Algorithms for the control and sizing of renewable energy communities

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Graph-Based Optimization Modelling Language

A modelling language geared towards the representation of linear programs

- involving the optimization of discrete time dynamical systems over a finite time horizon
- that exhibit a natural block structure that may be encoded by a sparse connected graph
- draws on a combination of concepts from both Algebraic Modelling Languages (AMLs) and Object-Oriented Modelling Languages (OOMLs)

AMLs

- Models are built with algebraic (linear) expressions involving parameters (known) and variables (unknown)

OOMLs

- Models are built with blocks that are assembled (connected)
- Blocks can be seen as nodes, and the connections as edges => Graph

Graph-Based Optimization Modelling Language (GBOML)

Optimization problem is a graph where nodes consist of a set of algebraic expressions involving parameters and variables and are connected by edges

Graph-Based Optimization Modelling Language

Each node consists of a set of variables, a set of constraints linking the variables, and an objective function, nodes are:

- *Generic* – a few classes of nodes can simulate a broad range of problems
- *Parametrised* – readily adapted to a particular problem by tuning hyper-parameters
- *Abstract* – represent technologies (e.g. generation, storage) or processes (e.g. energy conservation)

The edges connecting the links:

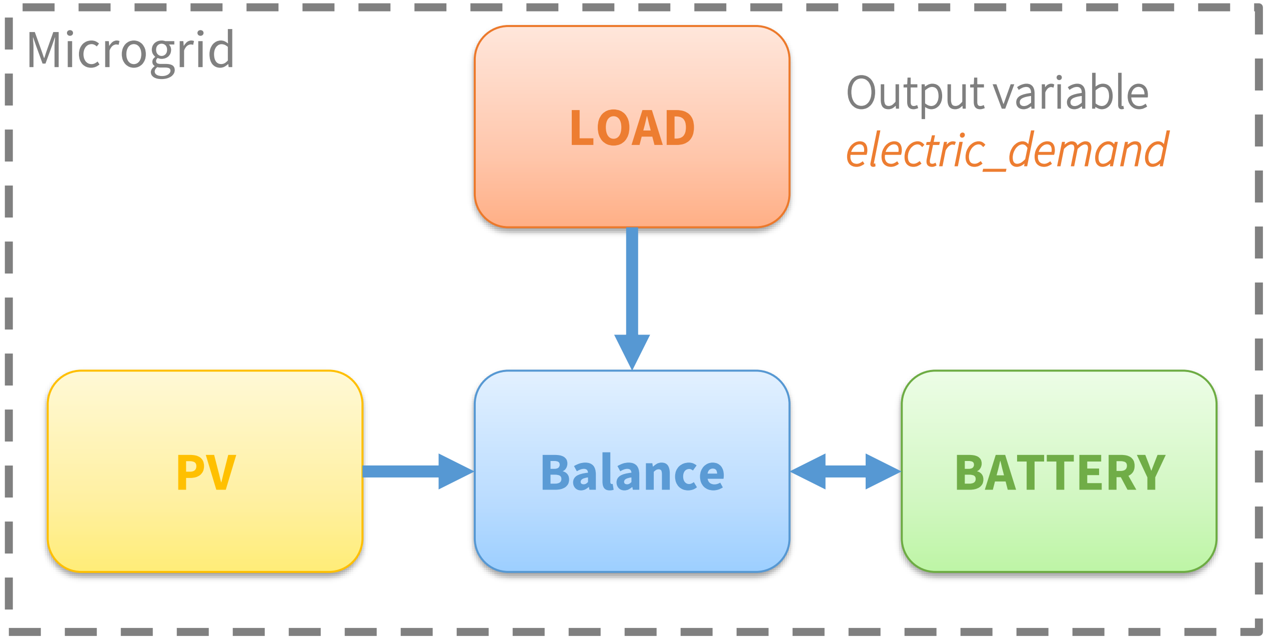
- Represent relationships between the nodes
- Link the output variables of one node to the input variables of another

