Dynamic prices for market participation of flexible and price-sensitive assets

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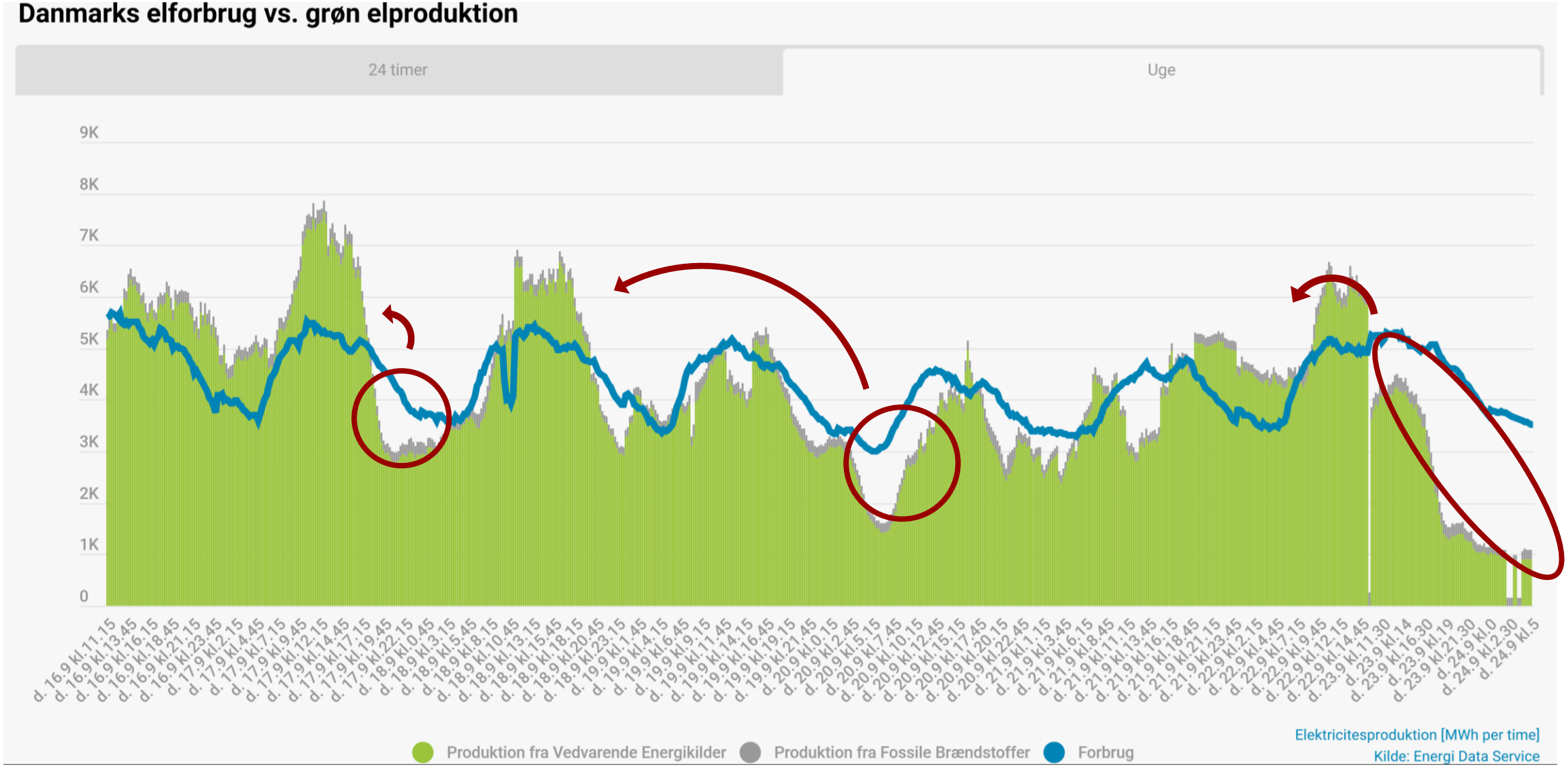
Motivation



