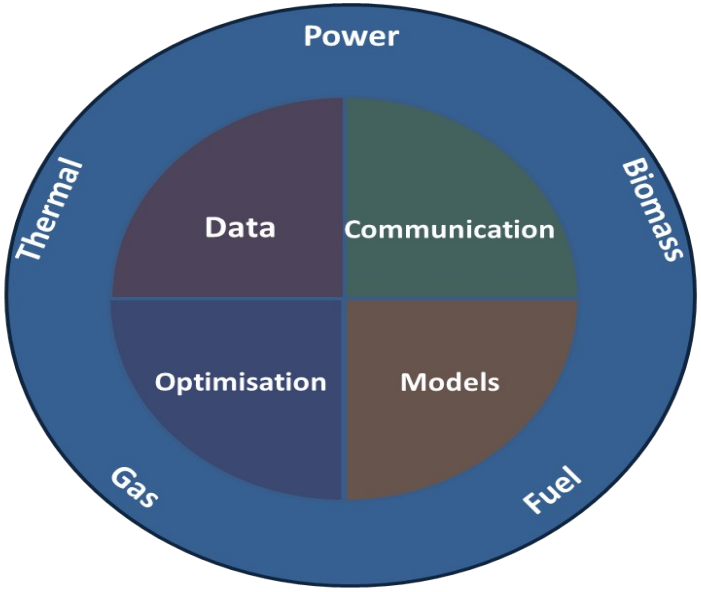
Stochastic Modelling of Energy Systems in Cities



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

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

EuroTech Universities
Excellence in Science and Technology

Quote by B. Obama:

(U.N. Climate Change Summit,

New York, Sept. 2014)

*We are the **first generation***
affected by climate changes,

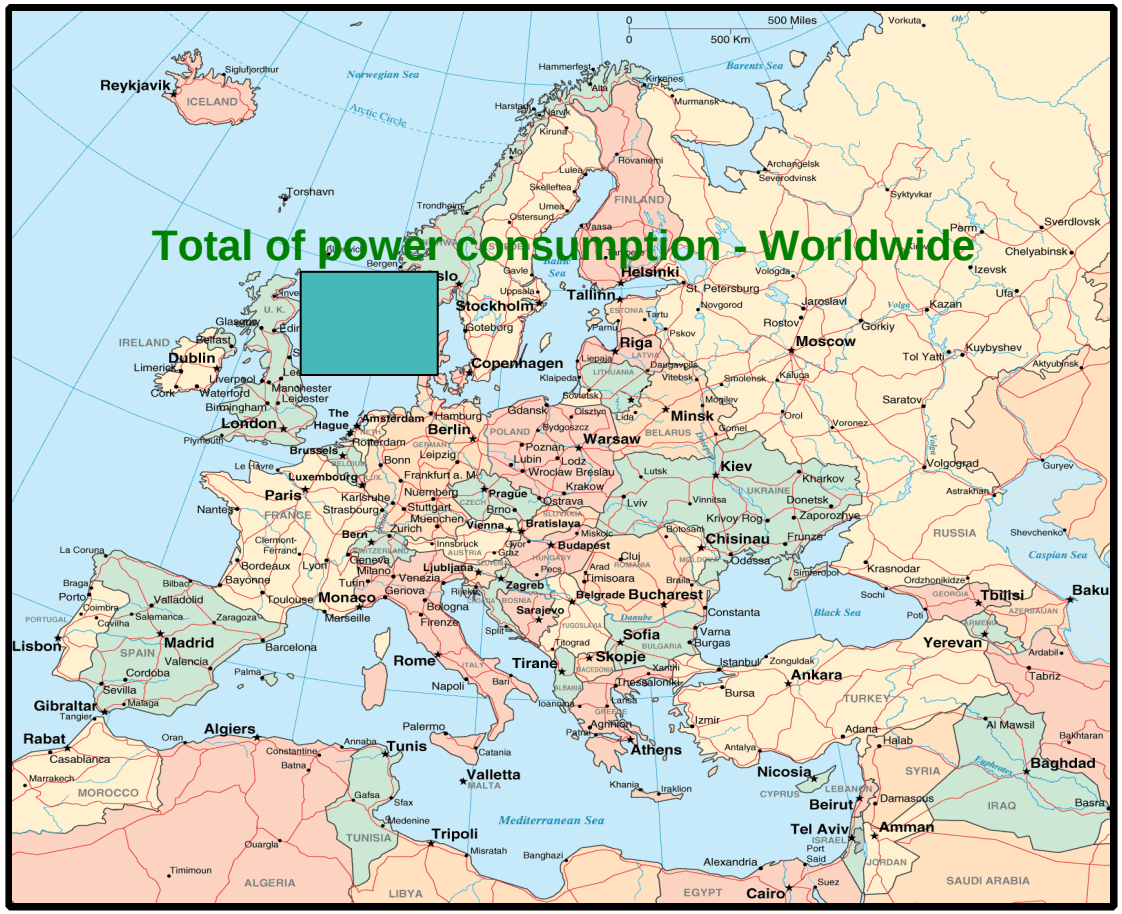
*and we are the **last generation***
able to do something about it!

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

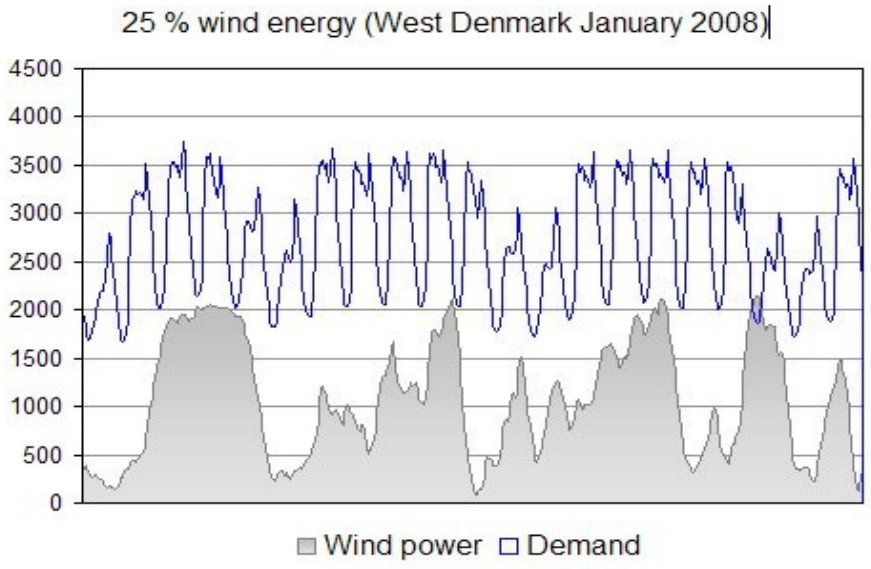
- **Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- **Conclusion**: Use intelligence ....
- Calls for **IT / Big Data / Smart Energy Solutions / Energy Systems Integration**



