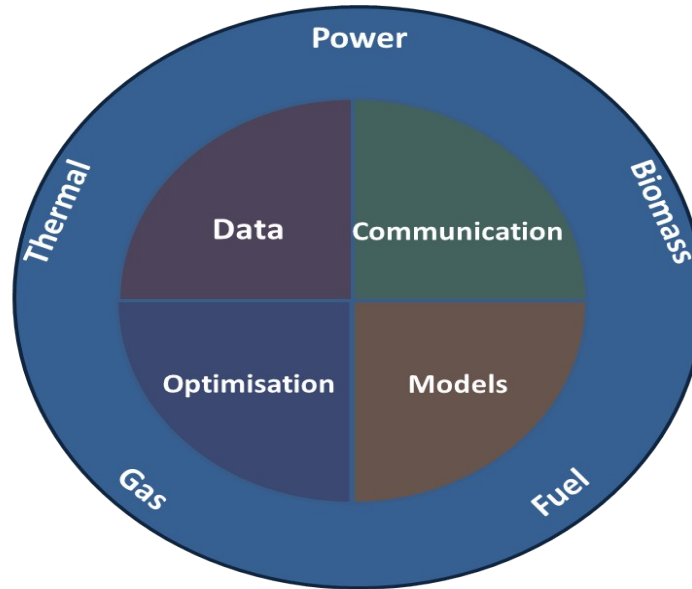


Energy Systems Integration; Research Challenges



Henrik Madsen, DTU Compute

<http://www.henrikmadsen.org>

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

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!*



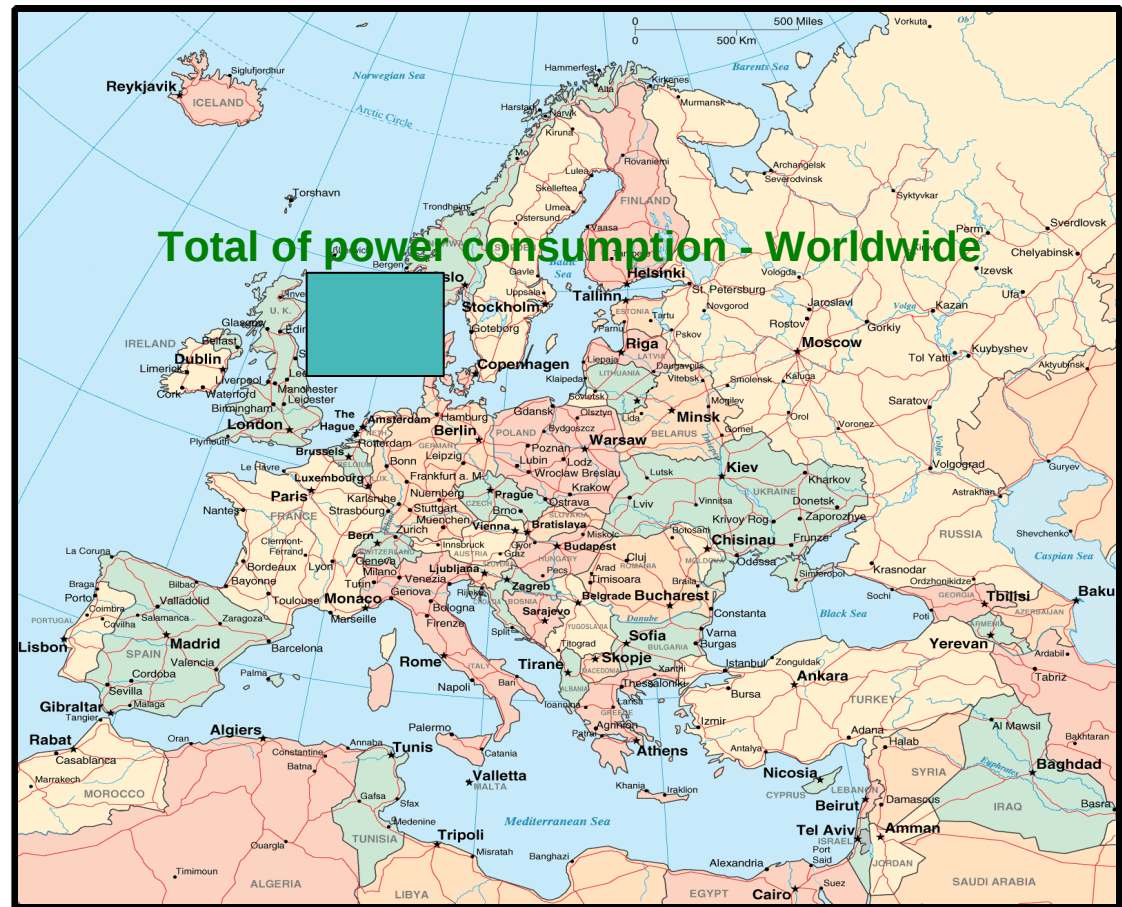
Potentials and Challenges for renewable energy

- **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

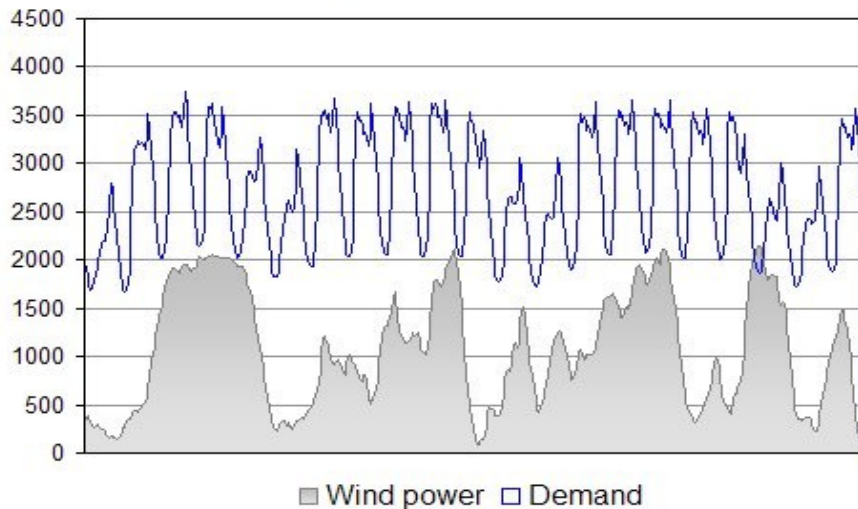
- **Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- **Conclusion:** Use intelligence
- Calls for **IT / Big Data / Smart Energy Solutions/ Models / Energy Systems Integration**



