Das Land Steiermark
Wirtschaft, Tourismus, Wissenschaft und Forschung

ZUKUNFTSFONDS STEIERMARK
NEXT GREEN TECH

Pricing Mechanism
for Decentralized Coordination in Energy Communities

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18. Symposium Energieinnovation 2024-02-16

Motivation

Energy Communities (ECs) for **active participation** in the energy transition

Operation of ECs involves many decentralized decisions:

a) power levels for charging and discharging stationary batteries
b) power levels for charging (and discharging) electric vehicles
c) starting times of energy-intensive loads

Goal: efficient local energy use → KPIs: local-suffiency, local-supply, …

Problem: with simple, myopic decision-making rules applied by each individual member the full potential of ECs is not exhausted

Coordinated Decision-Making

Option 1: Central Optimization Model (ILP)

→

Collective Objective: min. grid usage

Constraints: time windows, mobility behavior, etc.

Problem: central decision-making is hard to implement in a real-world context

Idea: monetary incentives to shift demand and storage decisions towards the system-wide optimum

$$s_{i,t} + \overleftarrow{q}_{i,t}^{grid} + \sum_{\forall s} \overleftarrow{q}_{i,s,t}^{batt} + \sum_{\forall v} \overleftarrow{q}_{i,v,t}^{car} + \overleftarrow{q}_{i,t}^{com} = \tag{2}$$

$$d_{i,t} + \sum_{\forall s} \overrightarrow{q}_{i,s,t}^{batt} + \sum_{\forall v} \overrightarrow{q}_{i,v,t}^{car} + \overrightarrow{q}_{i,t}^{com} + \sum_{\forall j} \overrightarrow{q}_{i,j,t}^{fload} + \overrightarrow{q}_{i,t}^{lost} \quad \forall (i,t)$$

$$s_{com,t} + \sum_{\forall i} \overrightarrow{q}_{i,t}^{com} + \sum_{\forall s} \overleftarrow{q}_{com,s,t}^{batt} = \sum_{\forall i} \overleftarrow{q}_{i,t}^{com} + \sum_{\forall s} \overrightarrow{q}_{com,s,t}^{batt} + \overrightarrow{q}_{com,t}^{grid} \quad \forall t \tag{3}$$

$$\overrightarrow{q}_{i,t}^{com} \leq \overline{q}_i^{out} \quad \forall (i,t) \tag{4}$$

$$\overrightarrow{q}_{i,t}^{com} \leq s_{i,t} + \sum_{\forall s} \overleftarrow{q}_{i,s,t}^{batt} - d_{i,t} - \sum_{\forall v} \overrightarrow{q}_{i,v,t}^{car} - \sum_{\forall j} \overrightarrow{q}_{i,j,t}^{fload} \quad \forall (i,t) | s_{i,t} - d_{i,t} \geq 0$$

$$\overrightarrow{q}_{i,t}^{com} \leq \sum_{\forall s} \overleftarrow{q}_{i,s,t}^{batt} \quad \forall (i,t) | s_{i,t} - d_{i,t} < 0 \tag{5}$$

$$\sum_{\forall s} \overleftarrow{q}_{i,s,t}^{batt} \leq d_{i,t} + \sum_{\forall v} \overrightarrow{q}_{i,v,t}^{car} + \sum_{\forall j} \overrightarrow{q}_{i,j,t}^{fload} \quad \forall (i,t) \tag{6}$$

$$\overleftarrow{q}_{i,s,t}^{batt} \leq \overline{q}_{i,s}^{\leftarrow batt}, \ \overrightarrow{q}_{i,s,t}^{batt} \leq \overline{q}_{i,s}^{\rightarrow batt} \quad \forall (i^*, s, t) \tag{7}$$

$$SoC_{i,s,start_t}^{batt} = SoC_{i,s}^{batt} \quad \forall i^* \tag{8}$$

$$SoC_{i,s,t}^{batt} = \gamma_{i,s} * SoC_{i,s,t-1}^{batt} + \overrightarrow{\gamma_{i,s}} * \overrightarrow{q}_{i,s,t}^{batt} - \overleftarrow{\gamma_{i,s}} * \overleftarrow{q}_{i,s,t}^{batt} \quad \forall (i^*, s, t) \tag{9}$$

$$SoC_{i,s,t}^{batt} \leq \overline{SoC}_{i,s}^{batt} \quad \forall (i^*, s, t) \tag{10}$$