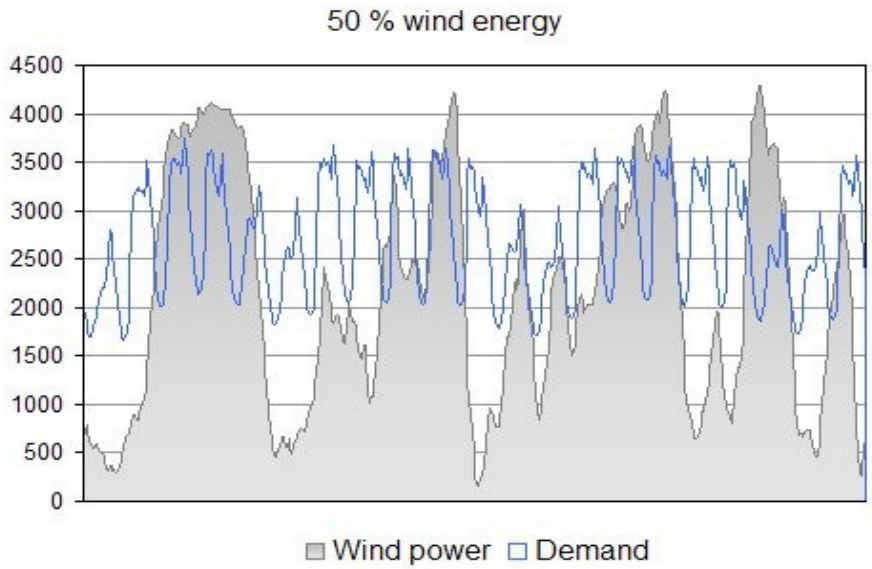
EuroTech Universities
Excellence in Science and Technology

The Danish Wind Power Case

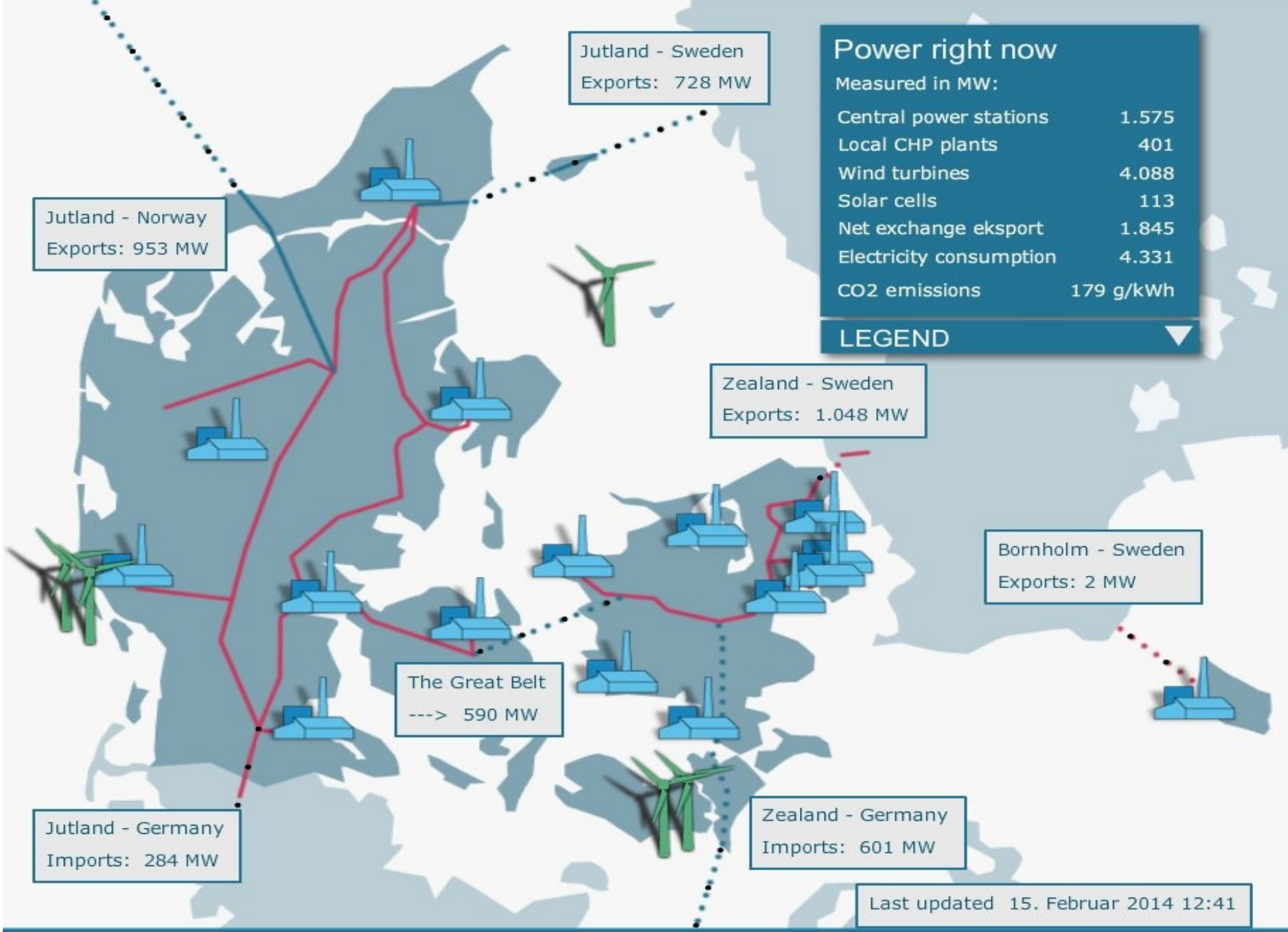
.... balancing of the power system



In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

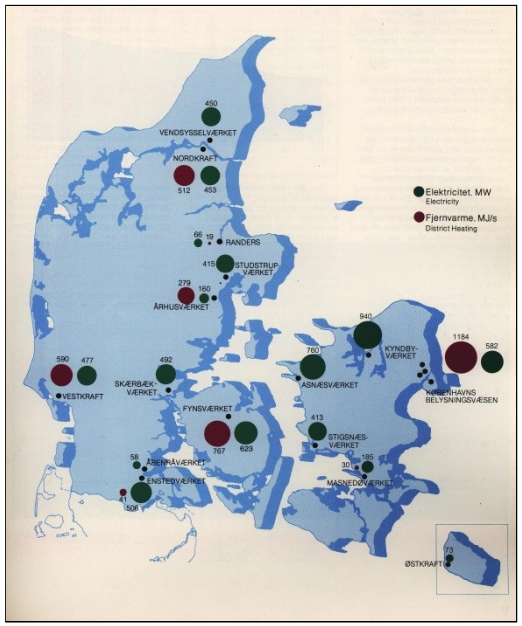


In December 2013 and January 2014 more than 55 pct of electricity load was covered by wind power. And for several days the wind power production was more than 120 pct of the power load

