

Unlocking End-user Flexibility



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<https://www.flexibleenergydenmark.dk/>

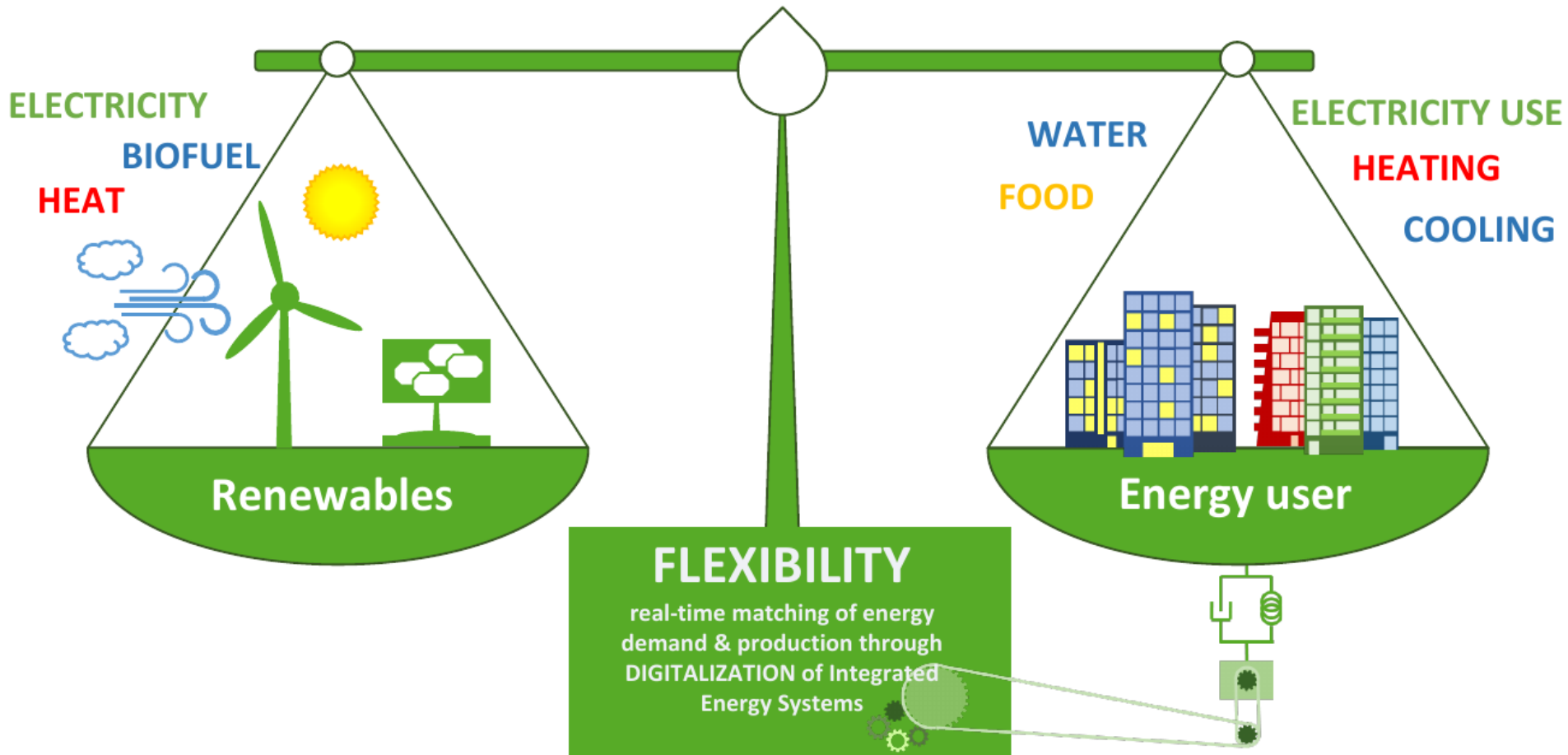
<https://www.smart-cities-centre.org>

<http://www.henrikmadsen.org>

Challenges



The Challenge: Denmark Fossil Free 2050



Markets - Needed changes

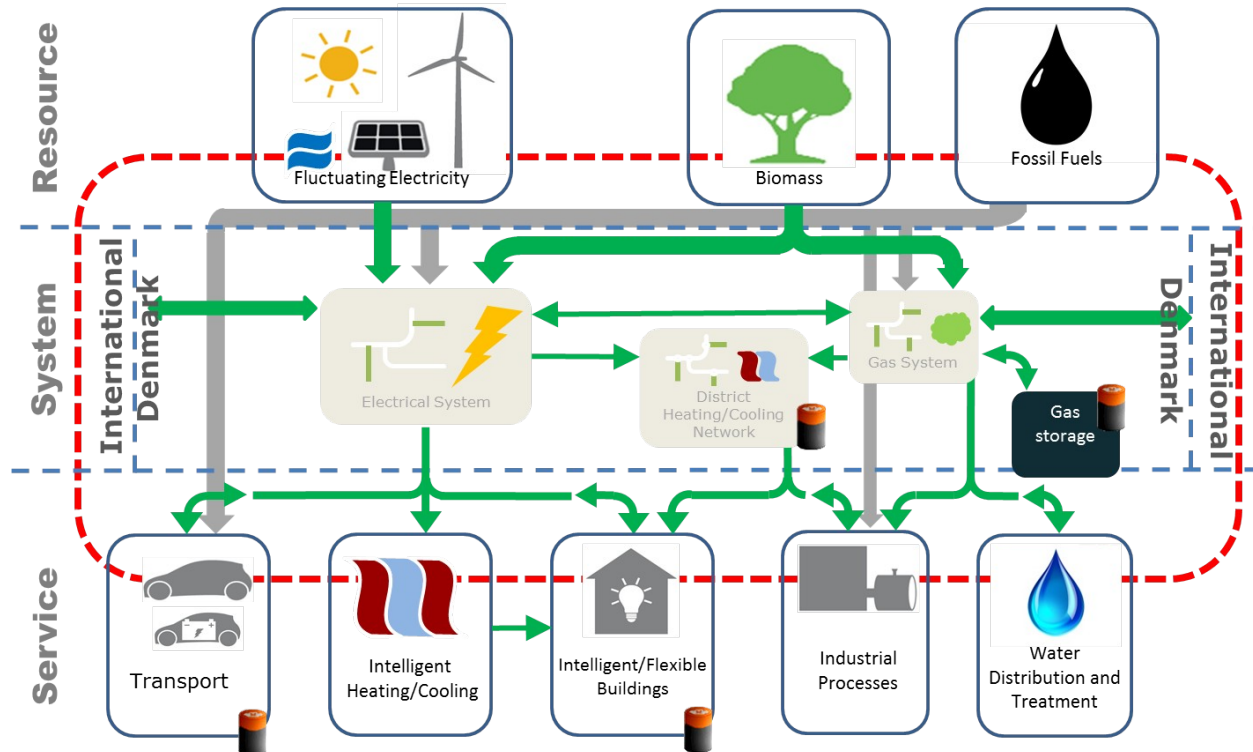
- Static -> **Dynamic**
- Deterministic -> **Stochastic**
- Linear -> **Nonlinear**
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, ...) -> **Coordination + Hierarchy**
- Speed / problem size -> **Decomposition + Control Based Solutions**
- Characterization of flexibility (bids) -> **Flexibility Functions**
- Requirements on user installations -> **One-way communication**

