Forecasting, Aggregation and Control for Future Electric Energy Systems

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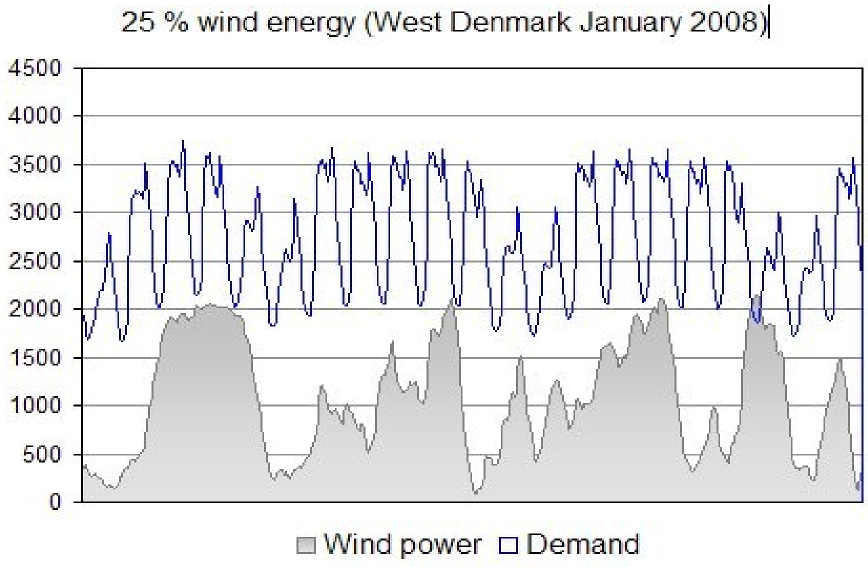
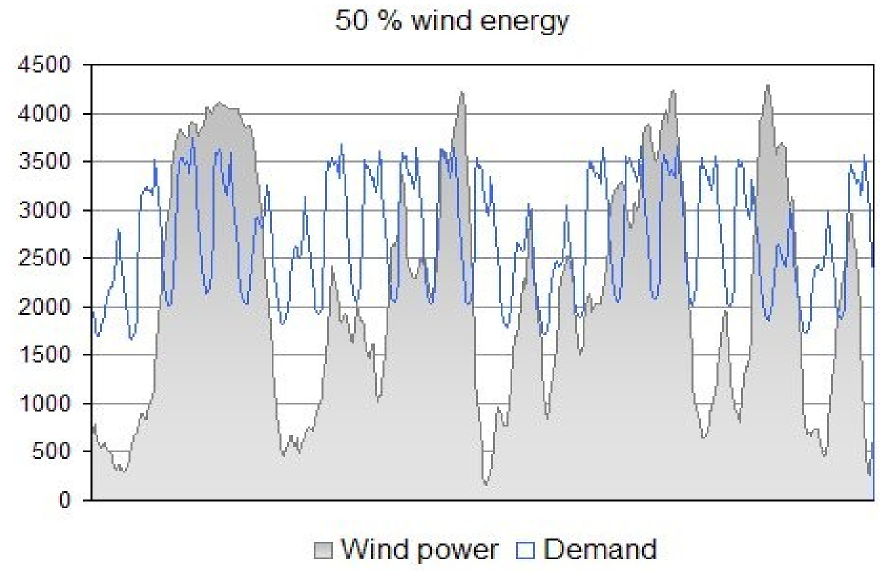
The Danish Wind Power Case

