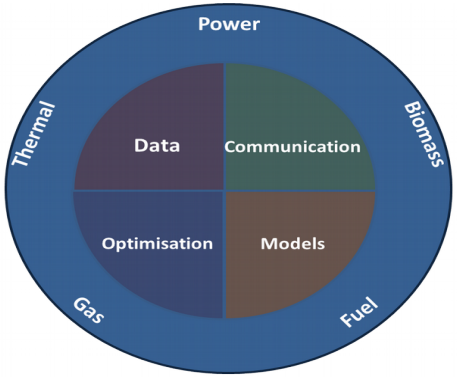
Methodologies for Implementing Future Intelligent and Integrated Energy Systems; Experiences from CITIES and EU SmartNet Projects



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DTU Compute

http://www.smart-cities-centre.org

http://smartnet-project.eu

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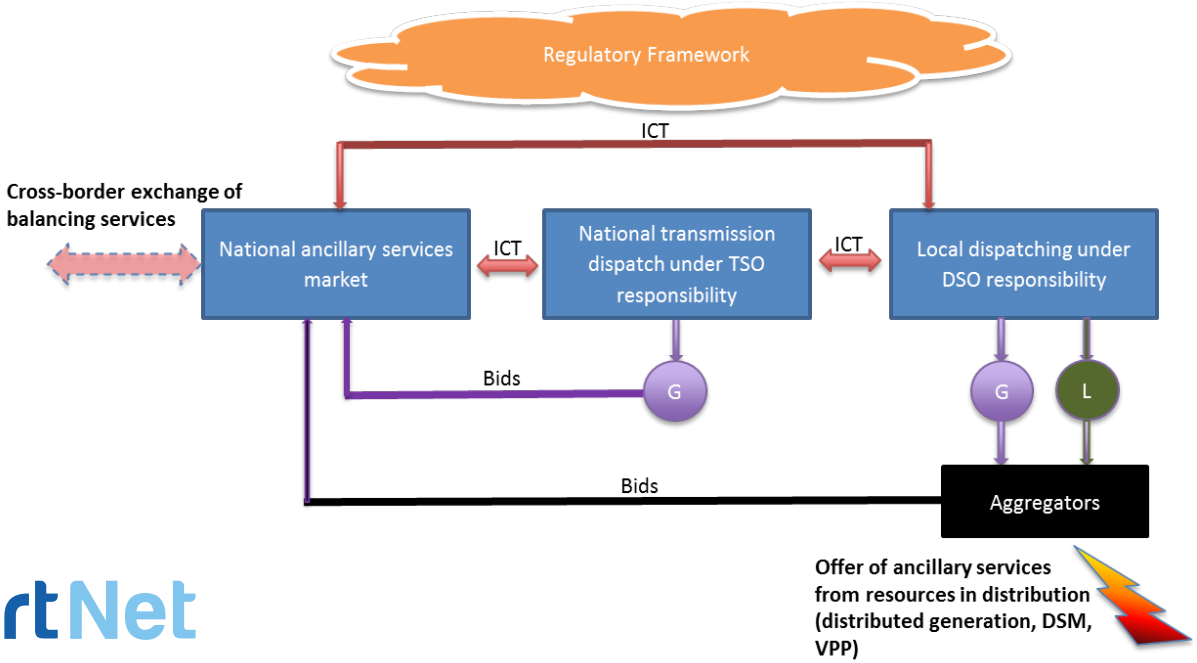
Power Grid is the Backbone - The SmartNet project
Lead by Gianluigi Migliavacca (RSE)

- The project SmartNet aims at comparing different **architectures for optimized interaction between TSOs and DSOs** in managing the purchase of ancillary services from subjects located in distribution.
- An *ad hoc* simulation platform is built (physical network, market and ICT) around **three national cases** (Italy, Denmark, Spain); a **CBA** is performed to assess which TSO-DSO coordination scheme is optimal for the three countries. The simulation platform is then implemented in a **full replica lab** to test performance of real controller devices.
- **Three physical pilots** are also developed to demonstrate capability to monitoring and control distribution by the TSO and flexibility services that can be offered by distribution (thermal inertia of indoor swimming pools, distributed storage of radio-base stations).



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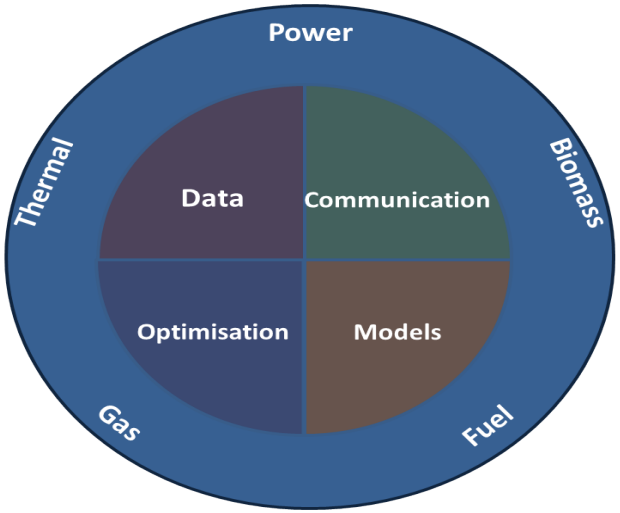
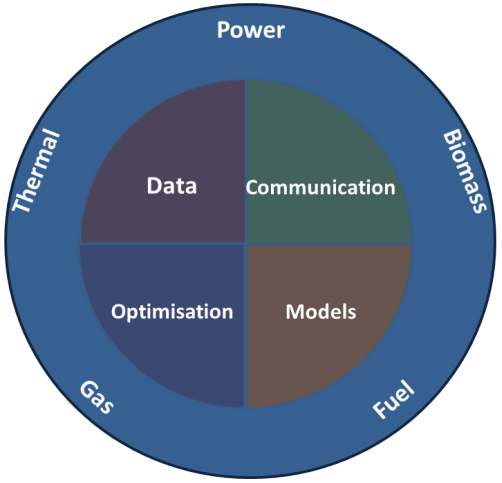
Intelligent and Integrated Energy Systems

Center for IT-Intelligent Energy Systems in Cities (CITIES) is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

CITIES is currently the largest Smart Energy and ESI research project in Denmark – see http://www.smart-cities-centre.org .



Energy Systems Integration



The **central hypothesis** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in cities we can balance very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

Intelligent integration will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.

Existing Markets - Challenges

- Dynamics
- Stochasticity
- Nonlinearities
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, …)
- Speed / problem size
- Characterization of flexibility
- Requirements on user installations