https://ing.dk/artikel/live-danmarks-elforbrug-og-elproduktion

Motivation

Energy storage systems

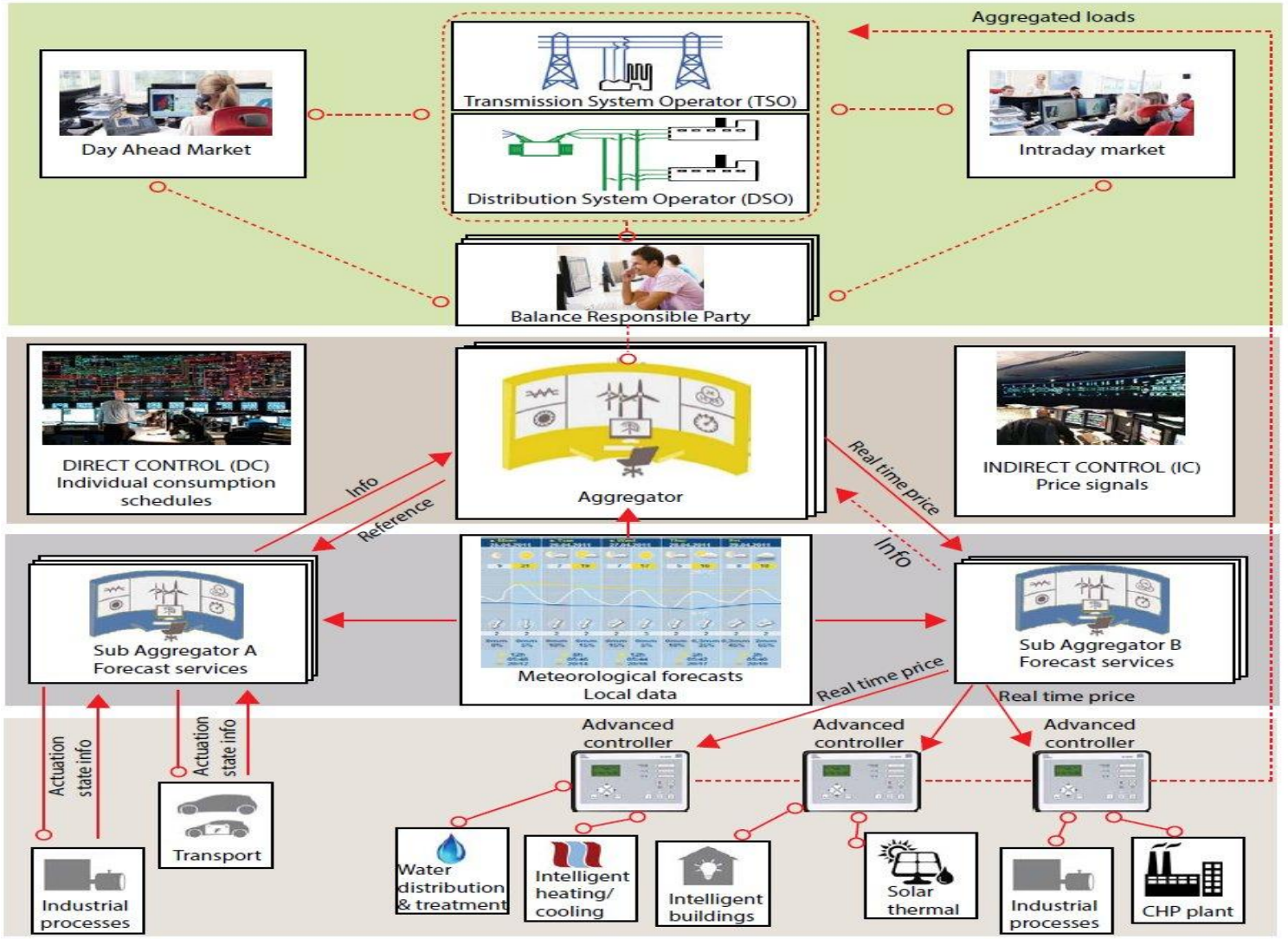
Increase renewable + curtail

Power-to-X

Demand-side flexibility

- Indirect exploitation
- Direct exploitation

Smart Energy Operating System (SE-OS)



(Static)

