Microgrids

Community microgrids

ELEN0445-1

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Version 4

Versions

- Version 1: November 22, 2017
- Version 2: November 22, 2017
- Version 3: November 23, 2017
- Version 4: November 15, 2018

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Introduction

Previous lectures

In previous lectures, we have learned about microgrids components, goals, how to operate them taking into account a time coupling induced by storage.

We made the hypothesis the microgrid is operated by a single (legal) entity.

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In this lecture

- What if several entities group to form a community microgrid?
- How should decisions be taken to ensure entities will trust the way they were computed, and implement them?
- How to share the profit generated by clustering several entities?
- What about fairness?

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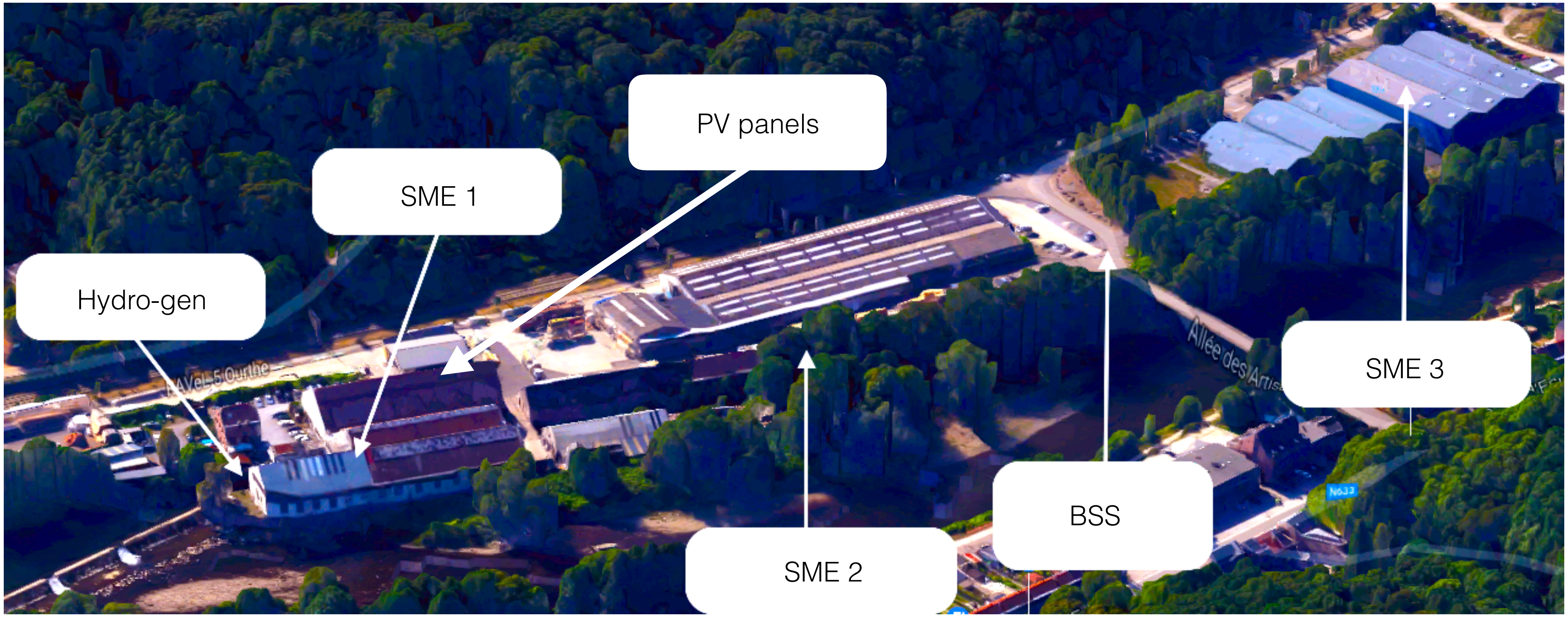
The MeryGrid project and the EMS we are developing



With the support of the Wallon Government, in collaboration with Nethys, CE+T, Sirris, MeryTherm, SPI

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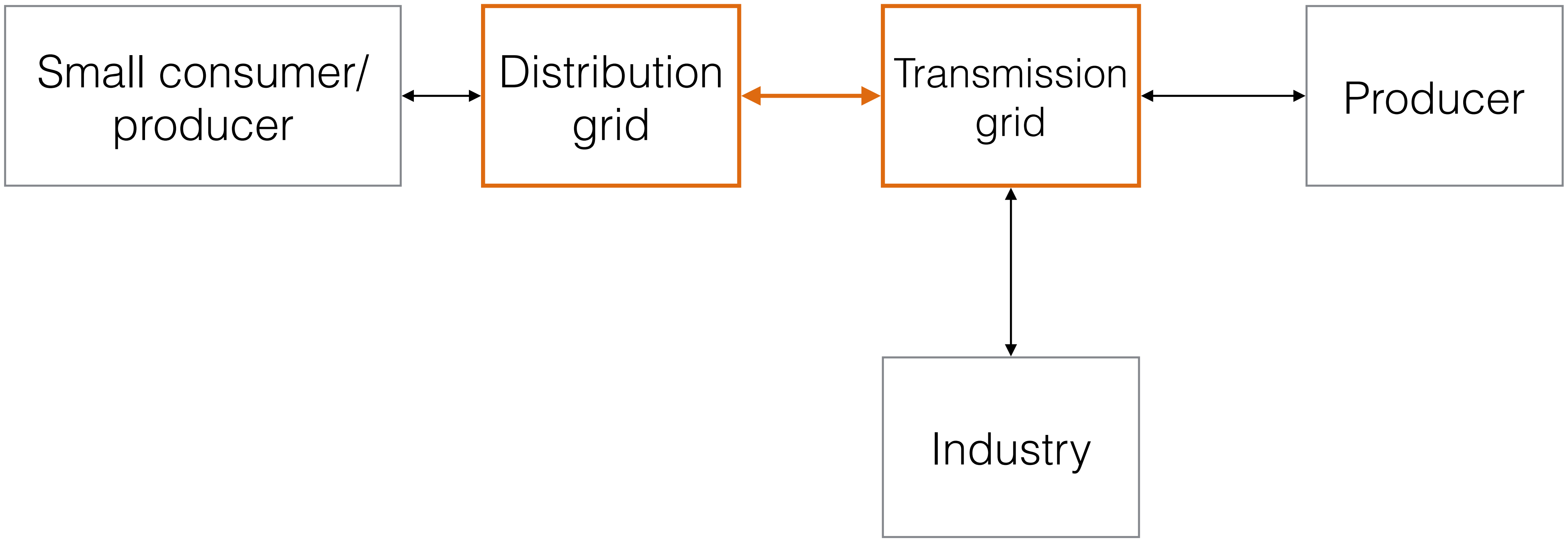
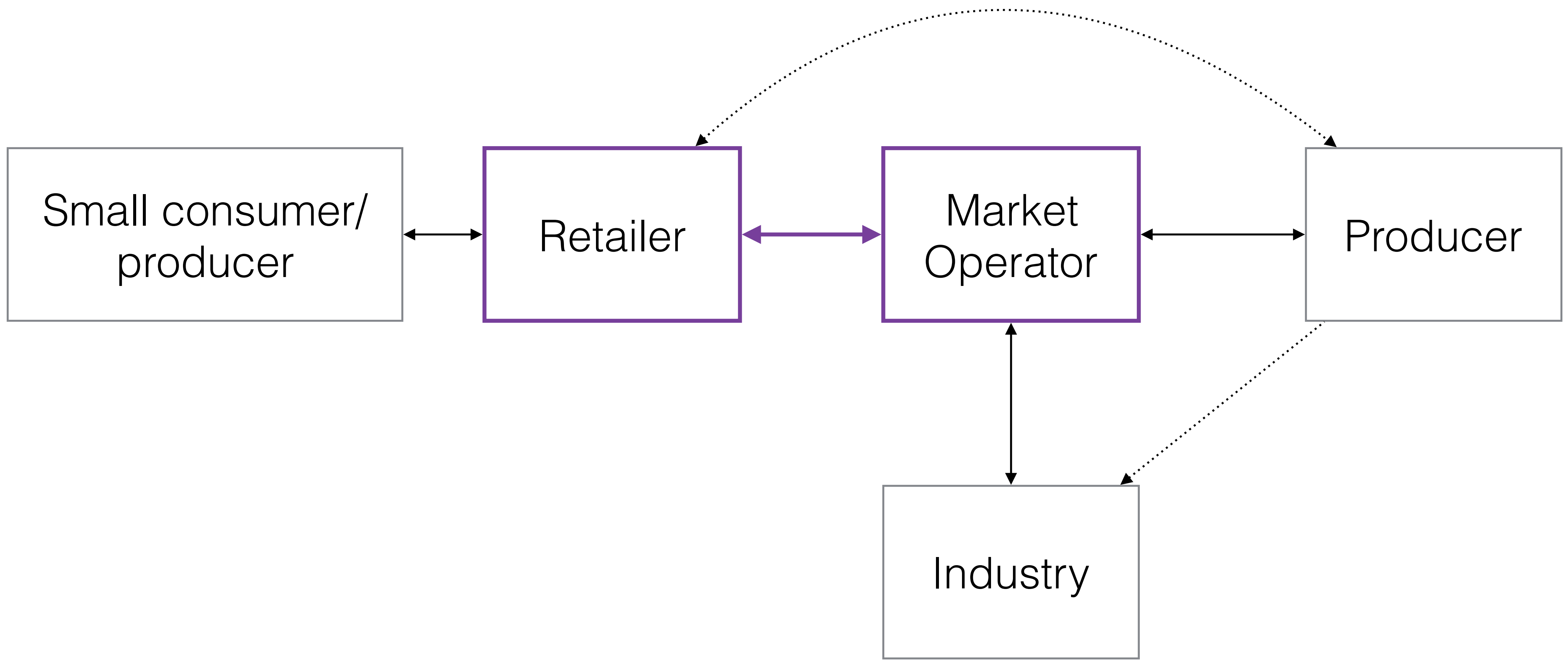
Energy exchanges - physical standpoint



Energy exchanges - Financial standpoint



The invoice

- Consumption
  - Wholesale energy price + retailer margin
  - Distribution
  - Transmission
  - green certificates contribution
  - Taxes

- Production
  - Residential
    - Net-metering
    - Nothing more if P > C
  - Industry
    - Wholesale price - retailer margin

+ subsidies

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Agenda

- Definitions
- Solutions
- Simulations

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Definitions

Single-user microgrid

A “single-user” microgrid is composed of consumer devices, generating devices, and energy storage.