Data-Intelligent and Flexible Energy Systems



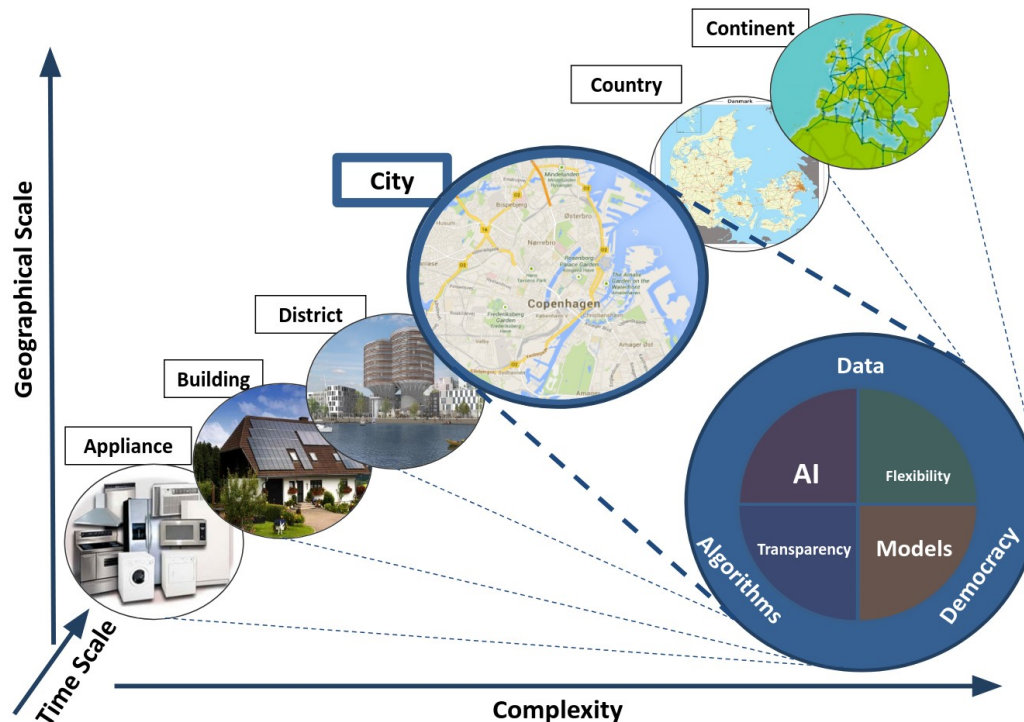
Energy System Models for Real Time Applications and Data Assimilation

Grey-box models are simplified models for the individual components facilitating system integration and use of sensor data in real-time



