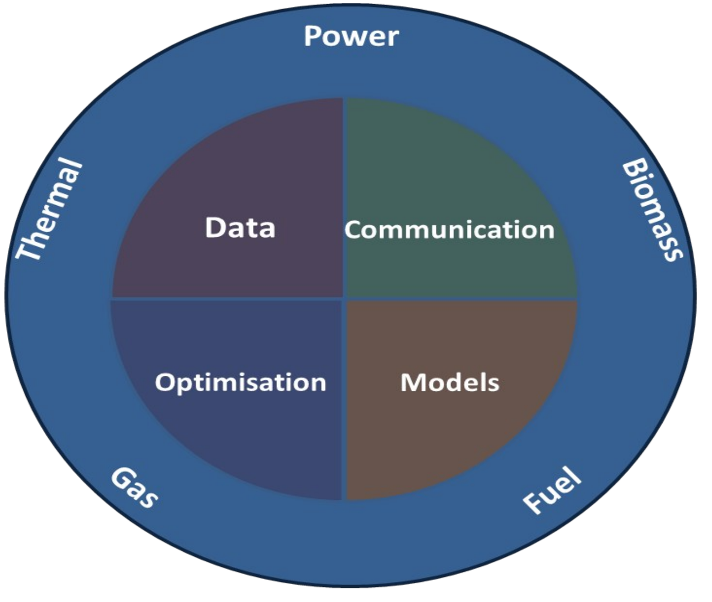
Energy Systems Integration in Cities

Chinese Mayors Training Program



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

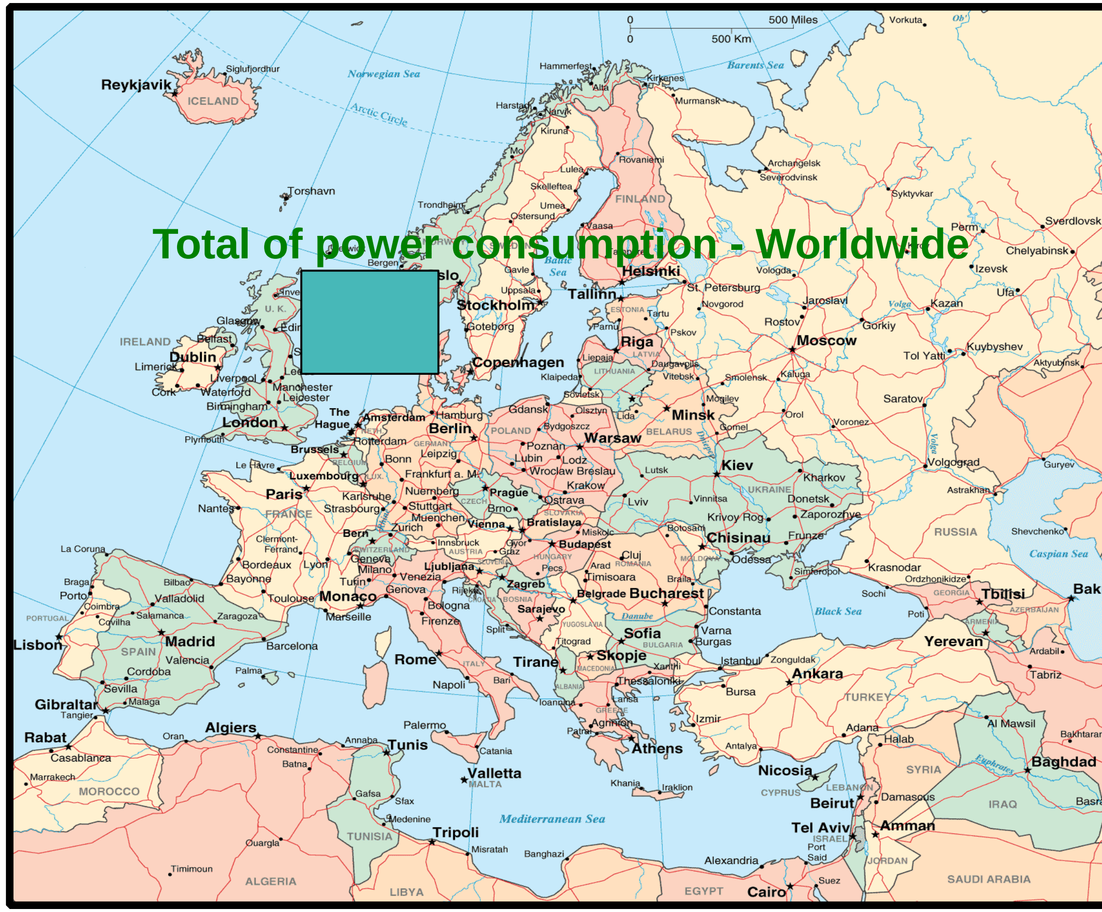
http://www.smart-cities-centre.org

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?

