

Online seminar course on renewable energy and sustainability

ERASMUS+ programme – 101082252 – ERASMUS-EDU-2022-CBHE

March 17th, 2026

Online Presentation

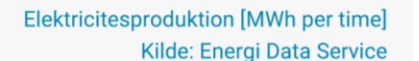
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Uge



Motivation

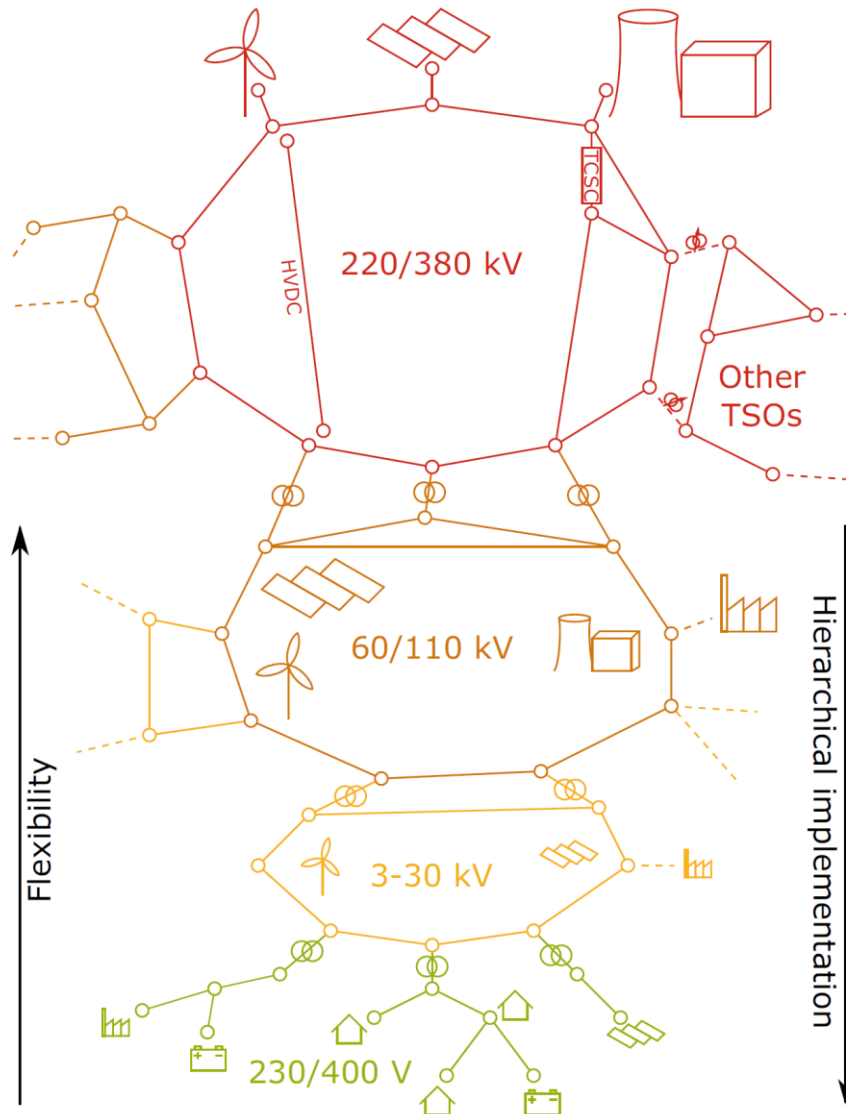
Energy storage systems

Increase renewable + curtail

Power-to-X

Demand-side flexibility

Hierarchical power systems: Grid flexibilities (2023)



Transmission grid

Economic optimal power flow

- Minimize cost
- Security constraints (N-1)
- Transient stability (network Laplacian)
- Demand of flexible nodes are free