$$\overleftarrow{q}_{i,v,t}^{car} \leq \overline{q}_{i,v}^{\leftarrow car} * a_{i,v,t}, \ \overrightarrow{q}_{i,v,t}^{car} \leq \overline{q}_{i,v}^{\rightarrow car} * a_{i,v,t} \quad \forall (i, v, t) \tag{11}$$

$$SoC_{i,v,start_t}^{car} = SoC_{i,v}^{car} \quad \forall (i, v) \tag{12}$$

$$SoC_{i,v,t}^{car} = \epsilon_{i,v} * SoC_{i,v,t-1}^{car} + \overrightarrow{\epsilon_{i,v}} * \overrightarrow{q}_{i,v,t}^{car} - \overleftarrow{\epsilon_{i,v}} * \overleftarrow{q}_{i,v,t}^{car} \quad \forall (i, v, t) | a_{i,v,t} = 1 \tag{13}$$

$$SoC_{i,v,t}^{car} \geq \underline{SoC}_{i,v}^{car} * a_{i,v,t} \quad \forall (i, v, t) | t \geq t' \tag{14}$$

$$SoC_{i,v,t}^{car} \leq \overline{SoC}_{i,v}^{car} \quad \forall (i, v, t) \tag{15}$$

$$SoC_{i,v,dep-1}^{car} \geq \underline{SoC}_{i,v}^{car} + v_{i,v} \quad \forall (i, v, trips) \tag{16}$$

$$SoC_{i,v,arr-1}^{car} = SoC_{i,v,dep-1}^{car} - v_{i,v} \quad \forall (i, v, trips) \tag{17}$$

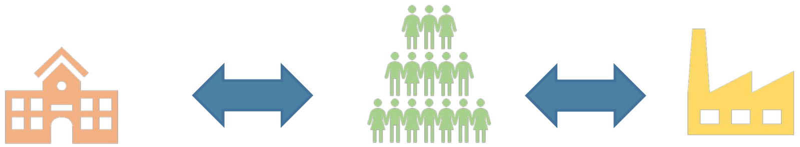
$$\overrightarrow{q}_{i,j,t}^{fload} = \sum_{k} x_{i,j,k}^{fload} * schedule_{i,j,k,t} \quad \forall (i, j, t) \tag{18}$$

$$\sum_{\forall k} x_{i,j,k}^{fload} = 1 \quad \forall (i, j) \tag{19}$$

$$x_{i,j,k}^{fload} = 1 \quad \forall (i, j, k) | task_j^{start} \leq start_t \tag{20}$$

Legal Framework

Electricity Quantities



municipalities citiziens SMEs

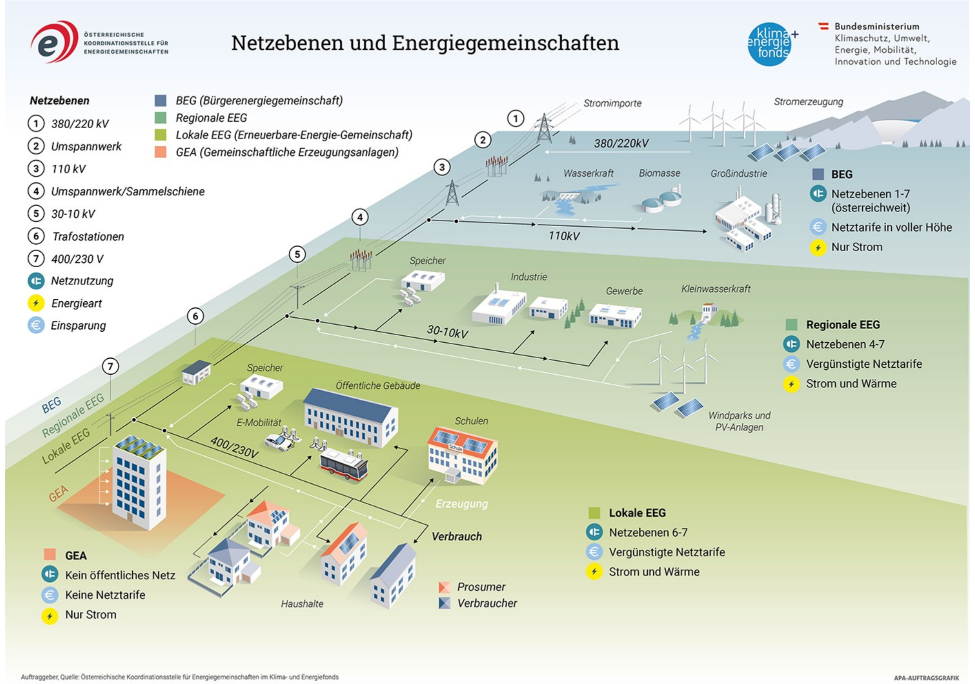
clear rules for allocation of electricity quanitities within ECs:
static or **dynamic allocation**

