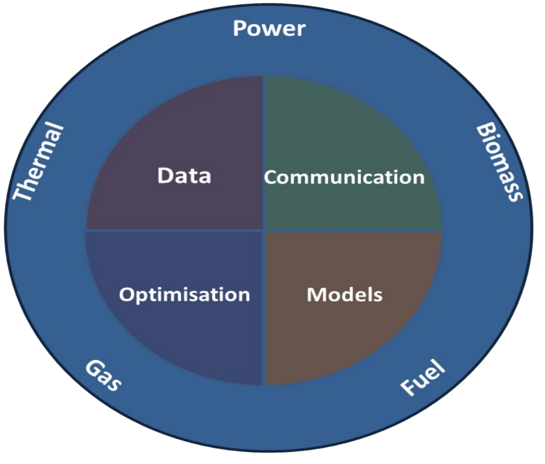
CITIES and TotalFlex
Possibilities for joint activities



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

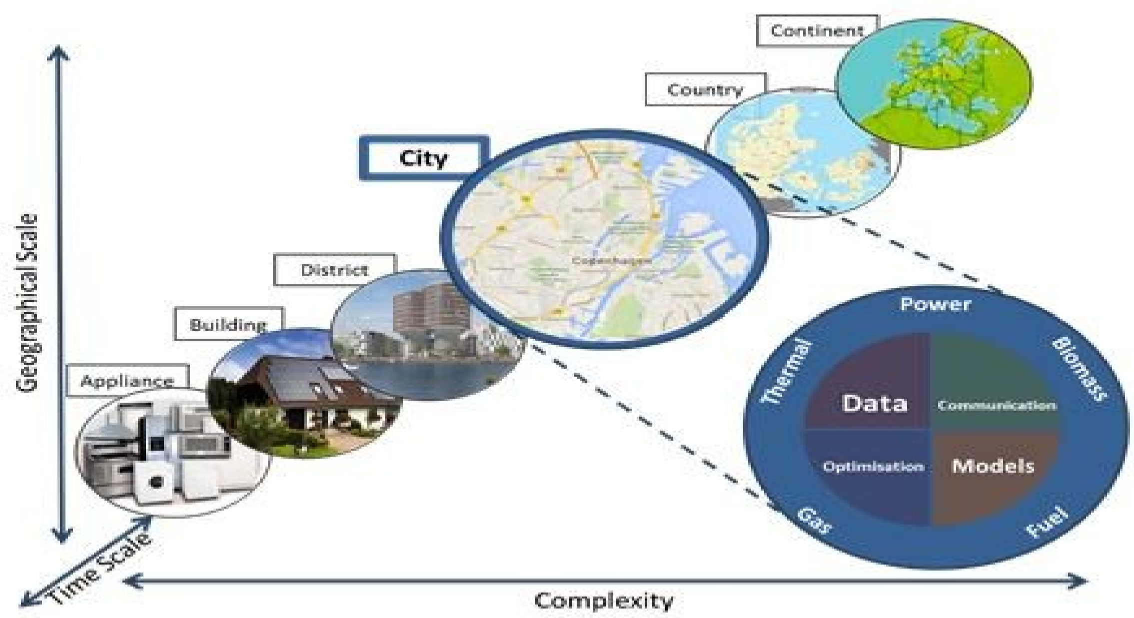
http://www.smart-cities-centre.org

CITIES
Centre for IT Intelligent Energy Systems

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.

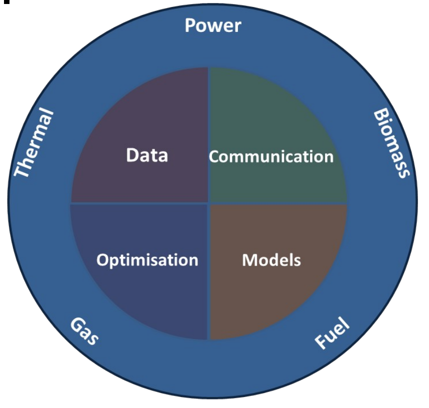
CITIES is a large Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org .



Flexibility Idea

The **central idea** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in we can enable **flexibility** and hence integrate 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**.



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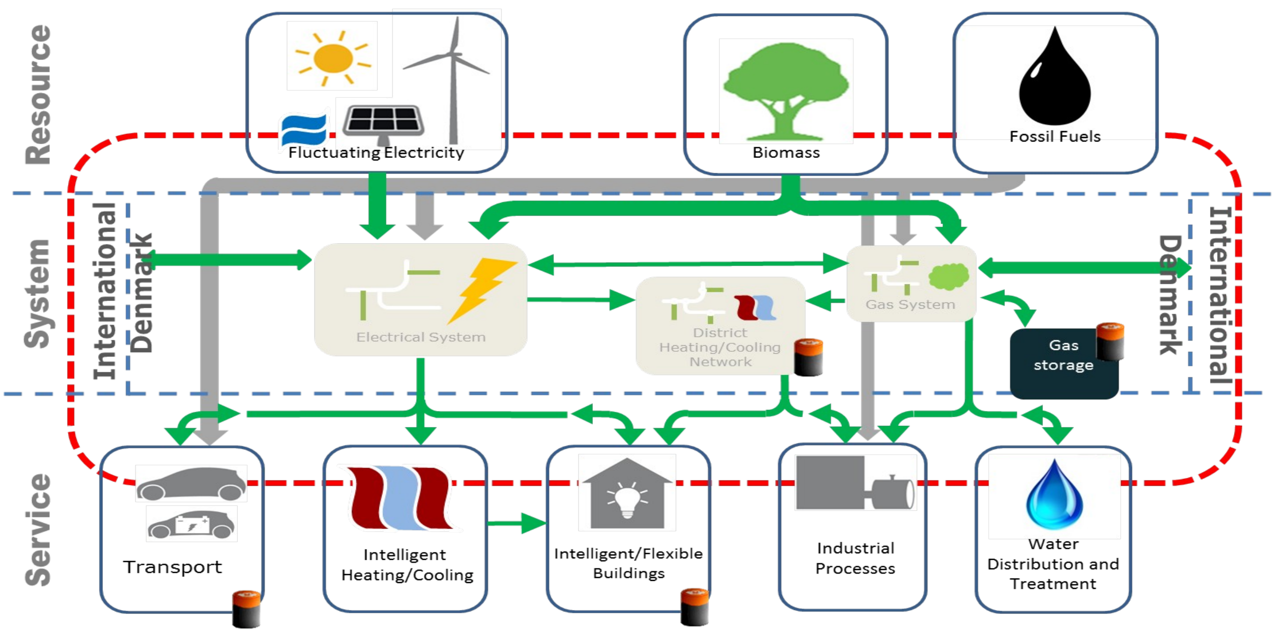
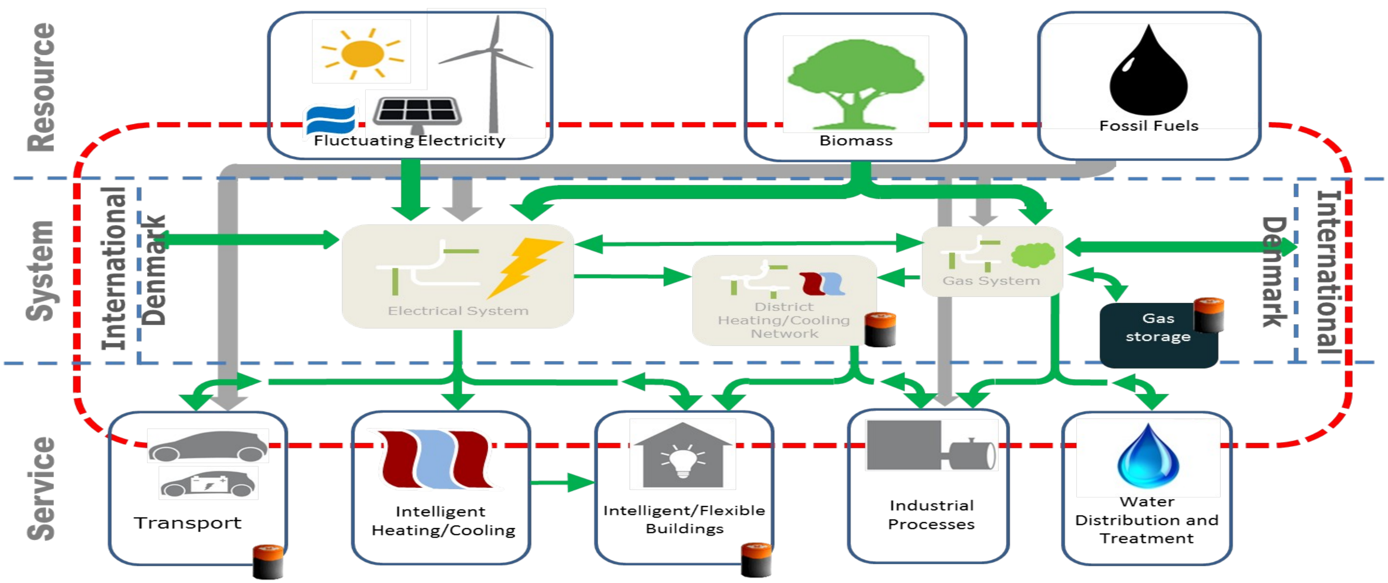
ICT implementable models

Energy Systems Integration using **data and ICT solutions** are used to establish (grey-box) **models and methods for planning and operation of flexible energy systems.**