Flexible distribution grid

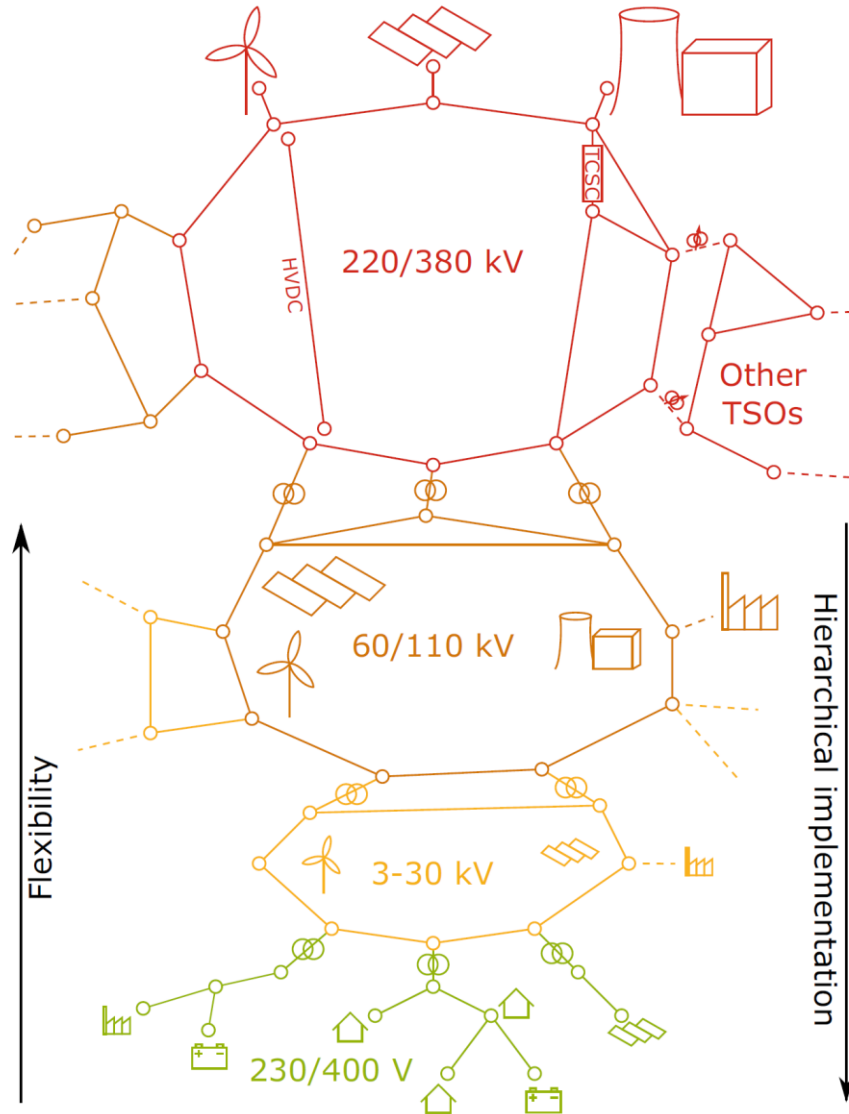
Min/max optimal power flow

- Min/max total energy demand
- Demands of flexible nodes are free

Flexible assets (e.g., microgrids or vertical agriculture)

Economic (price-sensitive) control

Remaining challenges



Demand response depends on “state of charge”

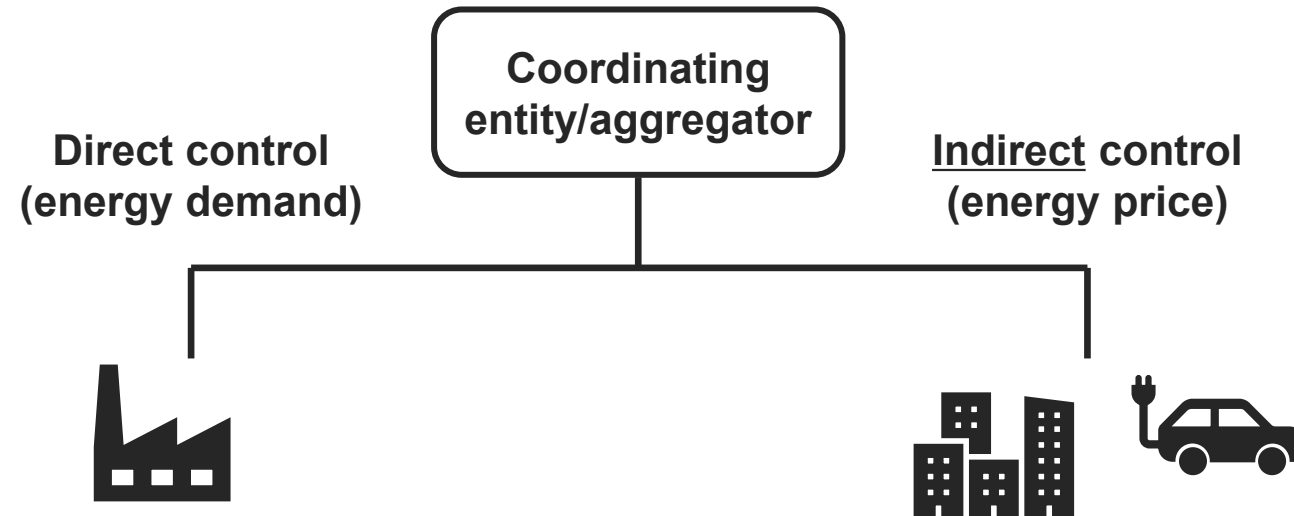


Flexibility may be finite



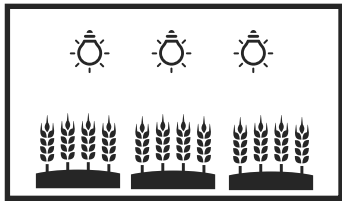
Requires full control of energy demand

Direct vs. indirect control (incentivization)

