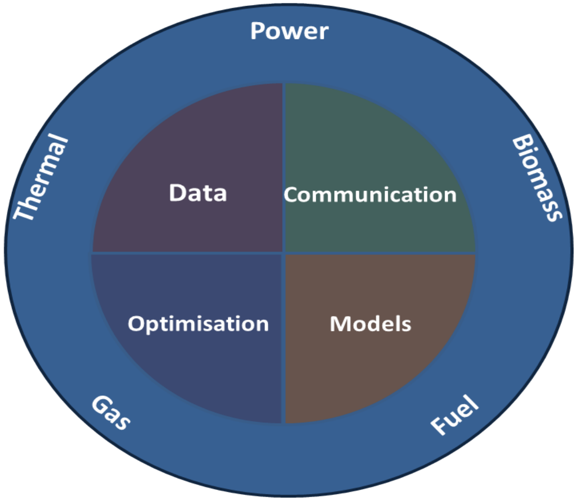
# Smart-Energy Operating-System; A Framework for Implementing Flexible Electric Energy Systems in Smart Cities




**Peder Bacher and Henrik Madsen, DTU Compute**

**http://www.henrikmadsen.org**

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

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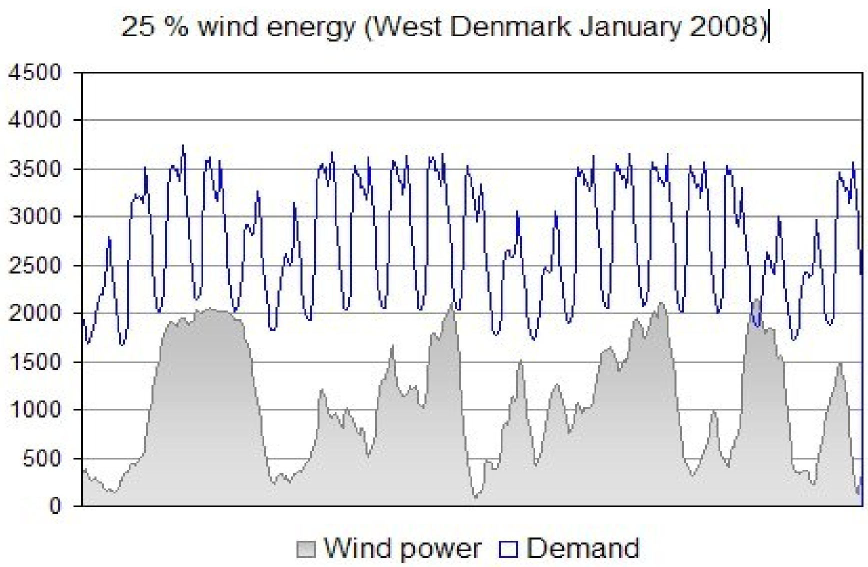
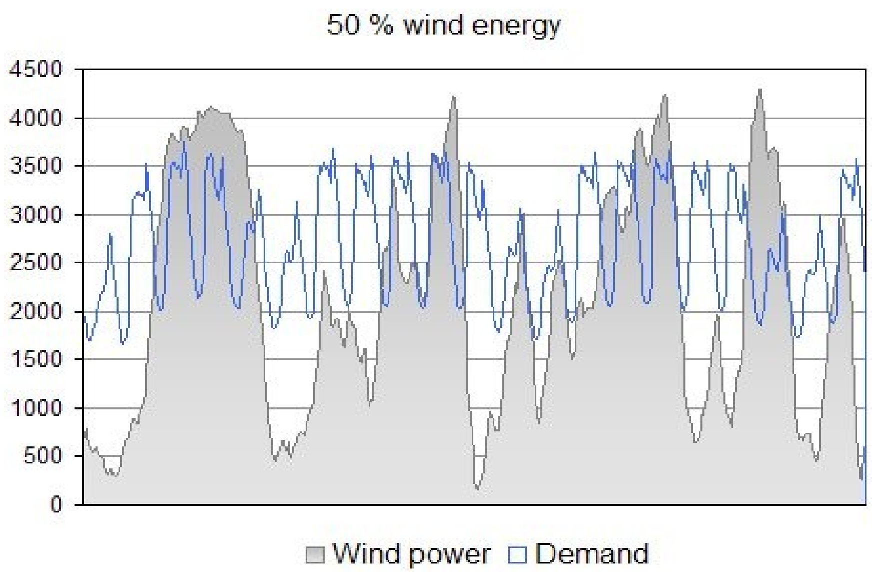
# The Danish Wind Power Case