The Danish Wind Power Case

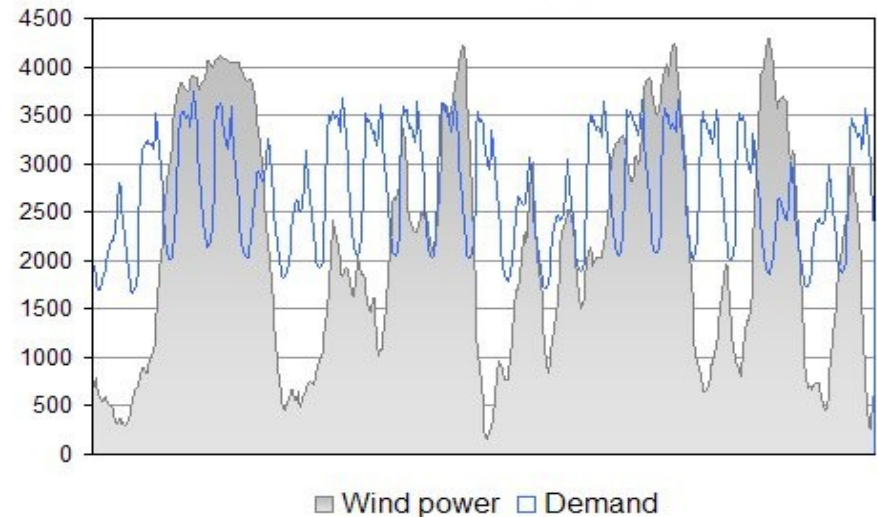
.... balancing of the power system

25 % wind energy (West Denmark January 2008)

