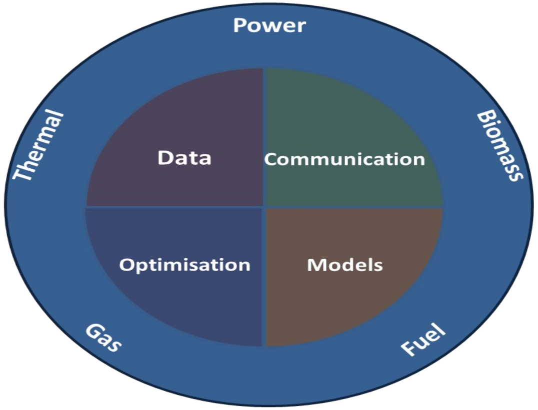
CITIES

Center for IT-Intelligent Energy Systems in Cities



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

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

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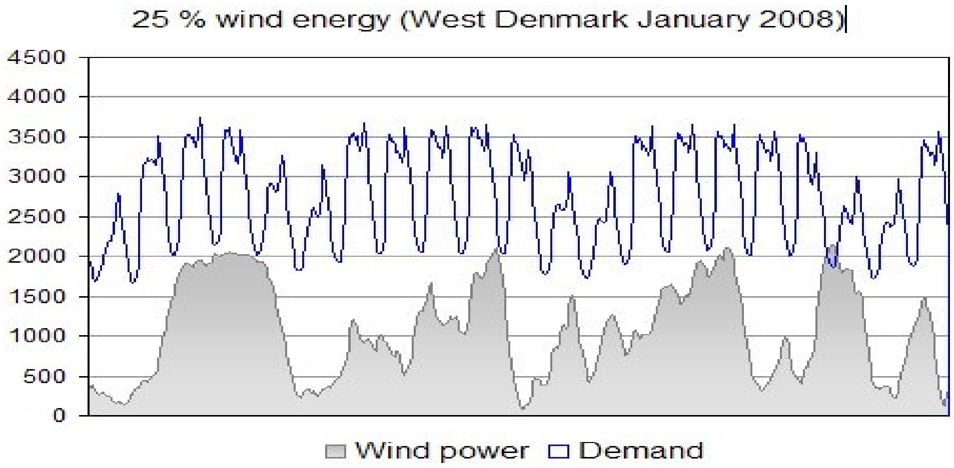
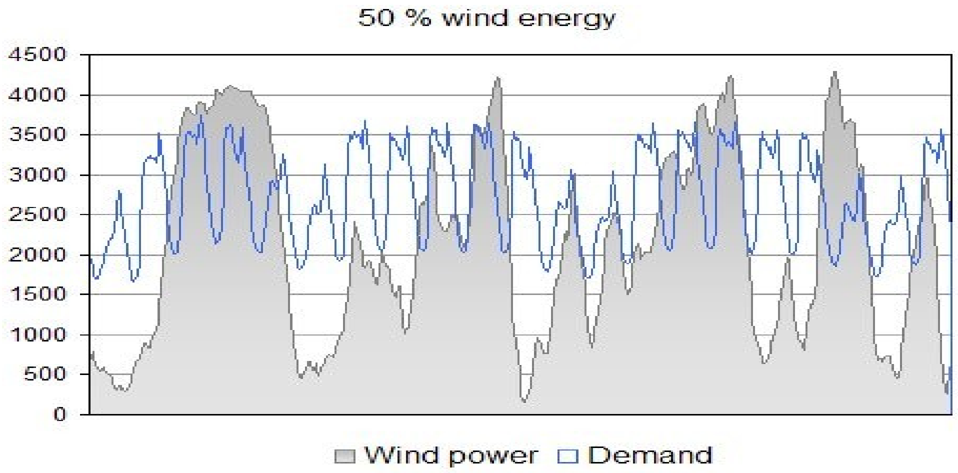
The Danish Wind Power Case

.... 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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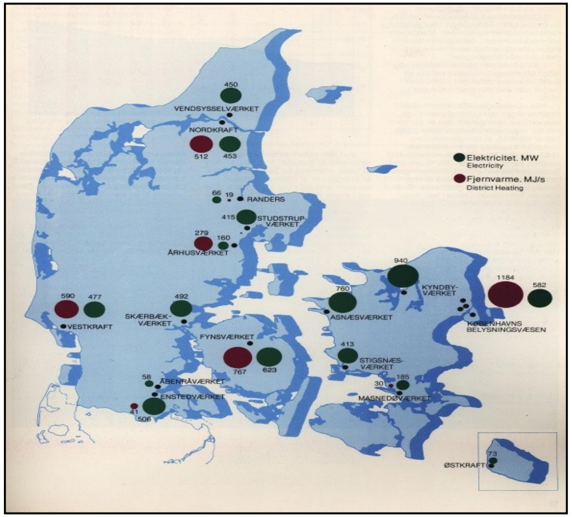
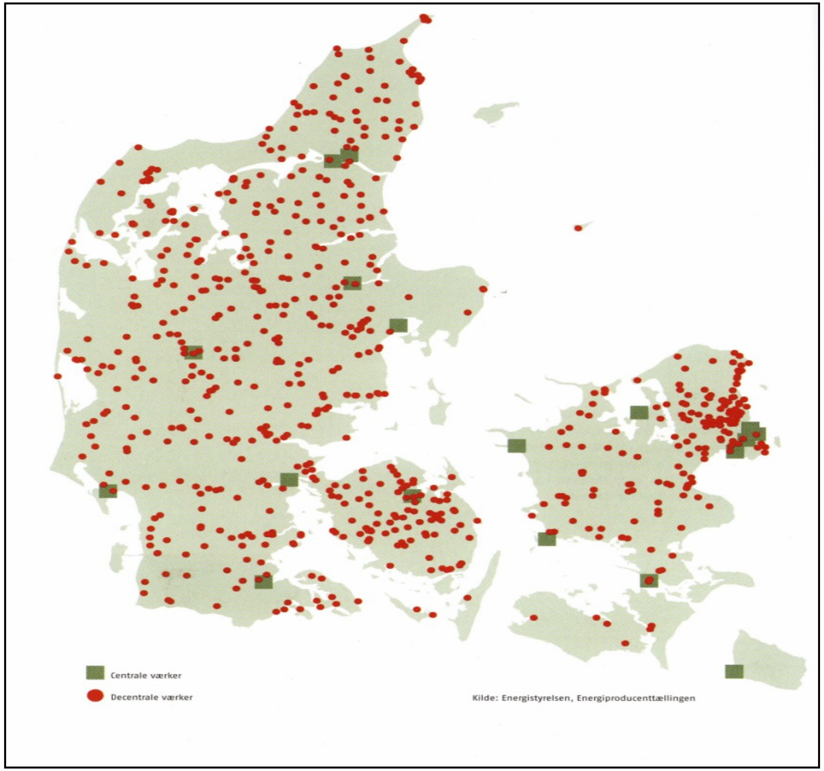
From large central plants to Combined Heat and Power (CHP) production