It is grid-tied.

It is operated according to the policy of its entity.

Example from the merygrid project : MeryTherm, or MeryBois, or CBV, or the BSS.

Community microgrid

A community microgrid is composed of several single-user microgrids plus an operator.

The goal of the operator is to minimize the cost of energy consumed, maximize revenue from the sale of energy and services, and manage relationships between community members.

Example : MeryGrid

Note: no connection between network configuration and community configuration => "virtual" microgrid

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Component models

The **devices consuming electricity** fall in three categories: non-flexible demand must be satisfied, hence can be seen as demand at maximum price; flexible demand must be satisfied as well but is specified as an amount of energy to be dispatched over the planning horizon; sheddable demand is not at maximum price and can be partially shed.

On the **generation** side, devices fall in two categories: steerable generation, e.g. diesel generator, with a known fuel cost, rated power and efficiency, and non-steerable generation which is zero marginal cost but causes a loss of subsidy if curtailed.

Storage devices are characterized by a rated power, energy capacity, charge and discharge efficiencies.

The electrical network connecting the entities is not modeled.

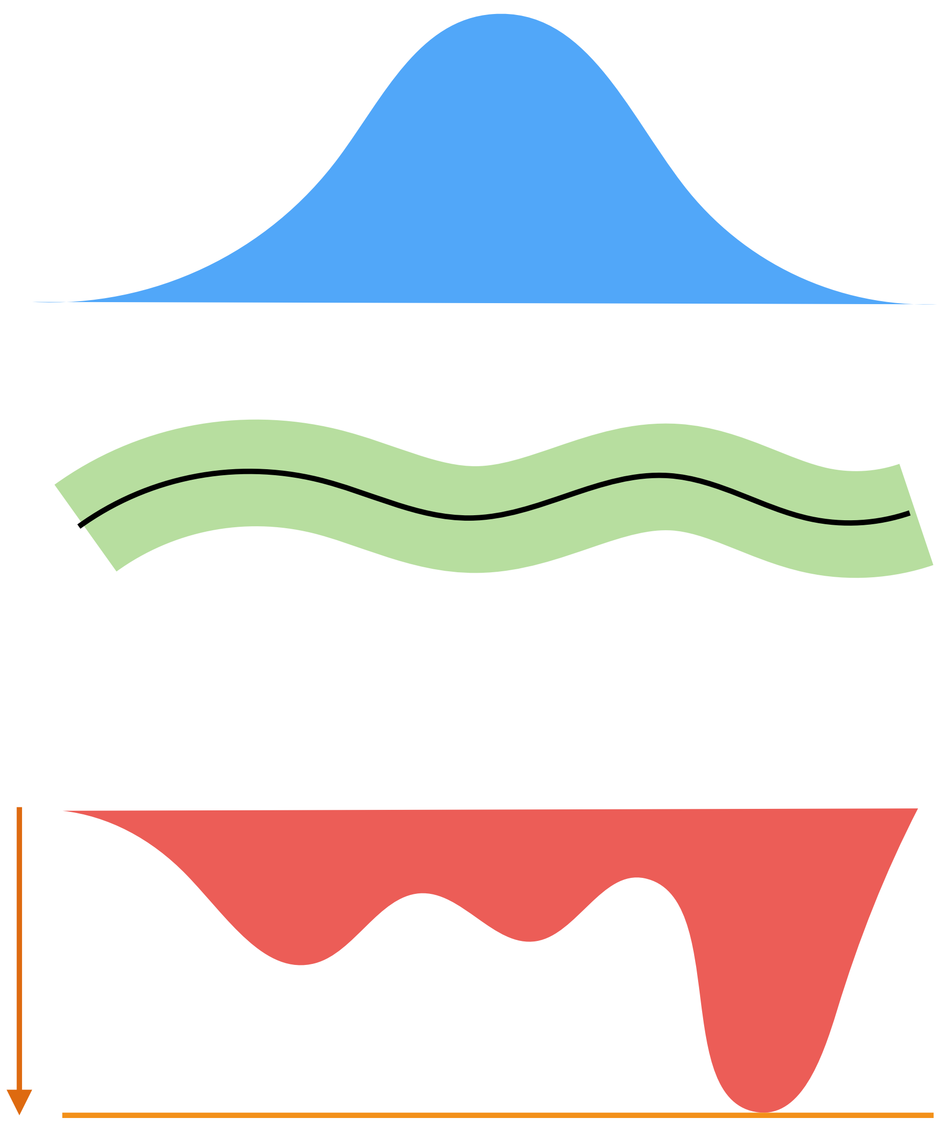
Single-user model

In summary, each single-user microgrid can contain

- non-flexible consumption
- flexible consumption (amount of energy)
- sheddable consumption (quantity, cost)
- flexible generation (e.g. diesel generator)
- non-flexible generation (e.g. PV)
- storage (with some efficiency)

Costs and revenues

- Revenues
  - Energy generation
  - Ancillary services
- Costs
  - Energy consumption
  - Peak



Time horizon

This presentation considers only the operational planning stage: one day in advance, according to a series of forecasts, operational planning plans the use of storage systems and the flexibility of demand and production.

Other horizons to consider: investment, real time, ex post (settlement) => see conclusion

Reminder: benefits of a single-user microgrid

Optimized management

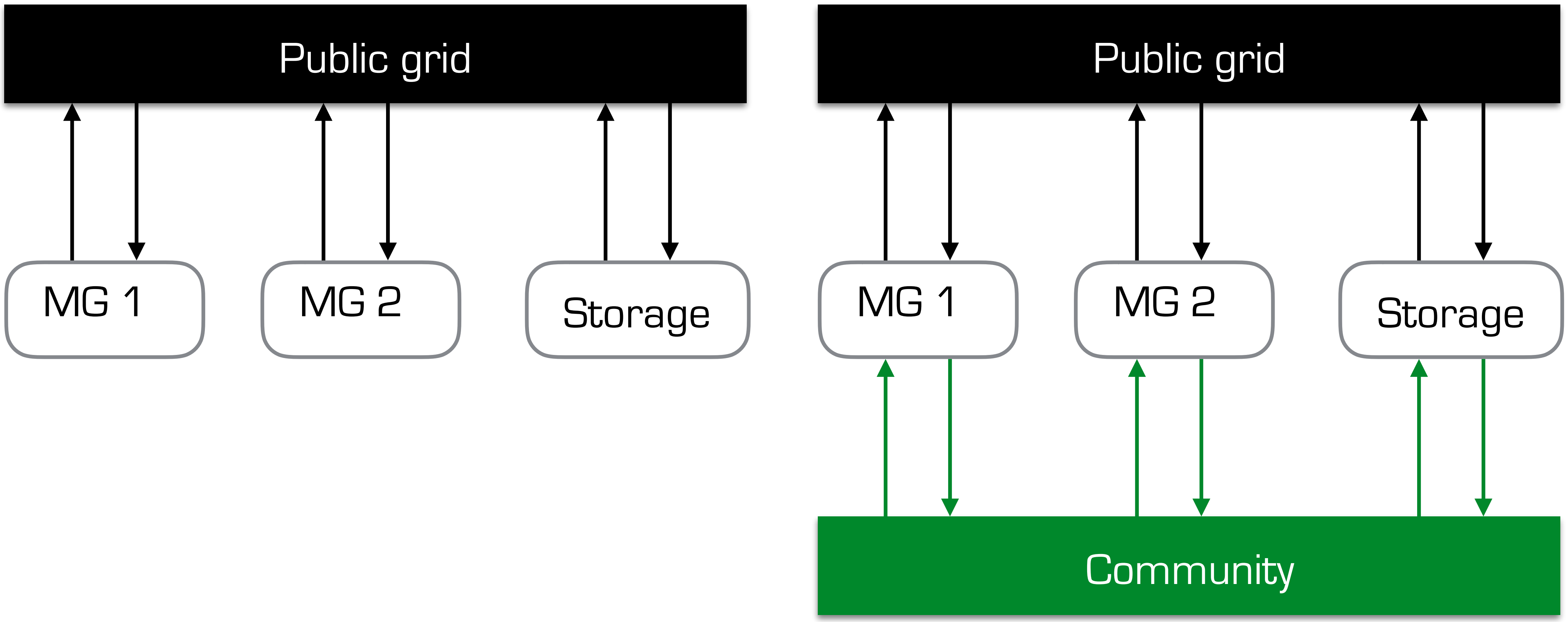
- of generation
- of consumption
- of storage
- of the reserve (ancillary service)
- of the peak (penalty)