Advantages of GBOML

- Models are built in a modular way and encoding them is easy
- Post-processing is simple (data stored in common formats)
- Possibility of using decomposition algorithms and specialized solvers to exploit the graph-based structure of the problem (faster solving)

Graph-Based Optimization Modelling Language

Illustrative example: **a microgrid**



Output variable
pv_output

Input variable
pv_generation
bat_discharge
bat_charge
demand

Output variable
bat_input
bat_output

Links

pv_output = *pv_generation*
bat_output = *bat_discharge*
bat_input = *bat_charge*
electric_demand = *demand*

Balance constraints

pv_generation + *bat_discharge*
==
bat_charge + *demand*

Problem of sizing energy systems

Energy systems can be represented by a set of nodes:

- they **represent technologies** (e.g. generation, storage) or **processes** (e.g. energy conservation)
- different energy systems can be **readily modelled** using a number of **generic nodes**
- they contain **variables representing quantities** (e.g. energy, money)
- **relationships** between technologies and processes are represented by **edges**

Optimal sizing of energy systems means determining:

- total **capacity of generation** (e.g. PV node) deployed in kWp
- total **capacity of storage** (e.g. battery node) deployed in kWh
- optimal **location** of these assets (which nodes)
- optimal **operation** of these assets (process nodes) over the lifetime of the system

Example of energy system – remote energy hub

Problem – feasibility assessment of the following process:

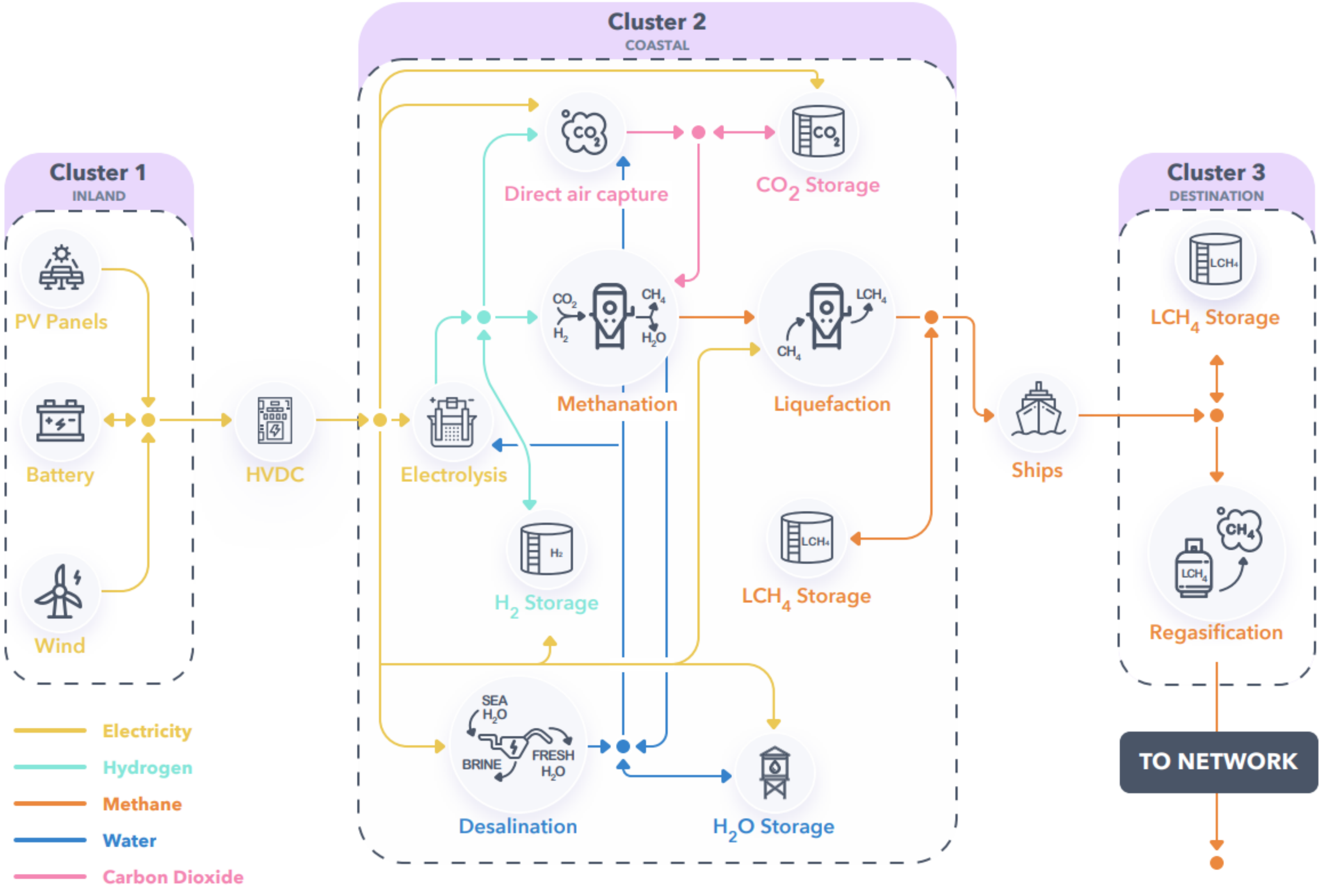
- Electricity generation in North Africa
- Synthesis of methane with this electricity and liquefaction
- Delivery and regasification in Europe.

