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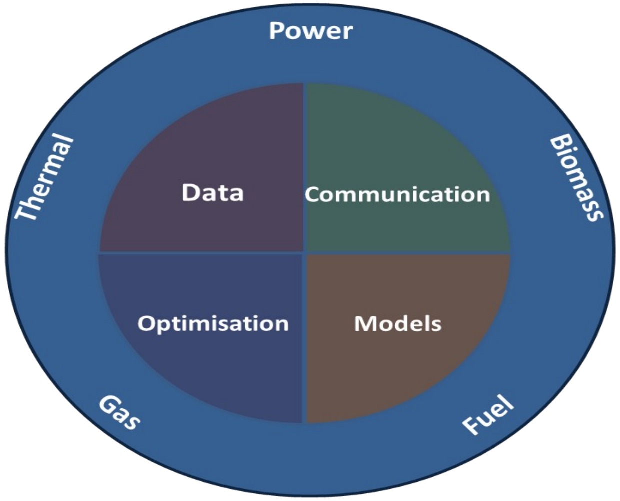
Methodologies for Implementing Energy Related Smart Cities Solutions



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

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

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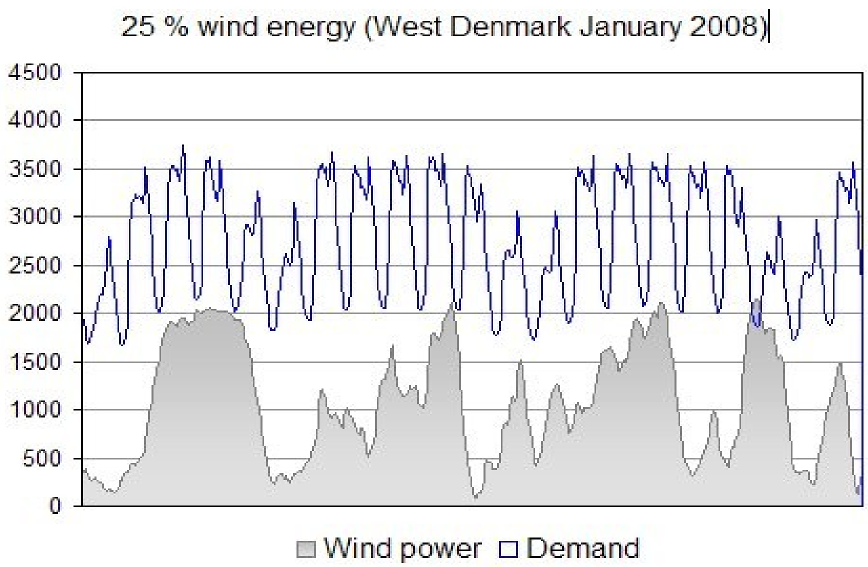
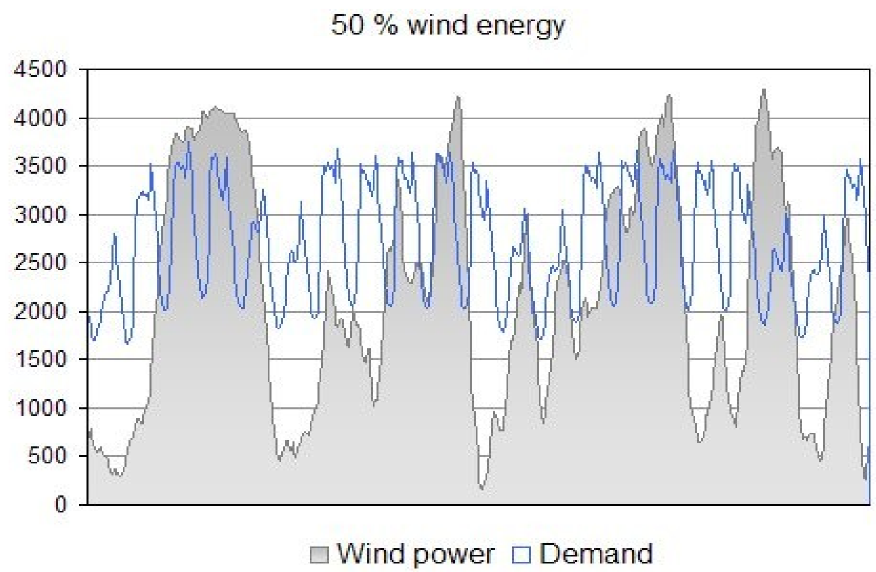
The Danish Wind Power Case

.... balancing of the power system





In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

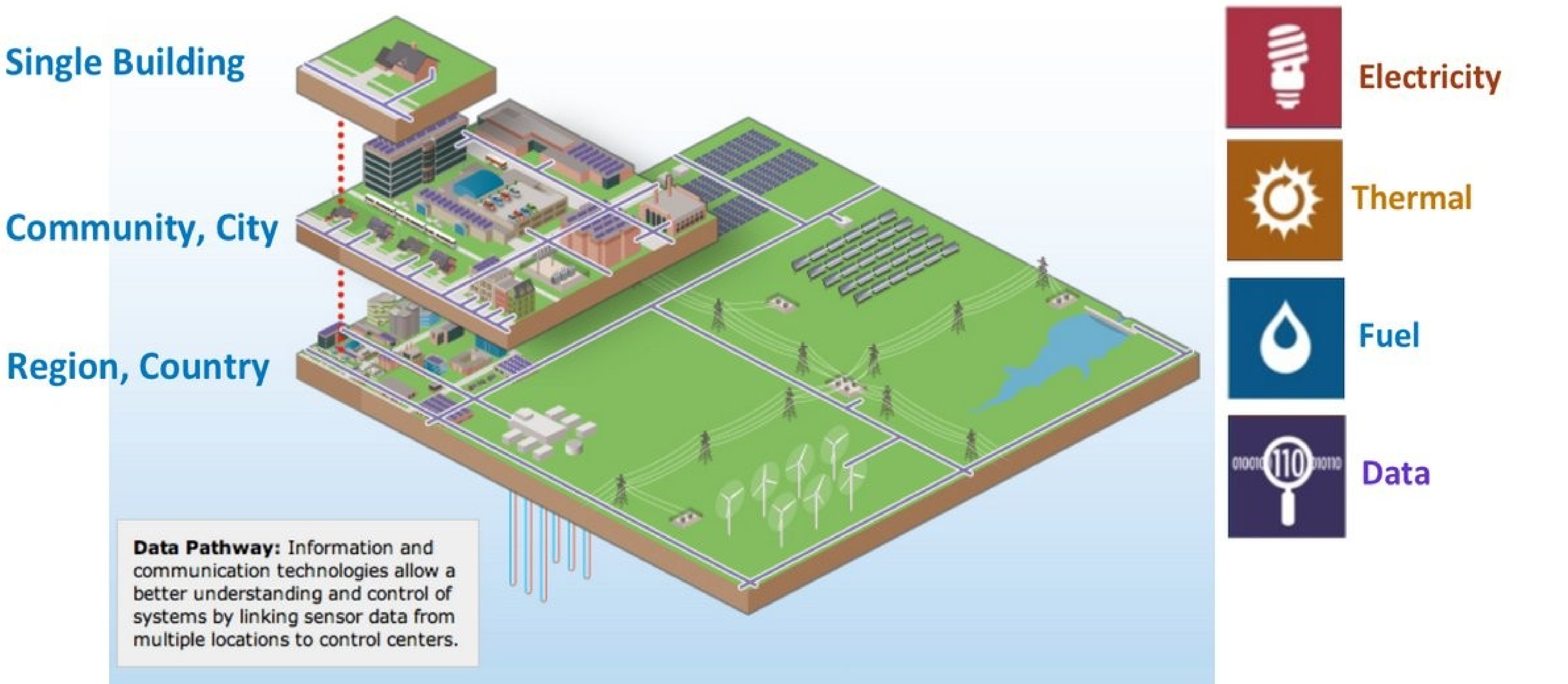
In 2015 more than 42 pct of electricity load was covered by wind power.

For several days the wind power production was more than 100 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power

Energy Systems Integration in Smart Cities

Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



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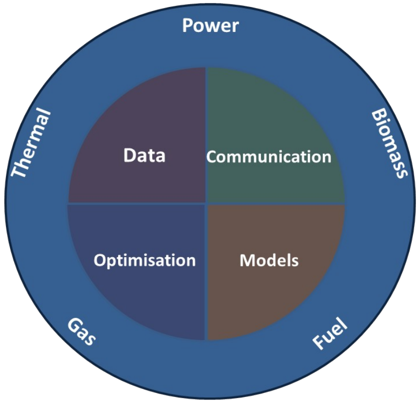
Assumptions, Goals and Methods

CITIES – Hypothesis

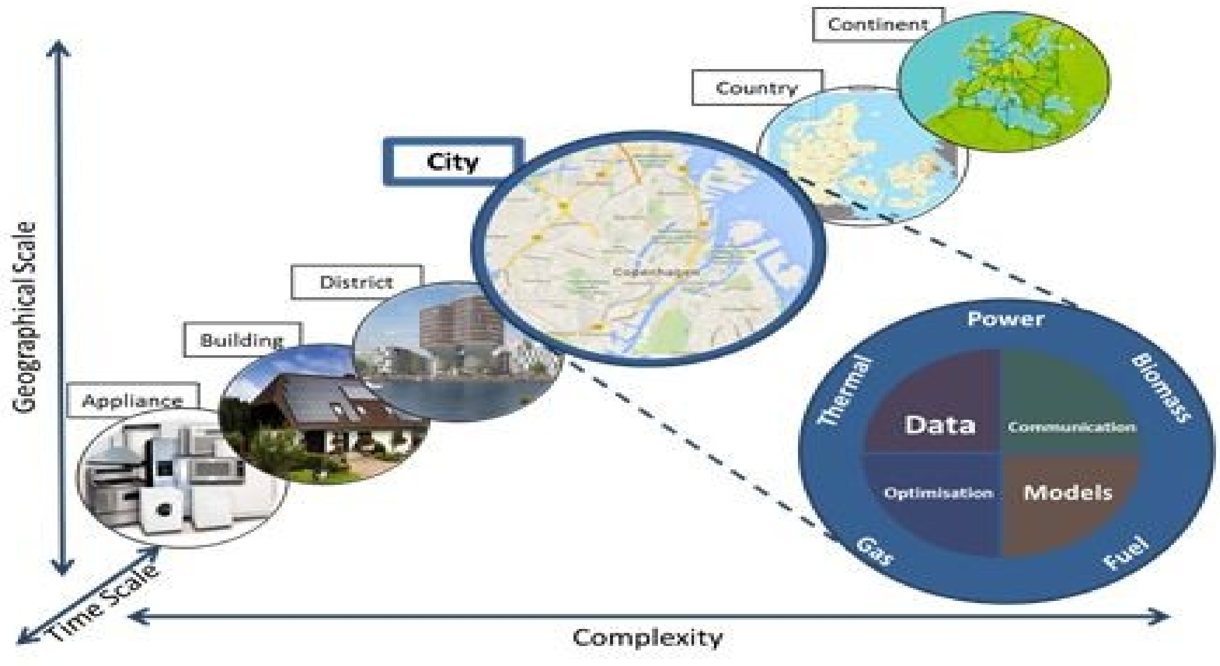
The **central hypothesis of ESI** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in we can enable very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