Interests of the Community microgrid

In addition to the advantages of the simple microgrid:

- an exchange of energy at a better price than with the public network
- a group effect
  - peak
  - reserve

Single-user vs community



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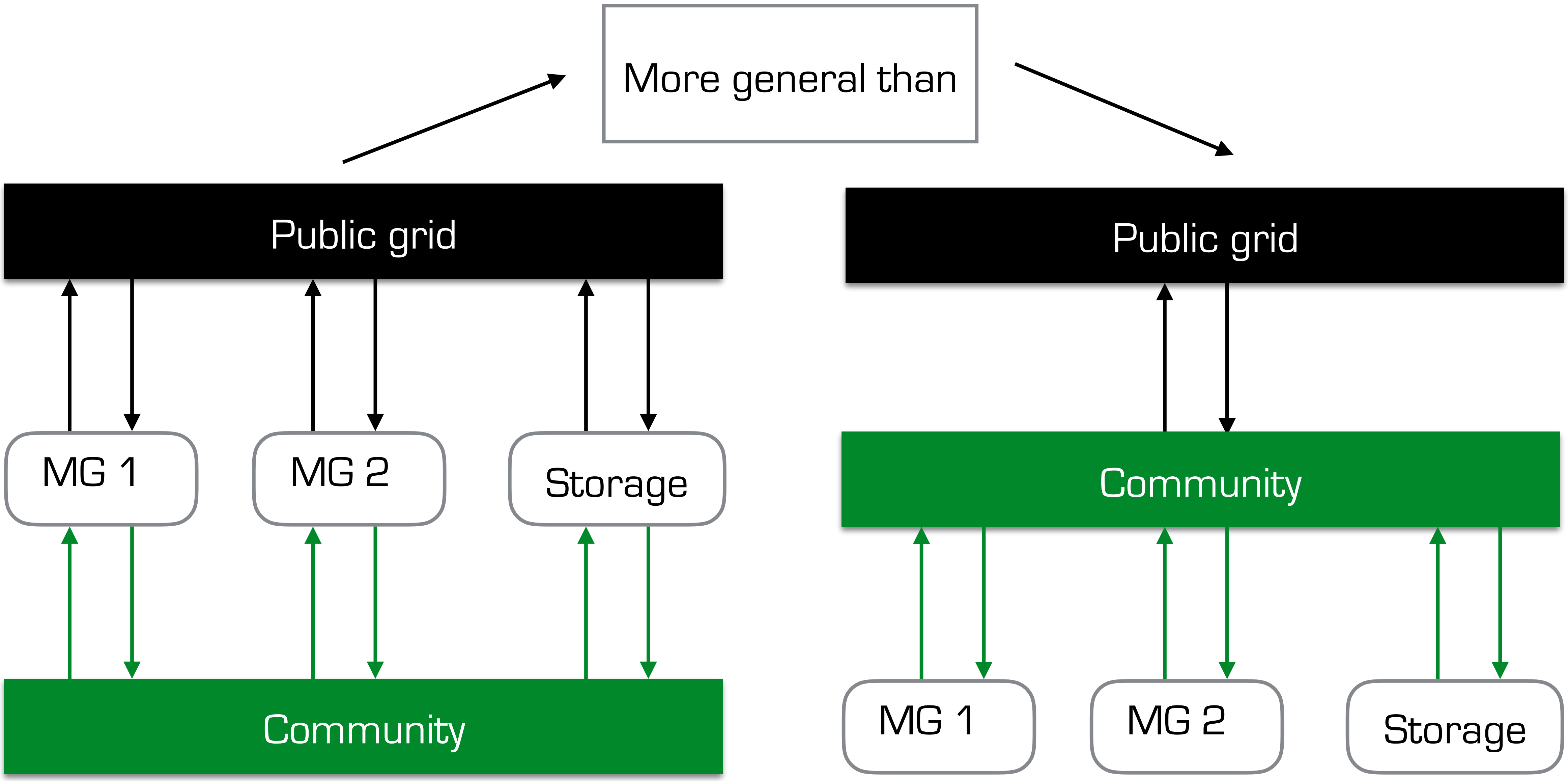
Remark


More general than
Public grid
MG 1
MG 2
Storage
Community
Public grid
Community
MG 1
MG 2
Storage

Questions

- We know how to manage a simple microgrid!
- How to
  - optimize the functioning of the community microgrid?
  - make sure members follow the plan?
  - ensure a fair distribution of the gain?
- Underlying issues:
  - how to pay for flexibility?
  - how to remunerate the operator?

Solutions

Approach

This is formulated as a bilevel optimization problem

- Low level: (variables y)
  - determination of the quantities exchanged, stored, produced, consumed
  - dual constraints => price
  - strong duality constraint
  - linear
- High level: (variables x)
  - sharing rules
  - minimum profit constraint => non-linear

$$\max_{x \in \mathcal{X}} F(x, y^*)$$
$$\text{s.t.} \quad y^* = \arg\max_{y \in \mathcal{Y}} f(y; x)$$

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Special features

- A tariff for the use of storage according to the quantities of energy stored / discharged from storage
- A tariff for the use of the community per kWh imported and exported
- No explicit constraints to avoid simultaneous charging / discharging, simultaneous import/export
  - => Non-linear or MIP
- But systematic verification a posteriori

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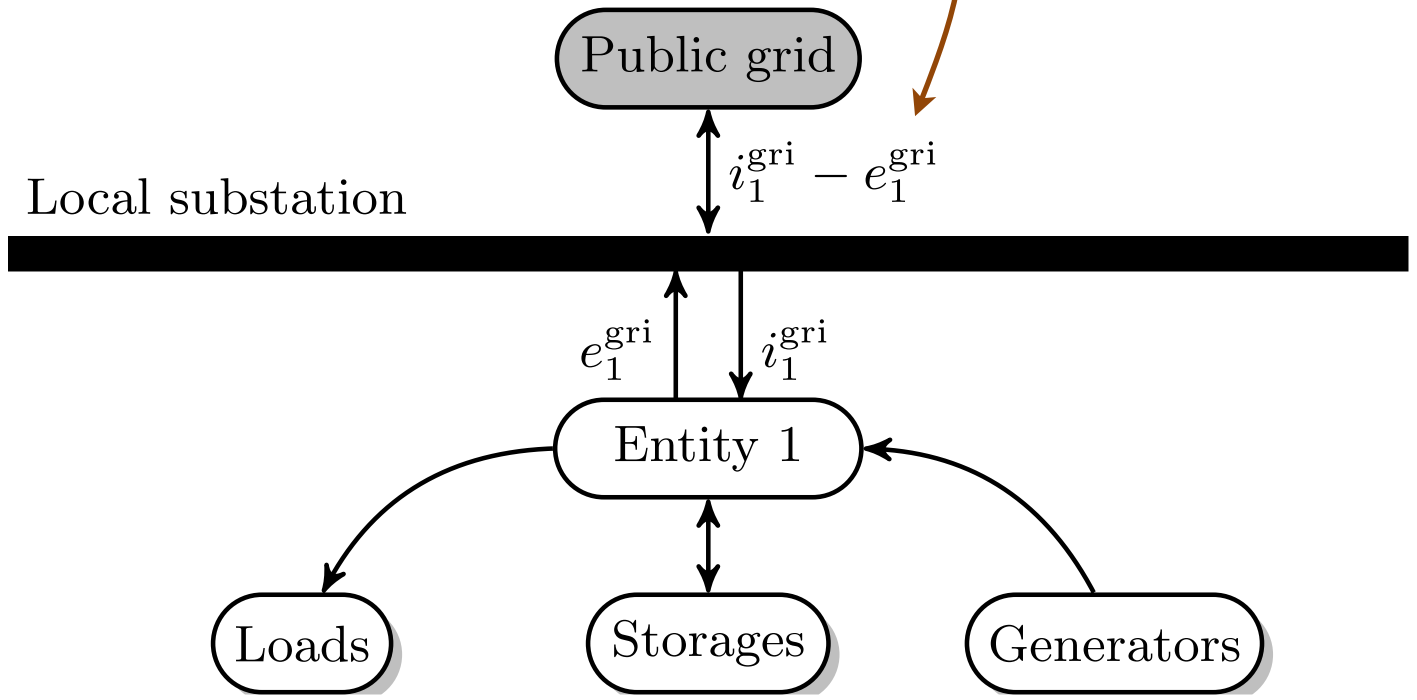
Single user model

Single user model

Peak penalty applied on



Single user model - objective function

$$\max J_u^{\text{SU}} = J_u^{\text{SU, energy}} + J_u^{\text{SU, reserve}} + J_u^{\text{SU, peak}} \tag{4.1}$$
$$\text{s.t. } (4.2) \text{ to } (4.35)$$

- u denotes a user, or entity
- SU denotes something related to the single user

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Single user model - energy exchange with grid

Energy exchanges with the public grid are modeled by two variables by time step by entity:

- $i_{u,t}^{\text{grid}}$ is the quantity of energy imported from the grid at a price $\pi_{u,t}^{\text{purchase}}$, which is either known or forecast.
- $e_{u,t}^{\text{grid}}$ is the quantity of energy exported to the grid at a price $\pi_{u,t}^{\text{sale}}$, which is either known or forecast.

$$e_{u,t}^{\text{grid}} - i_{u,t}^{\text{grid}} = \Delta_t \left(p_{u,t}^{\text{net}} + \sum_{b \in \mathscr{B}_u^{\text{assist}}} \left(\underline{P}_b a_{b,t}^{discharge} - \overline{P}_b a_{b,t}^{charge} \right) \right) \forall t \in \mathscr{T} \tag{4.2}$$

The variables of the right hand side are defined below.

