching the local electricity by means of **repartition keys**.



Repartition keys.

- Represent the proportion of total local production that is provided to each REC's member.
- Have one key per time-step in the time-series (namely, per metering period).
- Their sum across members must be ≤ 100%.
- They are computed **ex-post** by the ECM, and communicated to the DSO – alternatively they may be computed directly by the DSO.

Repartition keys.

The DSO uses the repartition keys to update the meter readings of each REC's member, then:

- Retailers (each member may have a different one) charge REC's members according to the updated meter readings.
- The electricity bill of each member is **divided into two**:
  - **local exchanges**: imports and exports within the REC (among REC's members), and,
  - **grid exchanges**: imports and exports with the main network based on the meters corrected with the repartition keys.

Note that a discount on the distribution component of the overall electricity price may be offered for the local exchanges.

Ex-post allocation.

After the electricity has been served and with real measurements, an **optimization problem** can be formulated to compute the repartition keys – an **ex-post** optimization of the **financial** exchanges (the electricity flows cannot be optimized at this point).

Inputs.

- Total local production available in the REC – measured per member.
- Total demand of the REC – measured per member.
- A set of **price signals**: grid imports, local imports, grid exports, and local exports.
- A set of initial (default) repartition keys – an **initial guess** of how the production should be allocated.

Outputs.

- An optimal set of repartition keys that **minimizes the sum of electricity bill**s of the REC's members.
- The allocation of local production associated to these keys.

Problem formulation - objective function.

The optimization problem is formulated so as to minimize the sum of electricity bills of the REC's members, denoted as B, and expressed by the following equation:

$$B = \sum_{t=0}^{T} \sum_{i=1}^{I} \left[\xi_i^{b} \cdot \left(C_{t,i}^{n} - a_{t,i} \right) + \xi_i^{l-} \cdot a_{t,i} - \xi_i^{l+} \cdot y_{t,i} - \xi_i^{s} \cdot \left(P_{t,i}^{n} - y_{t,i} \right) \right] \quad \forall (t, i)$$

- Each REC's member is represented by ***i*** (the total number or members being ***I***), and each time-step of the optimization is represented by ***t*** (the time horizon being ***T***).
- $\xi_i^{b}, \xi_i^{l-}, \xi_i^{l+}$, and ξ_i^{s} represent the prices for grid imports, local imports, local exports, and grid exports, respectively.
- $C_{t,i}^{n}$ and $P_{t,i}^{n}$ represent consumption and production of each REC's member, respectively.
- $a_{t,i}$ and $y_{t,i}$ represent allocated production and local sales, respectively.

Problem formulation - constraints.

The optimal keys, given by $k_{t,i}$, must deviate from the initial ones, given by $K_{t,i}$, by maximum a tolerance $X_{t,i}$:

$$X_{t,i} \geq \left| k_{t,i} - K_{t,i} \right| \quad \forall (t, i)$$

The allocated production associated to the set of optimal keys is:

$$a_{t,i} = k_{t,i} \cdot \sum_{i \in \mathcal{I}} P^n_{t,i} \quad \forall t$$

The allocated production must be equal to the local sales, when summing over the REC's members:

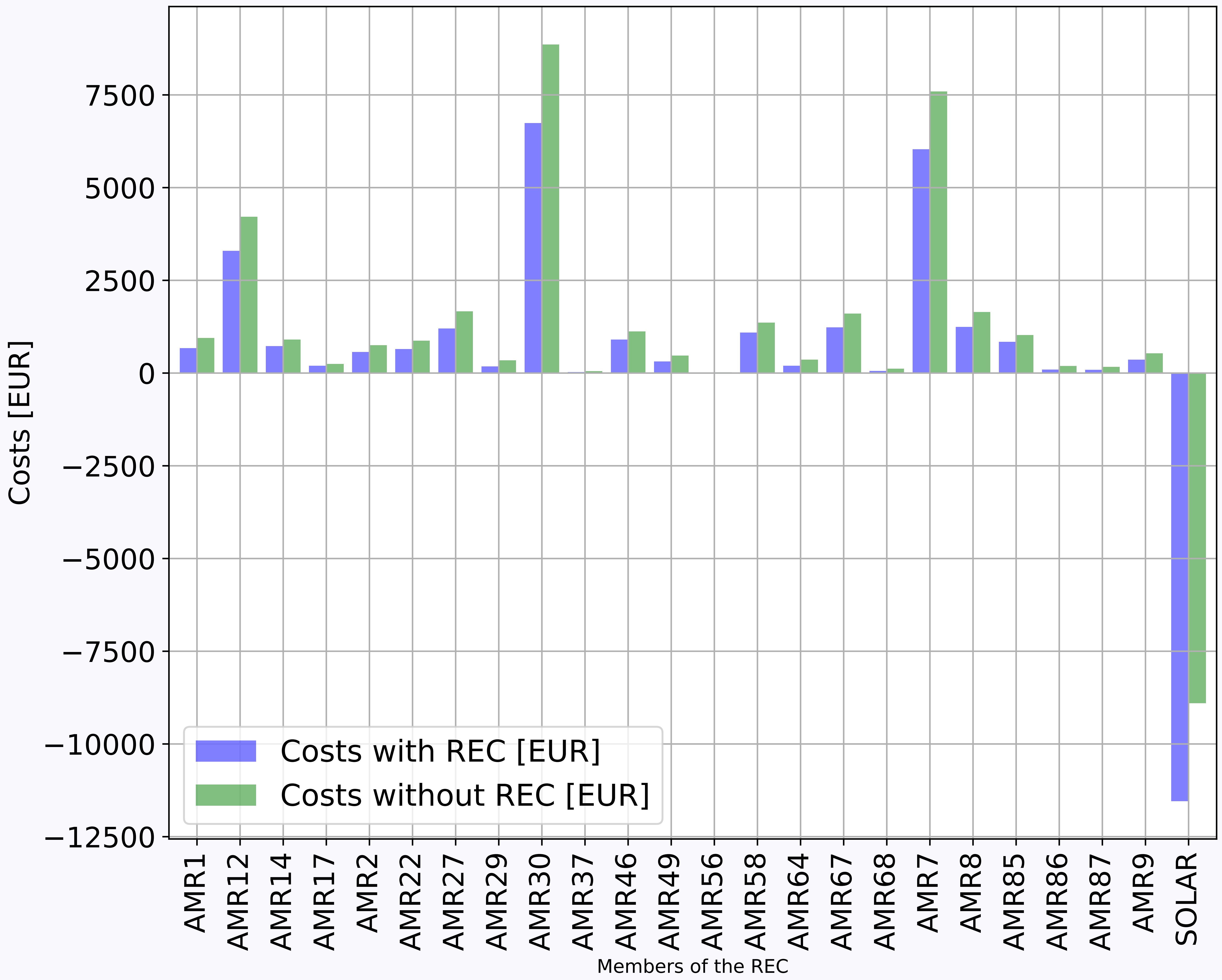
$$\sum_{i \in \mathcal{I}} a_{t,i} = \sum_{i \in \mathcal{I}} y_{t,i} \quad \forall t$$

The local sales are bounded by the total production whereas the allocated production is bounded by the total consumption:

$$y_{t,i} \leq P^n_{t,i} \quad \forall (t, i)$$

$$a_{t,i} \leq C^n_{t,i} \quad \forall (t, i)$$

Example - Cost analysis.



Moving toward real time.

- These examples show how **optimizing ex-post** the financial exchanges can lead to **economic benefits**.
- There is only so much this optimization can achieve, since –real– electricity flows are fixed.

A new **optimization layer** is needed where these **electricity flows are optimized in real time** (using for example storage devices), taking into account:

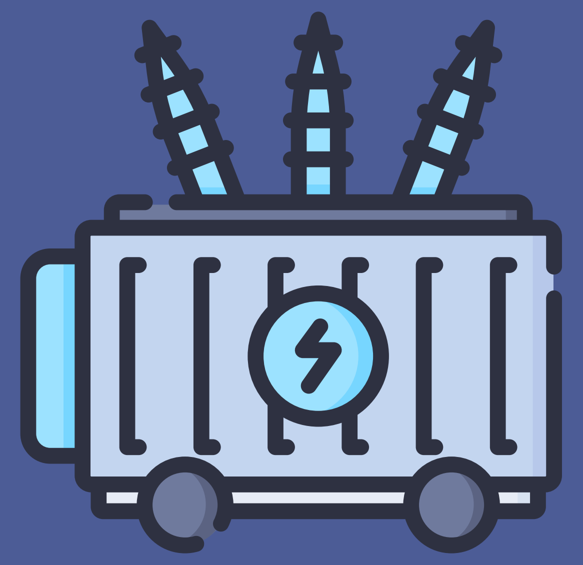
- The **intermittent** nature of renewable generation.
- The change in electricity prices (peak and off-peak).

In this new optimization layer, in addition to the **metering periods** for which we denote each time-step by t, we introduce **real-time periods**, for which each time-step is denoted by t'.

Introducing storage systems in RECs.

The **new optimization layer** can be built over the previous one, in a two-step process that:

- Optimizes in **real-time** the electricity flows.
- Optimizes **ex-post** the financial flows.

