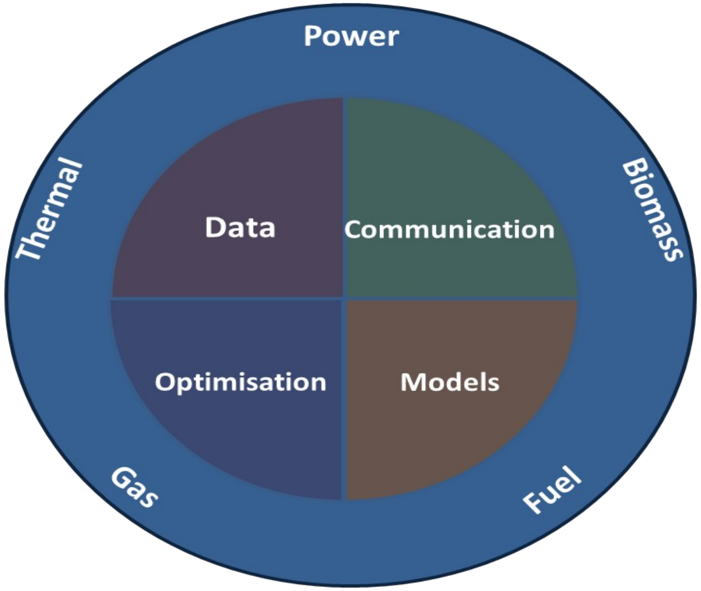
Energy Systems Integration Research Challenges



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

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

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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!*

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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?

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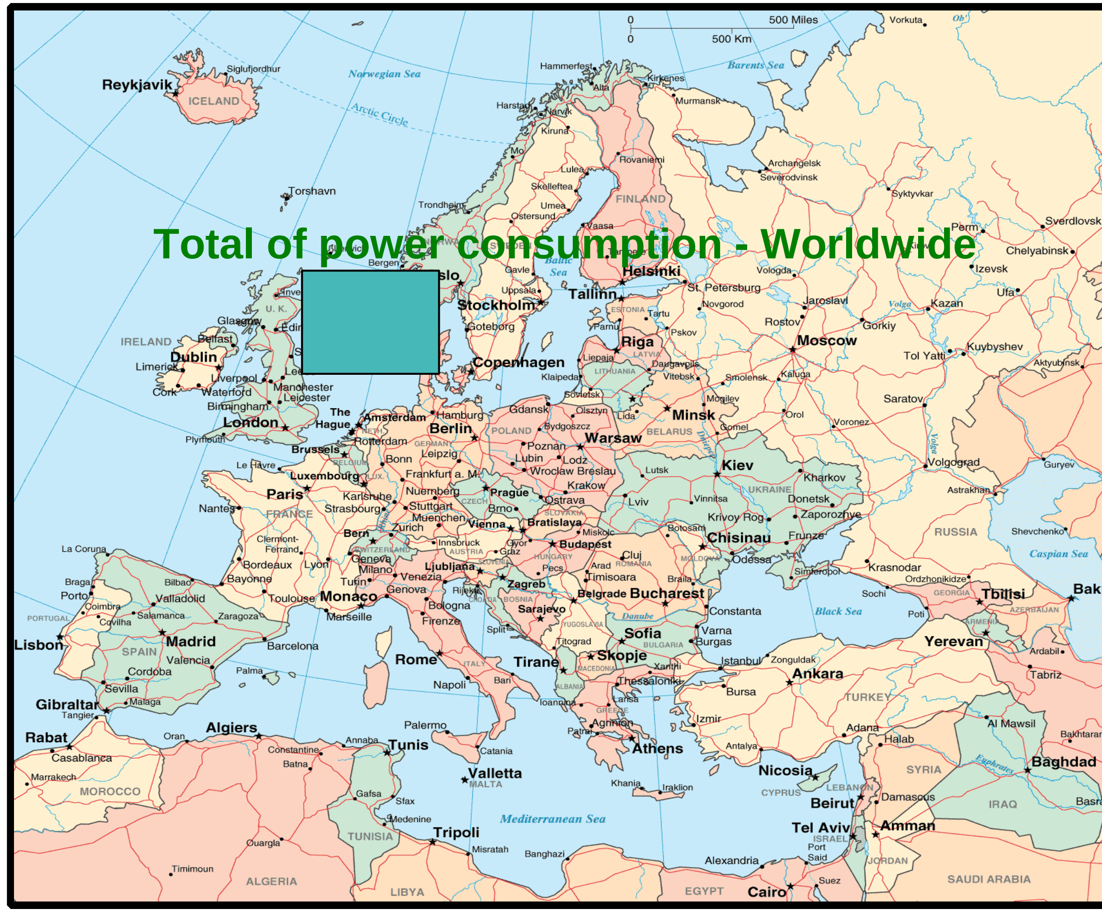
Potentials and Challenges for renewable energy

DTU

- **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**



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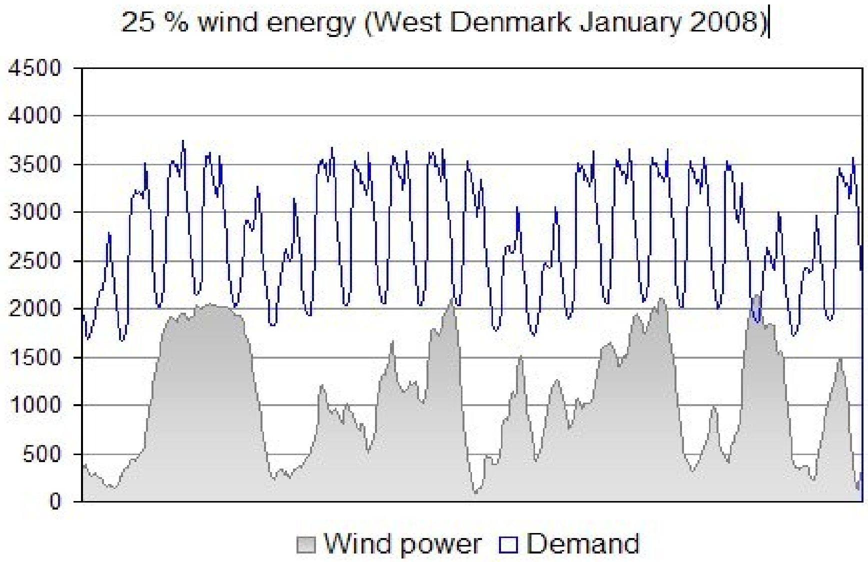
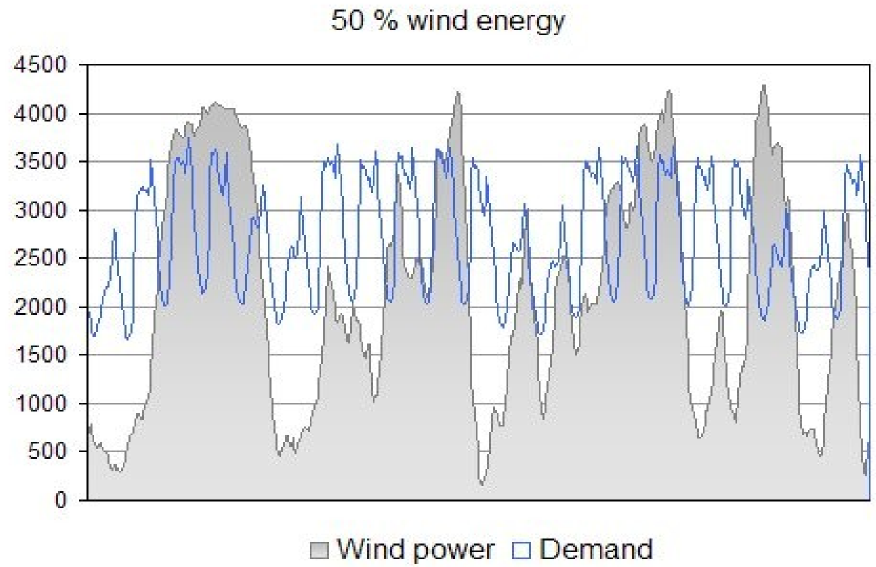
The Danish Wind Power Case