1980



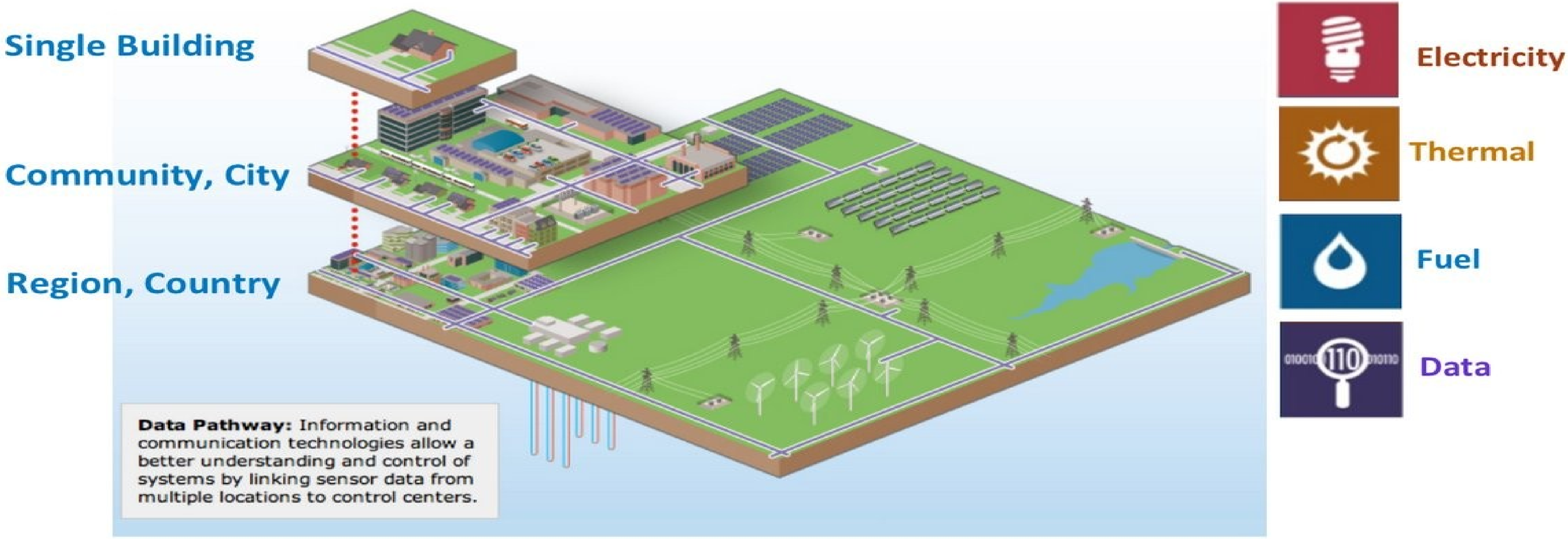
Today



From a few big power plants to many small ***combined heat and power*** *plants – however most of them based on coal*

Energy Systems Integration

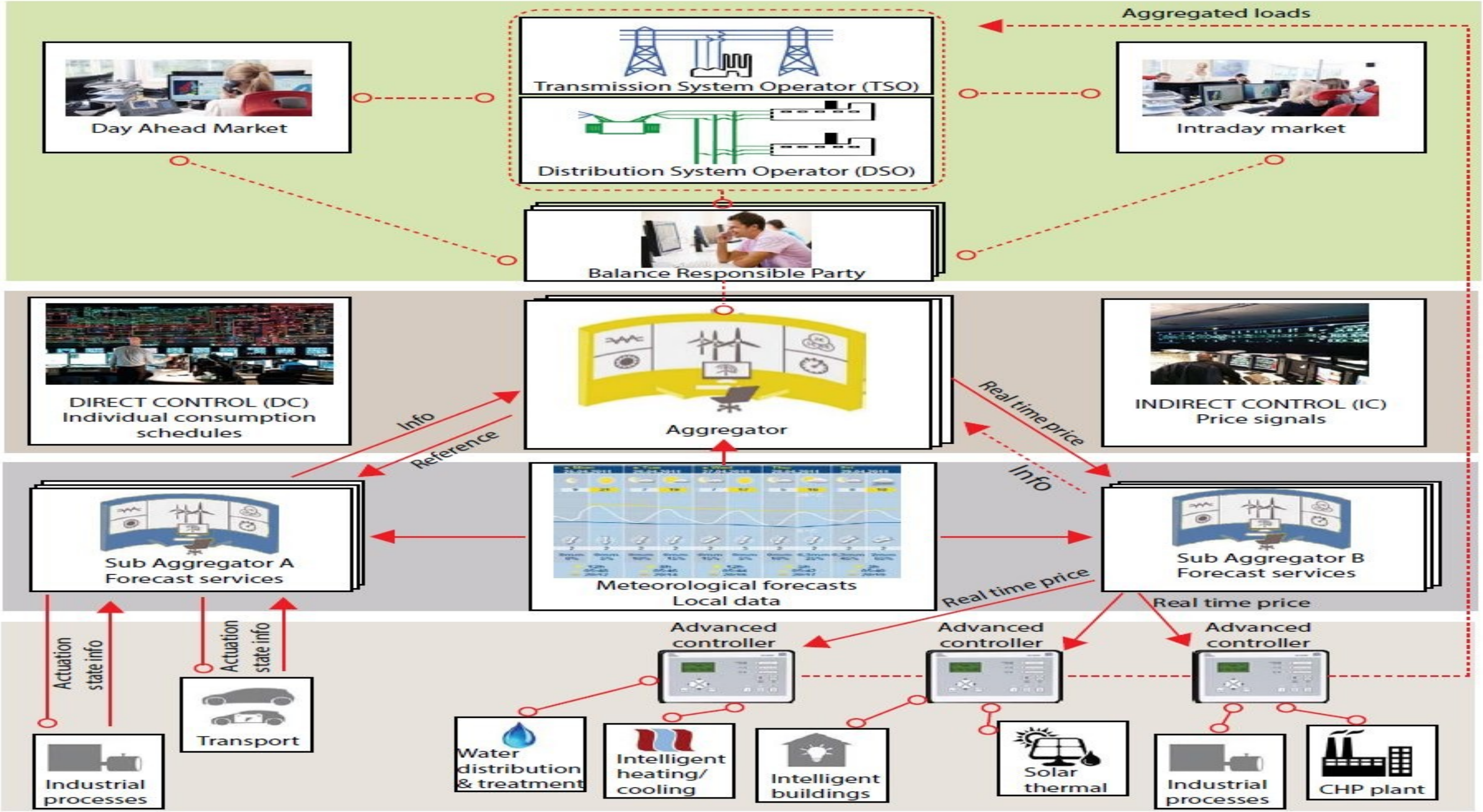
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



Flexible Solutions and CITIES

The ***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.

