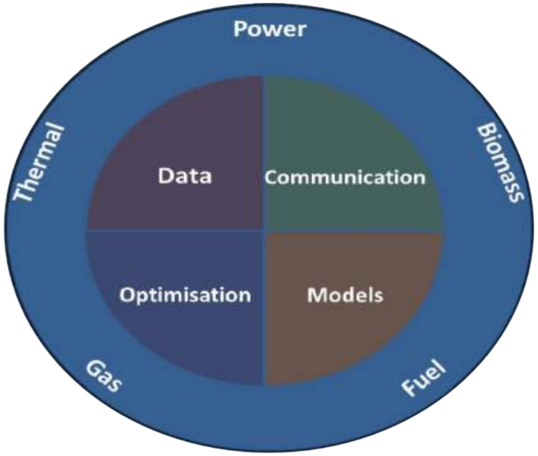
Strategies of Energy Flexible Buildings and Districts



Henrik Madsen, DTU Compute

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

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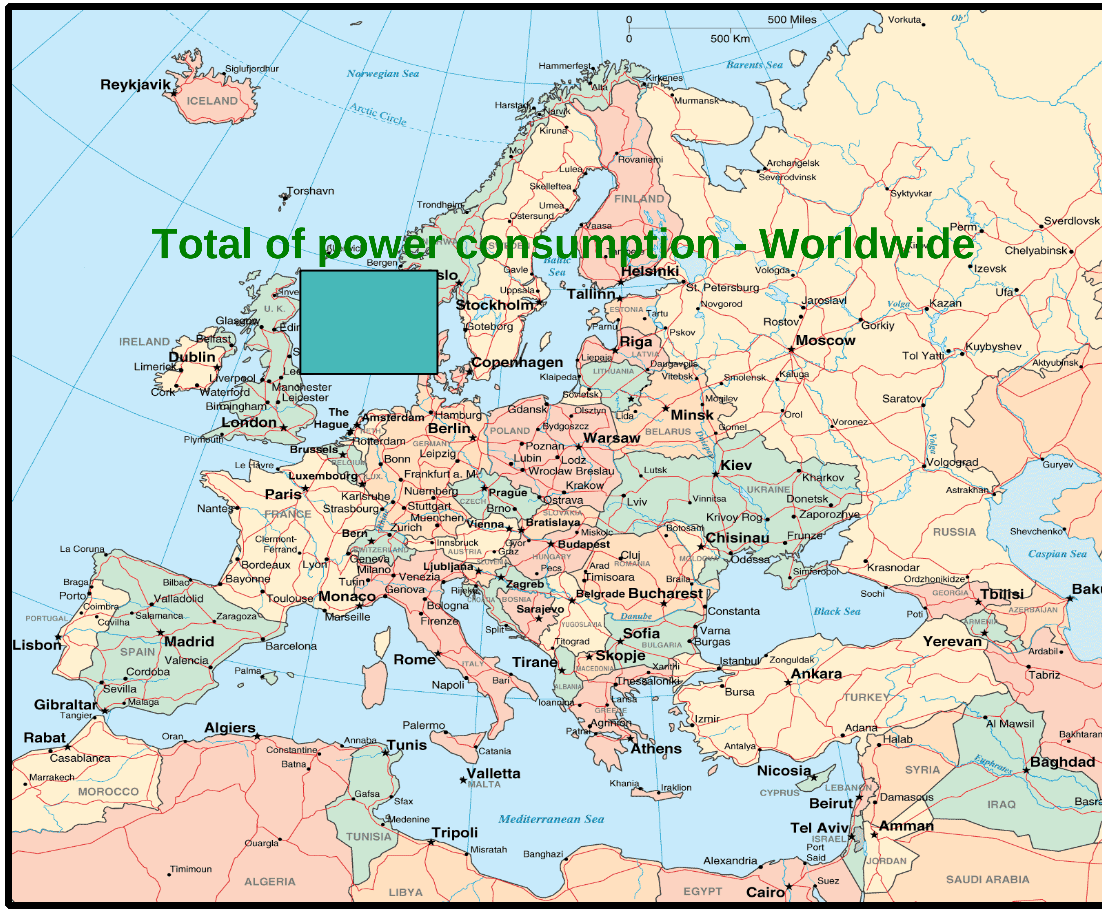
Potentials and Challenges for renewable energy

- **Scenario**: We want to cover the worlds entire need for power using wind power.
- How large an area should be covered by wind turbines?

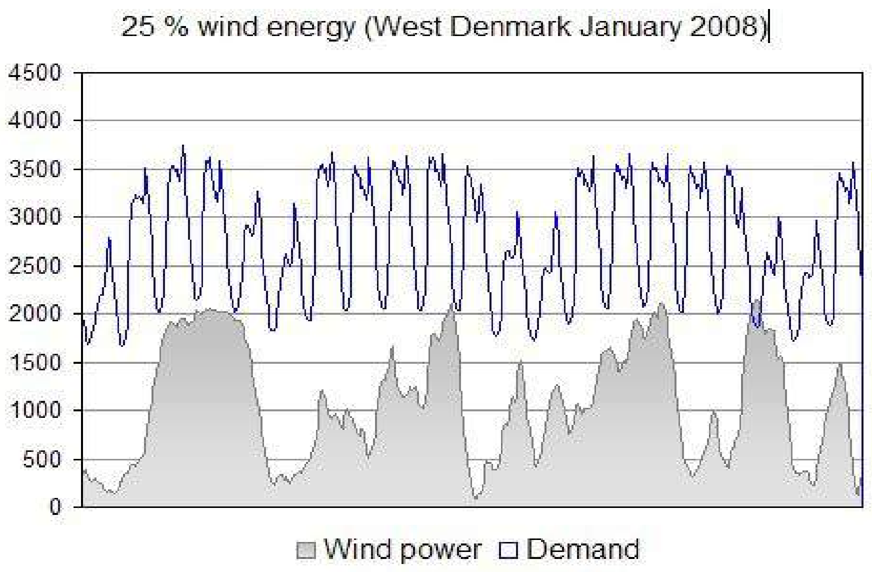
Potentials and Challenges for renewable energy

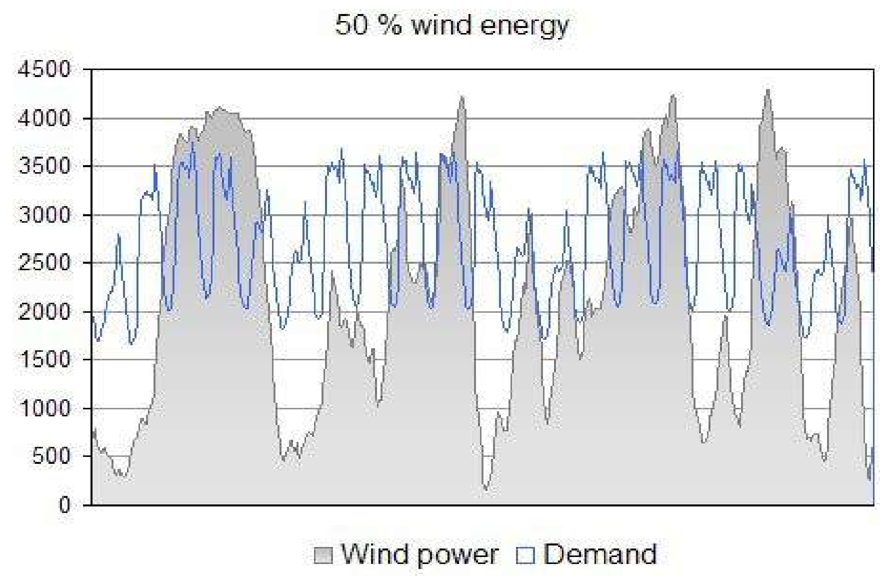
- **Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- **Conclusion**: Use intelligence ....
- Calls for **IT / Big Data / Smart Energy Solutions / Energy Systems Integration**



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 2014 more than 40 pct of electricity load was covered by wind power.