Conventional markets

Link markets to physics using MIMs

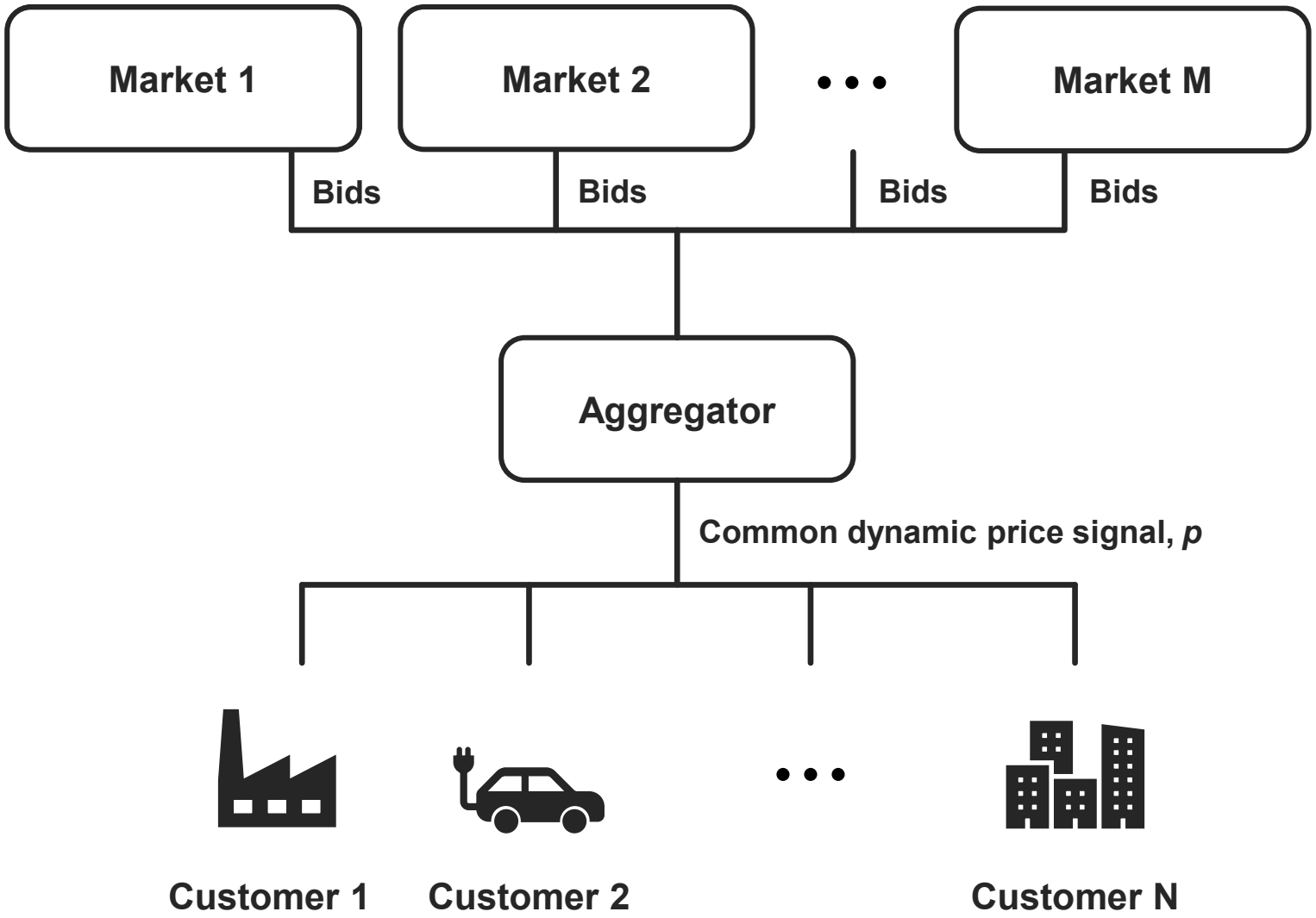
(Flexibility Functions)

(Dynamic)

Local incentive-based flexibility exploitation

(Hierarchy of controllers)