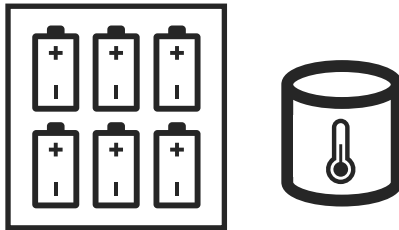


Types of flexible assets

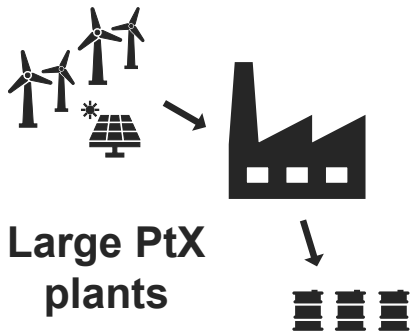
Large and intensive



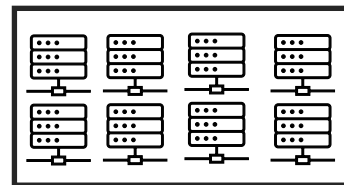
Greenhouses



Energy storage facilities



Large PtX plants



Data centers

Small but widespread



Heat pumps



Smart appliances



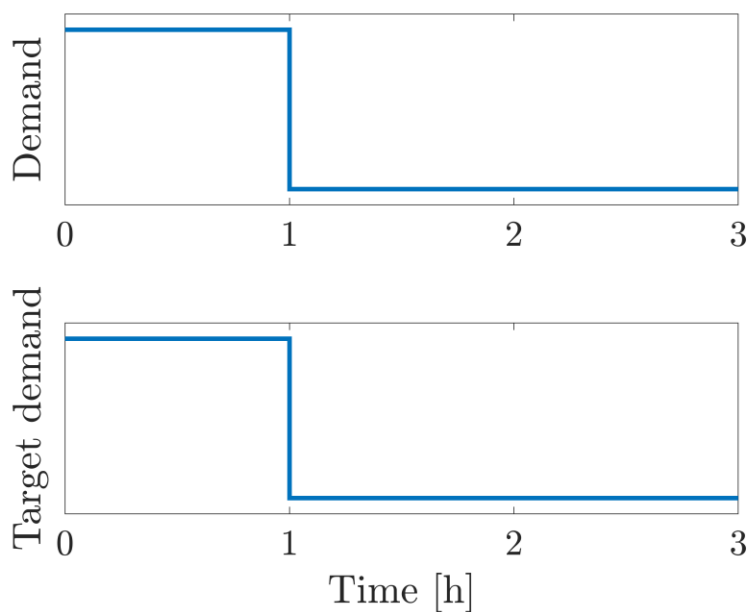
Household heating



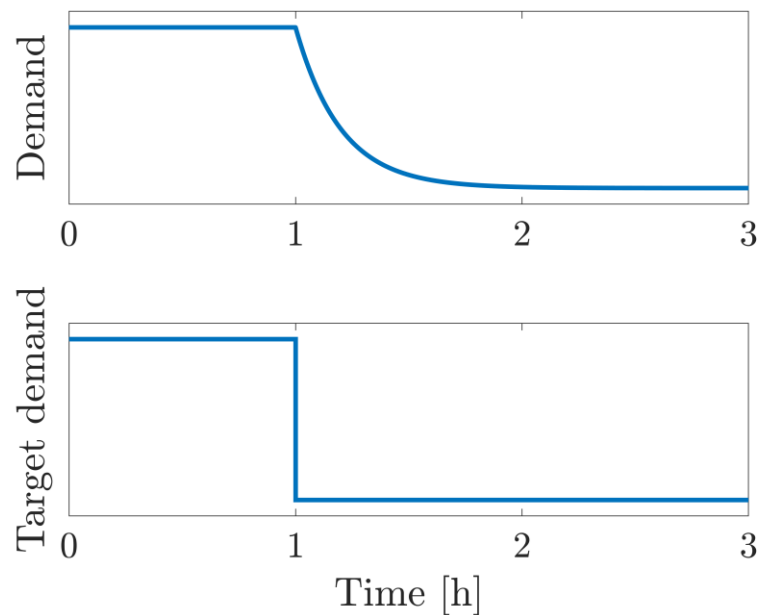