For several days in 2014 the wind power production was more than 120 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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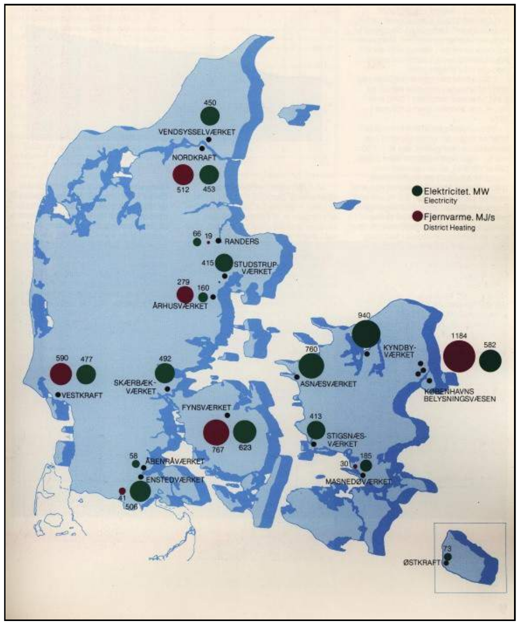
From large central plants to Combined Heat and Power (CHP) production

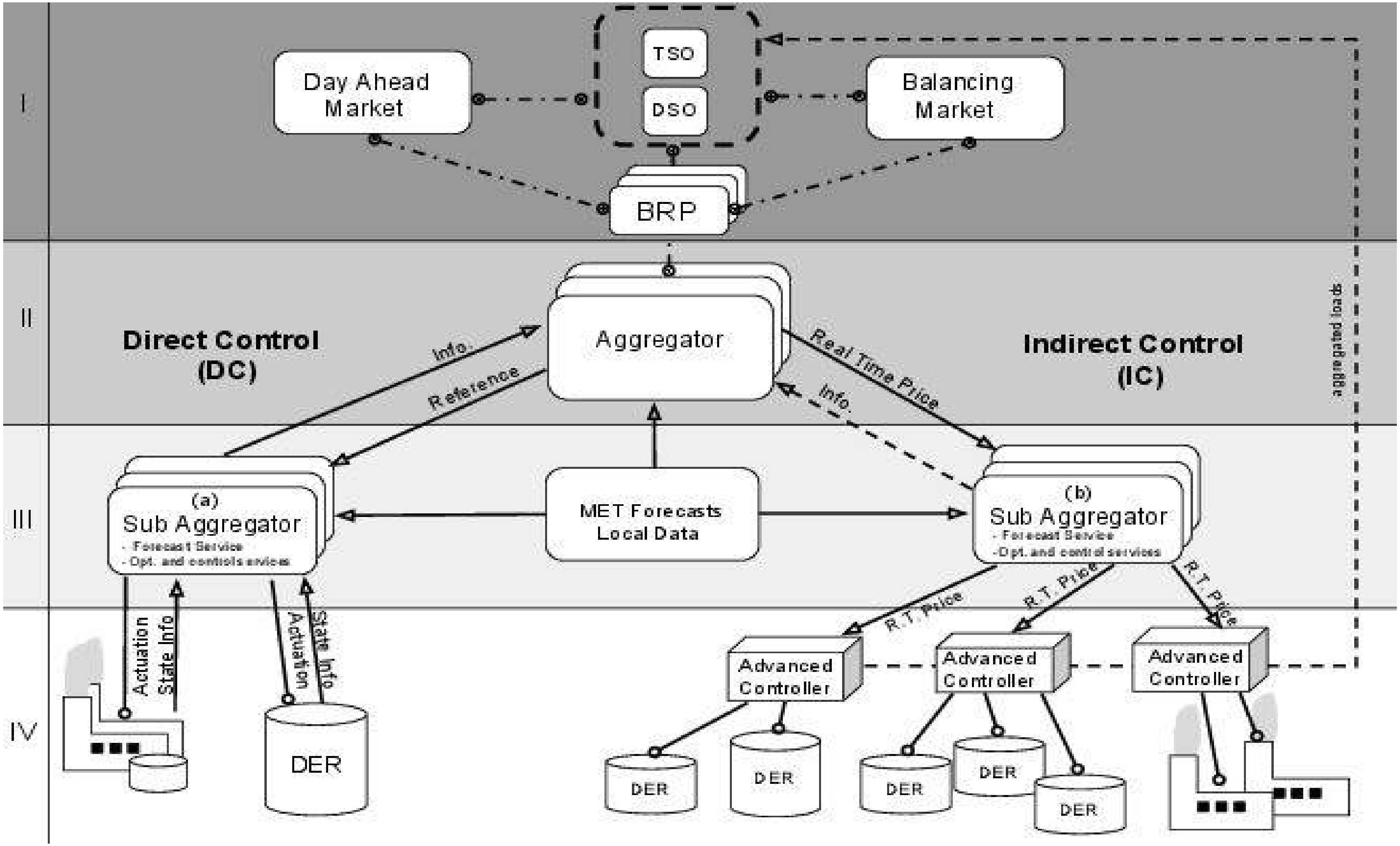
1980



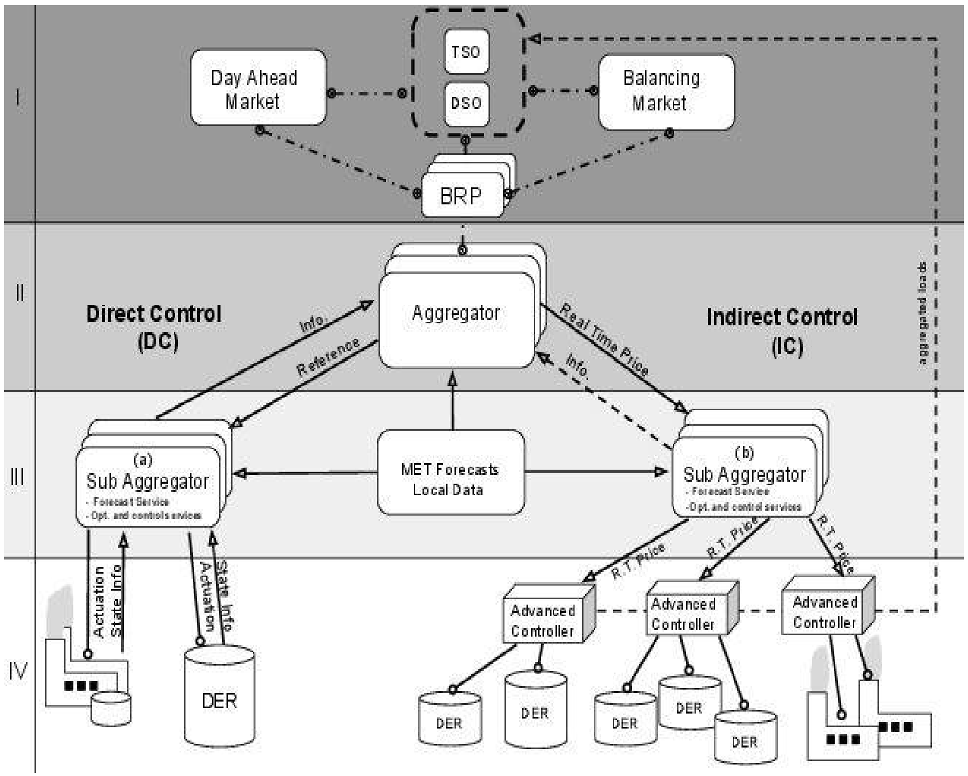
Today

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

Control and Optimization



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

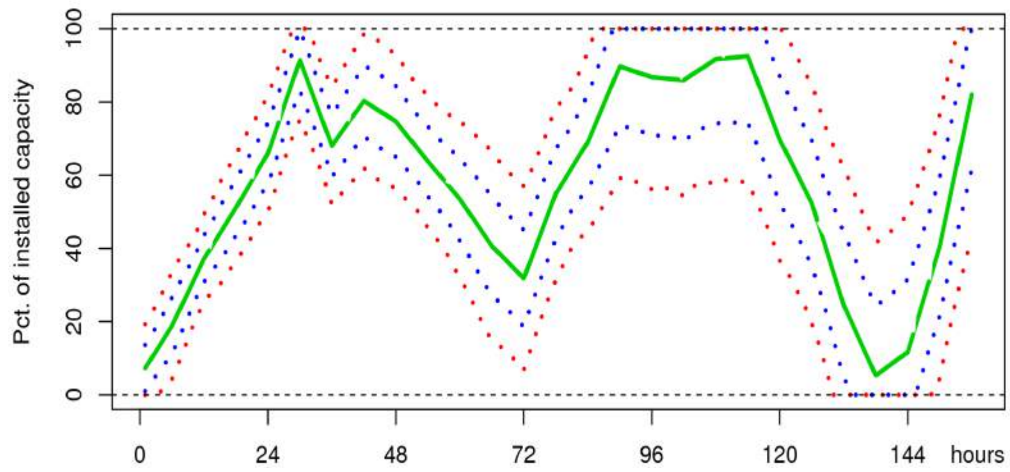
Models for DERs are not needed

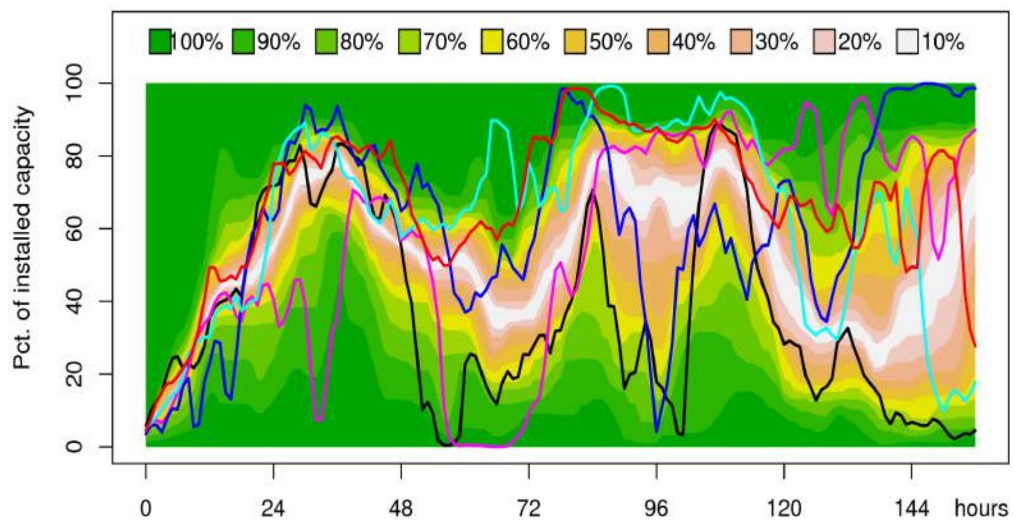
Simple 'contracts'