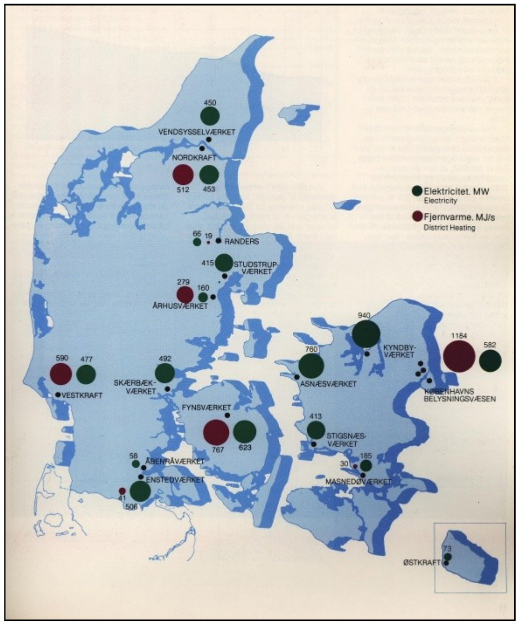
Virtual Storage by Energy Systems Integration



- **Denmark (2014) : 48 pct of power load by renewables (> 100 pct for some days in January)**
- **(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

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

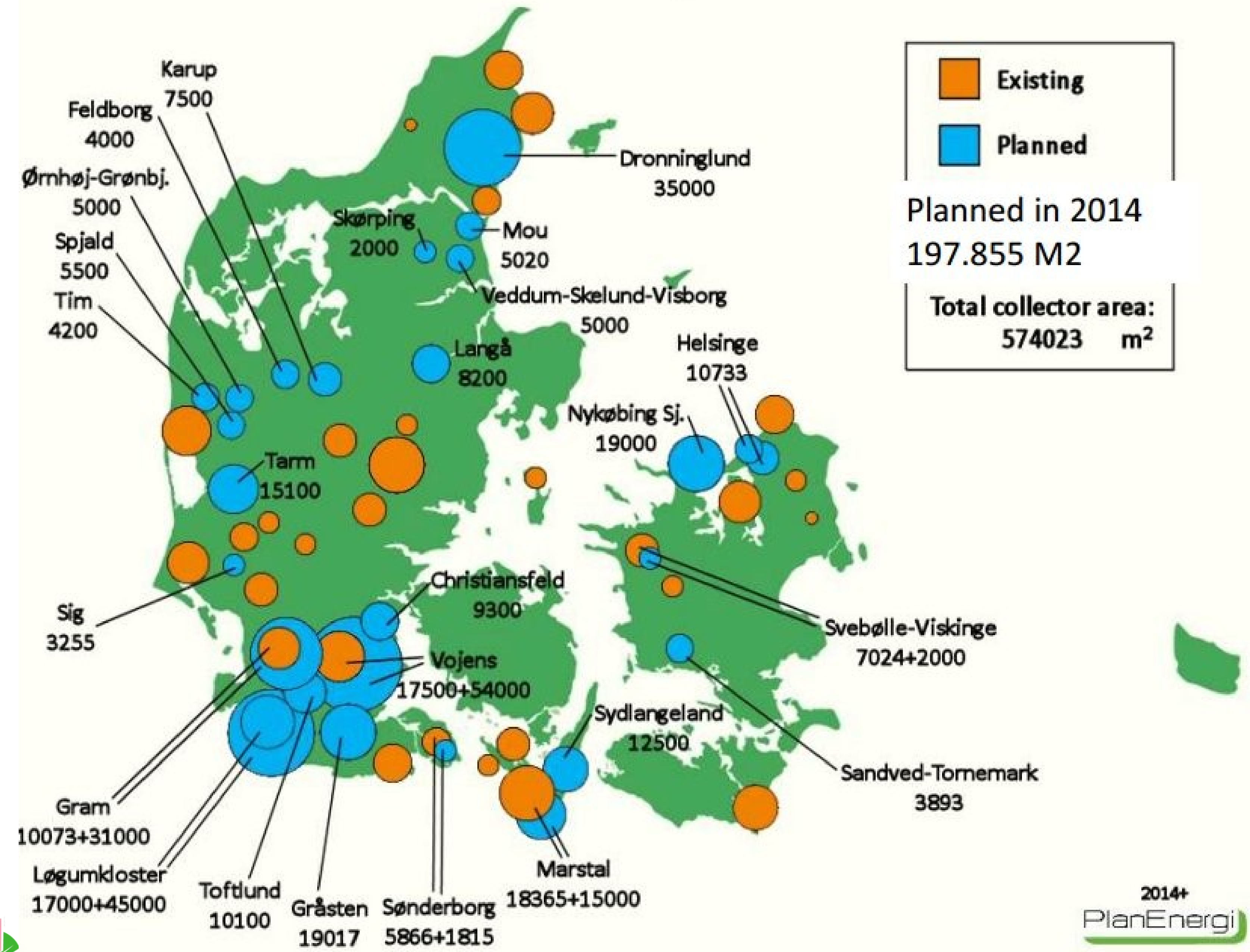
1980



Today

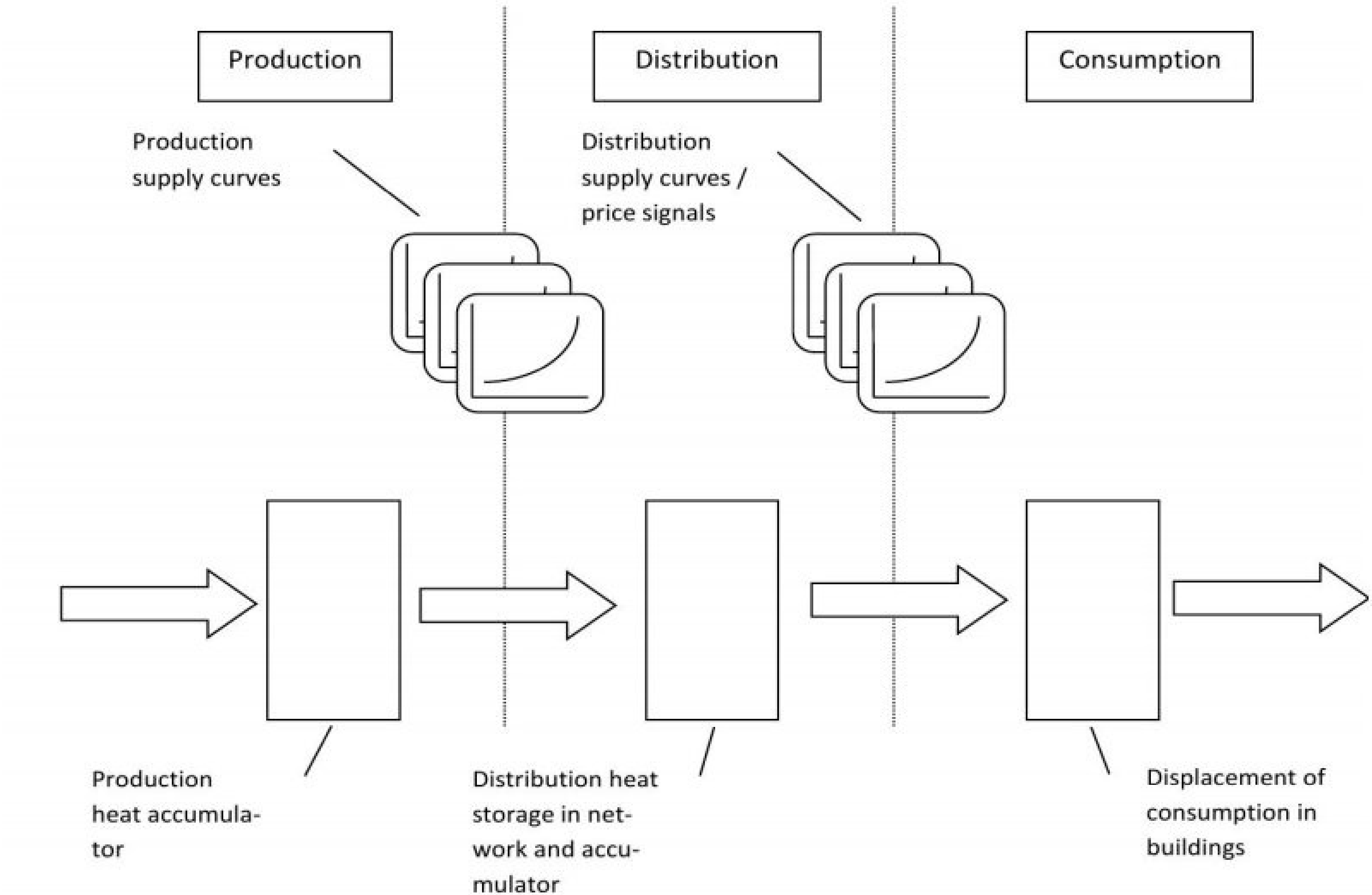
From a few big power plants to many small ***combined heat and power*** *plants – however most of them based on coal*