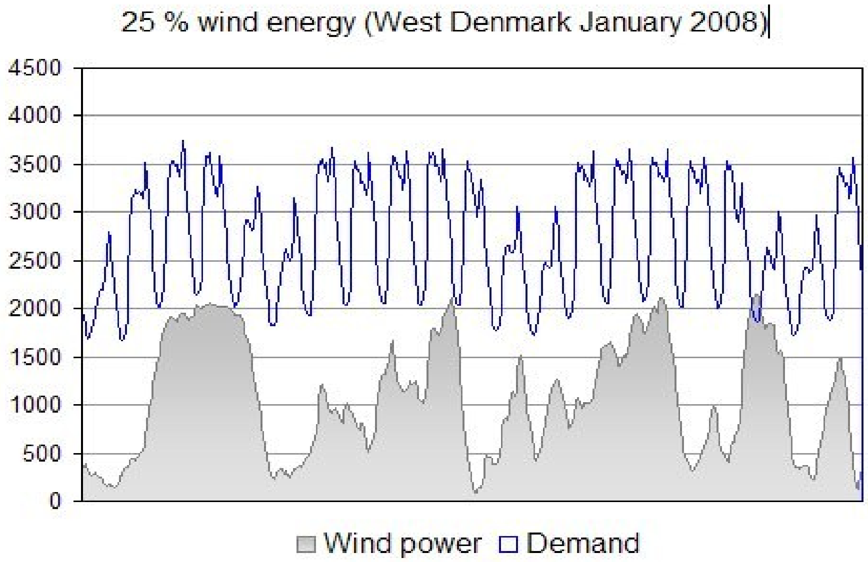
Potentials and Challenges for renewable energy

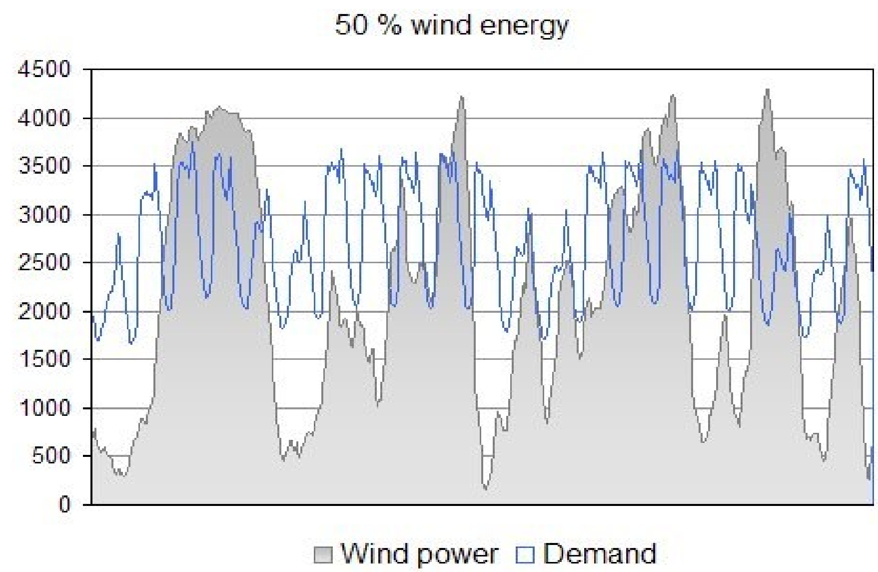
- **Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- **Conclusion**: Use intelligence ....
- Calls for **IT / Big Data / Smart Cities / Models /** **Energy Systems Integration**