Forecasting is Essential

Tools for Forecasting:

- **Power load**
- **Heat load**
- **Gas load**
- **Prices (power, etc)**
- **Wind power produc.**
- **Solar power produc.**

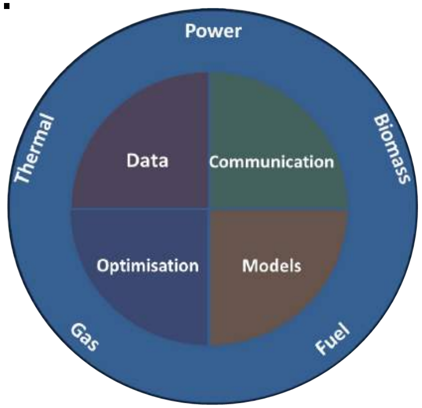




Flexibility Idea

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.

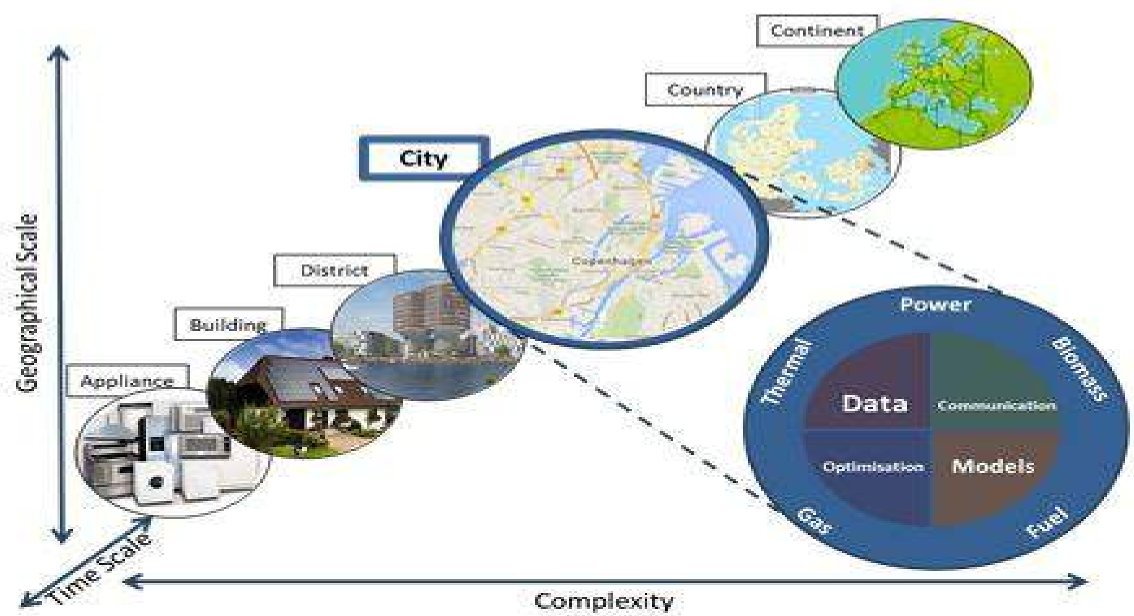
Intelligent integration will (for instance) enable lossless **virtual storage on a number of different time scales**.



Flexible Solutions and CITIES

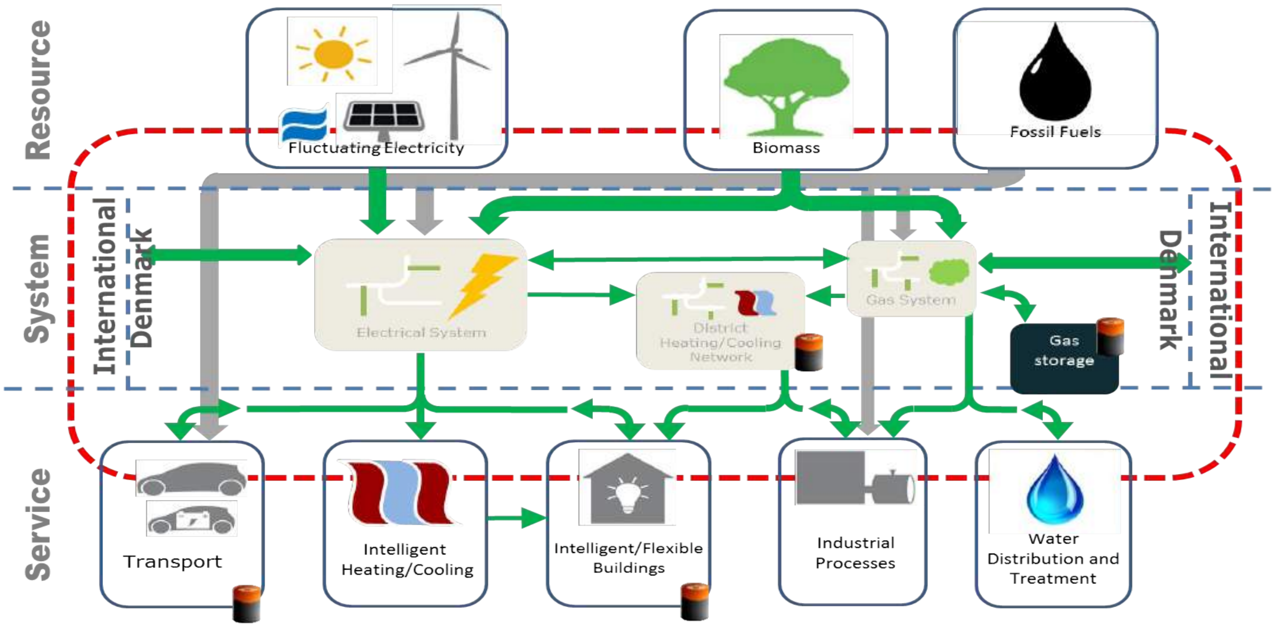
The ***Center for IT-Intelligent Energy Systems in Cities (CITIES)*** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