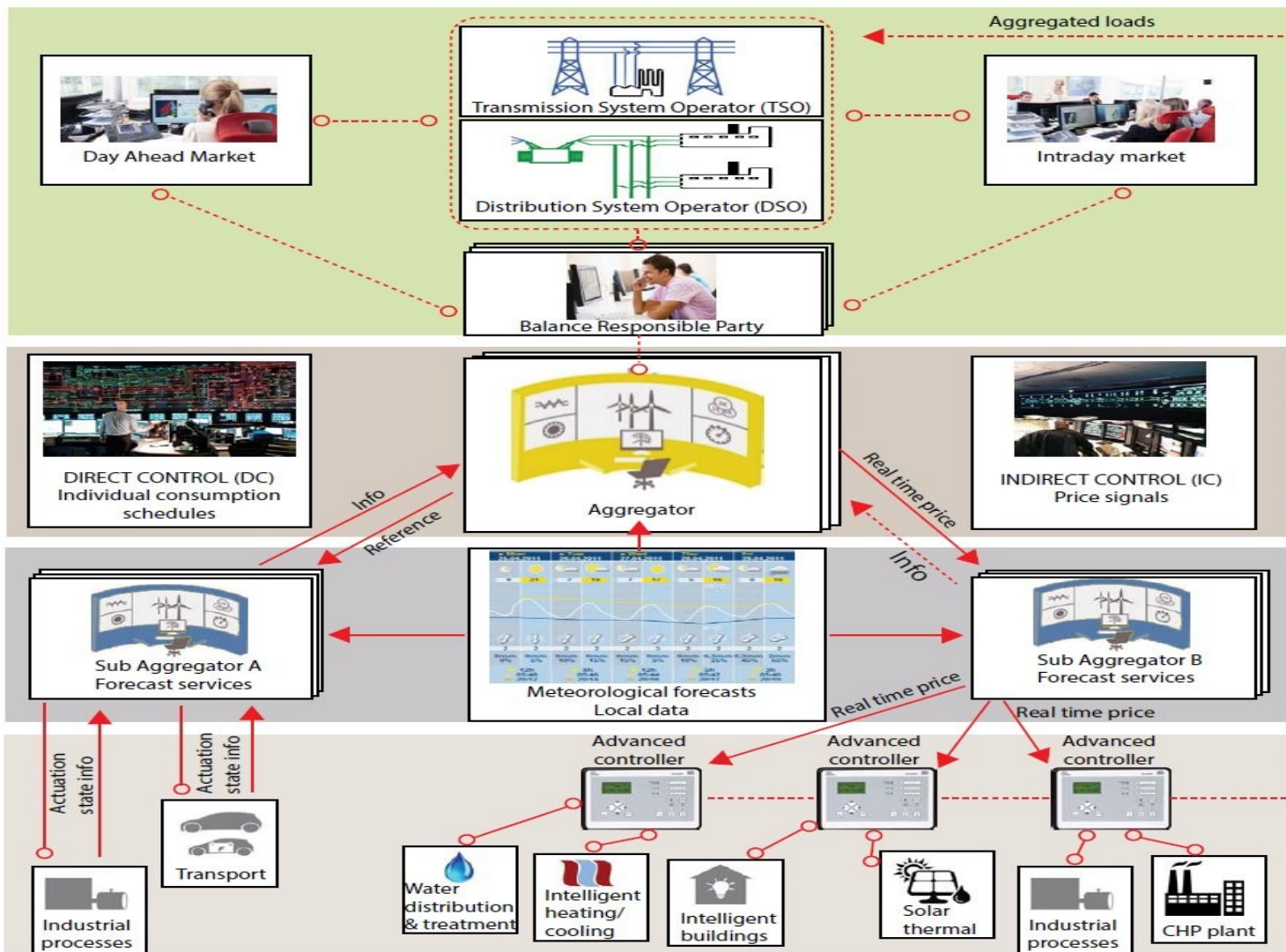
Temporal and Spatial Scales

A so-called **Smart-Energy Operating-System (SE-OS)** is developed in order to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for **operating flexible electrical energy systems at all scales**.



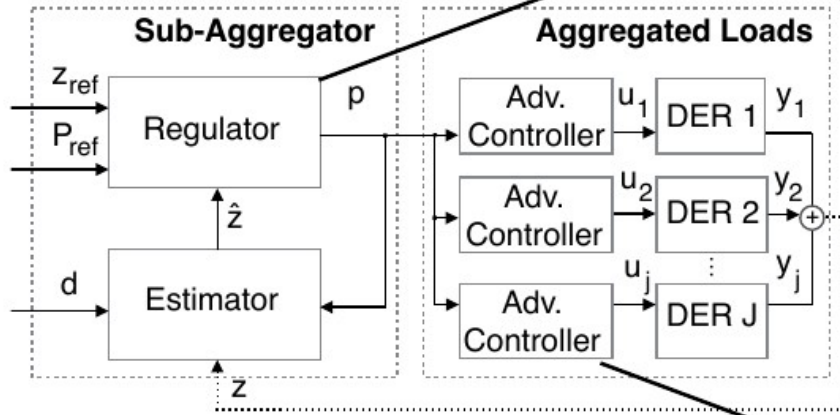
Smart-Energy OS

The Transformative Power of Digitalization



Proposed methodology

Control-based methodology



$$\min_p \quad \mathbb{E} \left[\sum_{k=0}^N w_{j,k} \|\hat{z}_k - z_{ref,k}\| + \mu \|p_k - p_{ref,k}\| \right]$$

$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$

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

$$\min_u \quad \mathbb{E} \left[\sum_{k=0}^N \sum_{j=1}^J \phi_j(x_{j,k}, u_{j,k}, p_k) \right]$$