The Danish Wind Power Case

…. balancing of the power system



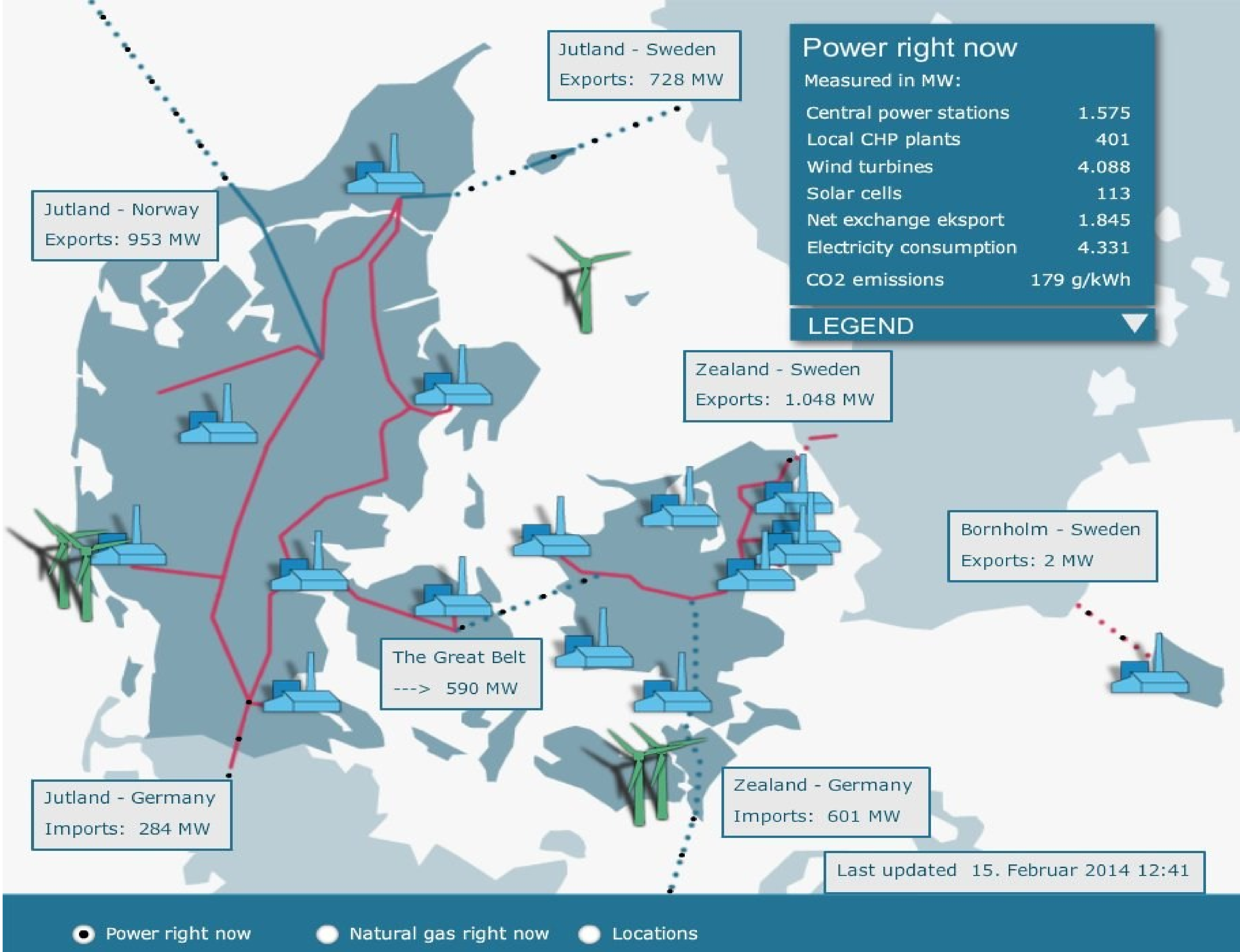


In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

In 2014 more than 40 pct of electricity load was covered by wind power.

For several days in 2014 the wind power production was more than 120 pct of the power load.

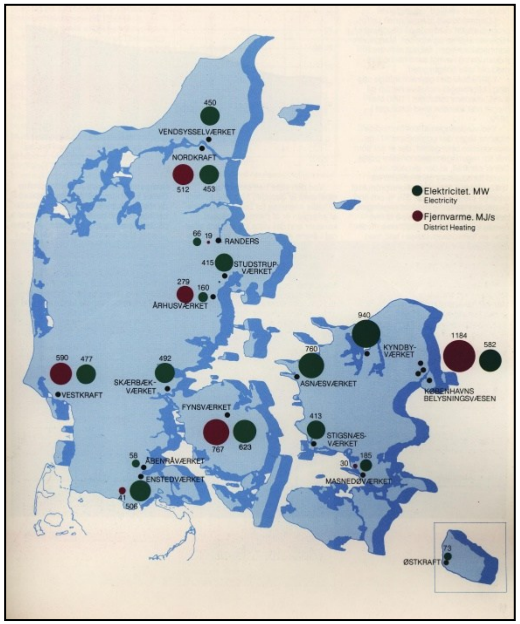
July 14th, 2015 more than 140 pct of the power load was covered by wind power