Electricity Prices

External:
remaining demand covered by individual electricity supplier

Internal:
reduced grid fees + exemption of green electricity support payments

exchange of electricity at **self-defined prices**



Pricing Mechanism

Idea: set purchasing prices based on **forecasted electricity balance**

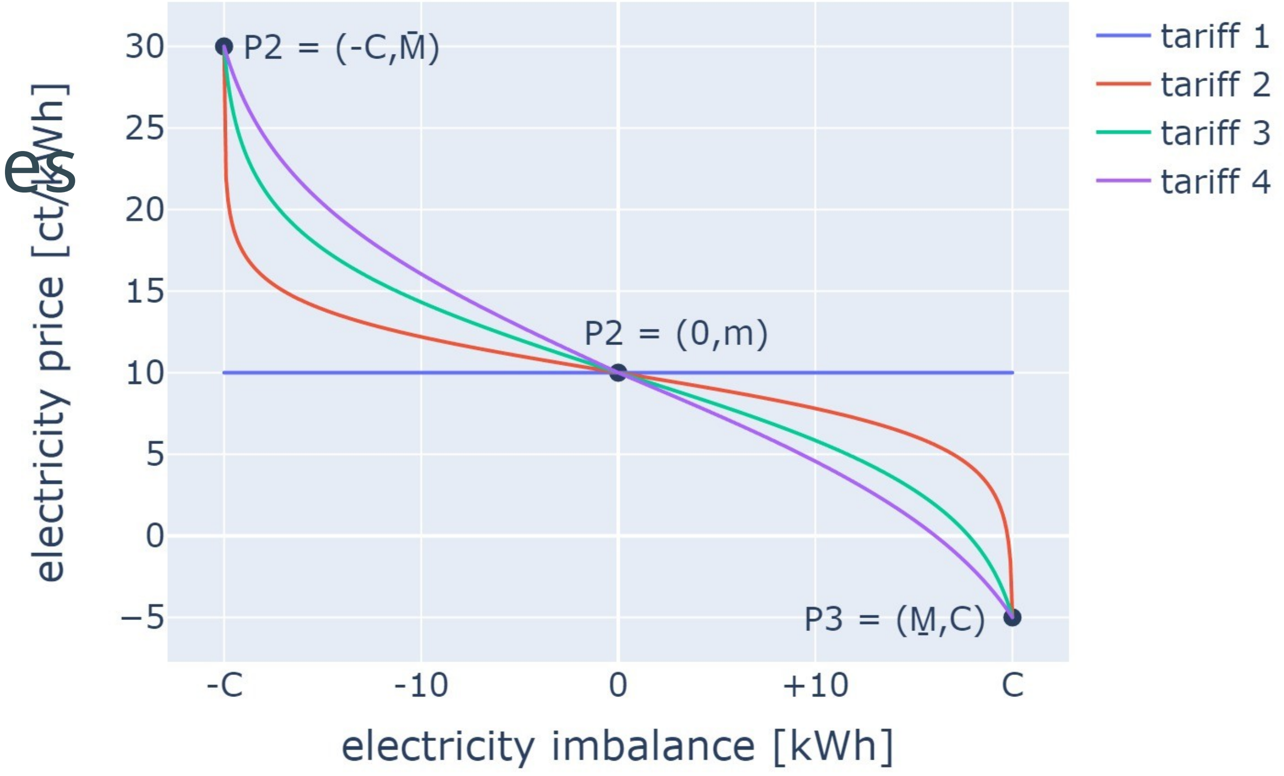
overproduction → low prices

underproduction → high prices

logarithmic pricing function:

$$f(x) = a * \ln\left(\frac{C - bx}{C + bx}\right) + m$$

$$with\ b = \begin{cases} \dfrac{\exp\left(\frac{\bar{M} - m}{a}\right) - 1}{\exp\left(\frac{\bar{M} - m}{a}\right) + 1} & if\ x \le 0 \\ \dfrac{\exp\left(\frac{m - \underline{M}}{a}\right) - 1}{\exp\left(\frac{m - \underline{M}}{a}\right) + 1} & if\ x > 0 \end{cases}$$



Requirements on EC Tariff Models

Guidelines for EC pricing policies[1]

Suggestions for Tariff Models based on dynamic prices:

Reliability

- agree on parameters for price determination once and stick to them for a defined period (e.g. a year)
- price calculation in 15-minute-resolution based on forecasts, updated once per day for stable day-ahead prices

Participation

selling price = f(x)
purchasing price = f(x) (+ markup)

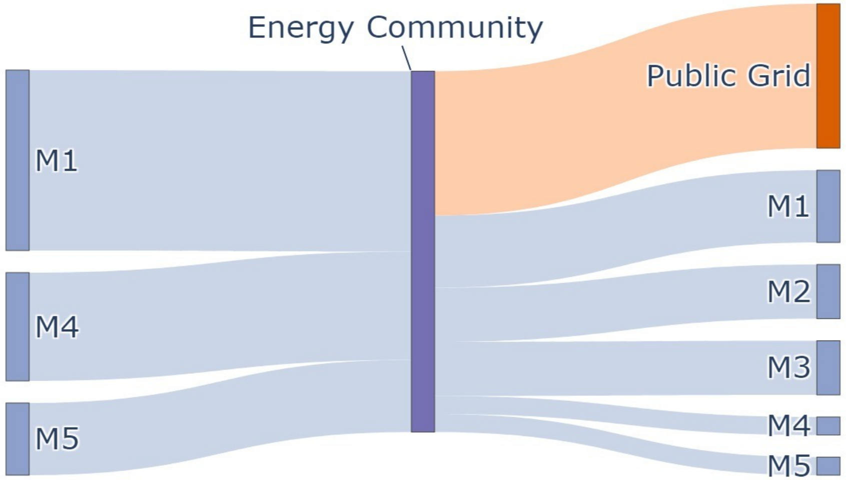
- orientation on levelized cost of energy for min. selling price
- ⌀ purchasing price ≤ purchasing price electricity provider

[1]https://energiegemeinschaften.gv.at/3-interne-vereinbarungen/

Requirements on EC Tariff Models

Community Bill (selling price = purchasing price)

expenses =
selling price ·
kWh surplus



revenues =
feed-in price · kWh sold to grid +
purchasing price · kWh consumed in community

Profits* if external feed-in price > ⌀ community selling price, else **losses**

*EC profits could be used …

- to cover administrative cost (instead of a flat rate)
- to offer special rates for vulnerable groups
- for savings for collective community investments

Assessment Framework

EC with 10 members*: week 1 in Q2 2023

	System-wide Optimum	Constant Tariff Model	Dynamic Tariff Model
Optimization Level	Community	Individual	Individual
Objective	$\min \sum_{\forall i,t} \overleftarrow{q}^{grid}_{i,t} + \sum_{\forall t} \overrightarrow{q}^{grid}_{com,t}$	$\min \sum_{\forall t} \overrightarrow{q}^{com}_{i,t} * \overrightarrow{p}^{com}_{t} - \sum_{\forall t} \overleftarrow{q}^{com}_{i,t} * \overleftarrow{p}^{com}_{t} - \sum_{\forall t} \overleftarrow{q}^{grid}_{i,t} * \overleftarrow{p}^{grid}_{t} \quad \forall i \in \text{Members}$	

*2 residential prosumers + 2 commercial prosumers with PV (34 kWp in total), 6 pure residential consumers, 1x 10 kWh battery, 1x 50 kWh electric vehicle (bi-directional charging), 3 flexible loads (1.2, 2.5 and 10 max. kW)