- t denotes a time period
- Delta t denotes a period duration

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Single user model - generation

The overall power generated during period t by entity u is modeled by the variable $p_{u,t}^{\text{prod}}$.

$$p_{u,t}^{\text{prod}} = \sum_{d \in \mathscr{D}_u^{\text{non steerable}}} (1 - a_{d,t}^{\text{curt}}) P_{d,t}^{\text{fatal}} + \sum_{d \in \mathscr{D}_u^{\text{steerable}}} a_d^{\text{steer}} P_{d,t}^{\text{steerable}} \tag{4.3}$$

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Single user model - consumption

The overall power consumed during period t by entity u is modeled by the variable $p_{u,t}^{\text{prod}}$.

$$
\begin{aligned}
p_{u,t}^{\text{cons}} = & \sum_{d \in \mathscr{D}_u^{\text{T,nonflexible}}} C_{d,t}^{\text{fatal}} \\
& + \sum_{d \in \mathscr{D}_u^{\text{sheddable}}} (1 - a_{d,t}^{\text{shed}}) C_{d,t}^{\text{sheddable}} \\
& + \sum_{d \in \mathscr{D}_u^{\text{flexible}}} c_{d,t}^{\text{flex}}
\end{aligned}
\tag{4.4}
$$

- Skipping constraints defining flexible loads.

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Single user model - storage

$$s_{b,t} = \Delta_t \eta_b^{\text{retention}} s_{b,t-1} + \Delta_t \left(\overline{P}_b \eta_b^{\text{charge}} a_{b,t}^{charge} - \underline{P}_b / \eta_b^{\text{discharge}} a_{b,t}^{discharge} \right) \quad \forall t \in \mathscr{T} \tag{4.13}$$

$$s_{b,0} = S_b^{\text{init}} \tag{4.14}$$

$$\underline{S}_b^{\text{end}} \leq s_{b,T} \leq \overline{S}_b^{\text{end}} \tag{4.15}$$

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Single user model - energy related objective

$$J_u^{\text{SU, energy}} = -\sum_t \Big(\pi^{\text{curtailment}} P_u^{\text{fatal}} \Delta_t a_{u,t}^{\text{curt}} + \pi^{\text{shedding}} C_{u,t}^{\text{sheddable}} \Delta_t a_{u,t}^{\text{shed}}$$

$$+ \pi^{\text{fuel}} P_u^{\text{steerable}} \Delta_t a_{u,t}^{\text{steer}} - \pi_t^{\text{sale}} e_{u,t}^{\text{grid}} + \pi_t^{\text{purchase}} i_{u,t}^{\text{grid}} \Big) \tag{4.32}$$

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Single user model - Reserve

We make the arbitrary choice that only symmetrical reserve)available for all the planning horizon is valorized (cf. Figure 4.2).

First, two variables are introduced per time step and per entity:

- $r^{\text{inc}}_{u,t}$ is the amount of generation increase or consumption decrease available
- $r^{\text{dec}}_{u,t}$ is the amount of generation decrease or consumption increase available

Both are expressed in power units.

$$
\begin{aligned}
r^{\text{inc}}_{u,t} = & \sum_{b \in \mathscr{B}_u} \left(\overline{S}_b - s_{b,t}\right)/\Delta_t \\
& + \sum_{d \in \mathscr{D}^{\text{steerable}}_u} P^{\text{steerable}}_d \left(1 - a^{\text{steer}}_{d,t}\right) \\
& + \sum_{d \in \mathscr{D}^{\text{sheddable}}_u} C^{\text{sheddable}}_{d,t} \left(1 - a^{\text{shed}}_{u,t}\right)
\end{aligned} \tag{4.25}
$$

$$
\begin{aligned}
r^{\text{dec}}_{u,t} = & \sum_{b \in \mathscr{B}_u} \left(s_{b,t} - \underline{S}_b\right)/\Delta_t \\
& + \sum_{d \in \mathscr{D}^{\text{steerable}}_u} P^{\text{steerable}}_u a^{\text{steer}}_{u,t} \\
& + \sum_{d \in \mathscr{D}^{\text{sheddable}}_u} C^{\text{sheddable}}_{u,t} a^{\text{shed}}_{u,t}
\end{aligned} \tag{4.26}
$$

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Single user model - Reserve

The overall amount of reserve available for the considered planning horizon is modeled by variables r_u^{inc} and r_u^{dec} for upward and downward reserve, respectively:

$$r_u^{\text{inc}} \leq r_{u,t}^{\text{inc}} \quad \forall t \in \mathscr{T} \tag{4.27}$$

$$r_u^{\text{dec}} \leq r_{u,t}^{\text{dec}} \quad \forall t \in \mathscr{T} \tag{4.28}$$

Finally, the amount of **symmetrical** reserve available for the considered planning horizon is modeled by variable r_u^{sym}:

$$r_u^{\text{sym}} \leq r_u^{\text{inc}} \tag{4.29}$$

$$r_u^{\text{sym}} \leq r_u^{\text{dec}} \tag{4.30}$$

which defines the profit generated by the reserve provision.

$$J_u^{\text{SU, reserve}} = \pi^{\text{reserve}} r_u^{\text{sym}} \tag{4.31}$$

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Single user model - peak

The peak penalty is applied as follows, as it is currently applied within the RESA network. The net withdrawal of the microgrid is measured on a 15 minutes basis. Every month, the maximum net withdrawal over the last 12 months is recorded. It is then penalized at a price per kVA and invoiced on a per month basis. This is not obvious to model in a day-ahead planning context since the penalty applies over a much longer time horizon. Let $\overline{p}_u^{\text{past}}$ be the peak recorded over the last 12 months, $\overline{p}_u$ be the peak arising from operational planning, and

$$\delta\overline{p}_u = \max\{0, (\overline{p}_u - \overline{p}_u^{\text{past}})\}.$$

The penalty incurred is $\pi_u^{\text{peak}}\delta\overline{p}_u$. However, this penalty should be scaled down to the planning horizon, and the benefit of the raised peak for the coming days should also be accounted for. We assume this is modeled by a discount parameter γ^{peak}.

$$i_{u,t}^{\text{grid}}/\Delta_t \leq \overline{p}_u \ \forall t \in \mathcal{T} \tag{4.33}$$

$$\left(\overline{p}_u - \overline{p}_u^{\text{past}}\right) \leq \delta\overline{p}_u \tag{4.34}$$

$$J_u^{\text{SU, peak}} = -\gamma^{\text{peak}}\pi^{\text{peak}}\delta\overline{p}_u \tag{4.35}$$

R This last value should be estimated from simulations over several scenarios or any other mean, but this is out of the scope of this section.

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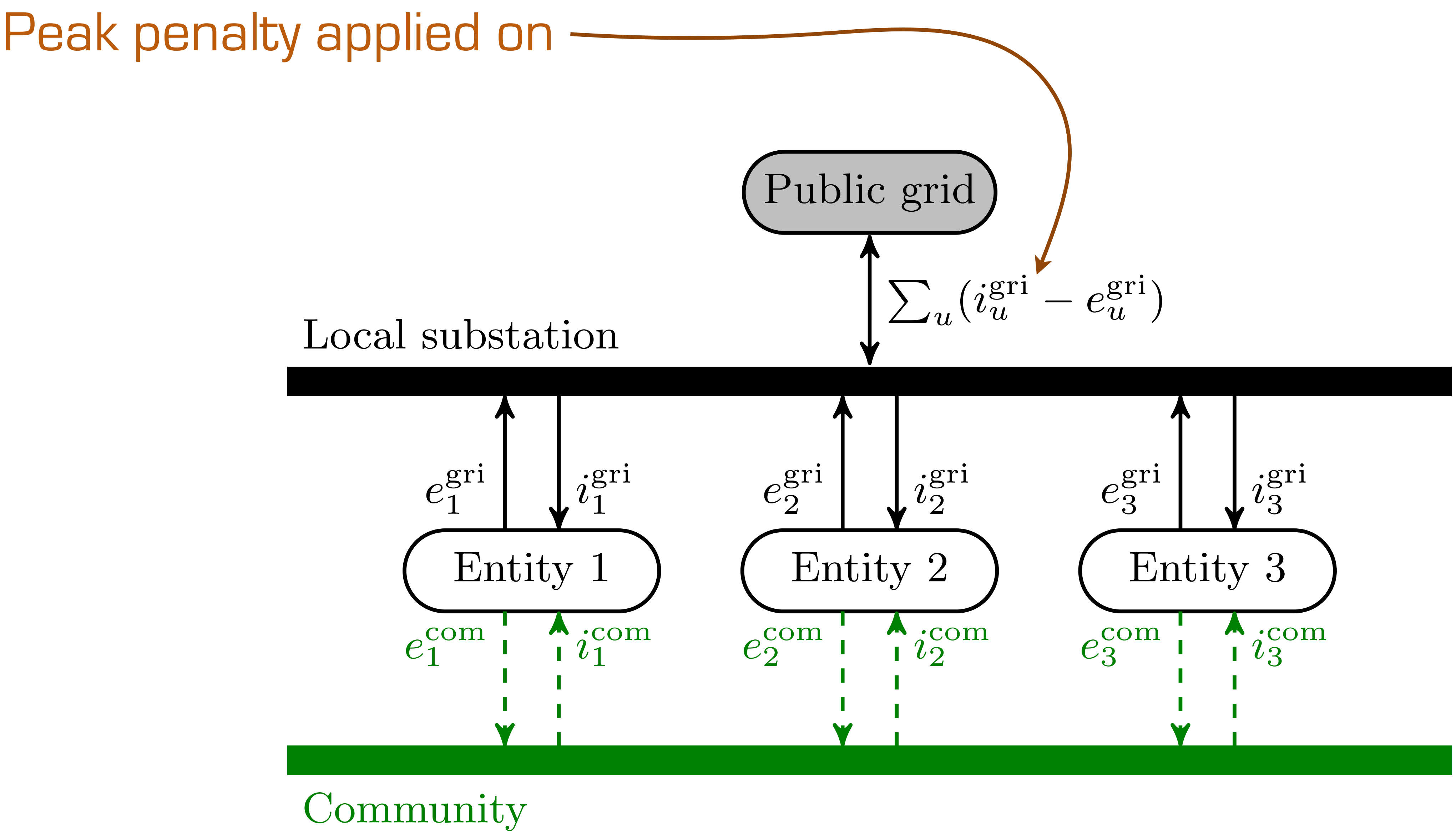
Community model