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

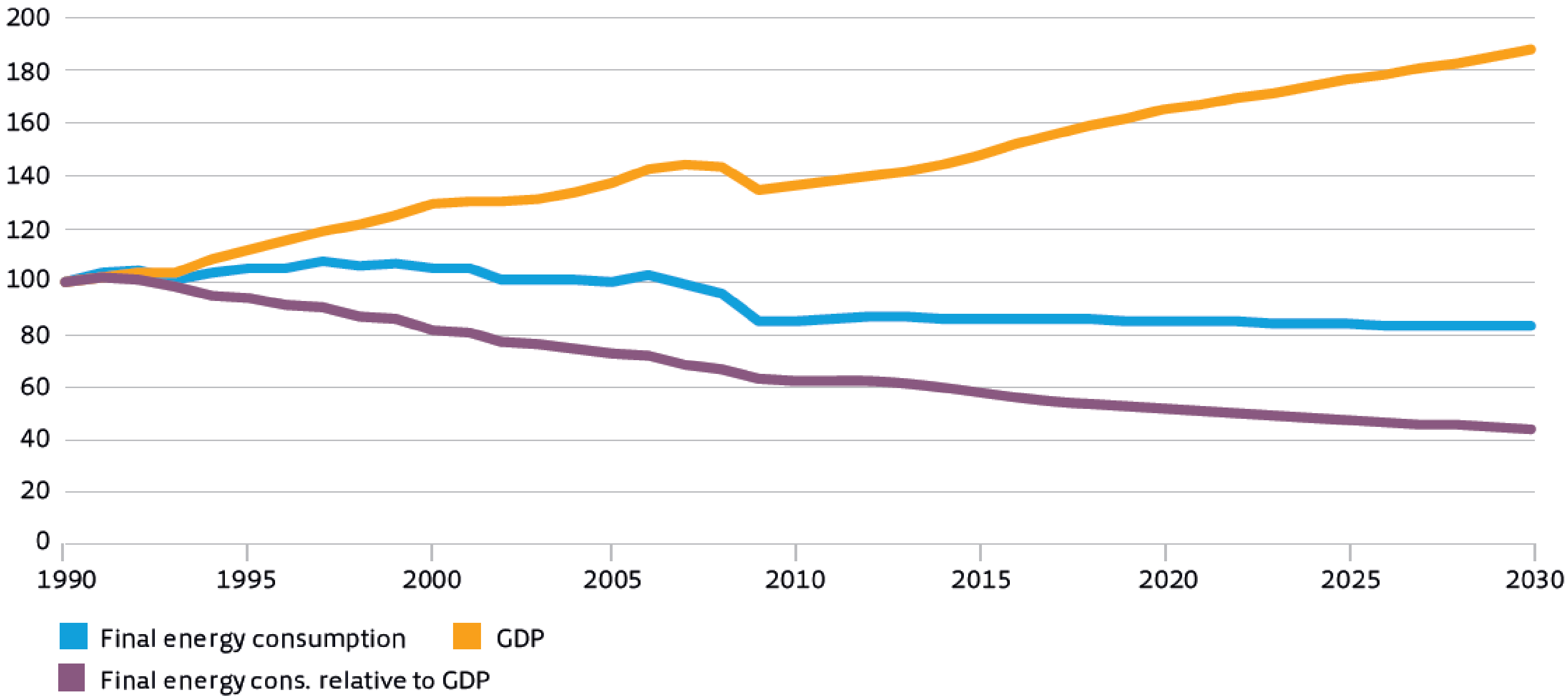
1980

Today



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

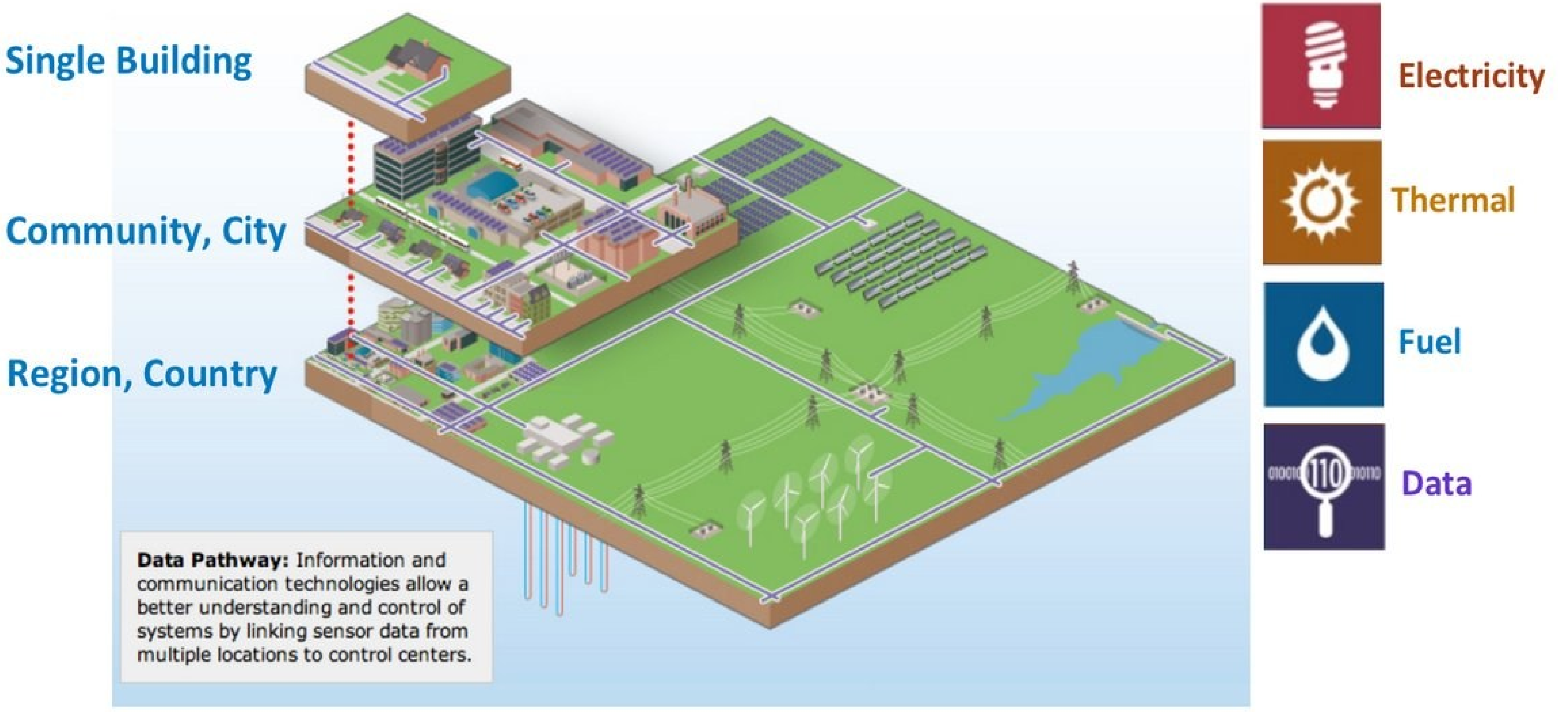
What has since been achieved: De-coupling of consumption and GDP growth



Source: Energy Policy in Denmark. Danish Energy Agency. December 2012

Energy Systems Integration in Smart Cities

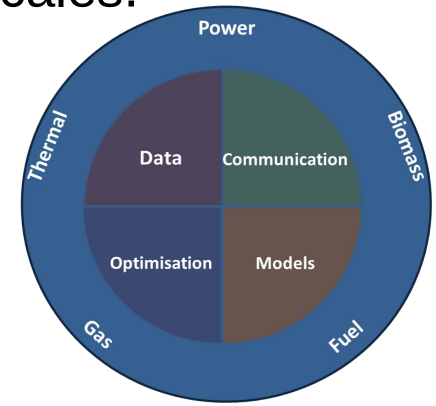
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