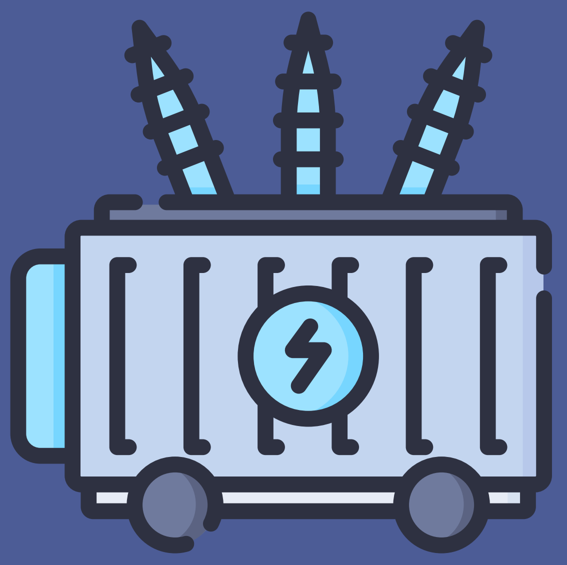


This approach benefits from the available body of work on **planning (electrical networks) under uncertainty**, as well as the newly brought concept of **repartition keys**.

As physical means for controlling in real-time the energy flows in the REC, we will consider storage devices:

- The local production that was inevitably injected into the grid can now be stored.
- There are greater opportunities for **matching supply** and demand within the REC.

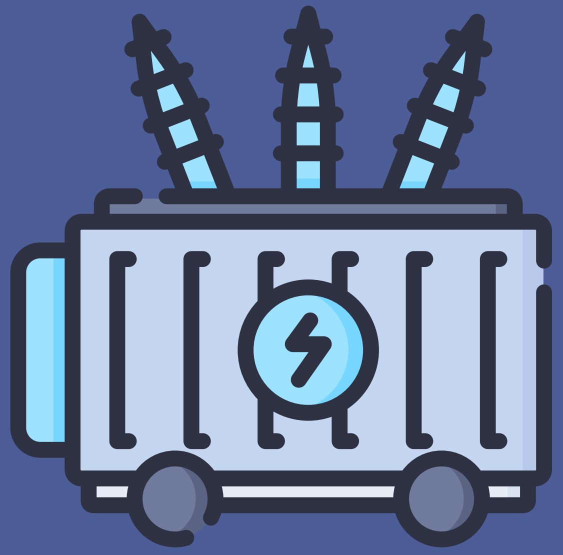
Dynamics of the battery.



For the sake of simplicity, a single battery is considered, whose dynamics is:

$$x_{t'+1} = x_{t'} + \delta_{t'} \left(\nu^{+} \cdot u_{t'}^{+} - \frac{u_{t'}^{-}}{\nu^{-}} \right) \quad \forall t'$$

- $x_{t'}$ and $x_{t'+1}$ represent the state of charge, measured at a fixed time rate (e.g., 1 minute).
- $u_{t'}^{+}$ and $u_{t'}^{-}$ represent the actions to control the energy flows into and out of battery, respectively.
- $\delta_{t'}$ is the time (in hours) between t' and $t'+1$.
- ν^{+}, ν^{-} represent the efficiency of charge and discharge of the battery, respectively.



Integration of batteries into RECs.

Let's consider that the battery corresponds to another REC member (the battery is behind its own meter):

- At each time-step t' the behavior of the battery is optimized in real time to either consume (by charging) or generate electricity (by discharging).
- Similarly, the behavior of the other REC's members is optimized at every t'.
- Then, at each time-step t', the meter readings of all REC's members (including the battery) are modified with the ex-post optimization.

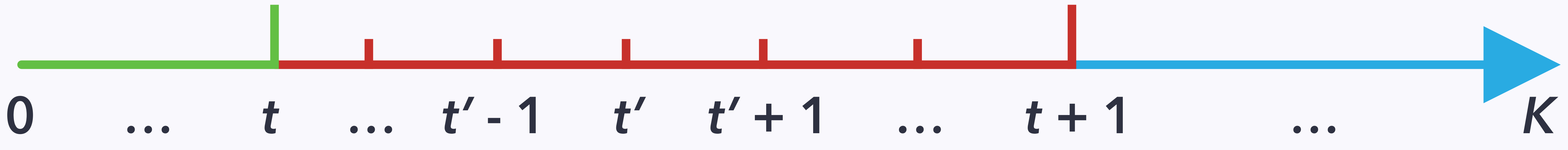
The battery can help decrease the sum of electricity bills of the REC's members:

- This requires a **control strategy** able to drive its decisions given the planning uncertainty control strategy to do so.

Control strategy.