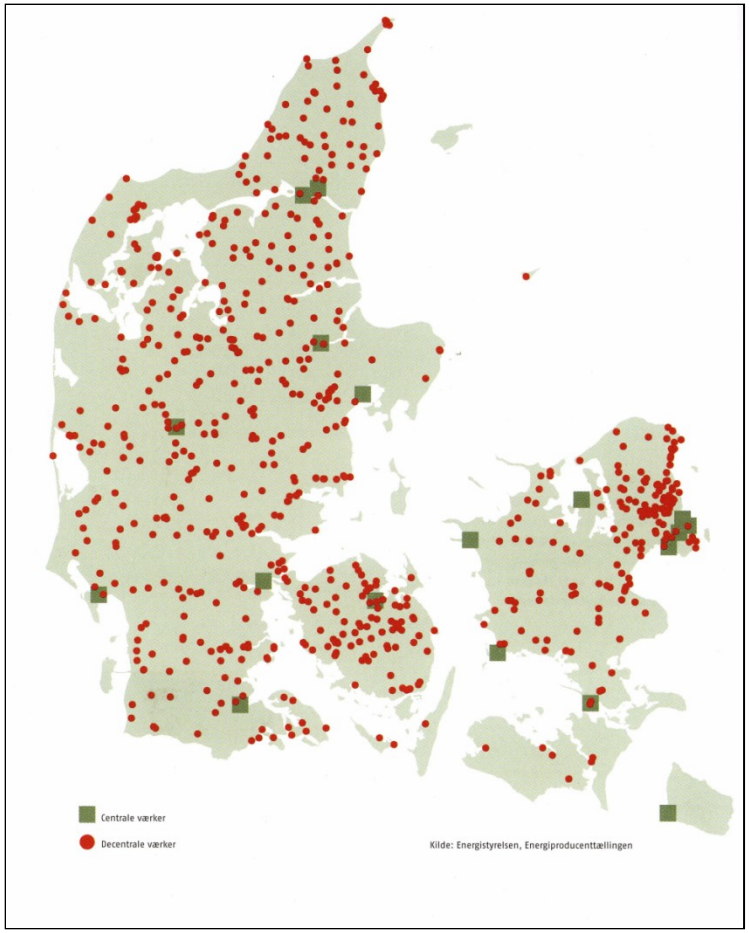

Jutland - Sweden
Exports: 728 MW
Power right now
Measured in MW:
Central power stations 1.575
Local CHP plants 401
Wind turbines 4.088
Solar cells 113
Net exchange eksport 1.845
Electricity consumption 4.331
CO2 emissions 179 g/kWh
LEGEND
Jutland - Norway
Exports: 953 MW
Zealand - Sweden
Exports: 1.048 MW
Bornholm - Sweden
Exports: 2 MW
The Great Belt
---> 590 MW
Jutland - Germany
Imports: 284 MW
Zealand - Germany
Imports: 601 MW
Last updated 15. Februar 2014 12:41
Power right now
Natural gas right now
Locations

From large central plants to Combined-heat and power production

1980



Today



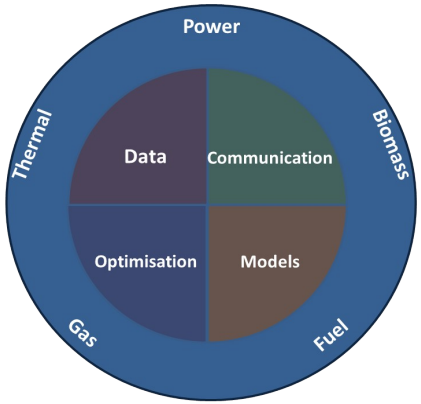
From a few big power plants to many small combined heat and power plants – however most of them based on coal

EuroTech Universities
Excellence in Science and Technology

Energy Systems Integration (ESI) Hypothesis

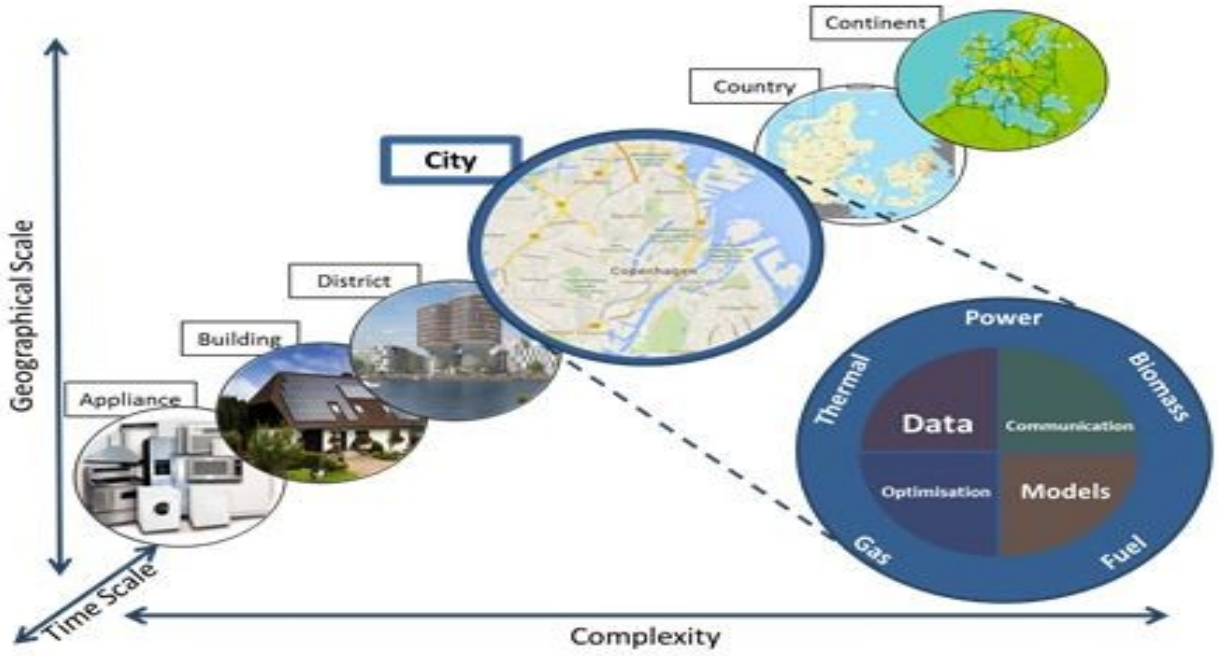
The **central hypothesis of ESI** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) in we can enable very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