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



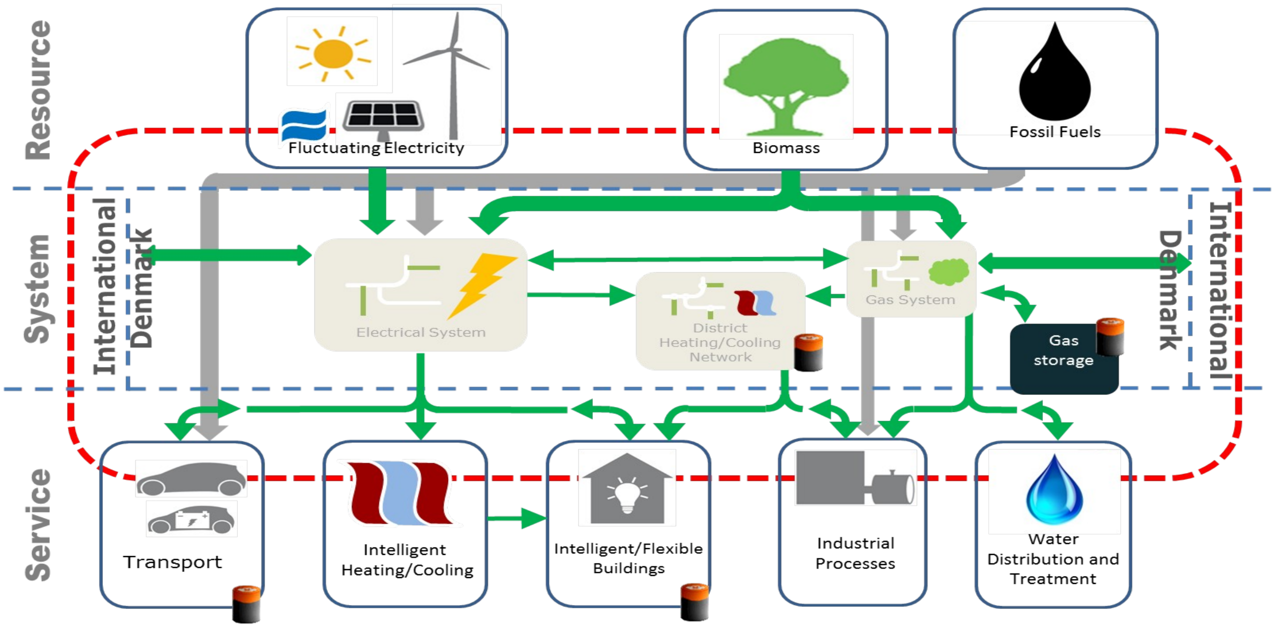
CITIES – Research Challenges

To establish methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales



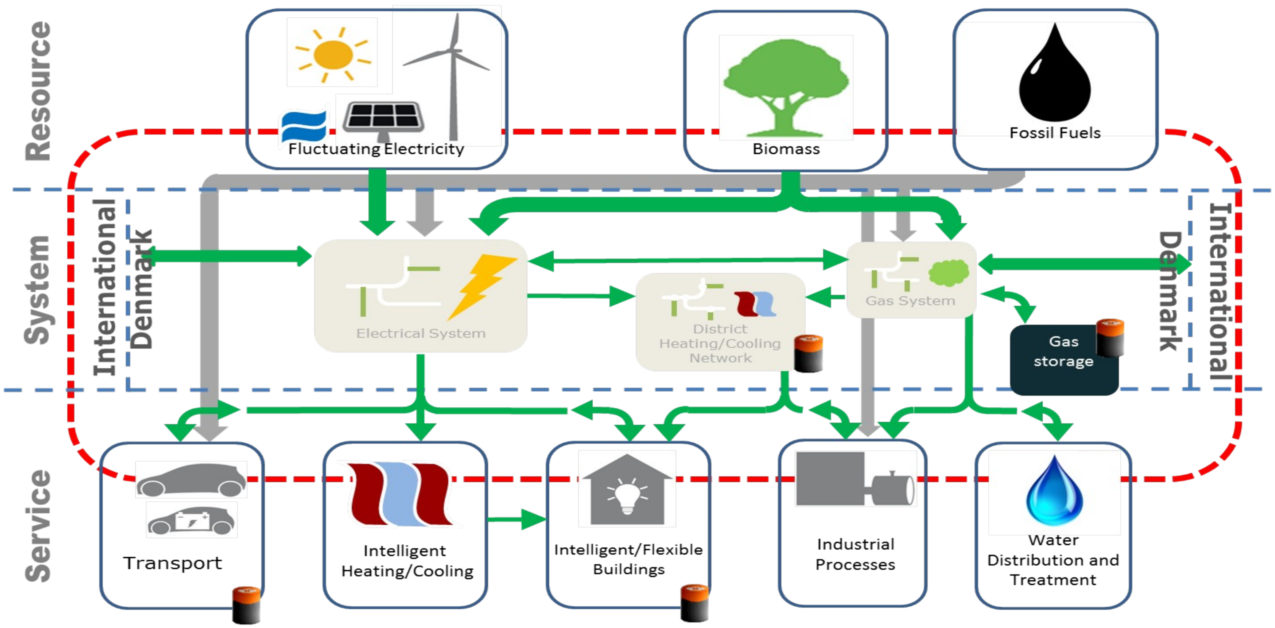
CITIES – Concept Challenges

Energy Systems Integration using data and IT solutions leading to **models and methods for planning and operation of future electric energy systems.**

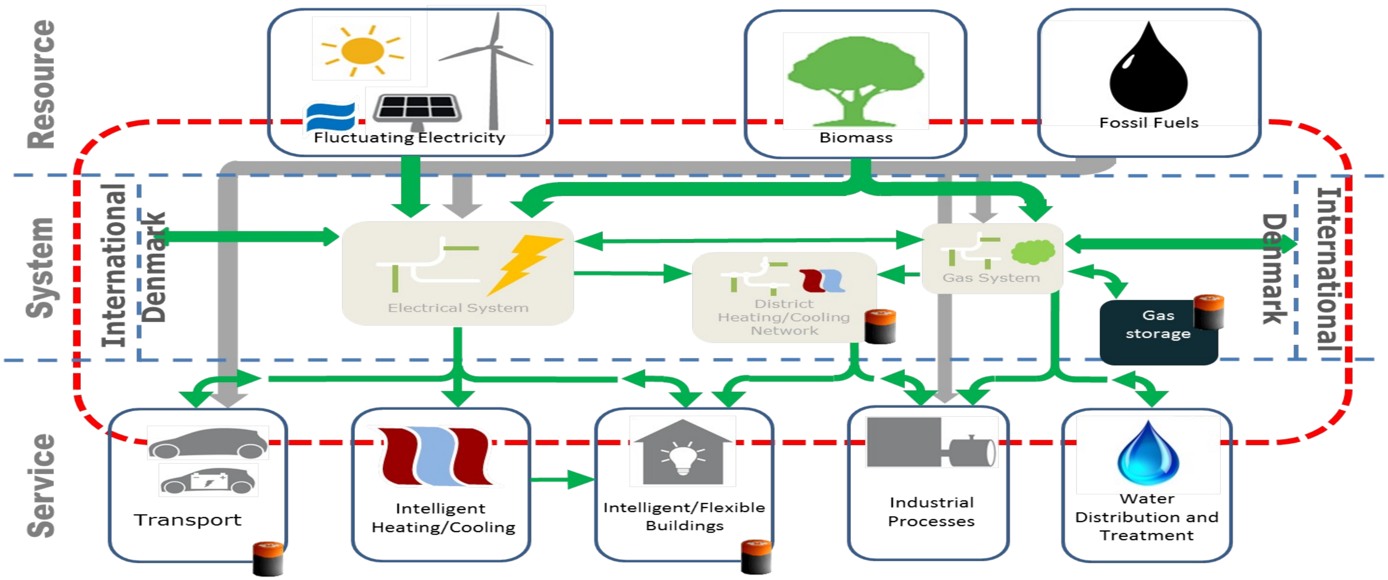


Models

Grey-box modelling are used to establish **models and methods for real-time operation of future electric energy systems**



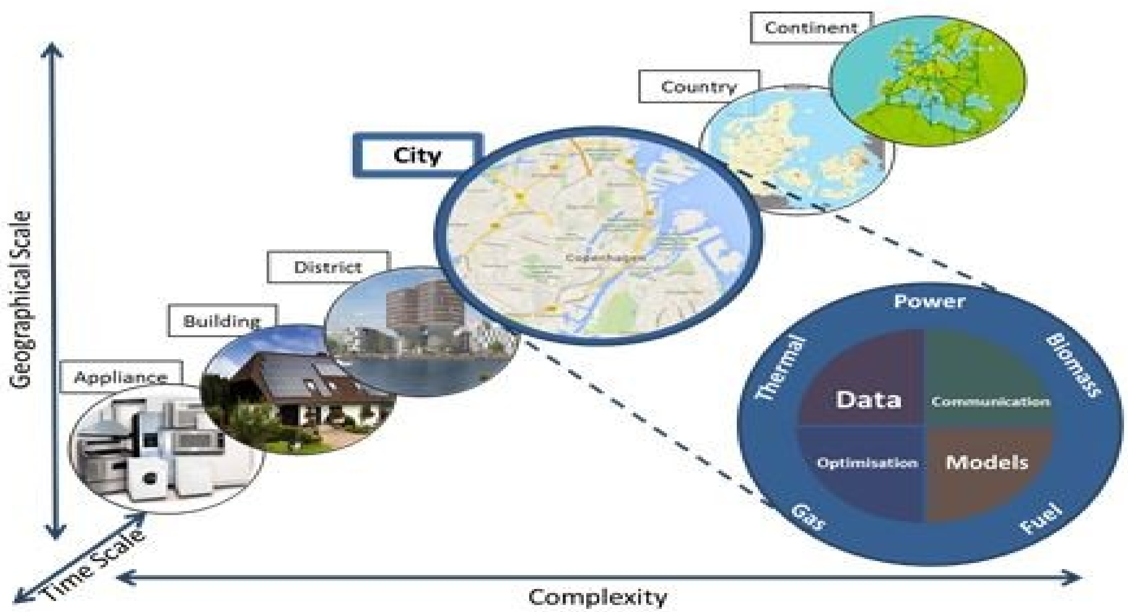
Example: Storage by Energy Systems Integration