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

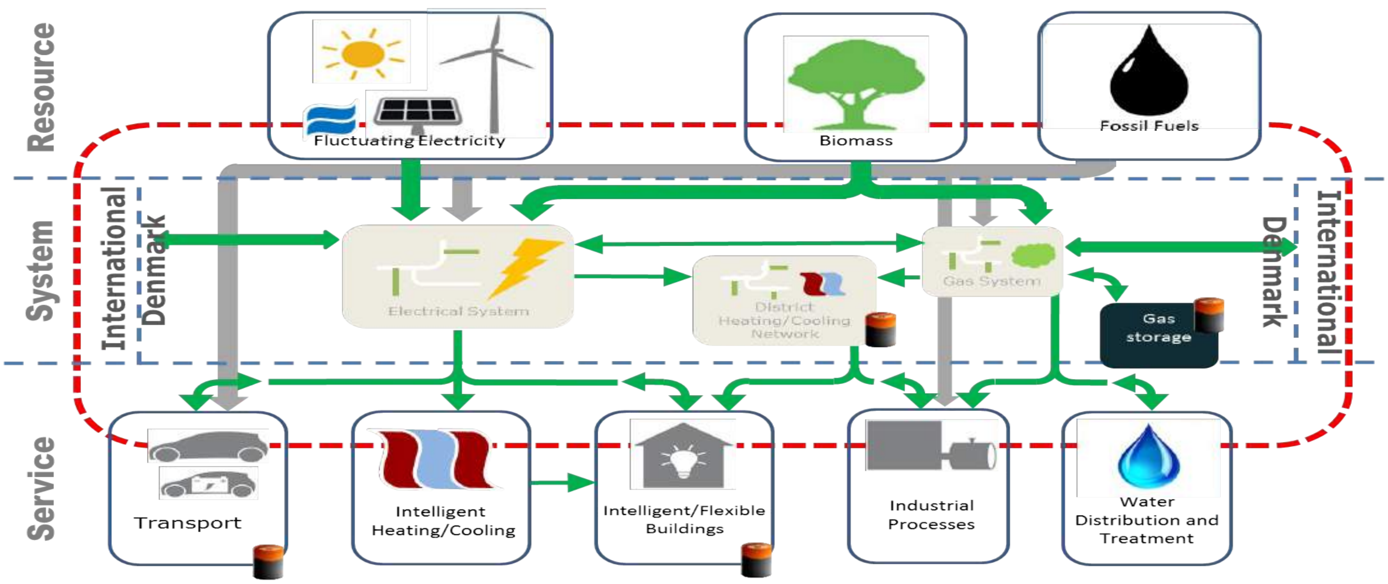


Flexibility Concepts

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



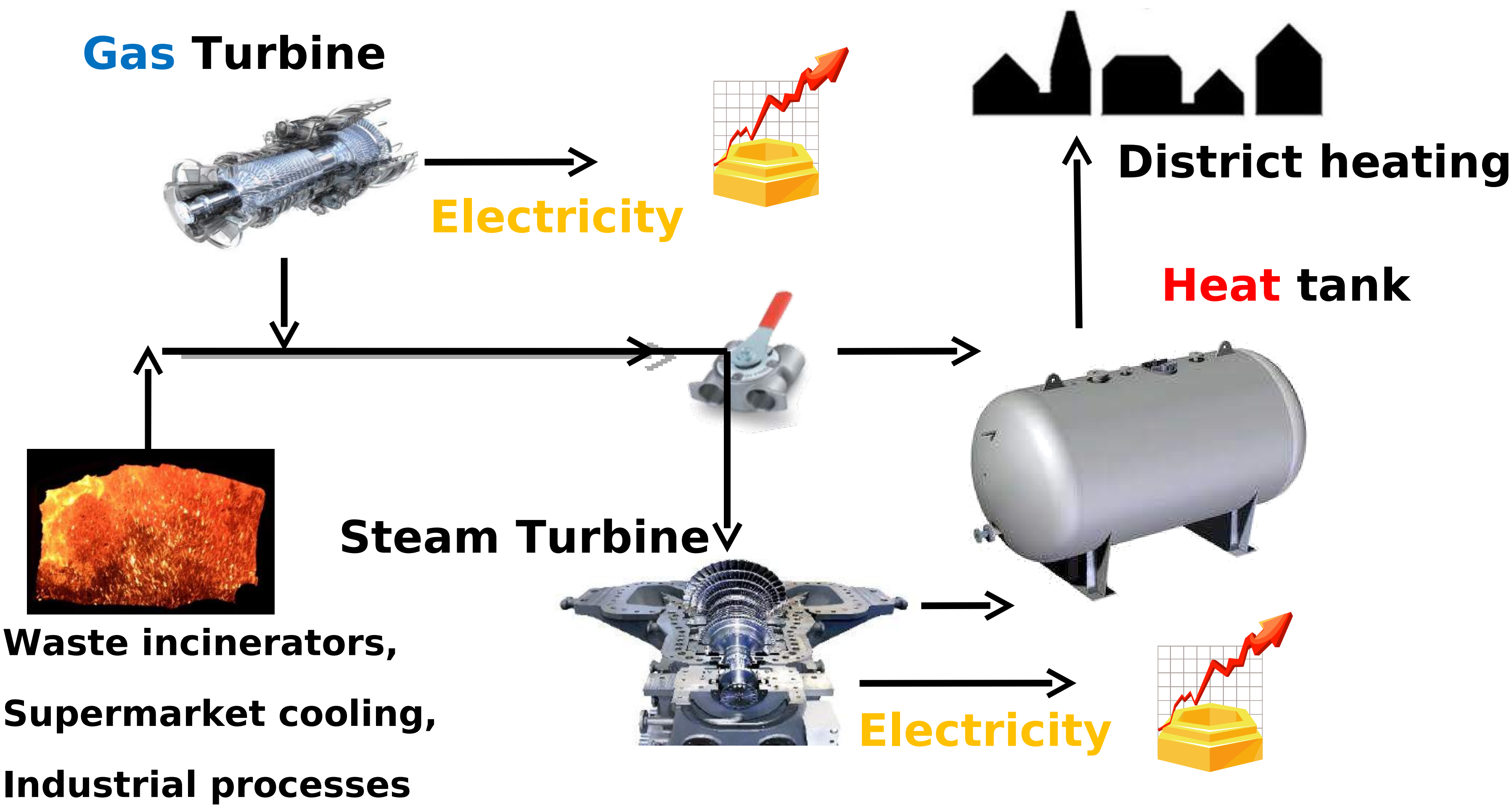
Virtual Storage by Energy Systems Integration



- **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

CHP gives Energy Flexible Energy Systems

(Paradigmatic example - Denmark)



Case study

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

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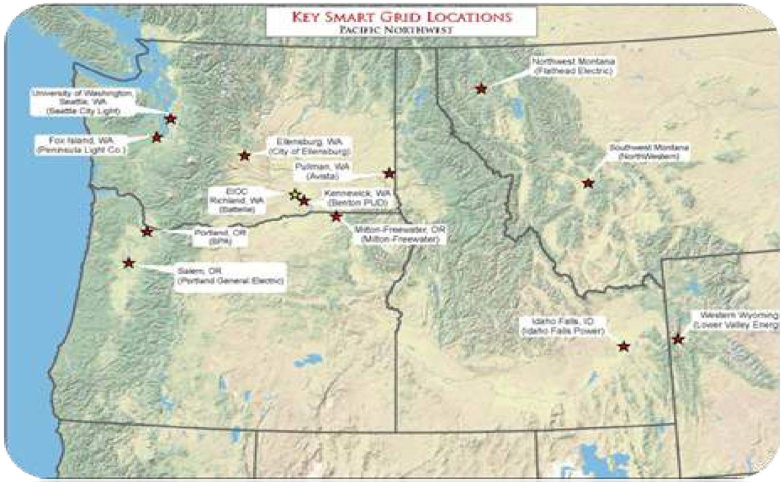
Data from BPA

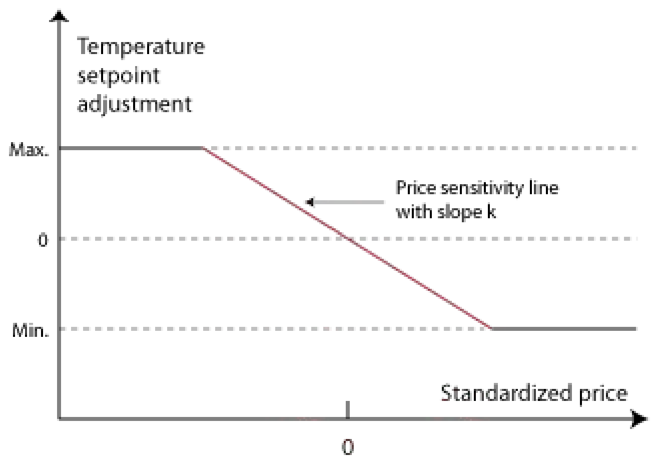
Olympic Pensinsula project

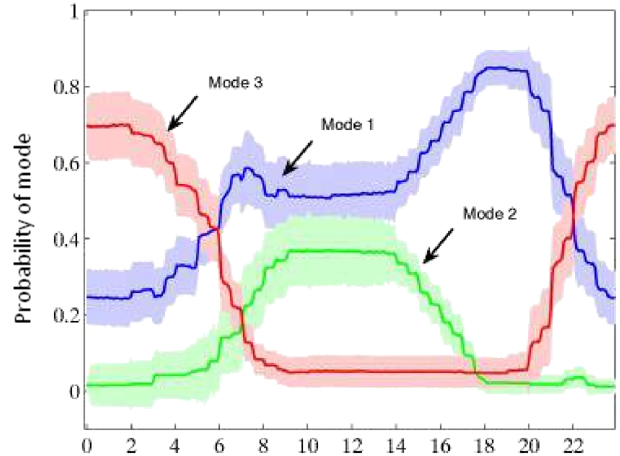
- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption

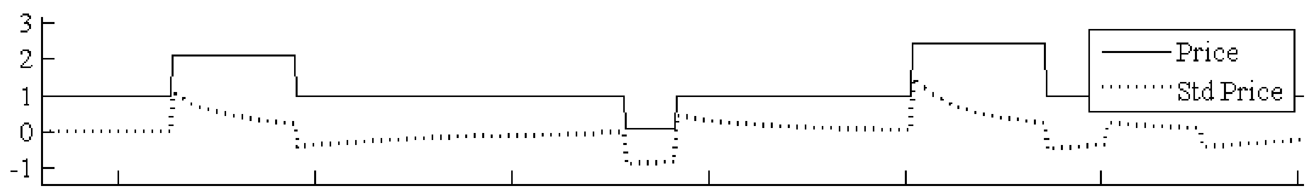


Price responsivity

Flexibility is activated by adjusting the temperature reference (setpoint)

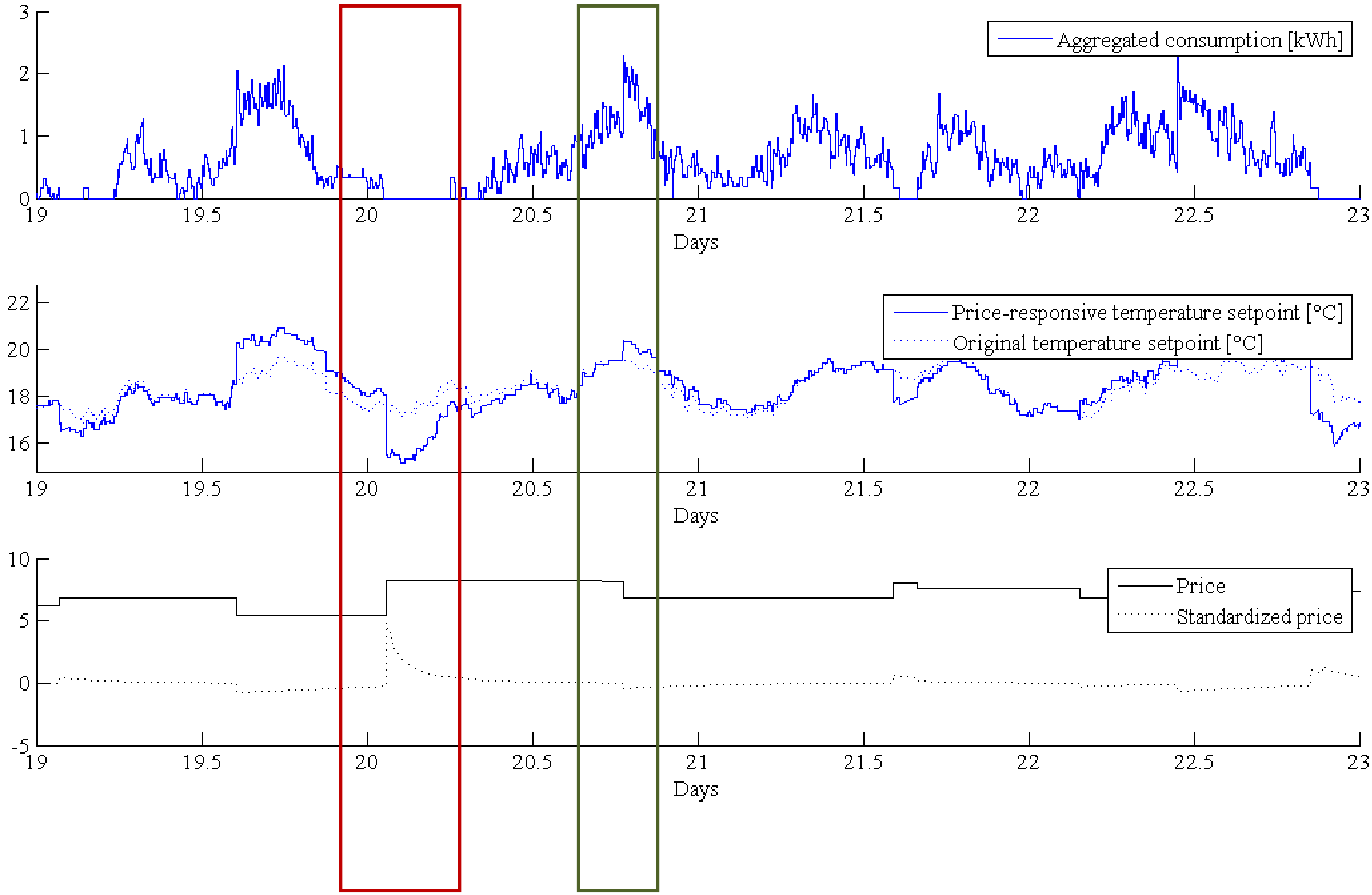




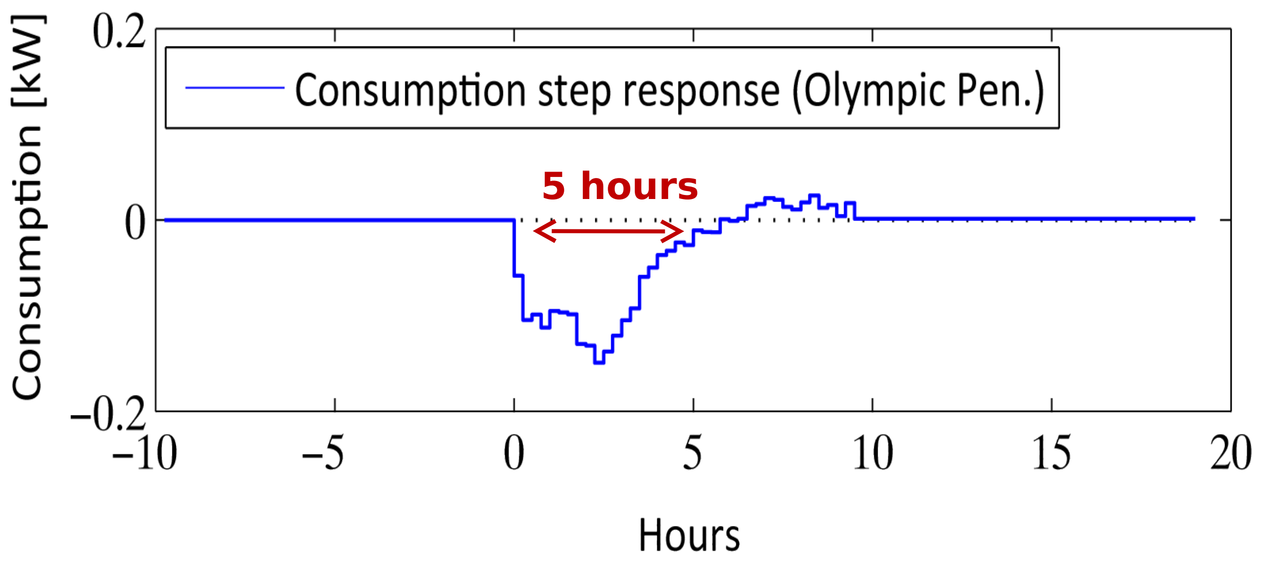


- **Standardized price** is the % of change from a price reference, computed as a mean of past prices with exponentially decaying weights.
- **Occupancy mode** contains a price sensitivity with its related comfort boundaries. 3 different modes of the household are identified (work, home, night)