Assessment Framework

Forecasts vs. Reality

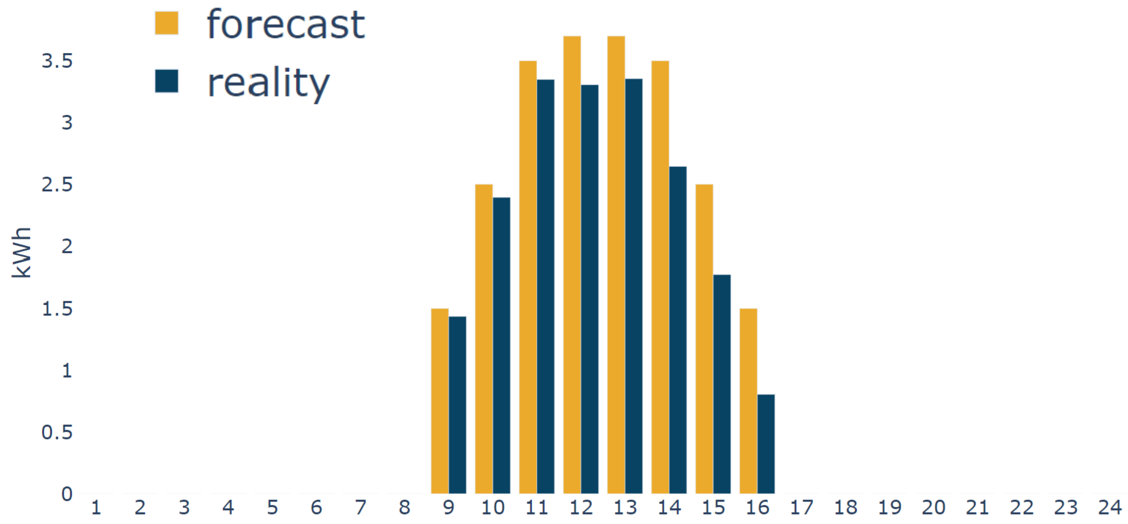


Fig. A: Production Profile

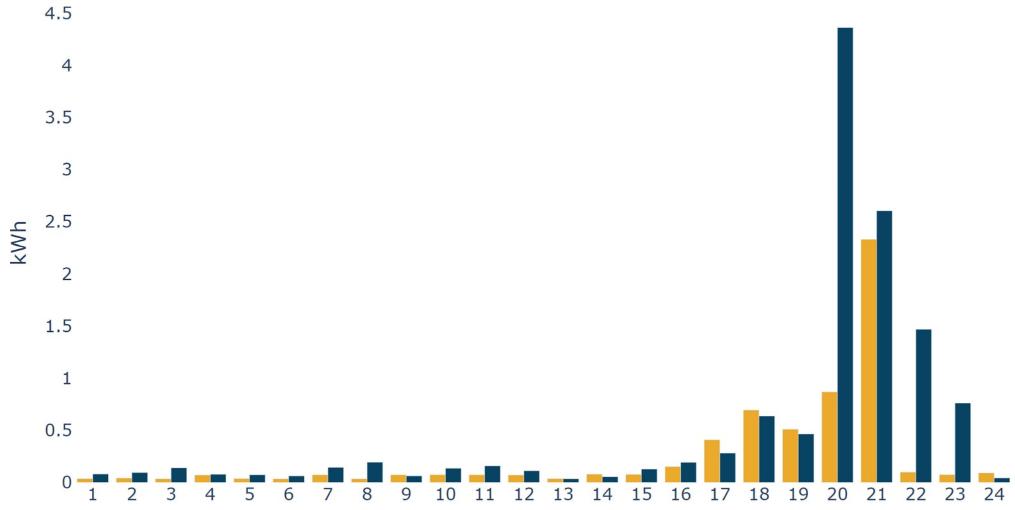
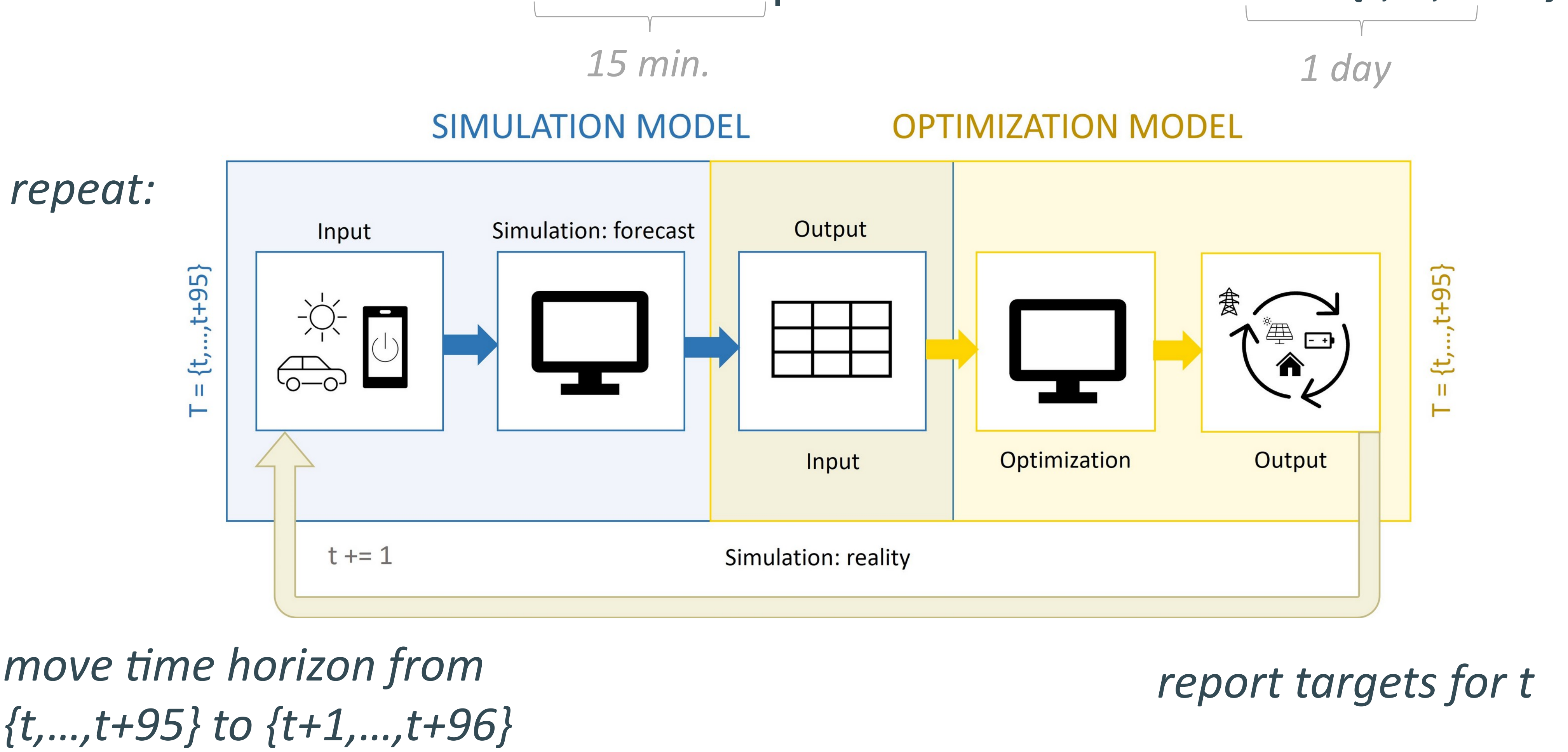