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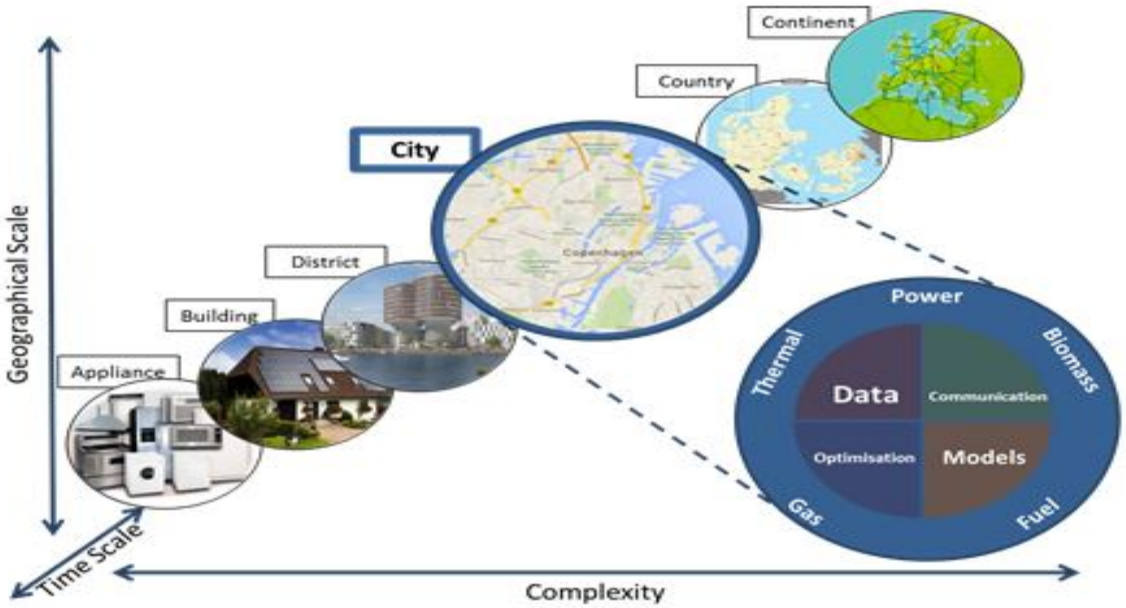
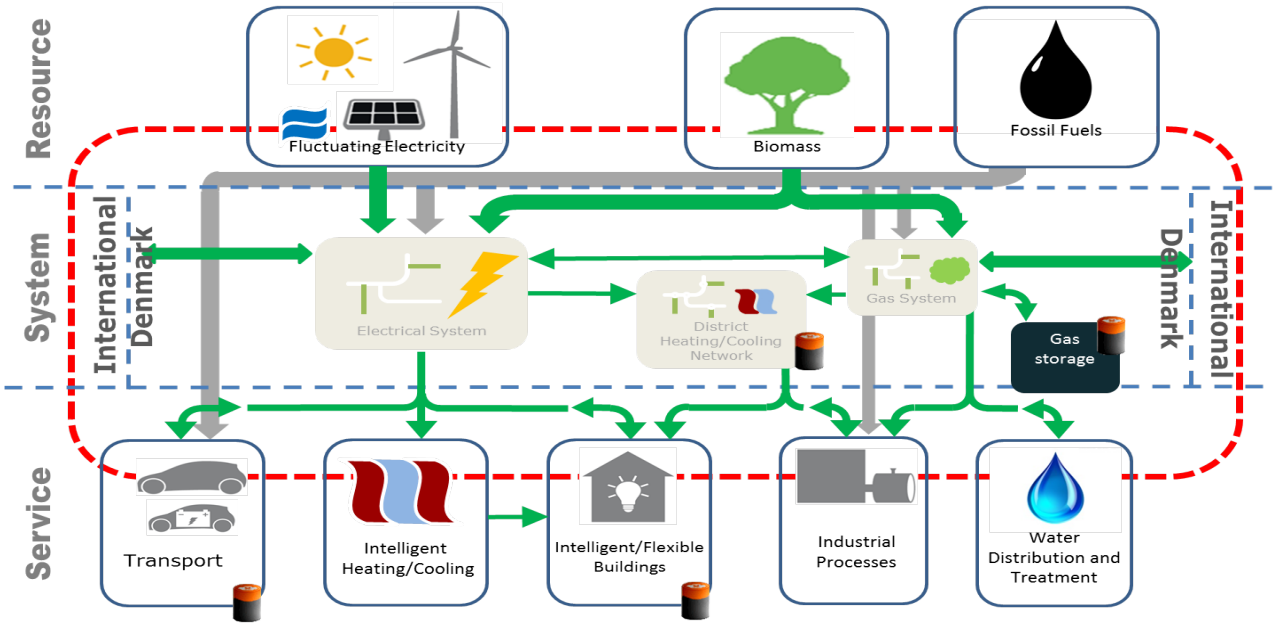
Temporal and Spatial Scales

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

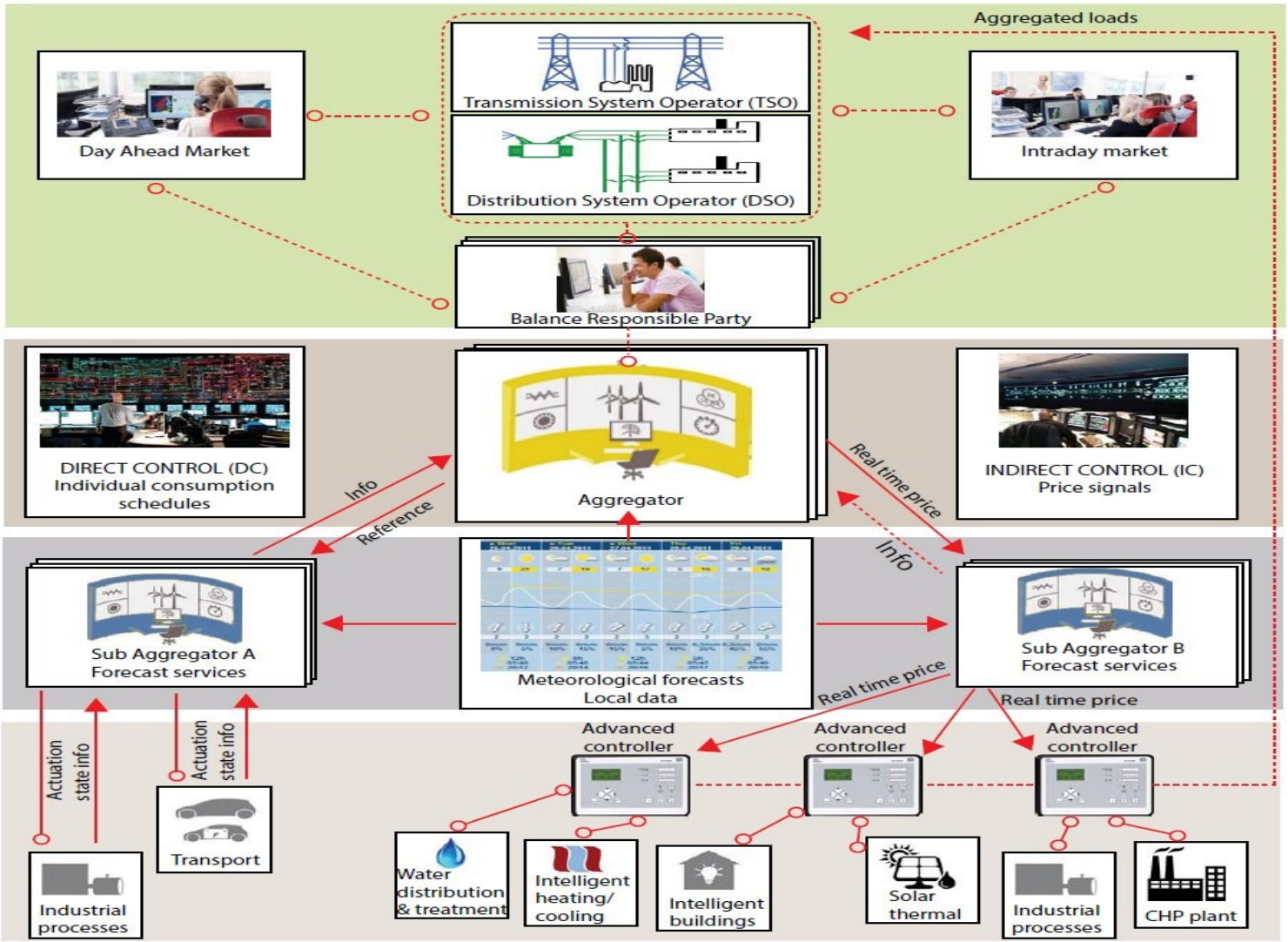


Models for systems of systems

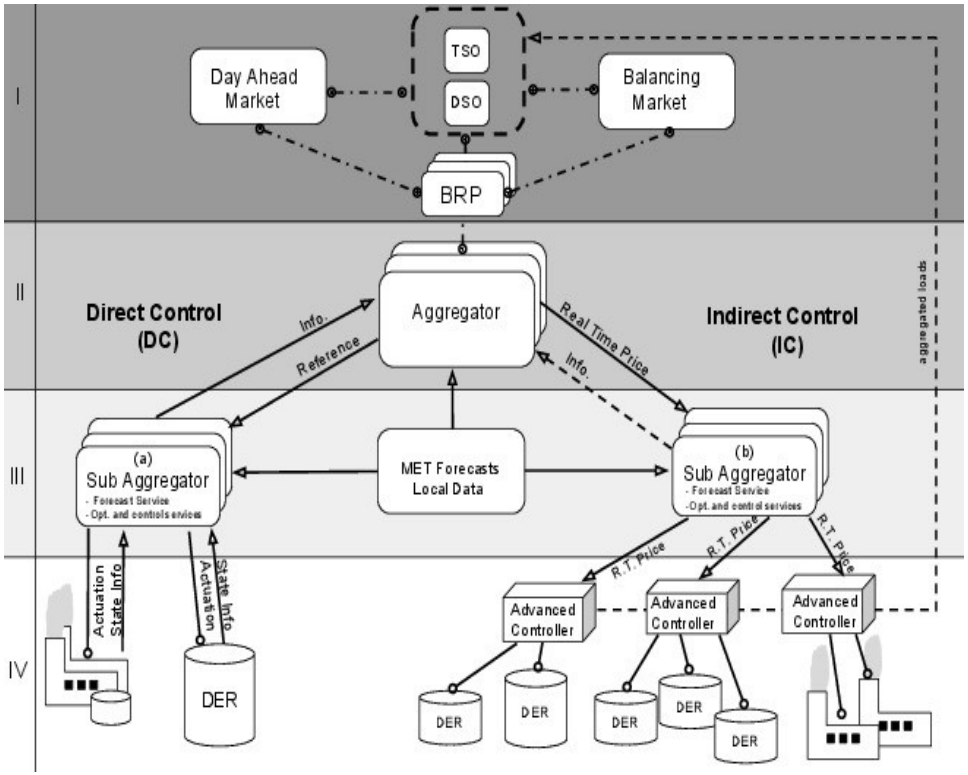
Intelligent systems integration using **data and ICT solutions** are used to establish **models and methods** **for real-time operation of flexible energy systems**



Smart-Energy OS



Control and Optimization



Day Ahead:

Stoch. Programming based on eg. Scenarios

Cost: Related to the market (one or two levels)

Direct Control:

Actuator: **Power**

Two-way communication

Models for DERs are needed

Constraints for the DERs (calls for state est.)

