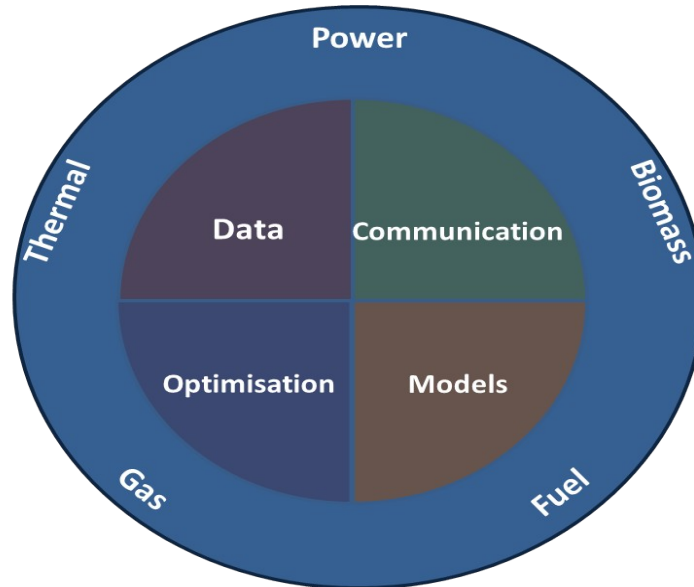


# Stochastic Modelling of Energy Systems in Cities



**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!*



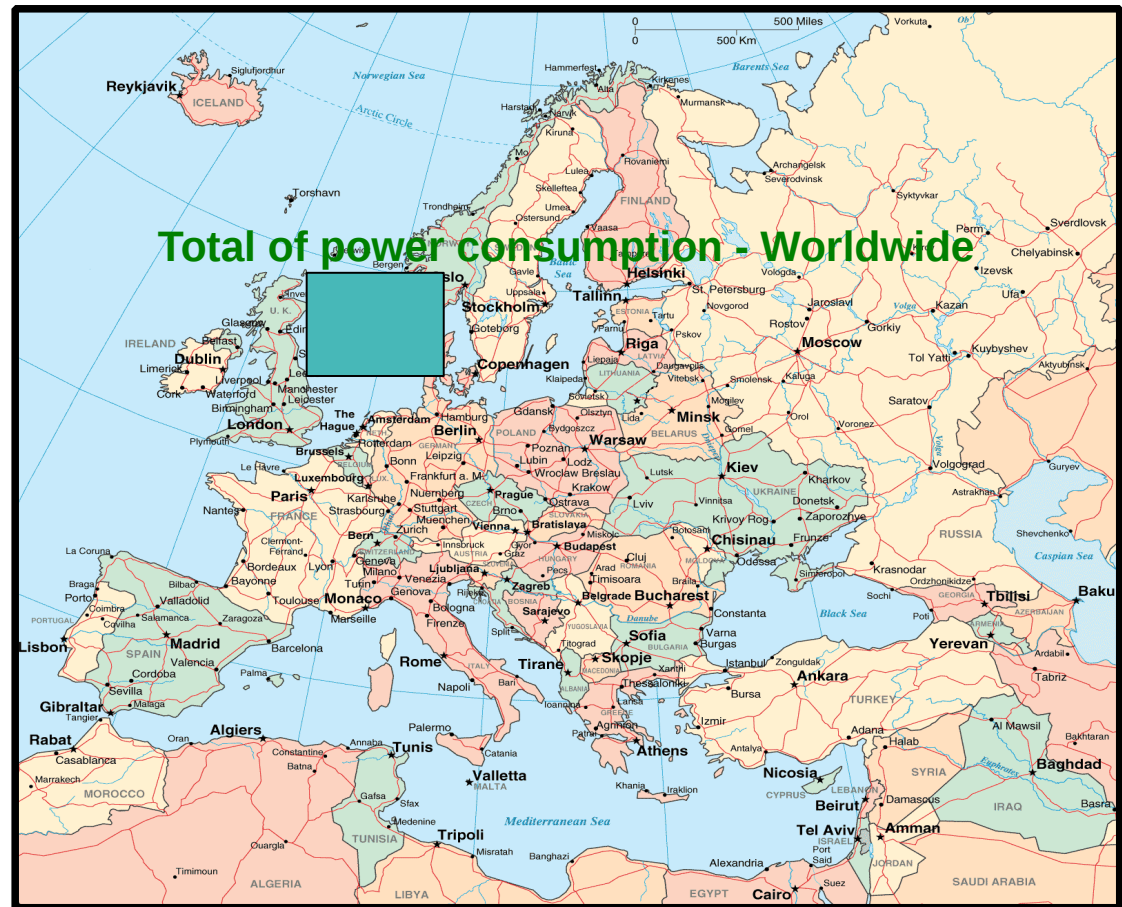
# Potentials and Challenges for renewable energy

- **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

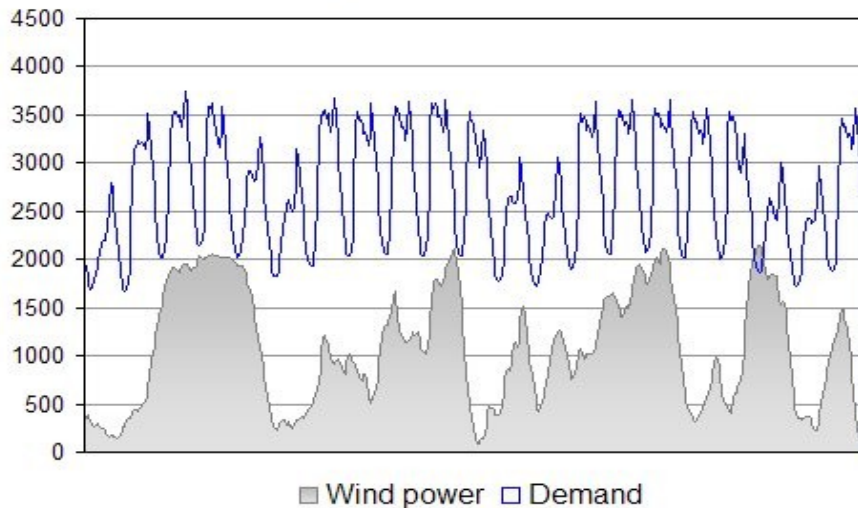
- Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- Conclusion:** Use intelligence ....
- Calls for **IT / Big Data / Smart Energy Solutions/ Energy Systems Integration**