$$\text{s.t.} \quad x_{k+1} = Ax_k + Bu_k + Ed_k,$$

$$y_k = Cx_k,$$

$$y_k^{\min} \leq y_k \leq y_k^{\max},$$

$$u_k^{\min} \leq u_k \leq u_k^{\max}$$

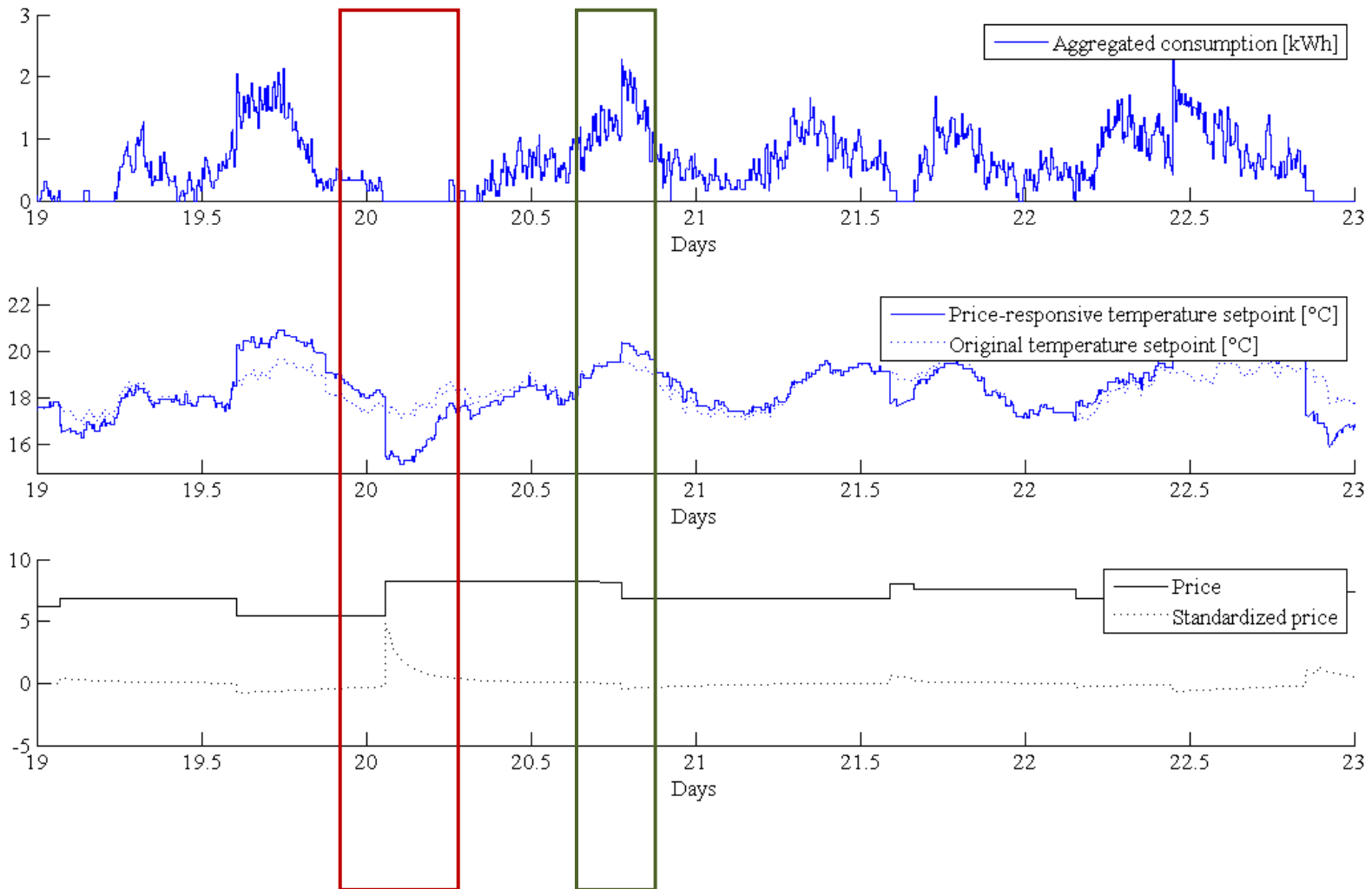


Case study (Level III)

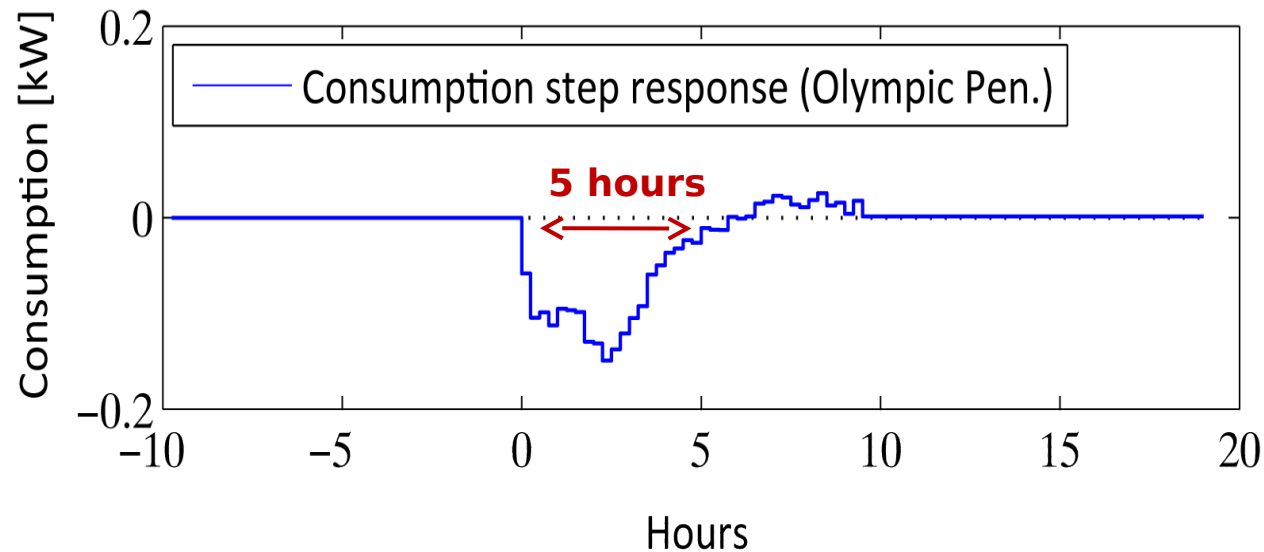
Price-based Control of Power Consumption (Peak Shaving)



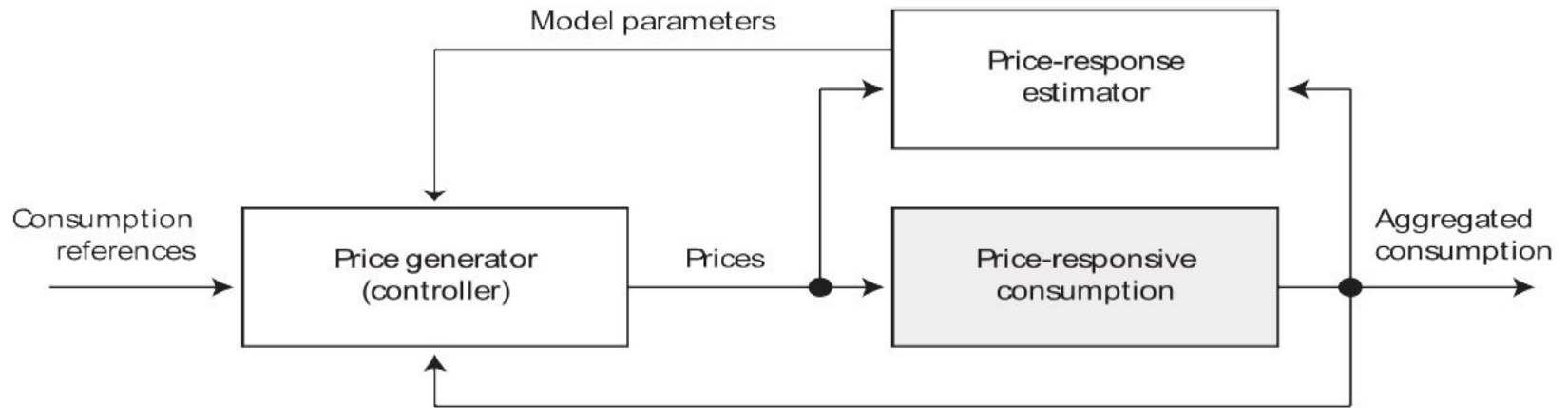
Aggregation (over 20 houses)