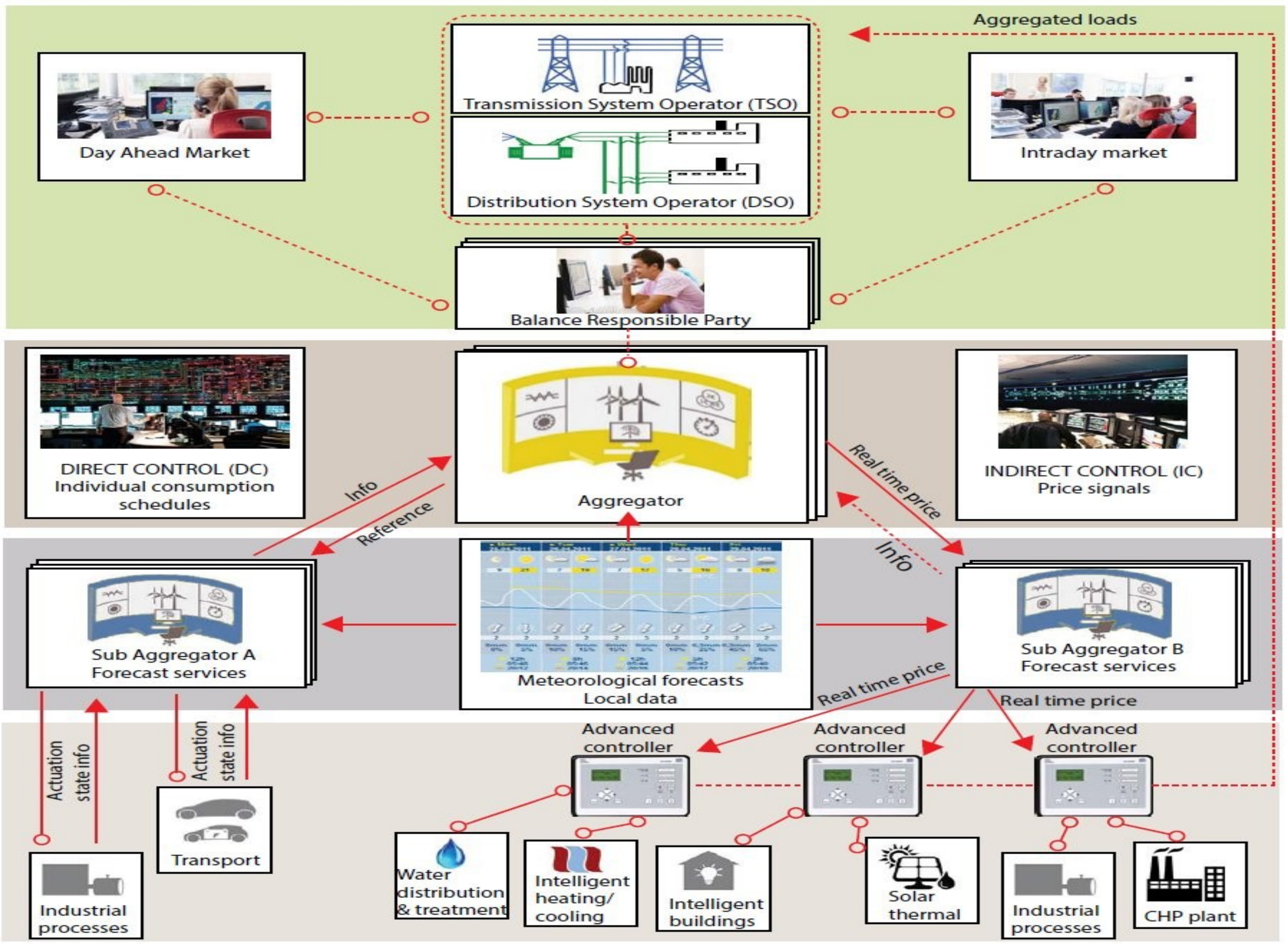
- **(Virtual) storage principles:**
  - Buildings can provide storage up to, say, 5-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - Gas systems can provide seasonal storage

Temporal and Spatial Scales

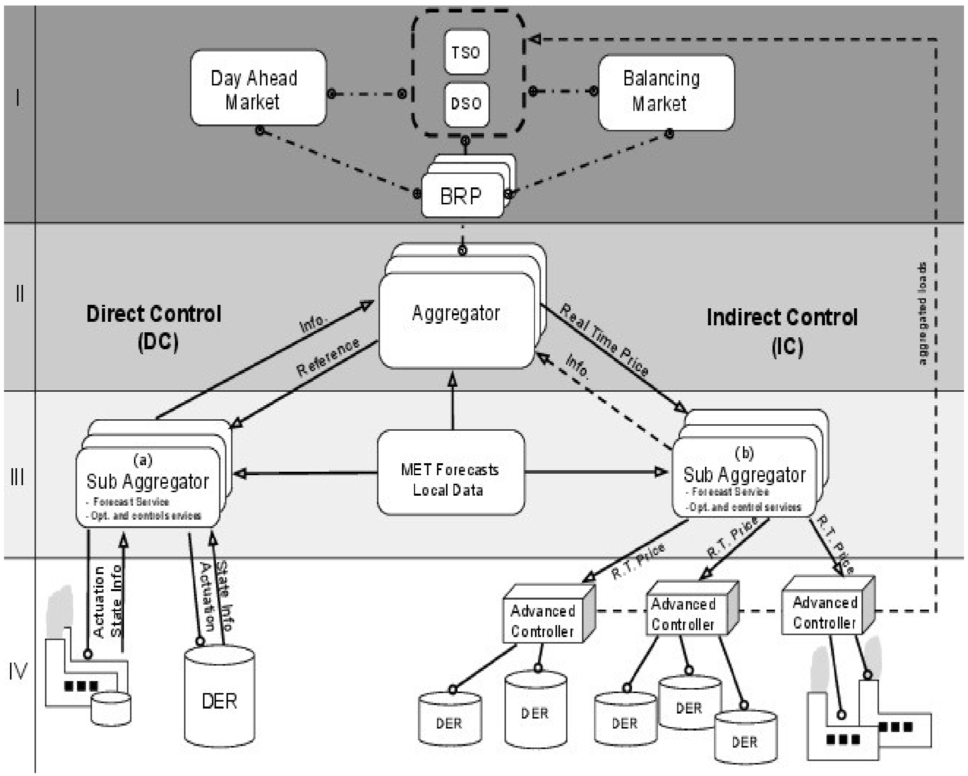
The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems*** at **all scales**.



Smart-Energy OS



Control and Aggregation



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

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'

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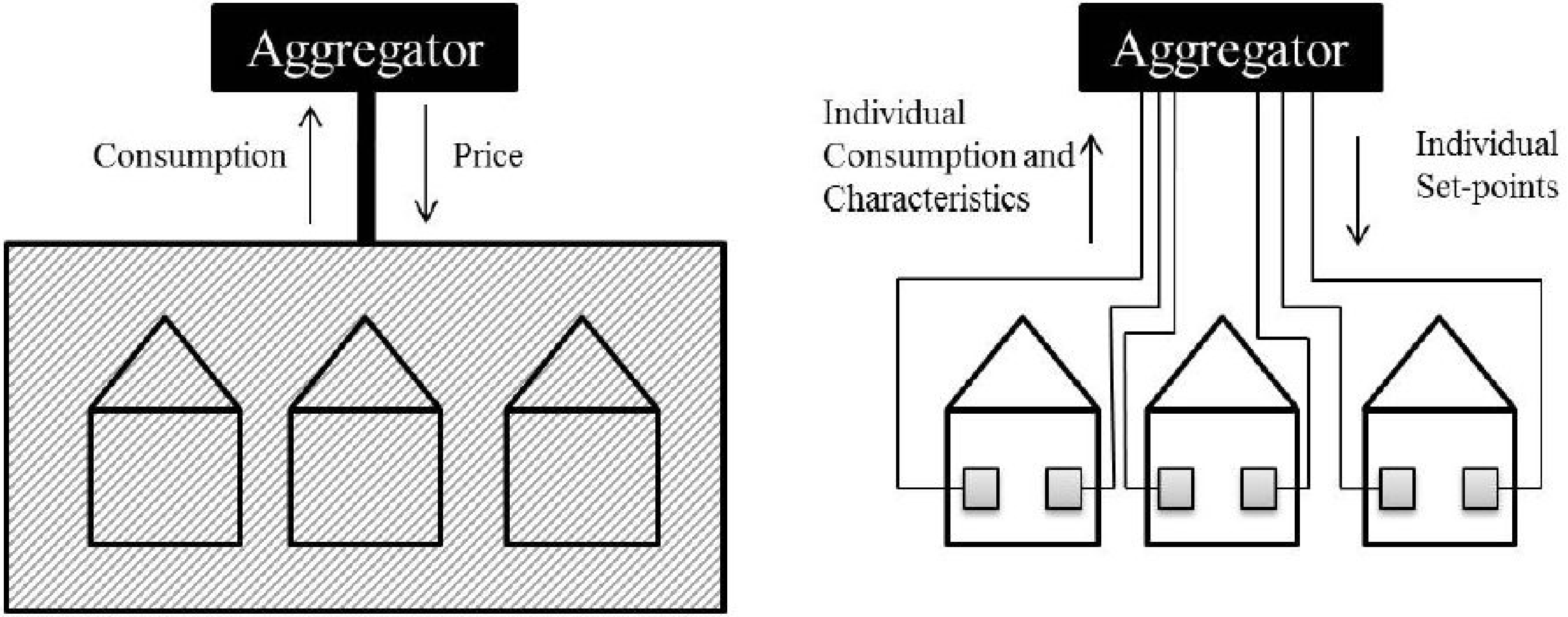
Direct and Indirect Control

For DC info about individual states and constraints are needed



(a) Indirect control

(b) Direct control

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Centre for IT-Intelligent Energy Systems in cities

Demo projects | **Software solutions** | Work Packages | Partners | Events | Communications | Publications | Vacant positions | Contacts

Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available on GitHub.

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R . The software is available on GitHub.

Search ...