Contracts are complicated

Indirect Control:

Actuator: **Price**

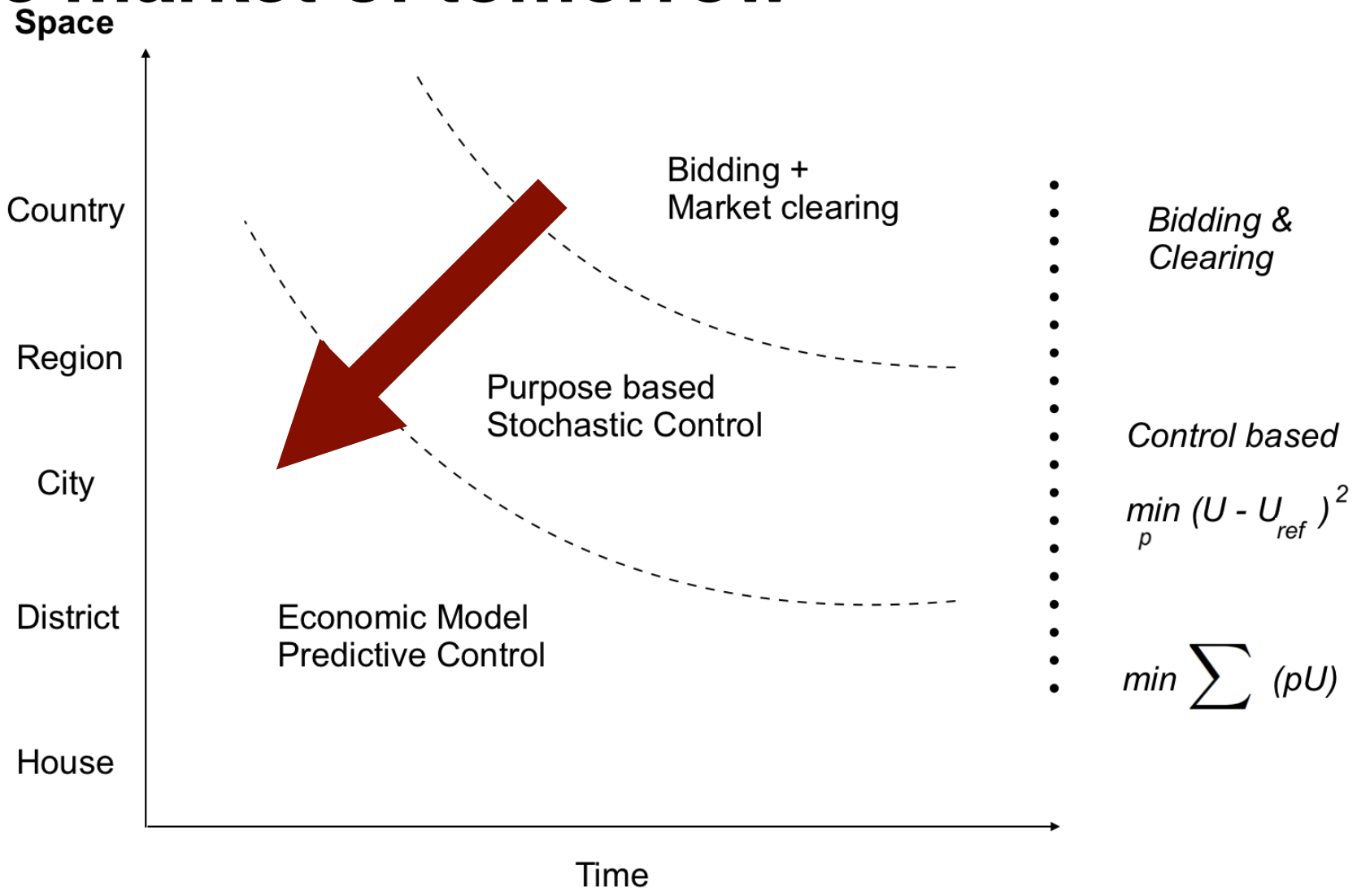
Cost: E-MPC at **low (DER) level**, One-way communication

Models for DERs are not needed

Simple 'contracts'

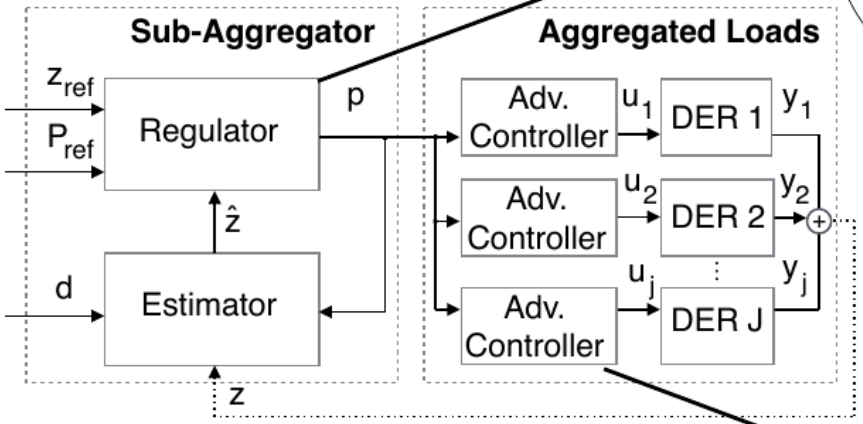
In New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

The market of tomorrow



Proposed methodology
Control-based methodology

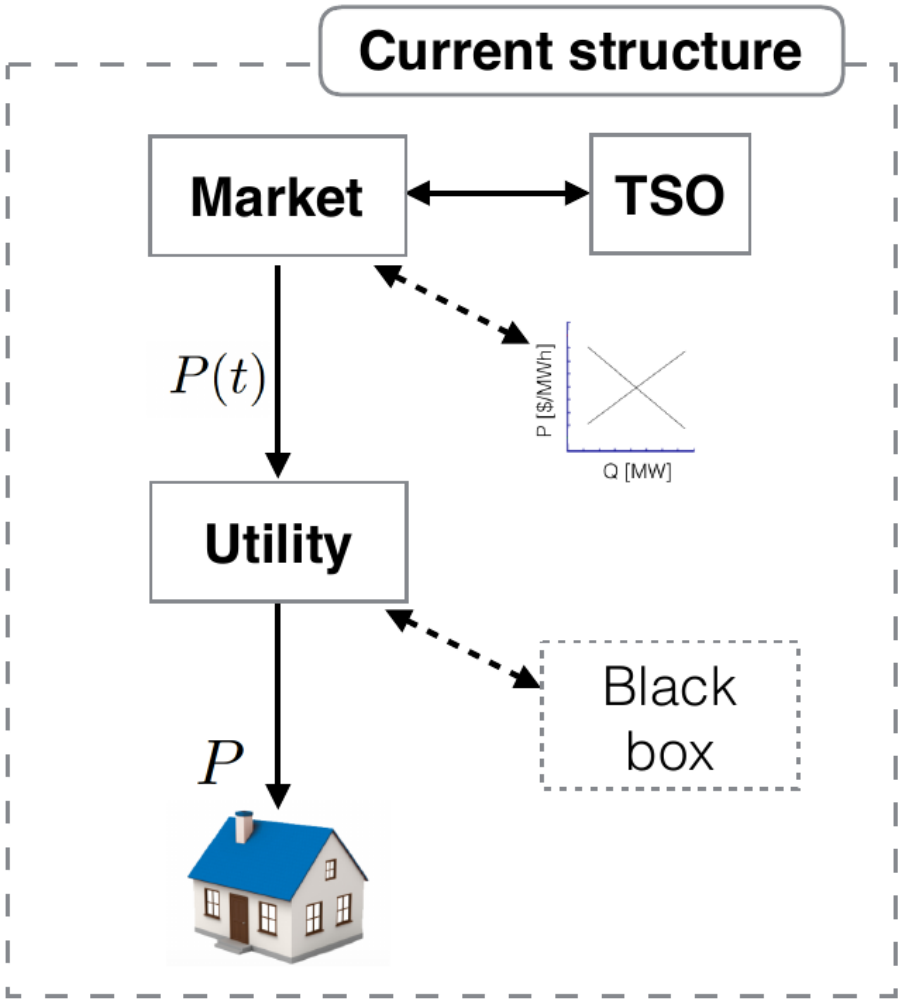
$$\min_{p} \quad \mathrm{E}[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||]$$
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$