.... balancing of the power system

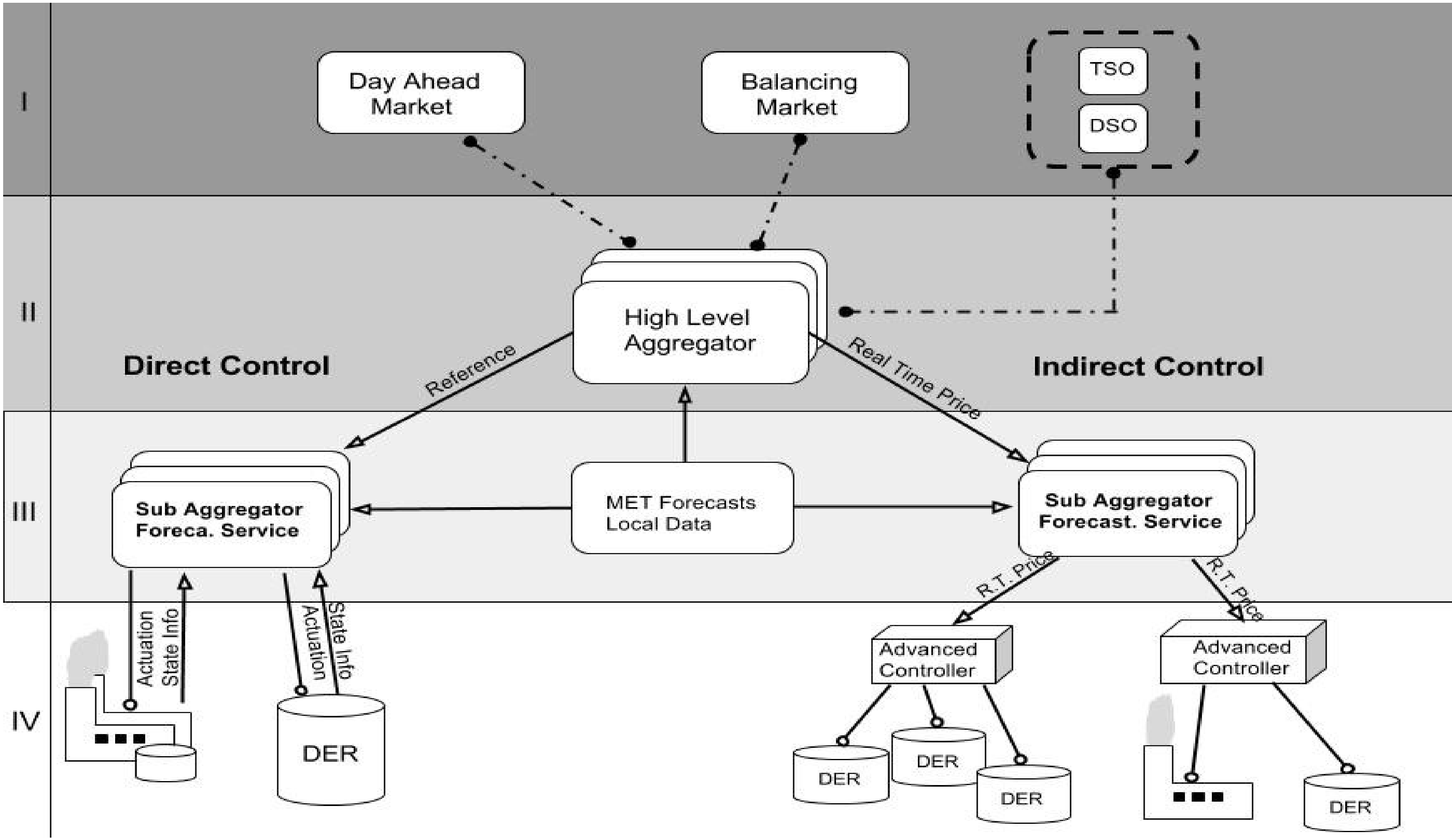




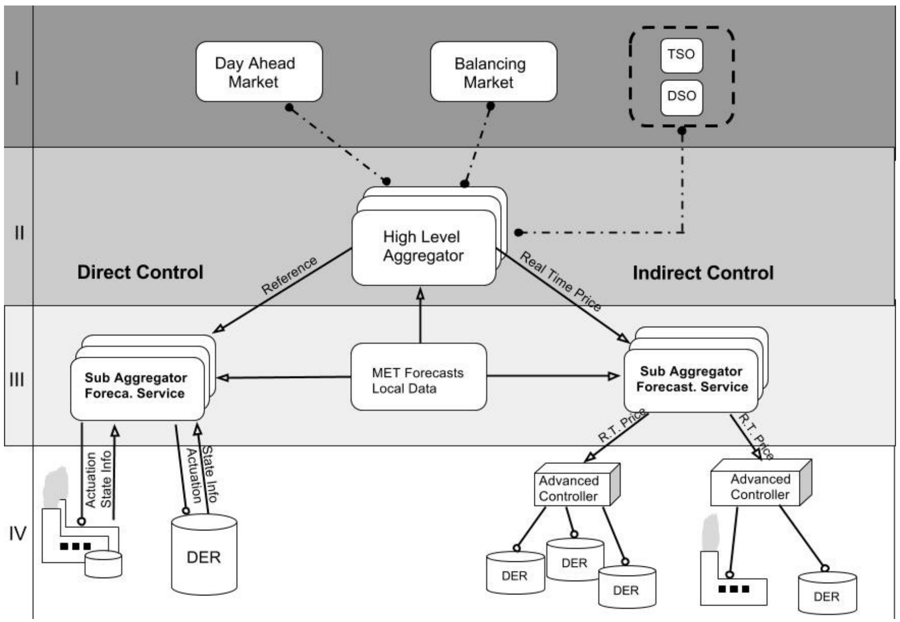
In 2008 wind power did cover the entire demand of electricity in200 hours (West DK)

In December 2013 and January 2014 more than 55 pct of electricity load was covered by wind power. And for several days the wind power production was more than 120 pct of the power load