Smart-Energy OS



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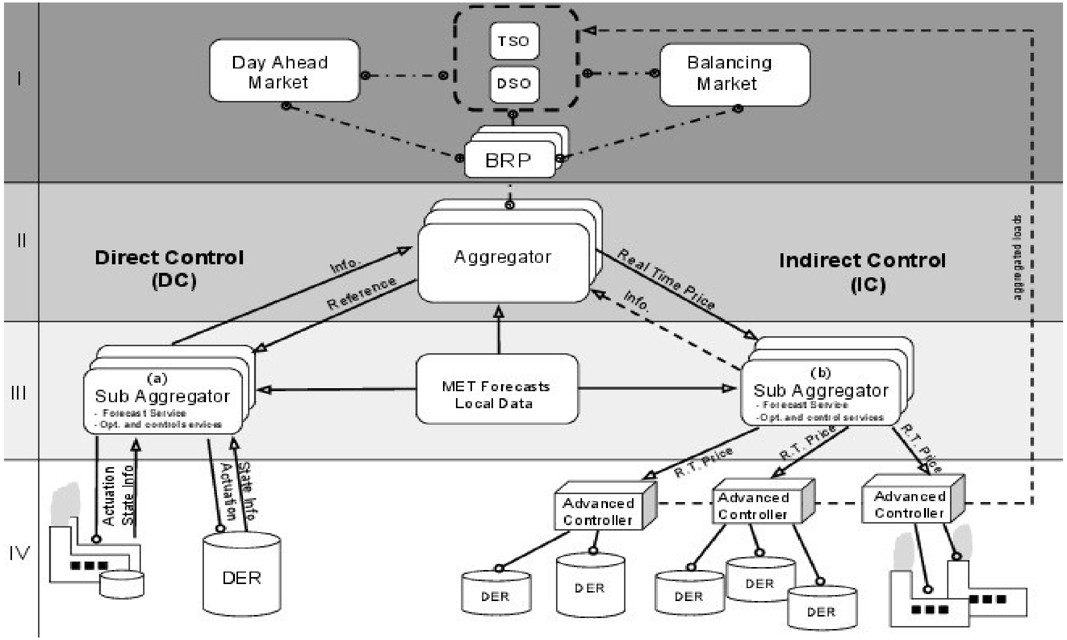
Control and Optimization



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**

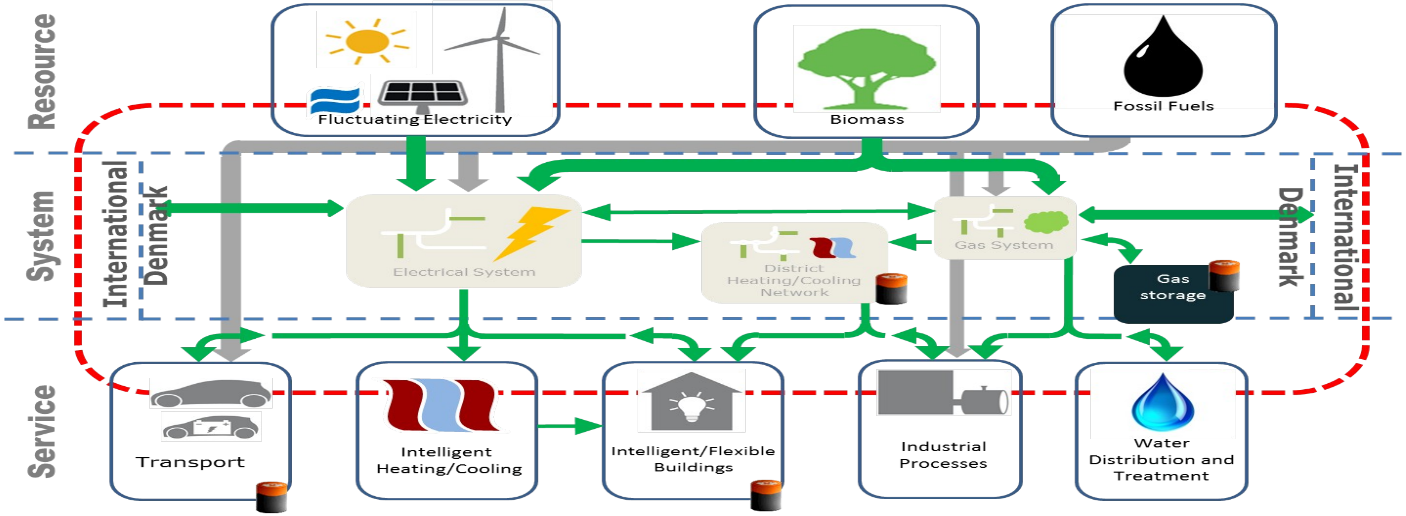
Cost: E-MPC at **low (DER) level**, One-way communication

Models for DERs are not needed

Simple 'contracts'

Models for Integration

Energy Systems Integration using **data** leading to **grey box models for operation of future flexible energy systems.**



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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