The entire supply chain is modelled and optimised in an integrated fashion over a time horizon of one year with hourly resolution

Objective

- **Determine optimal capacities** of all the technologies involved
- **Minimise total system cost** (CAPEX & OPEX) over the lifetime of the project

Example of energy system – remote energy hub



Example of energy system – remote energy hub

Results

- Different scenarios are studied
- Cost of synthetic methane in Europe is calculated as the ratio of total (annualised) system cost to 100 TWh HHV (higher heating value) of methane volume delivered (per year)

Generation technology	Investment funding	Cost of methane
PV panels only	From capital markets at 7% WACC	199.0 EUR/MWh
Hybrid wind and PV	From capital markets at 7% WACC	148.5 EUR/MWh
PV panels only	Zero financing costs	124.4 EUR/MWh
Hybrid wind and PV	Zero financing costs	87.4 EUR/MWh

Problem of sizing RECs

Several assumptions are inherent to the sizing problem of RECs

- *Central planning & Operation* – a central planner, the ECM, decides on the investment decisions and operates the system
- *Perfect foresight* – future demand and production of the REC members are known
- *One-off investment* – investments in generation or storage are made at the beginning of the time horizon only
- *Operational decisions* – the operational decisions (e.g. charge/discharge) are made every hour

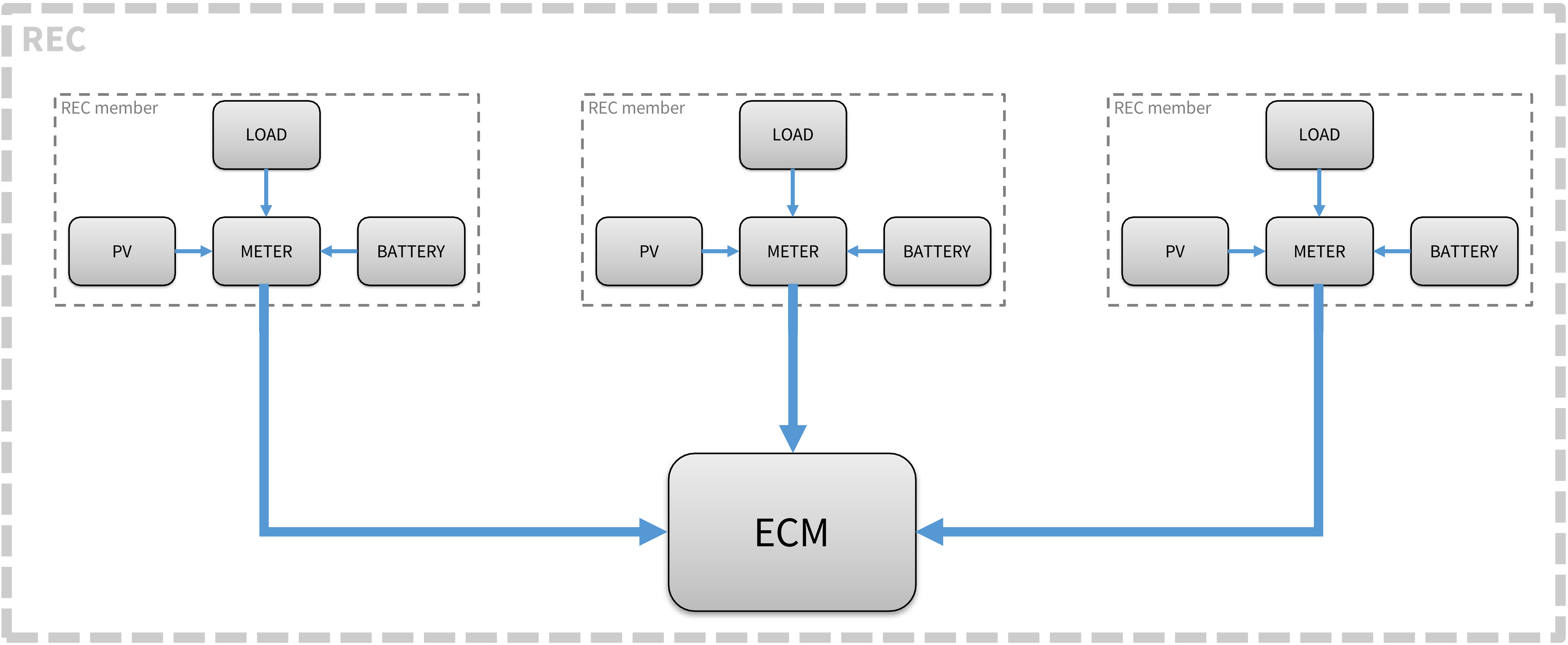
Required inputs:

- load profiles of REC members;
- solar irradiation data;
- electricity prices of the REC members (retailer tariffs);
- electricity prices inside the REC (including margin for the ECM).

Objective – maximisation of the net present value (NPV) of the REC

Output – optimal sizing configuration (PV & battery deployment) for each REC member

Problem of sizing RECs



Energy management system for RECs

Goal of the energy management system (EMS)

- Automatically **control the REC** in real-time (controllable assets such as batteries or sheddable loads) so as to minimise the sum of the electricity bills
- Help the ECM **distribute the local production** (electricity generated by REC members) among the REC members ***ex-post*** (decision making solution)

How local production is distributed

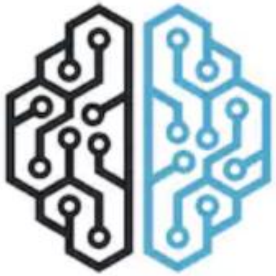
- **Repartition keys –** represent the proportion of total local generation allocated to each REC member
- **Optimised after physical delivery** of electricity (***ex-post***)

Energy management system for RECs

Optimal Repartition keys

Request computation of repartition keys

ECM



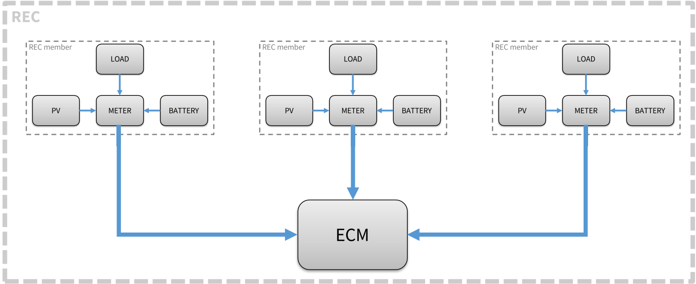
EMS

Retrieves measurements:

- *PV production*
- *State of charge*
- *Electricity demand*
- *…*

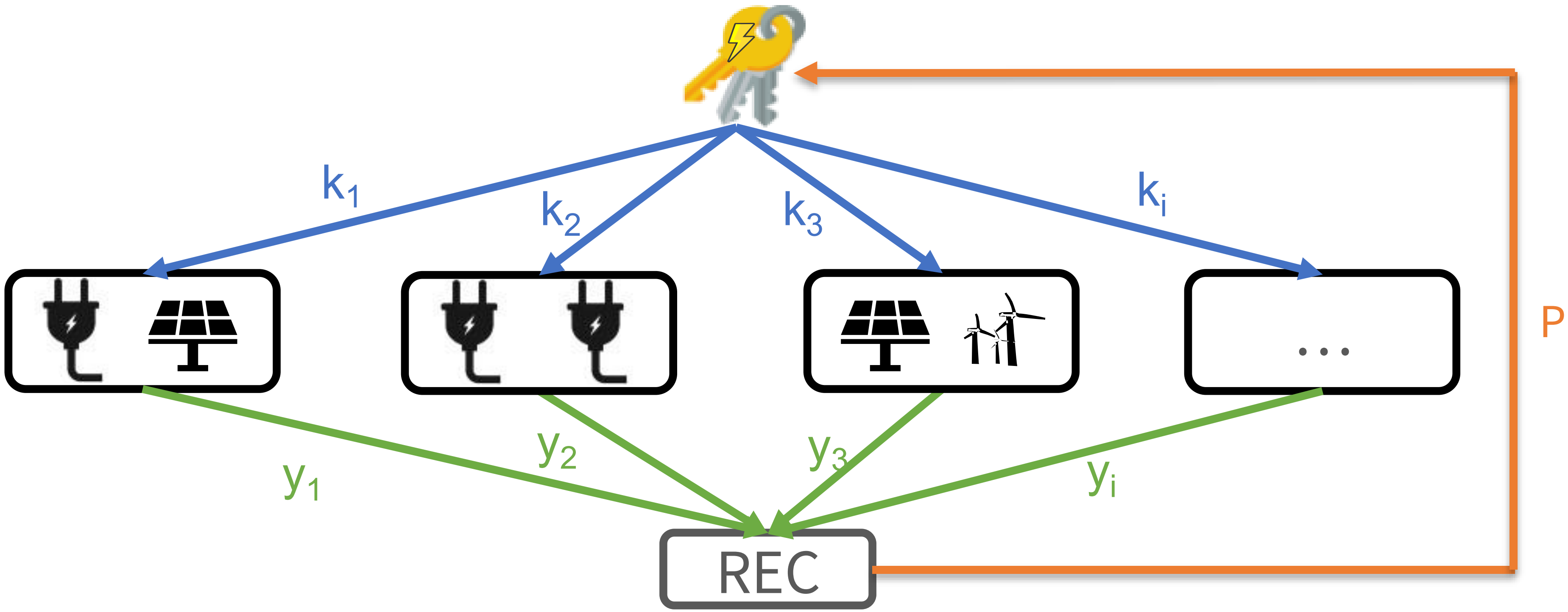
Send control actions:

- *Battery charge*
- *Battery discharge*
- *Shed load*
- *…*



REC

Repartition keys – concept



- P is the total electricity production
- y_i is the local production sold by REC member *i*
- k_i is the proportion of total local production allocated to REC member *i*

Repartition keys – optimisation

Objective

- Minimisation of the sum of electricity bills of the REC members

$$B = \sum_{i=1}^{I} \left[\xi_i^b \cdot (C_i^n - a_i) + \xi_i^{l-} \cdot a_i - \xi_i^{l+} \cdot y_i - \xi_i^s \cdot (P_i^n - y_i) \right]$$