*…. 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

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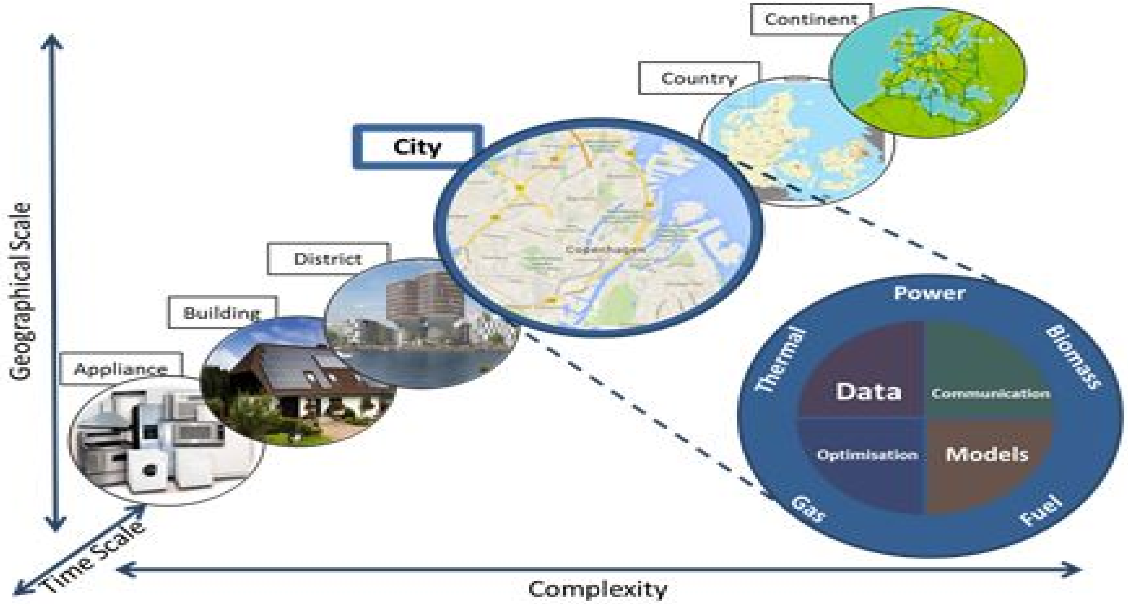
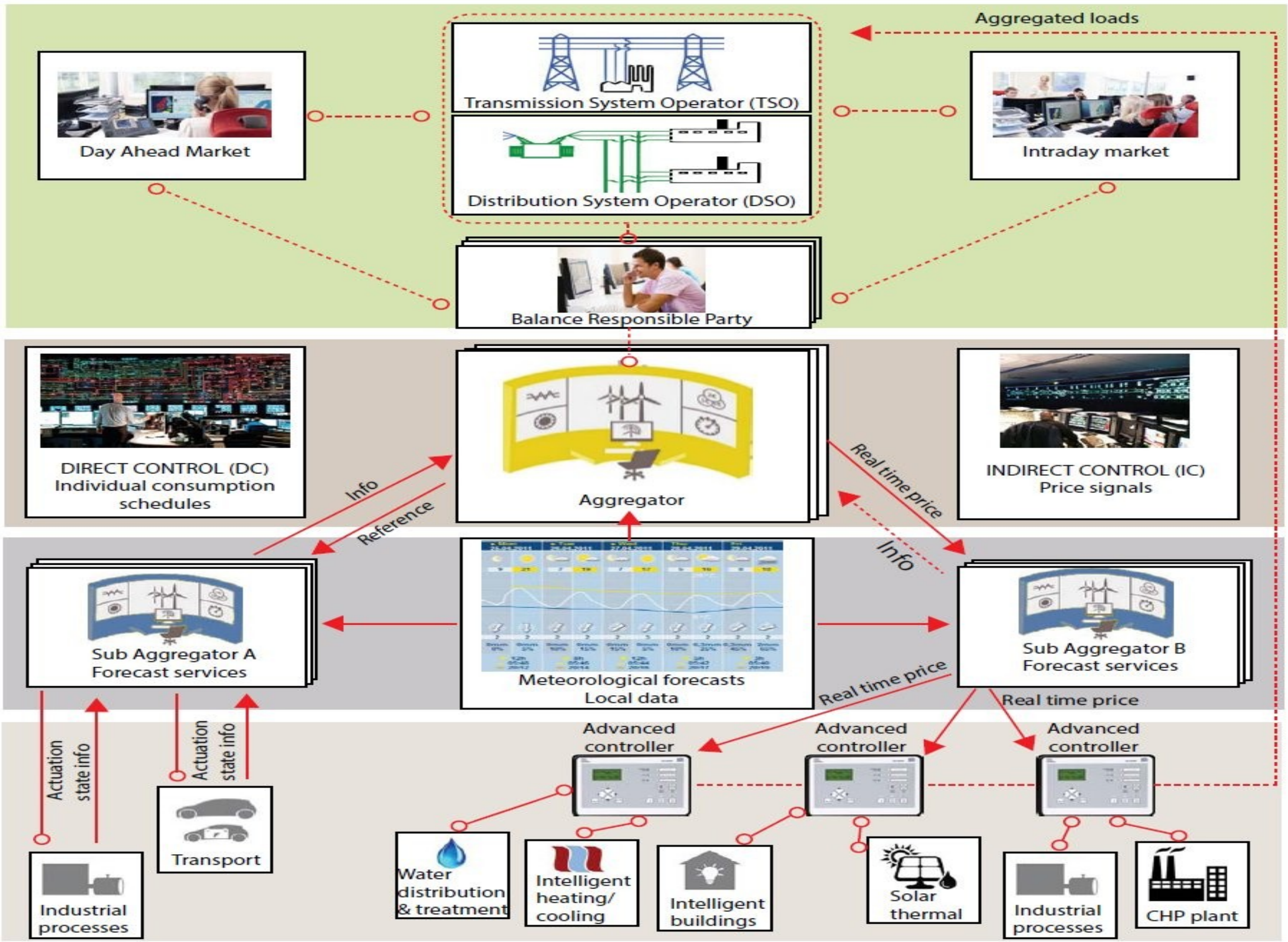
# Flexible Solutions and CITIES