Electric vehicle charging

Types of flexibility

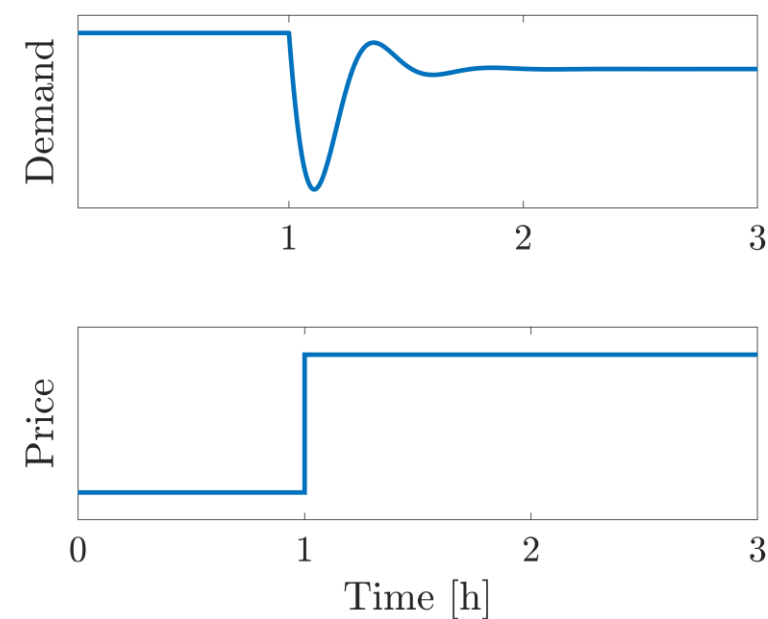
Flexible and fast



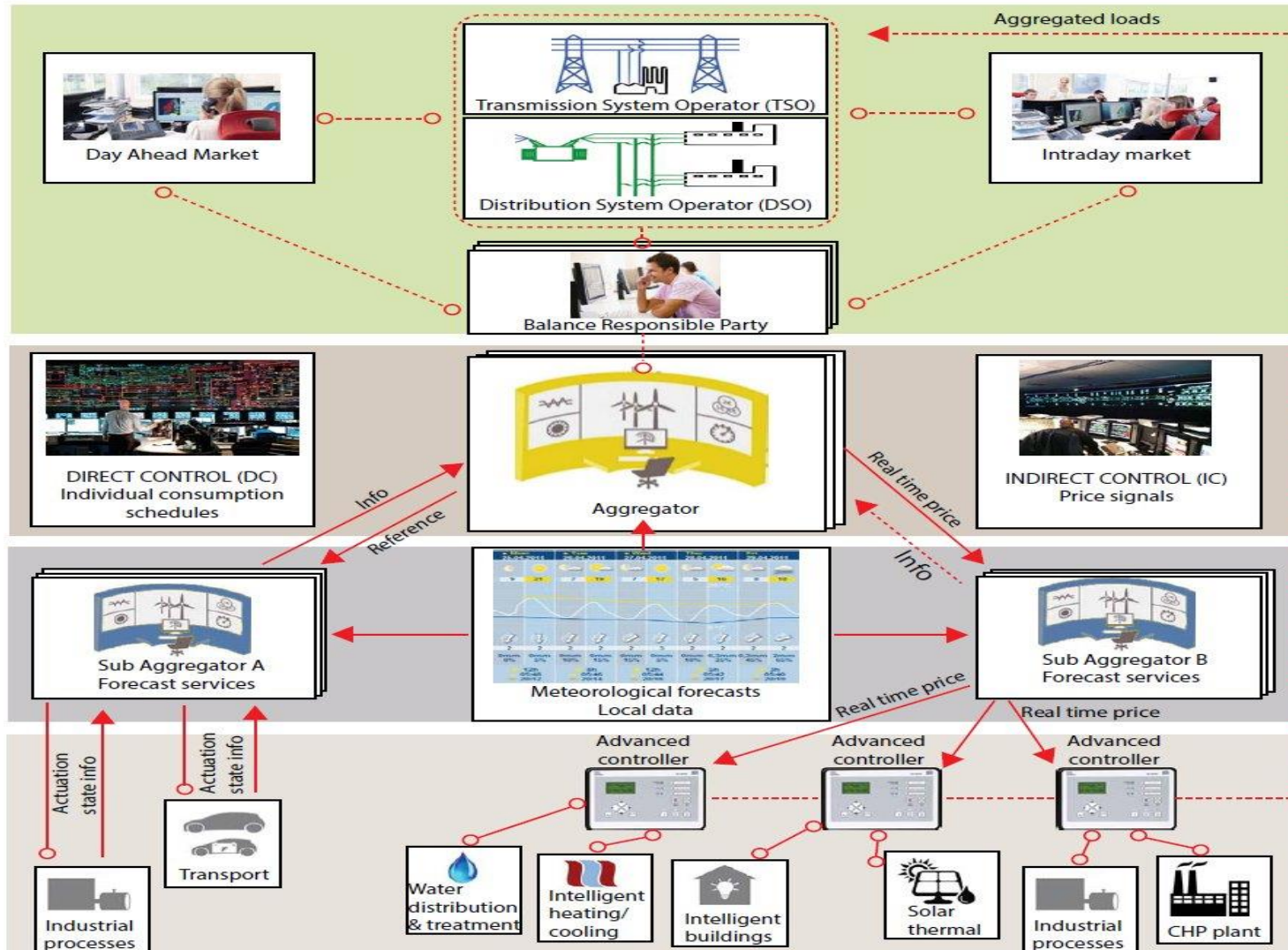
Flexible but slow



Complex



Smart Energy Operating System (SE-OS)



(Static)

Conventional markets



Link markets to physics using MIMs
(Flexibility Functions)

(Dynamic)

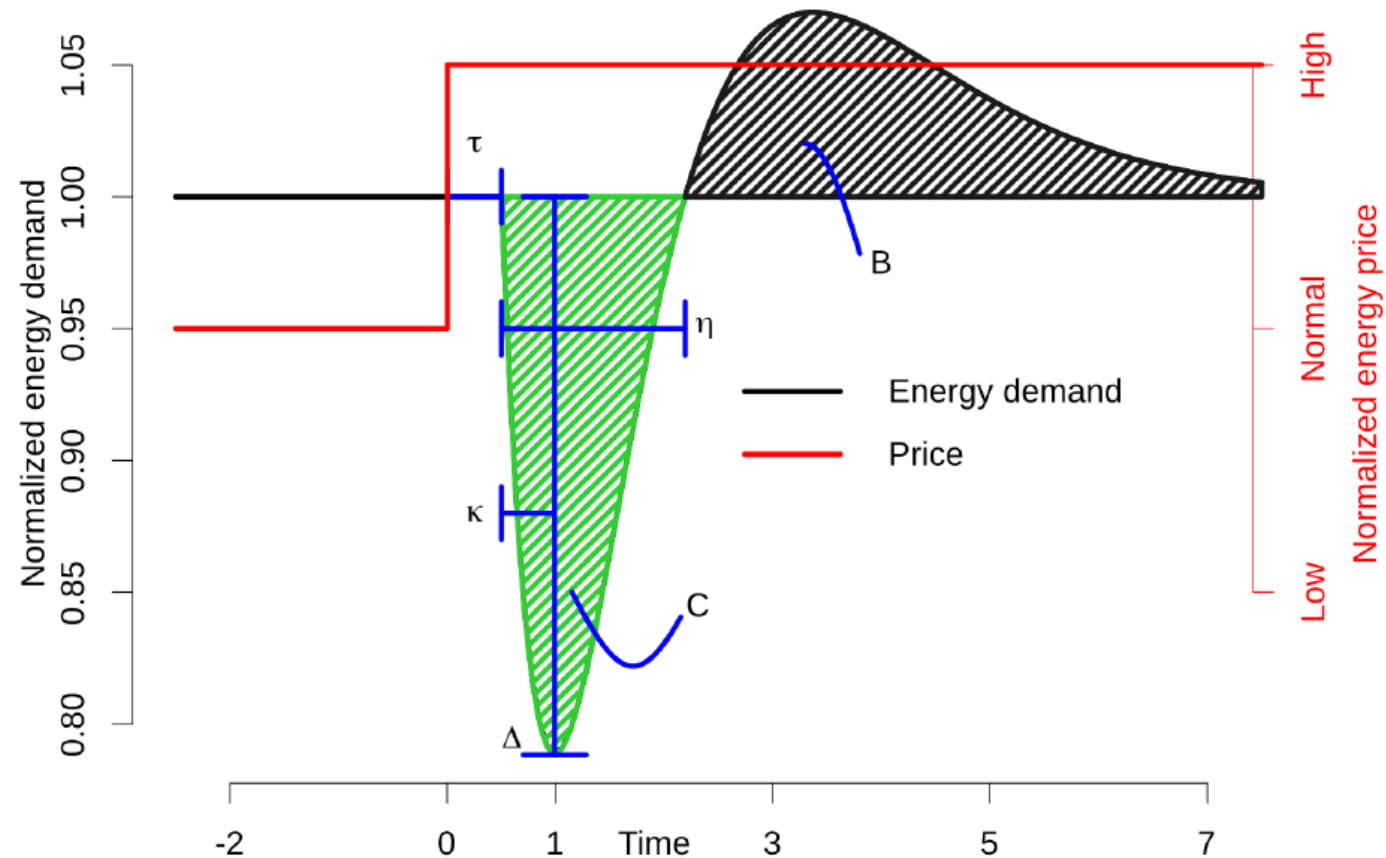
Local incentive-based flexibility exploitation