Control/Opt. Principles

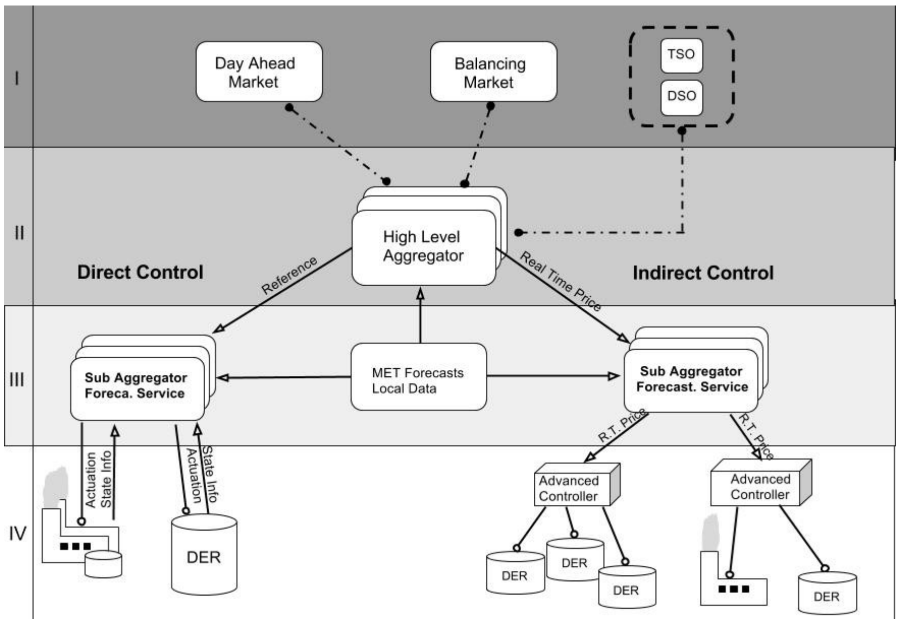


Stoch. Control/Opt. Principles



- **Day Ahead:**
  - Stoch. Programming based on scenarios
- **Direct Control:**
  - Actuator: Power
  - Cost: MV, LQG, GPC, ...
  - Two-way communication
  - Models for DERs are needed
  - Constraints for the DERs
  - Contracts on exceptions
- **Indirect Control:**
  - Actuator: Price
  - Cost: E-MPC, VaR-alike, ..
  - One-way communication
  - Models for DERs are not needed
  - Simple 'contracts'

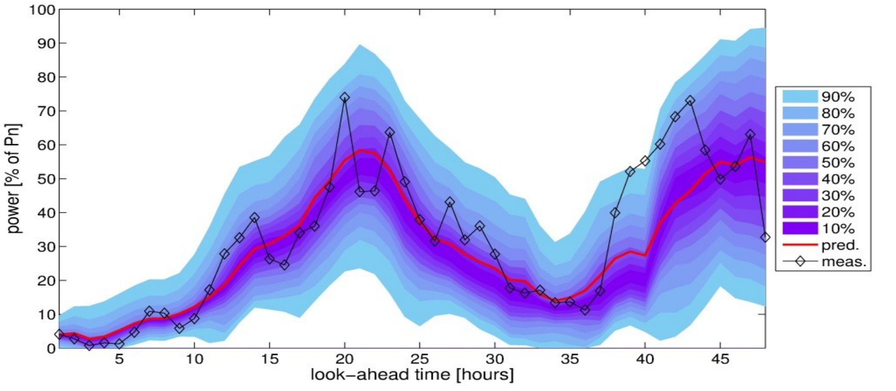
Forecast requirements

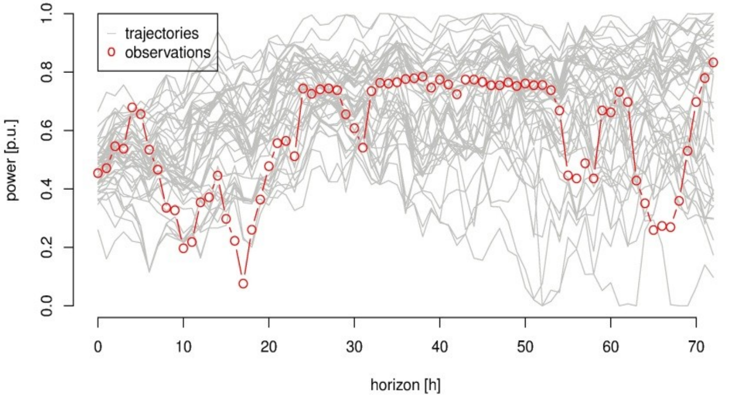


- **Day Ahead:**
  - Forecasts of loads
  - Forecasts of production (eg. Wind and Solar)
- **Direct Control:** .
  - Forecasts of states of DERs
  - Forecasts of flexibility
  - Forecasts of load
- **Indirect Control:**
  - Forecasts of prices
  - Forecasts of load.

Which type of forecast to use?