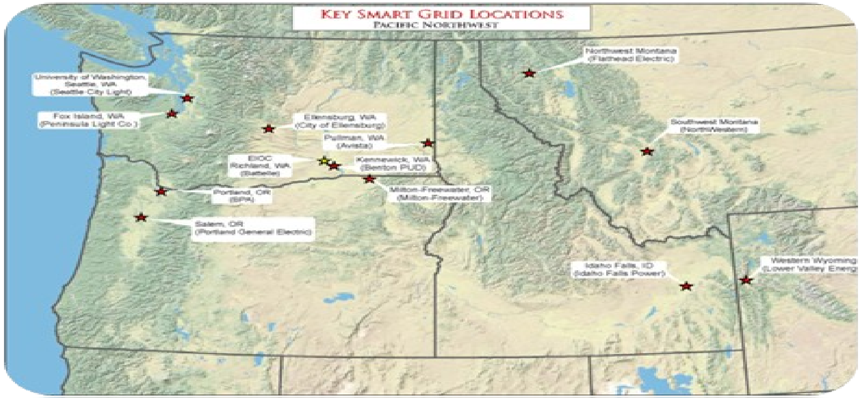
Case study

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

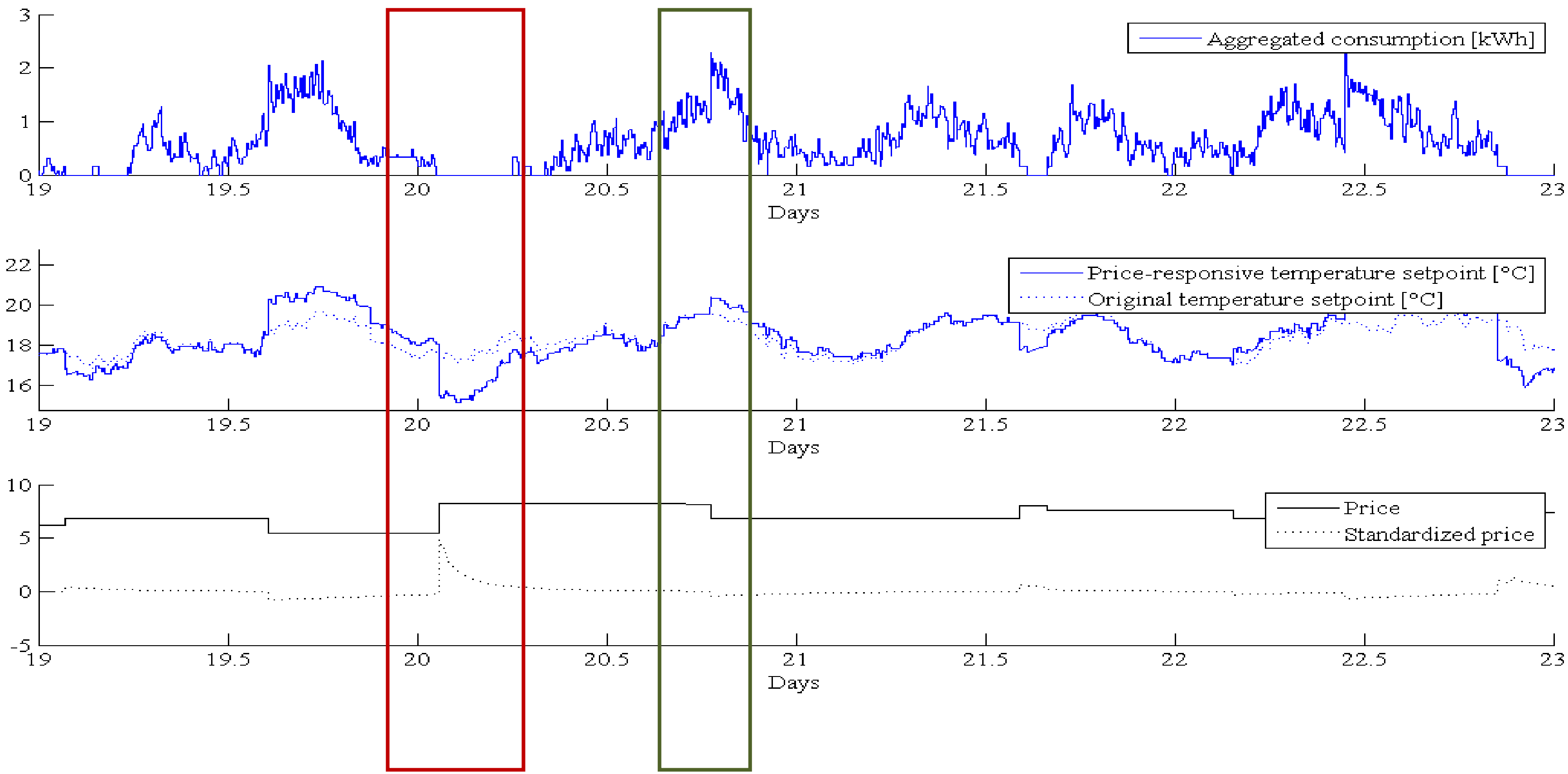
Data from BPA

Olympic Pensinsula project

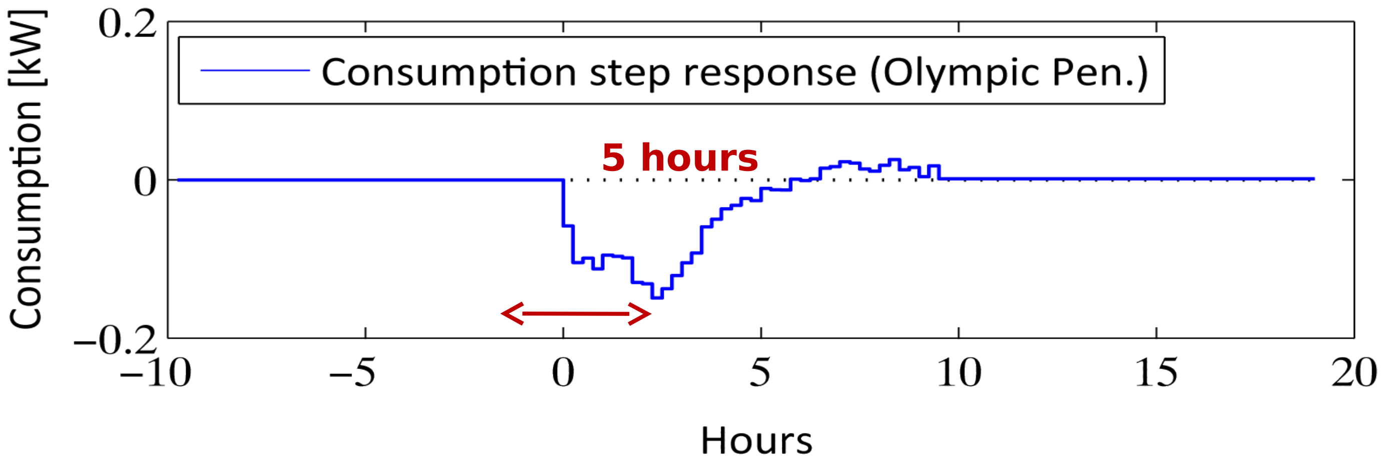
- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption



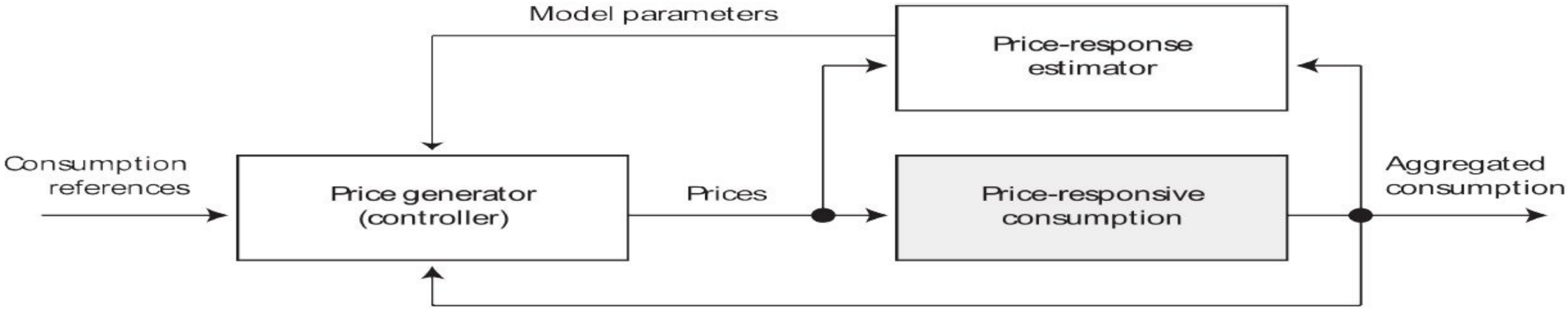
Aggregation (over 20 houses)