Response on Price Step Change

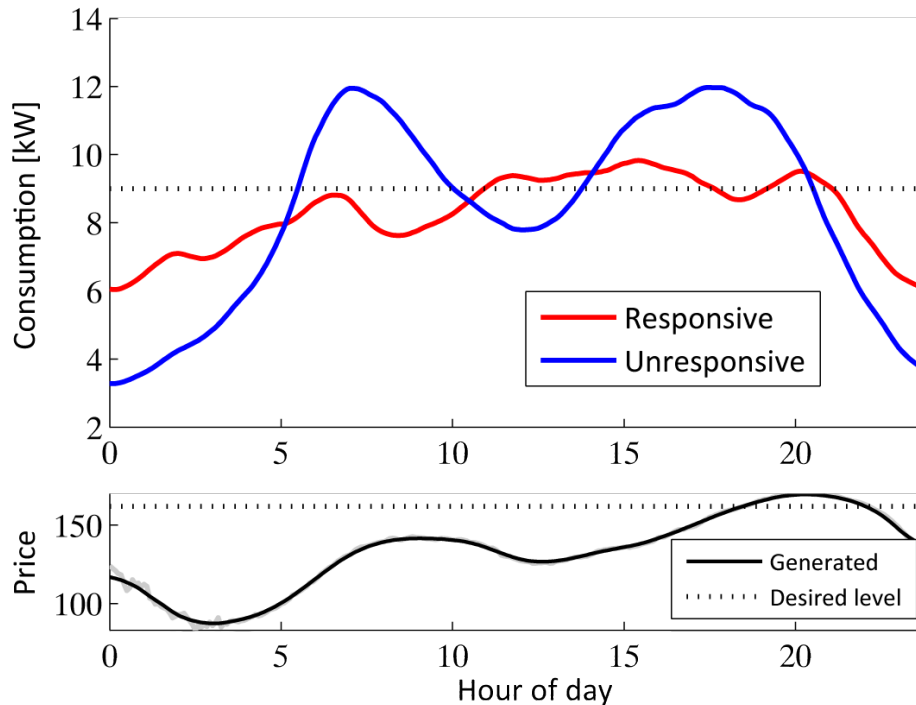


Control of Power Consumption



Control performance

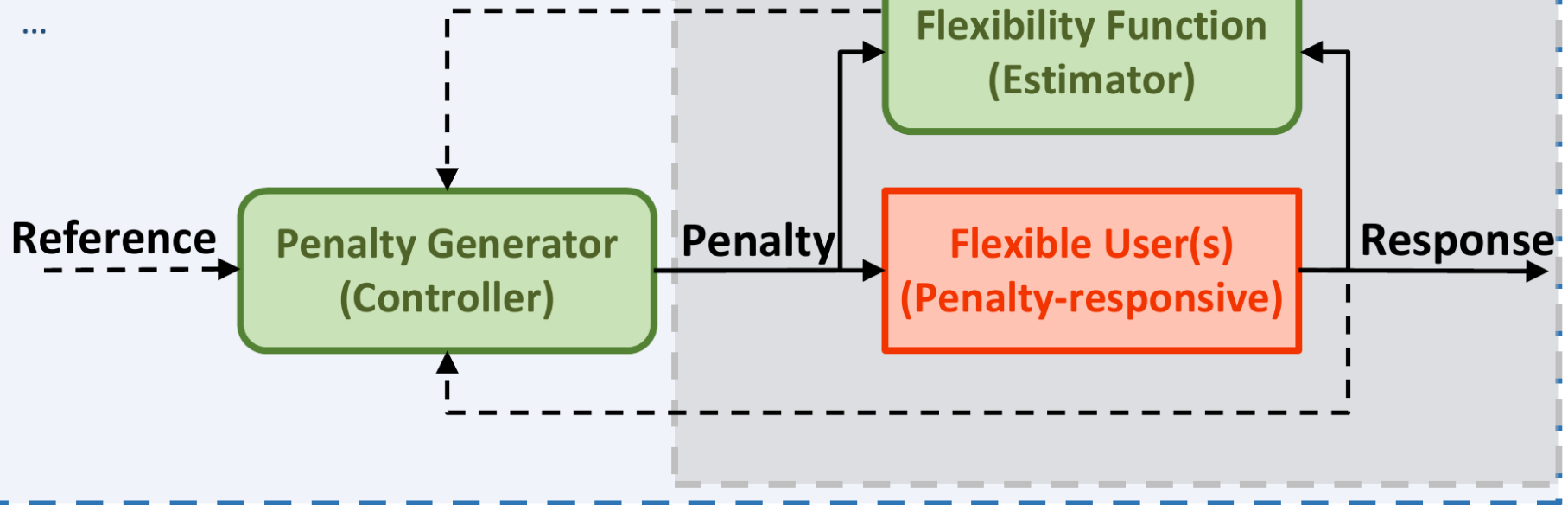
Considerable **reduction in peak consumption**



A FED example: Flexible Users and Penalty Signals

Penalty Generator for, e.g.:

Voltage Control,
Balancing,
Congestion Management
...



Case study (level IV)