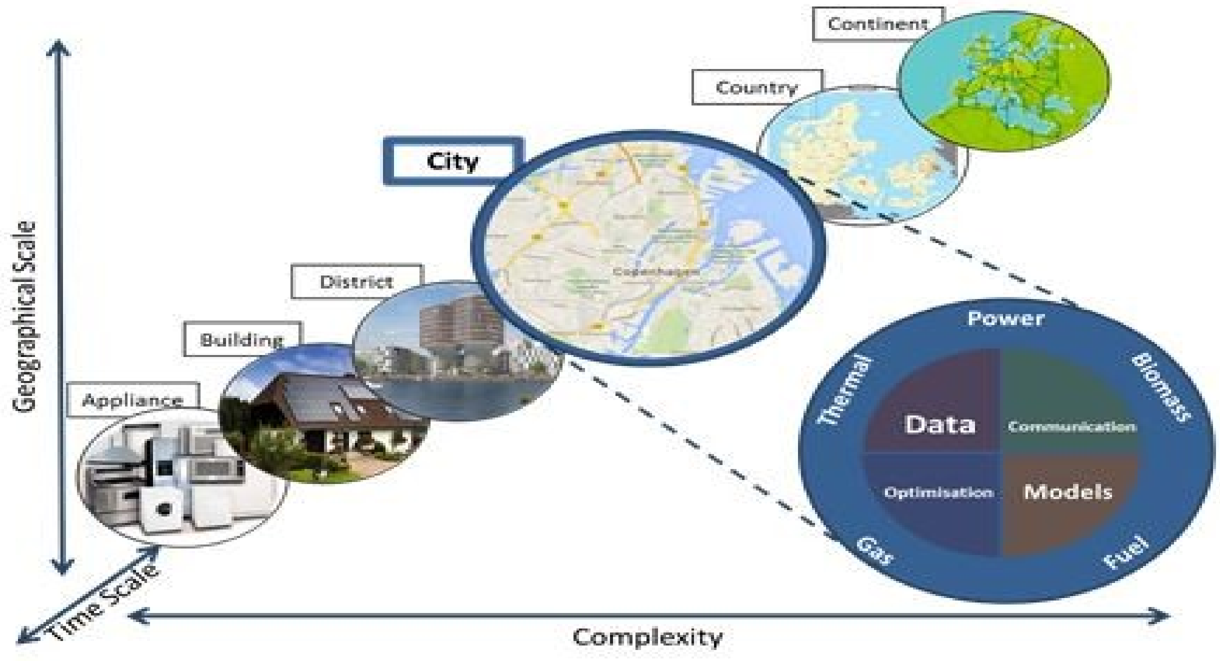
- Point forecasts
- Conditional mean and covariances
- Conditional quantiles
- Conditional scenarios
- Conditional densities
- Stochastic differential equations