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



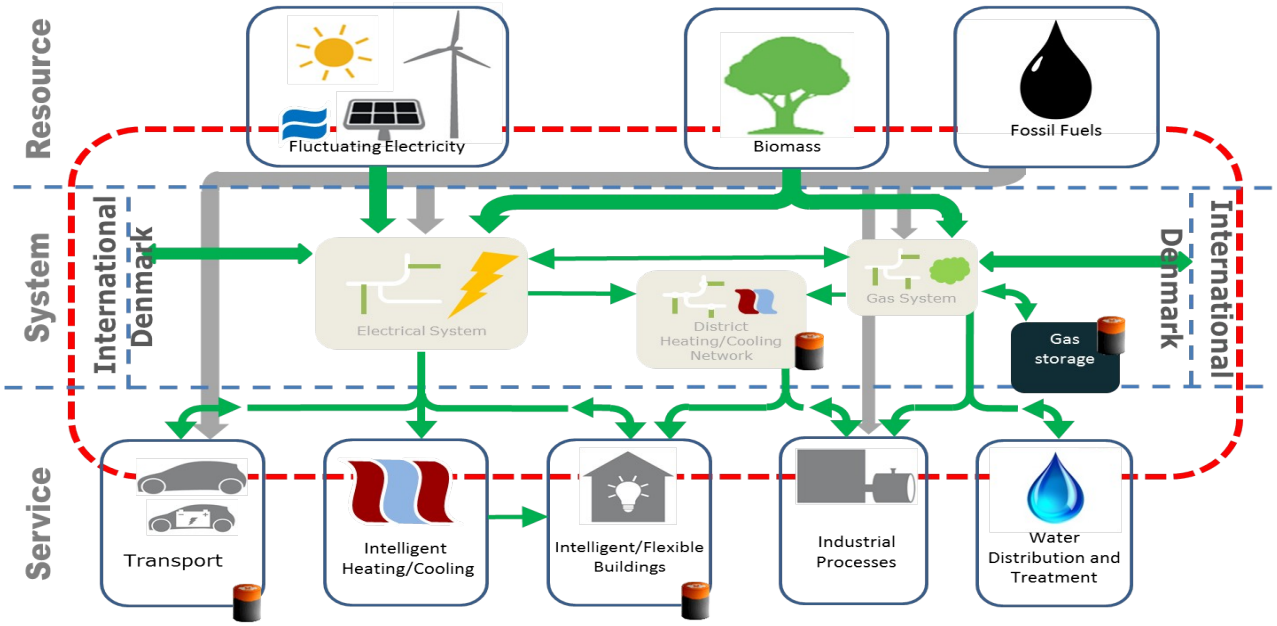
ESI – Research Challenges

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

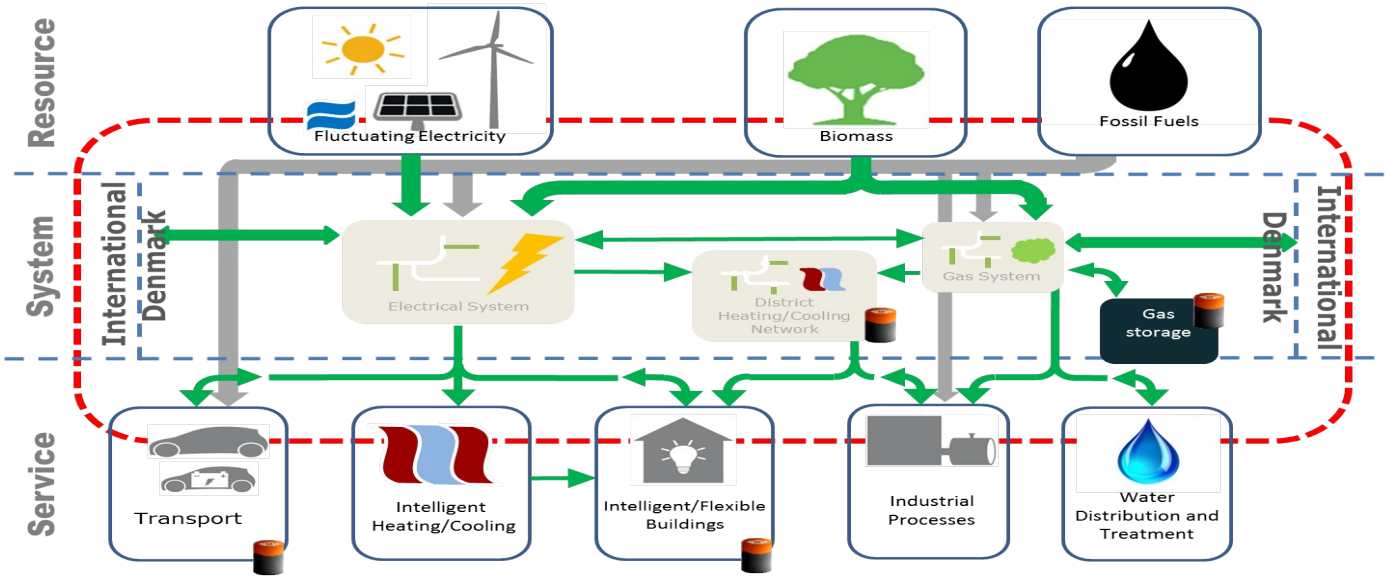


Grey-Box Modeling Concept

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



Example: Storage by Energy Systems Integration



- **Denmark (2014) : On average 40 pct of power load by wind power (> 100 pct at some days in January, 62 pct on average 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

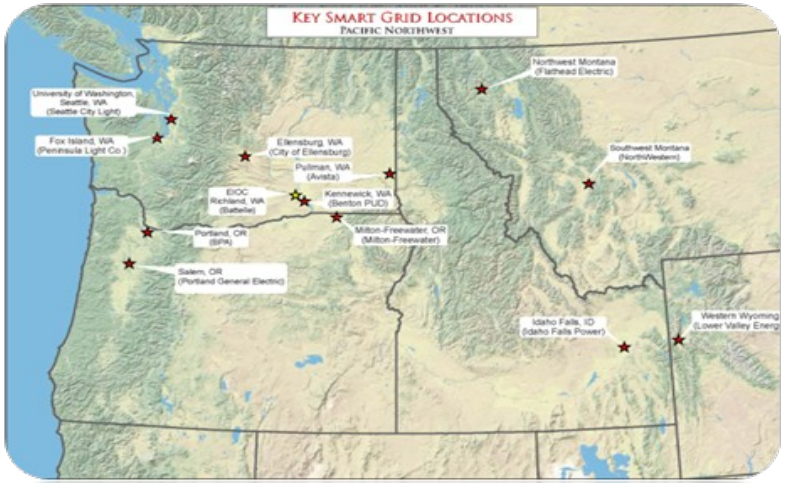
Case study

Control of Power Consumption (DSM)