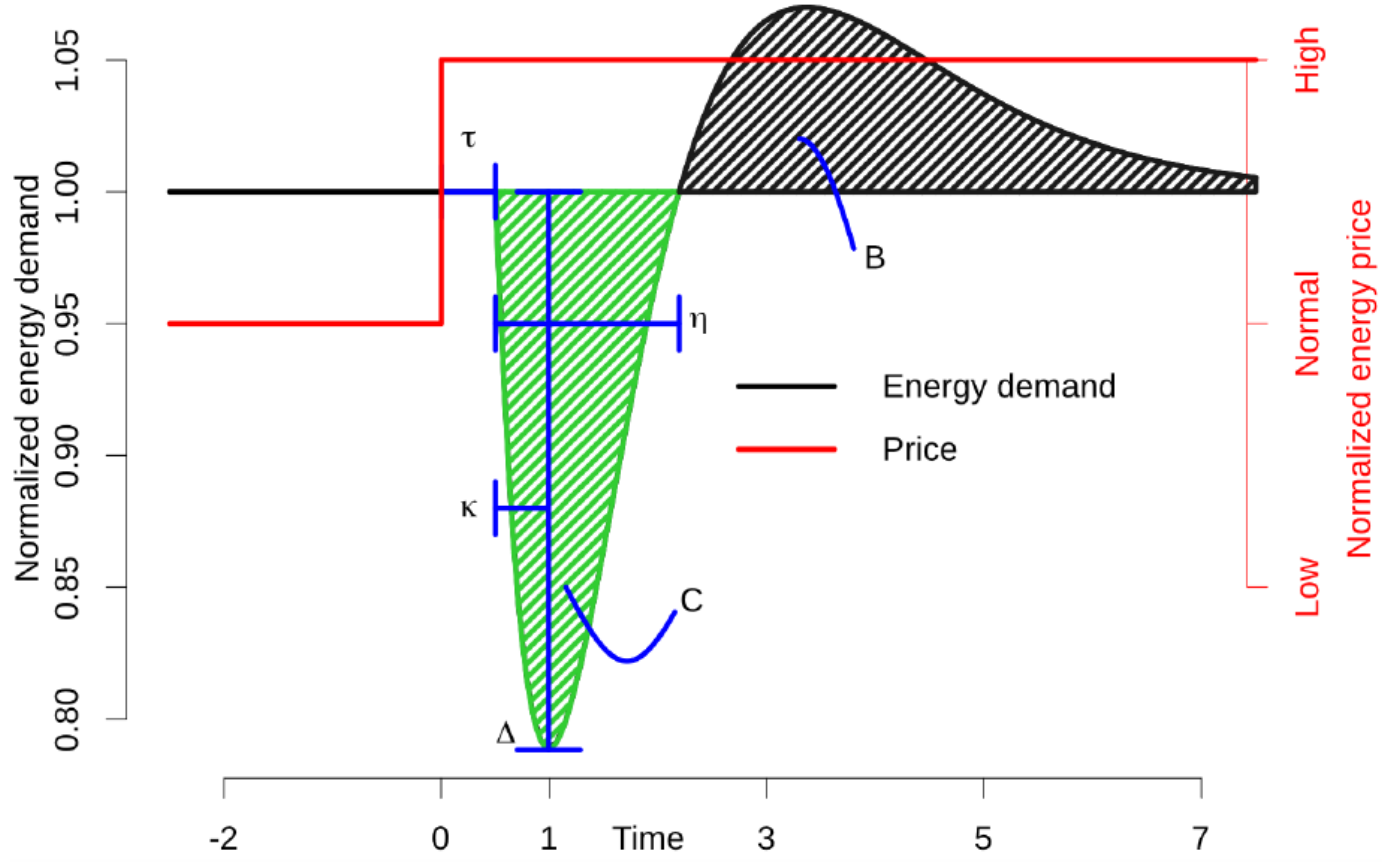
Aggregator


Market 1
Market 2
Market M
Bids
Bids
Bids
Bids
Aggregator
Common dynamic price signal, p
Customer 1
Customer 2
Customer N

Minimal demand response models: Flexibility functions

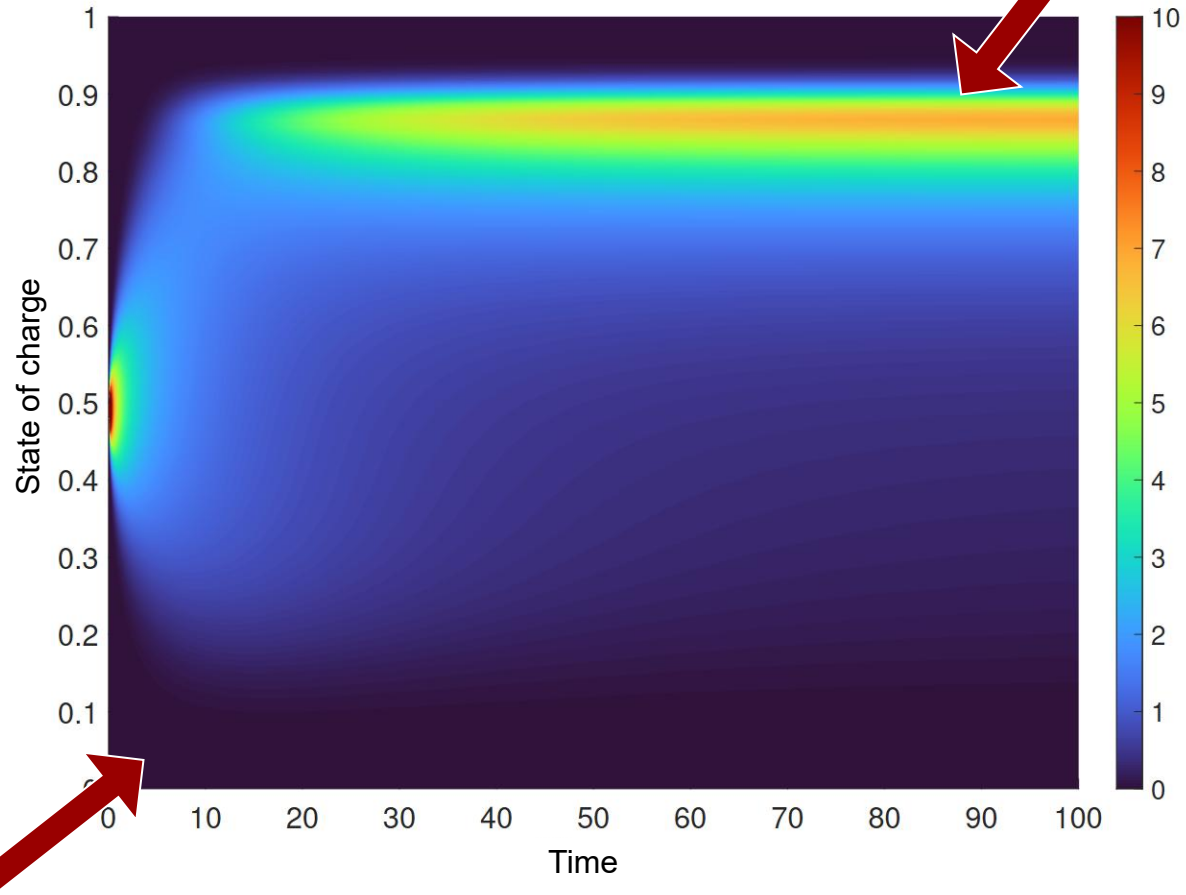
Flexibility function: Predict flexible demand as function of