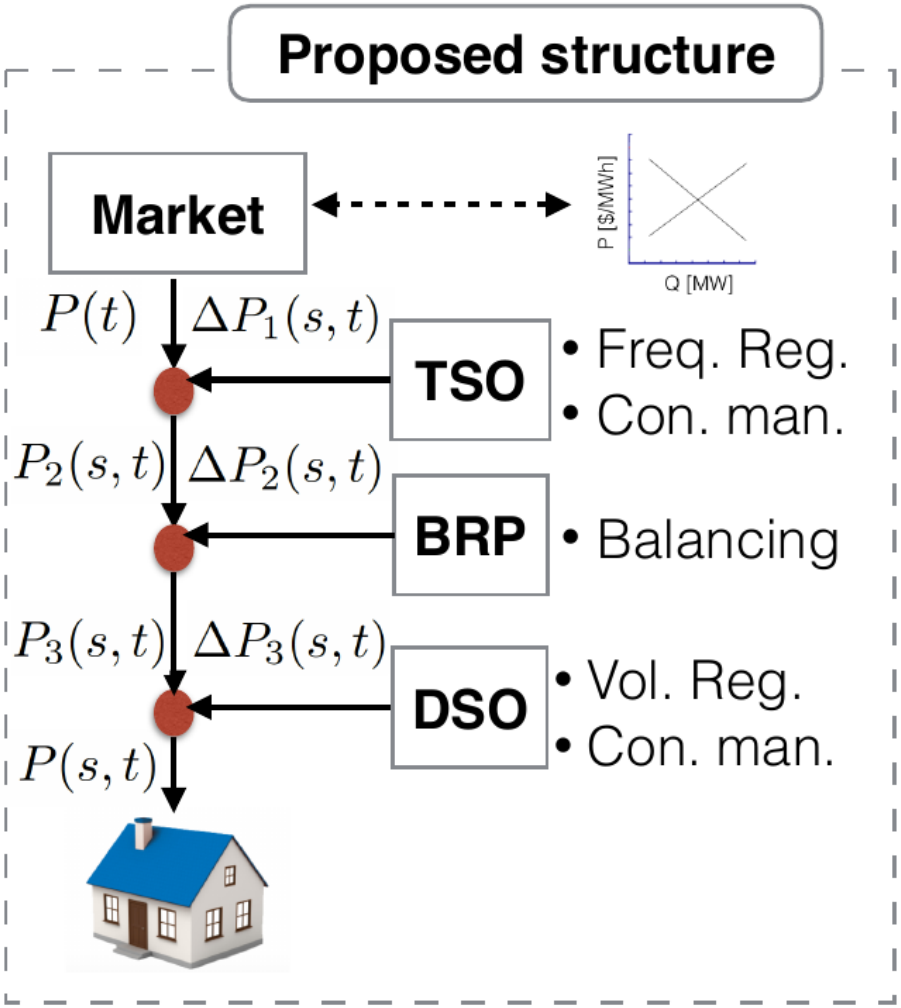


We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

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

Proposed methodology
Structures for the electricity price





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SE-OS Characteristics

- ‘Bidding – clearing – activation’ at higher levels
- Nested sequence of systems – systems of systems
- Hierarchy of optimization (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud or Fog (IoT, IoS) based solutions – eg. for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, …)
- Allow for new players (specialized aggregators)
- Simple setup for the communication and contracts
- Provides a solution for all ancillary services
- Harvest flexibility at all levels

Case study
EU SmartNet – Danish Pilot

Price-based Control of Power Consumption

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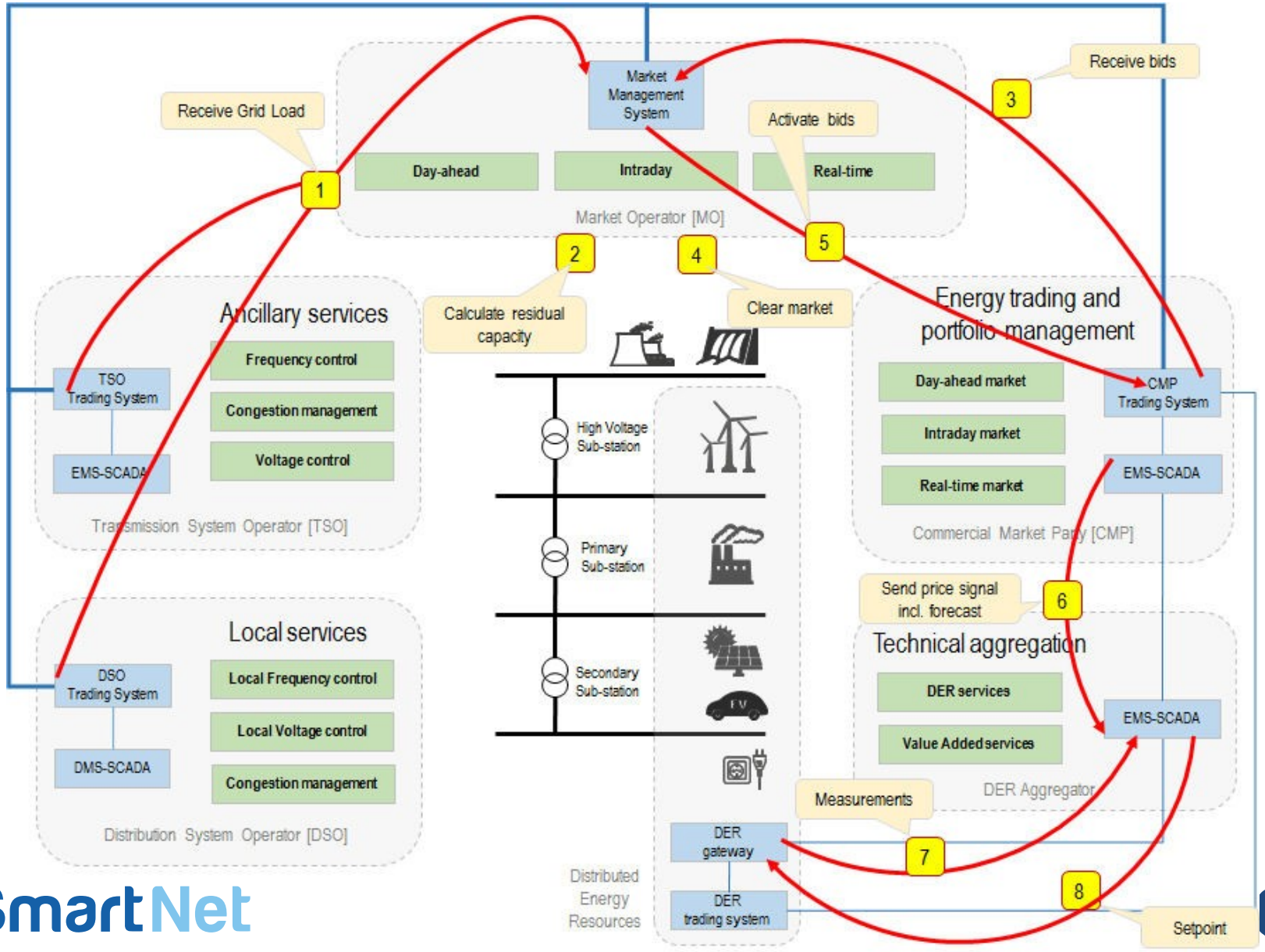
Overview – SmartNet – Danish Pilot