Fig. B: Consumption Profile

→ optimization embedded in a larger simulation framework (MPC-inspired)

Assessment Framework

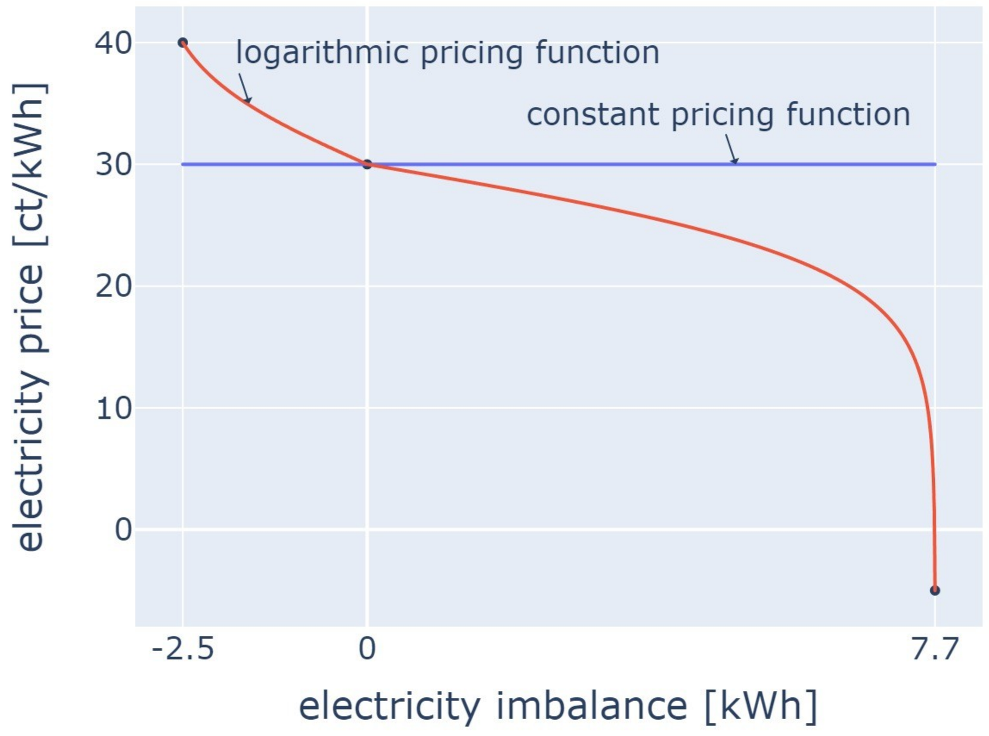
MILP: decisions for next time step *t* based on outlook for *{t,…,t+95}*