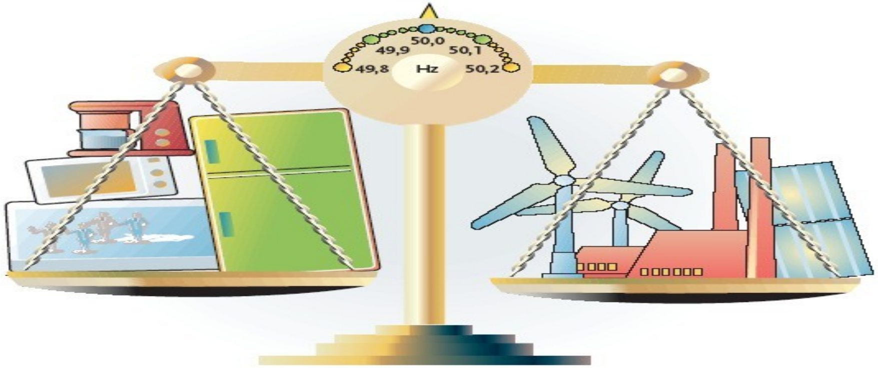


Response on
Price Step Change



Control of Power Consumption





Case study

Heat Pumps and Local Storage

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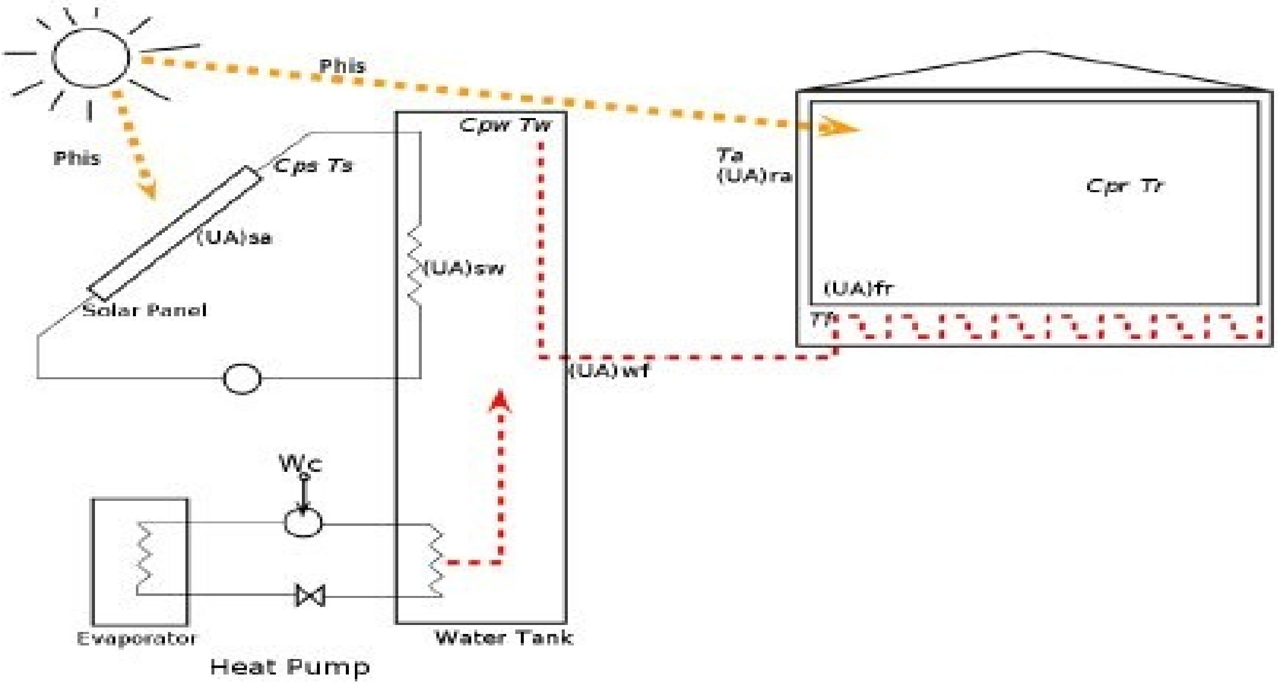
Modeling Heat Pump and Solar Collector