(Hierarchy of controllers)

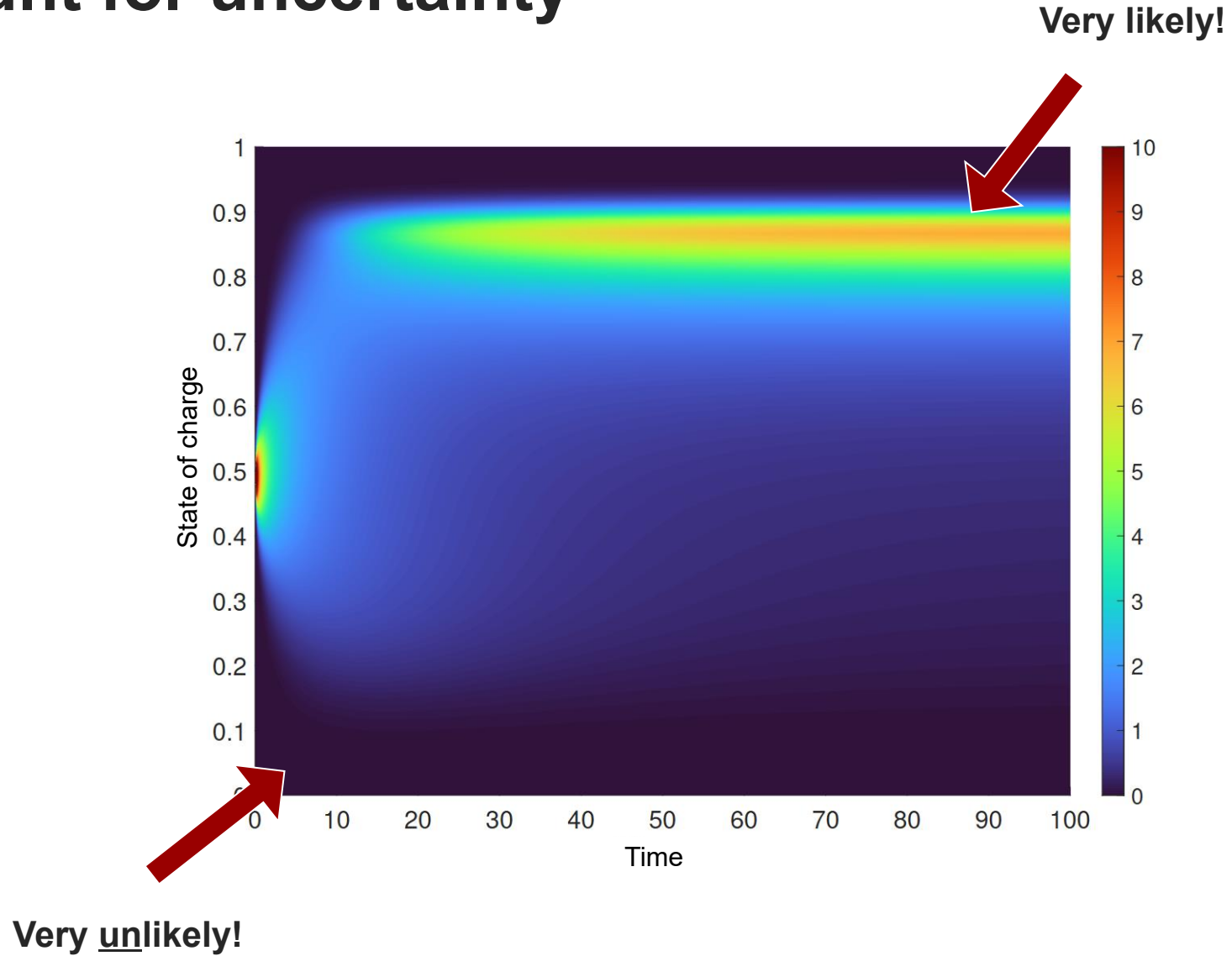
Minimal demand response models: Flexibility functions