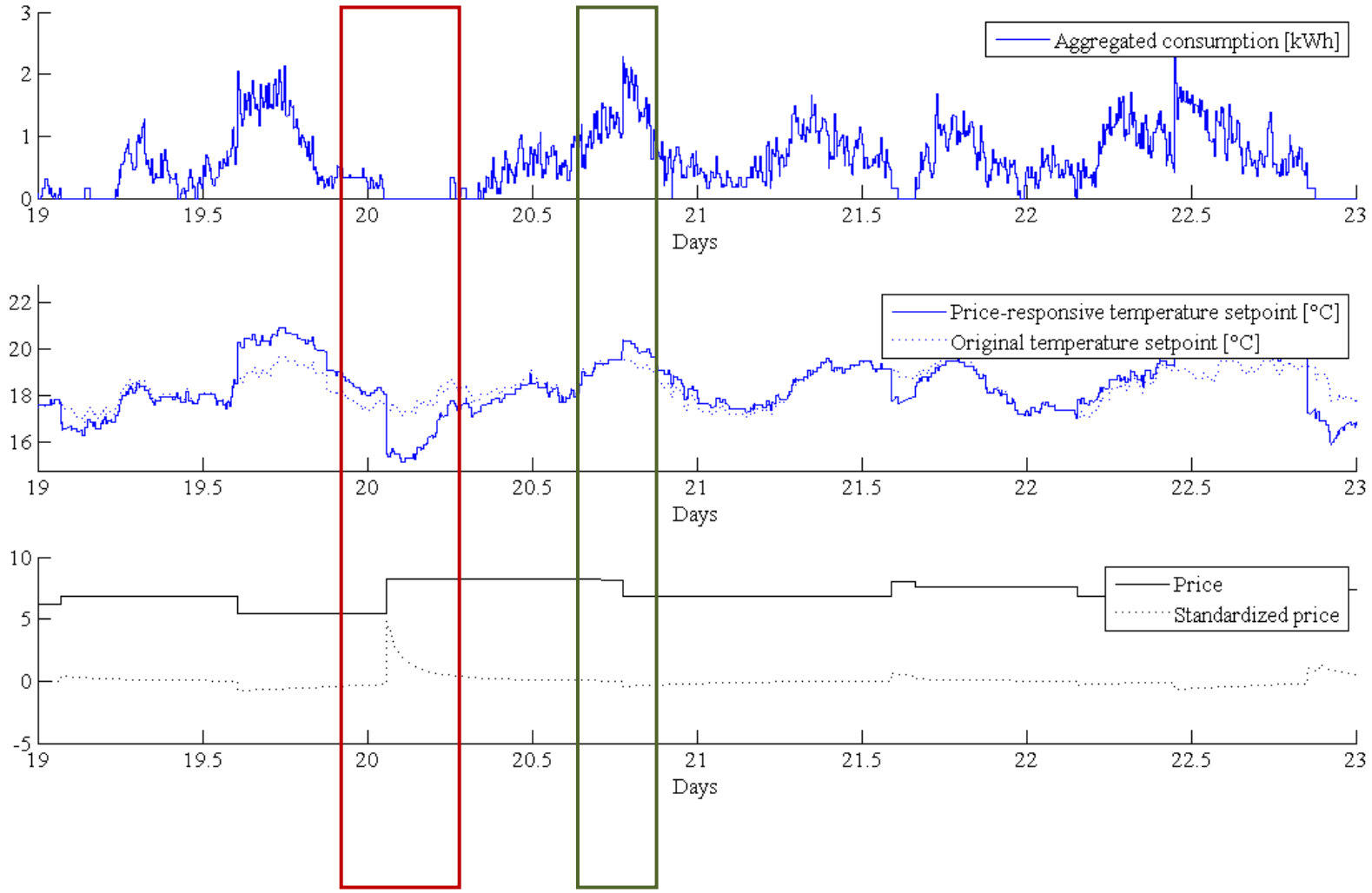
Data from BPA

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



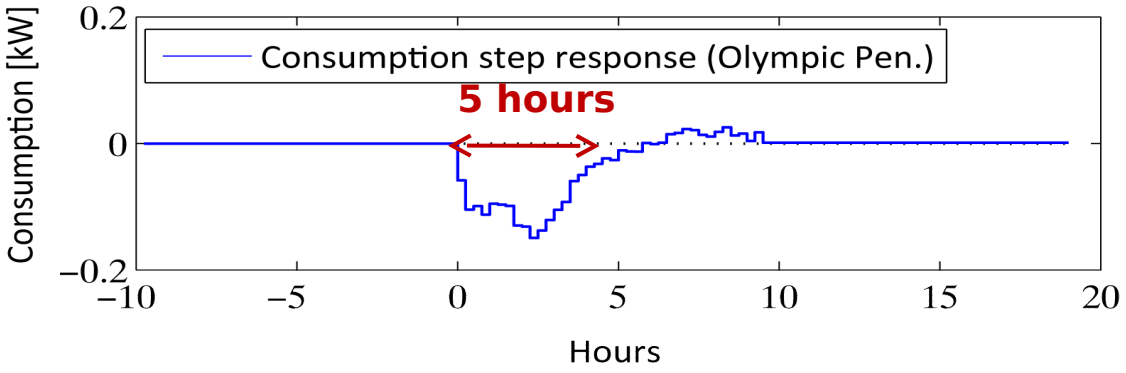
Aggregation (over 20 houses)



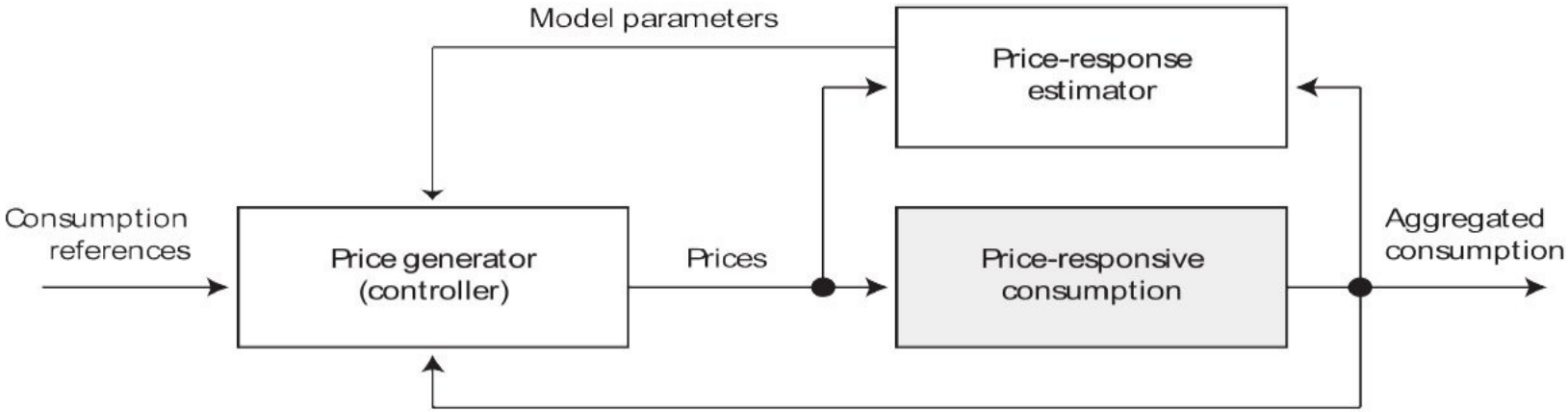
Non-parametric Response on Price Step Change