.... balancing of the power system





In 2008 wind power did cover the entire demand of electricity 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

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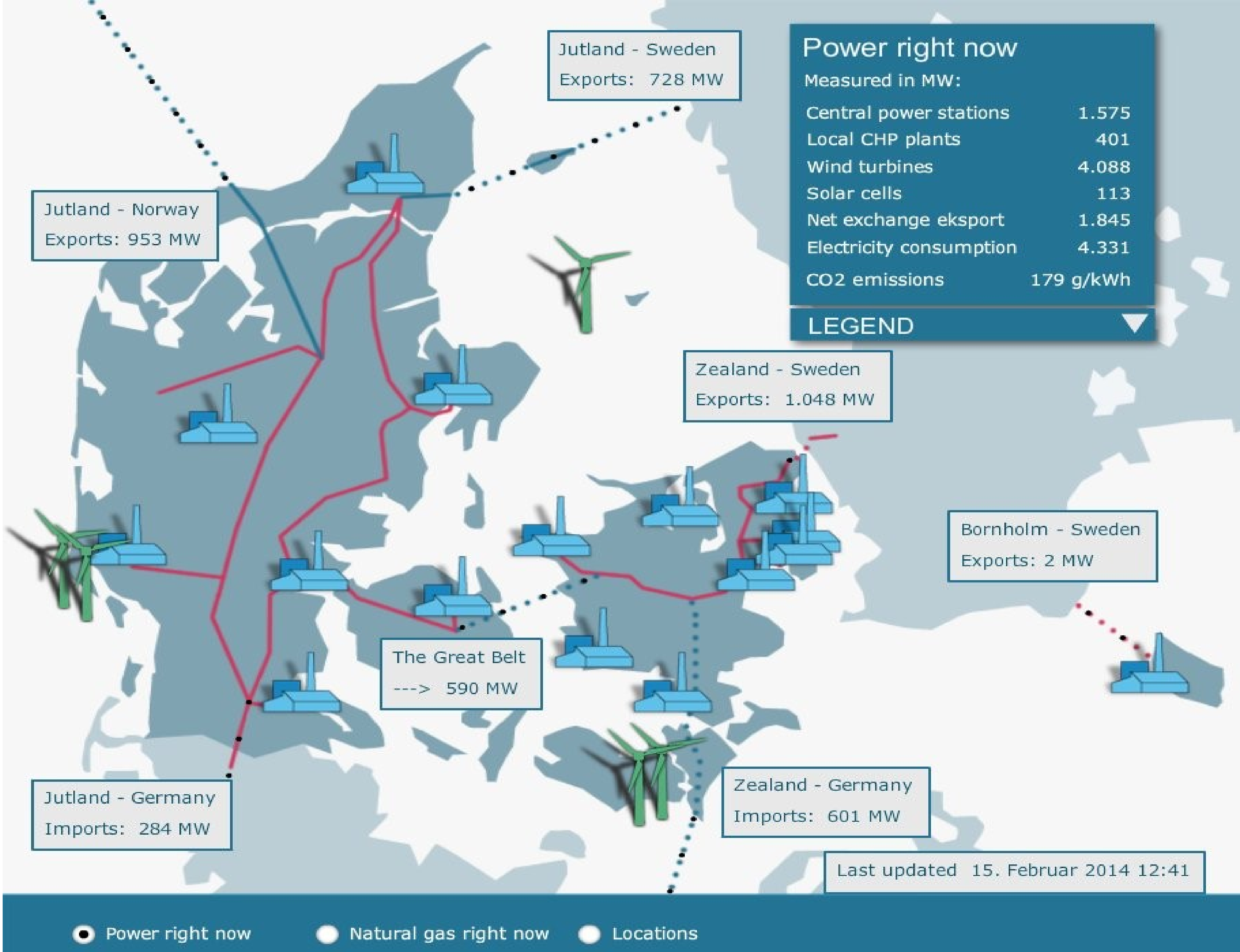
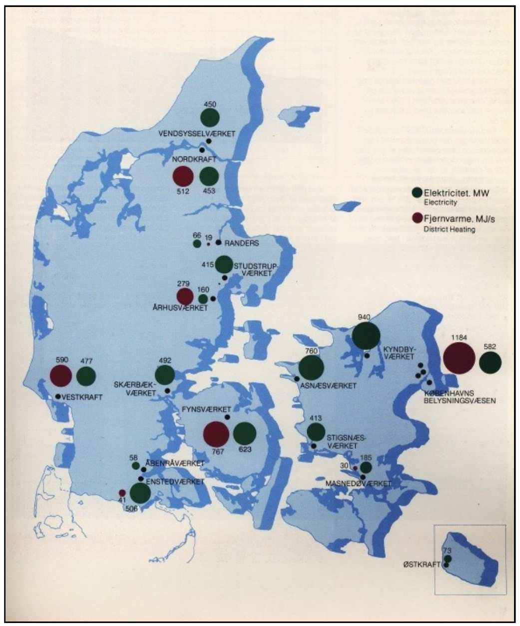


Jutland - Sweden
Exports: 728 MW
Power right now
Measured in MW:
Central power stations 1.575
Local CHP plants 401
Wind turbines 4.088
Solar cells 113
Net exchange eksport 1.845
Electricity consumption 4.331
CO2 emissions 179 g/kWh
LEGEND
Jutland - Norway
Exports: 953 MW
Zealand - Sweden
Exports: 1.048 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

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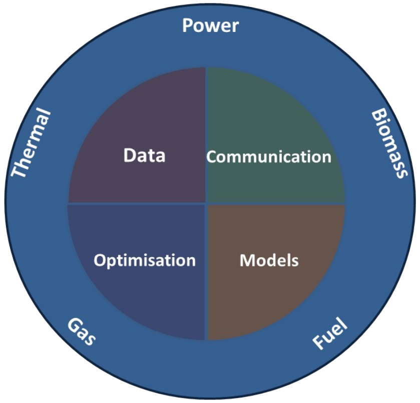
ESI – Hypothesis

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.