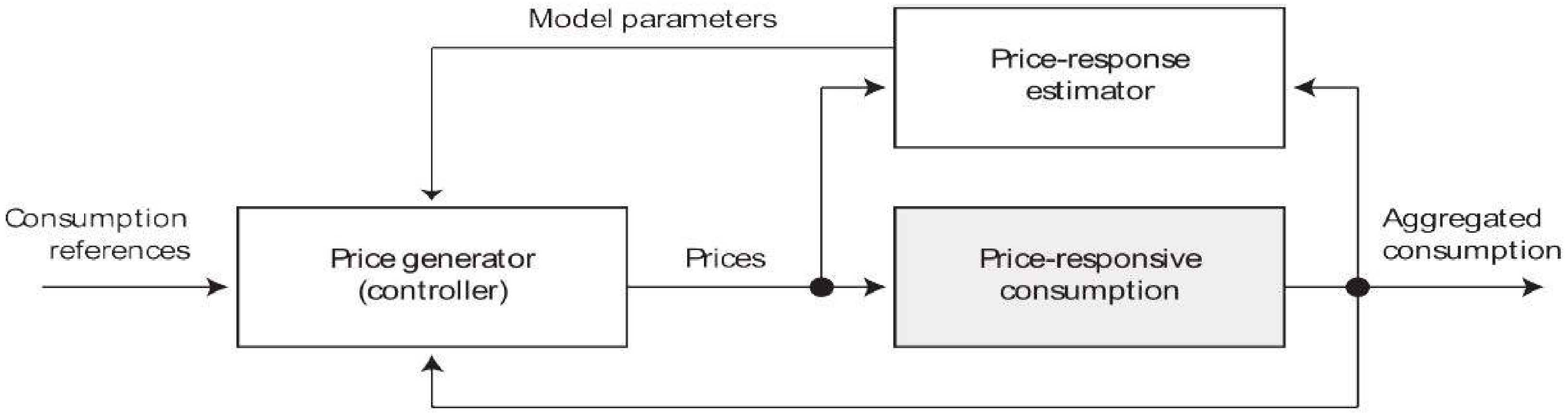
Aggregation (over 20 houses)