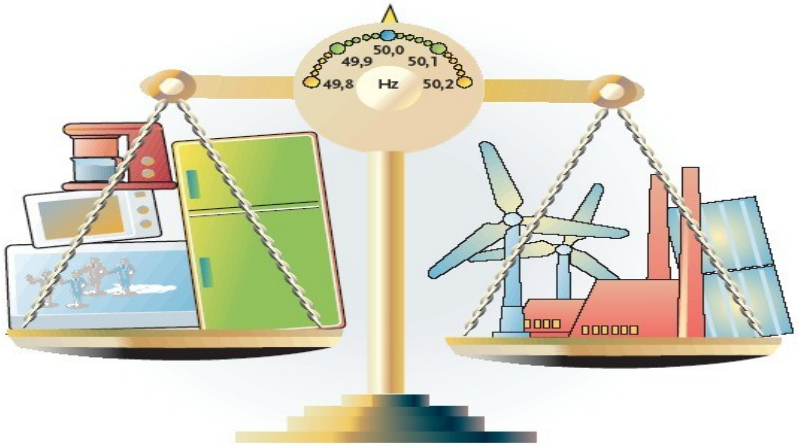
Model inputs: pice, minute of day, outside temperature/dewpoint, sun irrandianc

Olympic Peninsula



Control of Energy Consumption

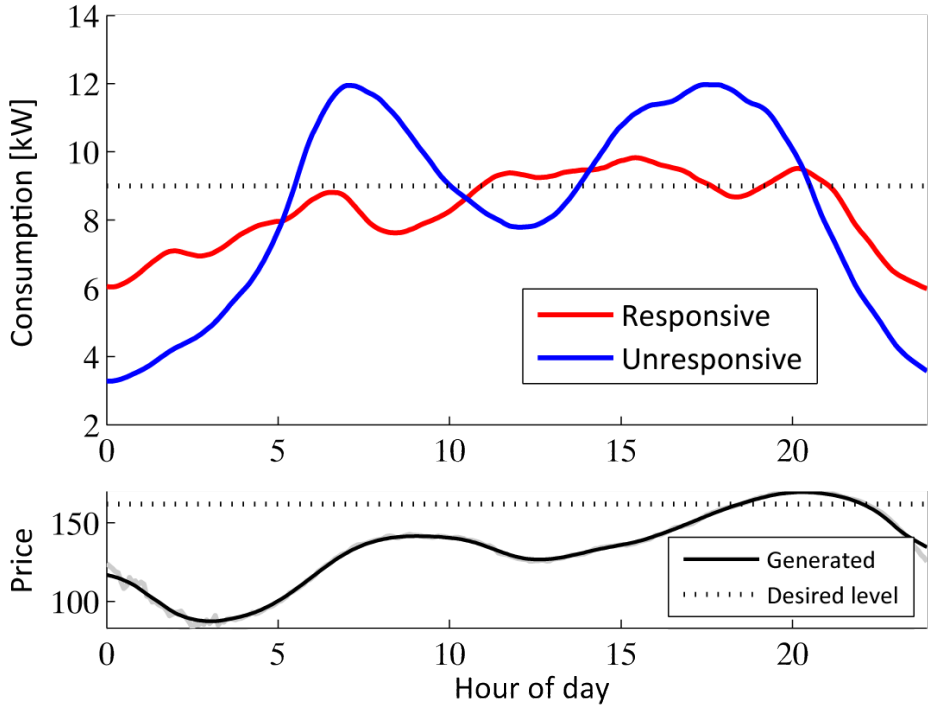




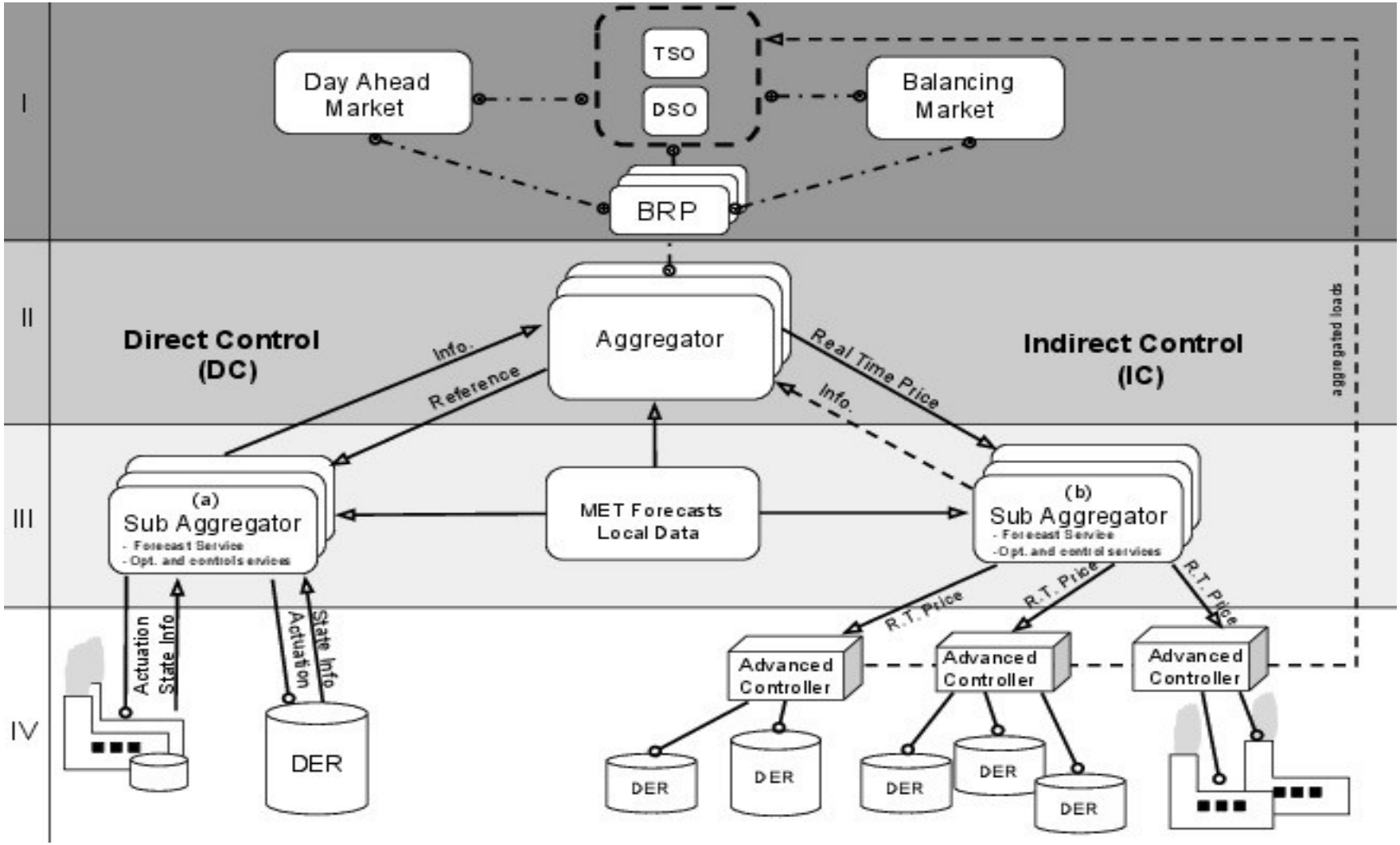
Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift