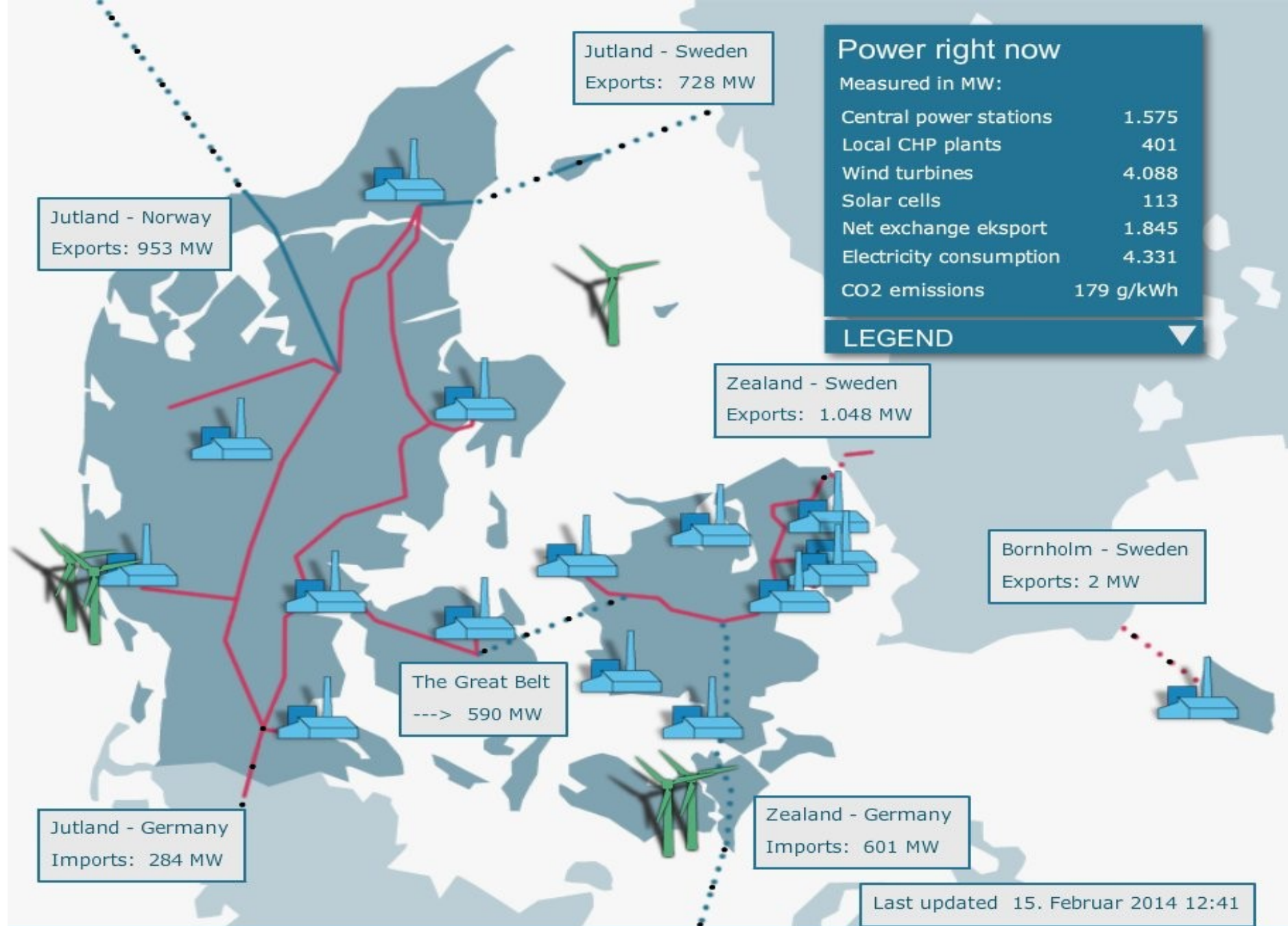


In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

50 % wind energy

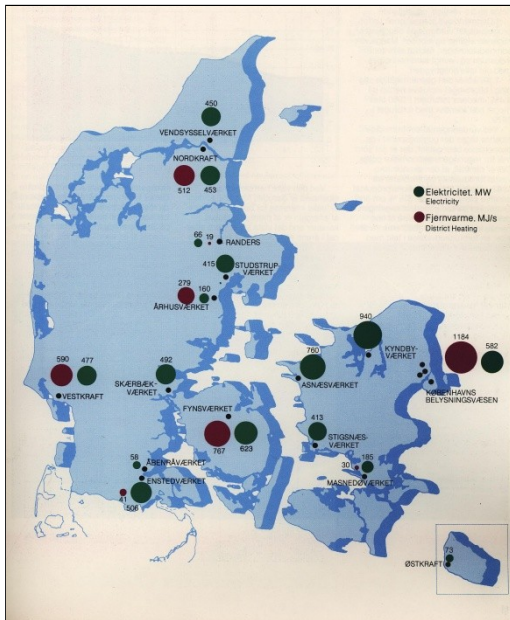


In December 2013 and January 2014 more than 55 pct of electricity load was covered by wind power. And for several days the wind power production was more than 120 pct of the power load



From large central plants to Combined-heat and power production

1980



Today

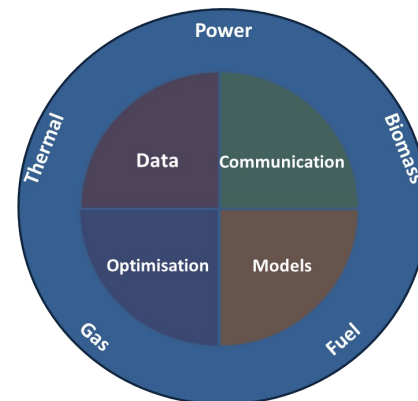


From a few big power plants to many small combined heat and power plants – however most of them based on coal

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.