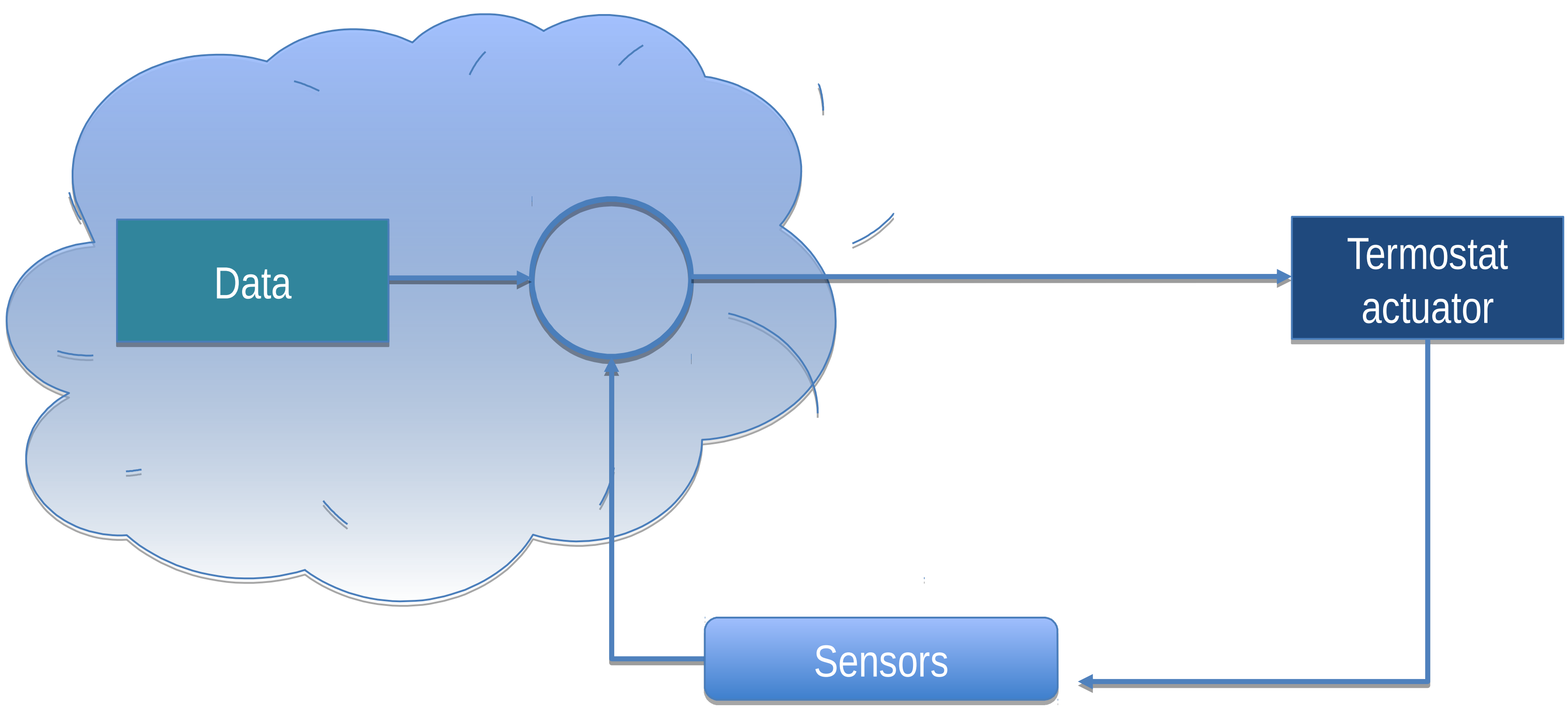
Latest news

- Summer School at DTU, Lyngby, Denmark – July 4th-8th 2016
- Summer School – Granada, Spain, June 19th-24th 2016
- Third general consortium meeting – DTU, May 24th-25th 2016
- Smart City Challenge in Copenhagen – April 20th 2016
- Guest lecture by Pierluigi Mancarella at DTU, April 6th

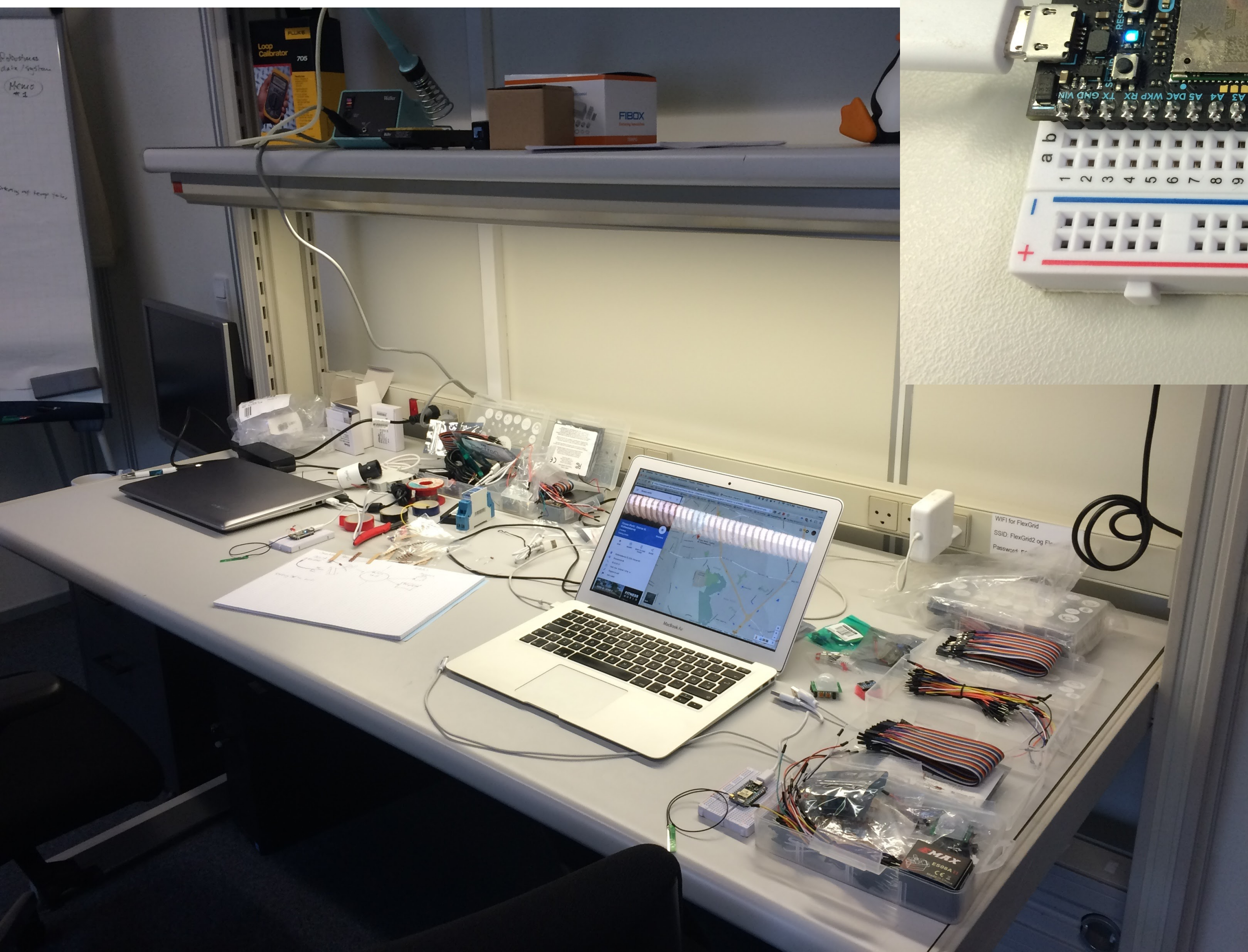
SE-OS Characteristics

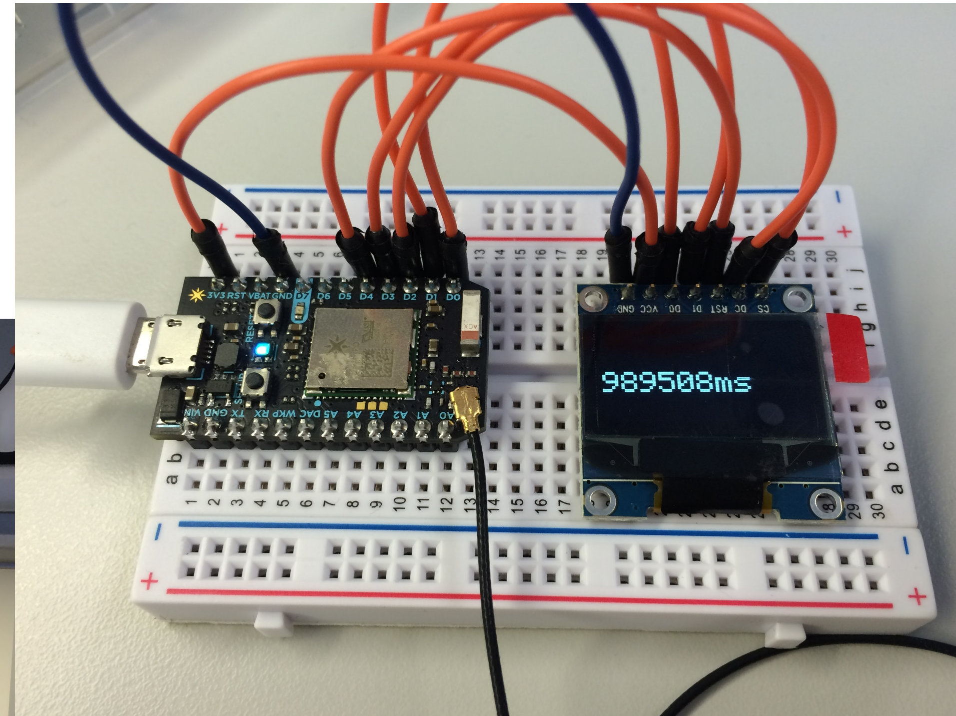
- Bidding – clearing – activation at higher levels
- Control principles at lower levels
- Cloud based solution for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, ...)
- Allow for new players (specialized aggregators)
- Simple setup for the communication
- Simple (or no) contracts
- Rather simple to implement
- Harvest flexibility at all levels in Smart Cities