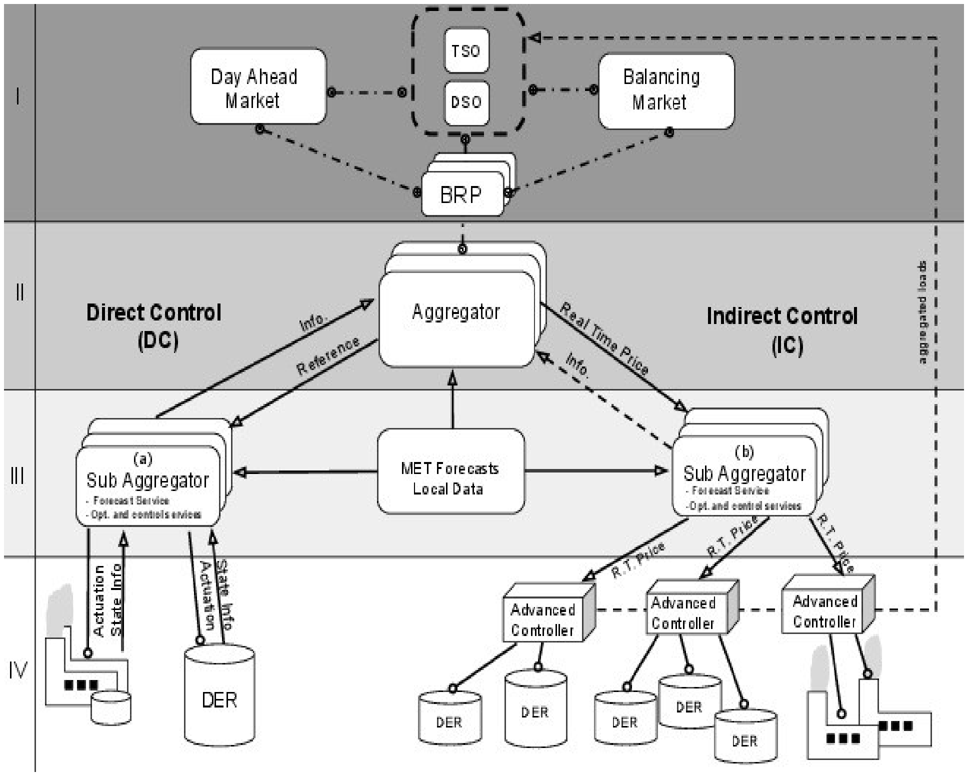
The ***Center for IT-Intelligent Energy Systems (CITIES)*** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.