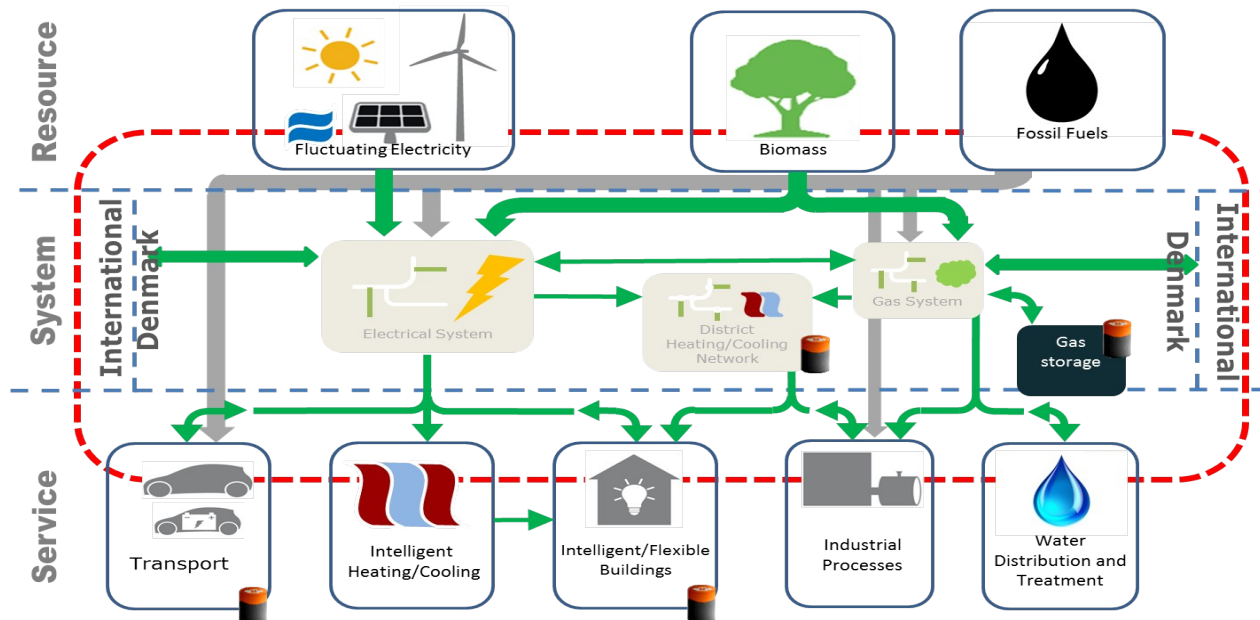
ESI – Research Challenges

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

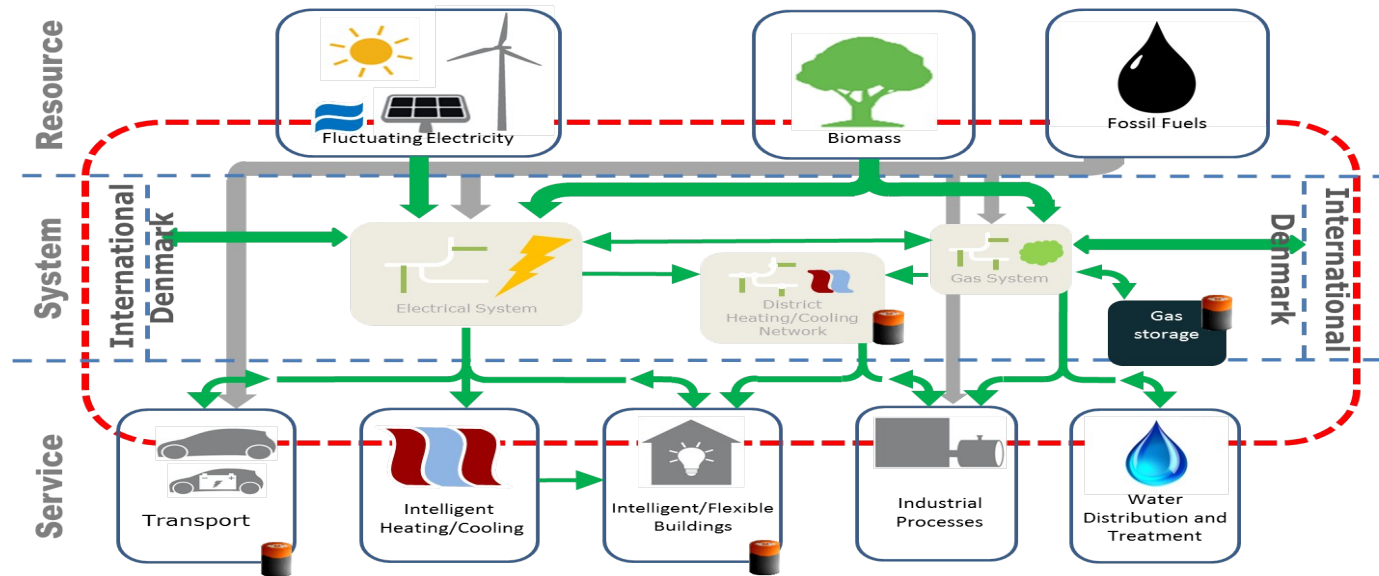


ESI – Concept Challenges

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) : 48 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

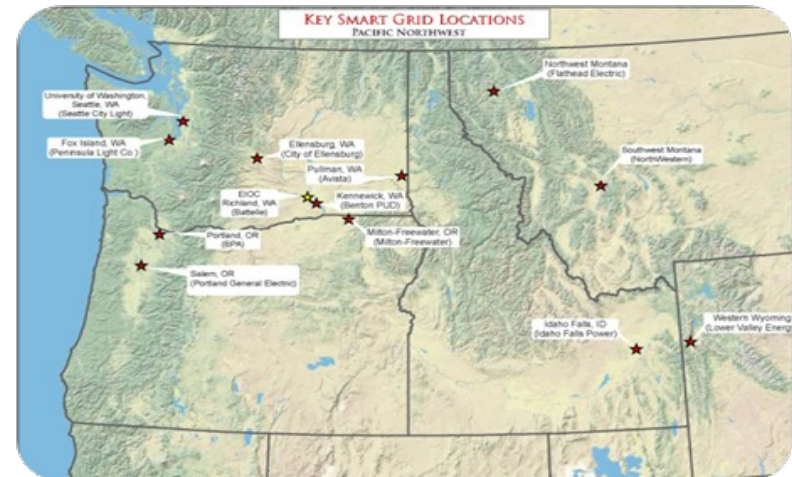
Control of Power Consumption (DSM)