# The Danish Wind Power Case

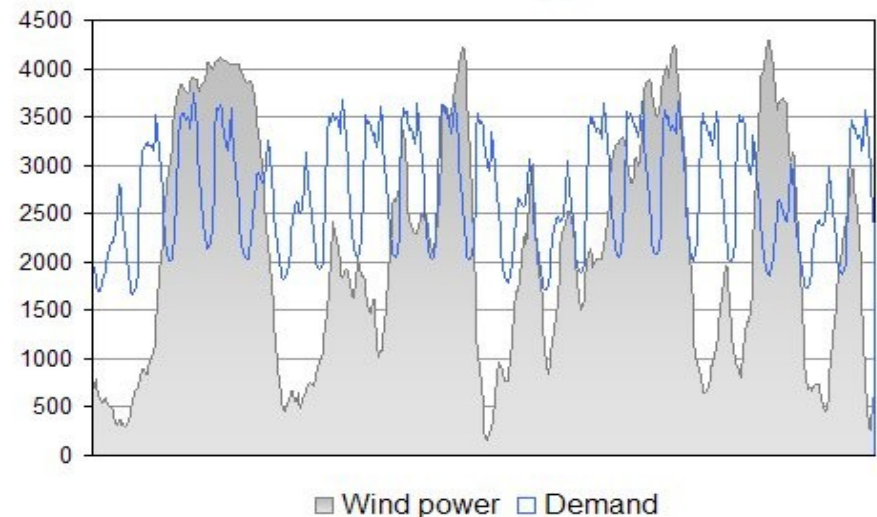
*.... balancing of the power system*

25 % wind energy (West Denmark January 2008)



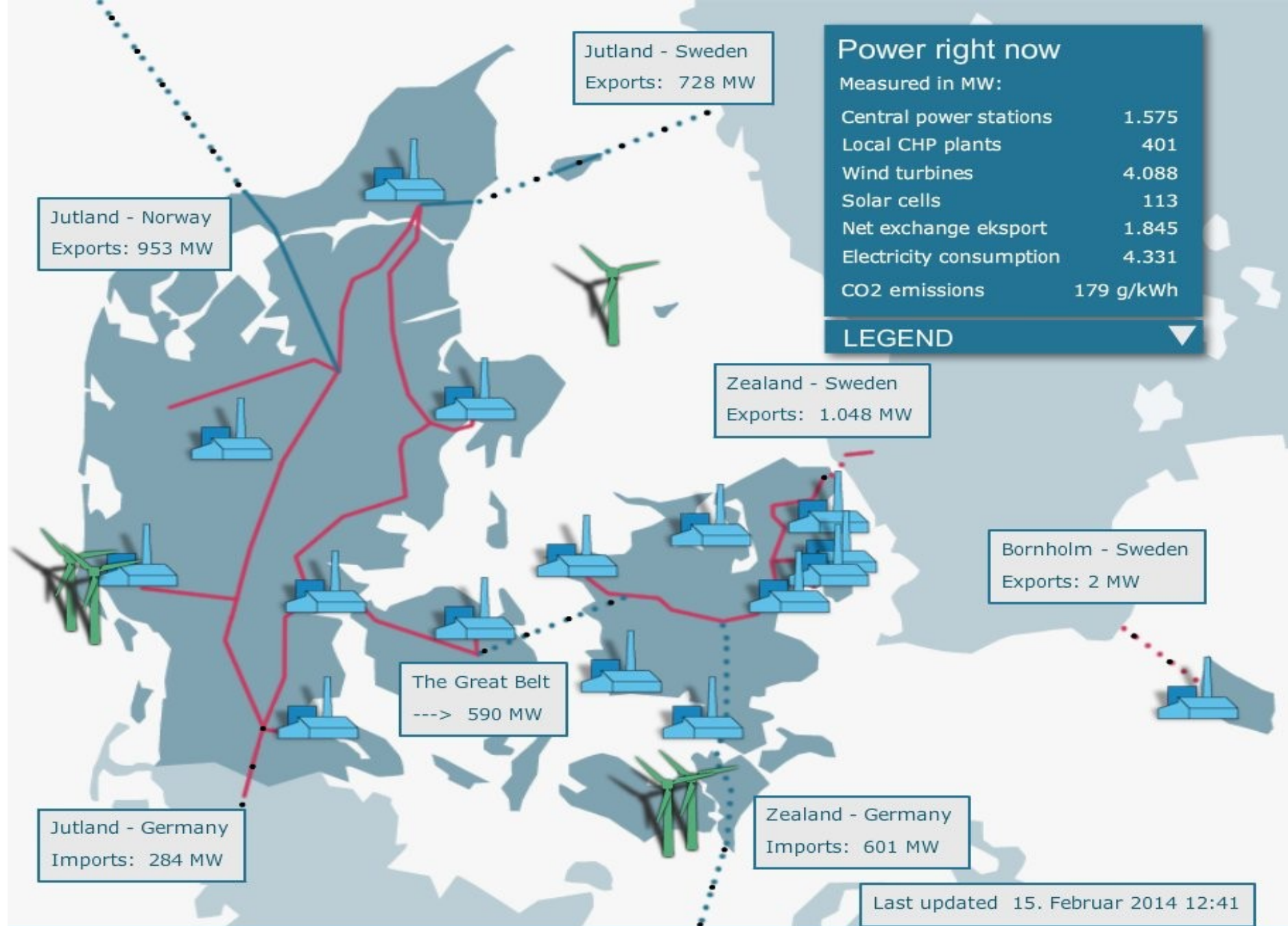
In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