Solar district heating in Denmark

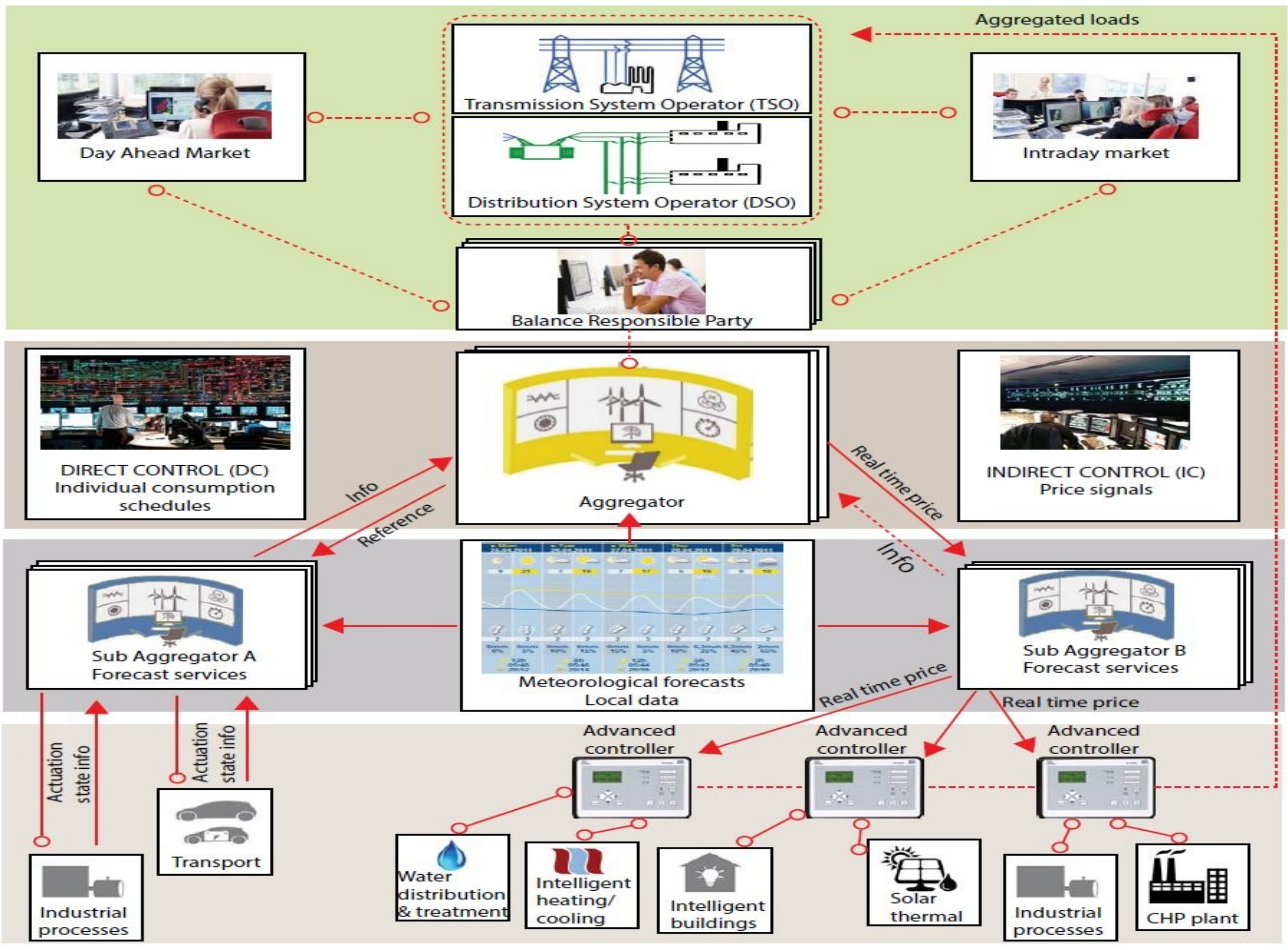


Planned in 2014
197.855 M2

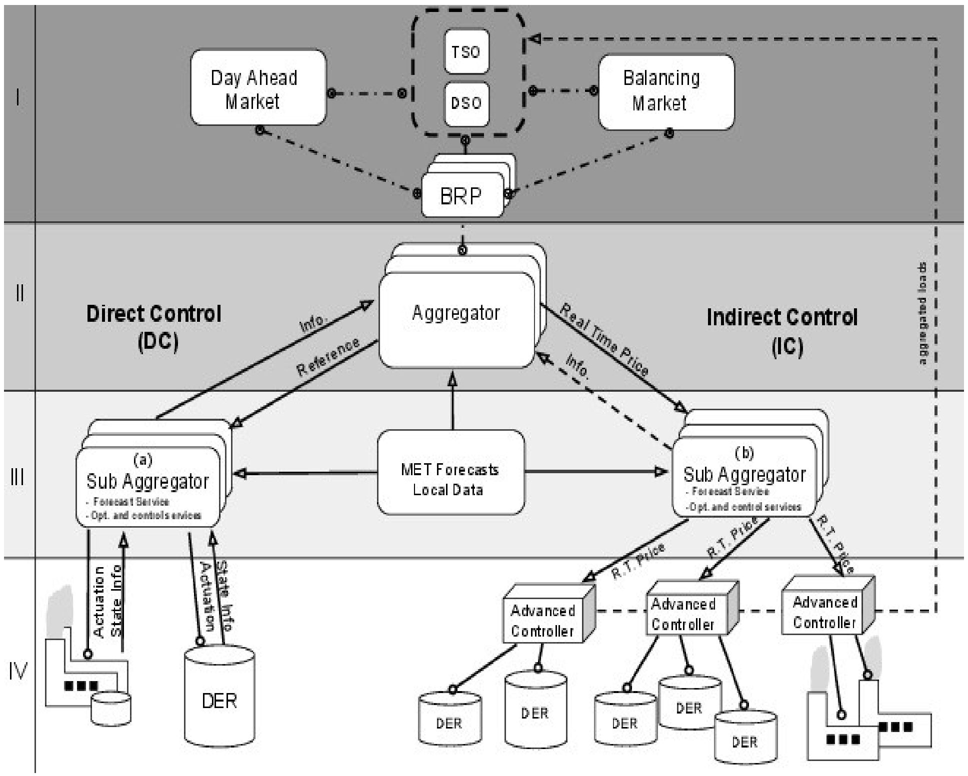
Flexibility in District Heating



Control and Optimization



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

Direct vs Indirect Control

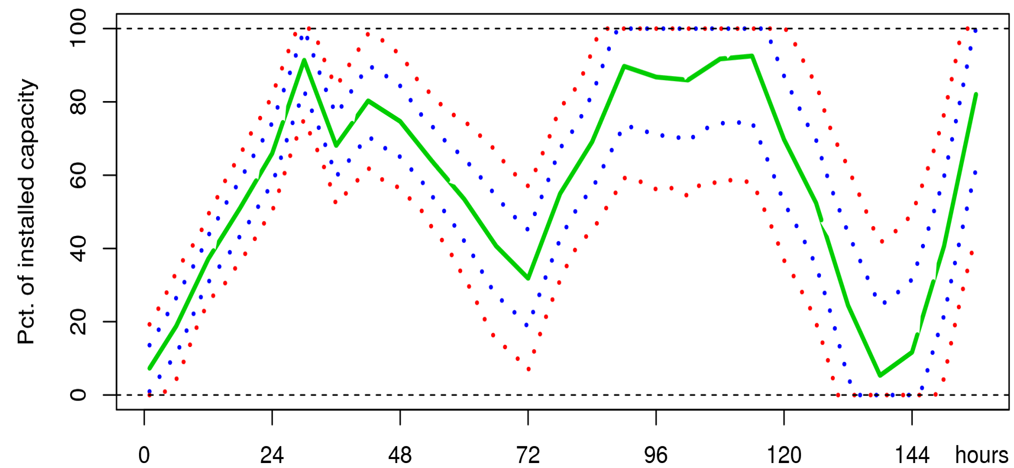
<table>
<tr><th>Level</th><th>Direct Control (DC)</th><th>Indirect Control (IC)</th></tr>
<tr><td>III</td><td rowspan="2">$\min_{x,u} \sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k})$
$\downarrow_{u_1} \cdots \downarrow_{u_J} \quad \uparrow_{x_1} \cdots \uparrow_{x_J}$
s.t. $\quad x_{j,k+1} = f_j(x_{j,k}, u_{j,k}) \quad \forall j \in J$</td><td>$\min_{\hat{z},p} \sum_{k=0}^{N} \phi(\hat{z}_k, p_k)$
s.t. $\quad \hat{z}_{k+1} = f(p_k)$</td></tr>
<tr><td>IV</td><td>$\min_{u} \sum_{k=0}^{N} \phi_j(p_k, u_k) \quad \forall j \in J$
s.t. $\quad x_{k+1} = f_j(x_k, u_k)$</td></tr>
</table>

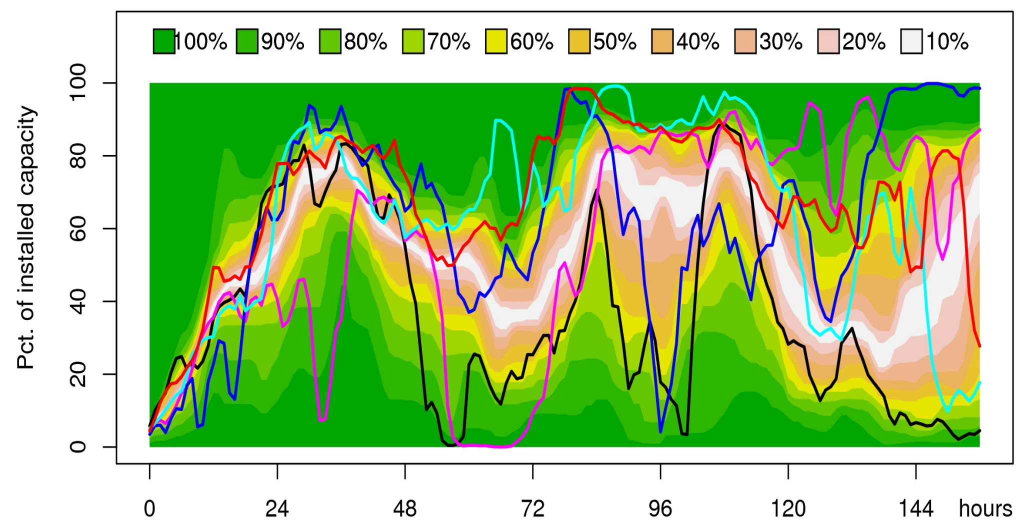
Table 1: Comparison between direct (DC) and indirect (IC) control methods. (DC) In direct control the optimization is globally solved at level III. Consequently the optimal control signals u_j are sent to all the J DER units at level IV. (IC) In indirect control the optimization at level III computes the optimal prices p which are sent to the J-units at level IV. Hence the J DERs optimize their own energy consumption taking into account p as the actual price of energy.