Flexibility function: Predict flexible demand as function of

- **Price**
- **“State of charge”**

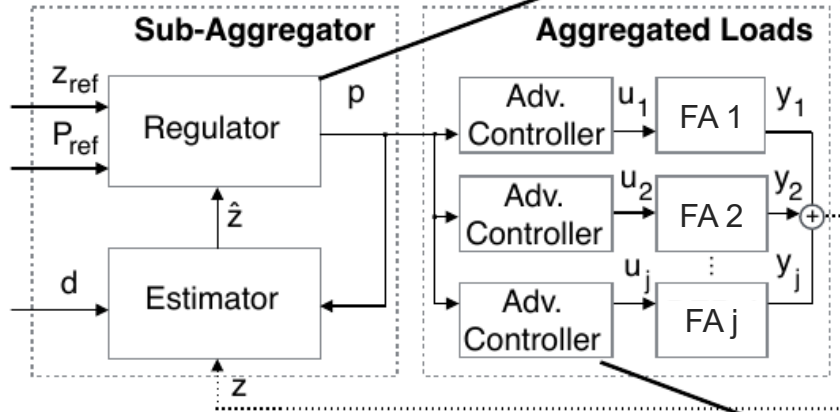


Account for uncertainty



Interoperability through incentivization

Price signal generator



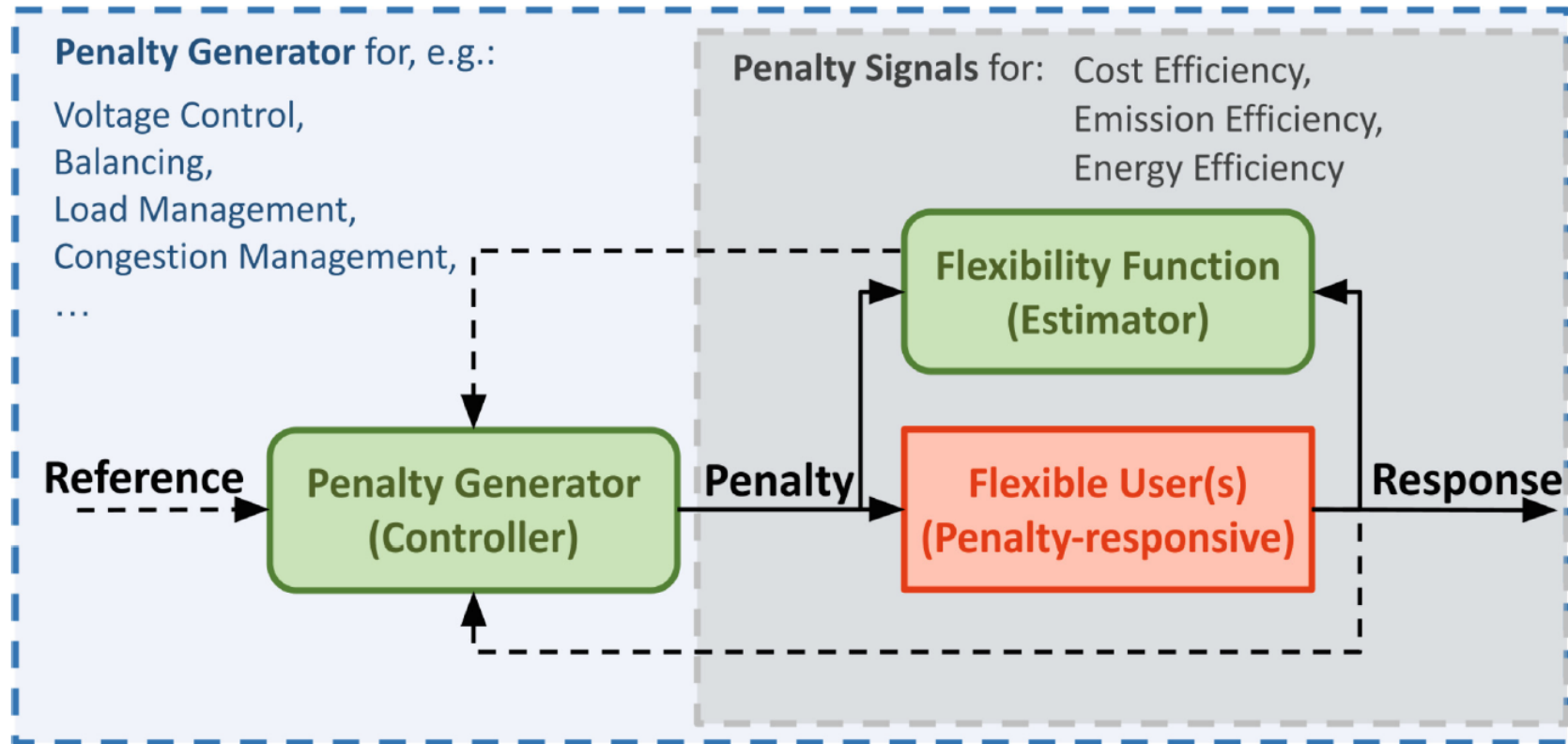
$$\begin{aligned} \min_p \quad & \mathbb{E} \left[\sum_{k=0}^N w_{j,k} ||\hat{z}_k - z_{ref,k}|| + \mu ||p_k - p_{ref,k}|| \right] \\ \text{s.t.} \quad & \hat{z}_{k+1} = f(p_k) \end{aligned}$$