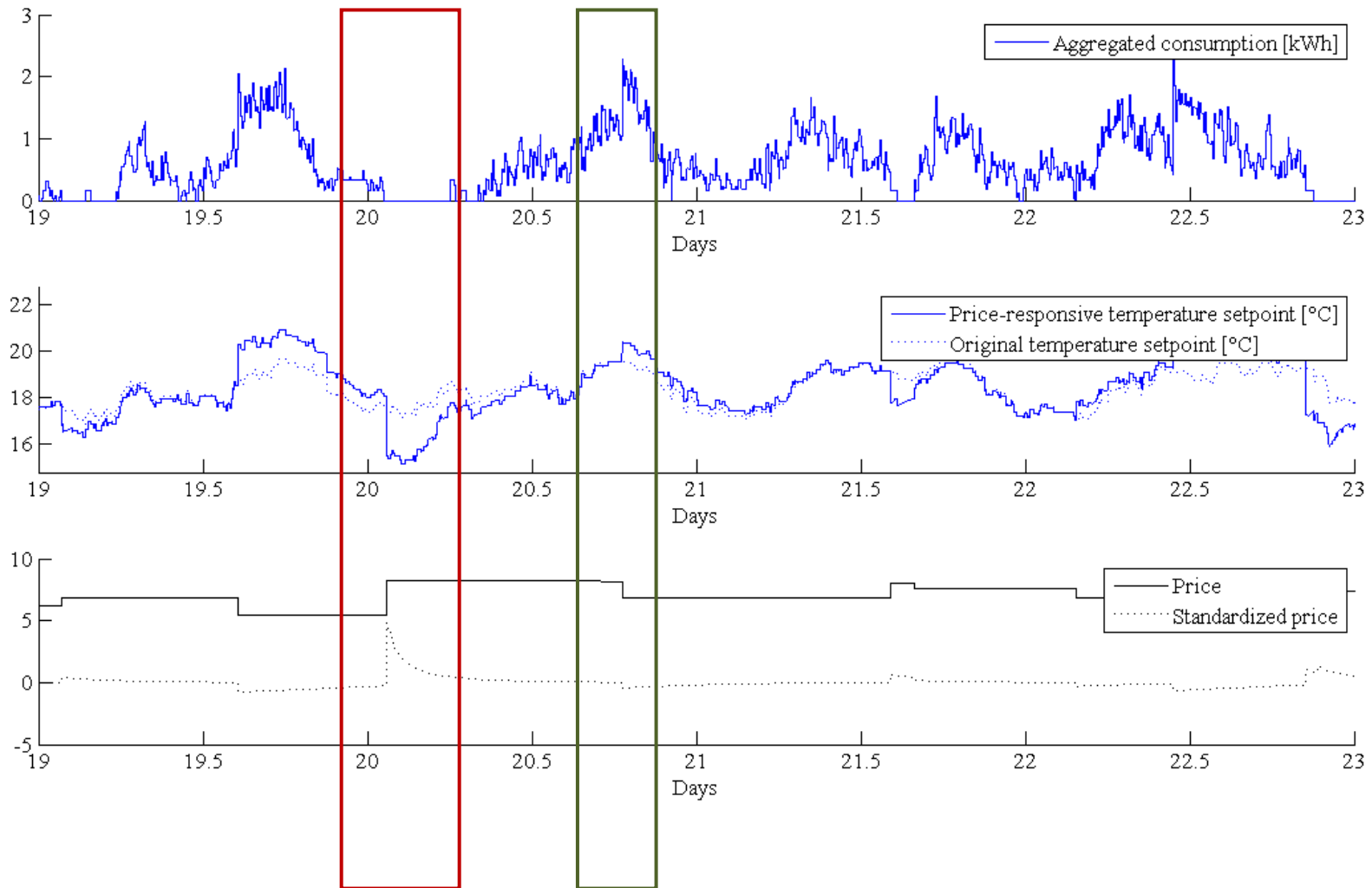
Data from BPA

Olympic Peninsula project

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

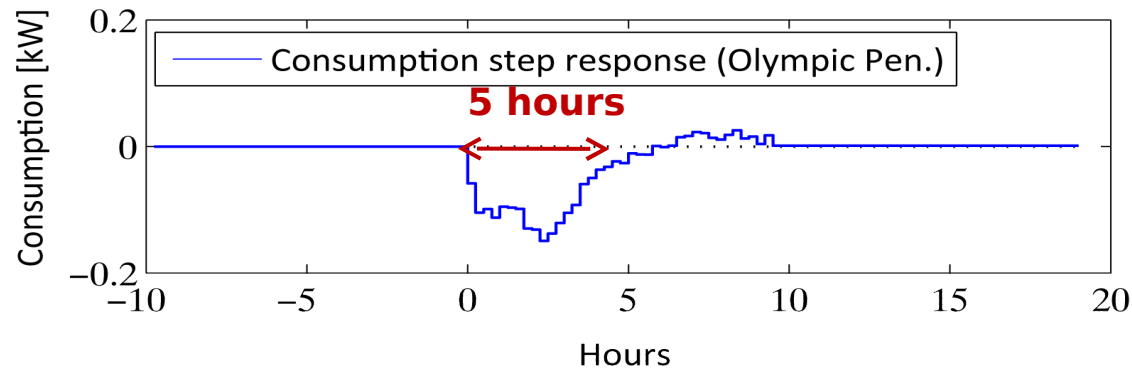


Aggregation (over 20 houses)