Forecasting is Essential

Tools for Forecasting: (Prob. forecasts)

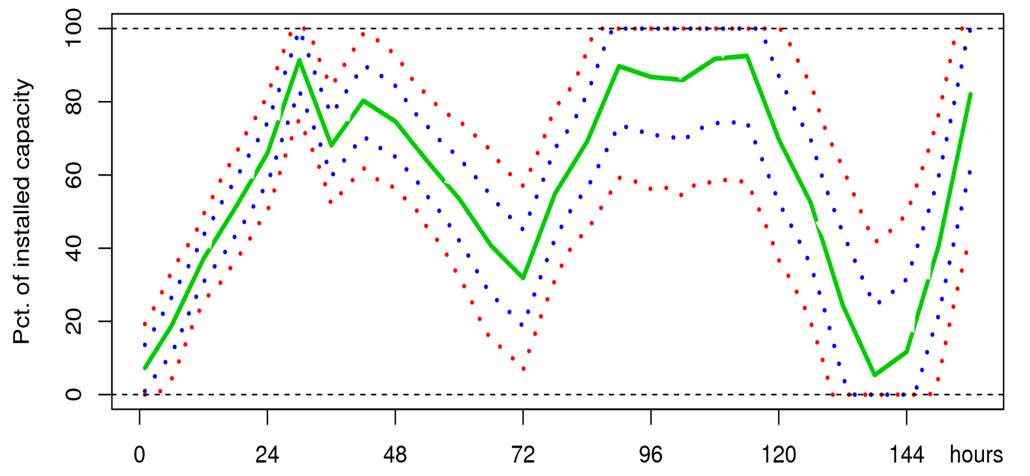
- Power load
- Heat load
- Gas load
- Prices (power, etc)
- Wind power produc.
- Solar power produc.
- State variables (DER)

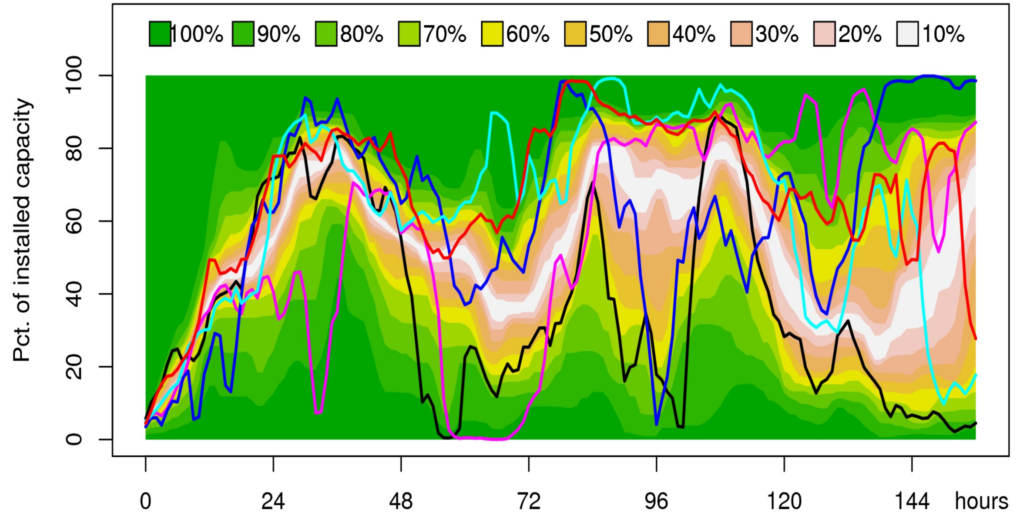




Which type of forecast to use?

- **Point forecasts**
- **Conditional mean and covariances**
- **Conditional quantiles (Prob. forecasts)**
- **Conditional scenarios**
- **Conditional densities**
- **Stochastic differential equations**





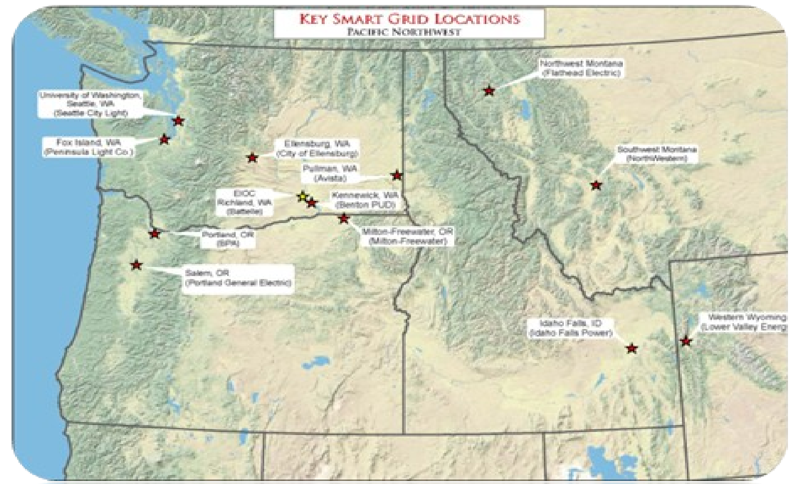
Case study

Control of Power Consumption (Thermal flexible buildings)

Data from BPA

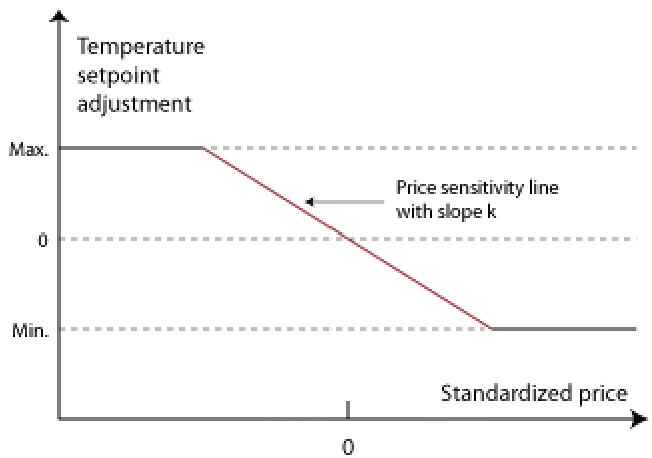
Olympic Pensinsula project

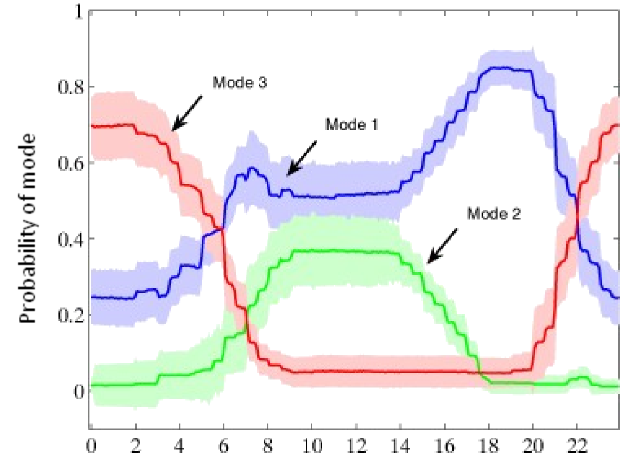
- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption

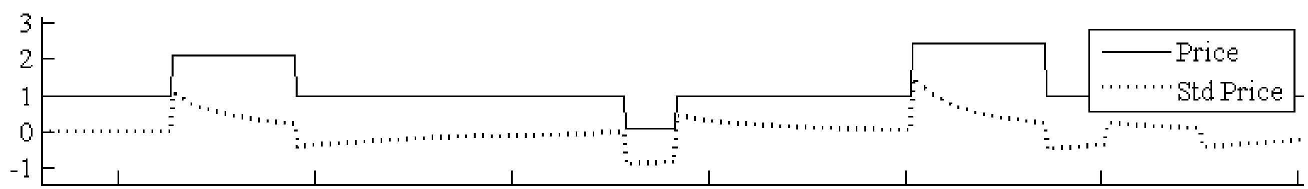


Price responsivity

Flexibility is activated by adjusting the temperature reference (setpoint)