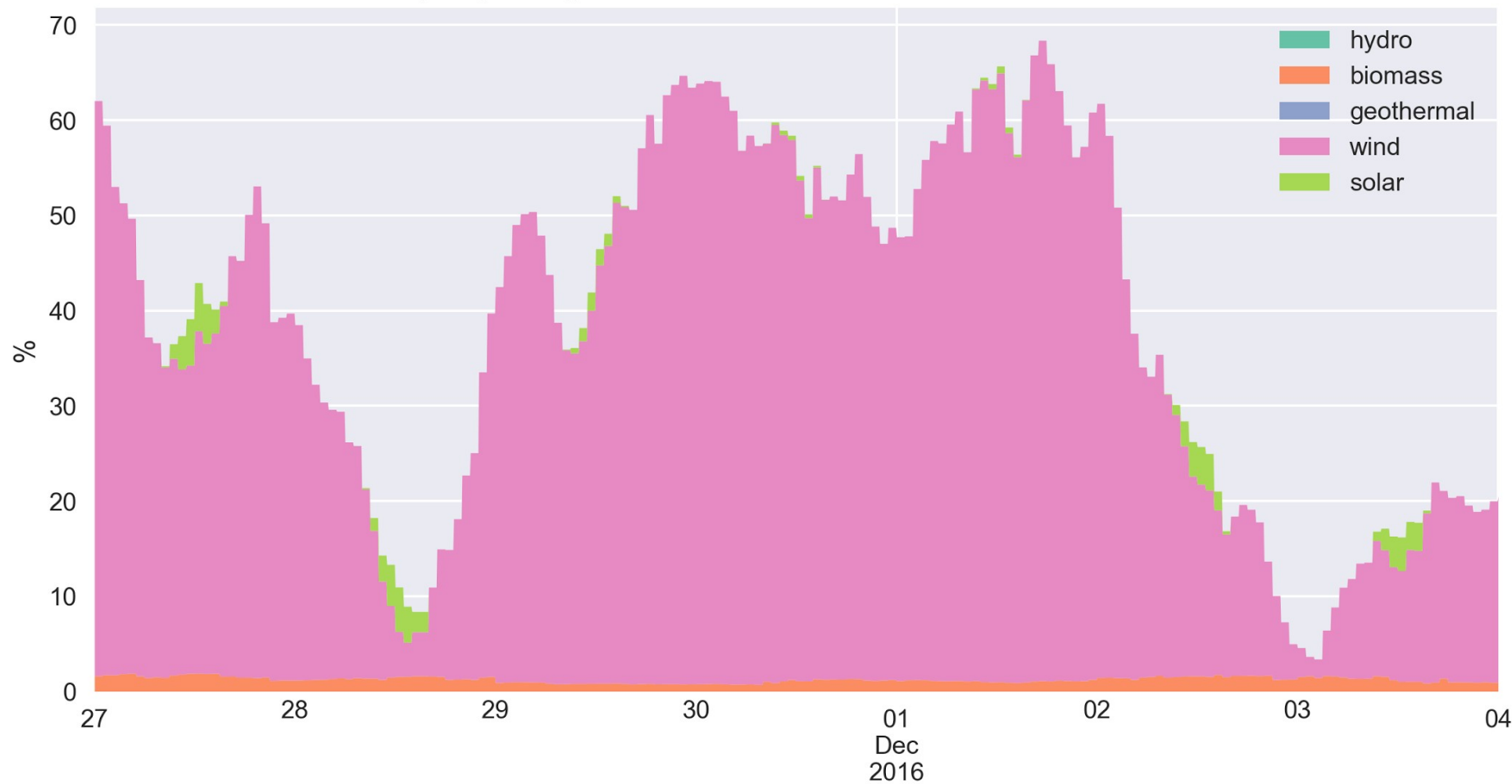
Control of heat pumps for buildings with a pool

(Price/CO₂-based control)





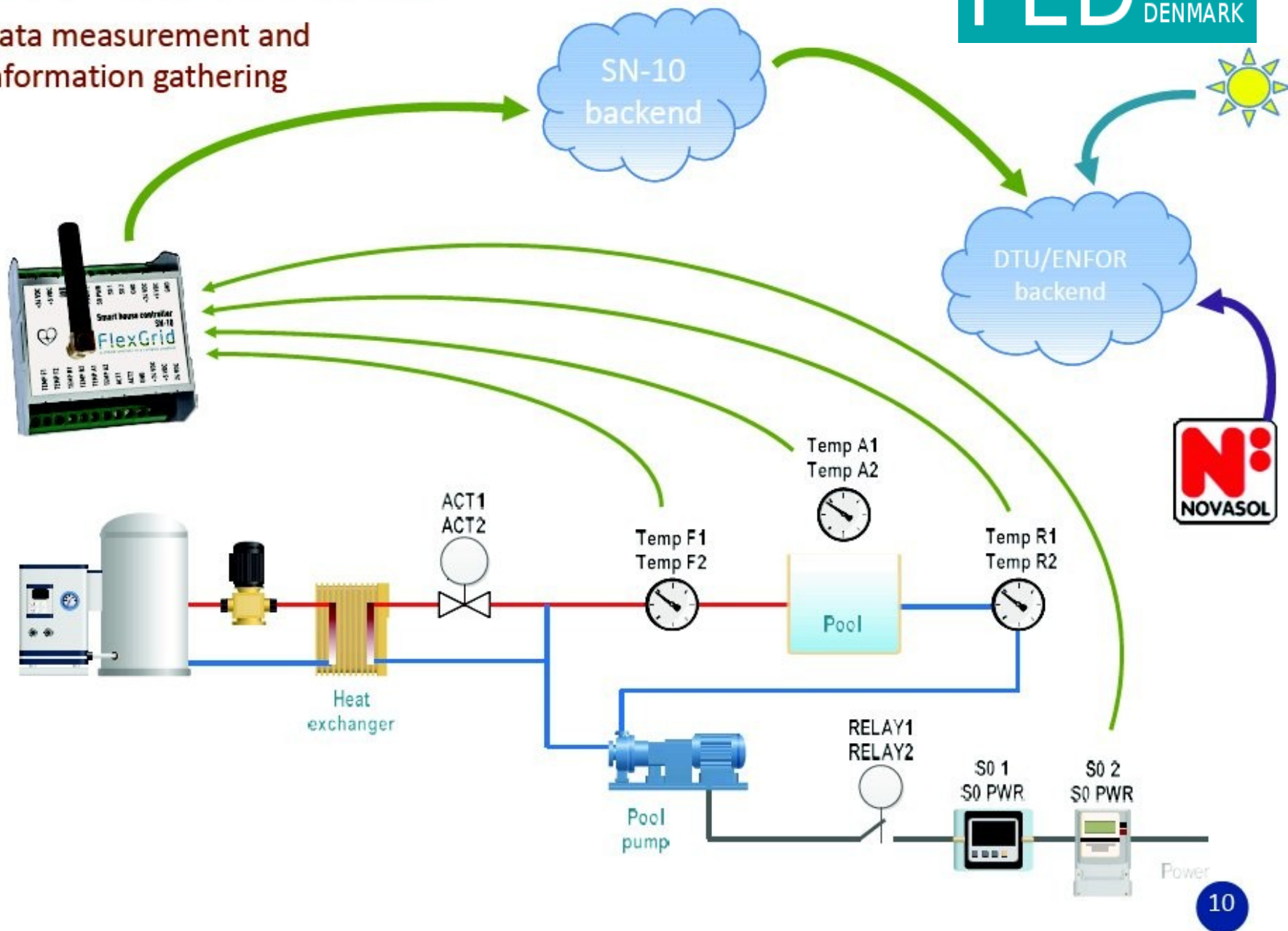
Share of electricity originating from renewables in Denmark Late Nov 2016 - Start Dec 2016