- **Price**
- **“State of charge”**
- **Publicly available data: Weather, temperature, time of day/week/season, etc.**



Account for uncertainty

Very likely!

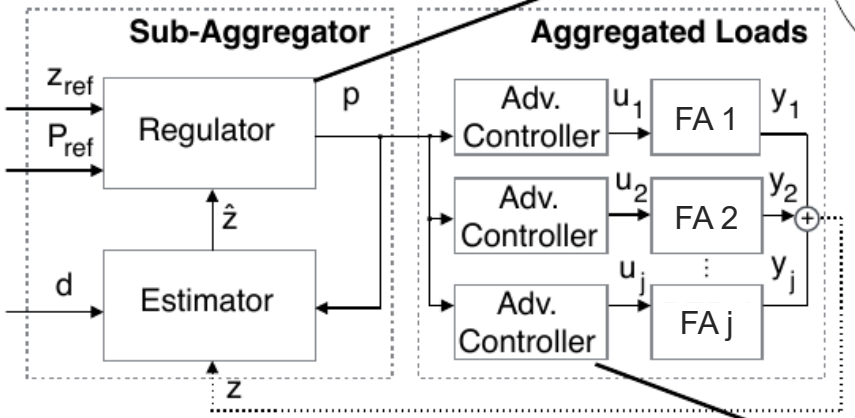


Very unlikely!

Interoperability through incentivization

Price signal generator

$$\min_{p} \quad \mathrm{E}[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||]$$
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$