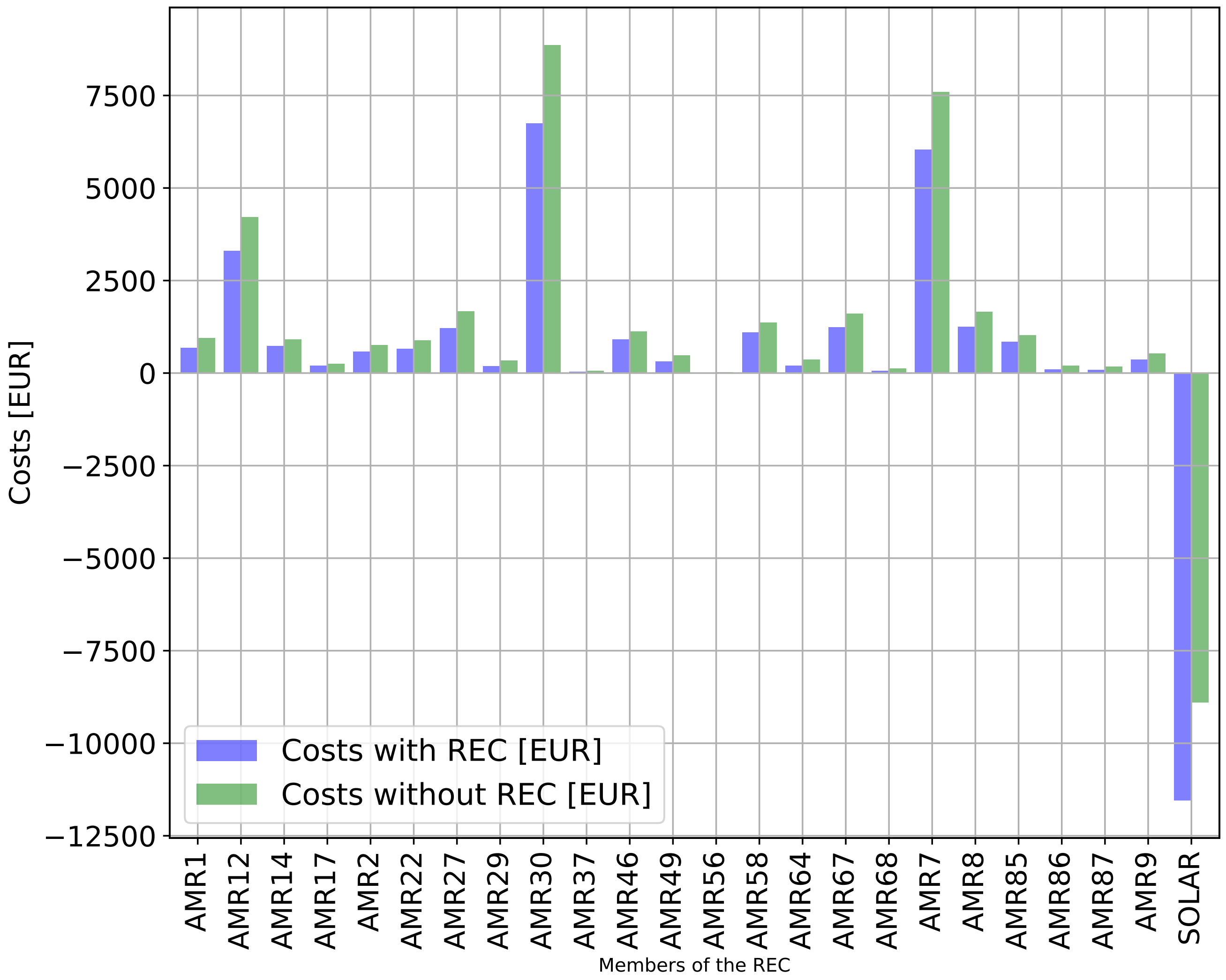
Grid import price | *Initial net consumption* | *Allocated production* | *Local import price* | *Local export price* | *Local sales* | *Grid export price* | *Initial net production*