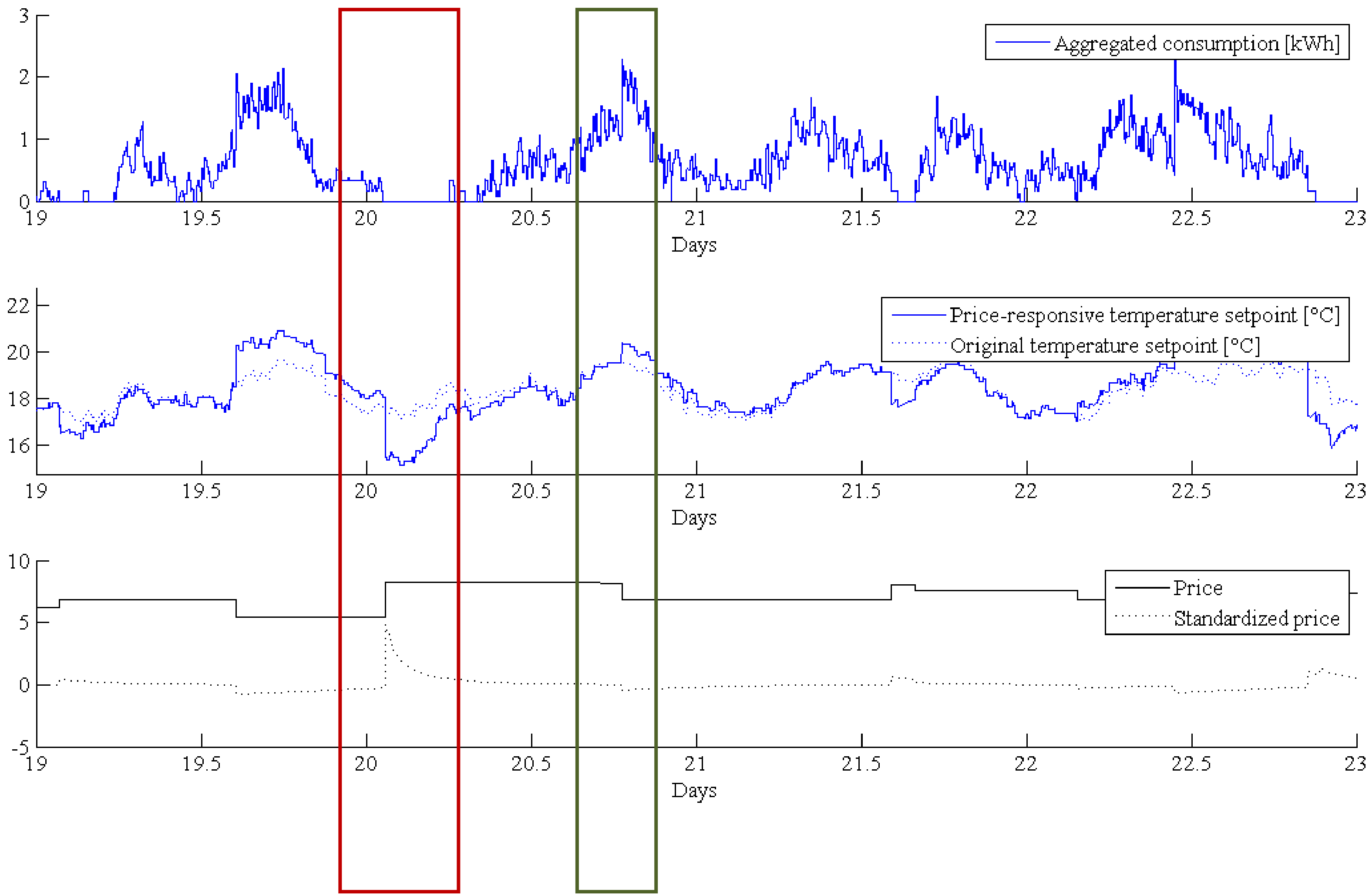




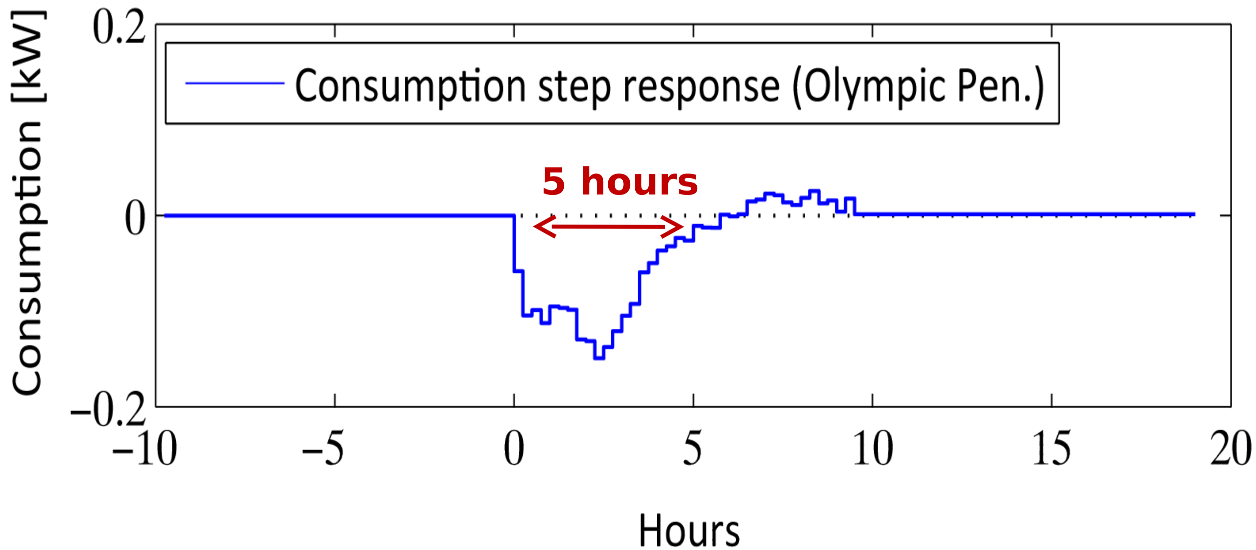


- **Standardized price** is the % of change from a price reference, computed as a mean of past prices with exponentially decaying weights.
- **Occupancy mode** contains a price sensitivity with its related comfort boundaries. 3 different modes of the household are identified (work, home, night)

Aggregation (over 20 houses)



Response on Price Step Change



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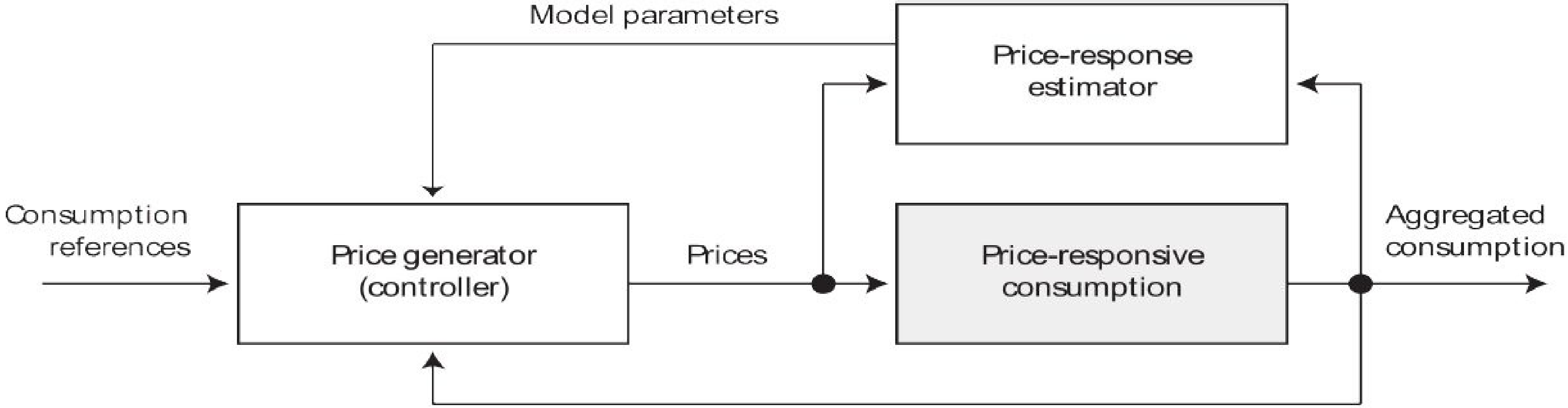
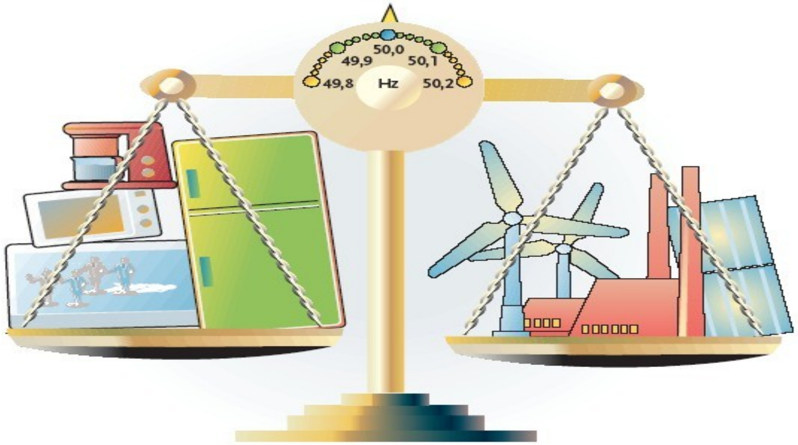
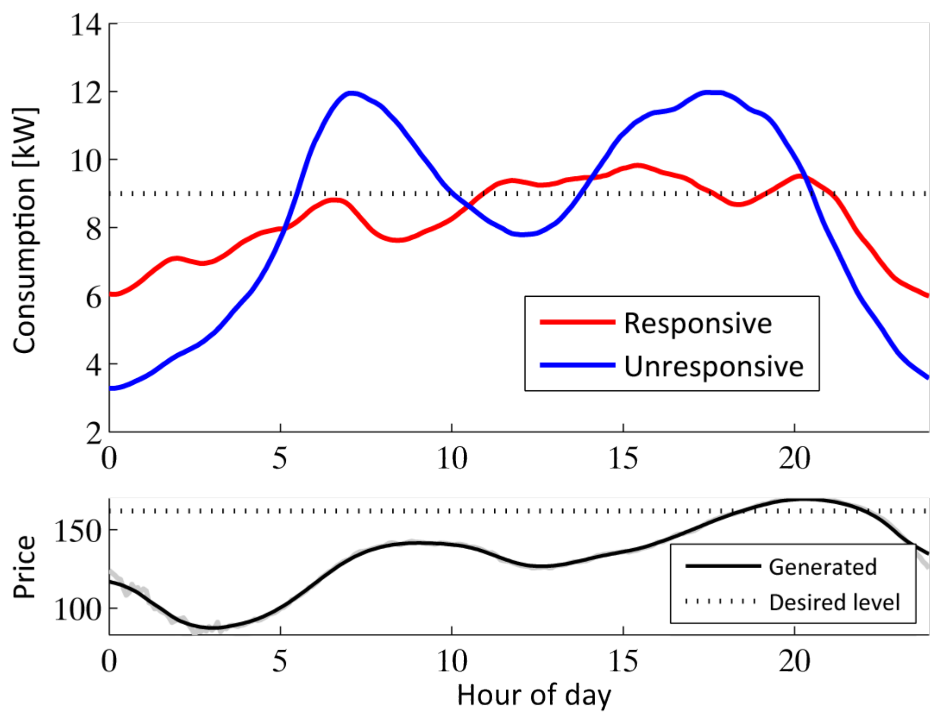
Control of Power Consumption