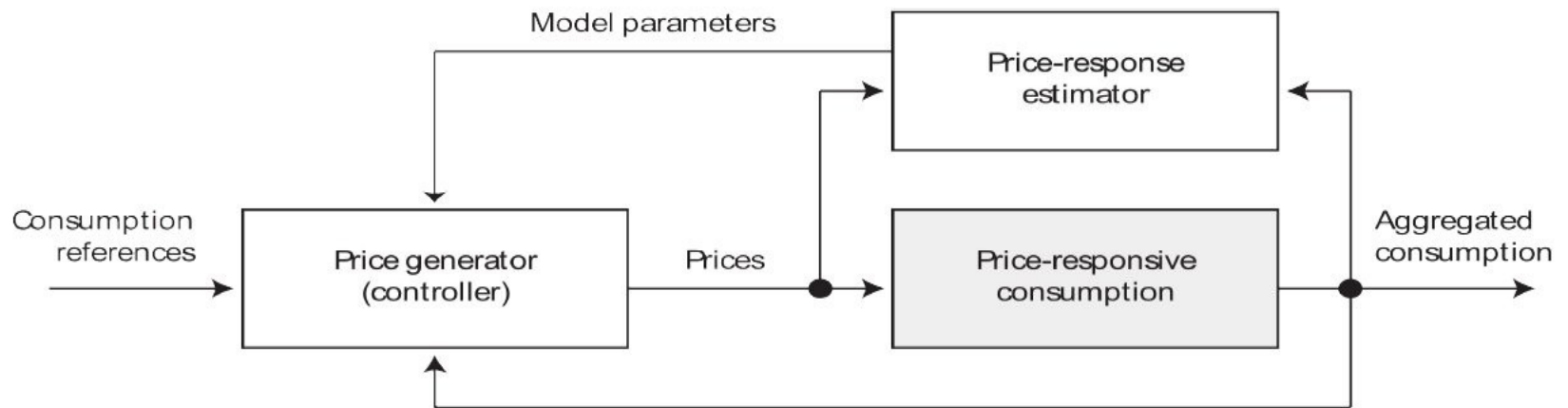


Non-parametric Response on Price Step Change

Olympic Peninsula



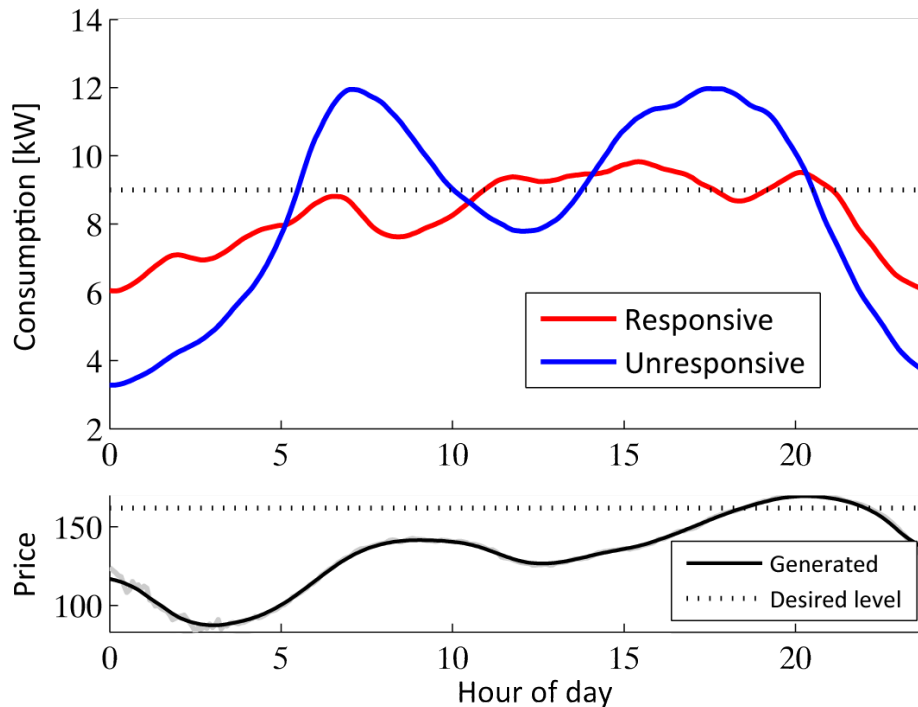
Control of Energy Consumption



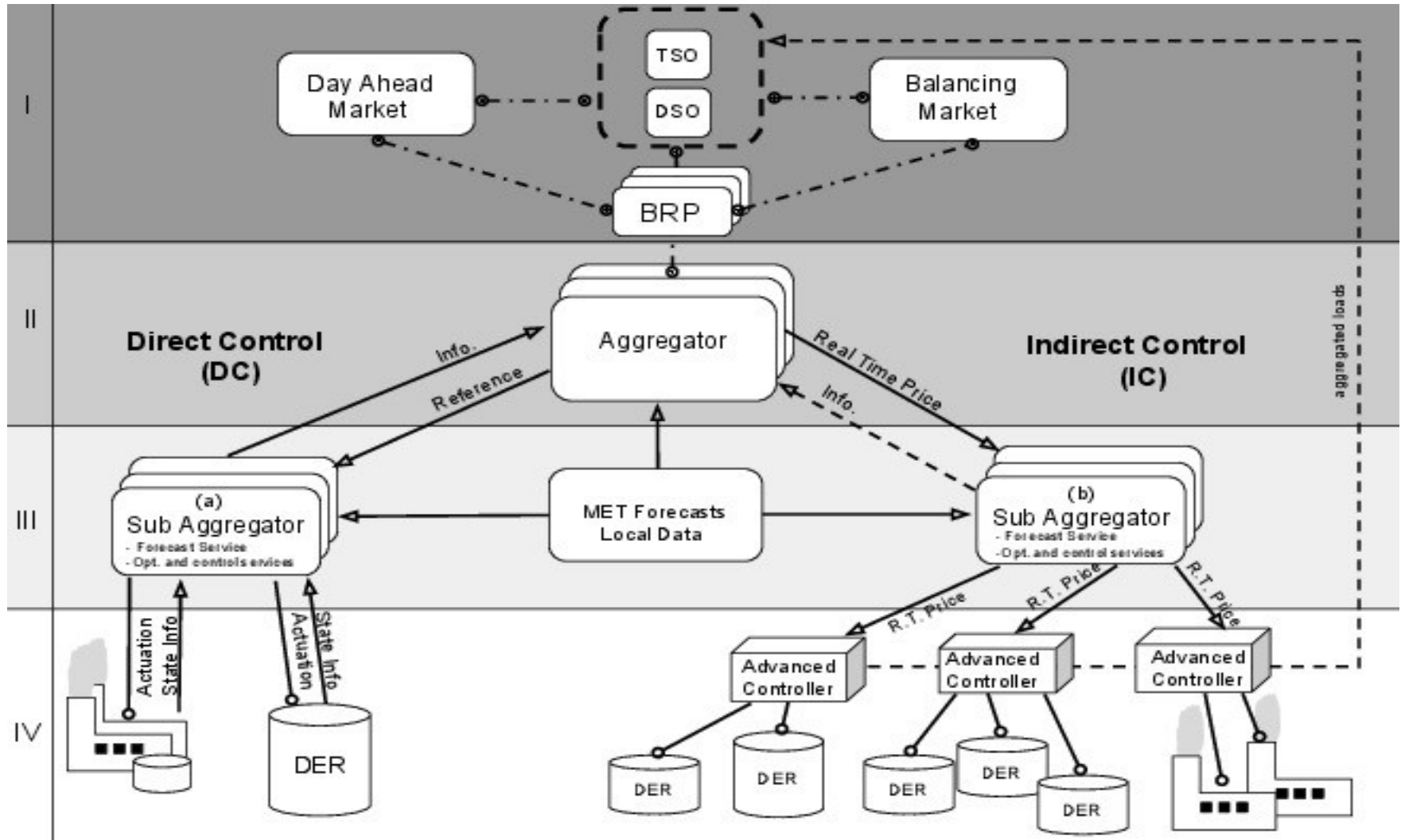
Control performance

Considerable **reduction in peak consumption**