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

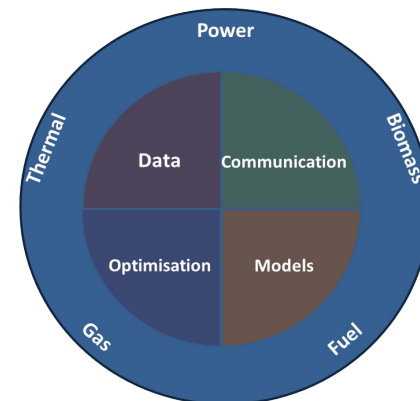


*From a few big power plants to many small combined heat and power plants – however most of them based on coal*

# 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 CO<sub>2</sub> emissions.

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





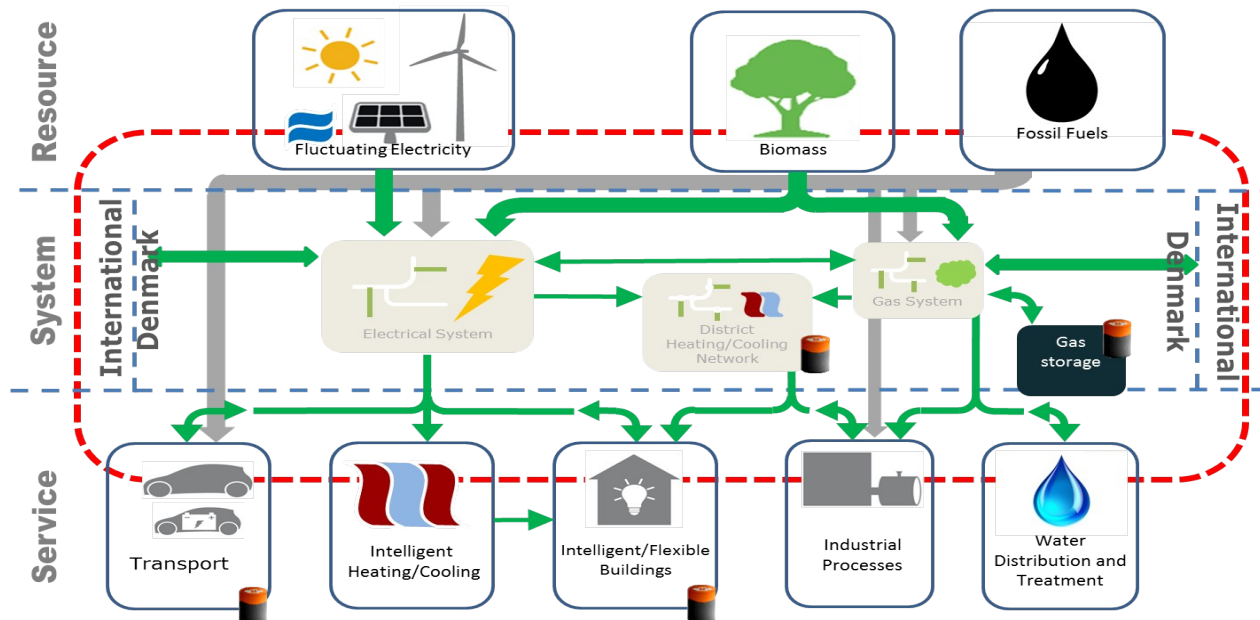
# ESI – Research Challenges

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

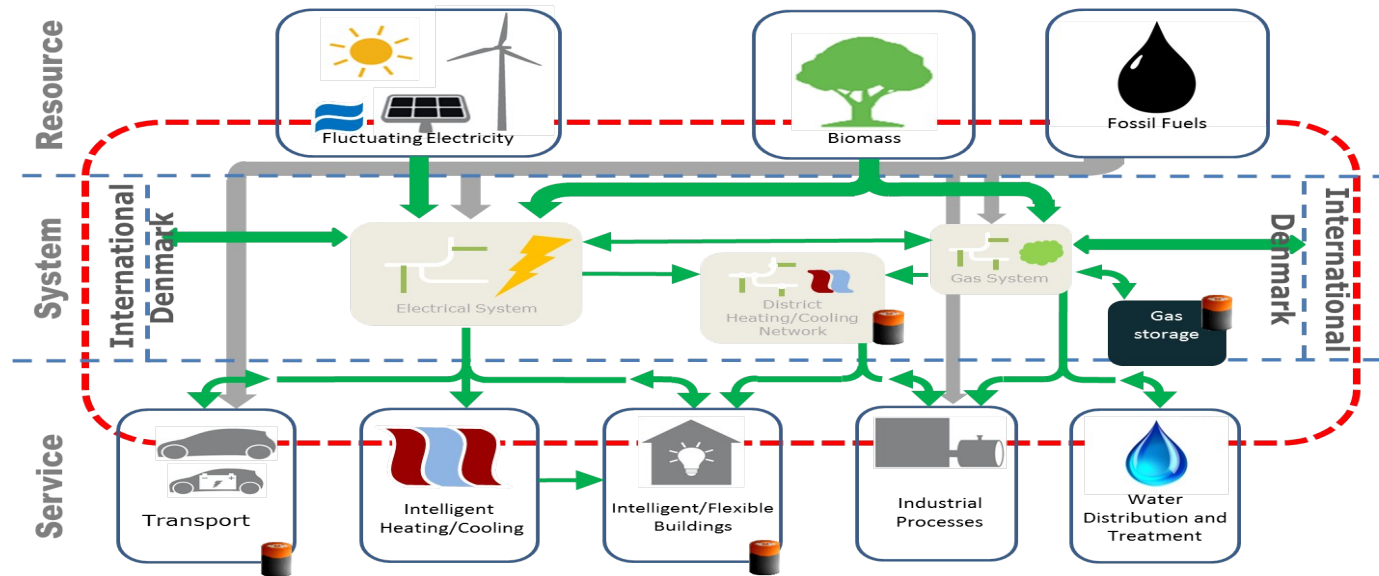


# Grey-Box Modelling Concept

**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) : 40 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)

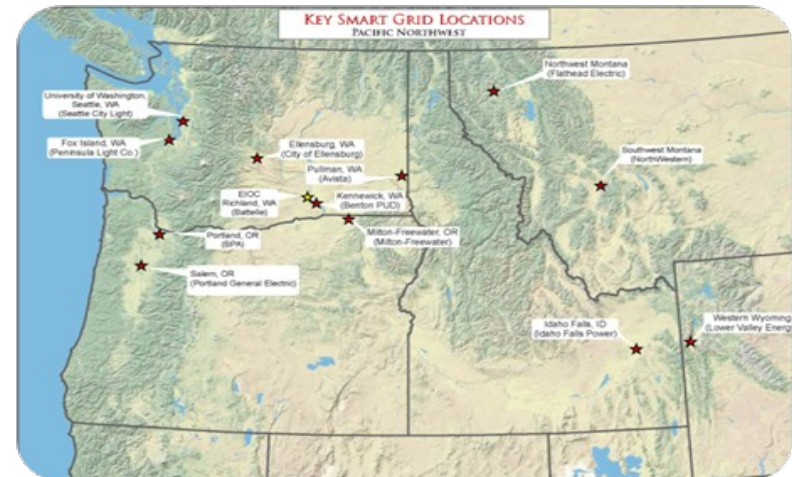