# Smart-Energy OS



# Control and Optimization




**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

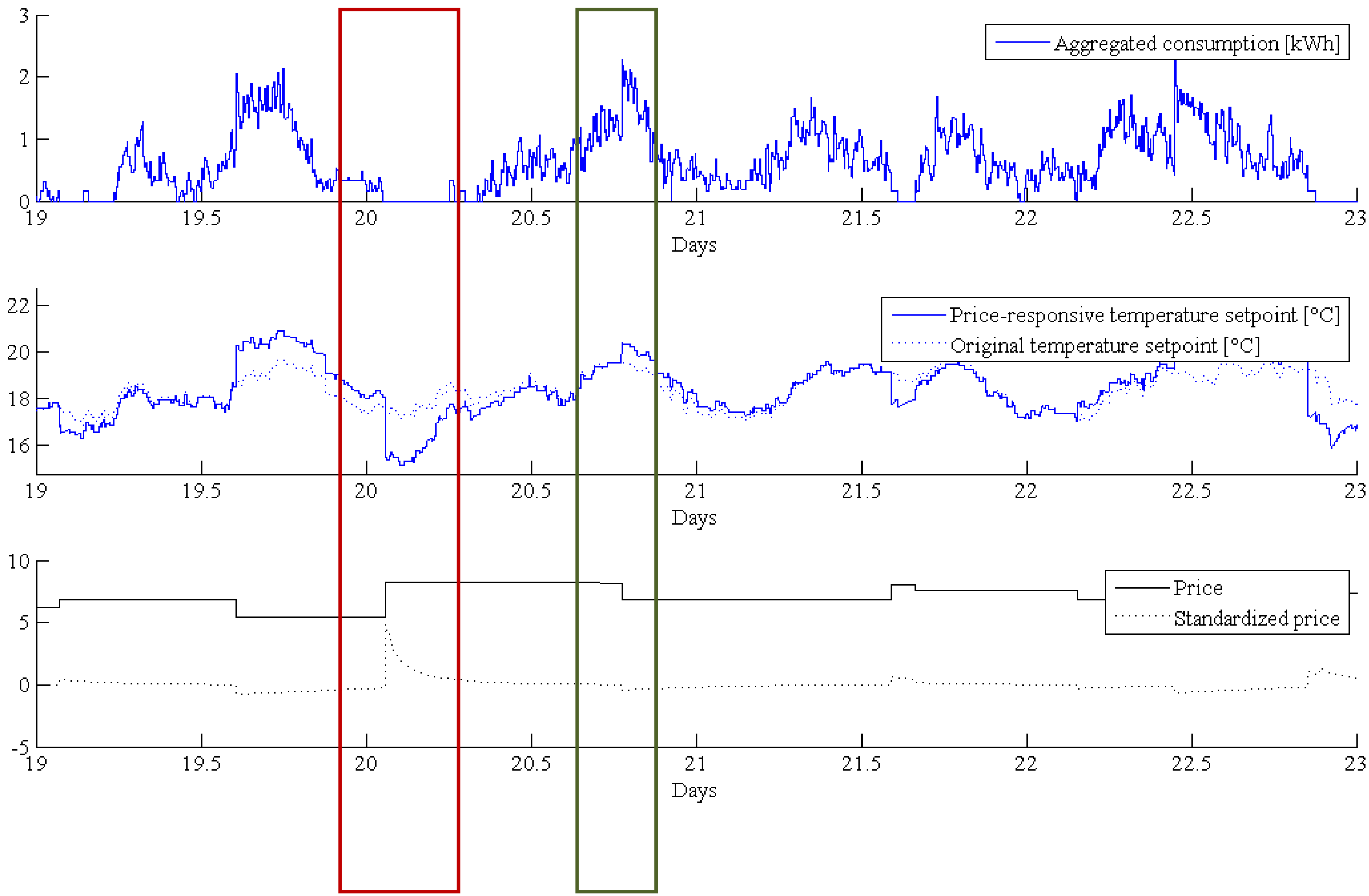
Models for DERs are not needed

Simple 'contracts'