Price-sensitive control system

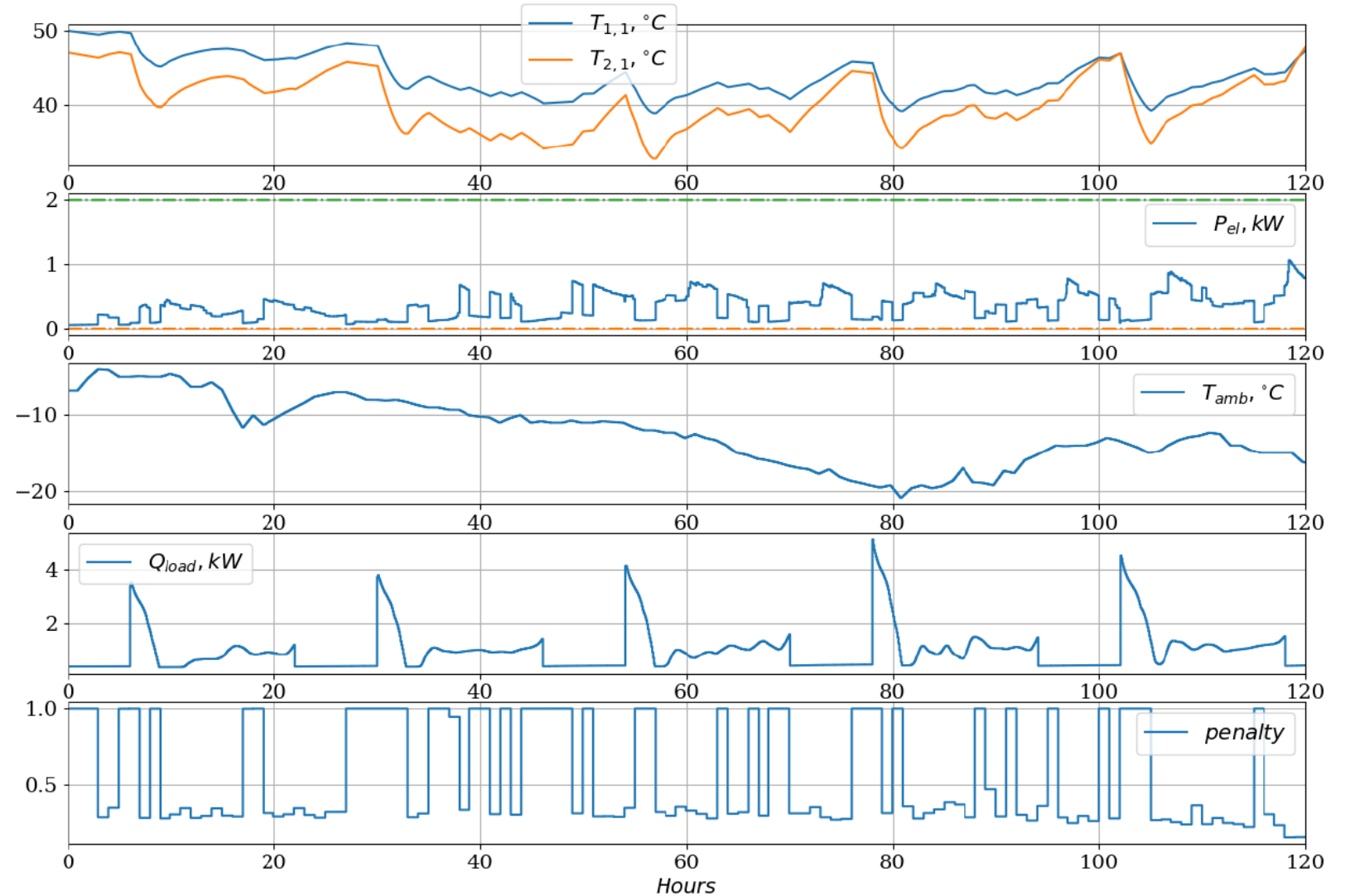
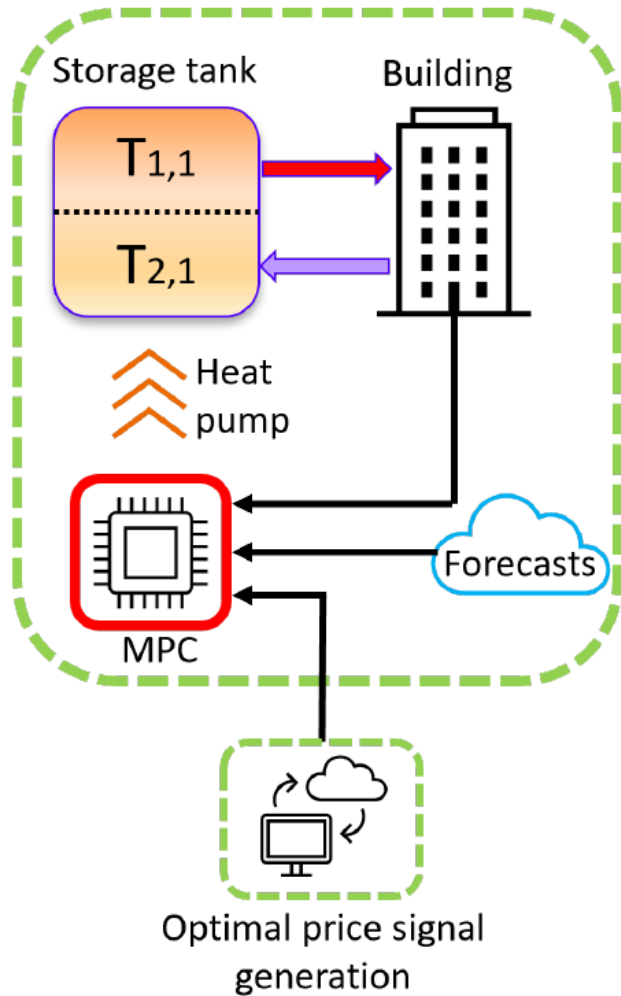
We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

$$\begin{aligned} \min_u \quad & \mathbb{E} \left[\sum_{k=0}^N \sum_{j=1}^J \phi_j(x_{j,k}, u_{j,k}, p_k) \right] \\ \text{s.t.} \quad & x_{k+1} = Ax_k + Bu_k + Ed_k, \\ & y_k = Cx_k, \\ & y_k^{min} \leq y_k \leq y_k^{max}, \\ & u_k^{min} \leq u_k \leq u_k^{max} \end{aligned}$$