SE-OS
Control loop design – **logical drawing**

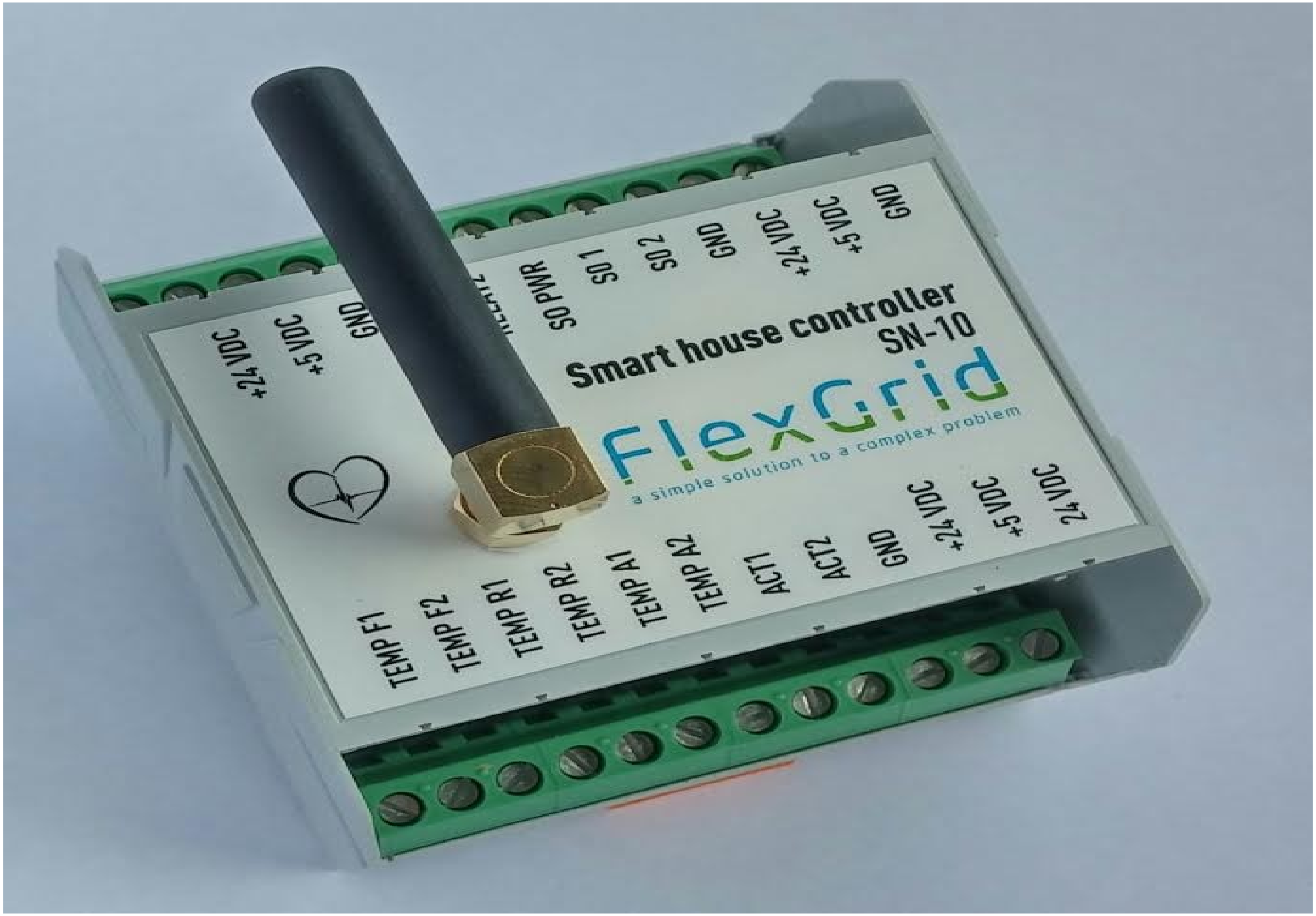


Lab testing ....





SN-10 Smart House Prototype



Case study

Control of Power Consumption (DSM) using the Thermal Mass of Buildings

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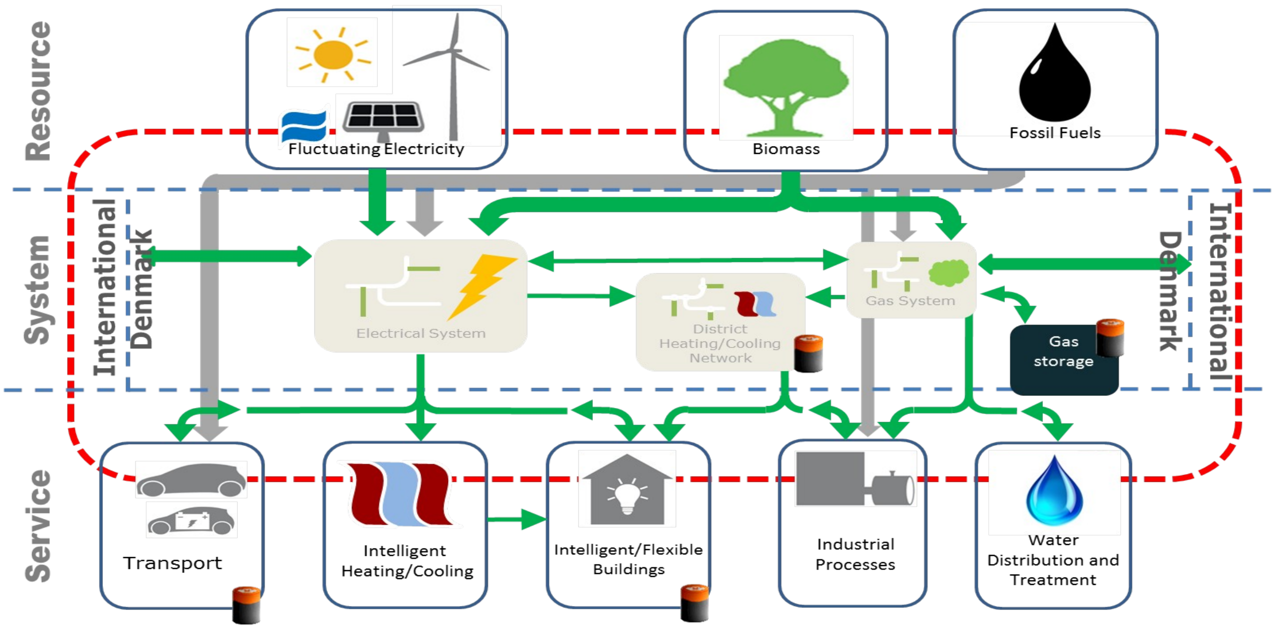
Models

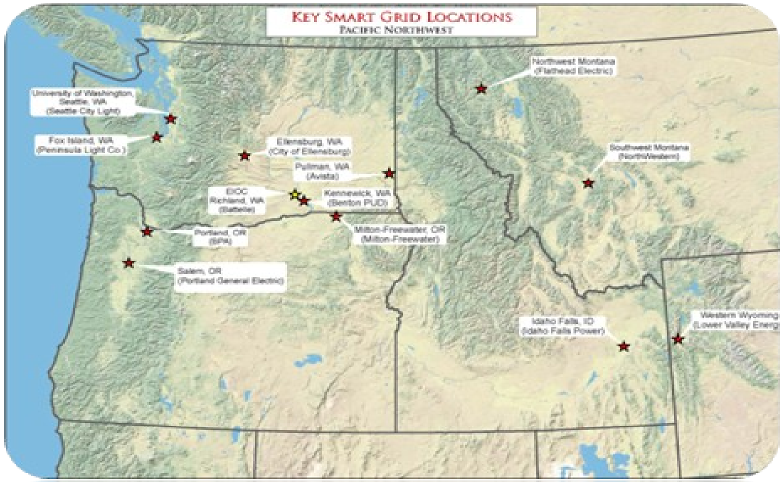
Grey-box modelling are used to establish **models and methods for real-time operation of future electric energy systems**