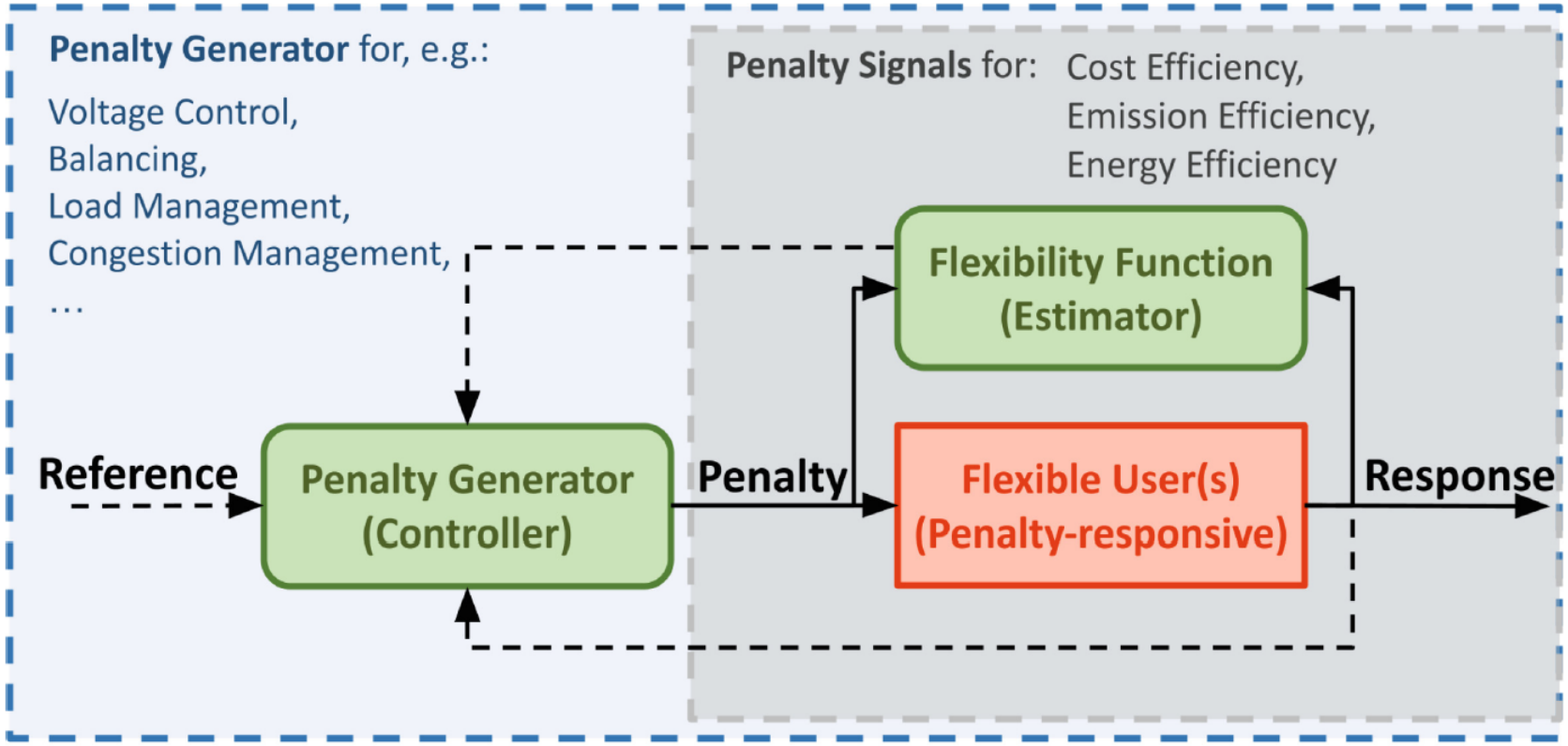


We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

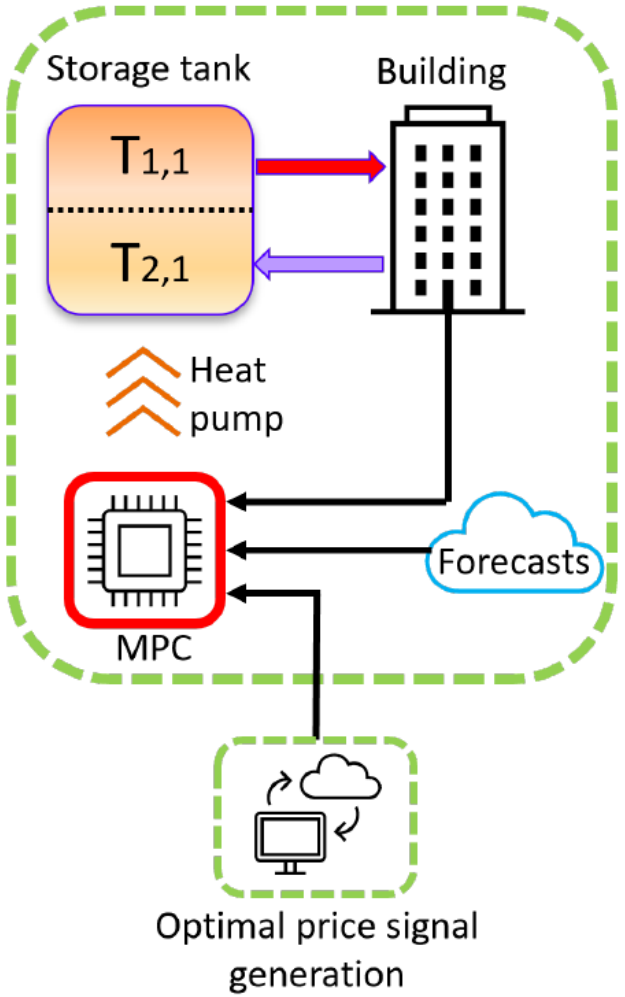
Price-sensitive control system

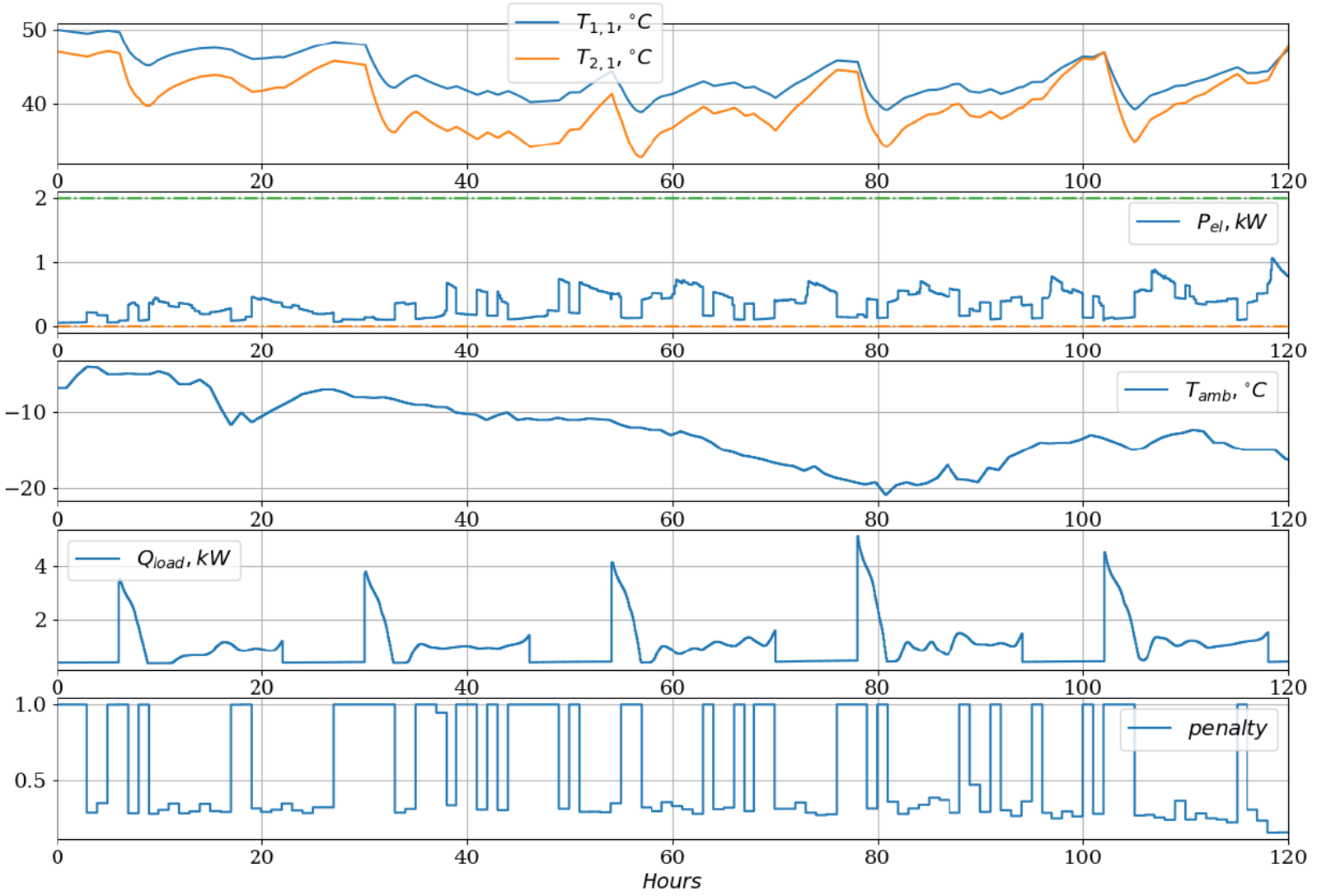
$$\min_{u} \quad \mathrm{E}[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)]$$
$$\text{s.t.} \quad x_{k+1} = Ax_k + Bu_k + Ed_k,$$
$$y_k = Cx_k,$$
$$y_k^{min} \le y_k \le y_k^{max},$$
$$u_k^{min} \le u_k \le u_k^{max}$$