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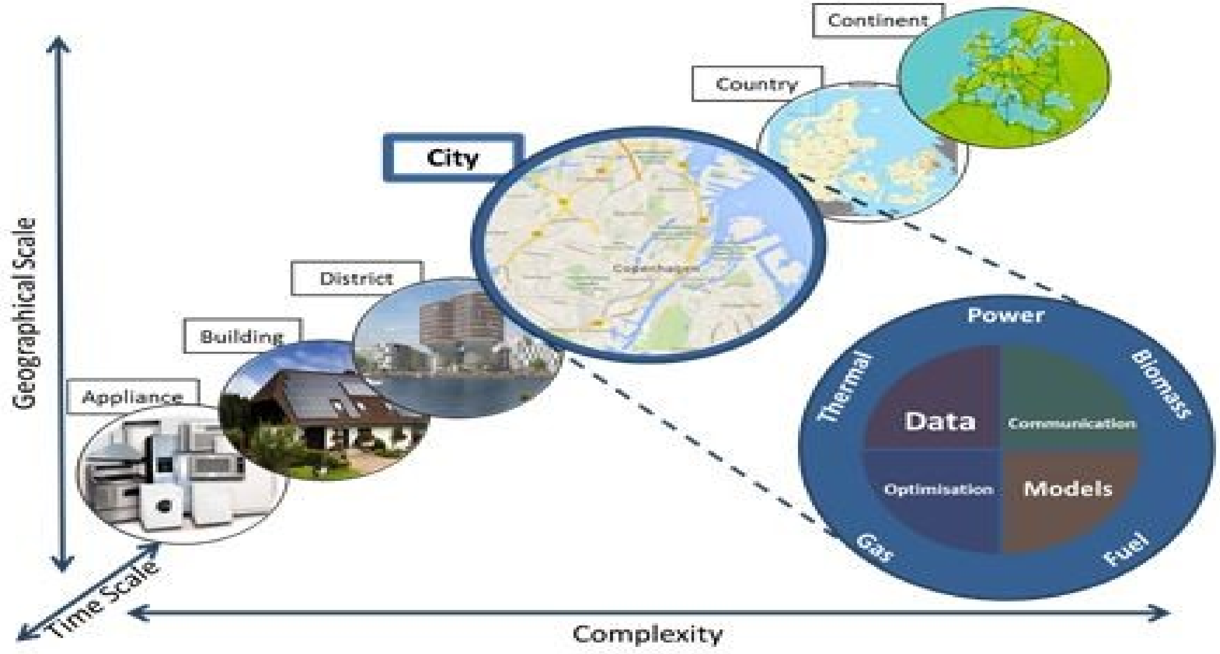
ESI – Research Challenges

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



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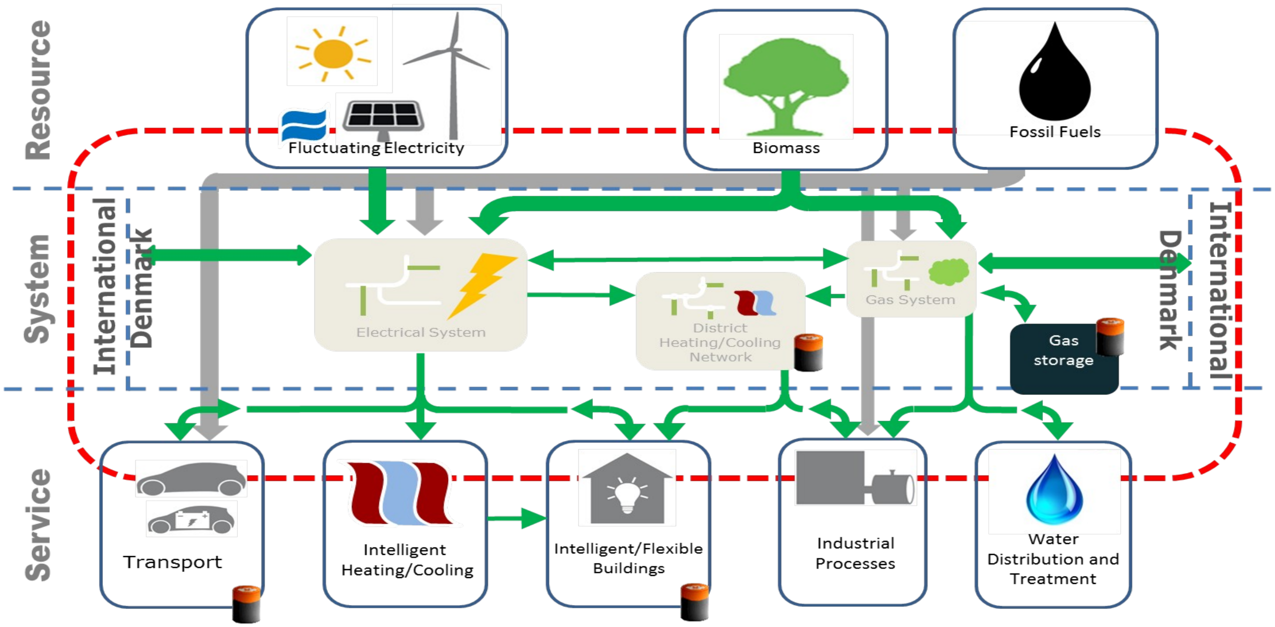
ESI – Concept Challenges

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



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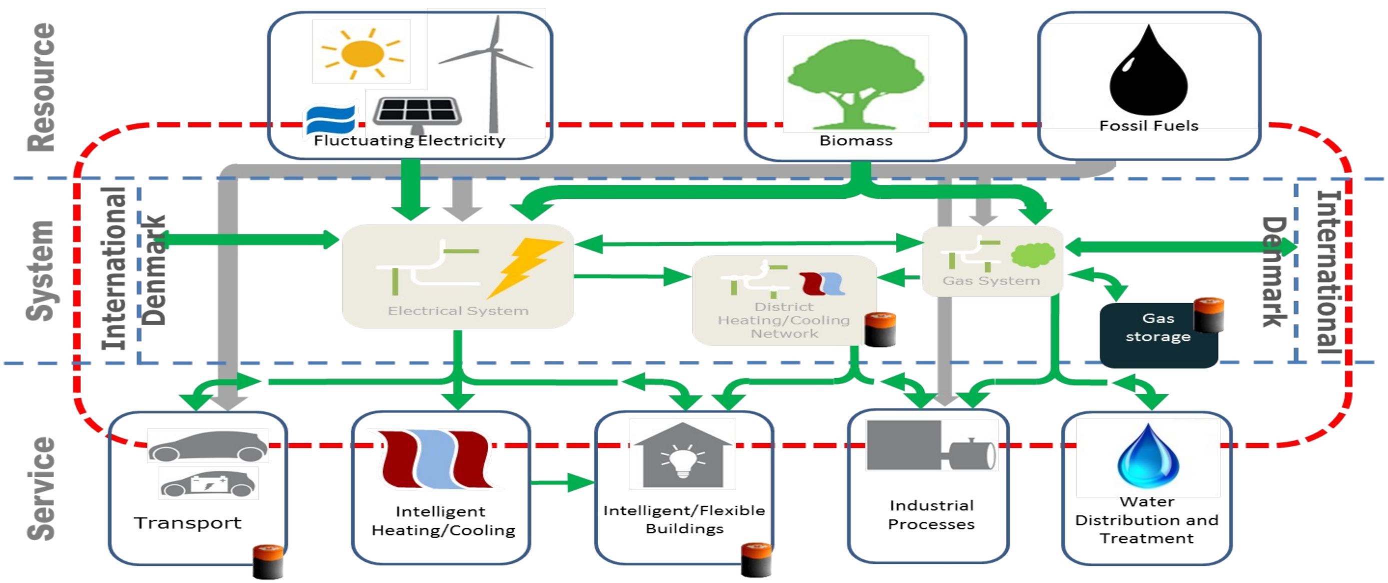
Example: Storage by Energy Systems Integration