Control performance

Considerable **reduction in peak consumption**

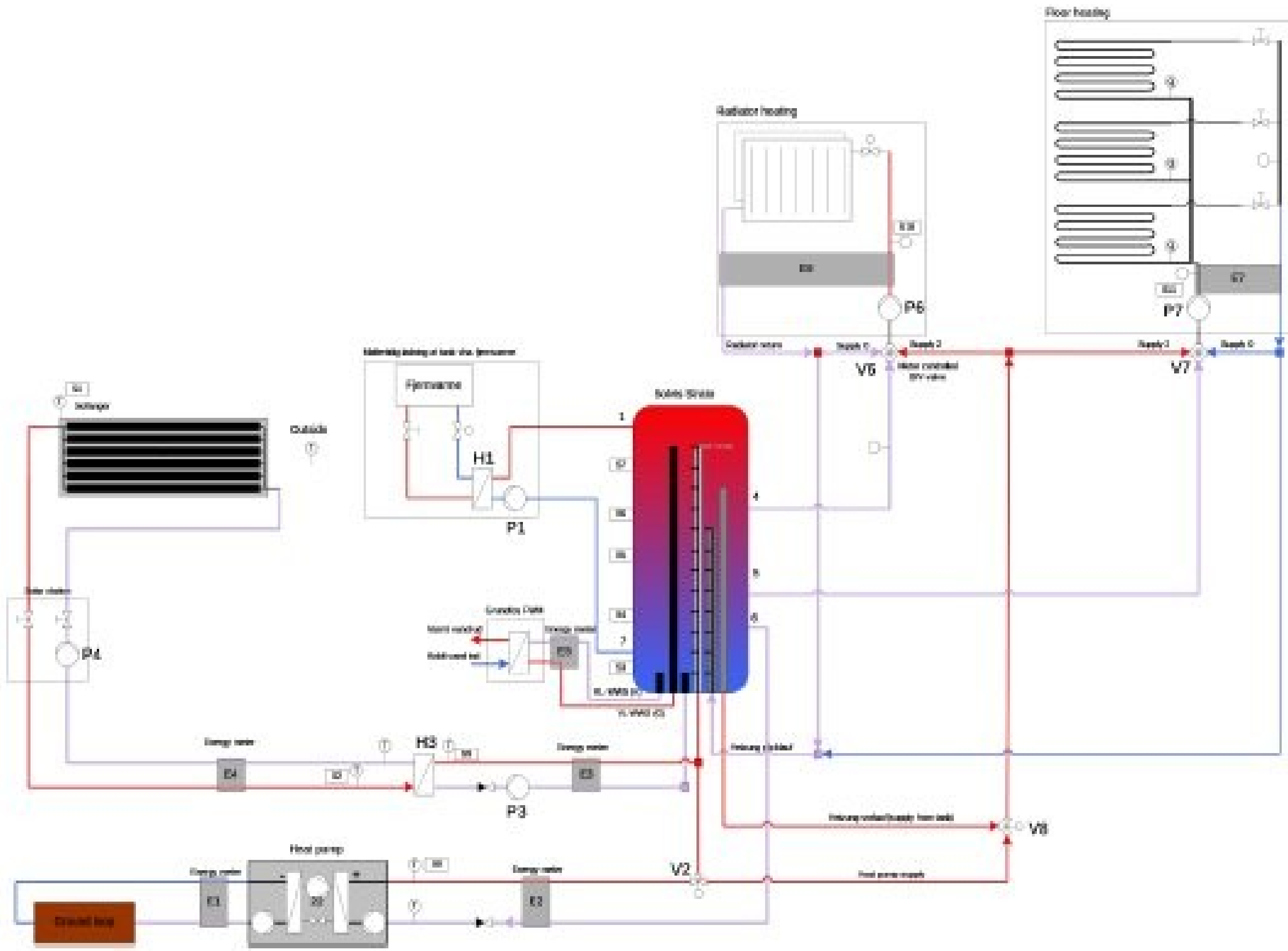


Case study

Control of Heat Pumps (based on varying prices)