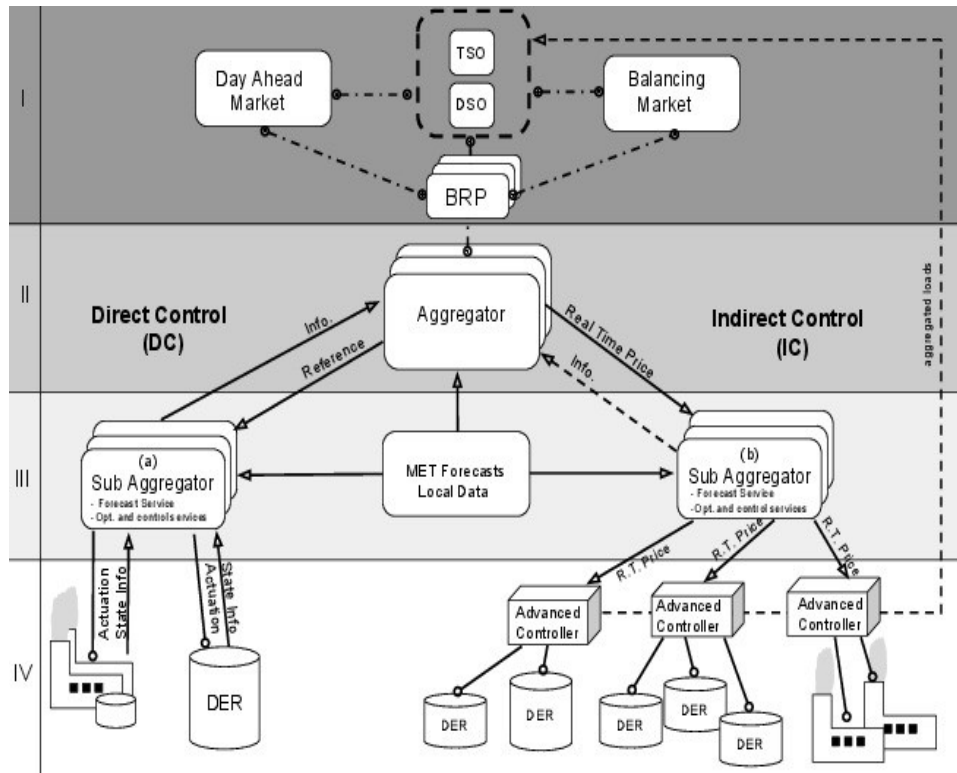
Mean daily consumption shift



Control and Optimization



Control and Optim. Challenges



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

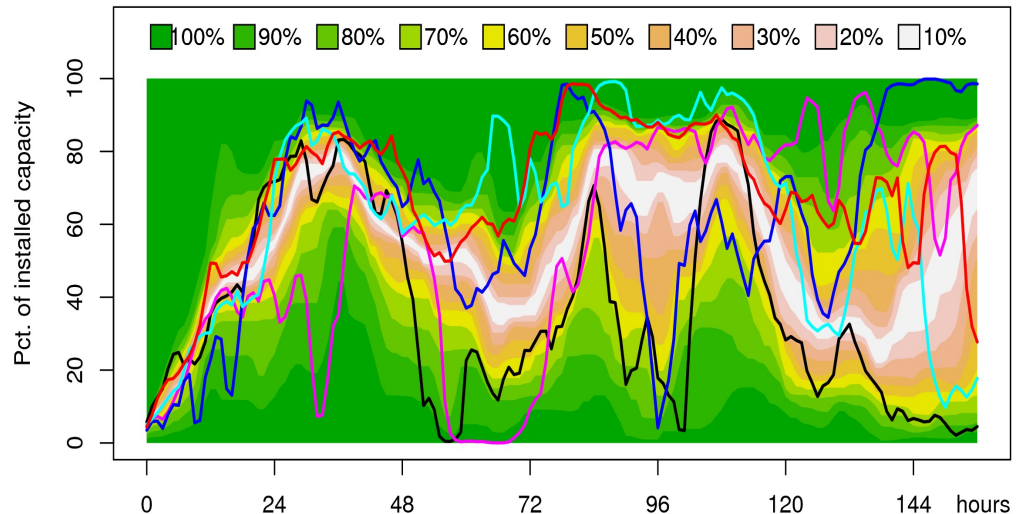
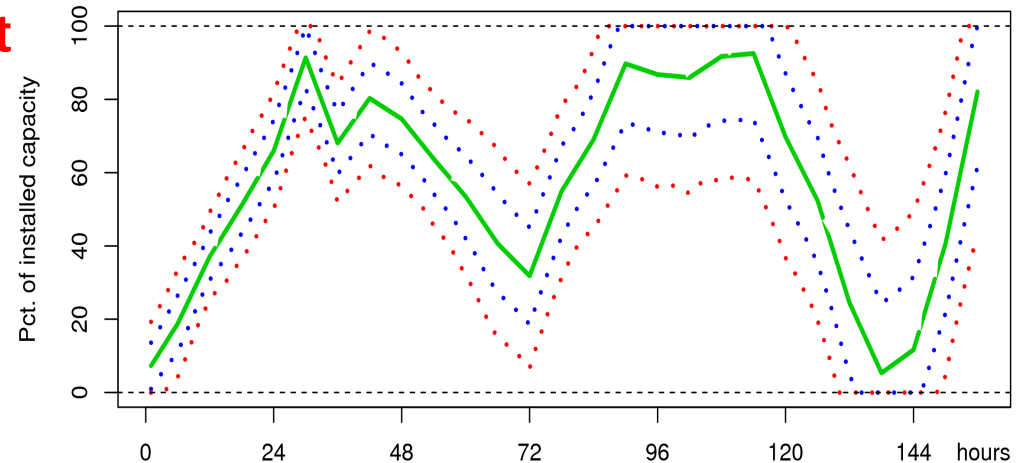
Simple 'contracts'