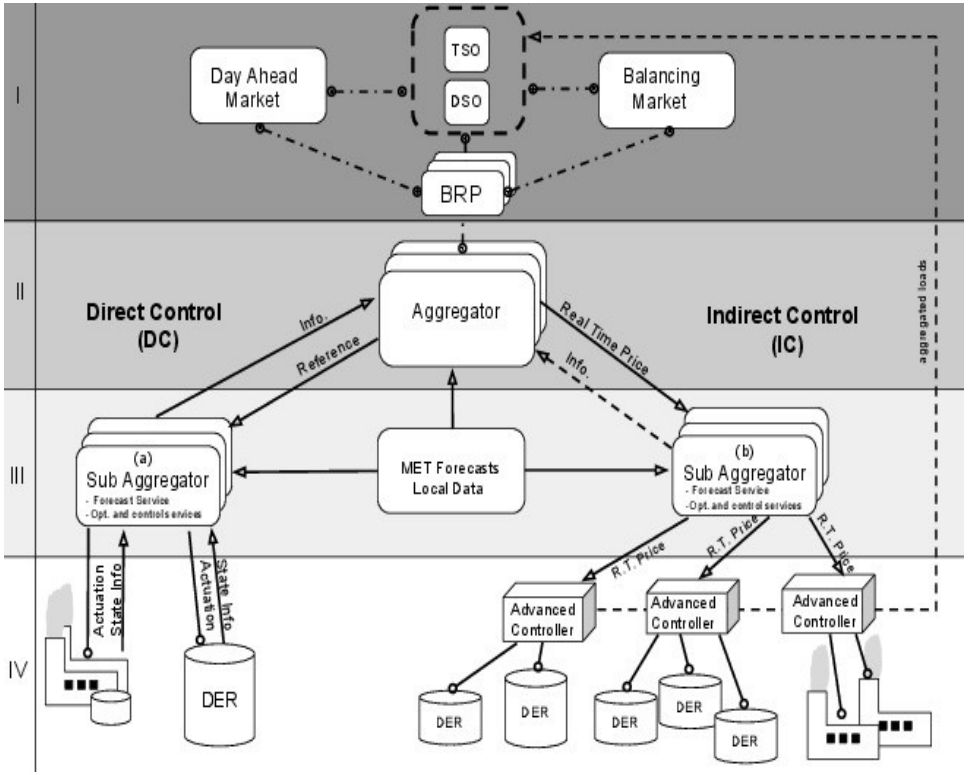


Control and Optimization



EuroTech Universities
Excellence in Science and Technology

Control and Optim. Challenges



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'

New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2014

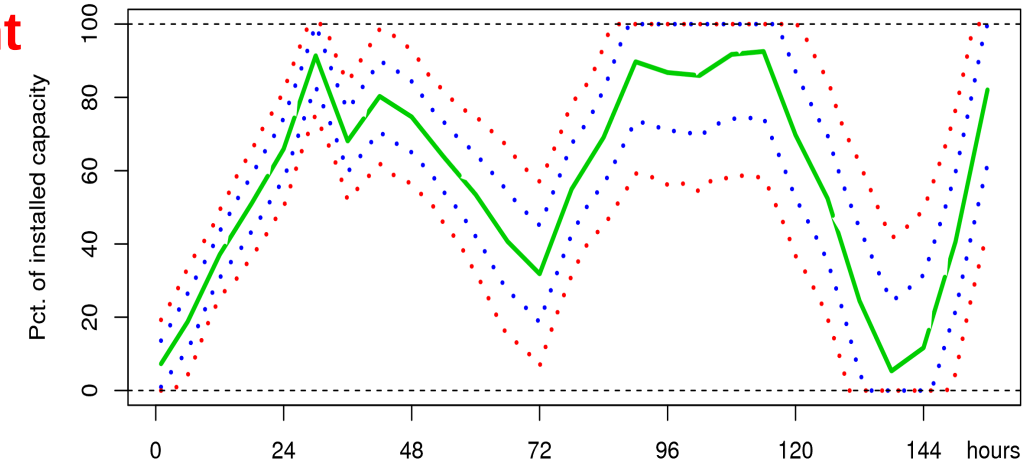
EuroTech Universities
Excellence in Science and Technology