Dynamic price signal generation



Example: Flexible building energy management system



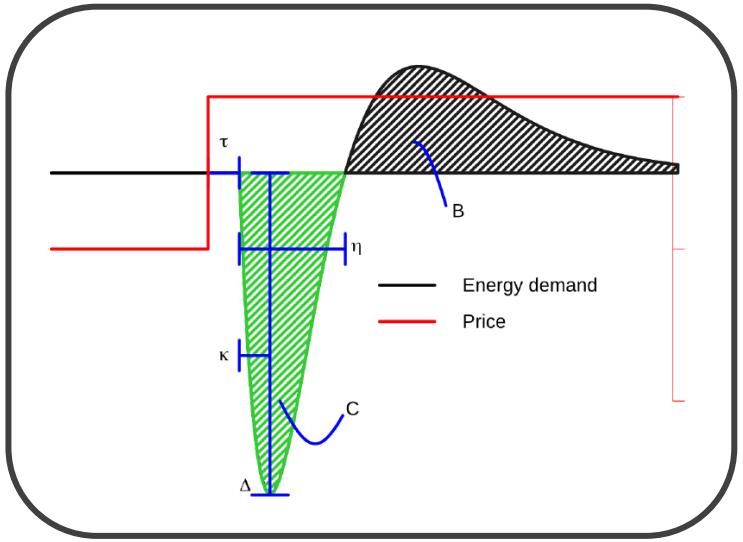


Determine customer prices and energy demand simultaneously

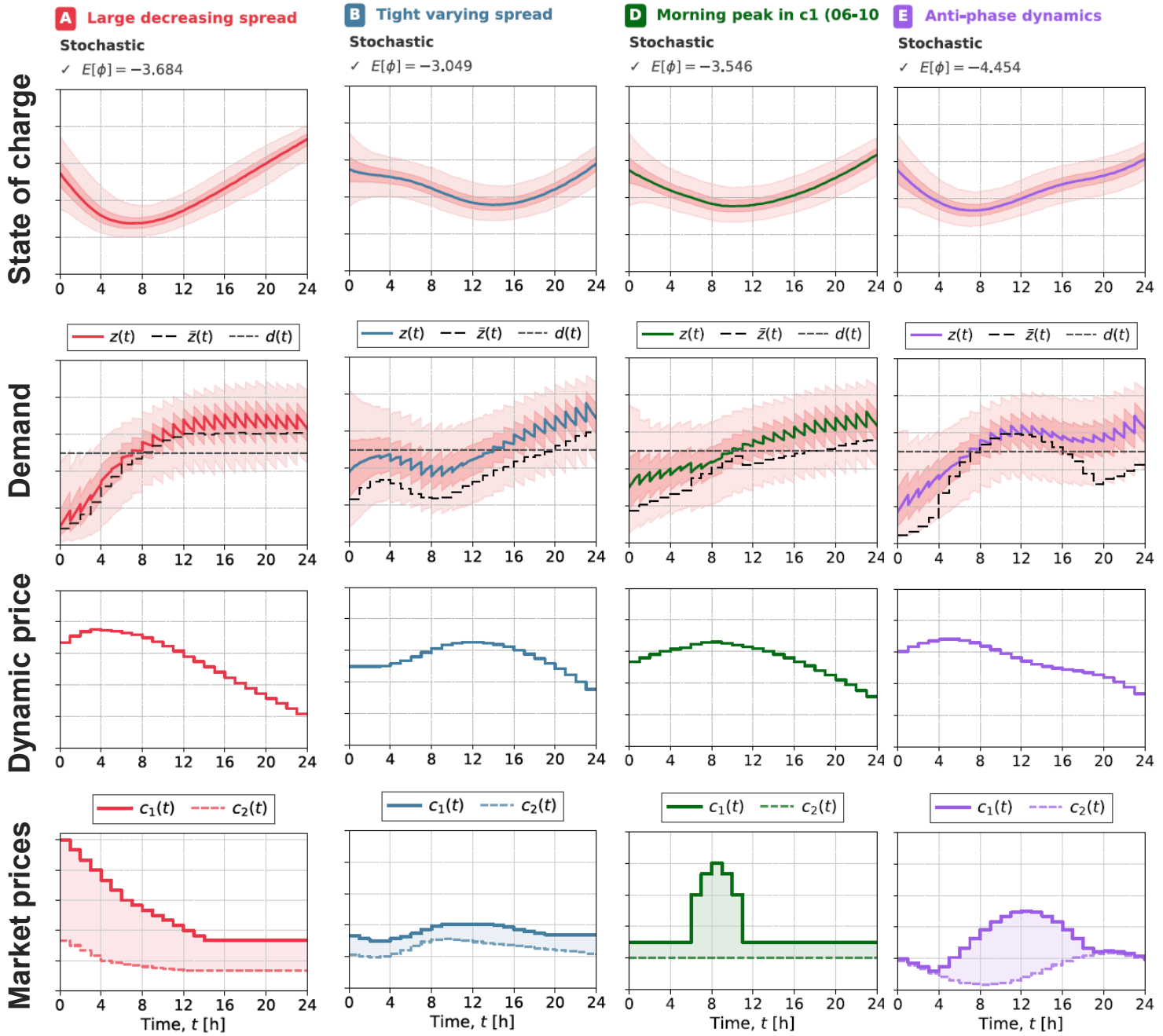
Minimize Worst-case Intraday cost + Day-ahead cost **and maximize** Revenue from customers

Subject to Average customer price bound

Based on Demand response model predictions (flexibility function)



Examples


A Large decreasing spread
B Tight varying spread
D Morning peak in c1 (06-10
E Anti-phase dynamics
Stochastic
✓ $E[\phi] = -3.684$
✓ $E[\phi] = -3.049$
✓ $E[\phi] = -3.546$
✓ $E[\phi] = -4.454$
State of charge
Demand
Dynamic price
Market prices
$z(t)$ $\bar{z}(t)$ $d(t)$
$c_1(t)$ $c_2(t)$
0 4 8 12 16 20 24
Time, t [h]

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
- Combine w. optimal bidding

Thank you