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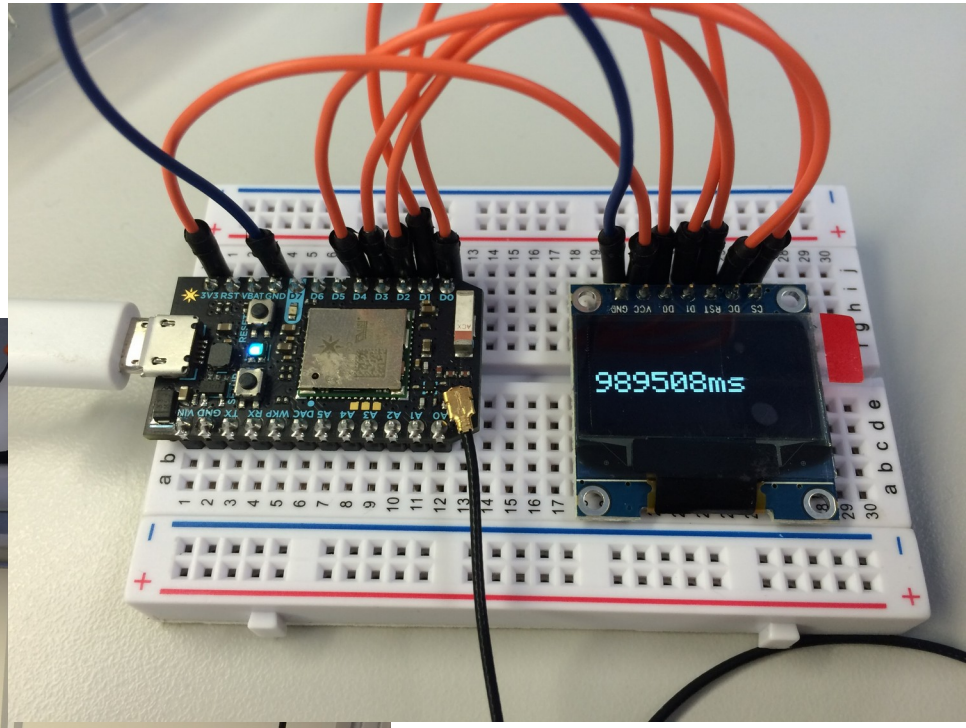
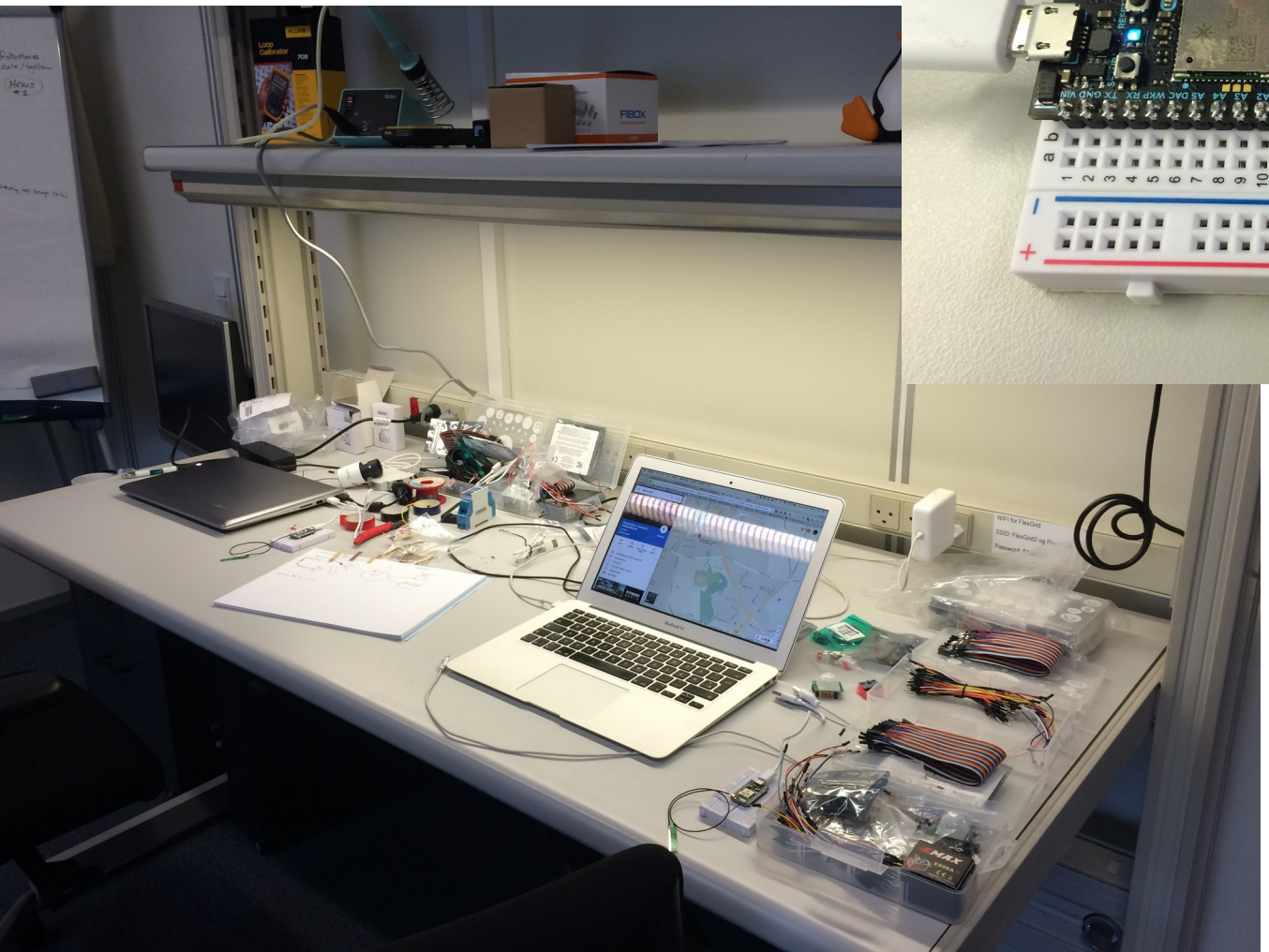
Lab testing ….





How does it work?

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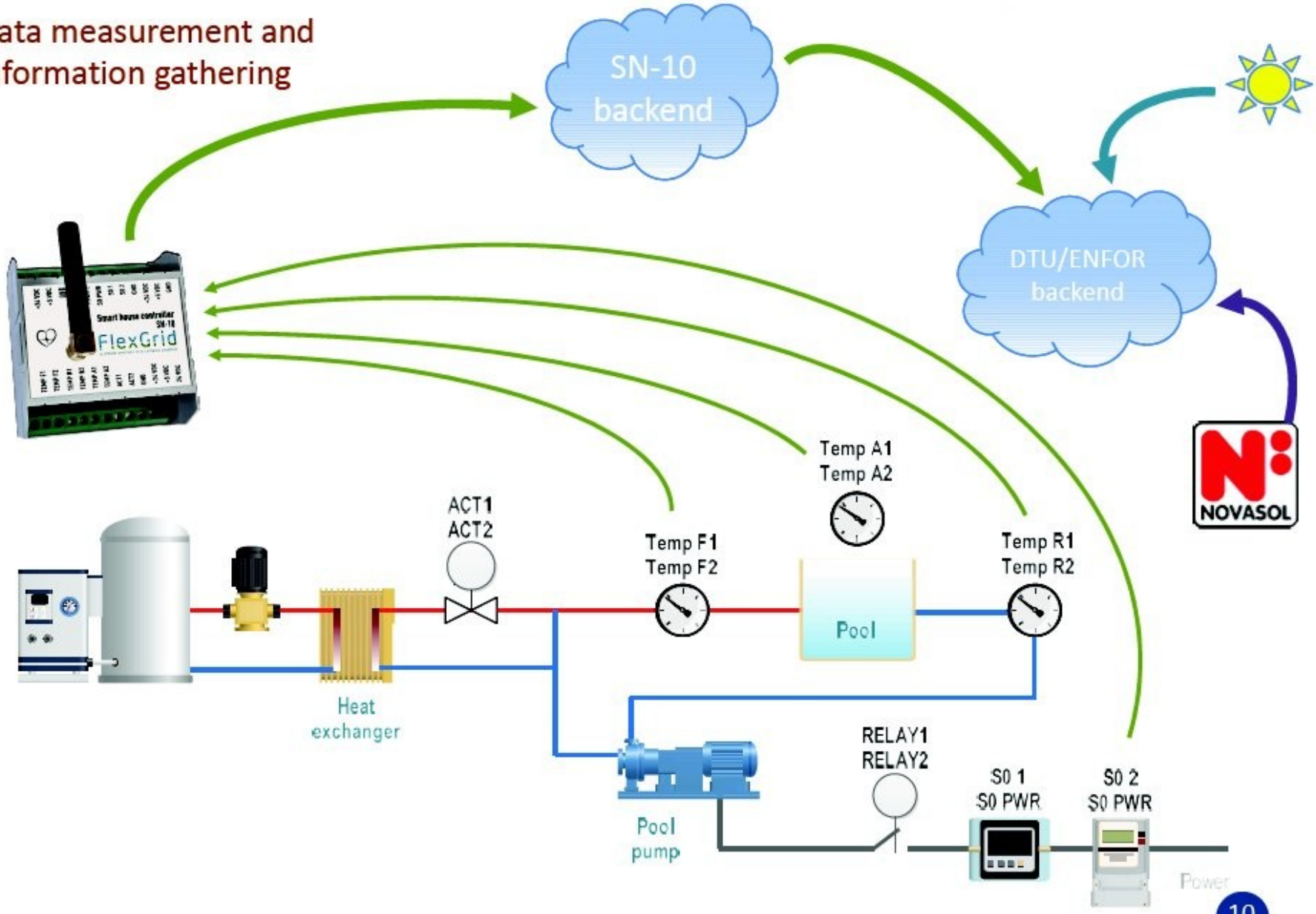
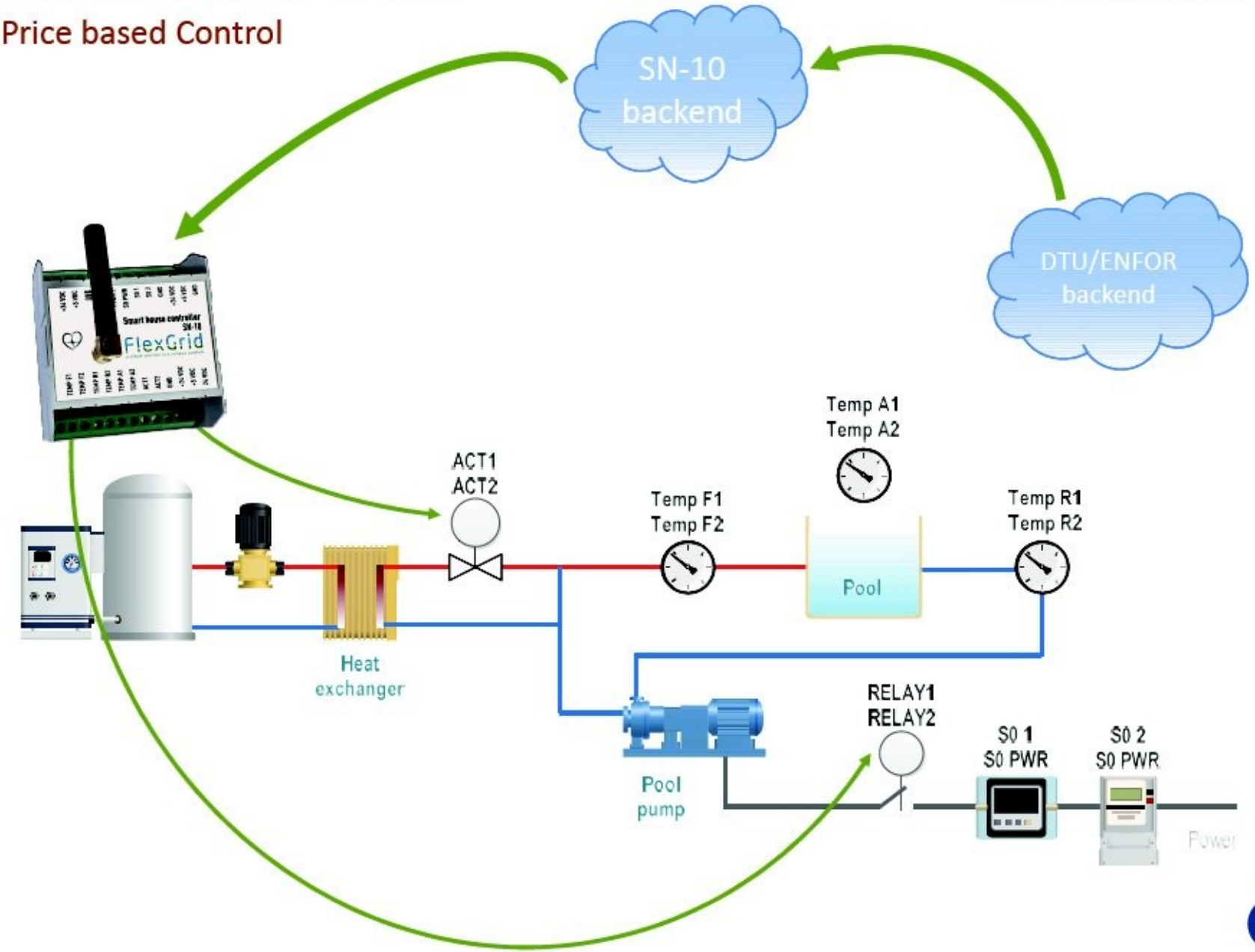
Data measurement and information gathering