- **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

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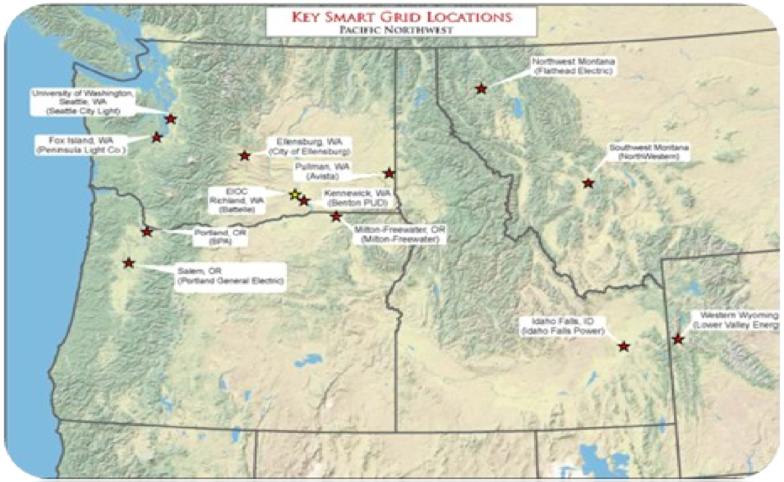
Case study

Control of Power Consumption (DSM)

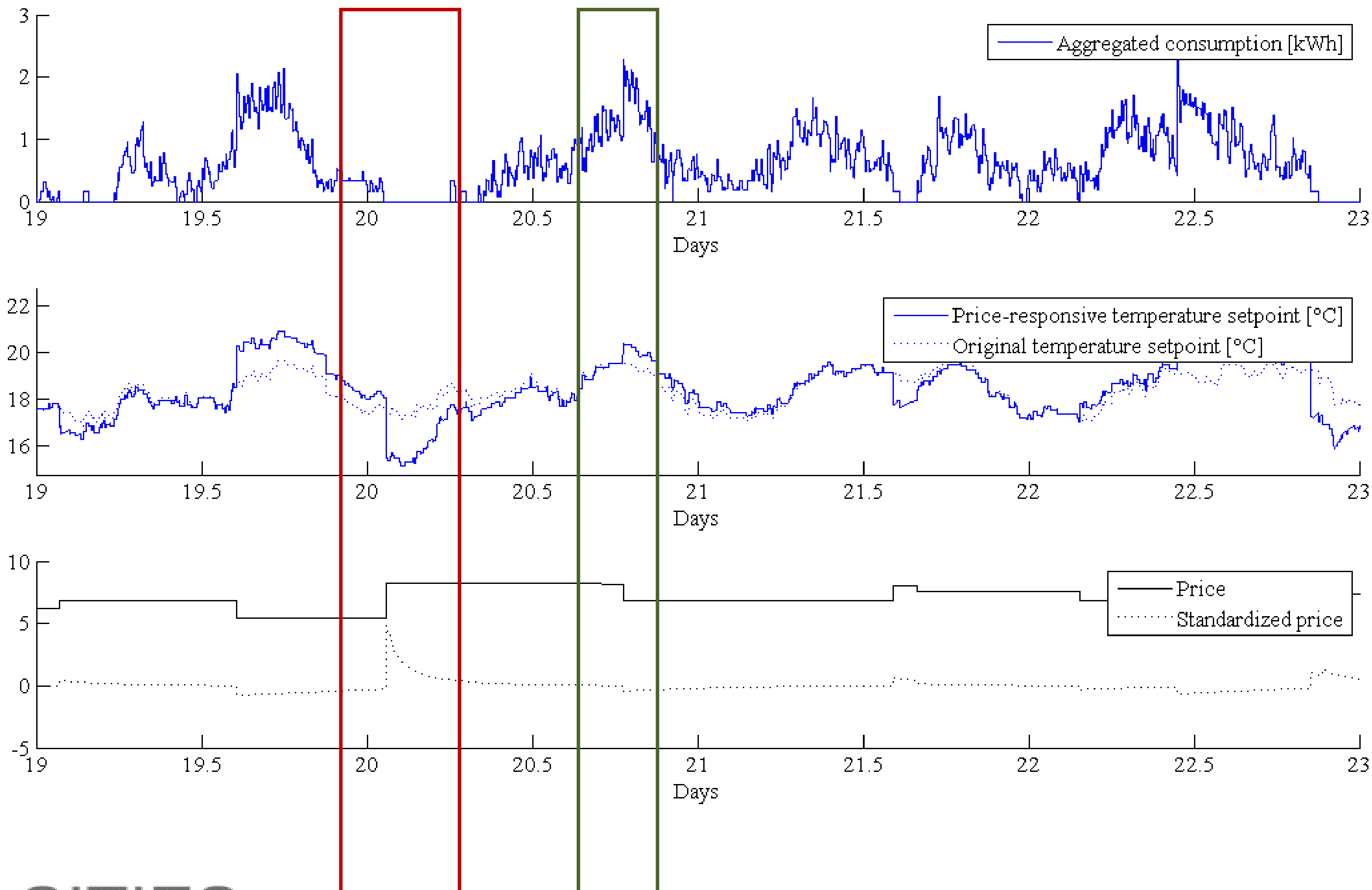
Data from BPA

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)