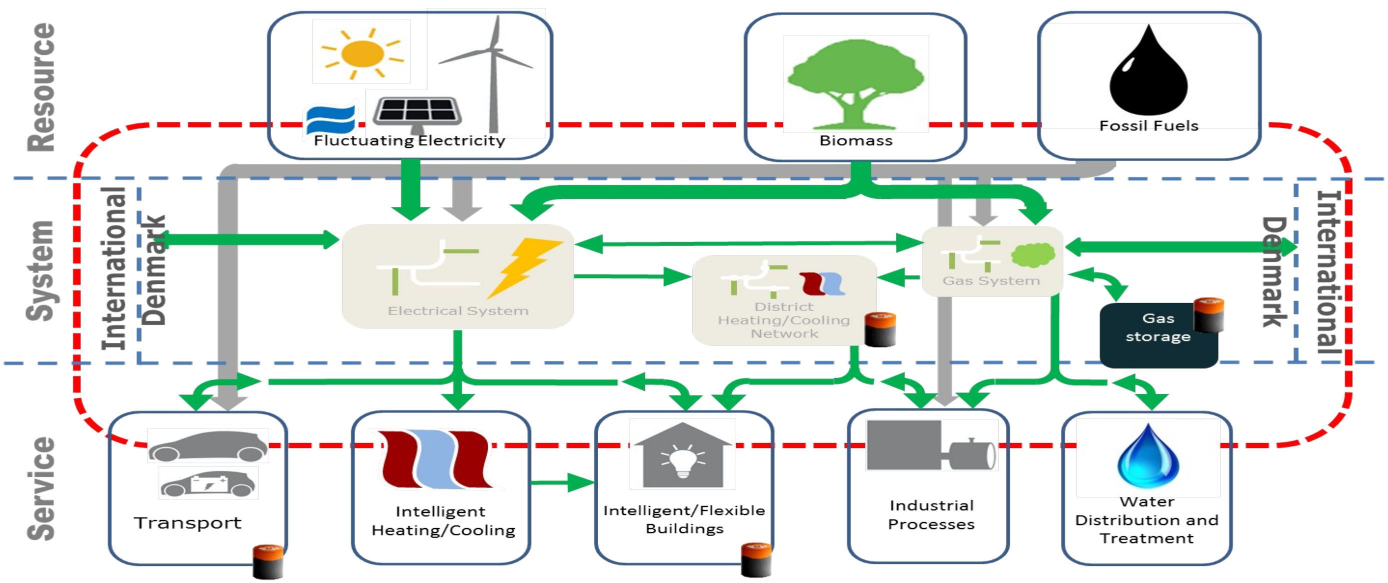


CITIES – Research Focus

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



Example: Storage by Energy Systems Integration



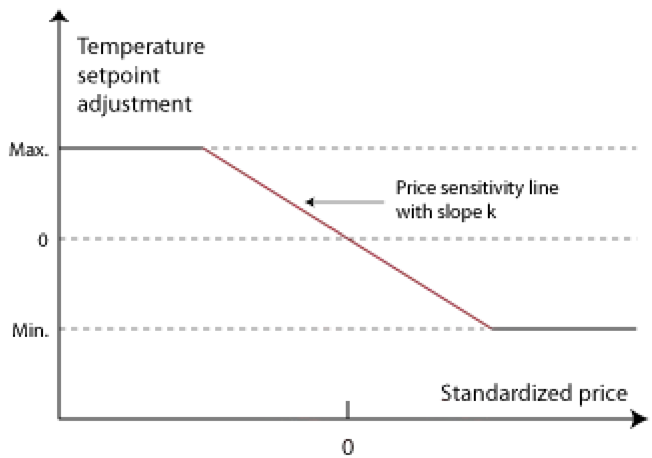
- **Denmark (2014) : 45 pct of power load by renewables (> 100 pct at some days in January)**
- **(Virtual) storage principles:**
  - Buildings can provide storage up to, say, 5-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - Gas systems can provide seasonal storage

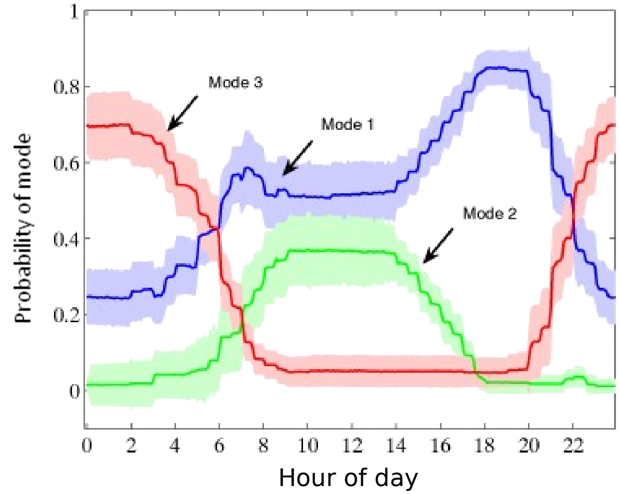
Case study

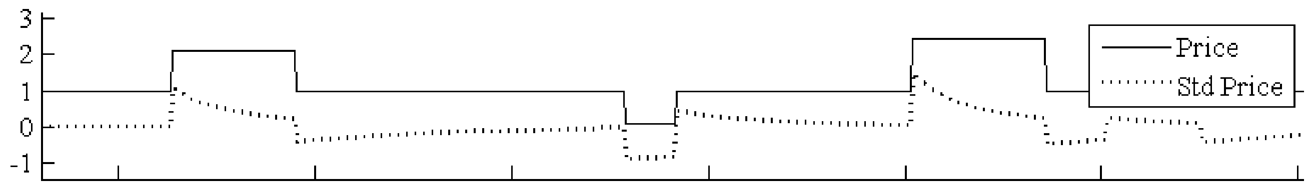
Control of Power Consumption (DSM)

Price responsivity

Flexibility is activated by adjusting the temperature reference (setpoint)





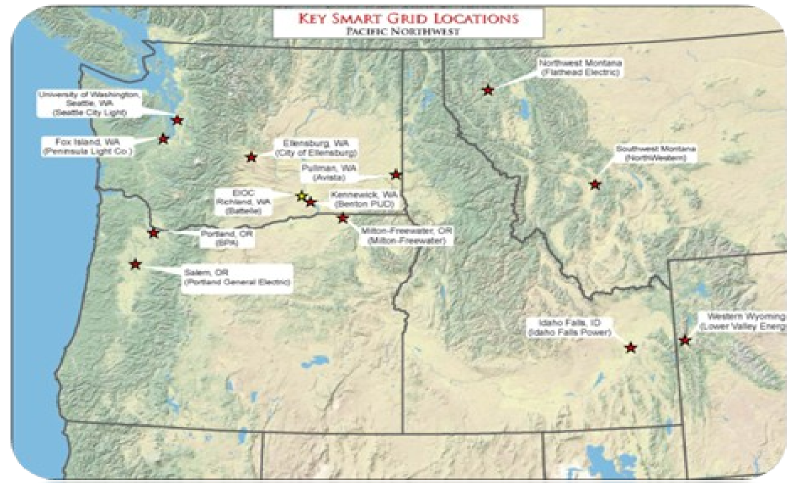


- **Standardized price** is the % of change from a price reference, computed as a mean of past prices with exponentially decaying weights.
- **Occupancy mode** contains a price sensitivity with its related comfort boundaries. 3 different modes of the household are identified (work, home, night)