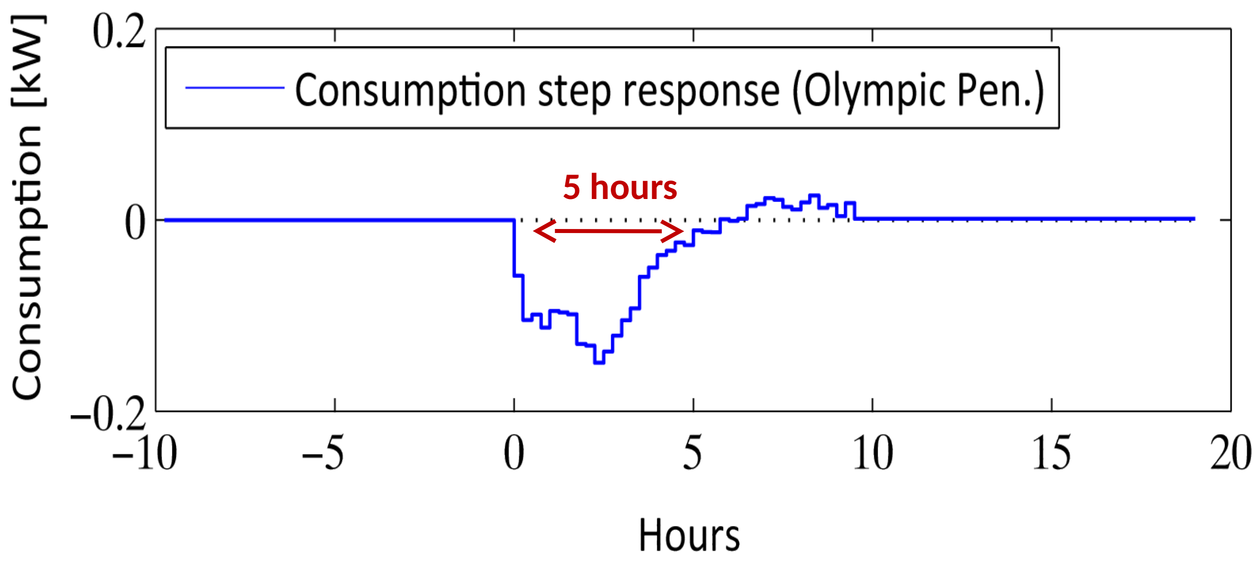
## Indirect Control

# Control of Heating Systems

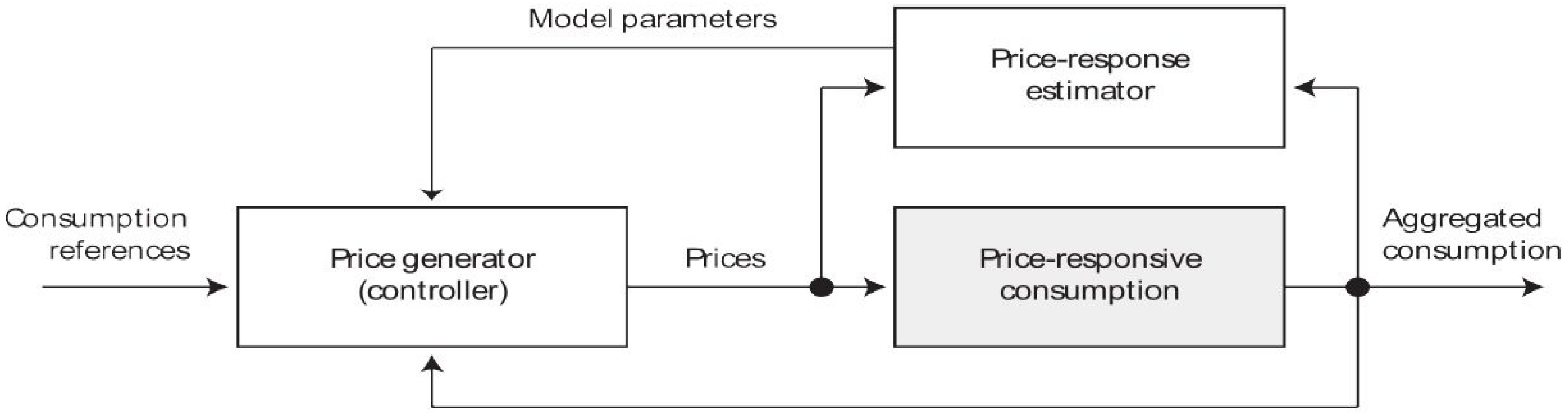
# Aggregation (over 20 houses)