Community model



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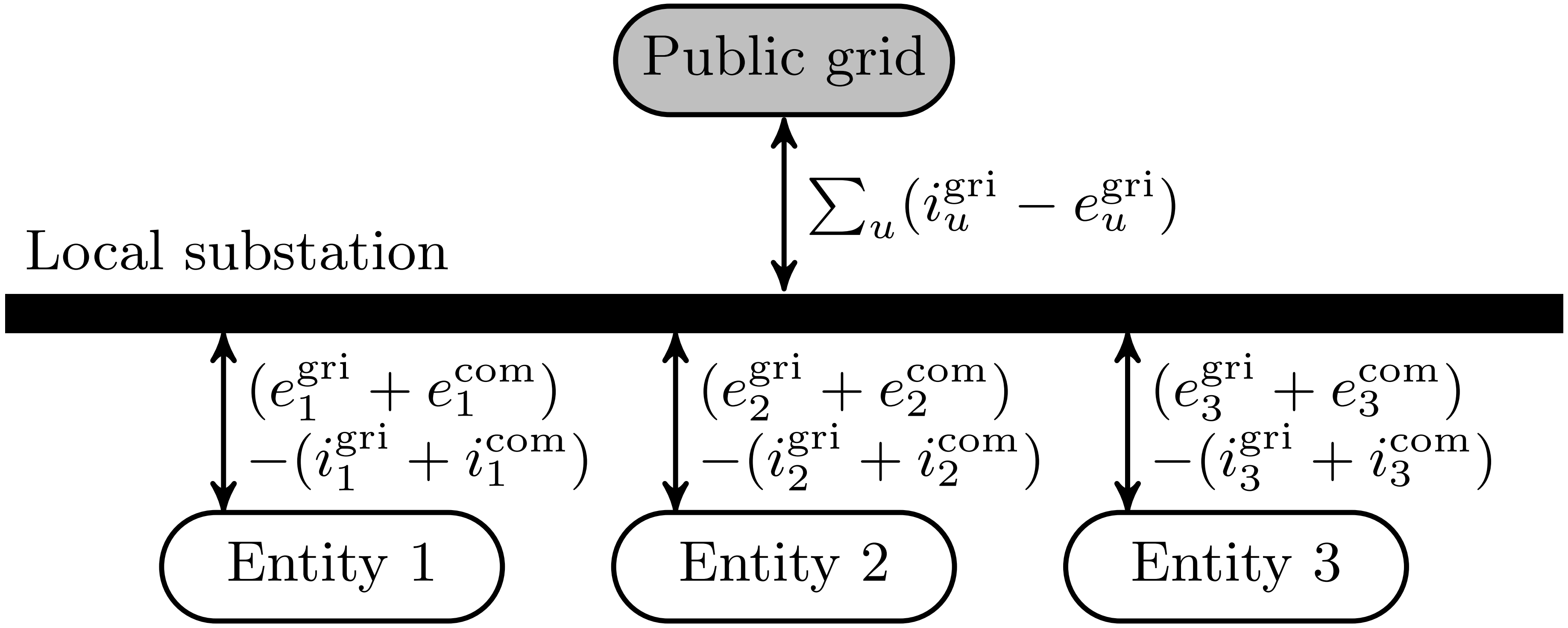
Remark: Physical flows



Principles

- Each member of the community can decide, at any time, to exchange either with the network or with the community (or both)
  - Everyone can keep their suppliers
  - no simultaneous import-export
- Each member provides its information to the operator, and in return sees the community price, its participation at the peak, and its participation in the reserve
- The microgrid operator must send corrected data to the market: incoming and outgoing flows, 15' by 15', without the remaining flows in the community

Local market architecture

- Formulation as a problem that simultaneously determines
  - “dispatch" decisions -> charging / discharging the battery, providing flexibility, limiting the peak, etc.
  - the prices
  - the distribution of profit between entities => sharing rules
  - under minimum profit constraint (an actor cannot lose money if he is in community compared to his isolated situation)

Sharing rules known “a priori”

- Internal energy exchange at a fixed price, chosen at any time within a predefined range
- Determination of the impact on the peak of each actor
- Determination of the contribution to the reserve of each actor

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Sharing rules principle

Table 1: A priori profit sharing principles.

1. The objective function is separable by entity

$$J^{\mathrm{MU}}(\cdot) = \sum_{u} J_u^{\mathrm{MU}}(\cdot).$$

2. Each cost or revenue stream is quantified.
3. The problem remains linear, or at least convex.
4. No entity suffers a profit degradation with respect to its selfish profit: $J_u^{\mathrm{MU}} \geq J_u^{\star,\mathrm{SU}}$.

Pareto superior condition

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Sharing rules

$$r_u^{\text{sym}} \leq \frac{1}{2}\left(r_{u,t}^{\text{dec}} + r_{u,t}^{\text{inc}}\right) \qquad \forall u \in \mathcal{U}, \forall t \in \mathcal{T} \qquad (7)$$

$$r^{\text{sym}} = \sum_{u \in \mathcal{U}} r_u^{\text{sym}} \qquad (8)$$

$$J_u^{\text{reserve}} = \pi^{\text{res}} r_u^{\text{sym}} \qquad \forall u \in \mathcal{U} \qquad (9)$$

$$\overline{p} = \sum_{u \in \mathcal{U}} \overline{p}_u \qquad (10)$$

$$J_u^{\text{peak}} = -\pi_u^{\text{peak}} \overline{p}_u \qquad \forall u \in \mathcal{U} \qquad (11)$$

$$\begin{aligned} J_u^{\text{energy}} = \\ = -\sum_{t \in \mathcal{T}} \Bigg(& \sum_{d \in \mathcal{D}_u^{\text{ste}}} \pi_{d,t}^{\text{ste}} P_{d,t}^{\text{ste}} \Delta_t a_{d,t}^{\text{ste}} + \sum_{d \in \mathcal{D}_u^{\text{she}}} \pi_{d,t}^{\text{she}} C_{d,t}^{\text{she}} \Delta_t a_{d,t}^{\text{she}} \\ & - \pi_t^{\text{egr}} e_{u,t}^{\text{gri}} + \pi_t^{\text{igr}} i_{u,t}^{\text{gri}} \\ & + \sum_{d \in \mathcal{D}_u^{sto}} \gamma_d^{\text{sto}} \Delta_t \left(\overline{P}_d \eta_d^{\text{cha}} a_{d,t}^{\text{cha}} + \underline{P}_d / \eta_d^{\text{dis}} a_{d,t}^{\text{dis}}\right) \Bigg) \\ + \sum_{t \in \mathcal{T}} & \pi_{u,t}^{\text{com}} \left(e_{u,t}^{\text{com}} - i_{u,t}^{\text{com}}\right) \qquad \forall u \in \mathcal{U} \qquad (12) \end{aligned}$$

$$J_u = J_u^{\text{energy}} + J_u^{\text{reserve}} + J_u^{\text{peak}} \geq J_u^{*,\text{SU}} \qquad \forall u \in \mathcal{U} \qquad (13)$$

Réserve

Pointe

Energie

Total

About fairness

- "Freedom of envy" : everyone treated equally
- "Efficiency" : optimal solutions are used
- "Accountability" : more effort, more gain
- "Altruism" : if a member has no interest in degrading the profit of another member (e.g. to increase his profit directly), he should not

Phulpin, Y., Begovic, M., Petit, M., & Ernst, D. (2009). **A fair method for centralized optimization of multi-TSO power systems**. International Journal of Electrical Power and Energy Systems, 31(9), 482–488.