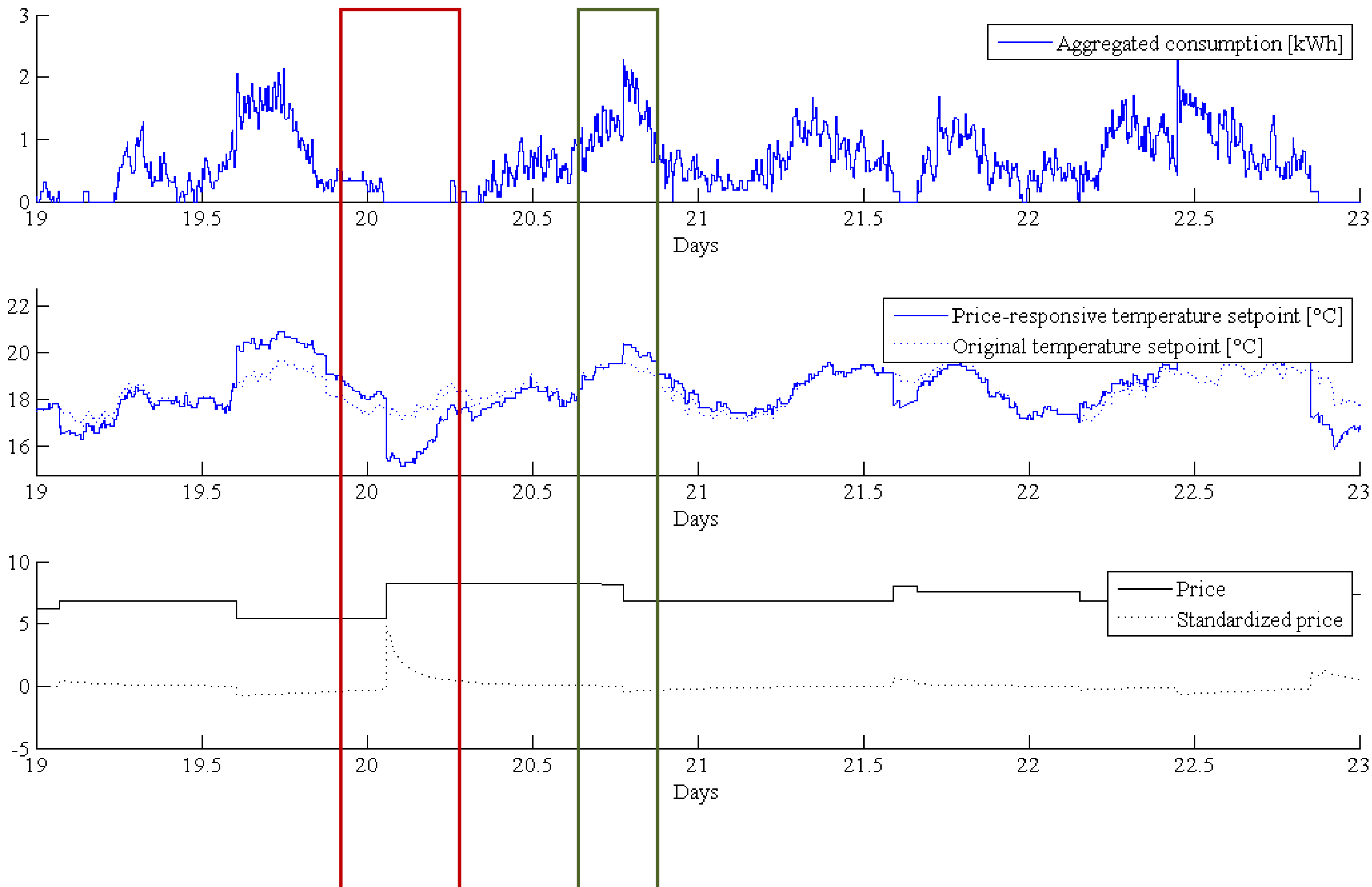
Data from BPA

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

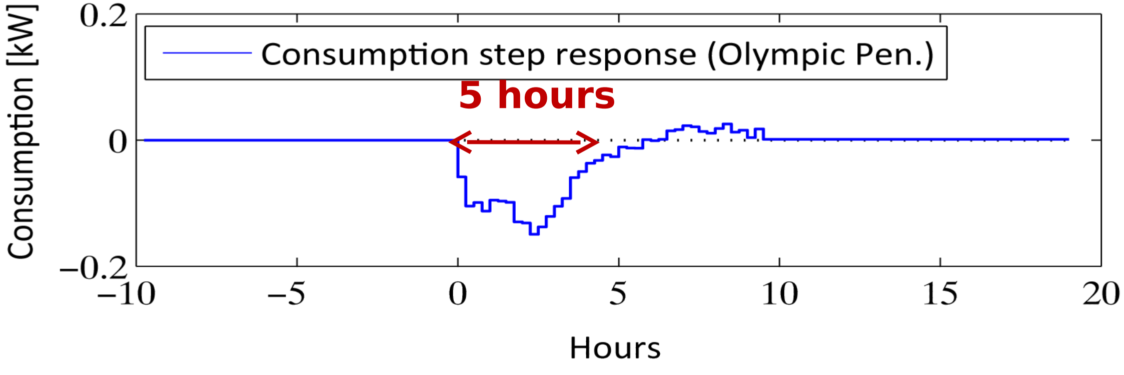


Aggregation (over 20 houses)