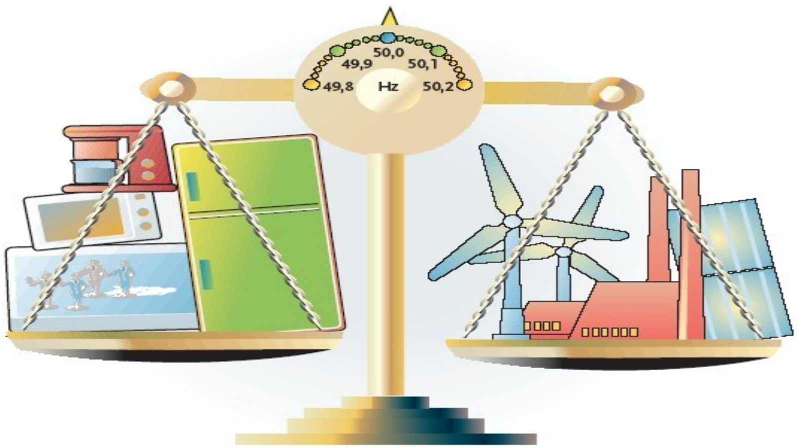


# Flexibility described by Step Response Functions



# Control of Power Consumption



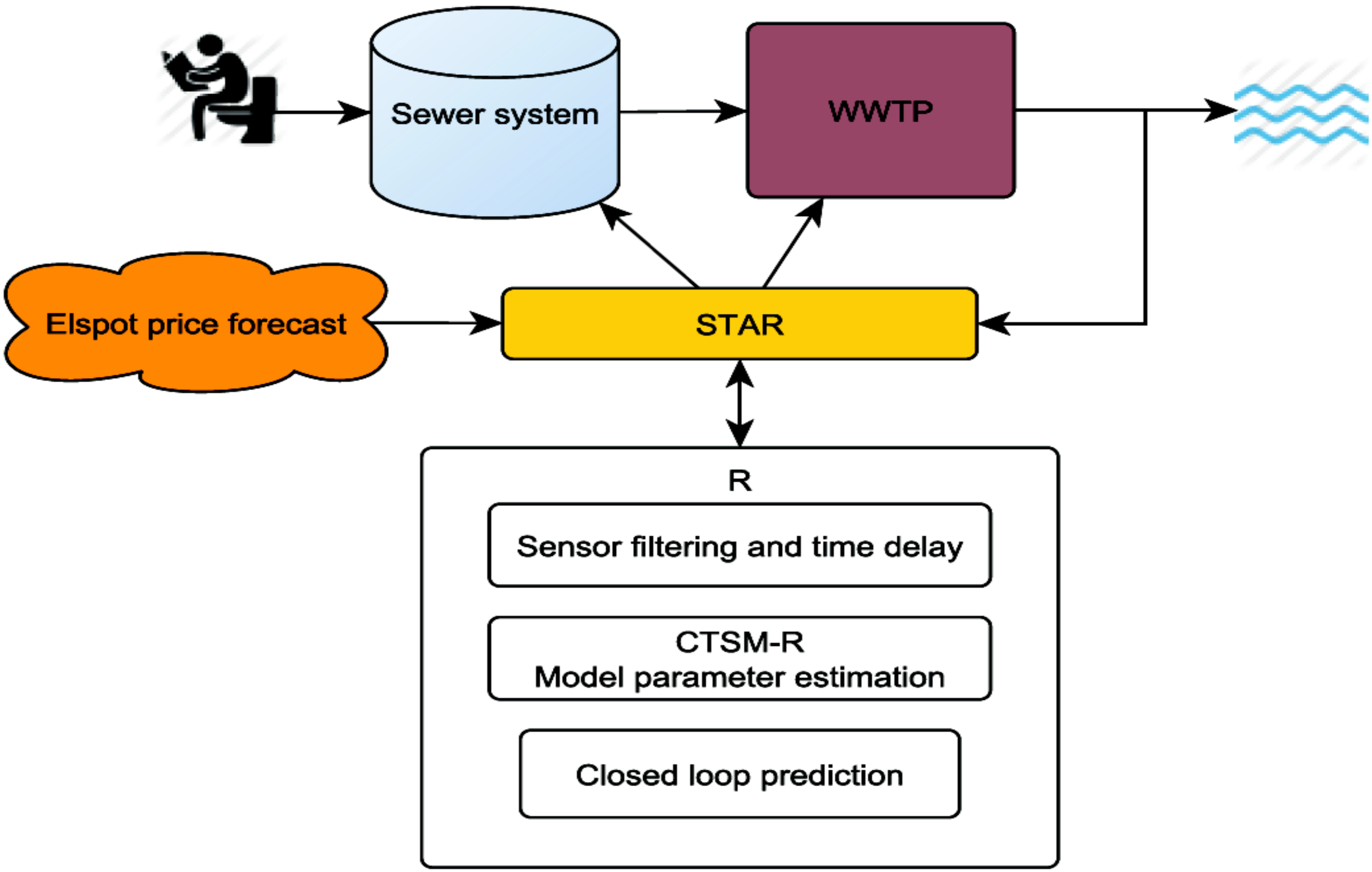



## Case study

# Control of Wastewater Treatment Plants

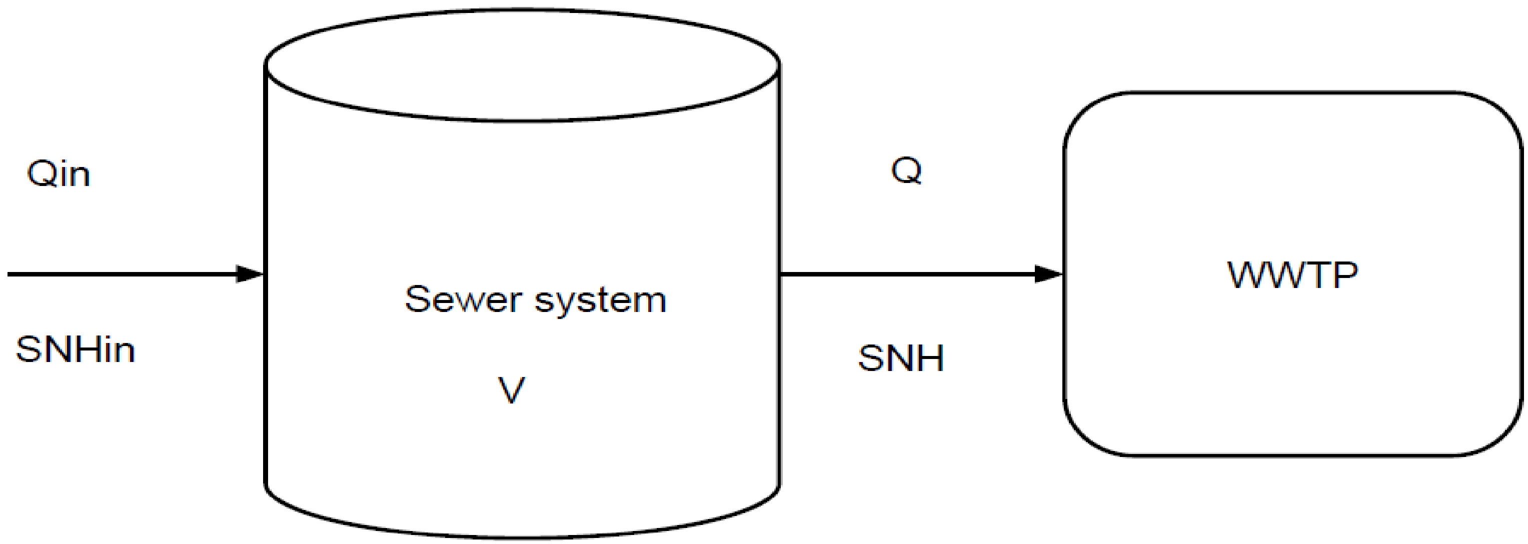
# Kolding WWTP

# Energy Flexibility in Wastewater Treatment

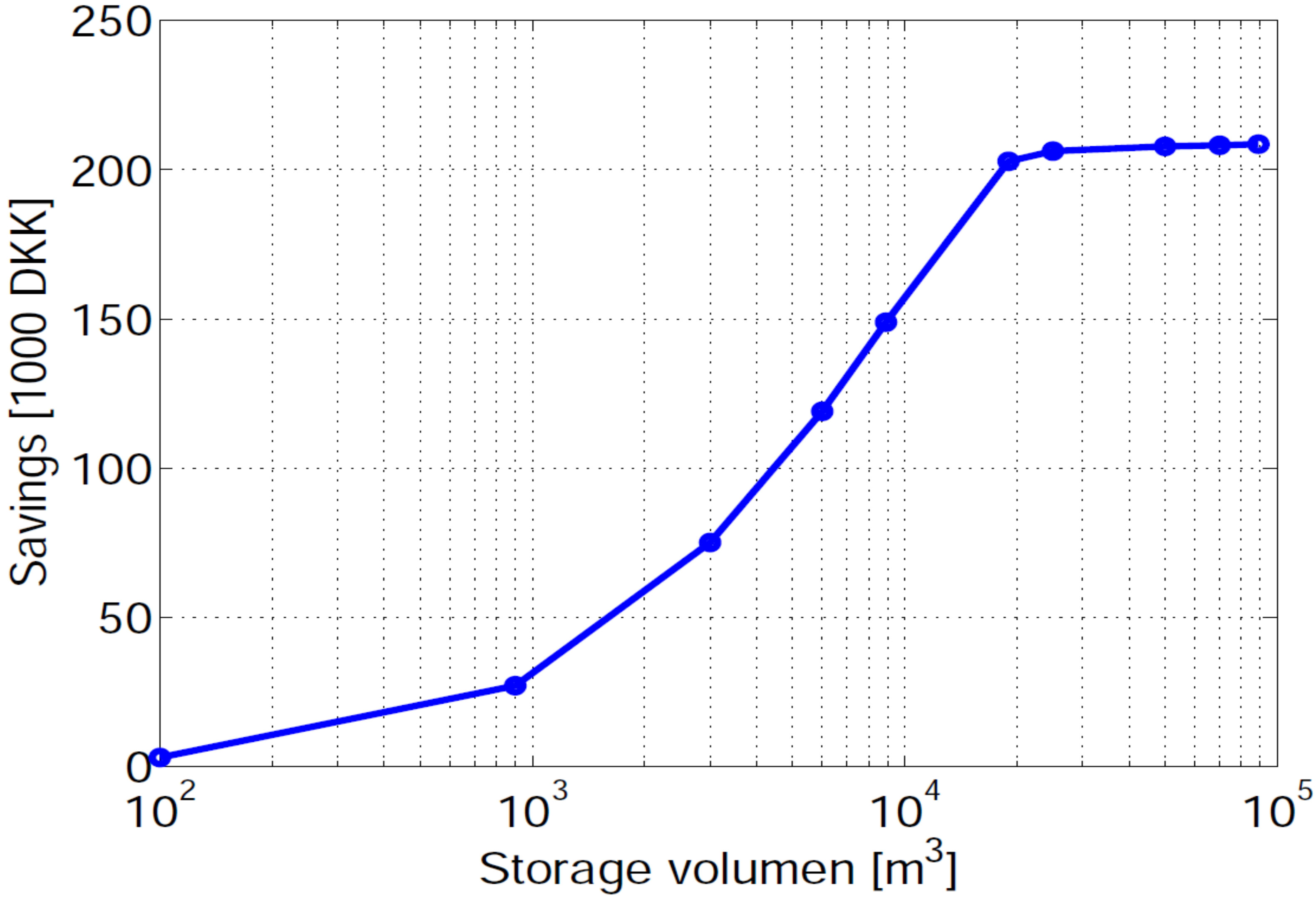


# Sewer System Control Goal

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



# Sewer System Annual Elspot Savings



# CITIES

Centre for IT-Intelligent Energy Systems in cities




## 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.

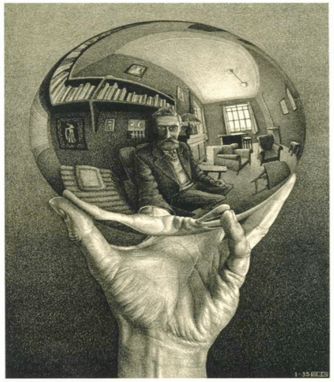
MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R . The software is available on GitHub.

Search ...

Latest news

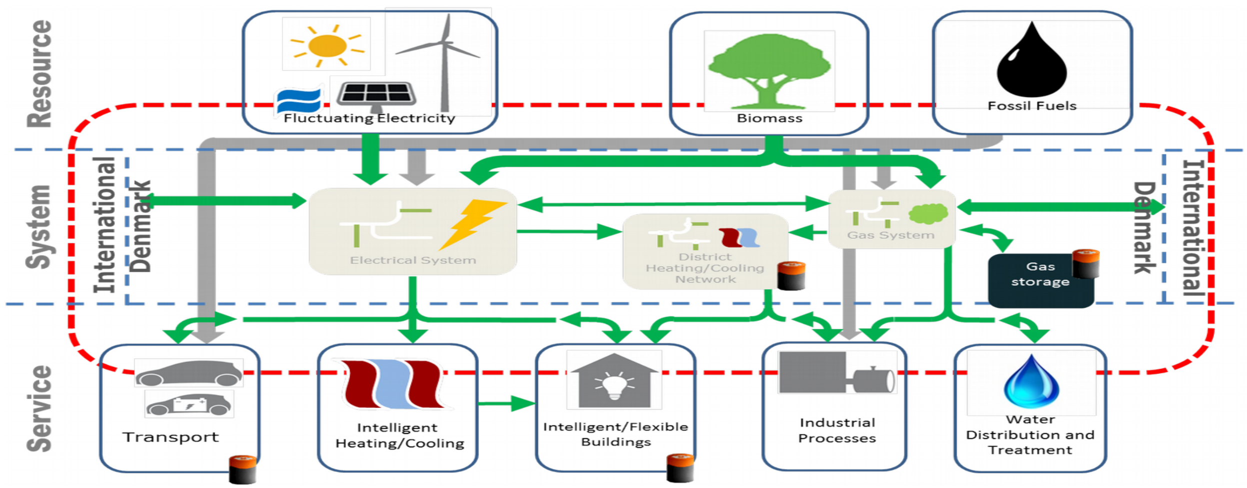
- Summer School at DTU, Lyngby, Denmark – July 4th-8th 2016
- Summer School – Granada, Spain, June 19th-24th 2016
- Third general consortium meeting – DTU, May 24th-25th 2016
- Smart City Challenge in Copenhagen – April 20th 2016
- Guest lecture by Pierluigi Mancarella at DTU, April 6th

# Integrated and Flexible Energy Systems
# Some Demo Projects in CITIES



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

# (Virtual) Storage Solutions




- **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
  - DH systems with thermal solar collectors can often provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions

# Summary

- A Smart-Energy OS for implementing flexible and integrated energy systems 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
- **Forecasting:** Framework (cloud based) for full probabilistic forecasting
- **Simulation:** Framework for simulating flexible power systems

# Discussion

- IT-Intelligent Energy Systems Integration 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 just 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)