Simplified System



Avanced Controller

Economic Model Predictive Control

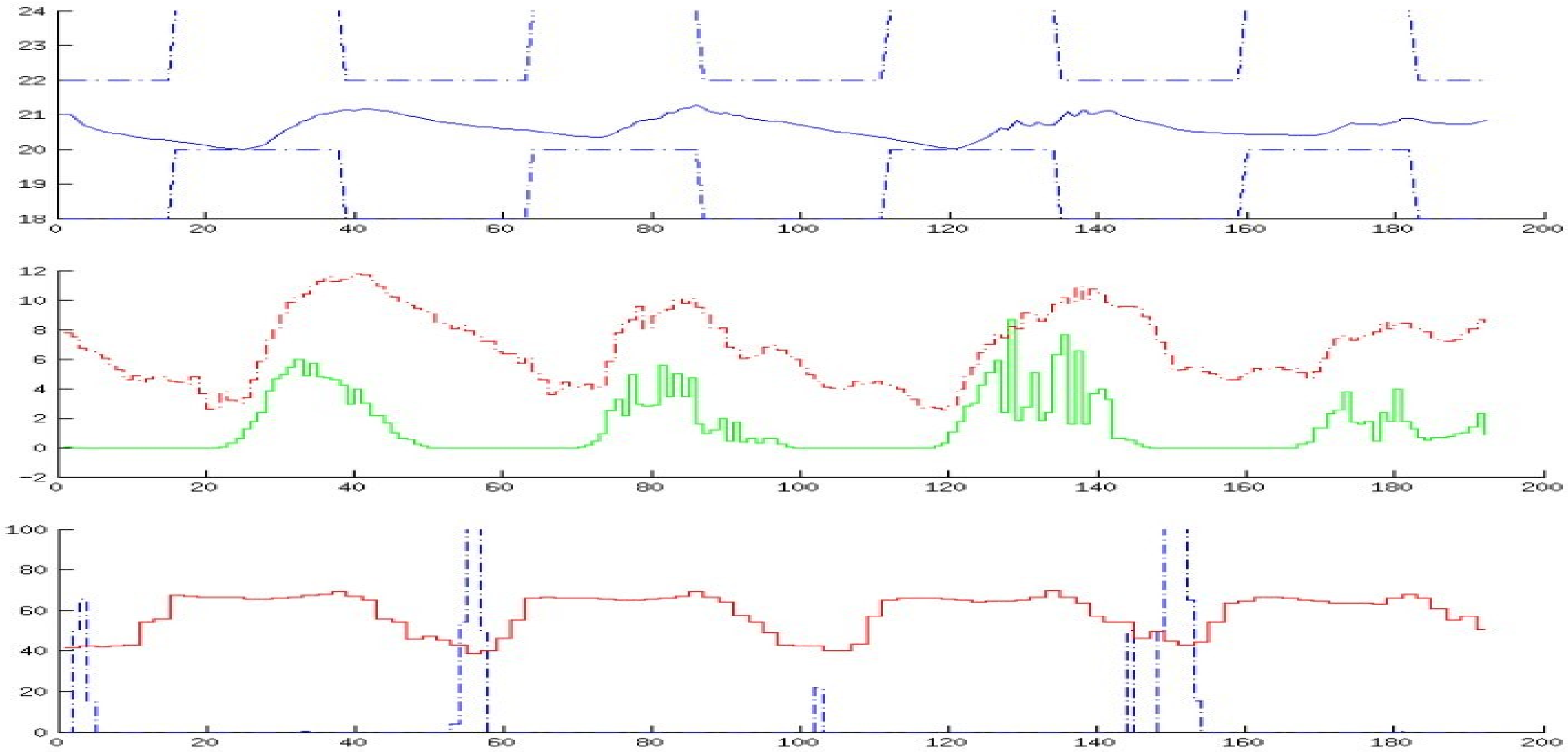
Formulation

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

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

$$\begin{aligned}
\text{Subject to} \quad & x_{k+1} = Ax_k + Bu_k + Ed_k \quad && k = 0, 1, \ldots, N-1 && (4b)\\
& y_k = Cx_k && k = 1, 2, \ldots, N && (4c)\\
& u_{min} \leq u_k \leq u_{max} && k = 0, 1, \ldots, N-1 && (4d)\\
& \Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} && k = 0, 1, \ldots, N-1 && (4e)\\
& y_{min} \leq y_k \leq y_{max} && k = 0, 1, \ldots, N && (4f)
\end{aligned}$$

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



Case study

Control of Wastewater Treatment Plants

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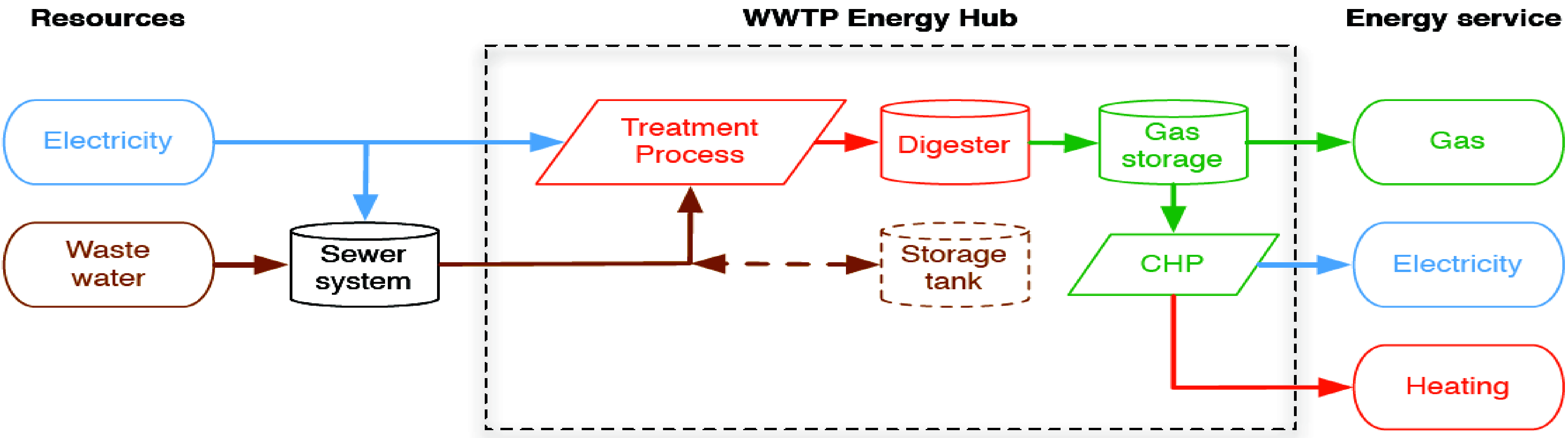
Waste-2-Energy



Kolding WWTP

Energy Flexibility in Wastewater Treatment

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

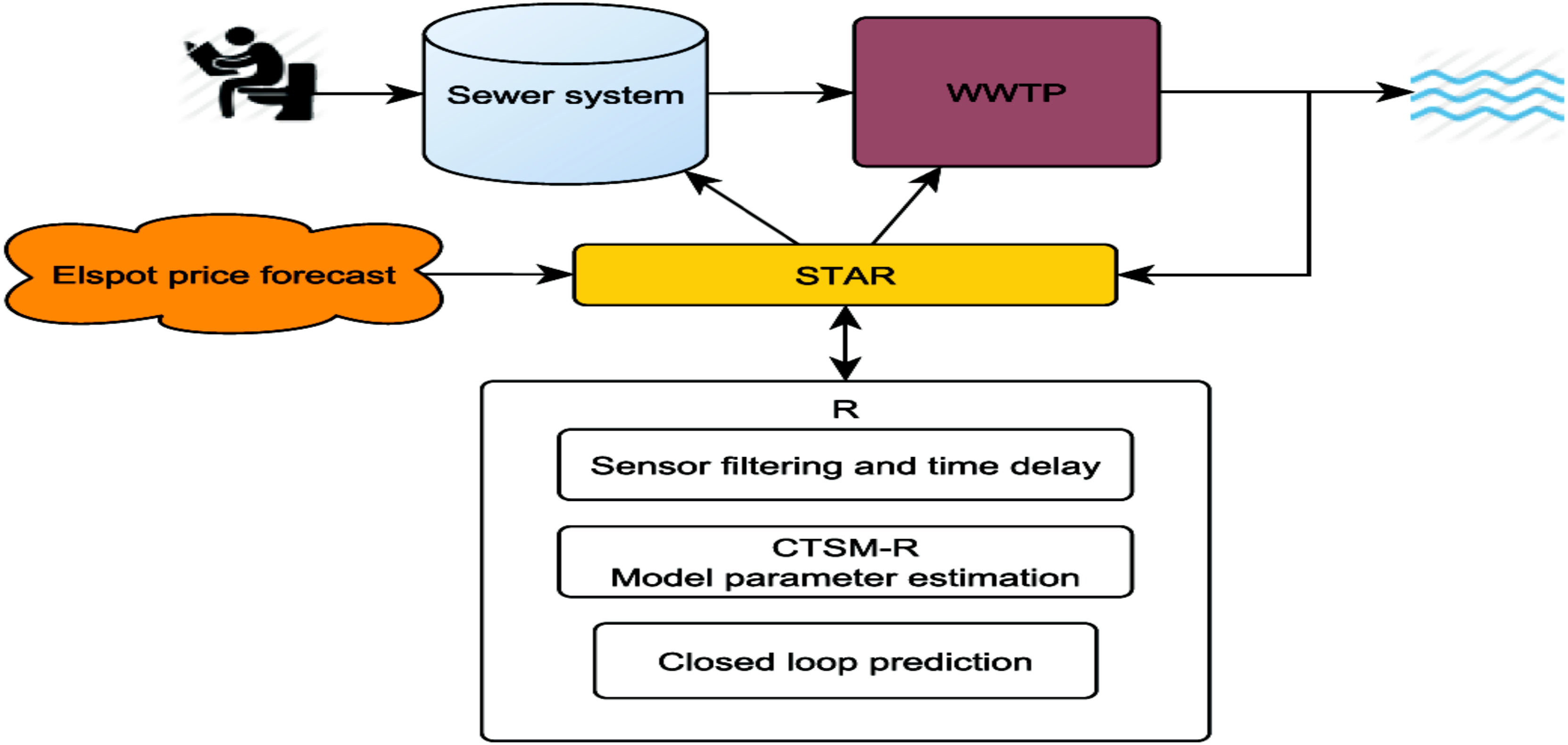
Overall goals:

Cost reduction

Minimize effluent concentration

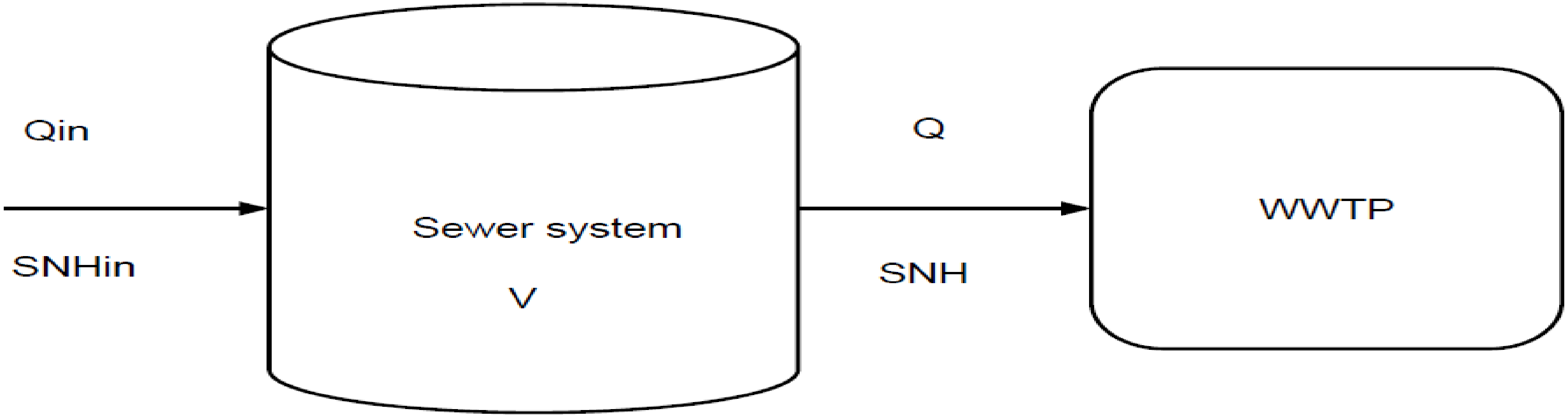
Minimize overflow risk

Energy Flexibility in Wastewater Treatment

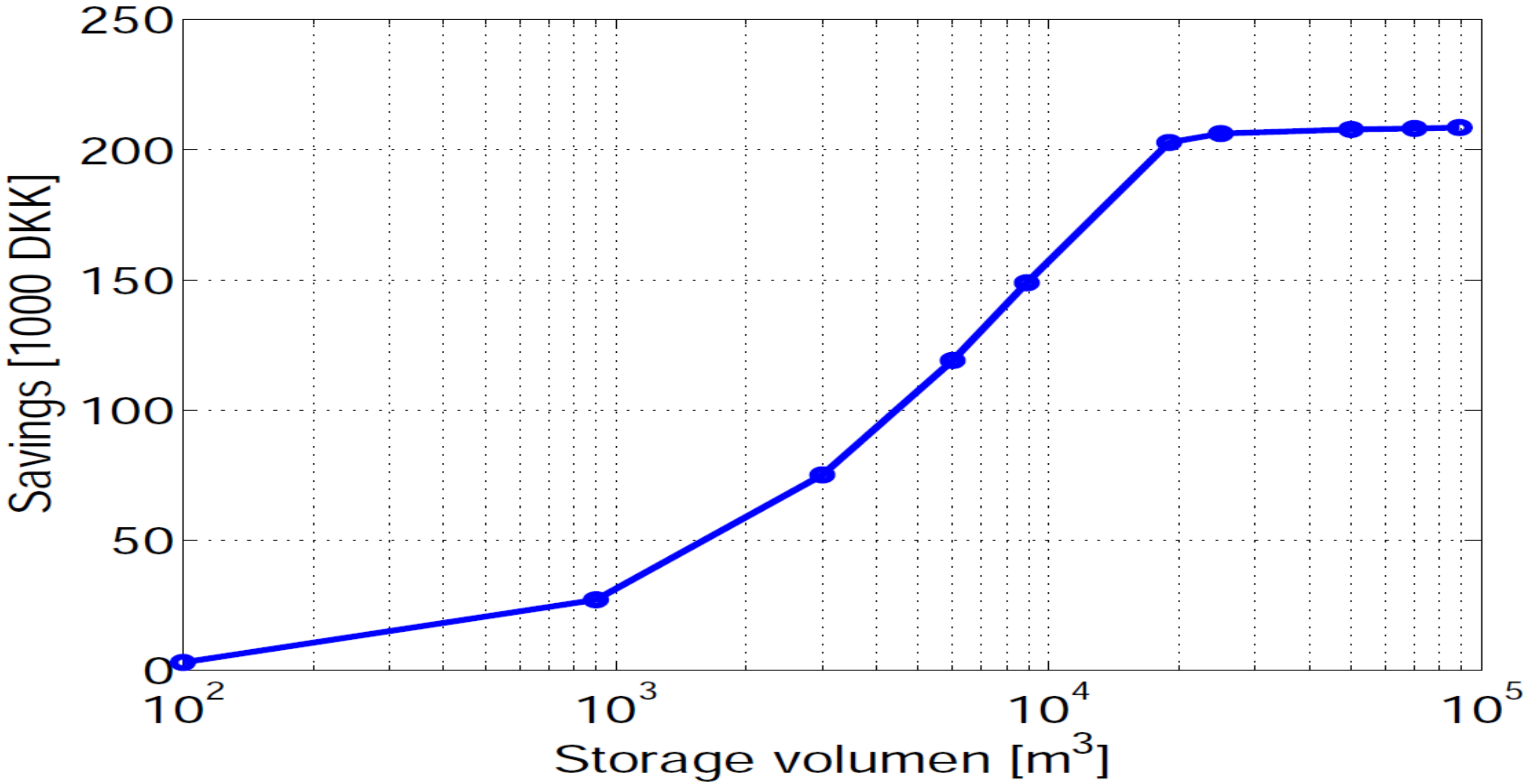


Sewer System Control Goal

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



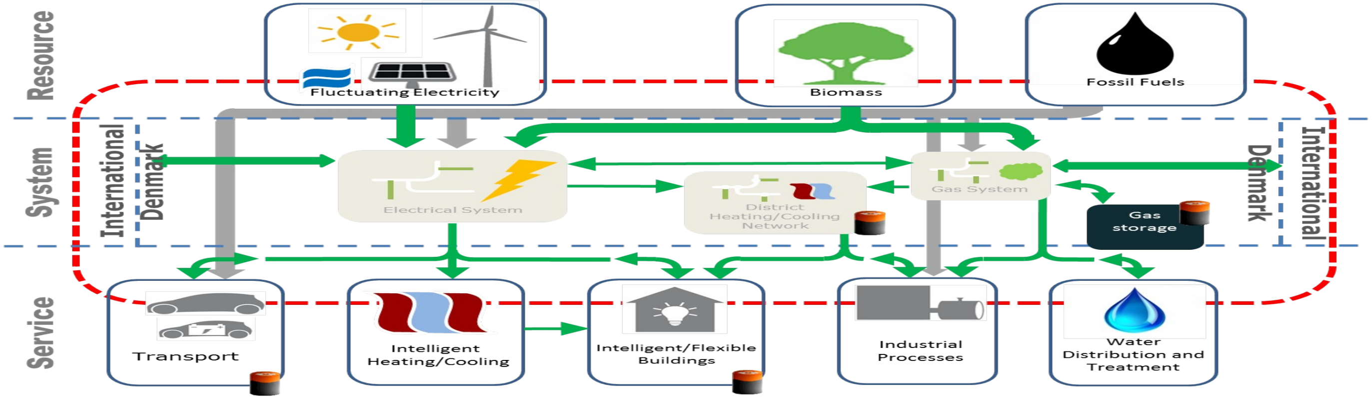
Sewer System Annual Elspot Savings



IT-Intelligent Energy Systems
Some 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, …)
- ……………

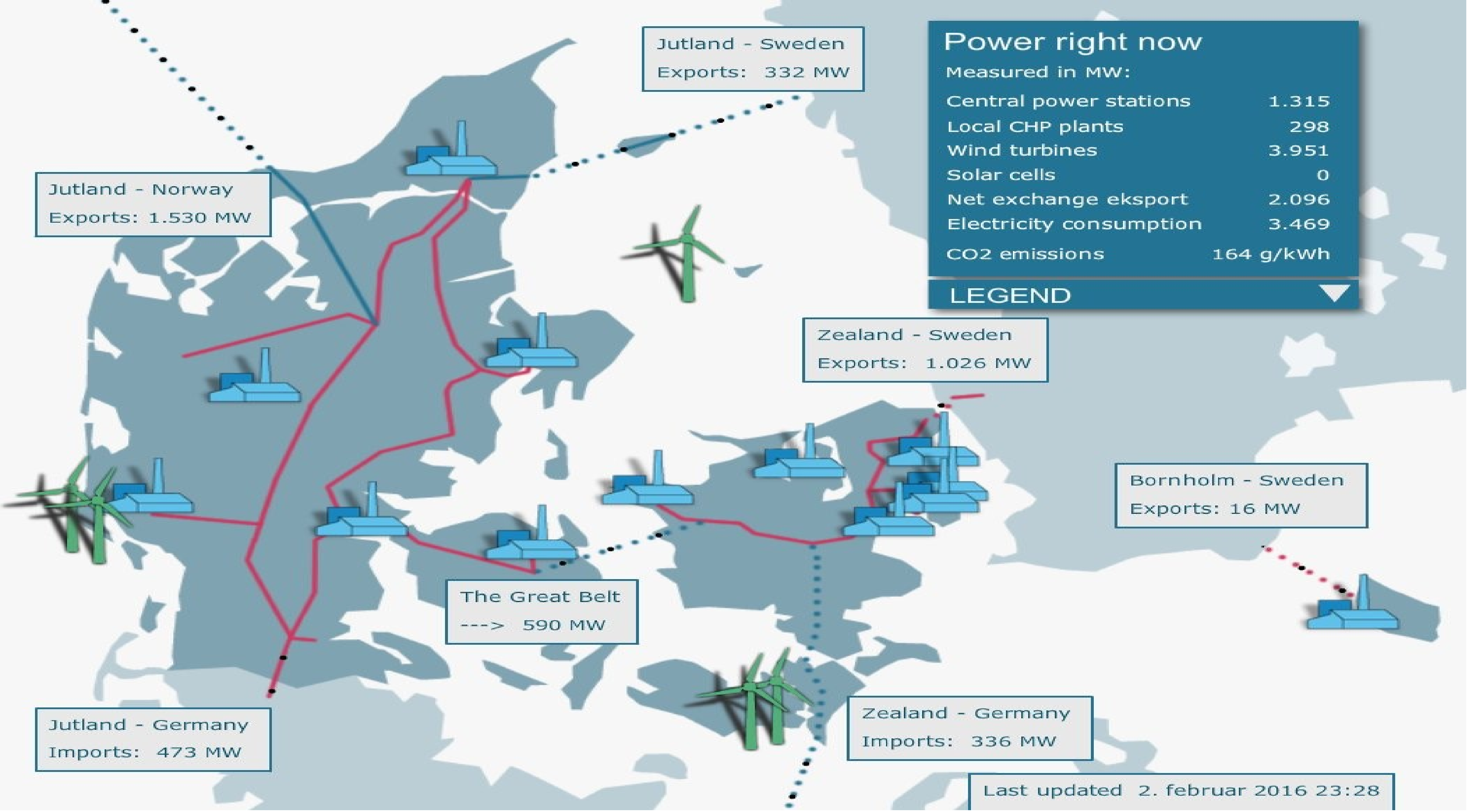
Virtual Storage or Flexibility Characteristics



- **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 can provide virtual storage solutions (so maybe we should put less focus on physical 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)


Jutland - Sweden
Exports: 332 MW
Power right now
Measured in MW:
Central power stations 1.315
Local CHP plants 298
Wind turbines 3.951
Solar cells 0
Net exchange eksport 2.096
Electricity consumption 3.469
CO2 emissions 164 g/kWh
LEGEND
Jutland - Norway
Exports: 1.530 MW
Zealand - Sweden
Exports: 1.026 MW
Bornholm - Sweden
Exports: 16 MW
The Great Belt
---> 590 MW
Jutland - Germany
Imports: 473 MW
Zealand - Germany
Imports: 336 MW
Last updated 2. februar 2016 23:28