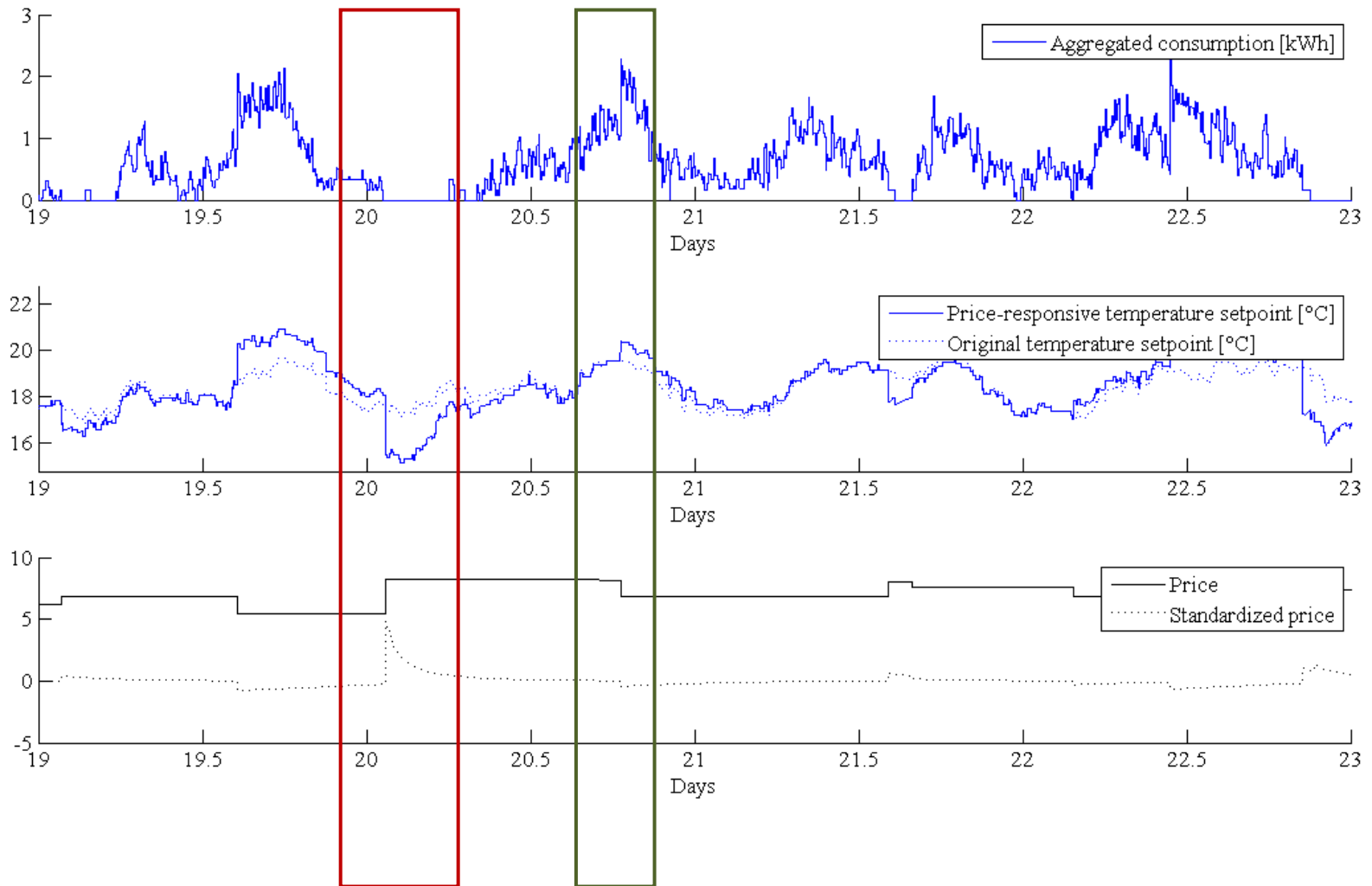
# Data from BPA

## Olympic 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)

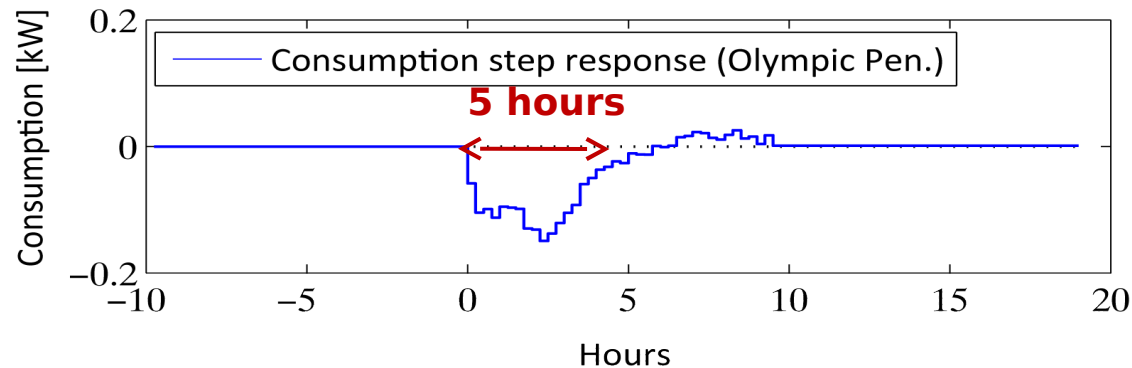


# Non-parametric Response on DTU Price Step Change

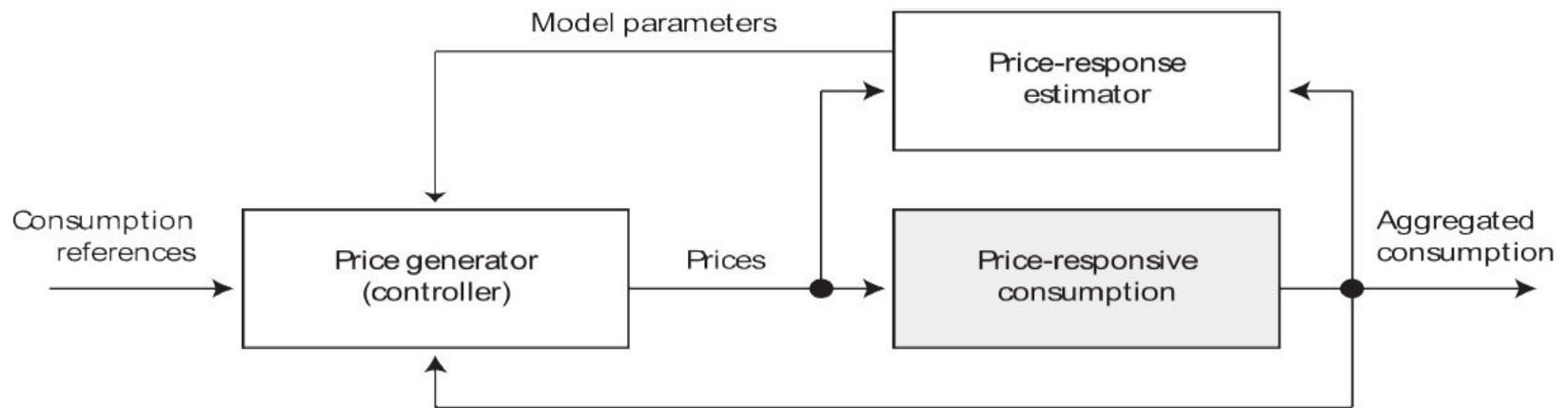


*Model inputs: price, minute of day, outside temperature/dewpoint, sun irradiance*