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Simulations

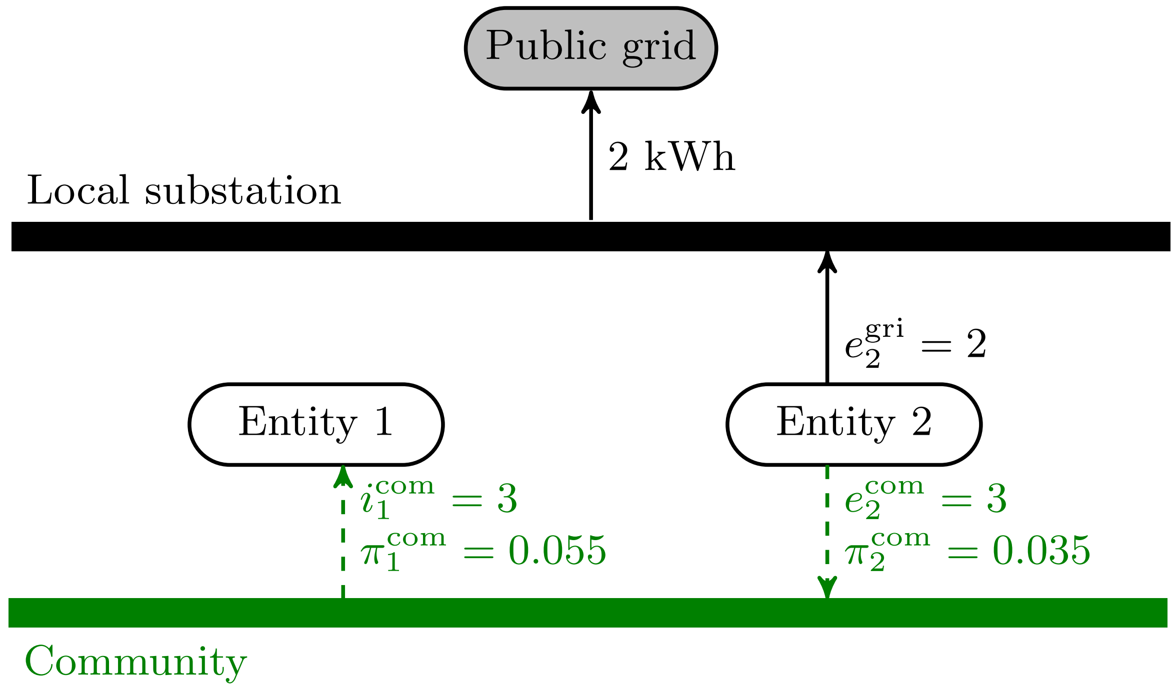
Exemple 1: 2 entities

Entity 1 consumes 3 kWh (non-flexible)

Entité 2 produces 5 kWh (PV)

Entity	Com	1	2
J	0.01	-0.165	0.175
J^{SU}	-0.725	-0.9	0.175
J^{energy}	-0.01	0.165	-0.175
$J^{\text{SU, energy}}$	0.275	0.45	-0.175
J^{peak}	0.0	0.0	0.0
$J^{\text{SU, peak}}$	0.45	0.45	0.0

(b) Summary of costs and profits



- Excess production => low com price (external market sell price)
- Operator margin

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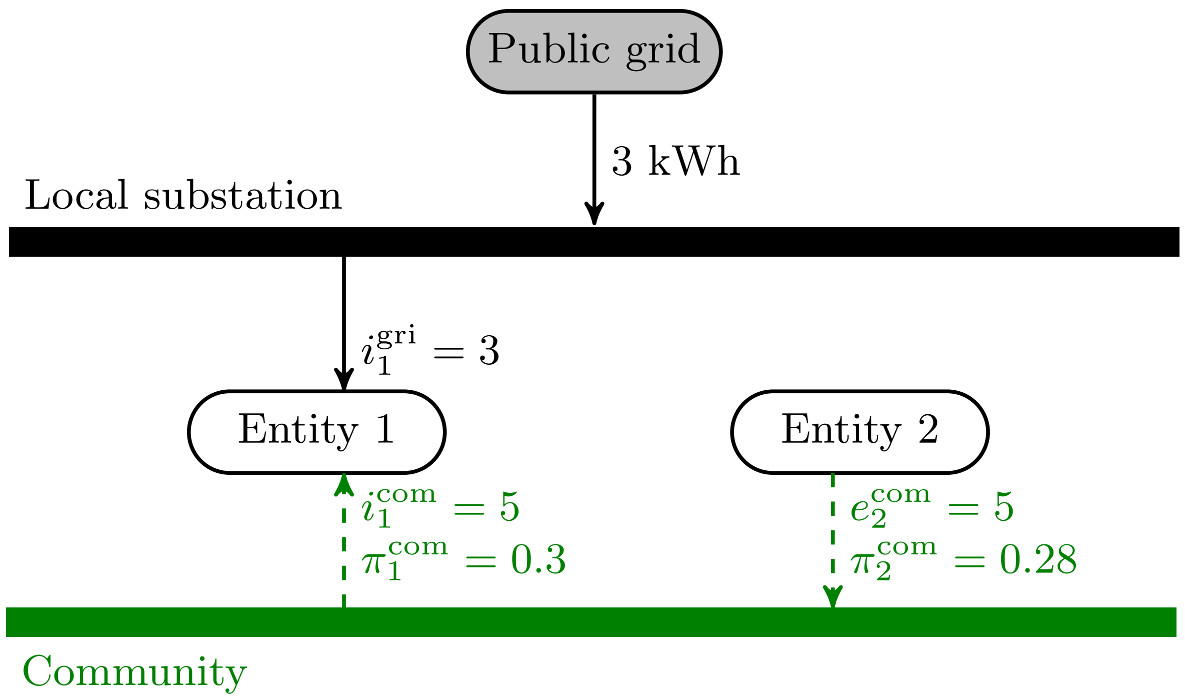
Exemple 2 : 2 entities

Entity 1 consumes 5 kWh (non-flexible)

Entité 2 produces 3 kWh (PV)

Entity	Com	1	2
J	-1.0	-1.95	0.95
J^{SU}	-2.225	-2.4	0.175
J^{energy}	0.55	1.95	-1.4
$J^{\text{SU, energy}}$	1.025	1.2	-0.175
J^{peak}	0.45	0.0	0.45
$J^{\text{SU, peak}}$	1.2	1.2	0.0

(b) Summary of costs and profits



- Excess consumption => high com price(= external market price + peak price)
- Operator margin

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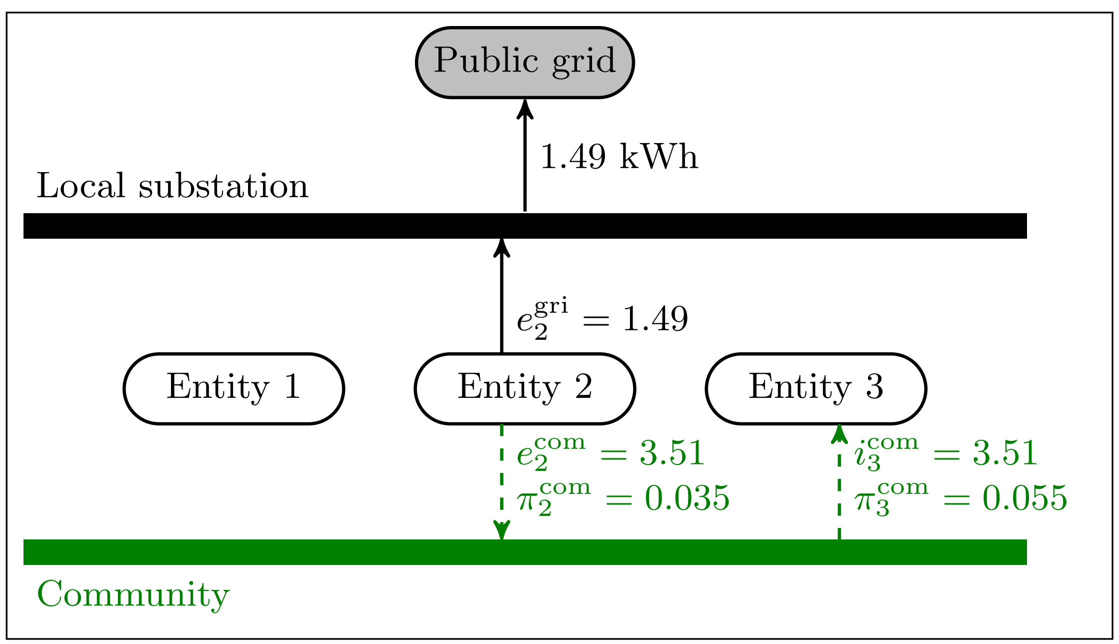
Exemple 3 : stockage, 3 entités