Forecasting Challenges

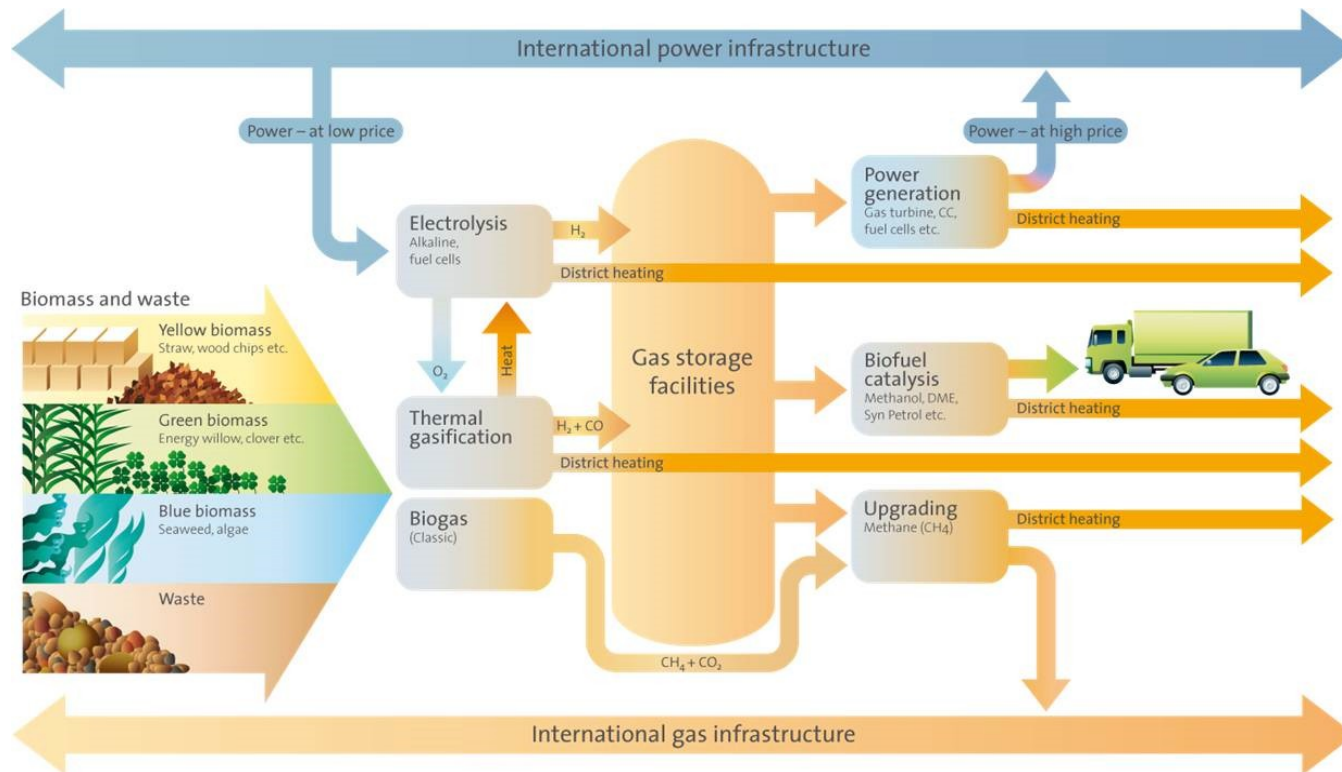
Forecasting is very important

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 ...

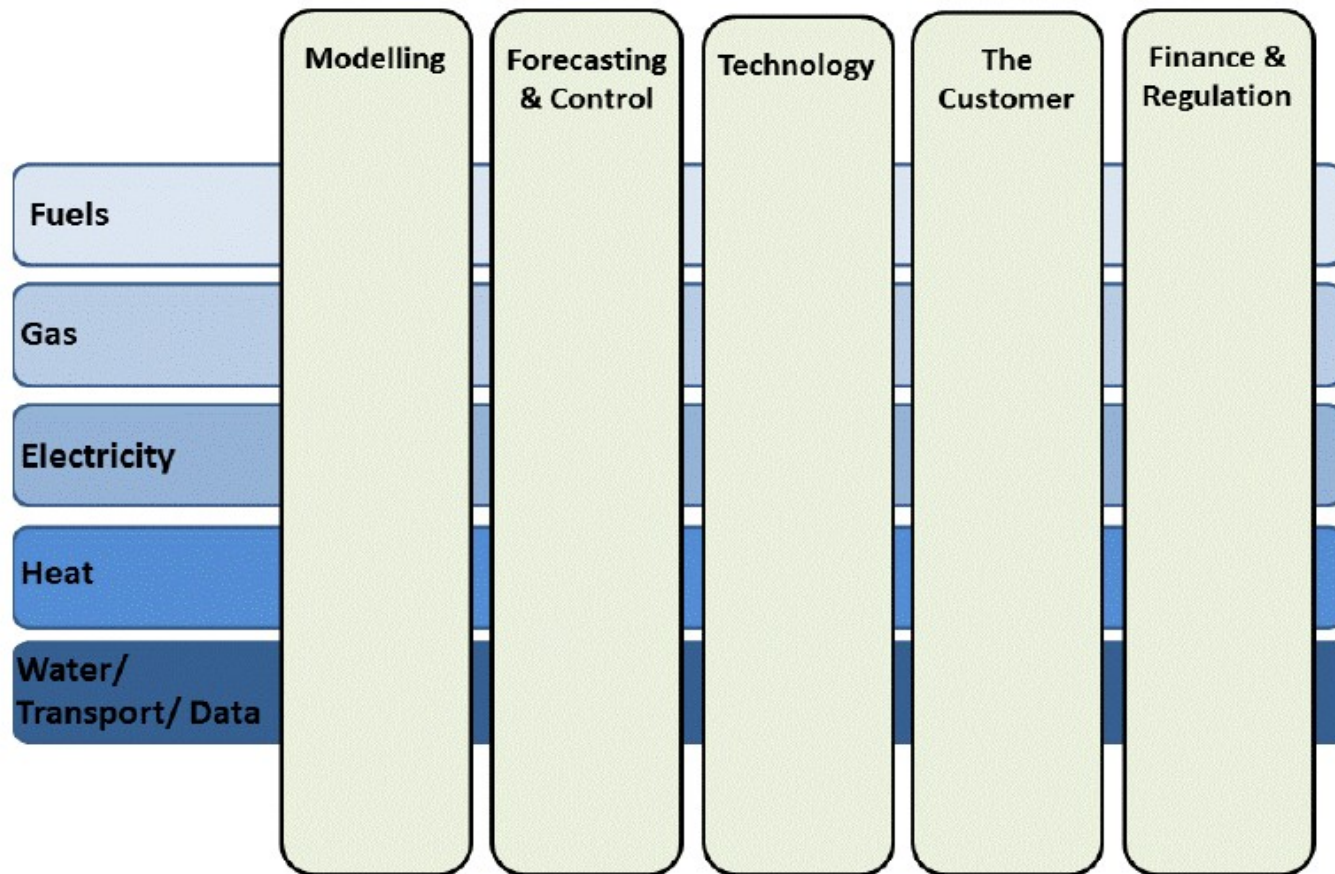


Meibom, P.; Hilger, K.B.; Madsen, H.; Vinther, D., "Energy Comes Together in Denmark: The Key to a Future Fossil-Free Danish Power System," *Power and Energy Magazine, IEEE* , vol.11, no.5, pp.46-55, Sept. 2013.

How can we make a difference ?



Proposal (UCD, DTU, KU Leuven):
**ESI Joint Program as a part of
 European Research (EERA)**





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, Hawaii, Brussels, Australia



Conclusions

- **Energy Systems Integration can provide virtual and lossless storage solutions (so maybe we should put less focus on physical storage solutions)**
- **Energy Systems Integration 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)**
- **Europe should put less focus on super-grids - I assume that ESI can solve a major part of the issues (the planned investments are huge - and maybe we don't need them)**
- **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)**