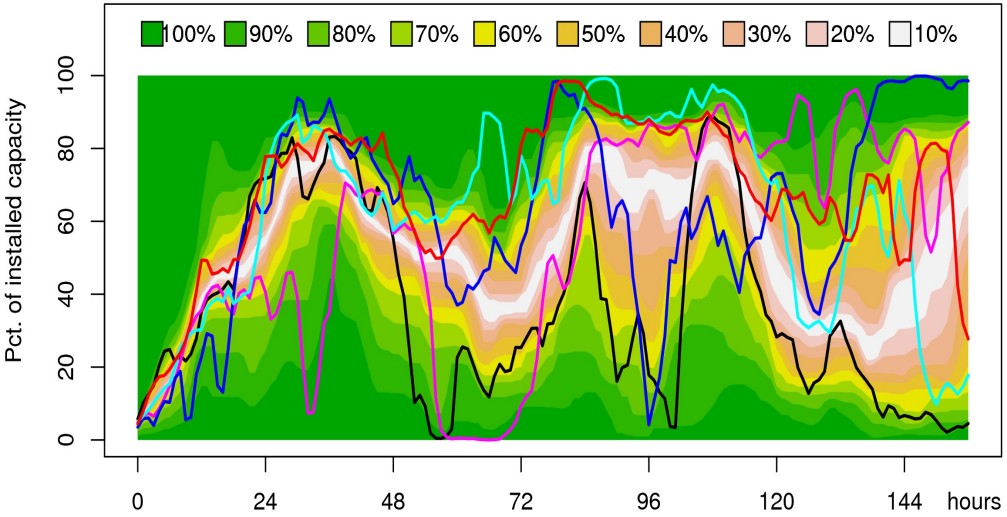
Forecasting Challenges

Forecasting is very important

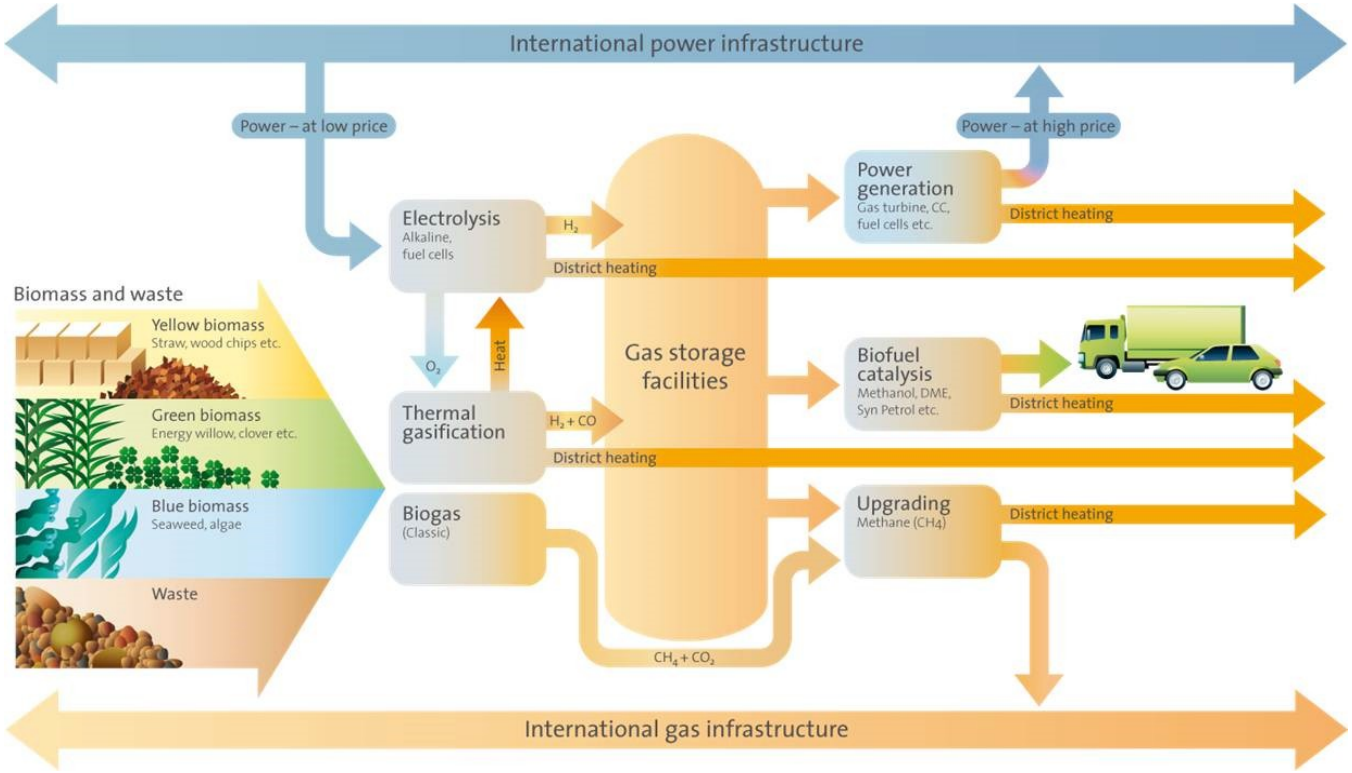
Type of forecasts:

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



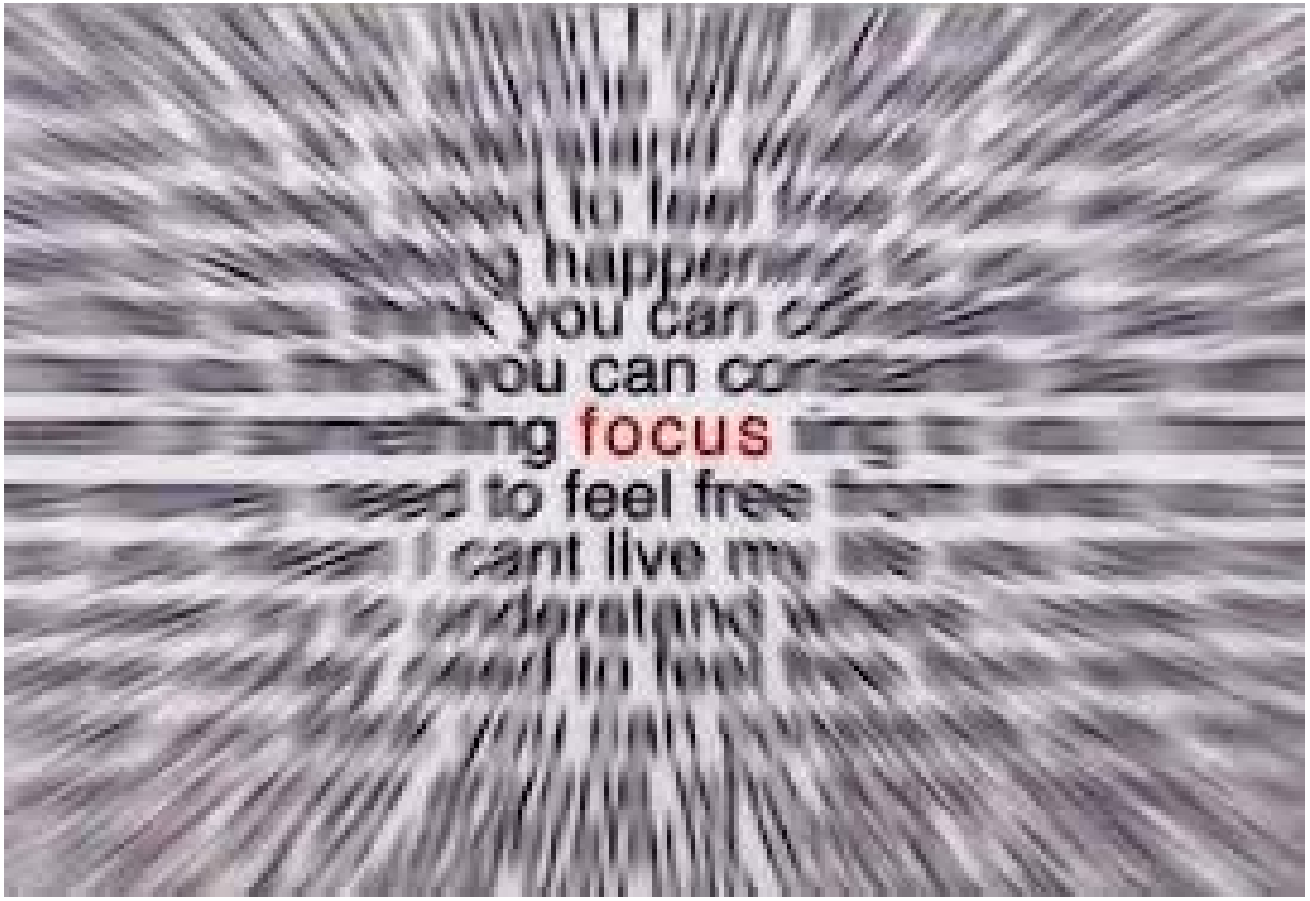


Gas systems are very important in ESI ...



Meibom, P.; Hilger, K.B.; Madsen, H.; Vinther, D., "Energy Comes Together in Denmark: The Key to a Future Fossil-Free Danish Power System," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.46-55, Sept. 2013.

How can we make a difference ?



Proposal (UCD, DTU, KU Leuven):

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