Source: pro.electricitymap.org

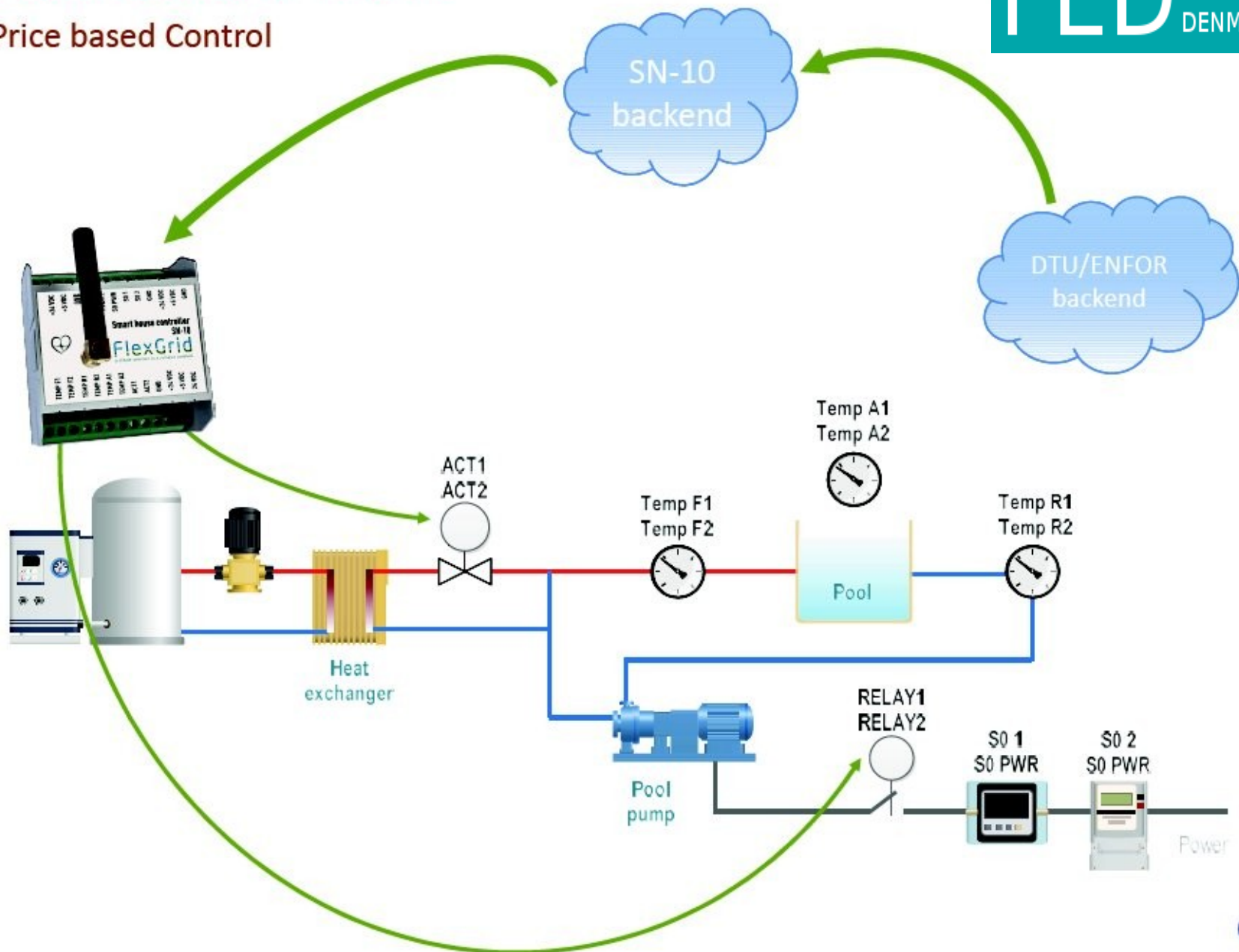
How does it work?

Data measurement and
information gathering



How does it work?