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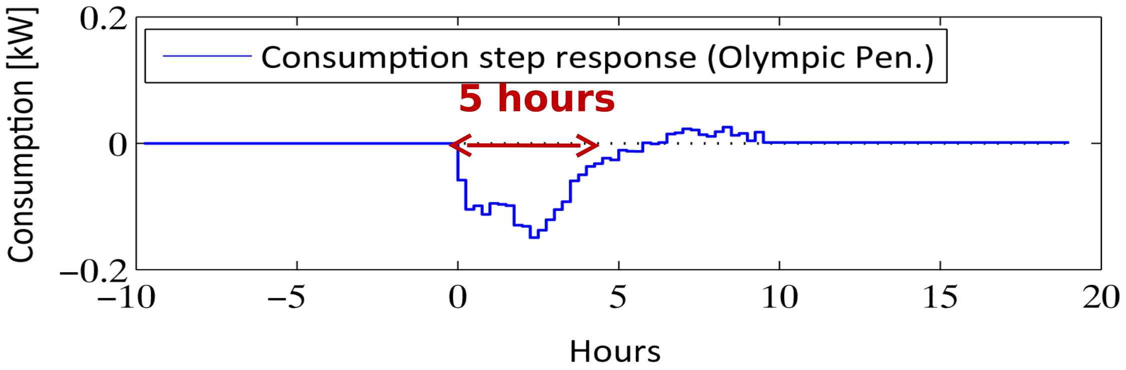
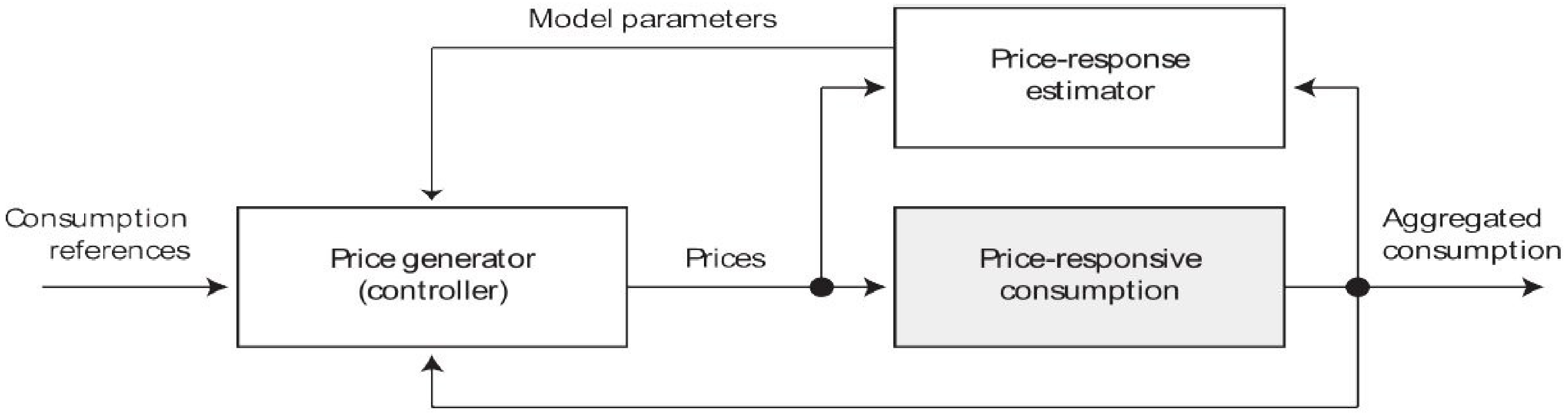
Non-parametric Response on Price Step Change

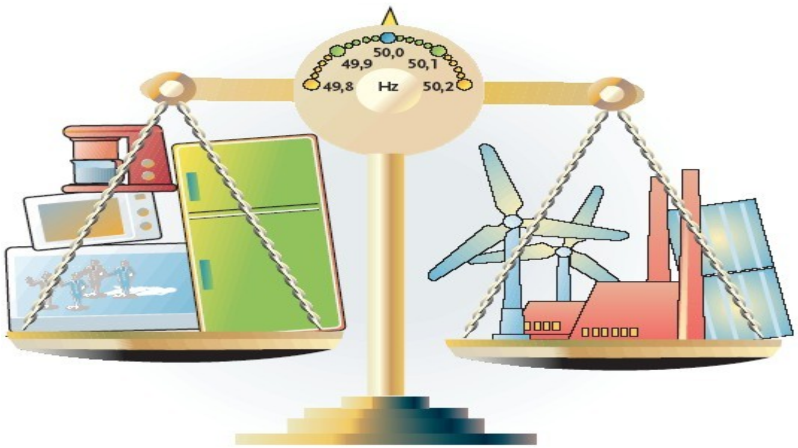
Model inputs: pice, minute of day, outside temperature/dewpoint, sun irrandianc

Olympic Peninsula



Control of Energy Consumption





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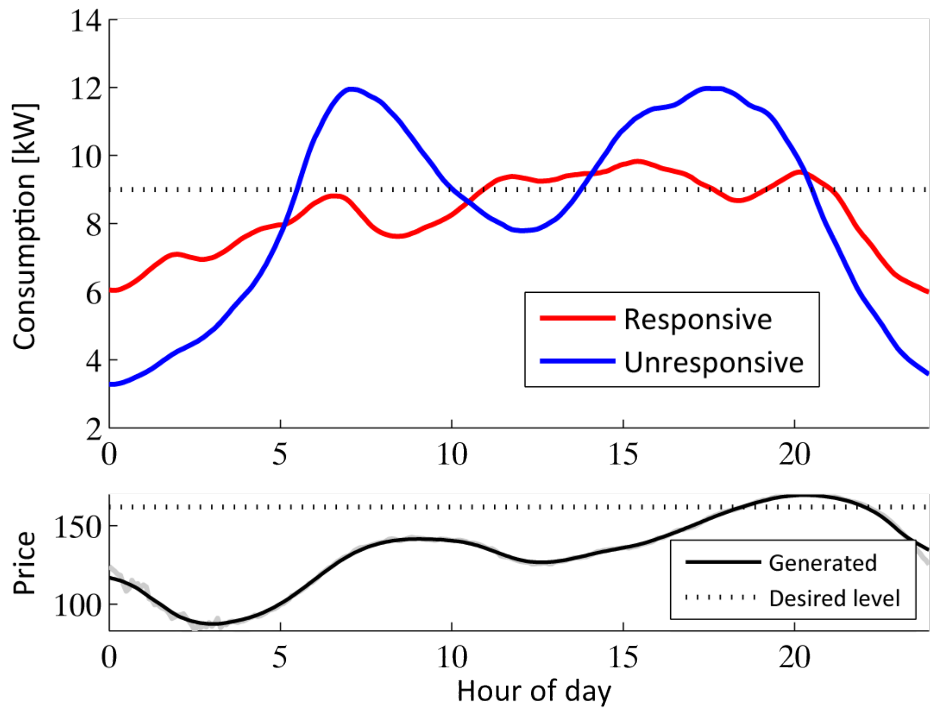
Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift



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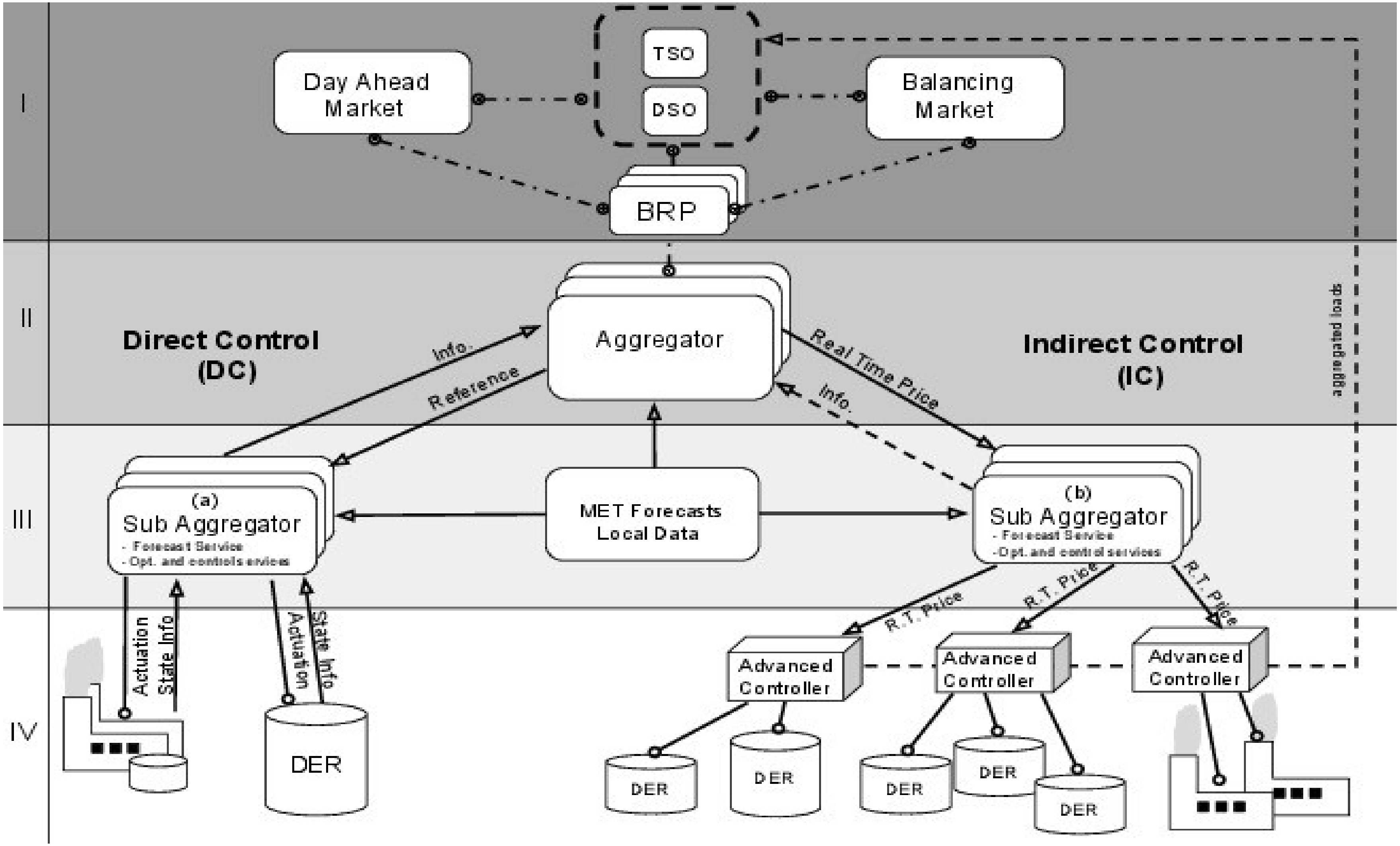
Control and Optimization



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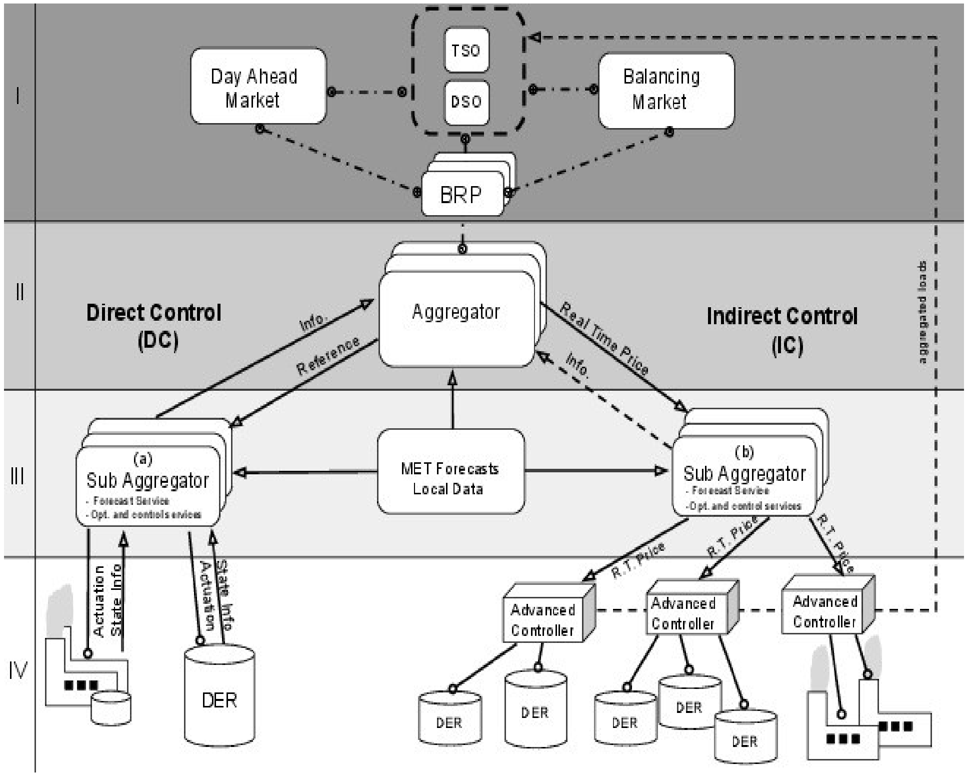
Control and Optim. Challenges



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

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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

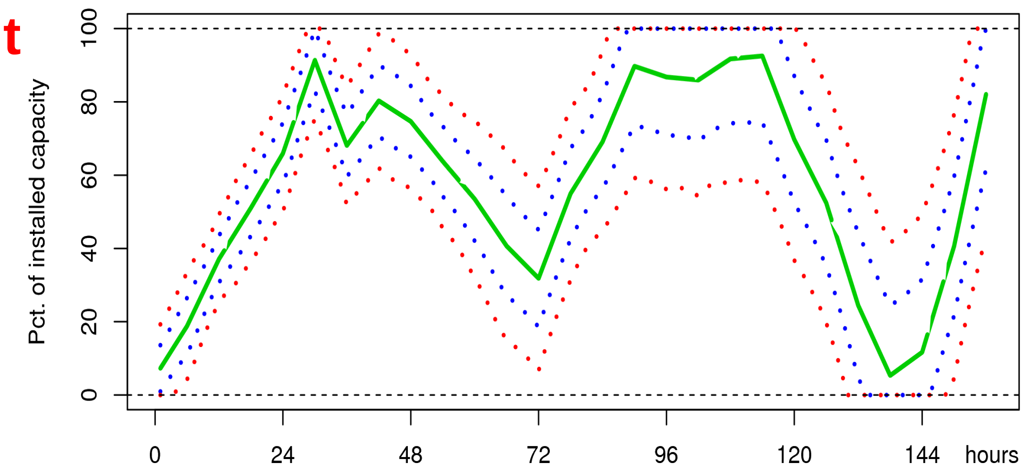
Simple 'contracts'