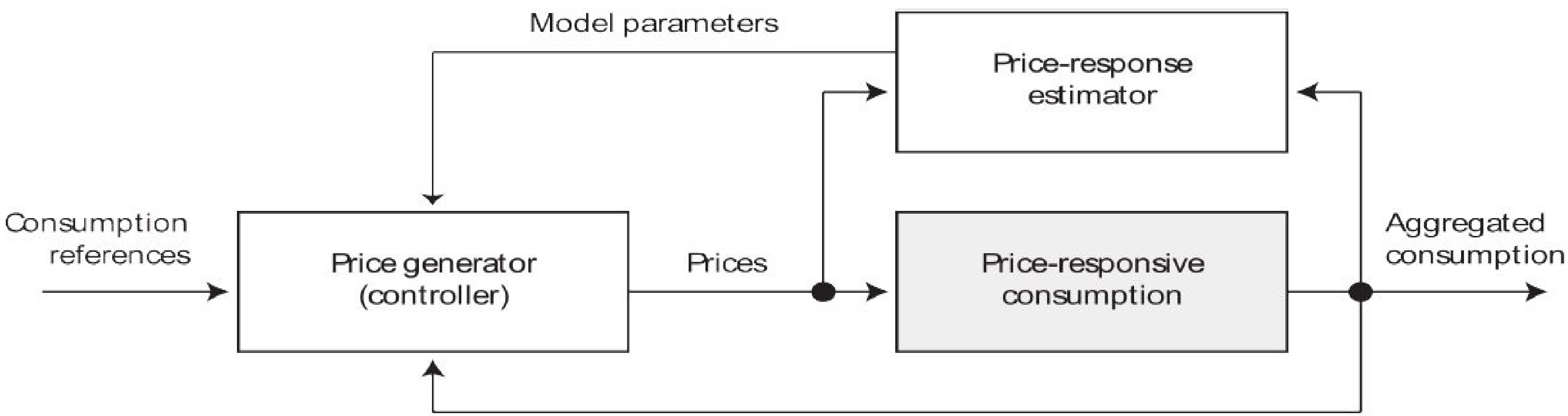


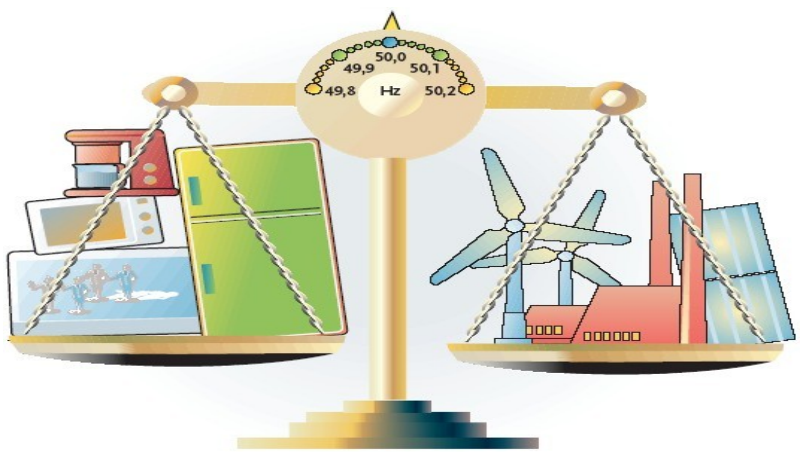
Non-parametric Response on Price Step Change