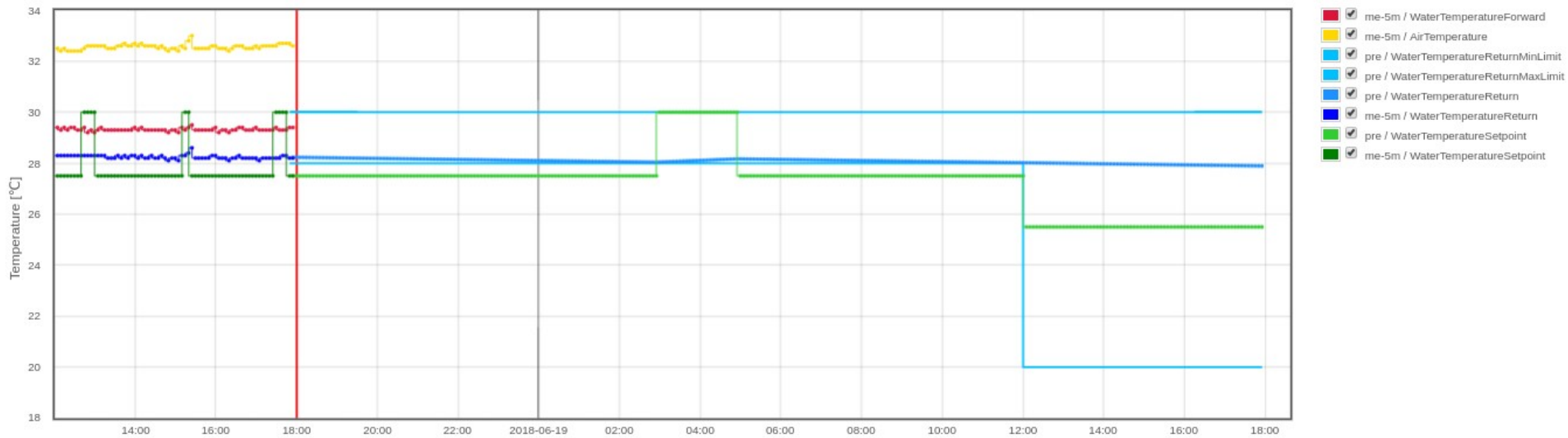
Price based Control



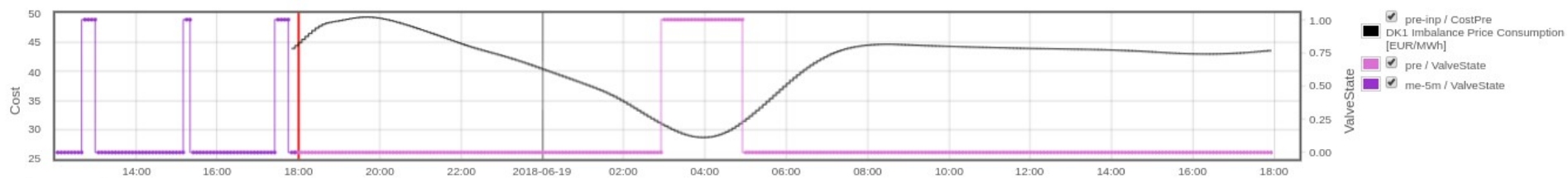
Example: Price-based control

A3074 Controller

Cost: DK1 Imbalance Price Consumption [EUR/MWh], Adaptive Estimation



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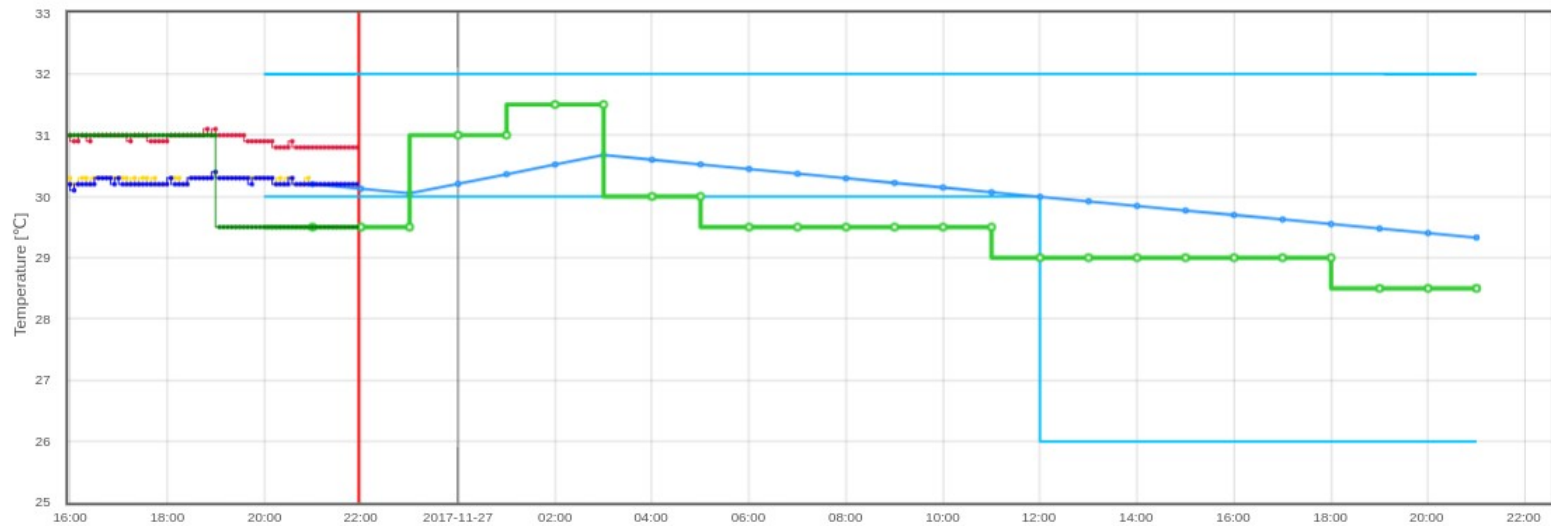


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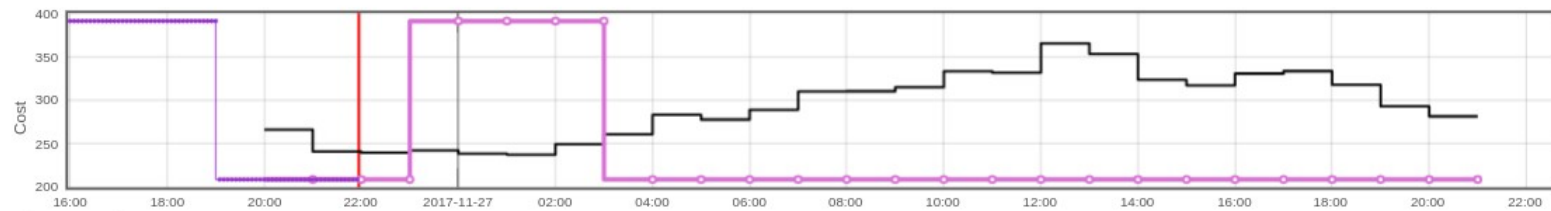
Example: CO2-based control (savings 10-30 pct)

D7811 Controller

Cost: co2intensity [g/kWh]



- ☒ me-5m / WaterTemperatureForward
- ☒ me-5m / AirTemperature
- ☒ pre / WaterTemperatureReturnMinLimit
- ☒ pre / WaterTemperatureReturnMaxLimit
- ☒ pre / WaterTemperatureReturn
- ☒ me-5m / WaterTemperatureReturn
- ☒ pre / WaterTemperatureSetpoint
- ☒ me-5m / WaterTemperatureSetpoint



- ☒ pre-inp / CostPre
- ☒ co2intensity [g/kWh]
- ☒ pre / ValveState
- ☒ me-5m / ValveState

Summary

- The **future weather-driven energy** system calls for digitalization of the energy systems in **Buildings** and **Smart Cities**.
- We need **a deep digitalisation** (AI, IoT, Cloud/Fog/Edge Computing, etc.)
- Buildings can provide **grid flexibility** (peak, voltage, congestion, temperature of transformers, ...)
- We need **data hubs** for energy related streaming data (like **Center Denmark**)