How does it work?

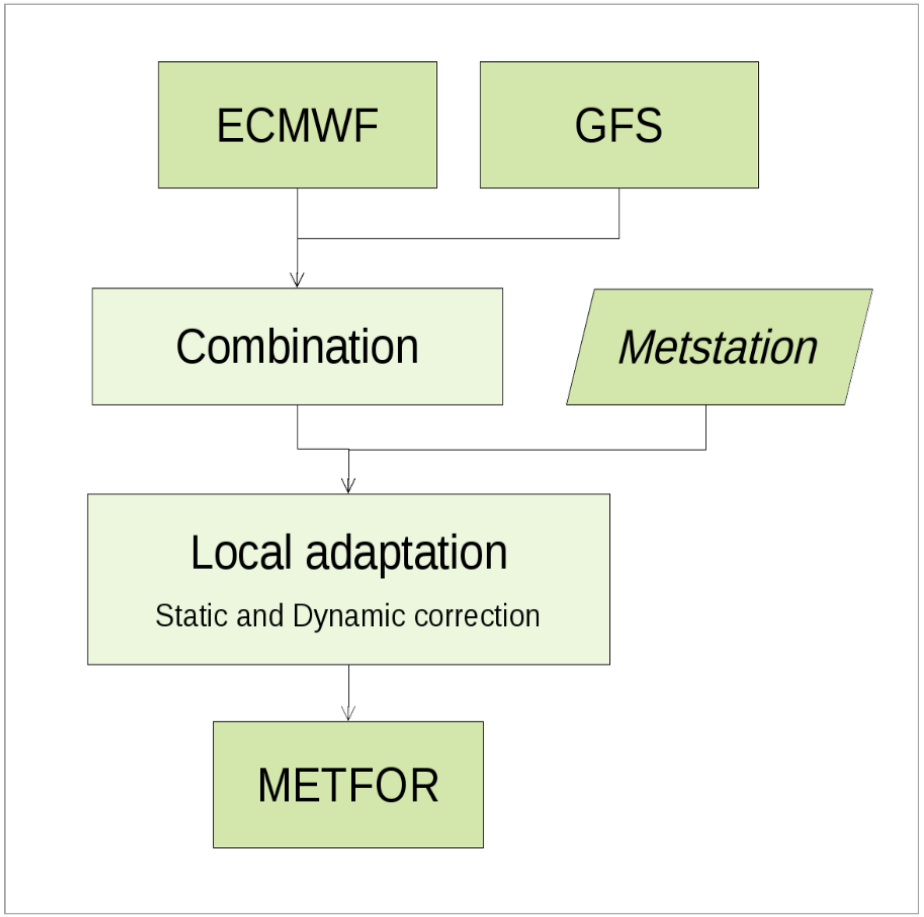
Price based Control



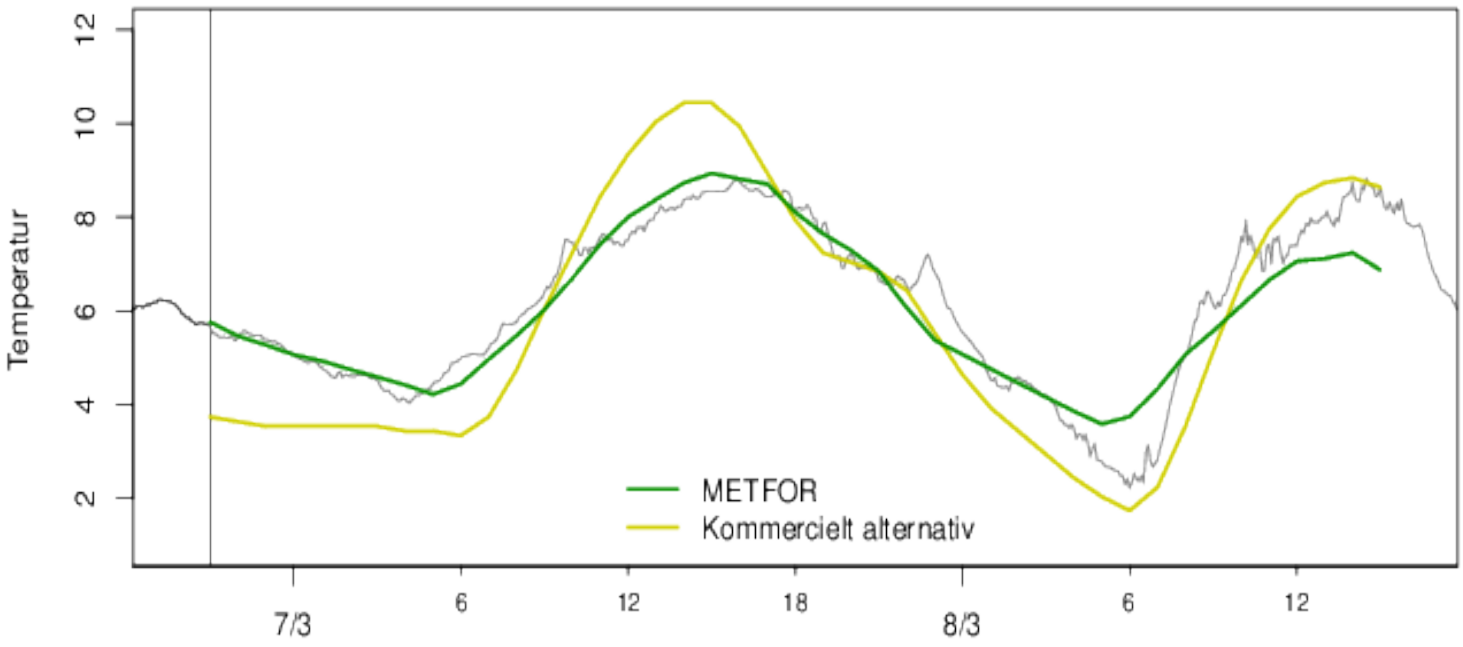
Weather data and forecasts

Optimize local weather forecast based on:

- **Local climate data**
- **Several MET forecasts**



MetFor forecast example



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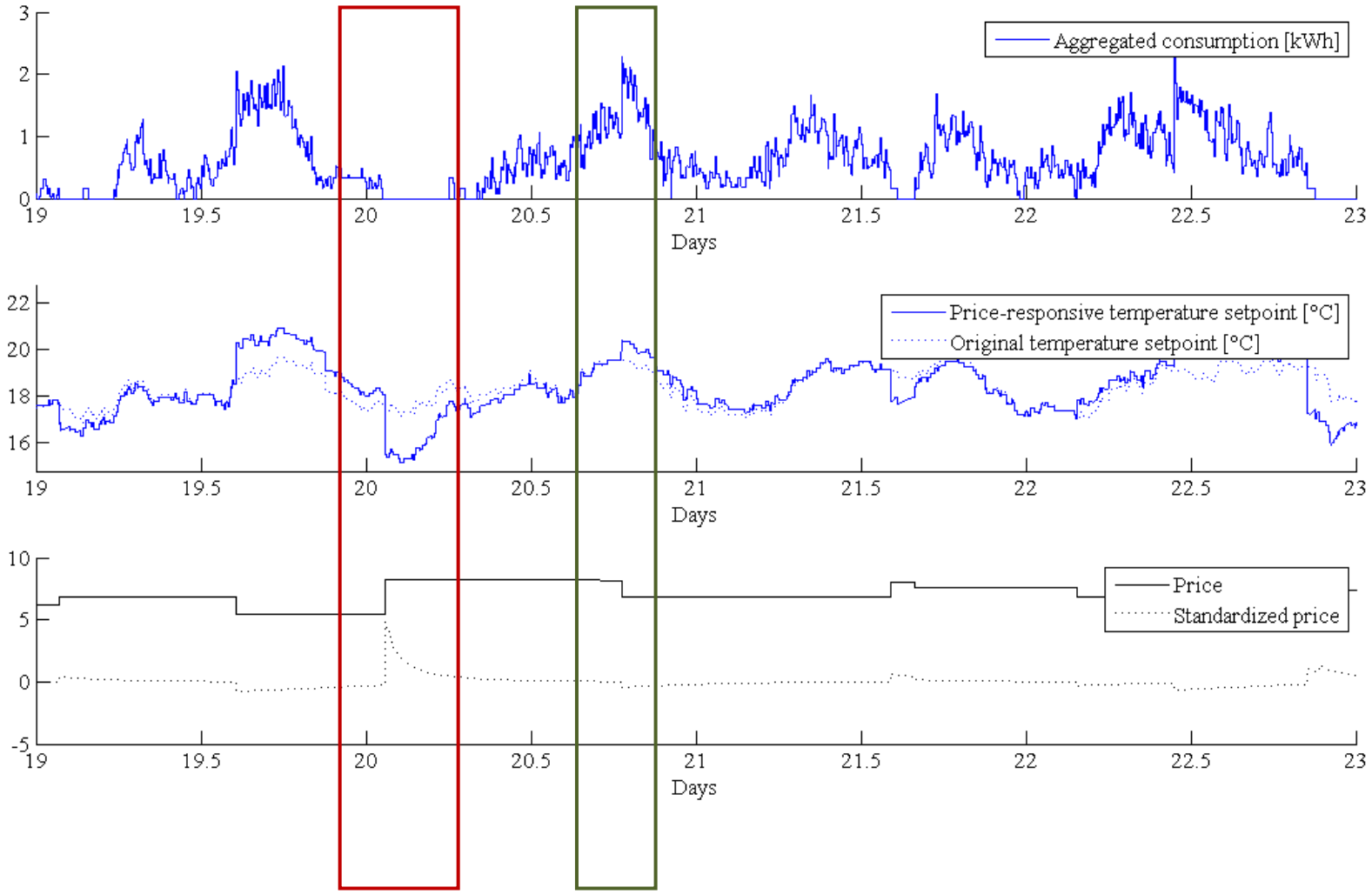
Aggregation (over eg 10 houses)



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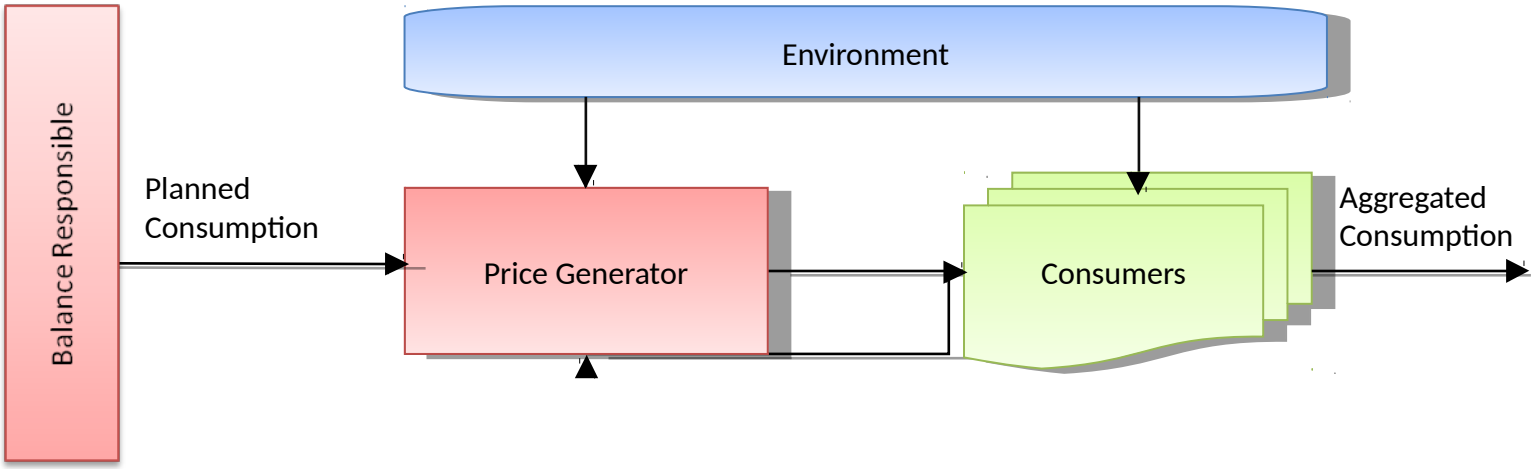
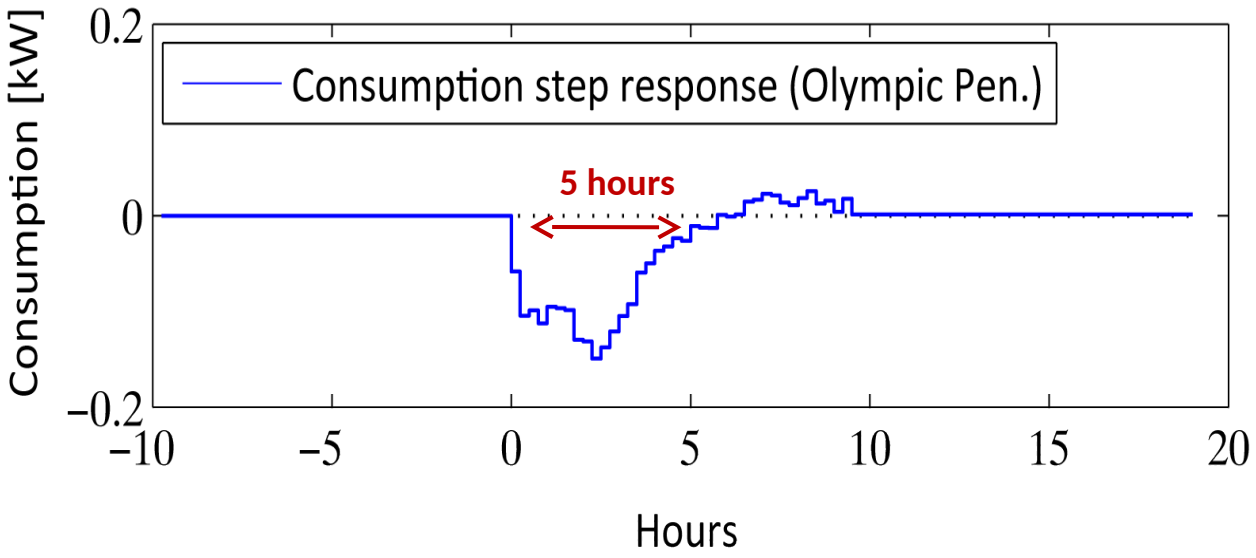
Concept