## Olympic Peninsula



# Control of Energy Consumption

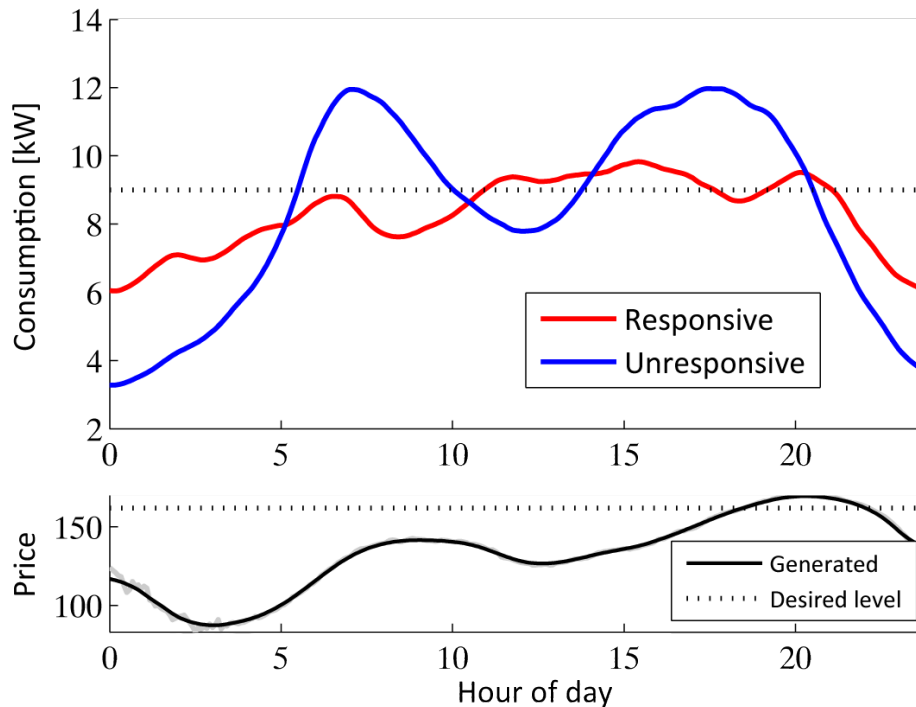




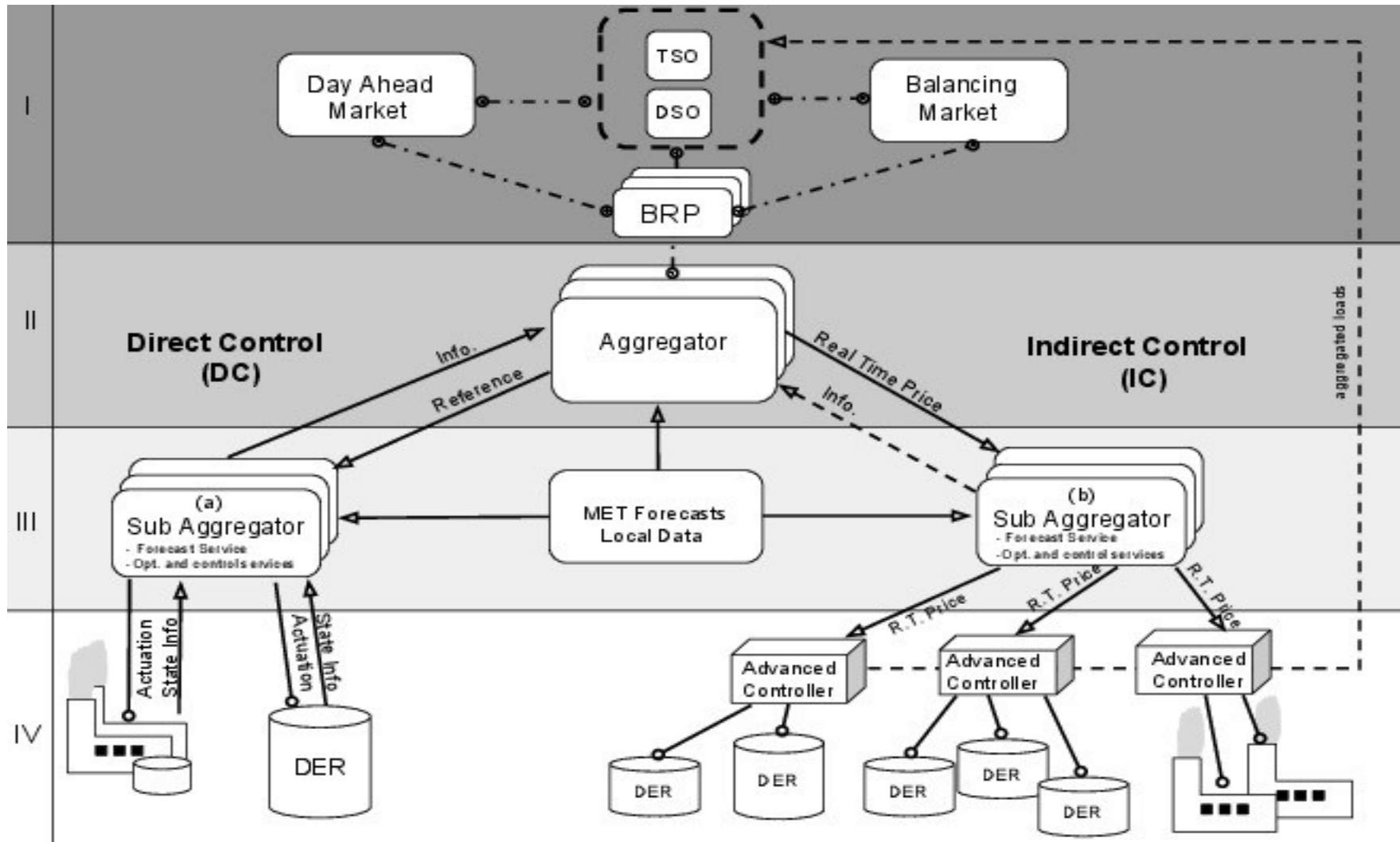
# Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift



# Control and Optimization



# 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

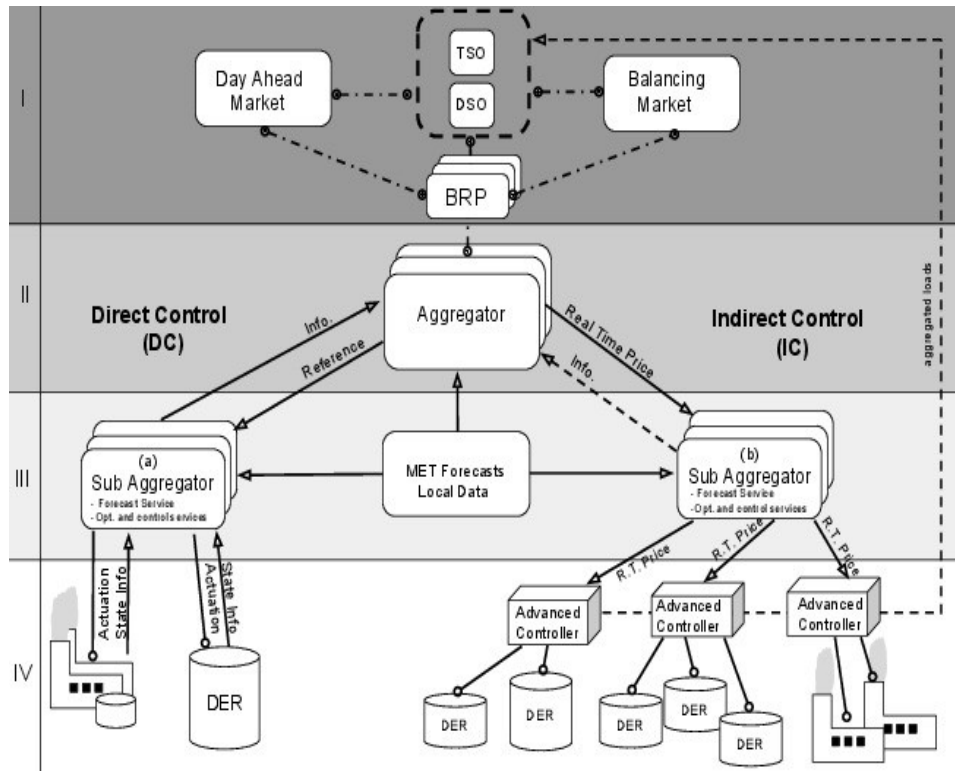
## Indirect Control:

Actuator: **Price**

Cost: E-MPC at **low (DER) level**, One-way communication

Models for DERs are not needed

Simple 'contracts'



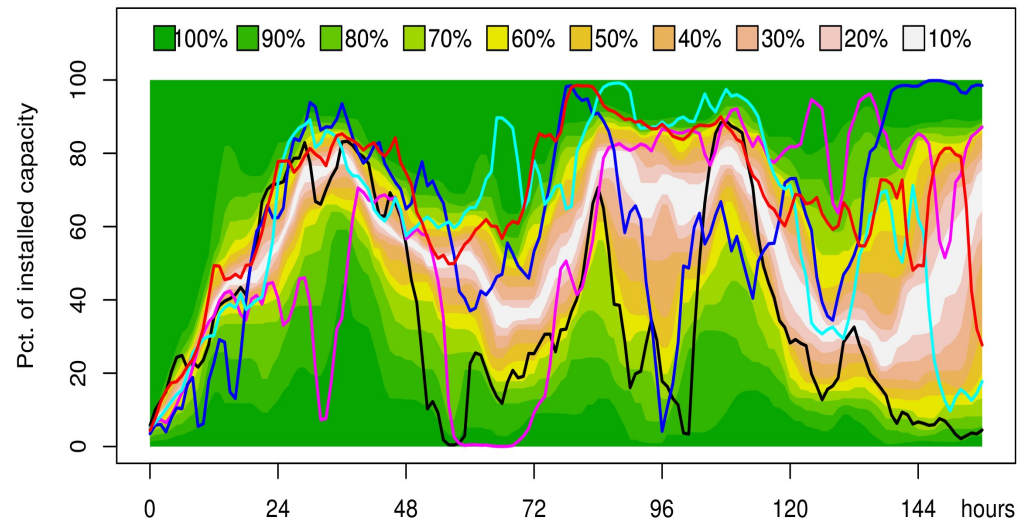
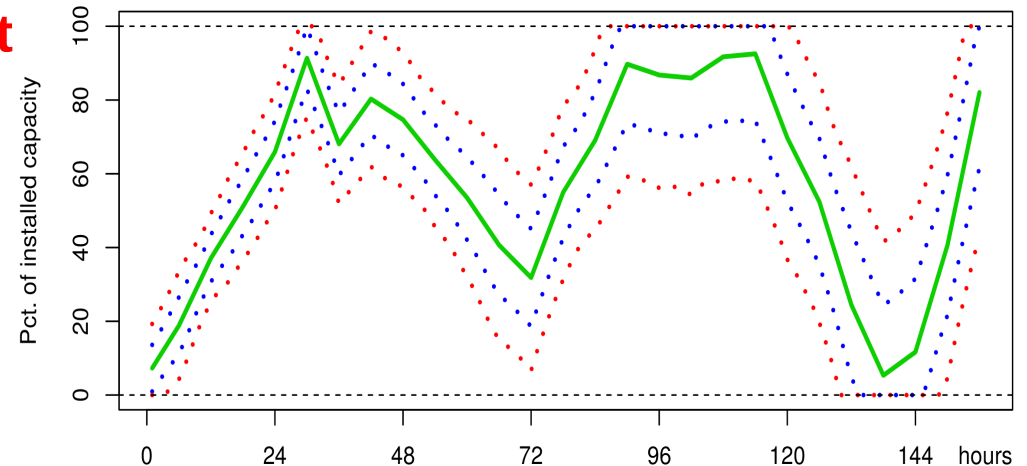
**New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2014**