Constraints

- Repartition keys
- Energy balance

$$a_i = k_i \cdot \sum_{i \in \mathcal{I}} P_i^n \qquad \sum_{i \in \mathcal{I}} a_i = \sum_{i \in \mathcal{I}} y_i \qquad y_i \leq P_i^n \qquad a_i \leq C_i^n$$

Repartition keys – results

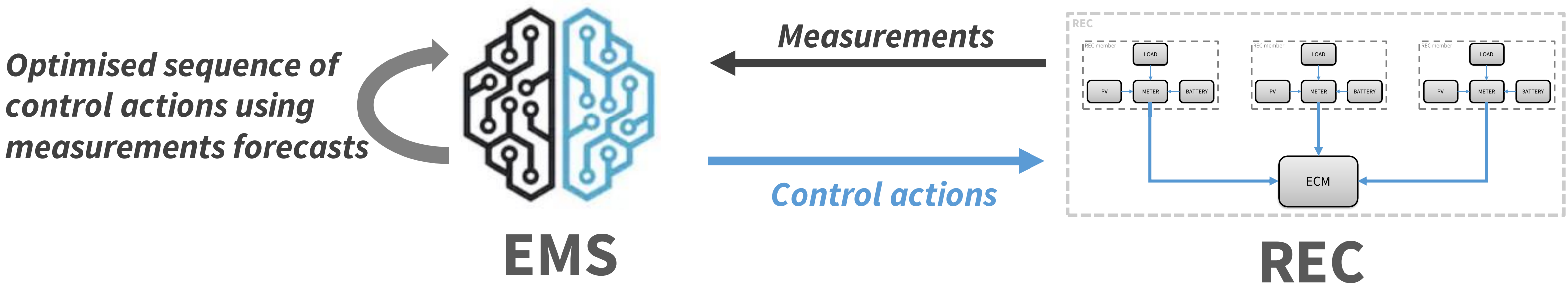


- Community with 24 REC members:
  - 23 net consumers
  - 1 net producer
- One year of operation

Computing **optimal repartition keys** for optimising the **financial exchanges** within an REC can induce **substantial savings** (up to 50% cost reduction for some members)

REC optimal control

Joint optimisation of the controllable assets (e.g. batteries, sheddable or flexible loads) and the repartition keys – algorithm based on model predictive control and artificial intelligence



- At each time step we solve an open-loop problem along predicted scenarios for the consumption and the production of each member.
- We compute a sequence of commands to minimise the sum of the electricity bills of the REC members
- Scenarios of production and consumption are predicted using artificial intelligence techniques (deep learning).
- Results show that it is important to simultaneously optimise the controllable assets and the repartitions keys

Related works

[1] Manuel de Villena, Miguel; Mathieu, Sébastien; Vermeulen, Eric; Ernst, Damien. "*Allocation of locally generated electricity in renewable energy communities*". Link: http://hdl.handle.net/2268/250878

[2] Aittahar, Samy; Manuel de Villena, Miguel; Castronovo, Michael; Boukas, Ioannis; Gemine, Quentin; Ernst, Damien. "*Towards the online planning and local production allocation for renewable energy communities with batteries*". Link: Working paper

[3] Berger, Mathias; Bolland, Adrien; Miftari, Bardhyl; Djelassi, Hatim; Ernst, Damien. "*Graph-Based Optimization Modeling Language: A Tutorial*". Link: http://hdl.handle.net/2268/256705

[4] Berger, Mathias; Radu, David; Detienne, Ghislain; Deschuyteneer, Thierry; Richel, Aurore; Ernst, Damien. "*Remote renewable hubs for carbon-neutral synthetic fuel production*". Link: http://hdl.handle.net/2268/250796