A control strategy $cs\left(x_{t'}, e_{t'}\right)$ can be defined such that the values of $u_{t'}^{+}$ and $u_{t'}^{-}$ are computed given $x_{t'}$ and $e_{t'}$:

- $e_{t'}$ is a vector containing all the information about the community at time-step t' (e.g., price curves, or consumption and production profiles).

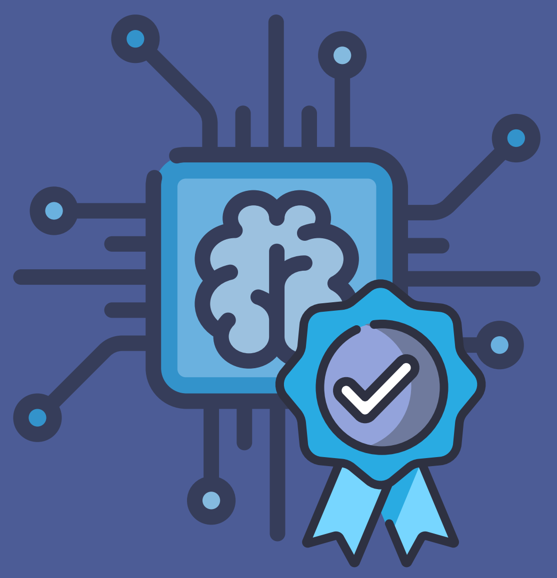


The time-steps t′ are a discretization of the tarification timespan K while the time steps t correspond to the metering periods.

The strategy $cs\left(x_{t'}, e_{t'}\right)$ can be applied for the time discretization described by the figure above, computing a sequence of states of charge $x_0, x_1, \ldots, x_K$:

- upon reaching *K* the vector $e_0, e_1, \ldots, e_K$ is known.

Quality of the control strategy.



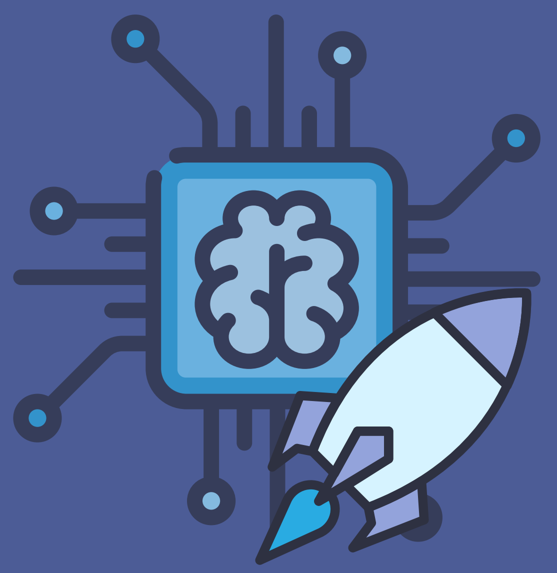
The quality of the control strategy is assessed by a function C as defined as:

$$C(x_0, \ldots, x_K, u_0^+, \ldots, u_K^+, u_0^-, \ldots u_K^-, e_0, \ldots, e_K) =$$

$$\sum_{t'=0}^{K} c_o(x_{t'}, u_{t'}^+, u_{t'}^-, e_{t'}) + \sum_{t \in M} c_m(x_t, \phi_t)$$

Where:

- c_o is a cost function representing the operational costs of the battery.
- c_m is a cost function representing the ex-post allocation of local production (i.e., the sum of billing costs of the REC's members B.
- M is the set of time-steps between 0 and K that correspond to metering periods.



Optimizing the control strategy.

A suitable (optimal) control strategy should minimize the total cost over a given time horizon – this control strategy, given by cs^* can be expressed as:

$$cs^* \in \arg\min_{cs} C(x_0^{cs}, \ldots, x_K^{cs}, u_0^{cs,+}, \ldots, u_K^{cs,+}, u_0^{cs,-}, \ldots u_K^{cs,-}, e_0, \ldots, e_K)$$

There is a caveat: this optimal strategy requires to know the information encapsulated in $e_{t'}$ in advance, which is not possible in realistic scenarios:

- To overcome this problem, forecasting techniques may be used to predict the vector $e_{t'}$, **recomputing** the control strategy at each time-step t'.

This approach is currently implemented and successfully running in a real REC case.

MeryGrid, a Real REC case.

Conclusion.

- A methodology for allocating **local electricity production** in the context of **RECs** is proposed.
- **Repartition keys** are used to dispatch this local production among the REC's members.
- A first **ex-post** approach is formulated to **optimize** the financial exchanges between the REC's members:
  - making use of real measurements of demand and production of the members, and,
  - modifying their meter readings.
- a **real-time control** strategy is added underneath the ex-post optimization:
  - bringing real-time control to the scheduling of the REC's members, and,
  - introducing batteries in this real-time control.

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Thank you !

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