Dynamic price signal generation

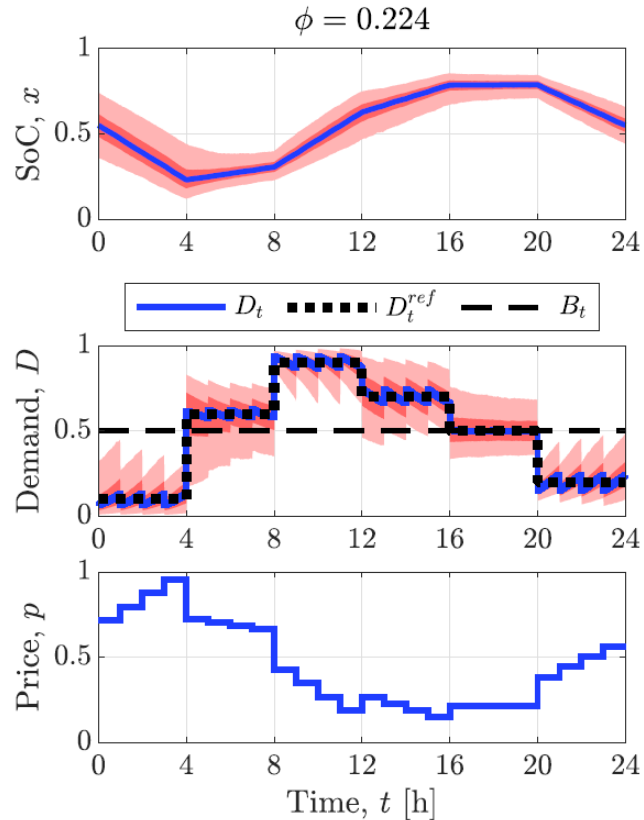


Example: Flexible building energy management system



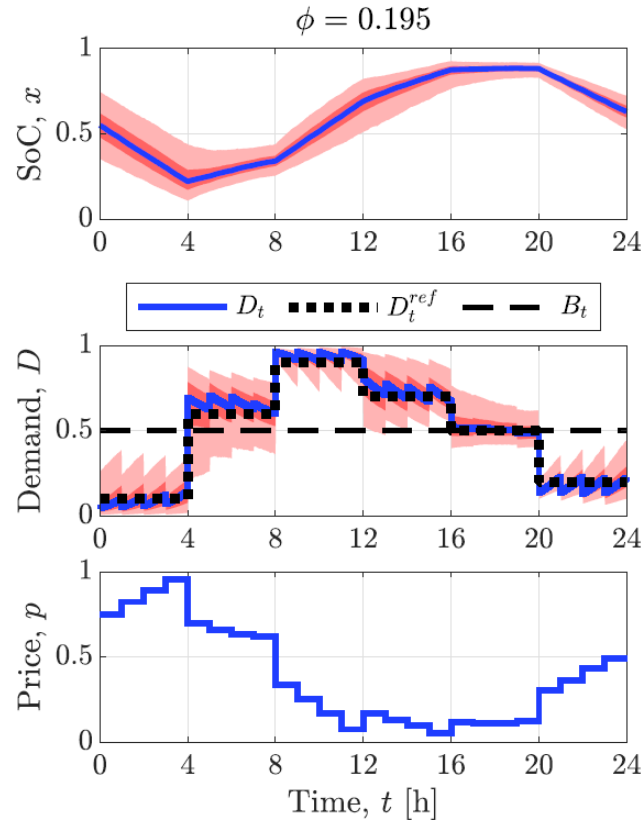
Comparison of price signal generation strategies

Day-ahead (no uncertainty)



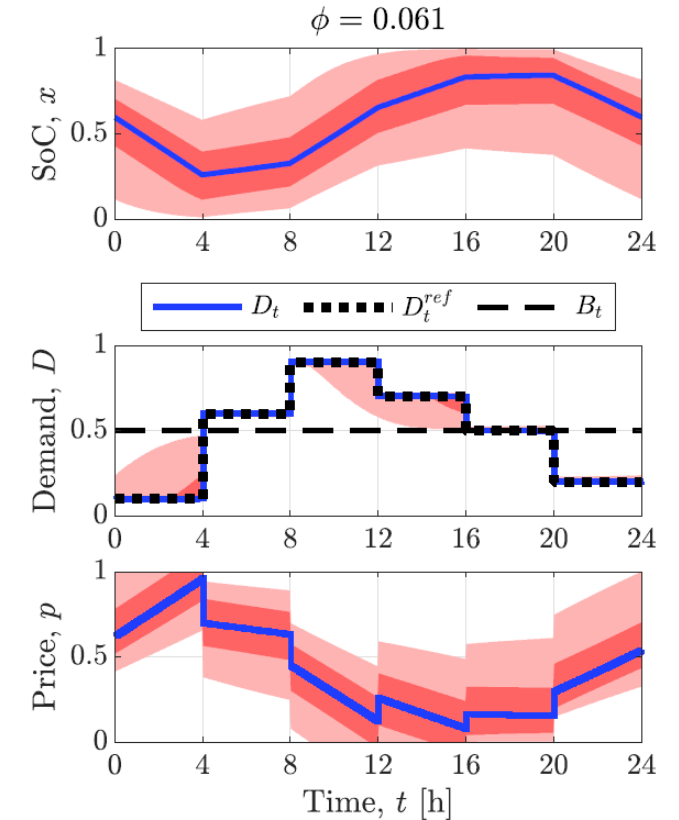
(a) Deterministic open-loop solution, hourly price update

Day-ahead (uncertainty)



(b) Stochastic open-loop solution, hourly price update

Real-time update of prices



(c) Stochastic closed-loop solution, continuous-time price update

Selected research activities



- Horizon Europe
- Flexible operation of district heating grids
- Demand-side flexibility exploitation in district heating

OPTIFLEX

- EUREKA Eurostars
- Demand-side flexibility exploitation
- Integrated market bidding



MISSION
GREEN FUELS



1. **GreenTwins:** Flexible operation of carbon capture units
2. **PtX Markets:** Demand-side flexibility exploitation
3. **CANSI:** Flexibility of electrolyzers
4. **PtX Sector Coupling and LCA:** Flexible operation of plastic waste to methanol
5. **PWtM-Flex:** Flexible operation of plastic waste to methanol
6. **PtX Risø project w. SemperCycle:** Flexible operation of plastic waste to methanol

Flexibility across hierarchies

- Load shift incentivization
- Hierarchies of aggregators

Demand response model

- Flexibility functions
- Time-varying (flexibility is finite)
- Real-time data assimilation

Dynamic energy prices

- Day-ahead prices
- Real-time price adjustments

Thank you