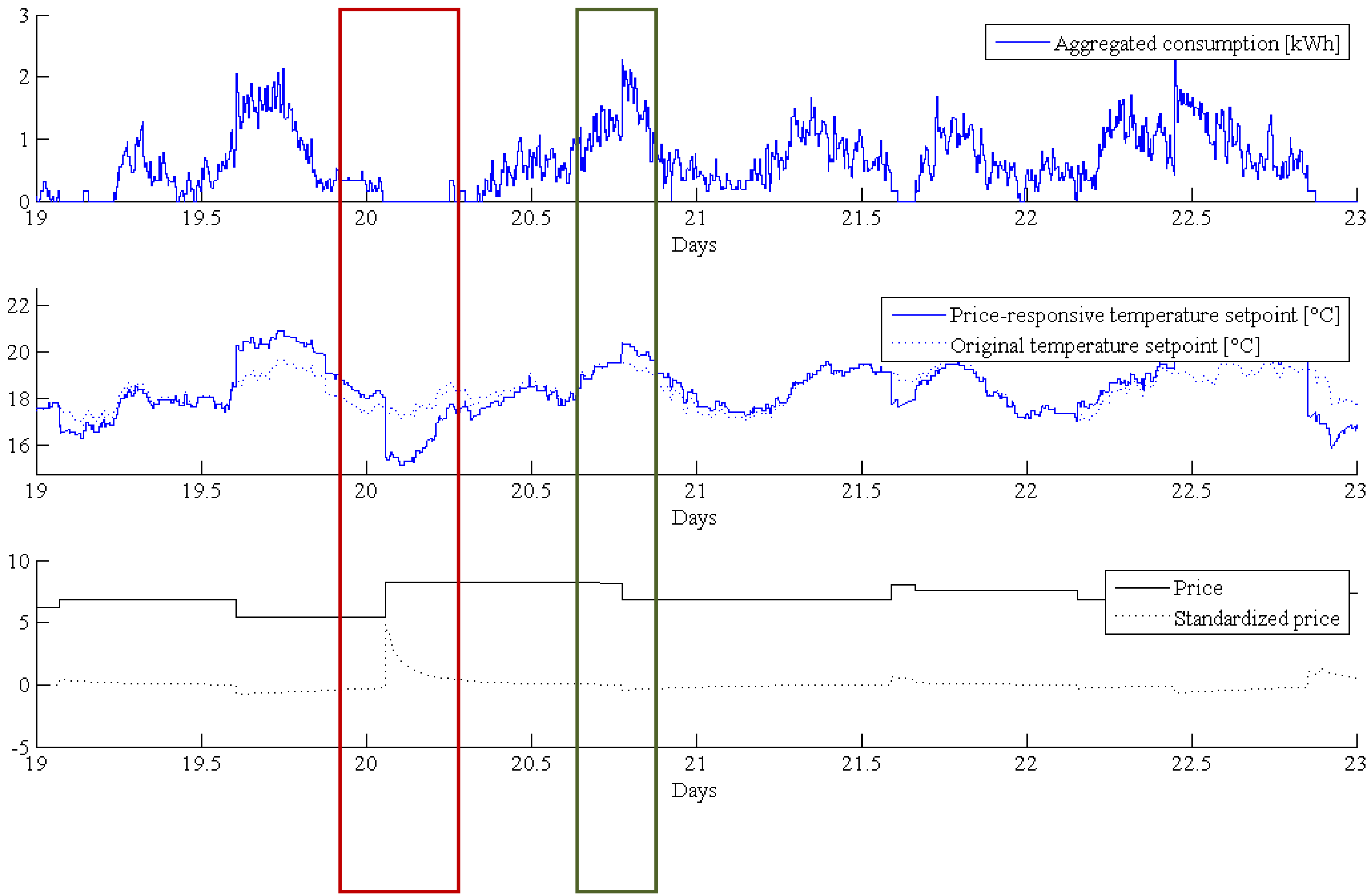
Data from BPA

Olympic Pensinsula project

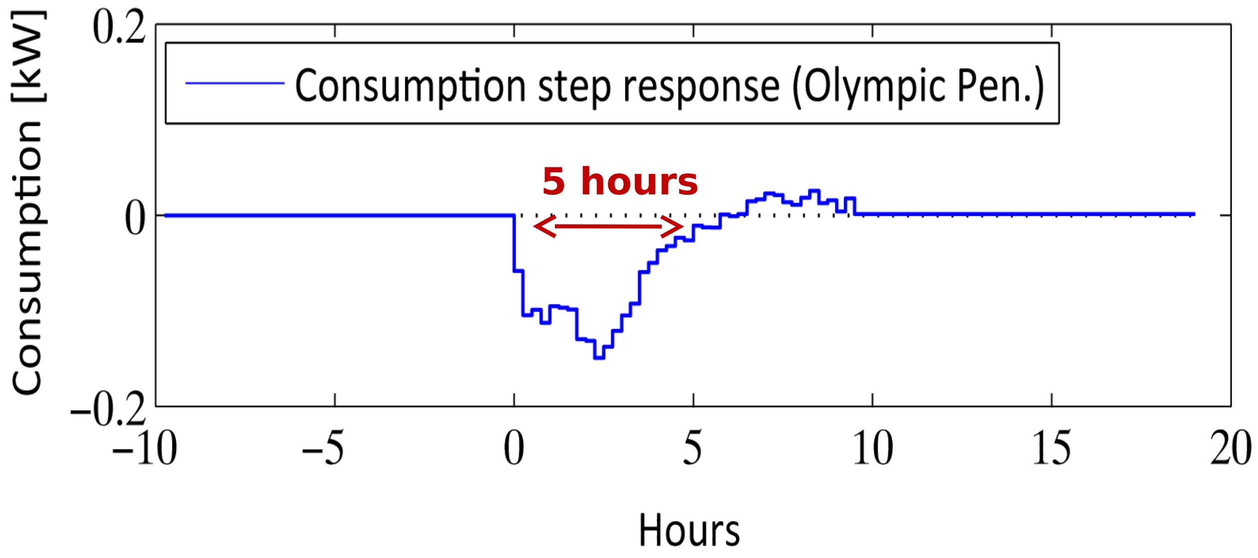
- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption



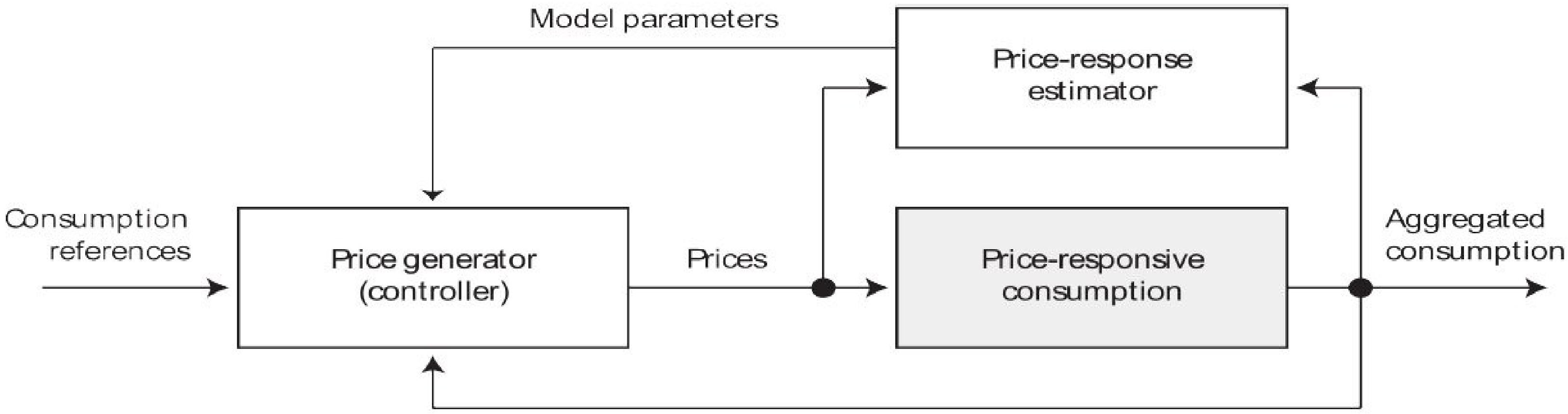
Aggregation (over 20 houses)



Response on Price Step Change

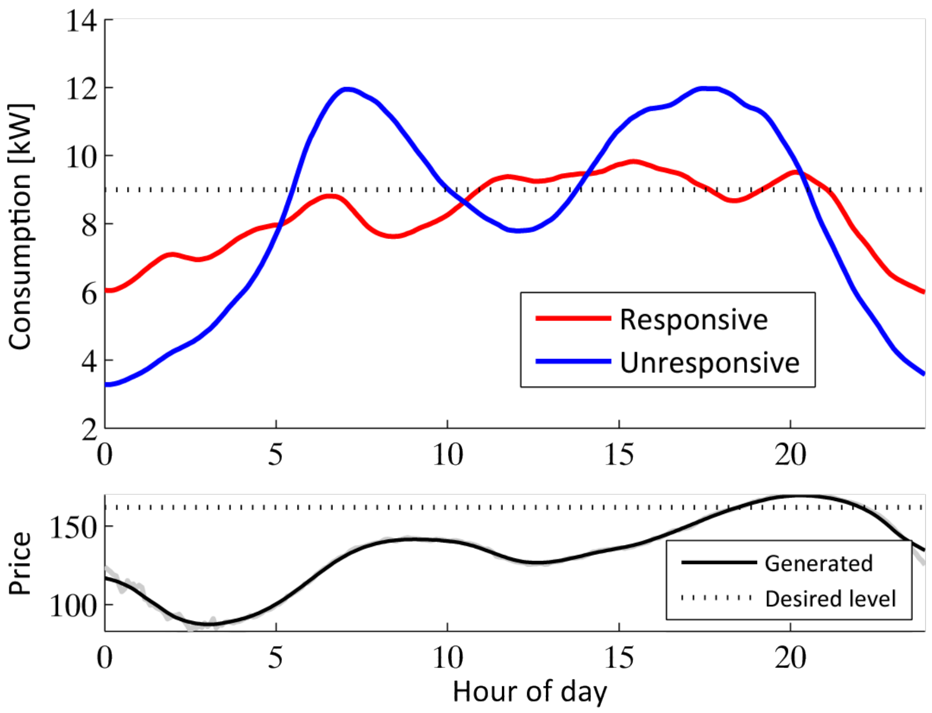


Control of Power Consumption



Control performance

Considerable **reduction in peak consumption**



Case study

Heat Pumps and Local Storage

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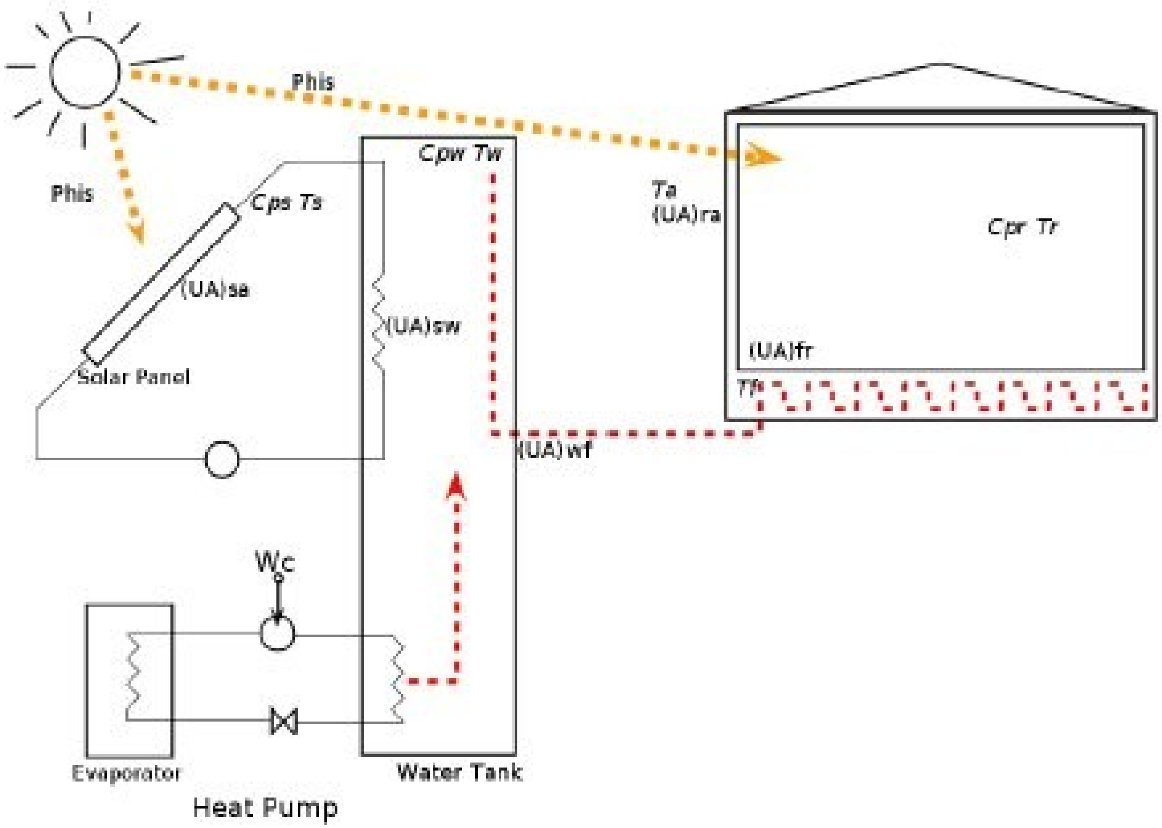
Modeling Heat Pump and Solar Collector