Olympic Peninsula



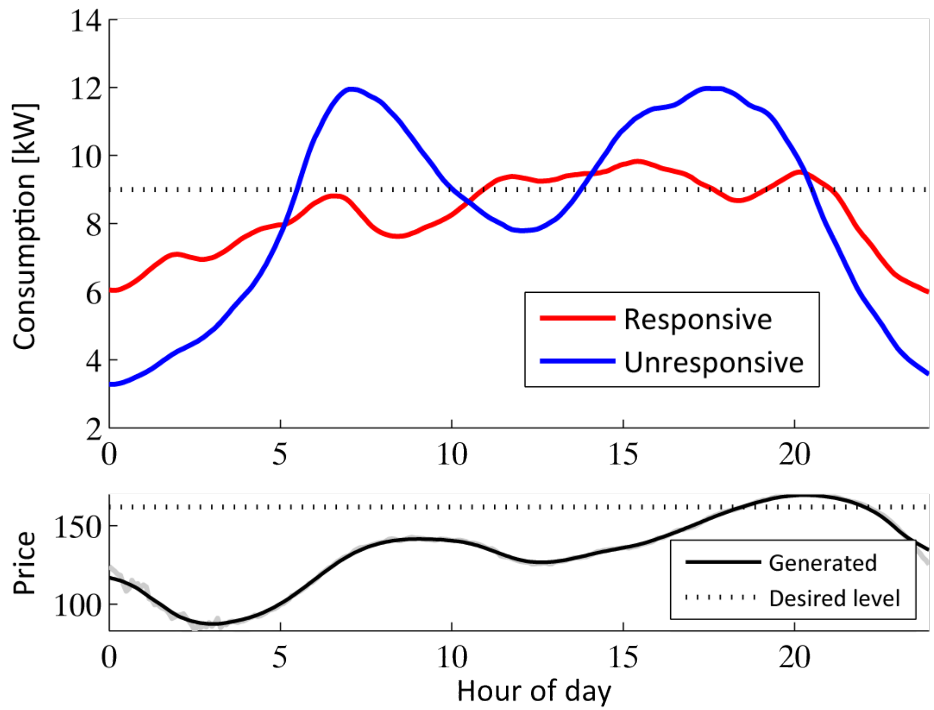
Control of
Power Consumption





Control performance

- Considerable **reduction in peak consumption**
- Mean daily consumption shift

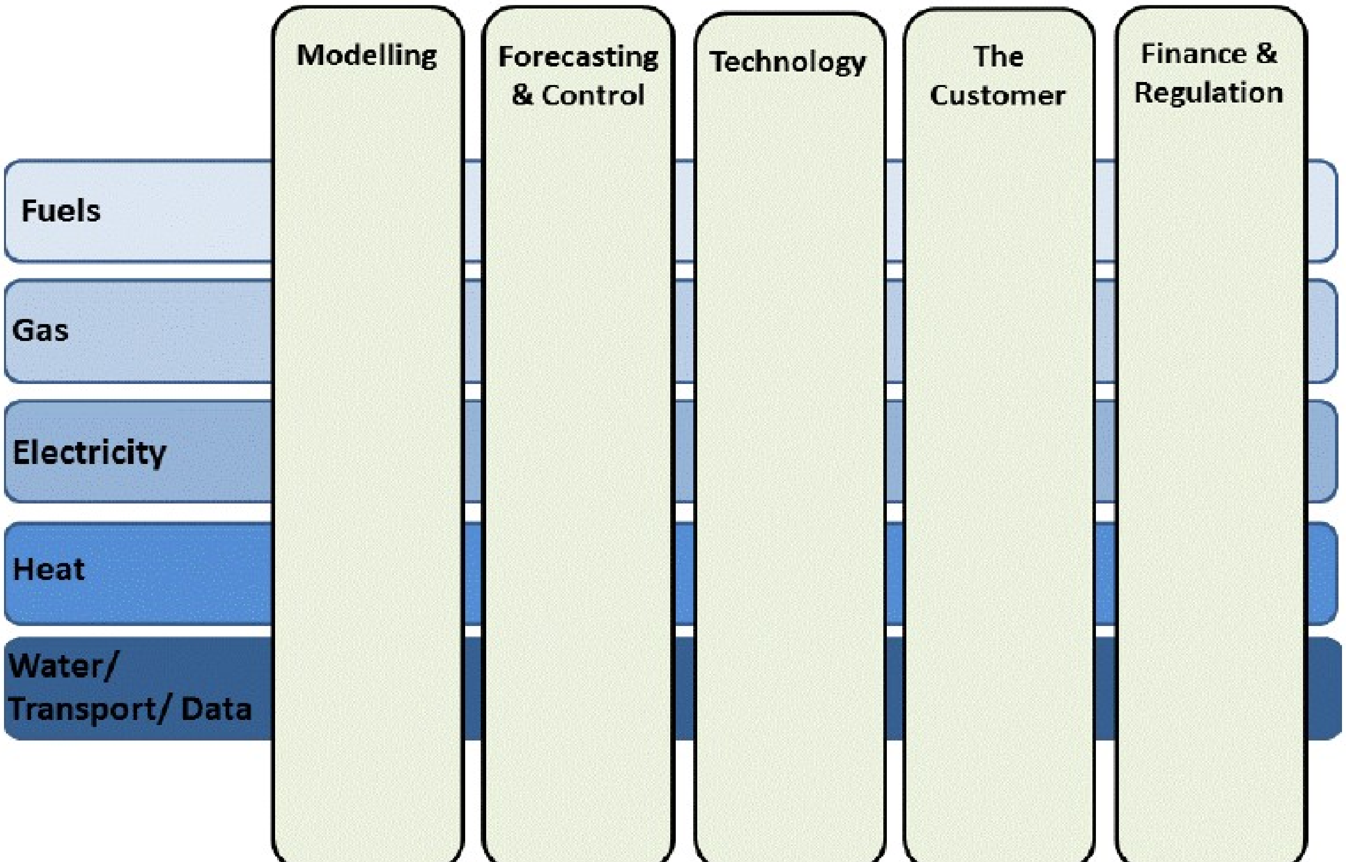


Ongoing projects with a focus on DSM

- **Temperature control in houses (Grundfos, ENFOR)**
- **HVAC systems (Grundfos, NREL)**
- **Supermarket cooling (Danfoss, UCD)**
- **Consumption in family houses (TI, ENFOR, ...)**
- **District heating networks (Cowi, ENFOR, Rambøll, DFF-EDB, Schneider Electric)**
- **Combined Heat and Power plants (Dong Energy)**
- **Heat Pumps in District Heating networks (HOFOR, Cowi, ENFOR)**
- **Rainfall Run-off Systems (DHI and Rambøll)**
- **Wastewater treatment plants (Krüger, Veolia)**
- **.............**

Proposal (UCD, DTU, KU Leuven):

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



iiESI International Institute for Energy Systems Integration™

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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, Hawaii, Brussels, Australia

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