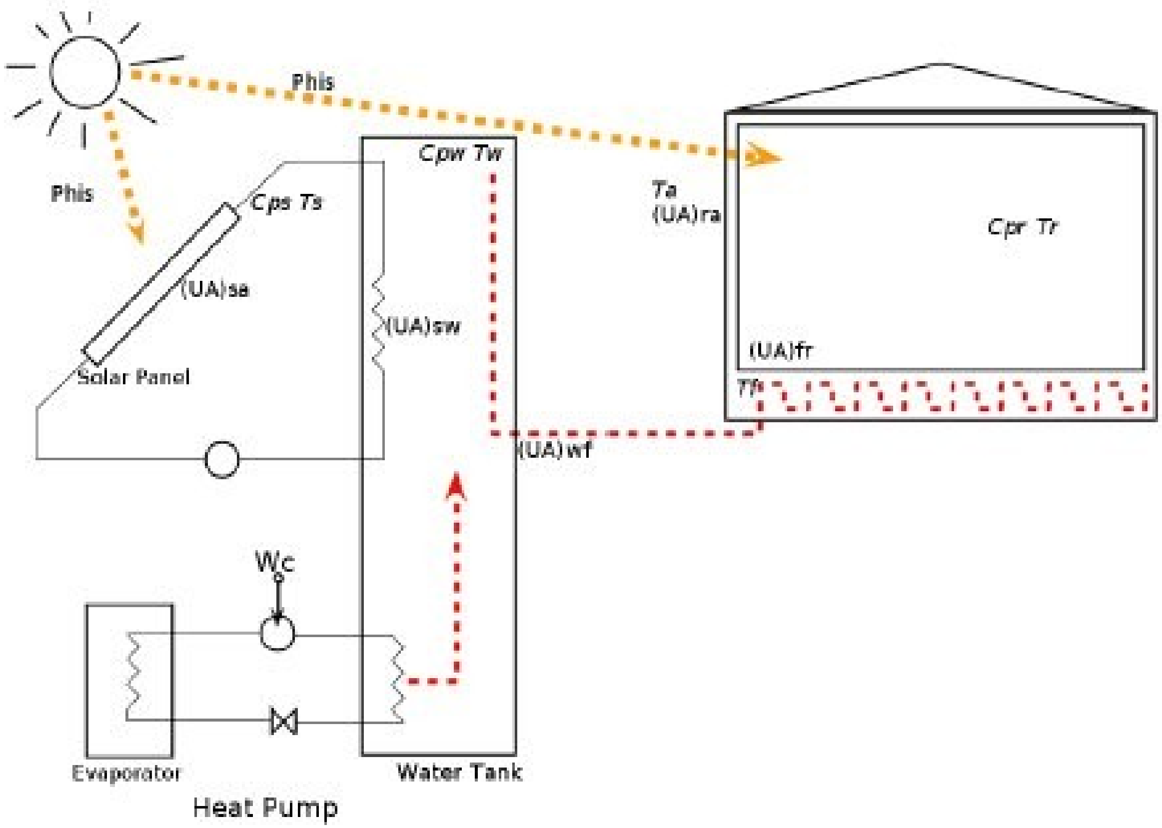
Grundfos Case Study

Schematic of the heating system



Modeling Heat Pump and Solar Collector

Simplified System



Avanced Controller

Economic Model Predictive Control

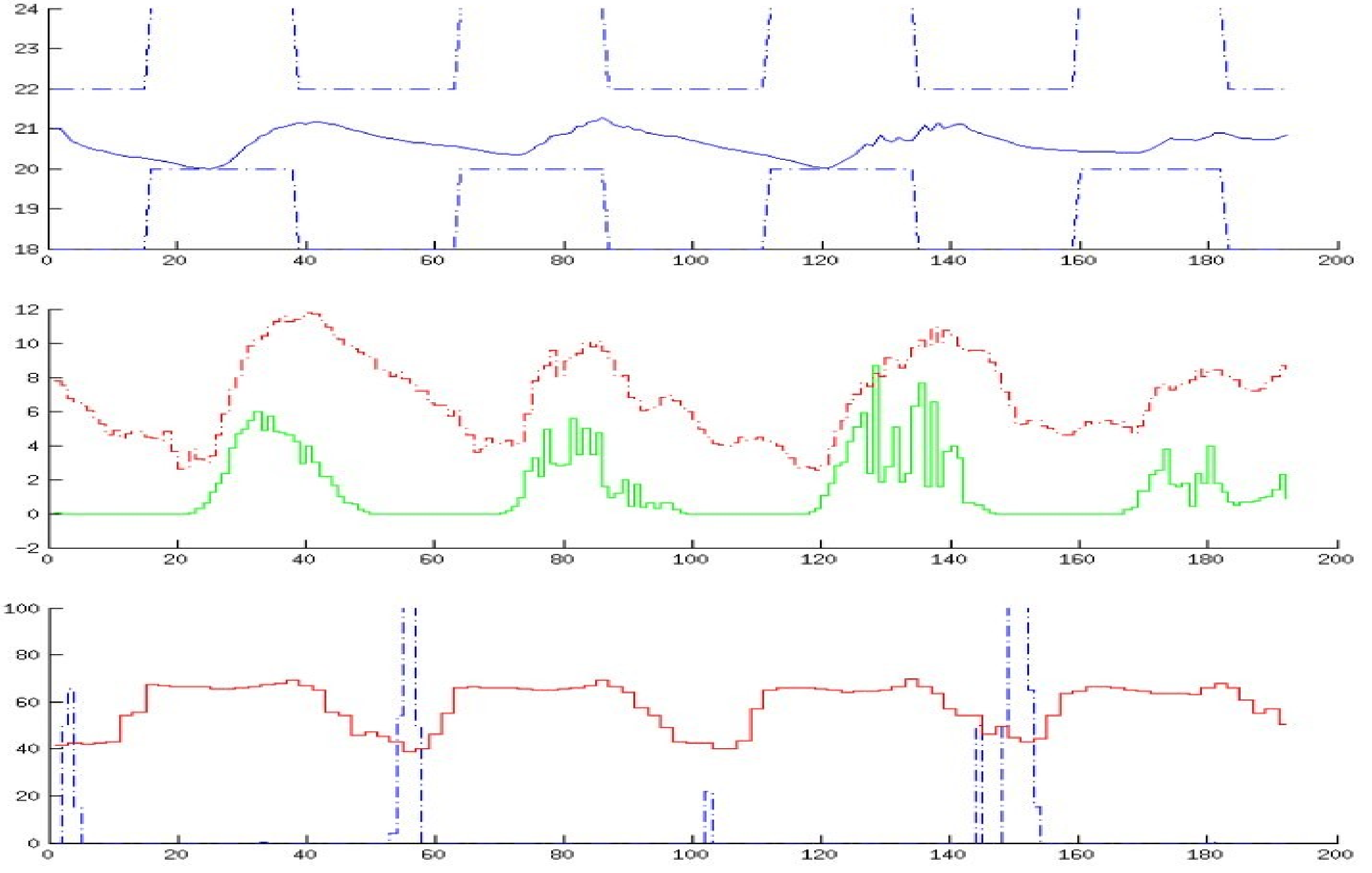
Formulation

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

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

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

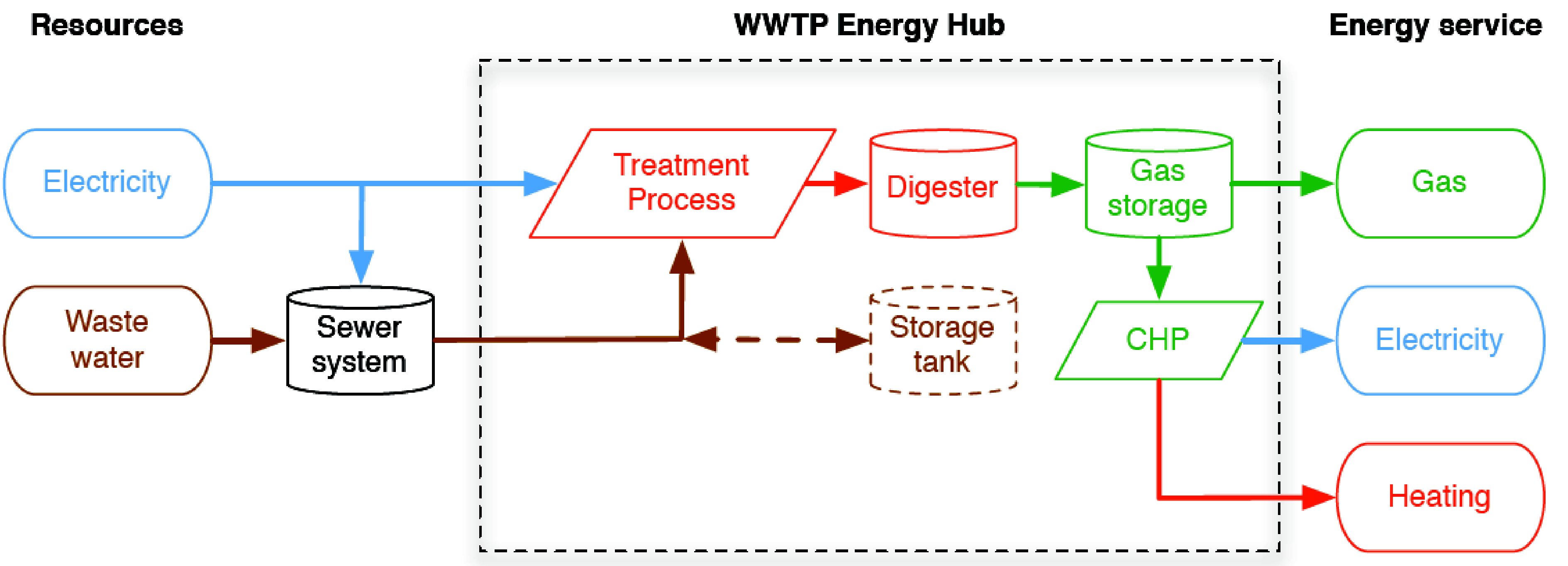
EMPC for heat pump with solar collector (savings 35 pct)



Case study

Control of Wastewater Treatment Plants

Waste-2-Energy



Energy Flexibility in Wastewater Treatment

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

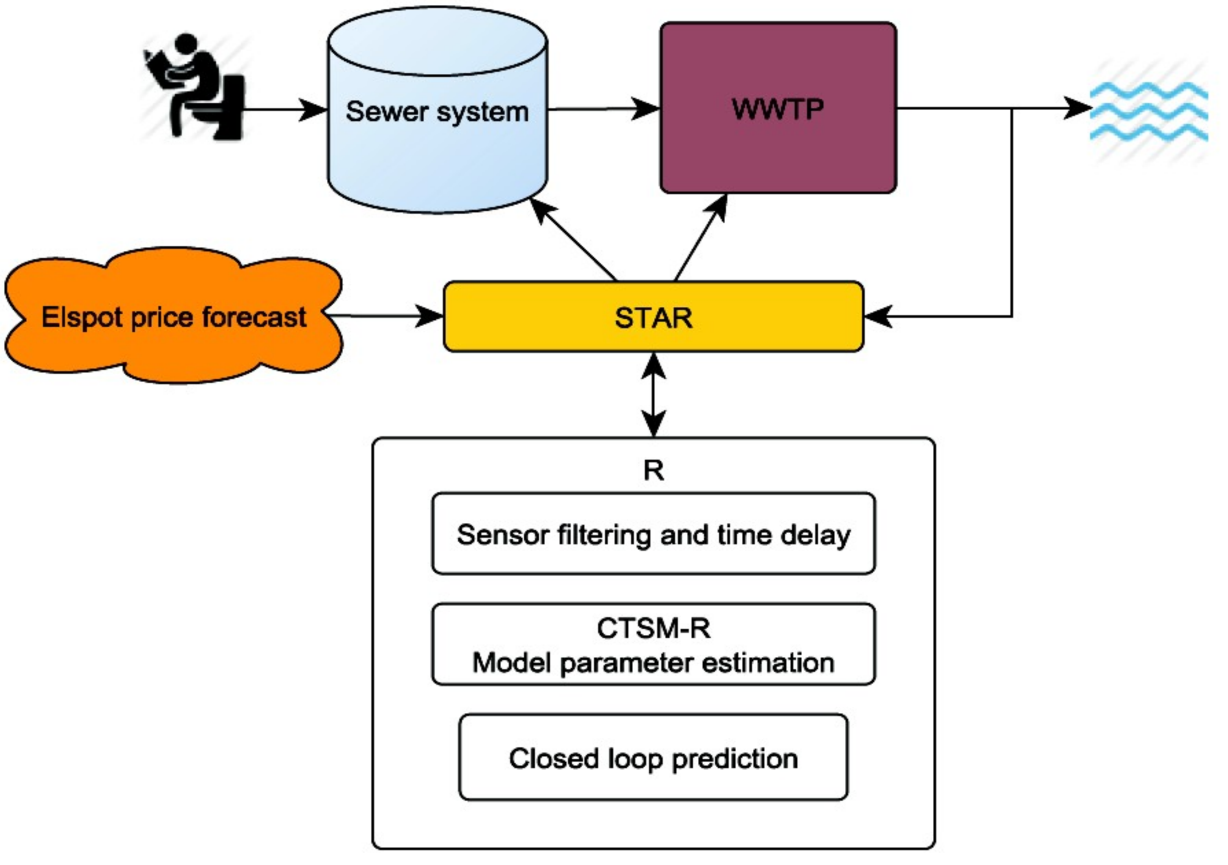
Overall goals:

Cost reduction

Minimize effluent concentration

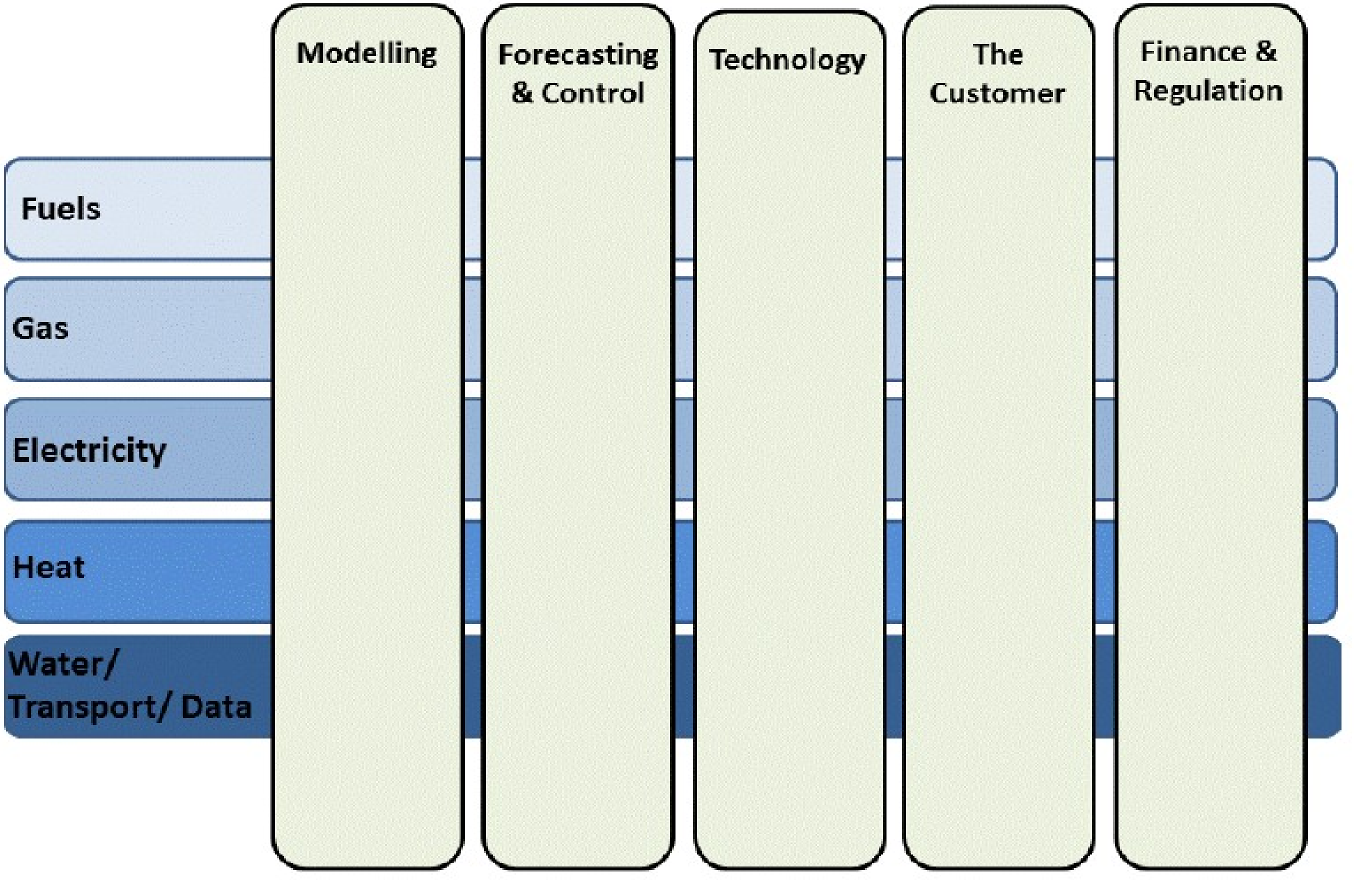
Minimize overflow risk

WWTP Control Architecture



Proposal (UCD, DTU, KU Leuven):

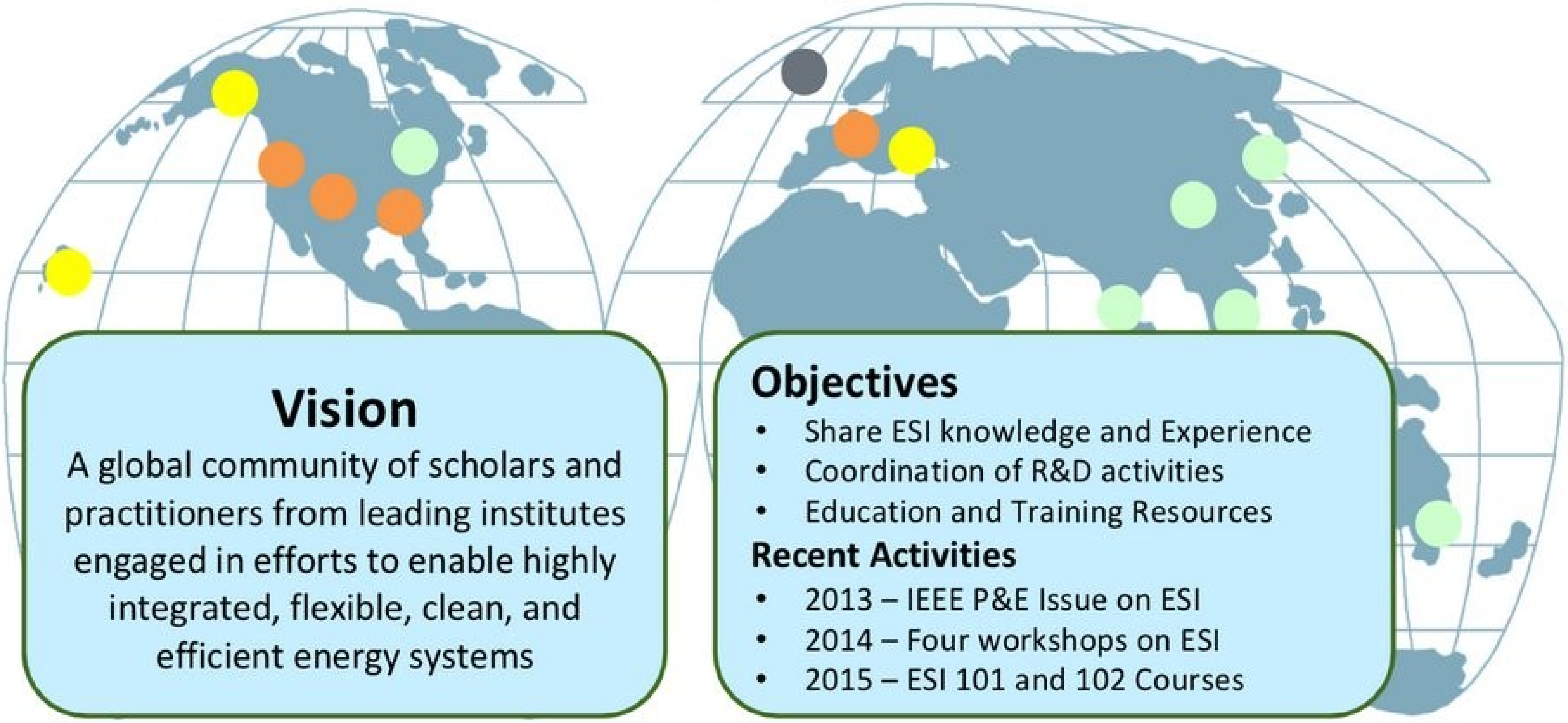
ESI Joint Program as a part of European Research (EERA)



Foster a Global Community

www.iiesi.org

iiESI International Institute™ for Energy Systems Integration



Vision

A global community of scholars and practitioners from leading institutes engaged in efforts to enable highly integrated, flexible, clean, and efficient energy systems

Objectives

- Share ESI knowledge and Experience
- Coordination of R&D activities
- Education and Training Resources

Recent Activities

- 2013 – IEEE P&E Issue on ESI
- 2014 – Four workshops on ESI
- 2015 – ESI 101 and 102 Courses

NREL NATIONAL RENEWABLE ENERGY LABORATORY · Pacific Northwest NATIONAL LABORATORY · EPRI ELECTRIC POWER RESEARCH INSTITUTE · UCD DUBLIN · DTU · KU LEUVEN

Possible Joint Activities

- TotalFlex for DC and Cities Dual Controller for IC
- CHP optimization (forecasting, control and optimization)
- Grey-box modelling – buildings, wwtp, ...
- Demo projects (3 have been shown)
- Additional Demo projects in CITIES:
  - Supermarkets (EUDP - Danfoss)
  - Summer houses (H2020 – Smart Net)
  - Green houses
  - Charging of Evs (H2020)
  - HVAC systems (.. with storage tank)
  - ....
- ICT technologies – including model based methods for forecasting and control

For more information ...

See for instance

www.henrikmadsen.org

www.smart-cities-centre.org

...or contact

– Henrik Madsen (DTU Compute)

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Acknowledgement CITIES (DSF 1305-00027B)