# Forecasting Challenges

Forecasting is very important

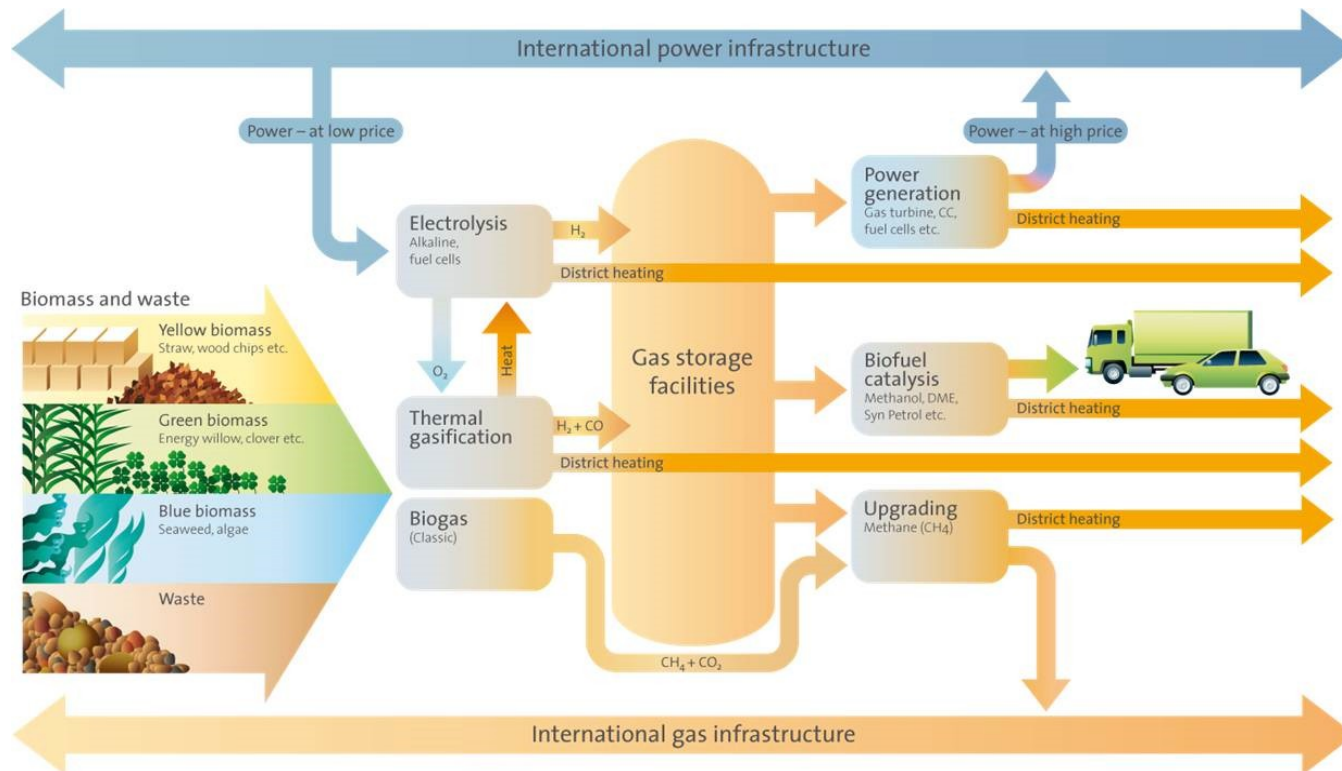
Type of forecasts:

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



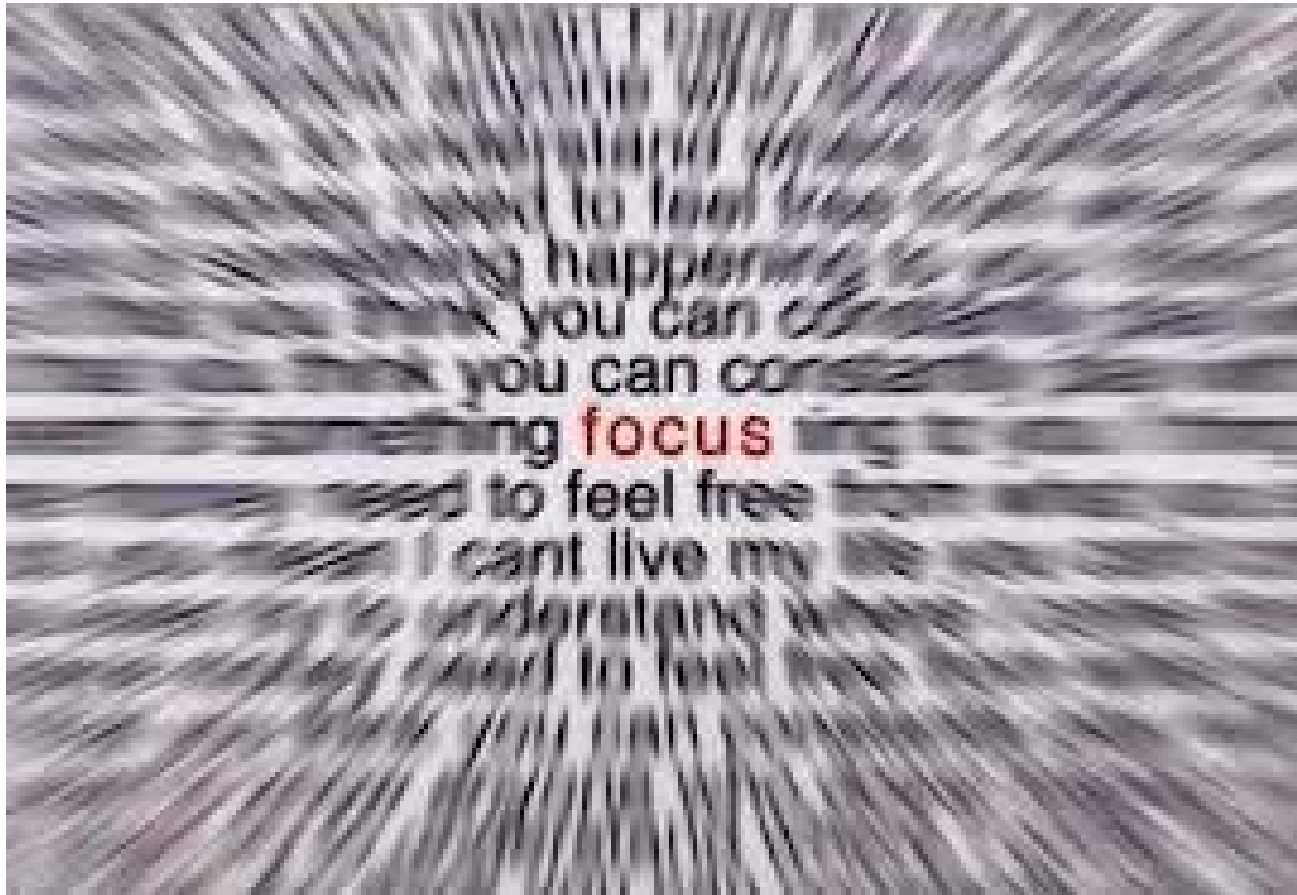


# Gas systems are very important in ESI ...



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)