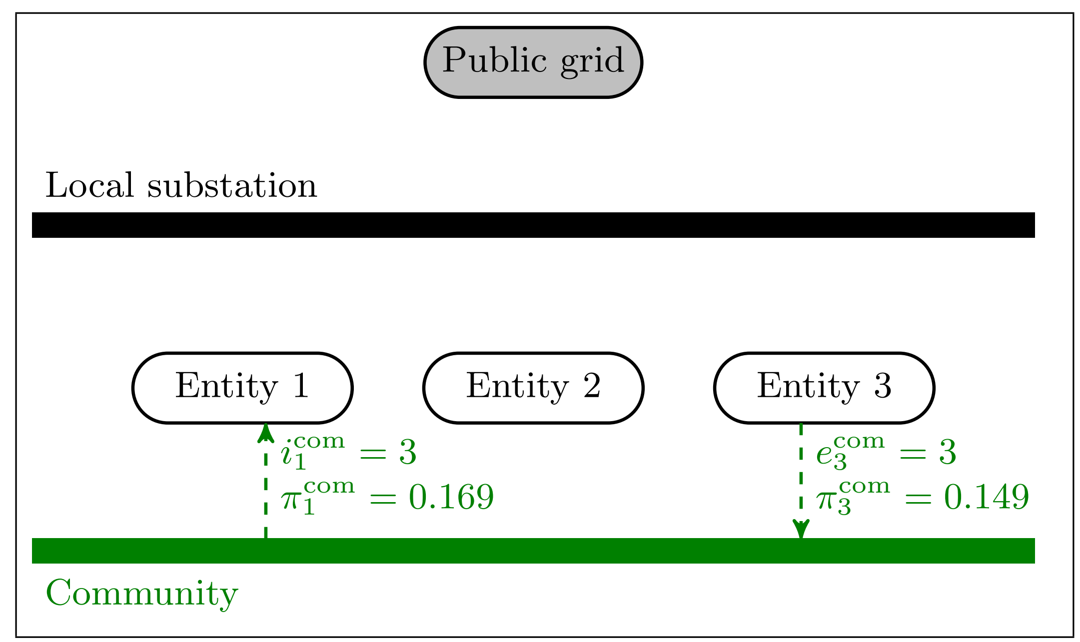
In this case a third entity is added and contains a storage device of 12 kWh, 6 kW (charge and discharge), and efficiencies of 0.95 and 0.9. Entity 2 produces 5 kWh in period 1, and entity 1 consumes 3 kWh in period 2, $\gamma_d^{\text{sto}} = 4$ c€/kWh. All other parameters remain unchanged with respect to Section 3.2.1.

Entity	Com	1	2	3
J	-0.331	-0.506	0.175	0.0
J^{SU}	-0.725	-0.9	0.175	0.0
J^{energy}	0.331	0.506	-0.175	0.0
$J^{\text{SU, energy}}$	0.275	0.45	-0.175	0.0
J^{peak}	0.0	0.0	0.0	0.0
$J^{\text{SU, peak}}$	0.45	0.45	0.0	0.0

(c) Summary of costs and profits



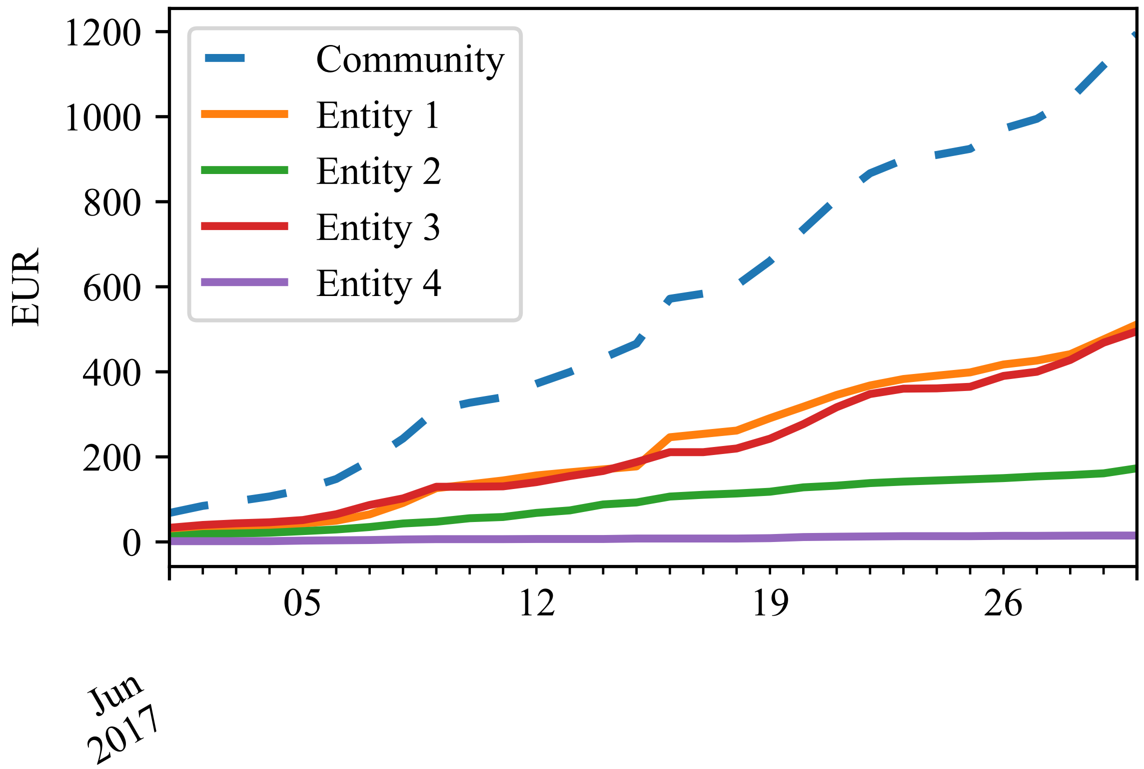
(a) Exchanges and prices, period 1



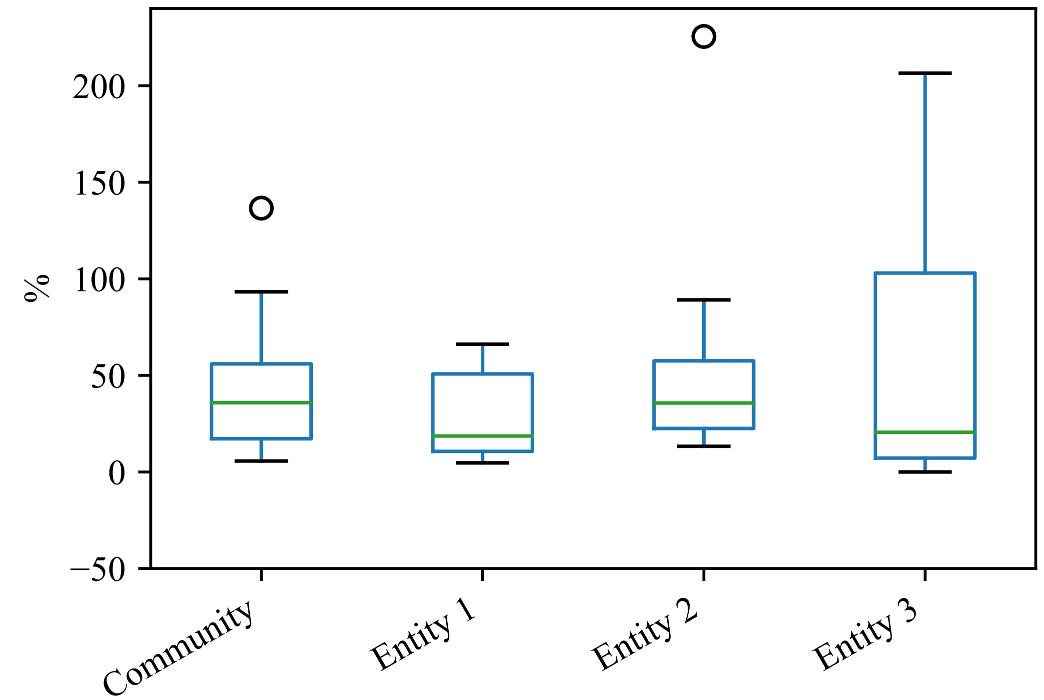
(b) Exchanges and prices, period 2

Results for MeryGrid (June 2017)