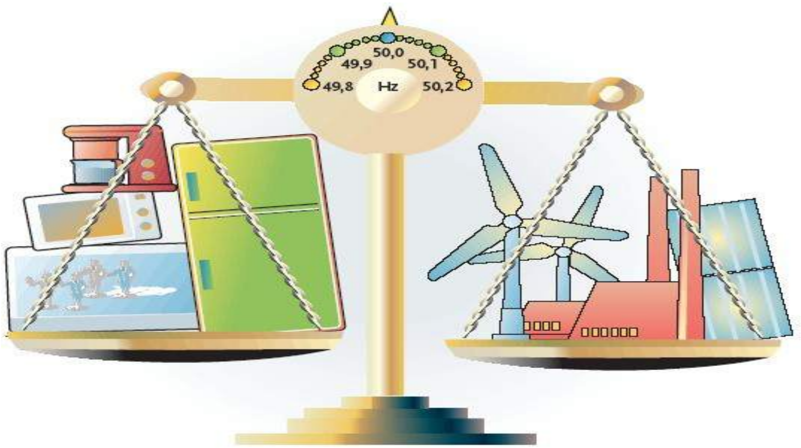


Response on Price Step Change



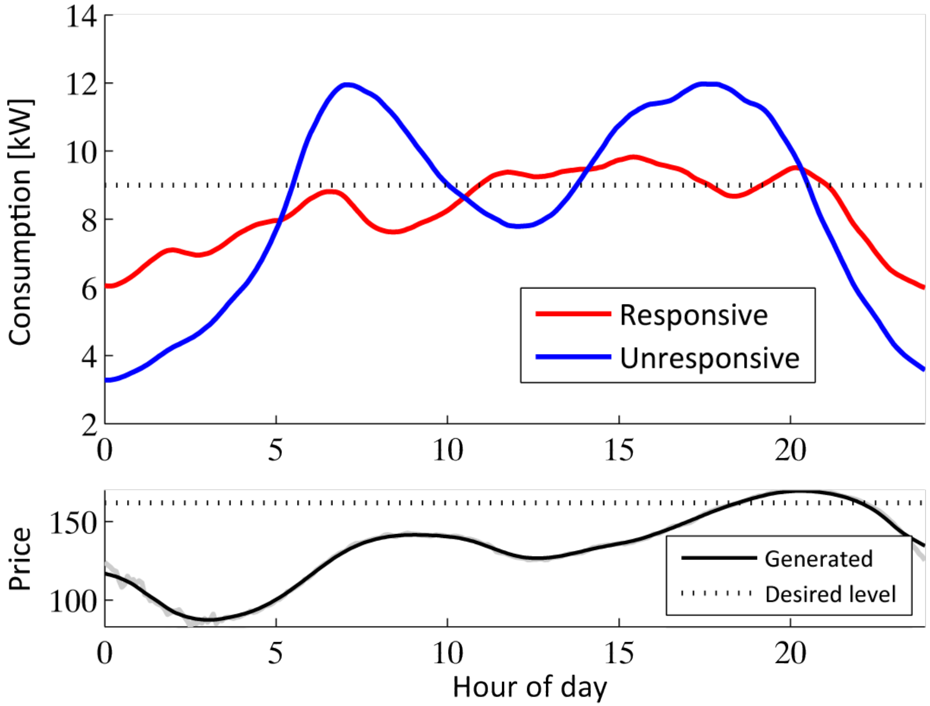
Control of Power Consumption





Control performance

Considerable **reduction in peak consumption**



Case study

Control of Heat Pumps

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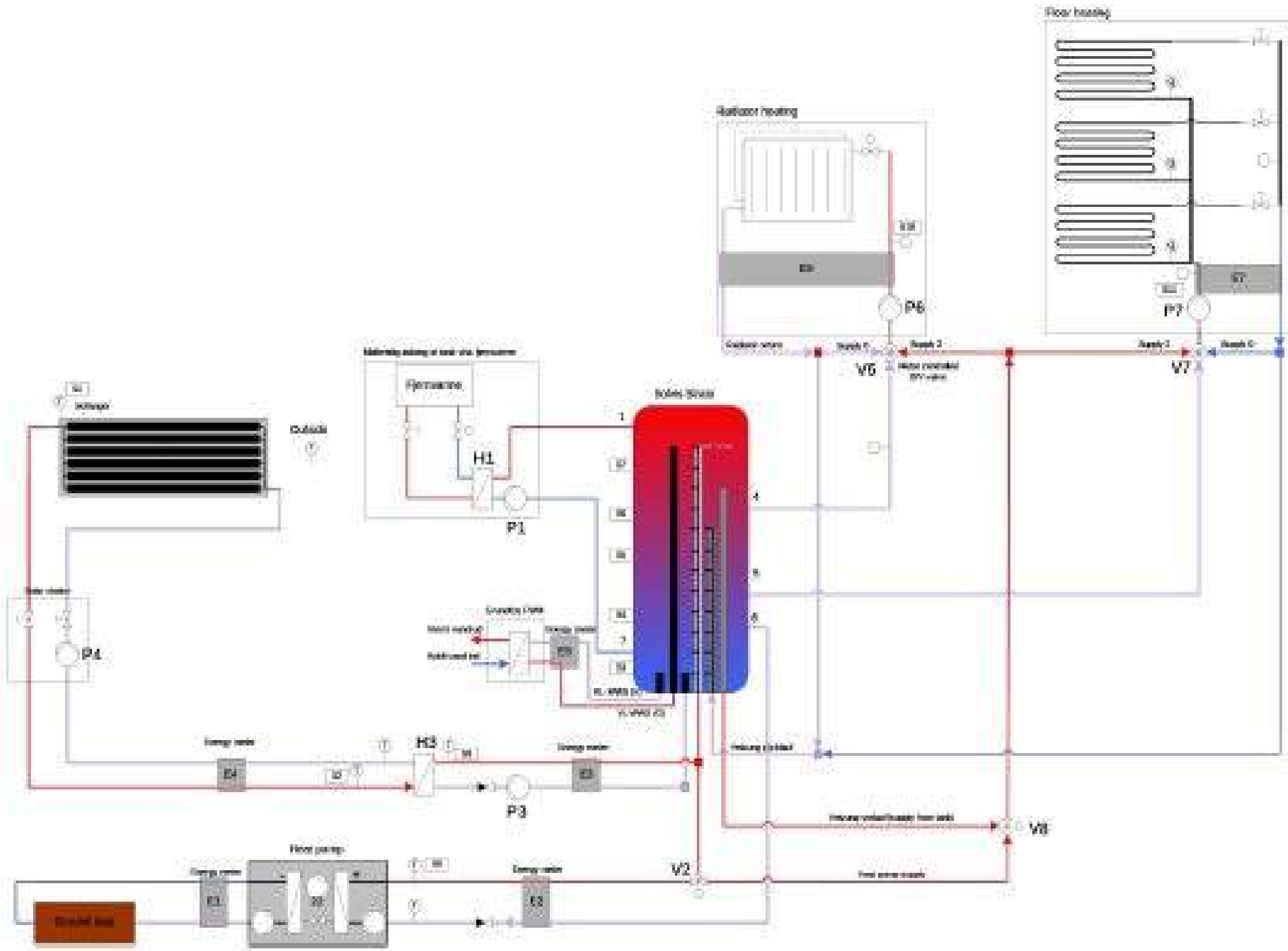
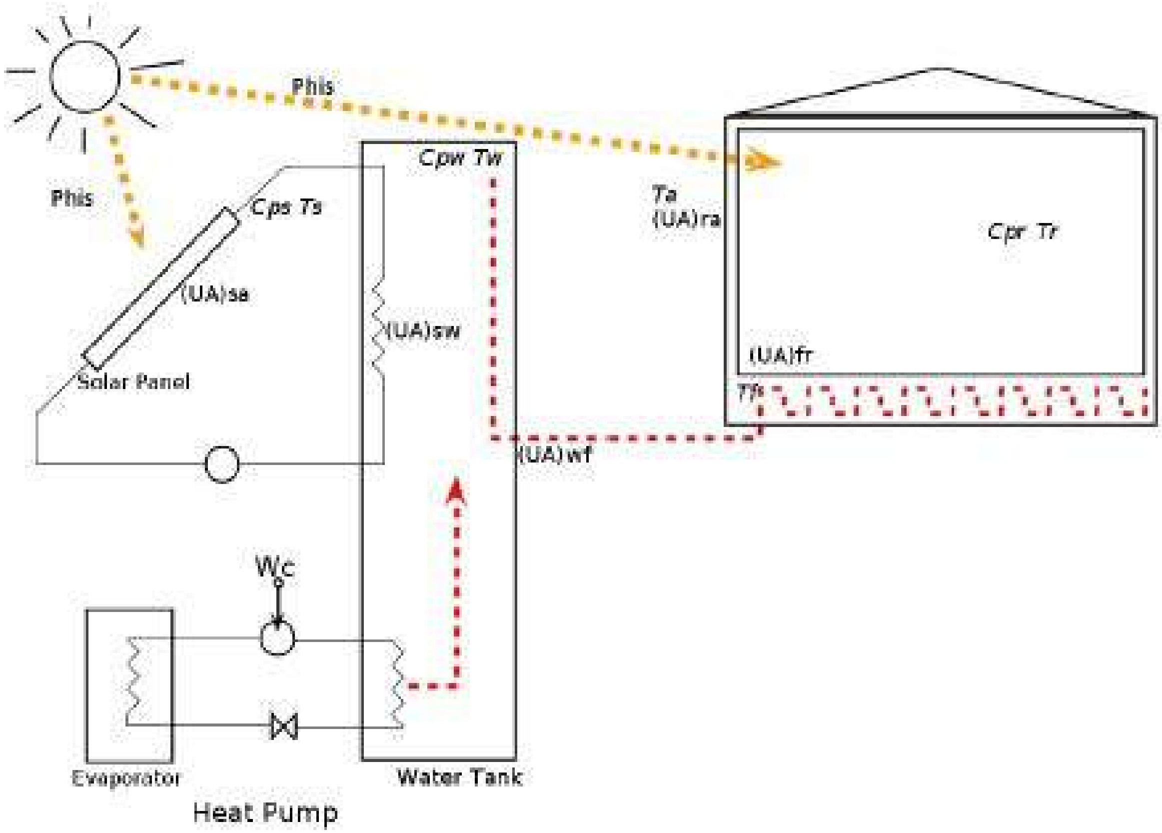
Grundfos Case Study

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:

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

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

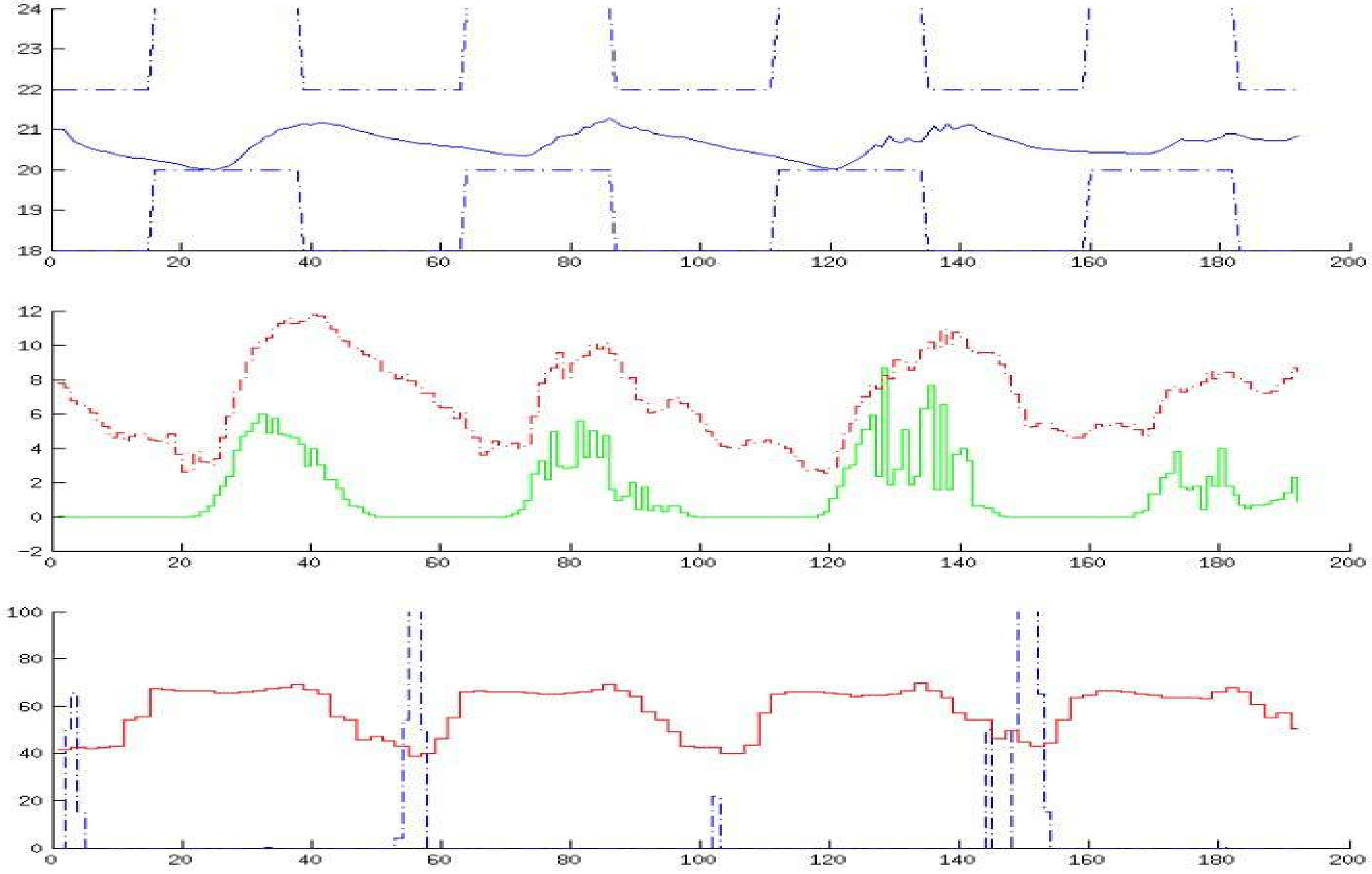
$$y_k = Cx_k \quad k = 1, 2, \ldots, N \tag{4c}$$