Simplified System



Avanced Controller

Economic Model Predictive Control

Formulation

The Economic MPC problem, with the constraints and the model, can be summarized into the following formal formulation:

$$\min_{\{u_k\}_{k=0}^{N-1}} \phi = \sum_{k=0}^{N-1} c' u_k \tag{4a}$$

Subject to

$$x_{k+1} = Ax_k + Bu_k + Ed_k \quad k = 0, 1, \dots, N-1 \tag{4b}$$

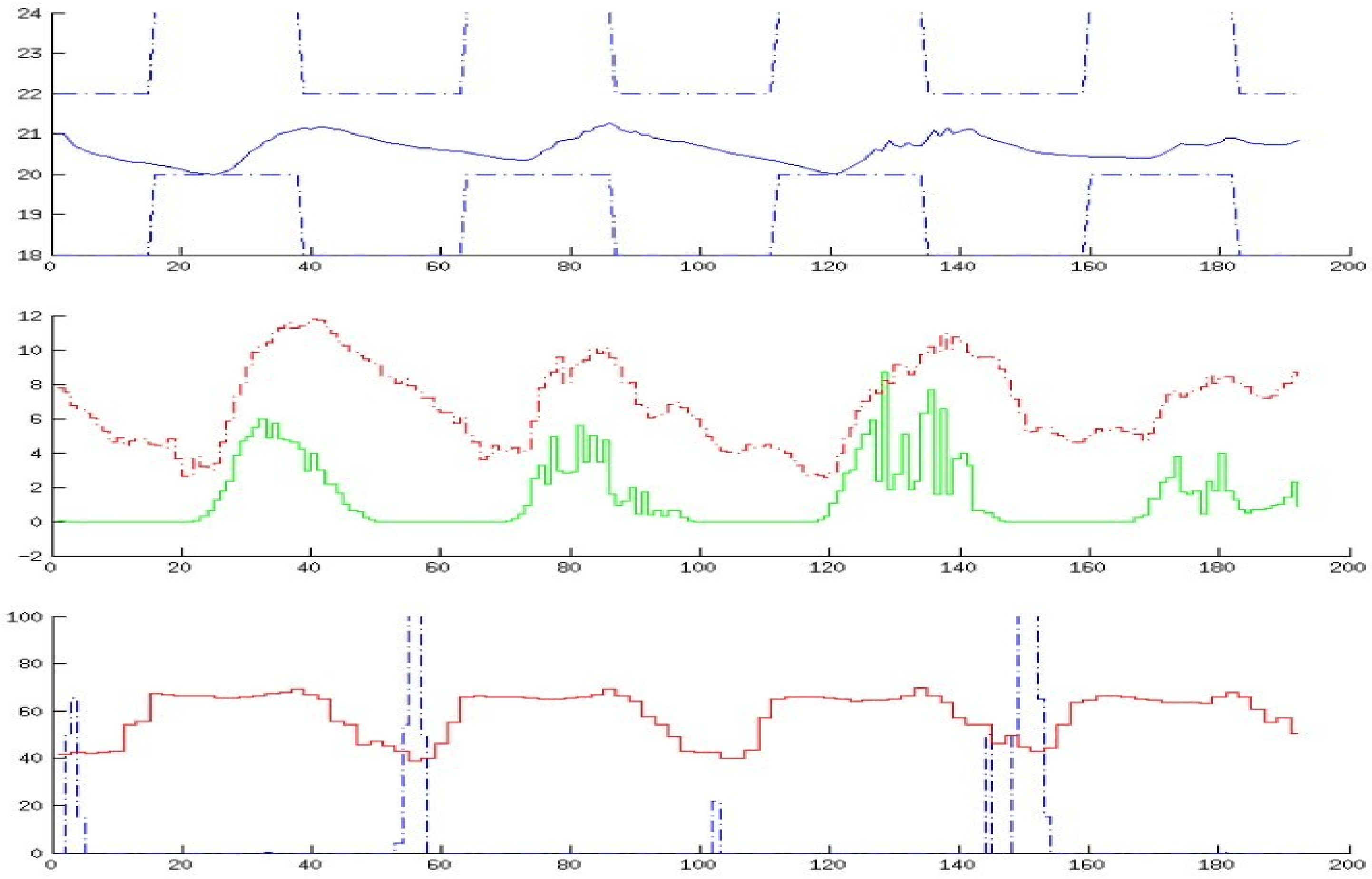
$$y_k = Cx_k \quad k = 1, 2, \dots, N \tag{4c}$$

$$u_{min} \leq u_k \leq u_{max} \quad k = 0, 1, \dots, N-1 \tag{4d}$$

$$\Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} \quad k = 0, 1, \dots, N-1 \tag{4e}$$

$$y_{min} \leq y_k \leq y_{max} \quad k = 0, 1, \dots, N \tag{4f}$$

Heat pump with thermal solar collector and storage (savings up to 35 pct)



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Case study

Control of Wastewater Treatment Plants

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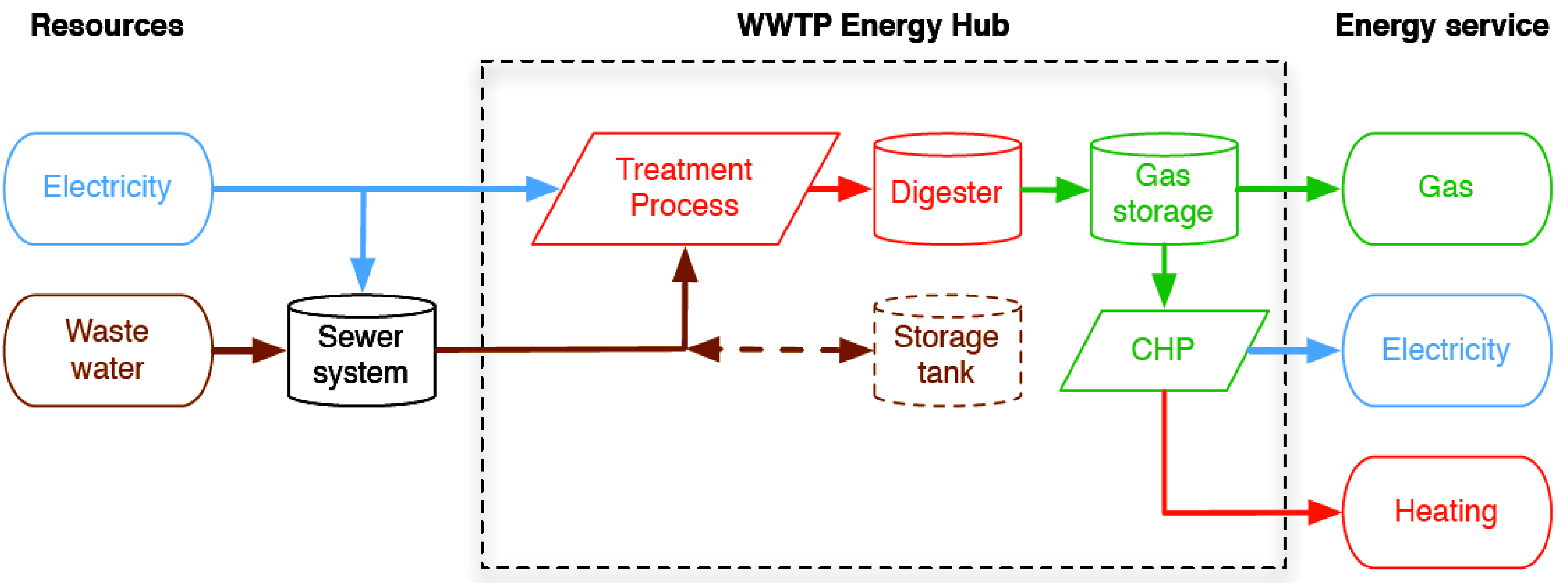
Waste-2-Energy



Kolding WWTP

Energy Flexibility in Wastewater Treatment

- Sludge -> Biogas -> Gas turbine ->Electricity
- Power management of the aeration process
- Pumps and storage in sewer system

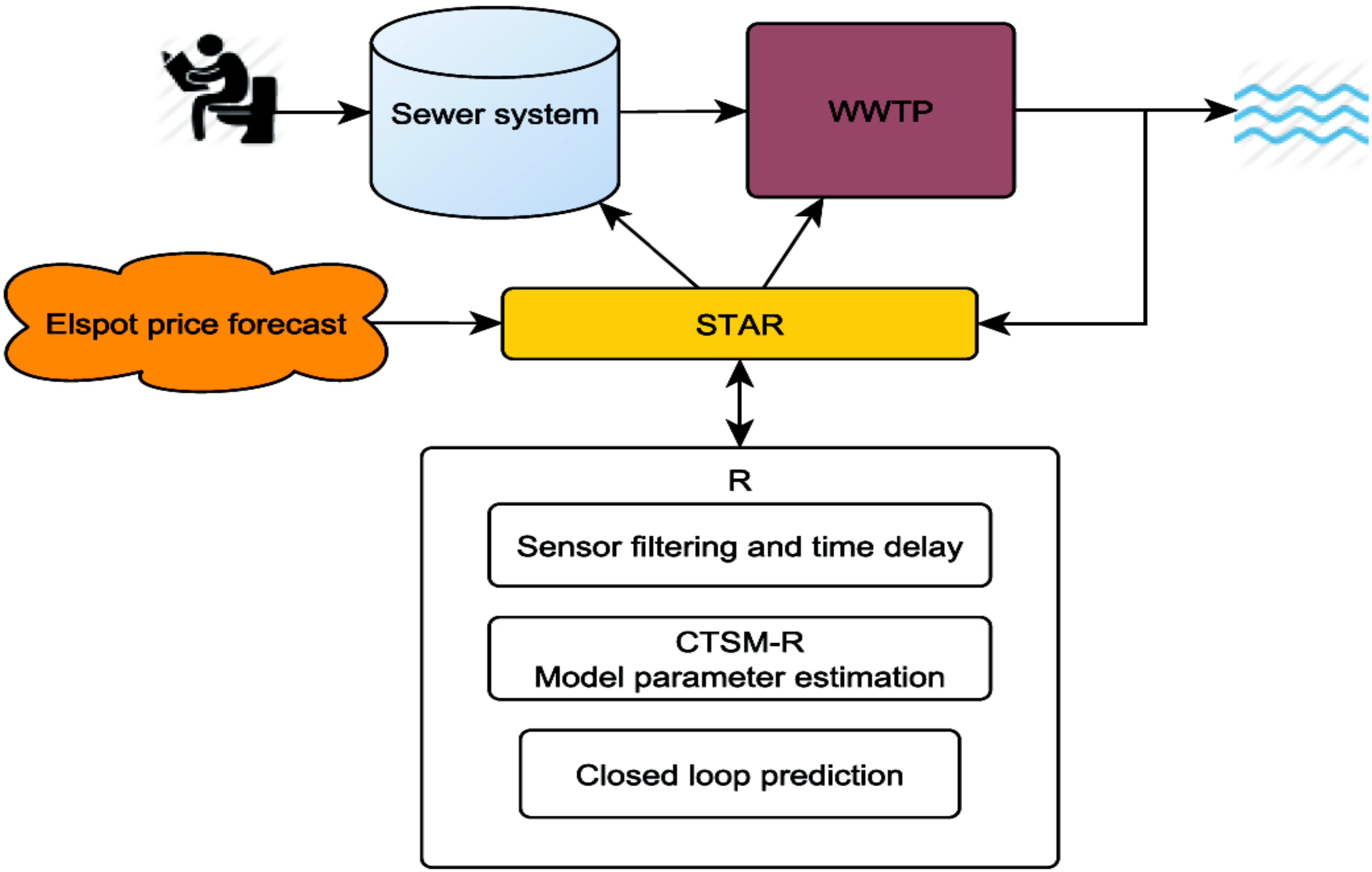
Overall goals:

Cost reduction

Minimize effluent concentration

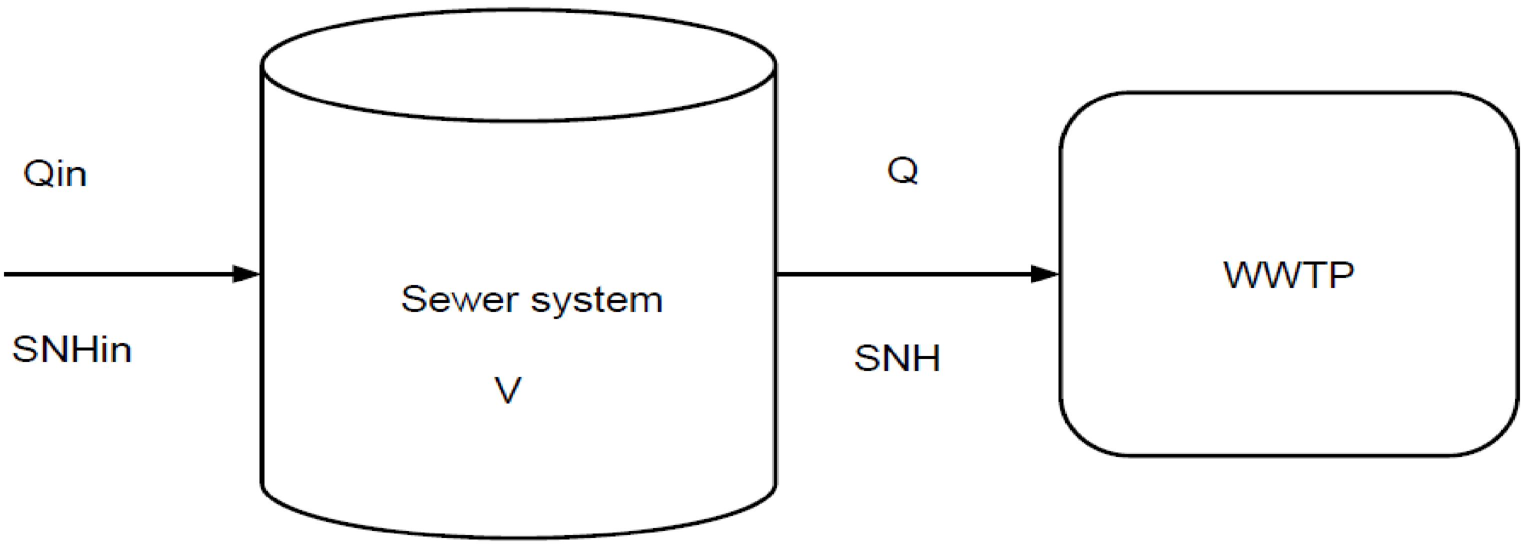
Minimize overflow risk

Energy Flexibility in Wastewater Treatment

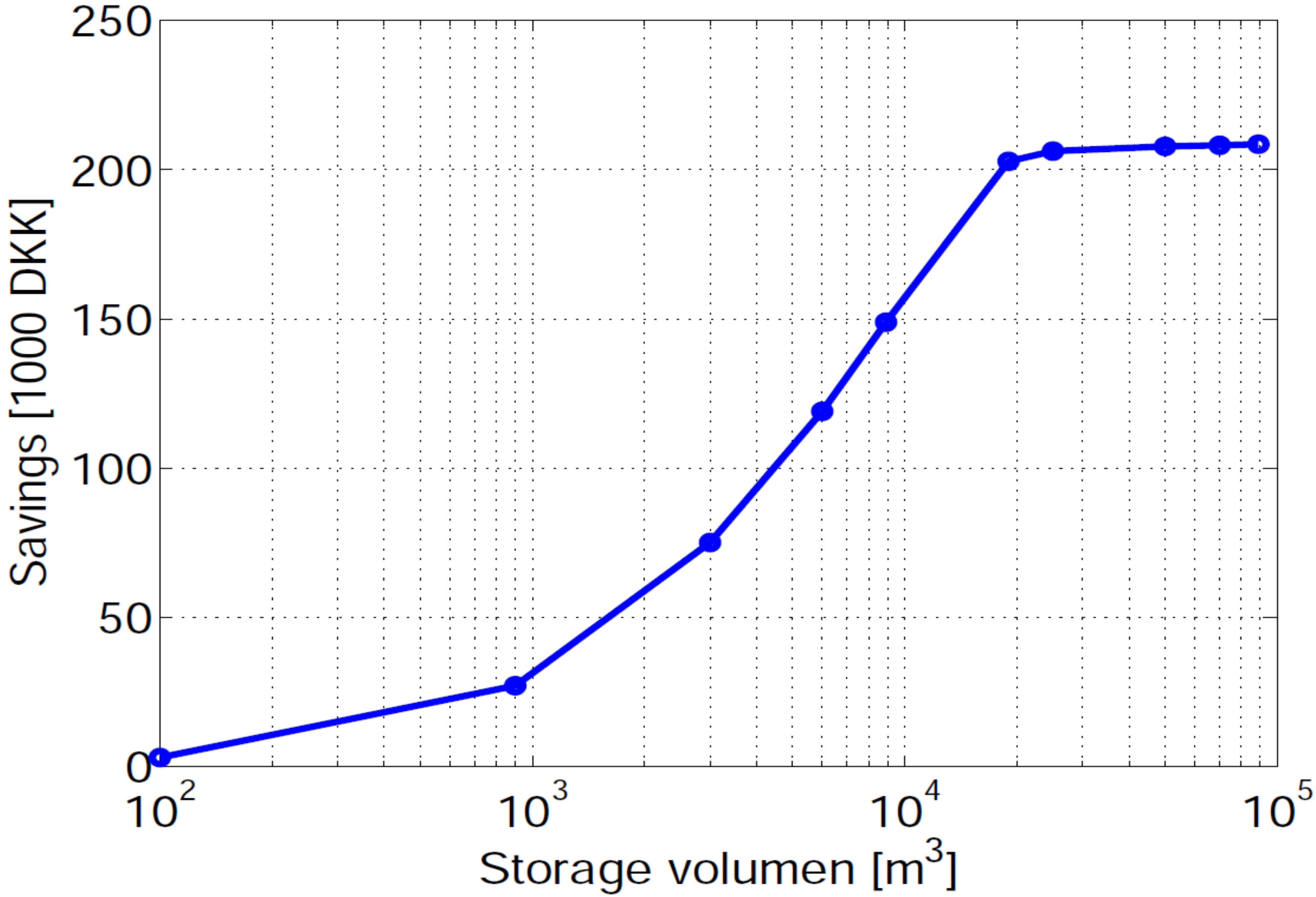


Sewer System Control Goal

$$\text{minimize overflow} + p_{elspot}^{T} f(Q)$$



Sewer System Annual Elspot Savings



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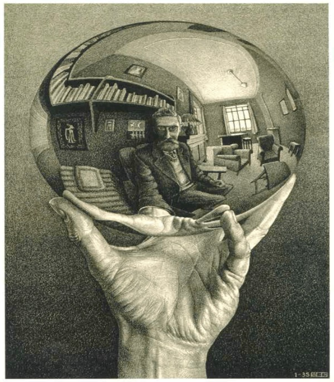
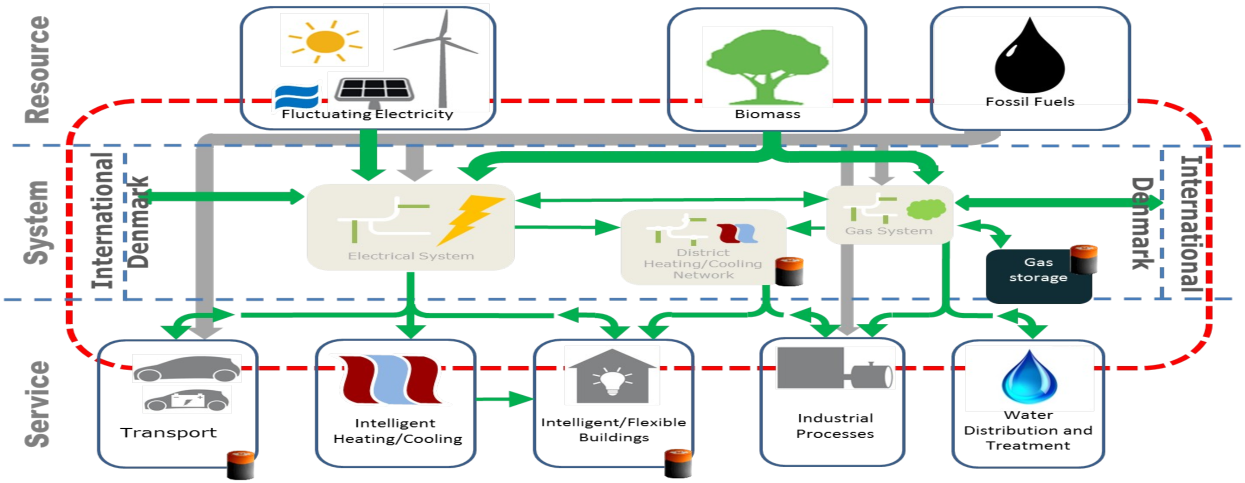
Smart-Energy OS
Examples from the CITIES project



- Control of WWTP (ED, Krüger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, SE, Energinet.dk, ..)
- Green Houses (NeoGrid, Danfoss, F.Fyn, ...)
- CHP (Dong Energy, FjernvarmeFyn, HOFOR, NEAS, ...)
- Industrial production (DI, ...)
- EV (charging) (Eurisco, ED, ...)
- PV and batteries (Cowi, ...)
- ....

Virtual Storage solutions in Smart Cities



- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - Gas systems can provide seasonal storage

Discussion

- IT-Intelligent Energy Systems Integration in Smart Cities can provide virtual storage solutions (so maybe we should put less focus on electrical storage solutions)
- District heating (or cooling) systems can provide flexibility on the essential time scale (up to a few days)
- Gas systems can provide seasonal virtual storage solutions
- Smart Cities are smart elements of a Smart Society
- We see a large potential in Demand Response. Automatic solutions, price based control, and end-user focus are important
- We see large problems with the tax and tariff structures in many countries (eg. Denmark).
- Markets and pricing principles need to be reconsidered; we see an advantage of having a physical link to the mechanism (eg. nodal pricing, capacity markets)

Summary

- Our CITIES developed **Smart-Energy OS** for implementing flexibility energy systems in smart cities has been described
- Built on: Big Data Analytics, Cyber Physical systems, Stochastic opt./control, Forecasting, IoT, IoS, Cloud computing, ...
- **Modelling**: Toolbox – CTSM-R - for combined physical and statistical modelling (grey-box modelling)
- **Control:** Toolbox – MPC-R - for Model Predictive Control
- **Simulation:** Framework for simulating flexible power systems.