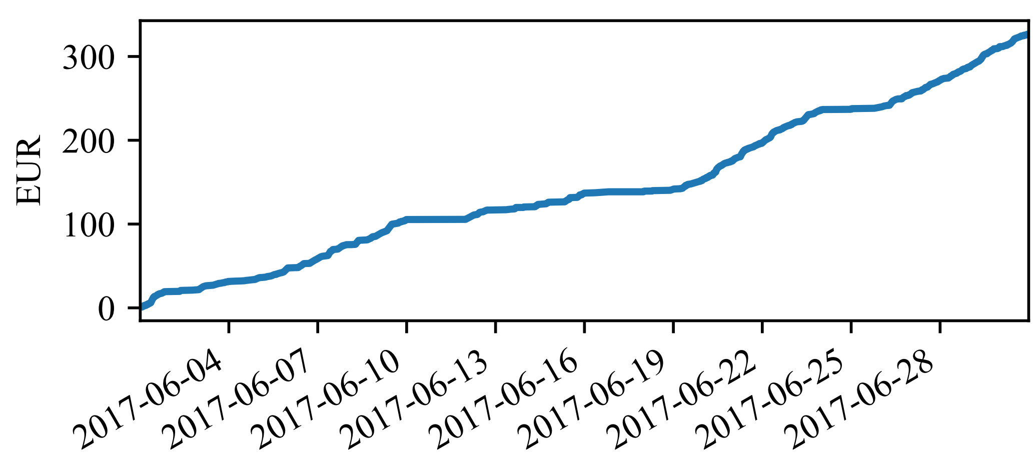
Cumulative gain, by entity



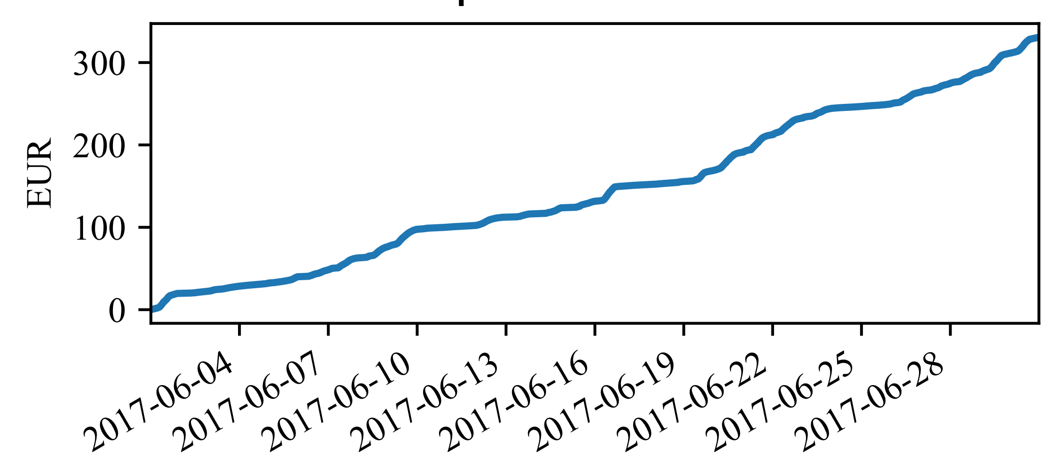
Relative gain distribution, by entity



Storage fee



Operator fee



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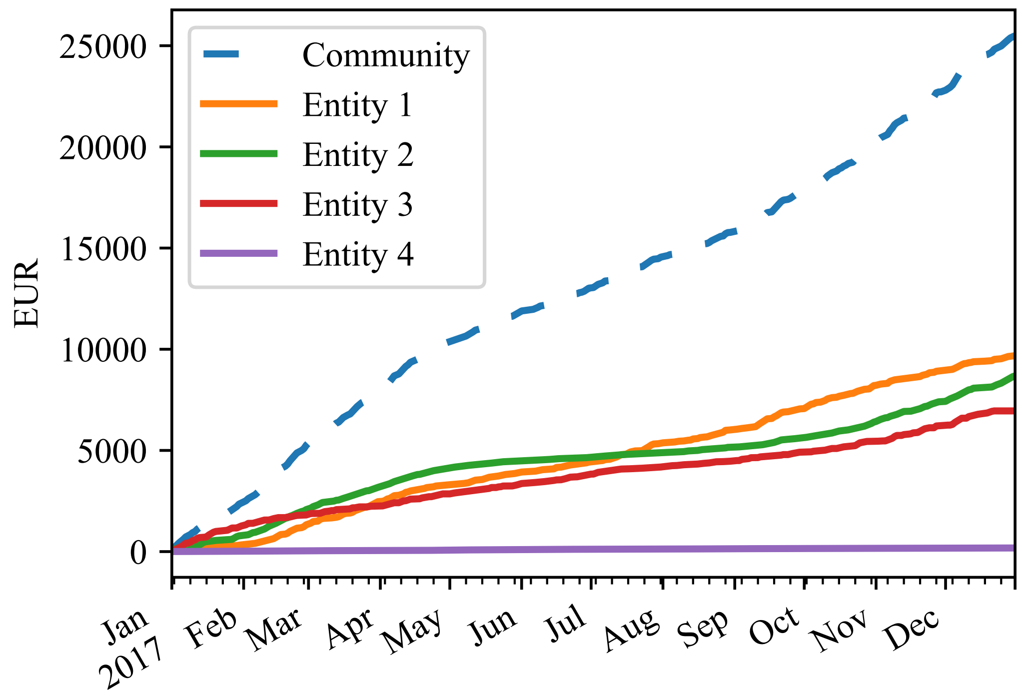
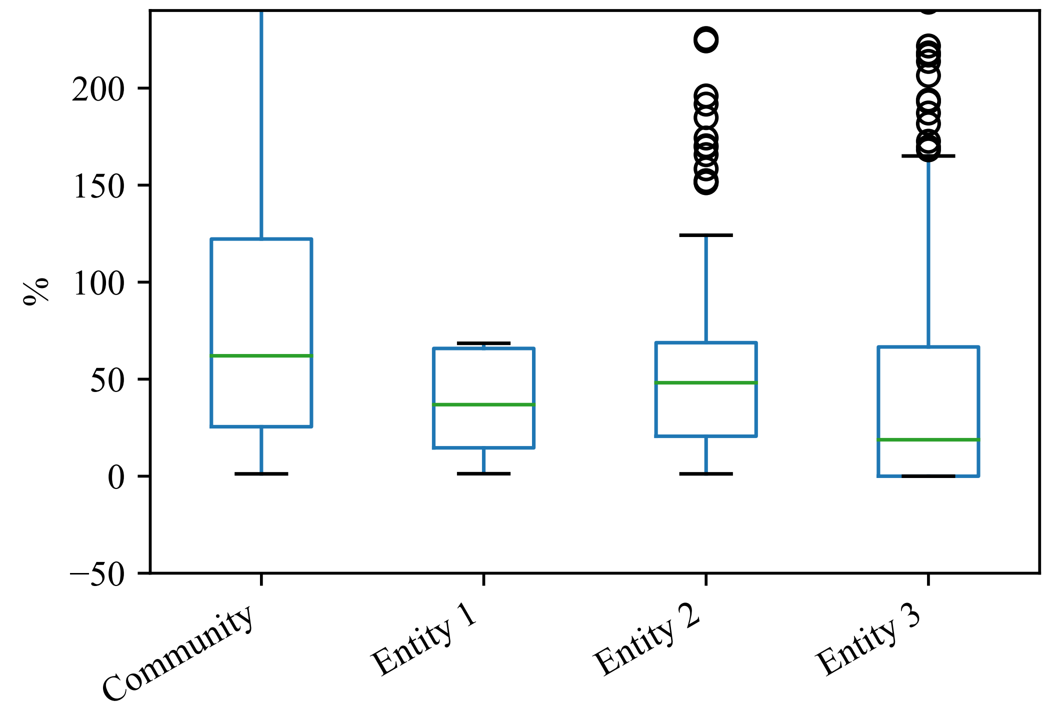
Results for MeryGrid (2017)

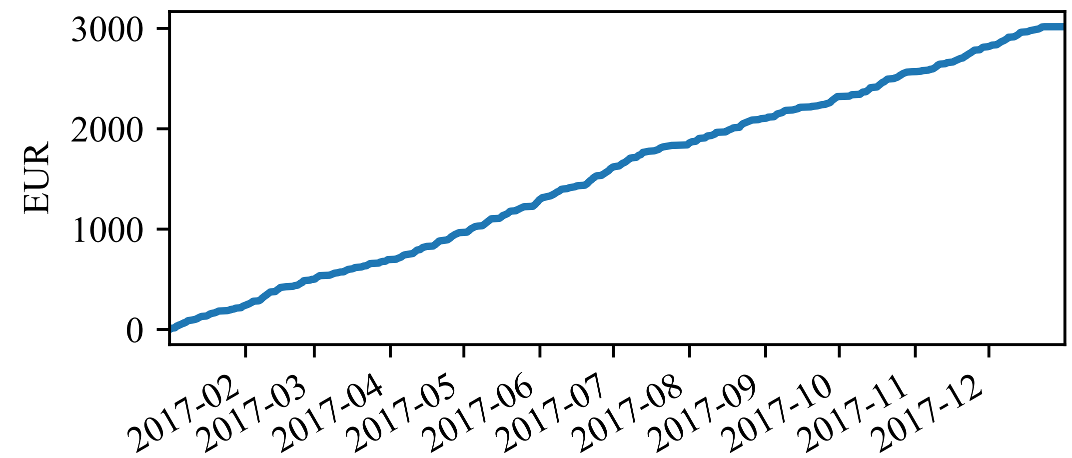
Cumulative gain, by entity



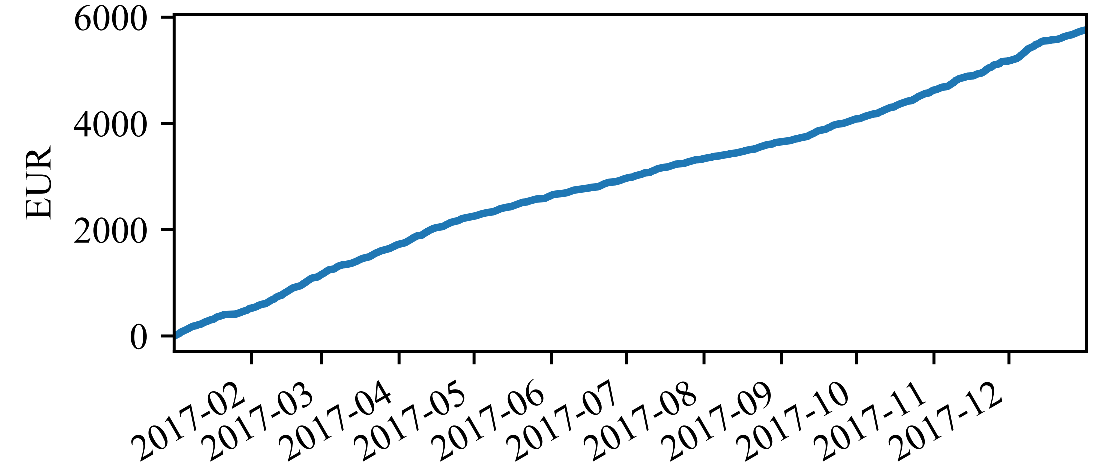
Relative gain distribution, by entity



Storage fee



Operator fee



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