Assessment Framework

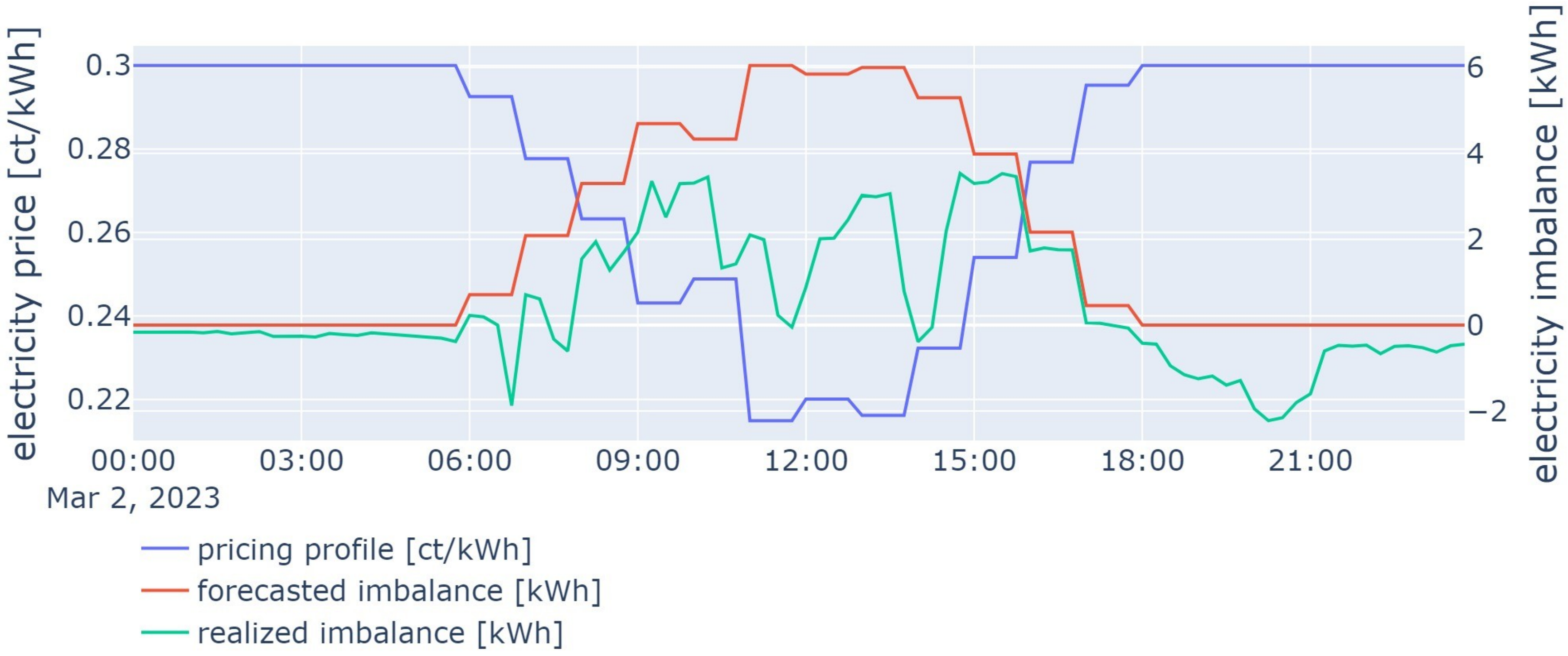
Price Settings

Parameters	Values
max. forecasted overproduction	7.7 kWh/timestep
max. forecasted underproduction	-2.5 kWh/timestep
max. community electricity price	40 ct/kWh
min. community electricity price	-5 ct/kWh
reference electricity price	30 ct/kWh
slope parameter	4
grid fees + taxes and duties	5.4 ct/kWh
external total electricity price	35 ct/kWh



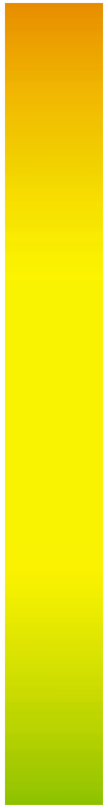
Preliminary Results

Flattened electricity imbalance (from forecast to realization) through dynamic prices on one representative day:

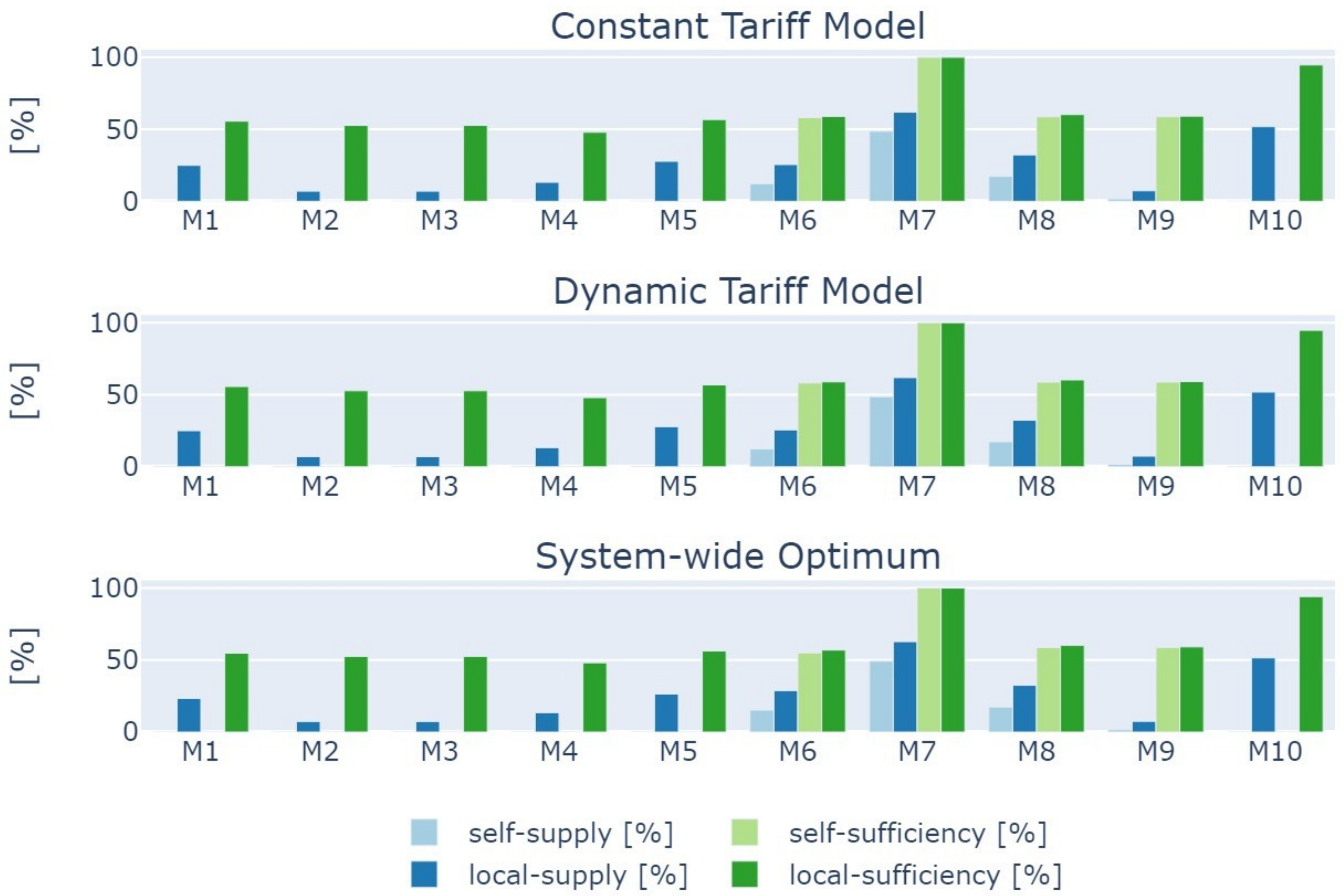


Preliminary Results

Standard
Approach



Central
Optimum



Community KPIs

local-supply: 30 %
local-sufficiency: 59 %

local-supply: 32 %
local-sufficiency: 60 %

local-supply: 33 %
local-sufficiency: 60 %

Outlook

Test Instances

evaluation of … a longer time horizon (year)

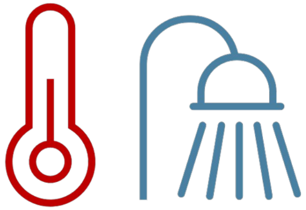
a wider set of performance indicators (financial outcome)

different community configurations

Other Decentralized Coordination Mechanisms

reinforcement learning for automated decision-making

at individual member nodes with joint reward function



Sector Coupling

integration of air & water heating to increase flexible loads

Questions

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