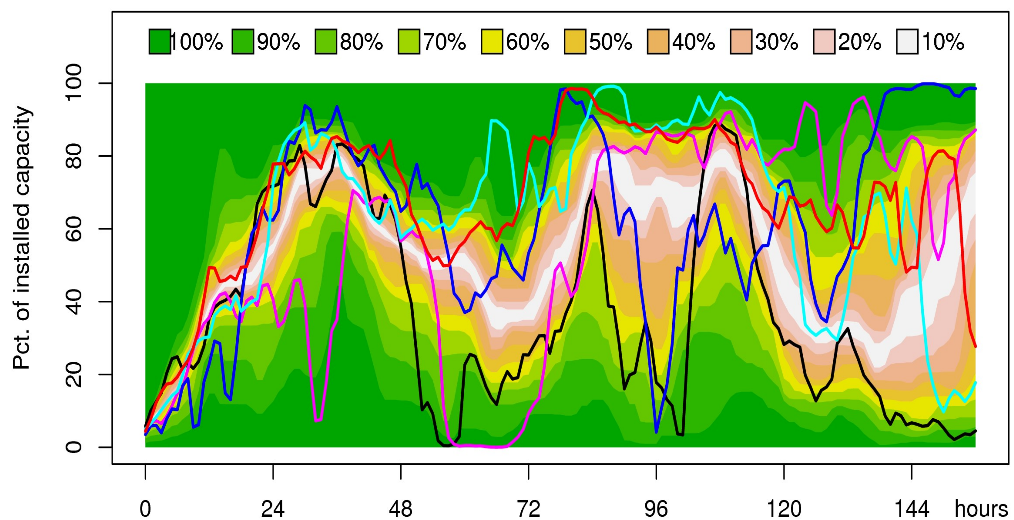
Forecasting Challenges

Forecasting is very important

Type of forecasts:

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





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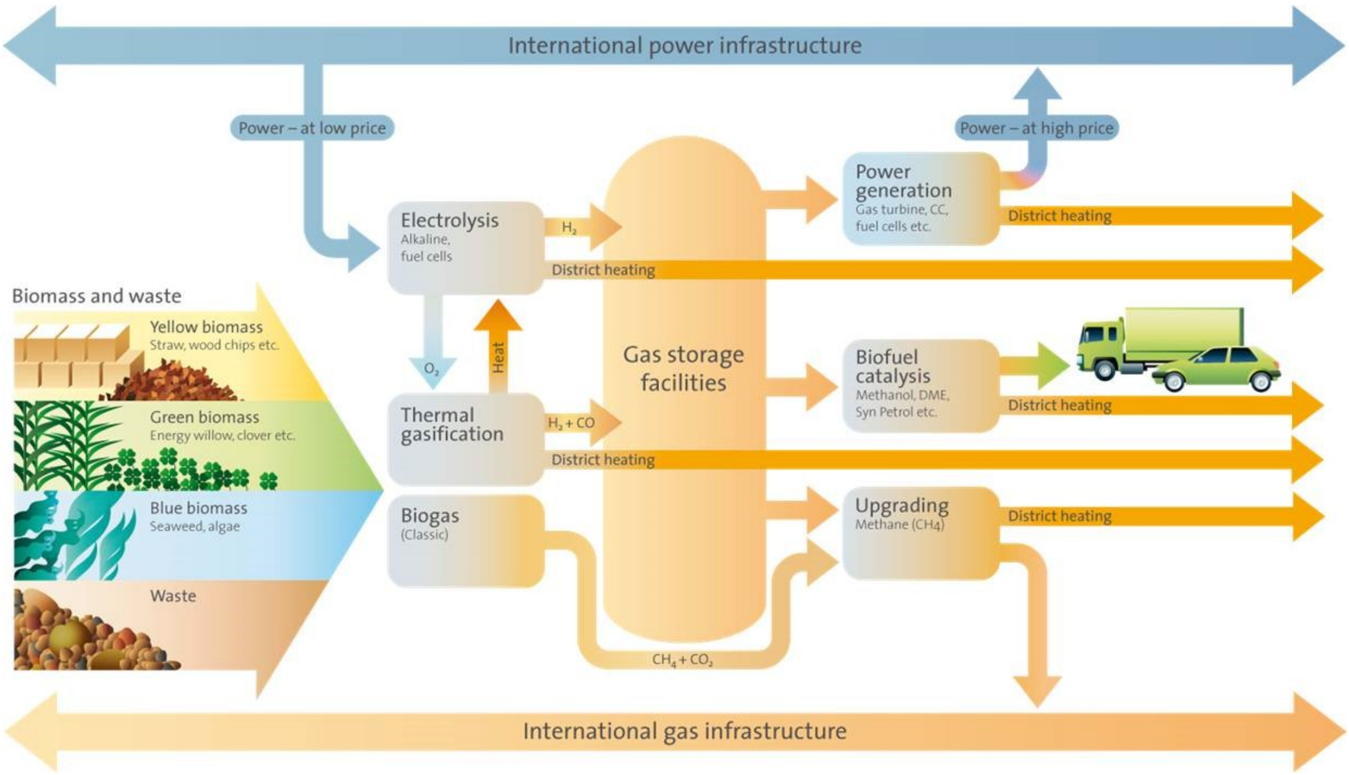
Gas systems are very important in ESI ...



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.