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

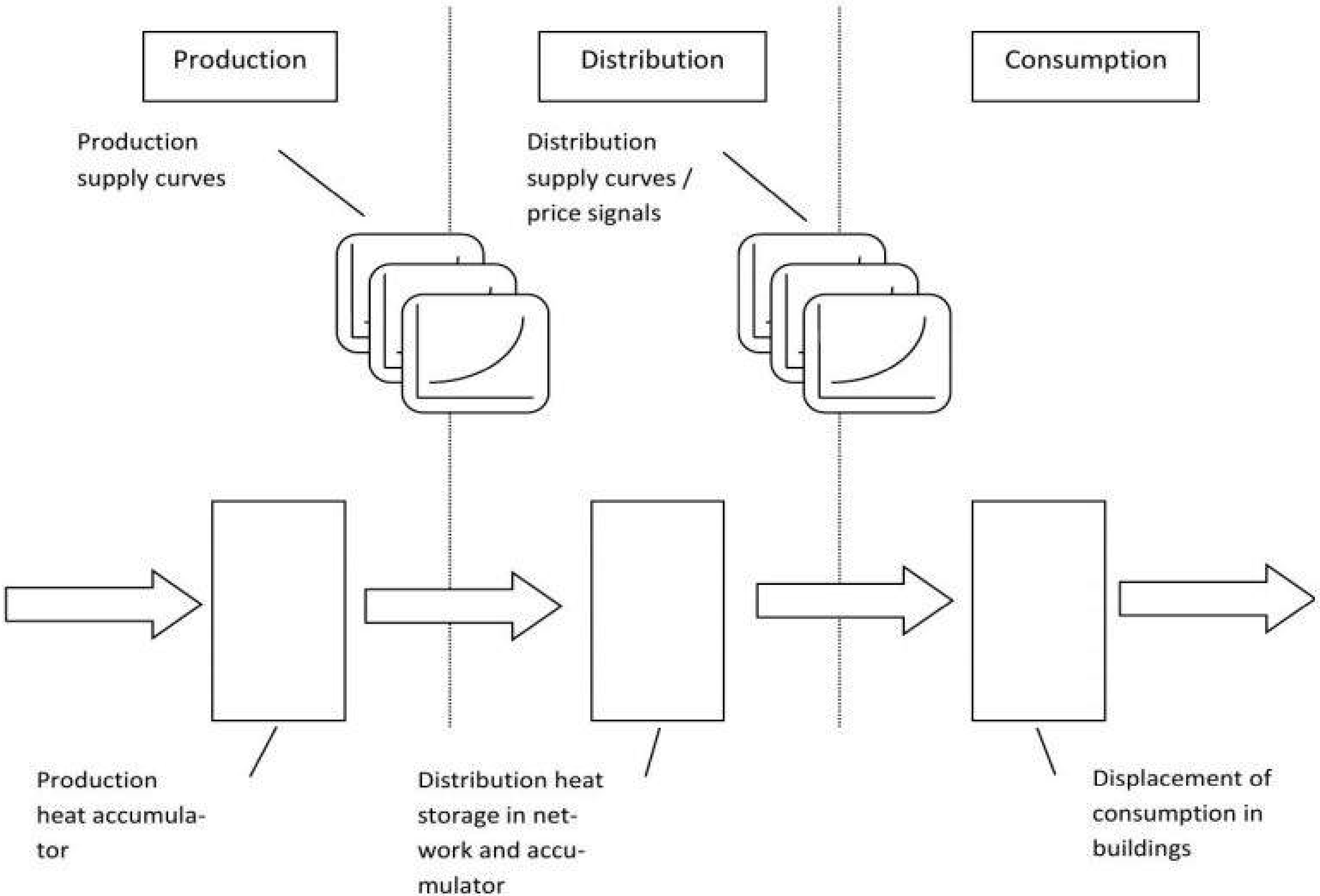
$$\Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} \quad k = 0, 1, \ldots, N-1 \tag{4e}$$

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

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

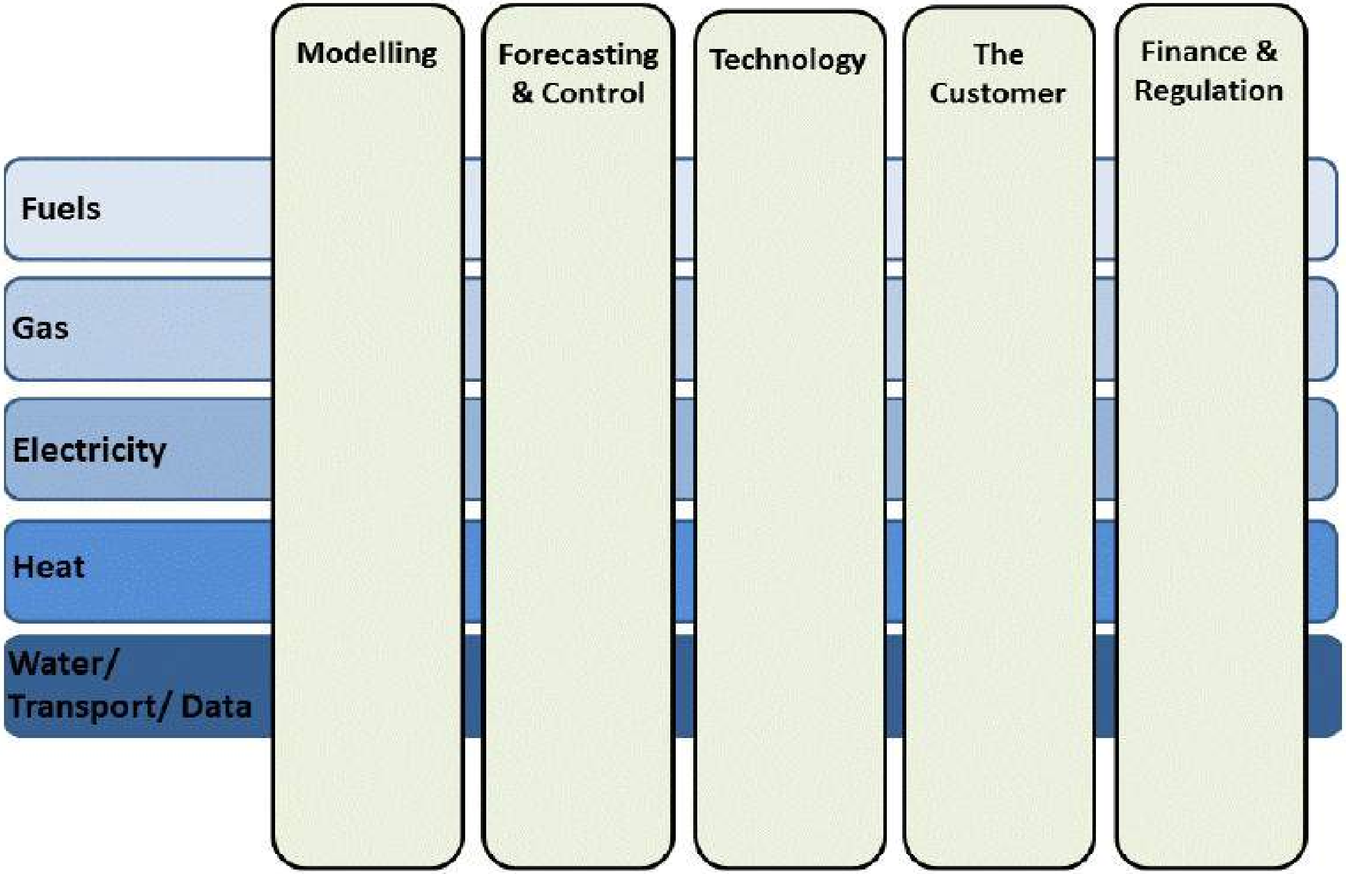


Flexibility in District Heating



Proposal (UCD, DTU, KU Leuven):

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



iiESI International Institute™ for Energy Systems Integration

Addressing energy challenges through global collaboration

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

Activities 2014

- Feb 18-19 Workshop (Washington)
- May 28-29 Workshop (Copenhagen)
- July 21 – 25, ESI 101 (Denver)
- Nov 17th Workshop (Kyoto)

Activities 2015

- Dublin, Denver, Brussels, Seoul

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

Discussion

- Energy Systems Integration can provide virtual and lossless storage solutions (so maybe we should put less focus on physical storage solutions)
- Flexible Energy Systems might be able to solve many of the problems Europe now is trying to solve by Super Grids (some of these huge investments might not be needed)
- Focus on zero emission buildings – and less on zero energy buildings (the same holds supermarkets, wastewater treatment plants, etc.)
- District heating (or cooling) provide virtual storage on the essential time scale (up to a few days)
- We see a large potential in Demand Side Management. Automatic solutions and end-user focus is important
- We see a large potential in coupling cooling (eg. for comfort) and heating systems using DH networks
- We see large problems with the tax and tariff structures in many countries (eg Denmark). Coupling to prices for carbon capture could be advantageous.
- 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)

For more information ...

See for instance

www.henrikmadsen.org

www.smart-cities-centre.org

...or contact

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Acknowledgement CITIES (DSF 1305-00027B)

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DTU

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