Price-based control of the aggregated consumption



1. **Collect** data from experiments (ongoing CO2 experiments)
2. **Identify** the consumption response to price using **only external variables**
3. **Control** the aggregated consumption by sending out a price signal

Response on Price Step Change (example)



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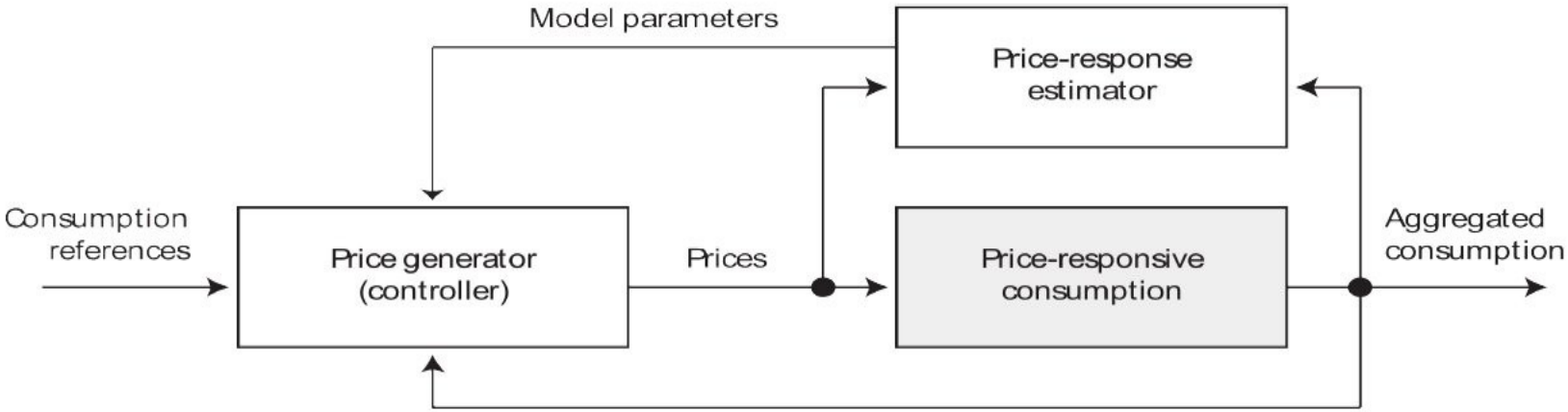
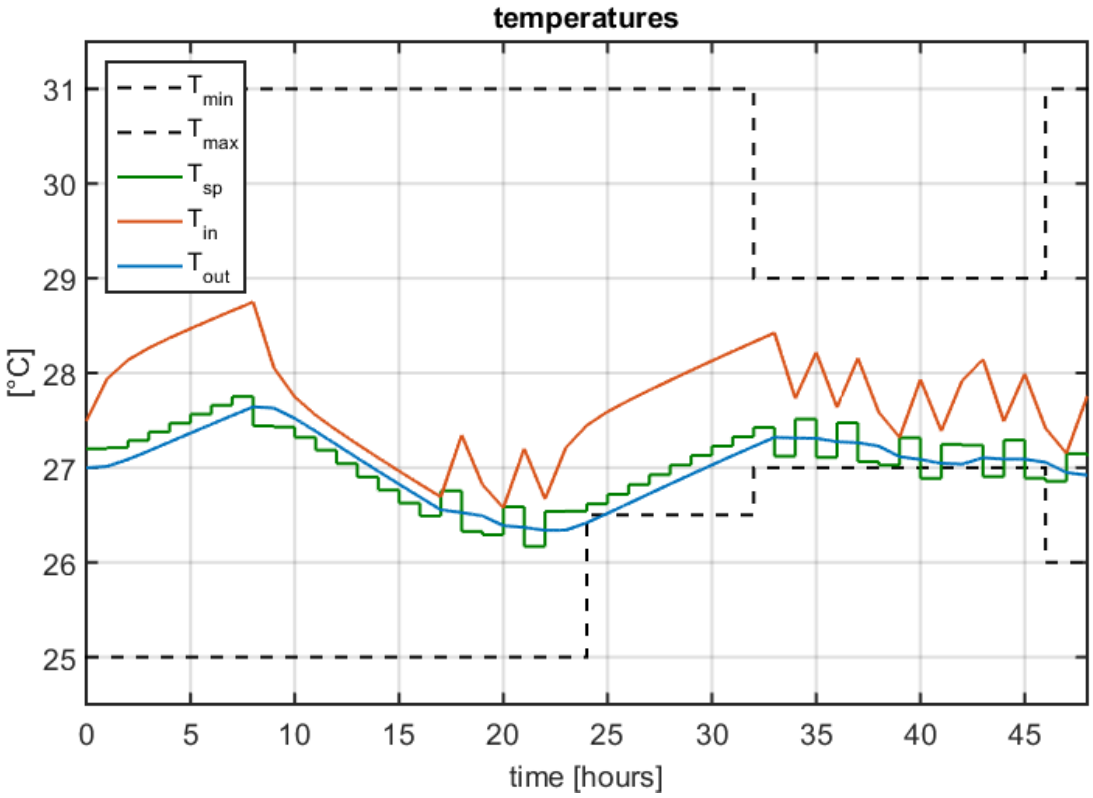
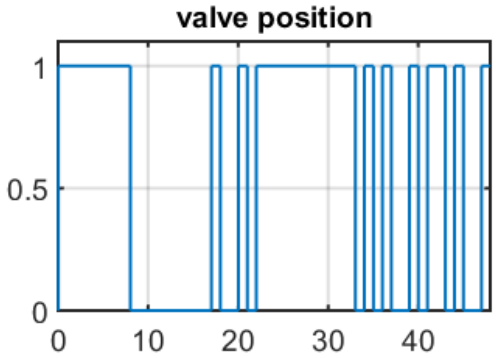
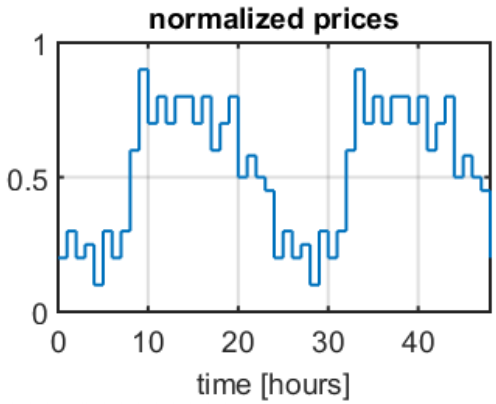
Control of Electricity Load



Results







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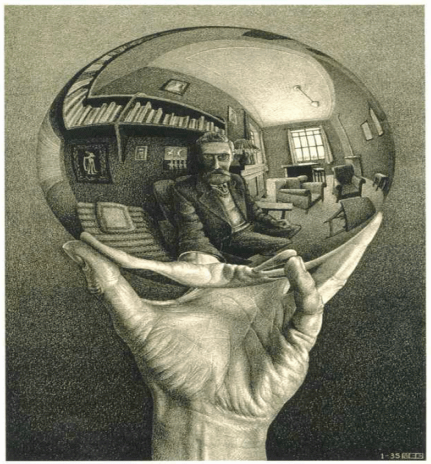
Intelligent Energy Flexibility
Some Demo Projects in CITIES

- Control of WWTP (ED, Kruger, ..)
- Heat pumps (Grundfos, EConGRID, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (ENDK, ONE, SE, Novasol, Eurisco, ...)
- Green Houses (NeoGrid, ENFOR, ...)
- CHP (Dong Energy, EnergiFyn, ...)
- Industrial production
- EV (Eurisco, Enfor, ...)
- .....



Summary

- A Smart-Energy OS for implementing future and flexible future electric energy systems has been described
- SmartGrid solutions with DSO – TSO coordinations and near real time markets – ie. EU SmartNet project – has been described
- **Modelling:** Toolbox – CTSM-R - for combined physical and statistical modelling (grey-box modelling)
- **Control:** Toolbox – MPC-R - for Model Predictive Control
- Examples from CITIES and EU SmartNet project (briefly)

For more information …

See for instance

www.smart-cities-centre.org

www.smartnet-project.eu

…or contact

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Acknowledgement: DSF 1305-00027B and EU SmartNet Project

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