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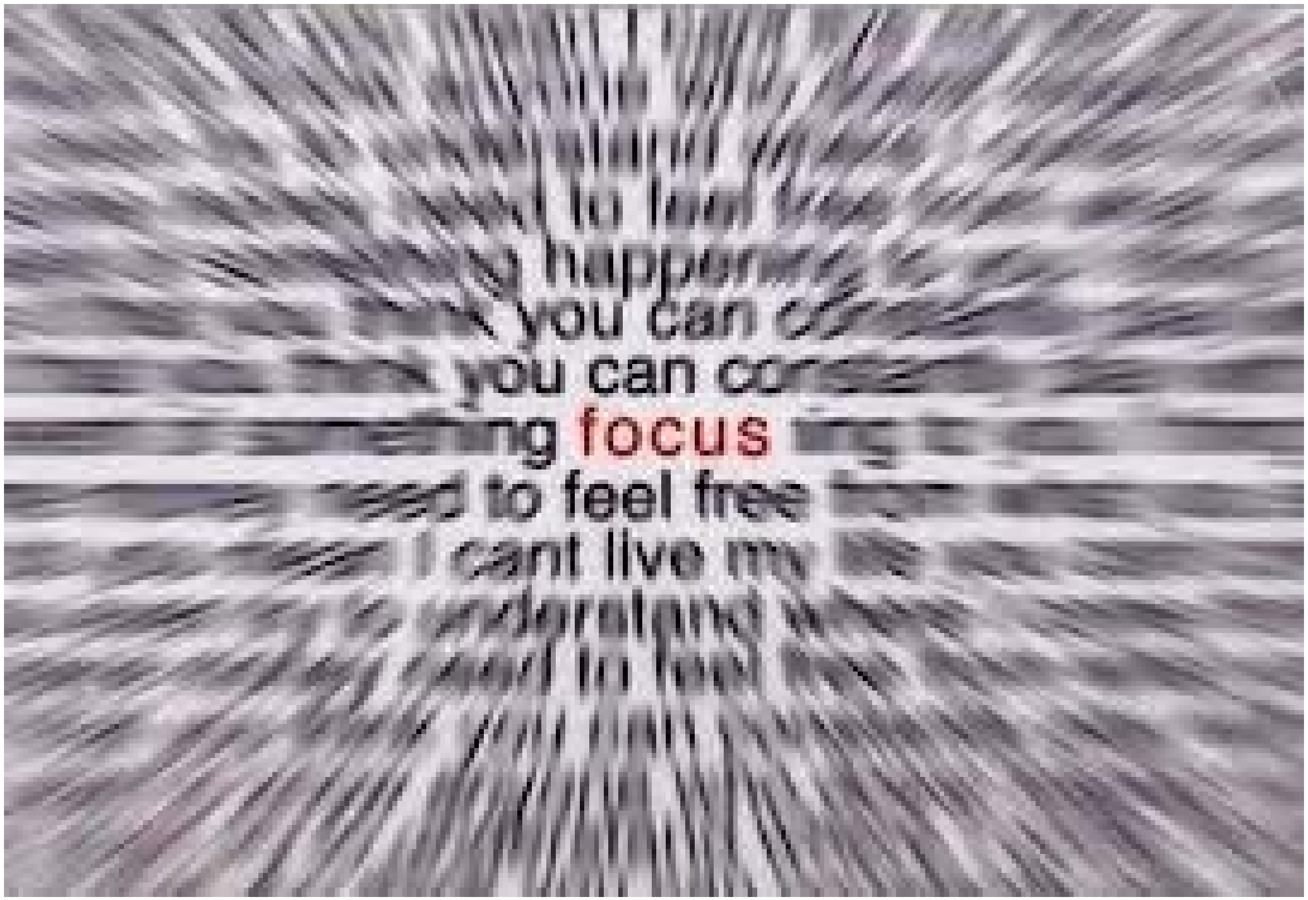
How can we make a difference ?



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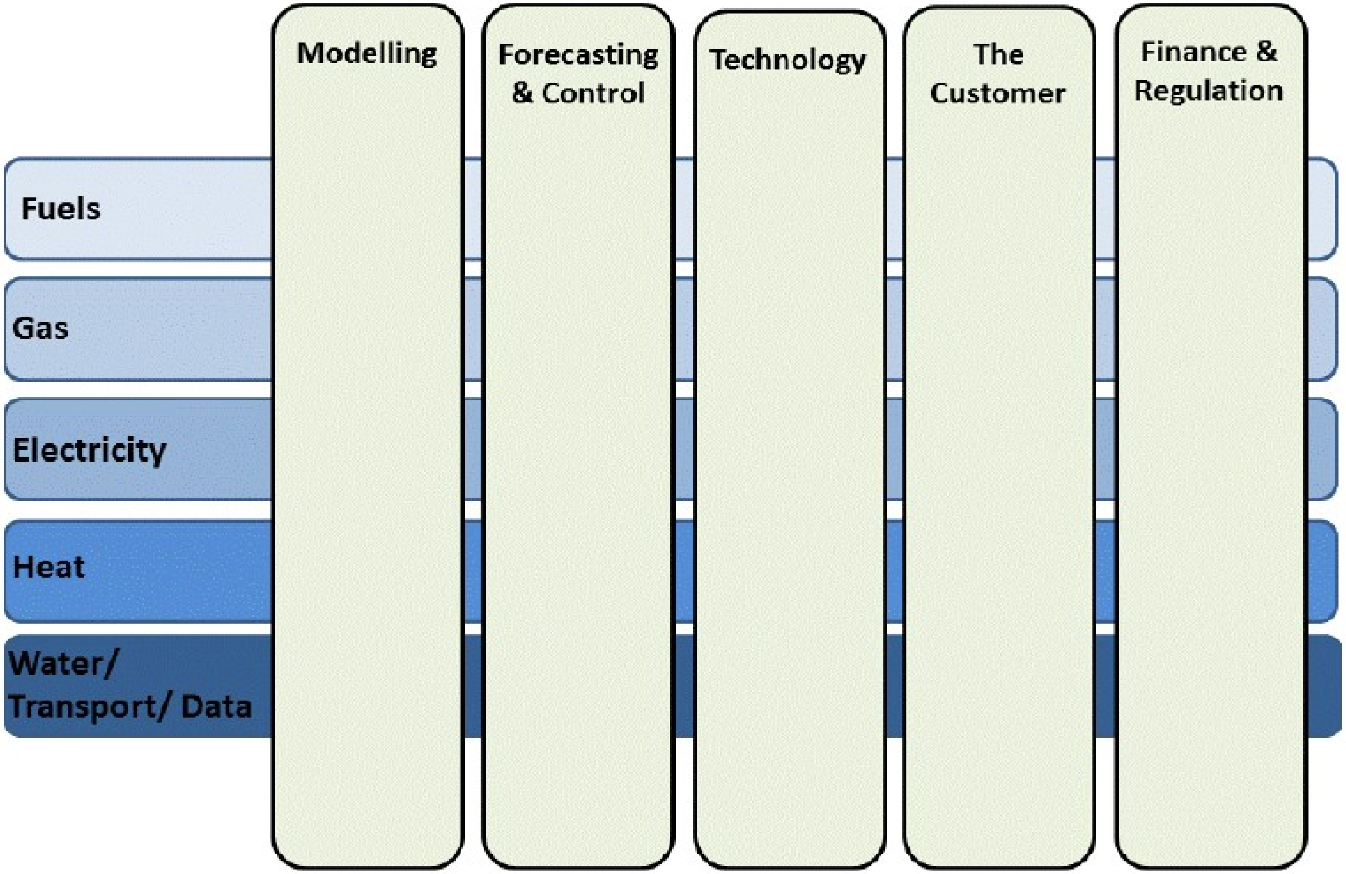
Proposal (UCD, DTU, KU Leuven):

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



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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, Hawaii, Brussels, Australia

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Pacific Northwest NATIONAL LABORATORY

EPRI ELECTRIC POWER RESEARCH INSTITUTE

UCD DUBLIN

DTU

KU LEUVEN

Conclusions / Statements for discussion
(I was asked to be a bit provocative)

- **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 investements 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)**

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