Energy Systems Integration Hypothesis

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

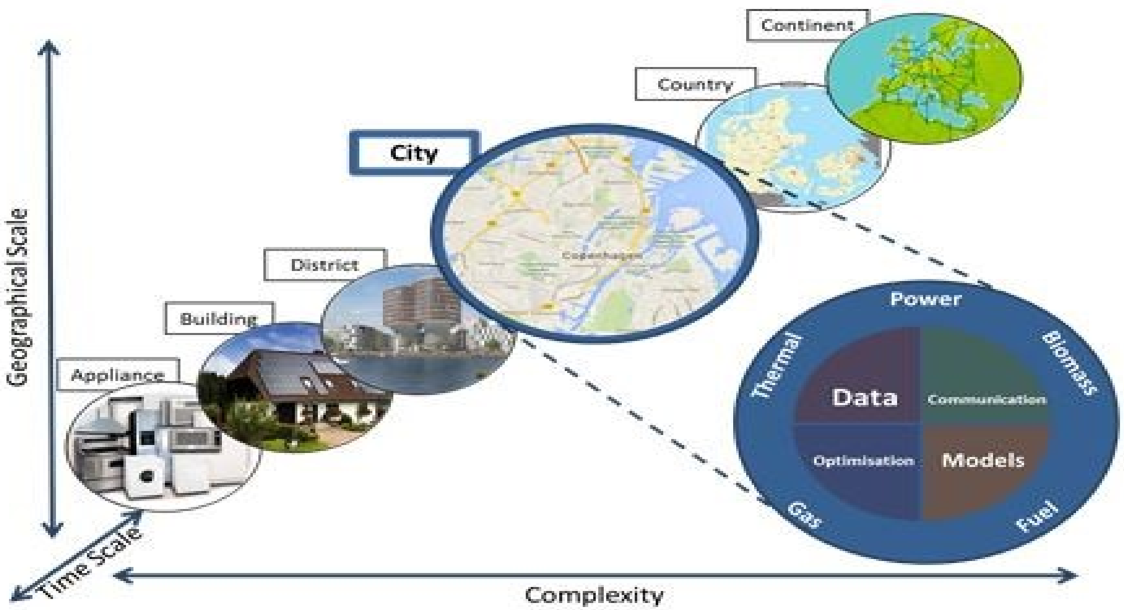
Intelligent integration will (for instance) enable lossless 'virtual' storage on a number of different time scales.



ESI Solutions

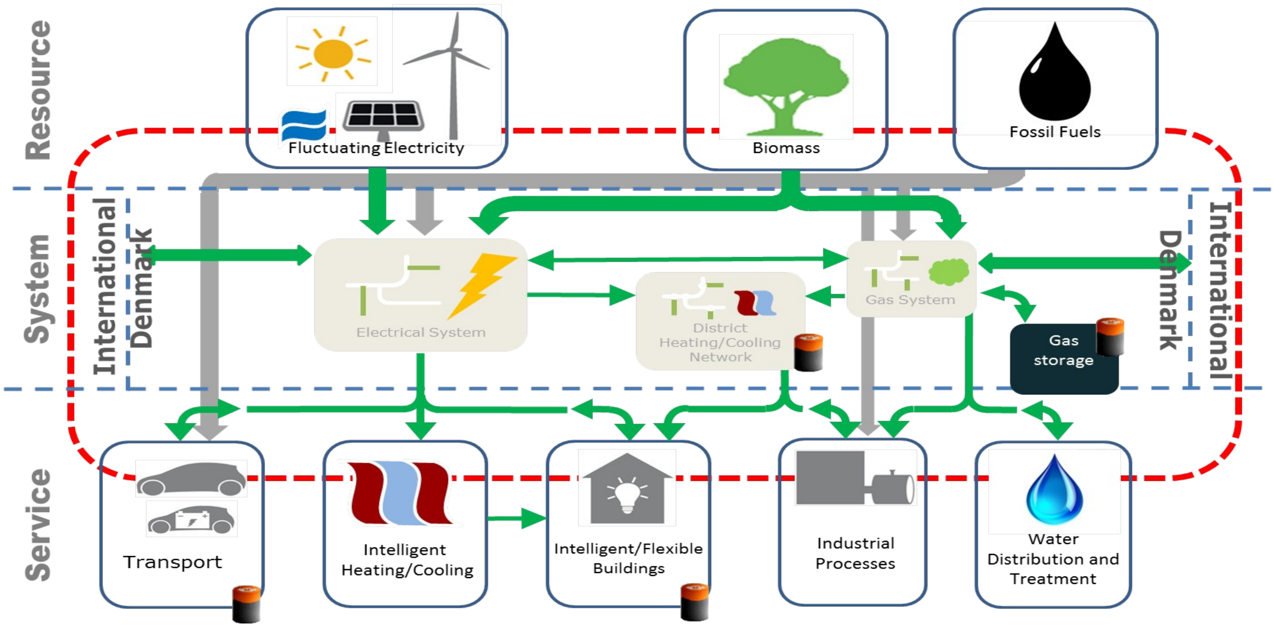
The ***Center for IT-Intelligent Energy Systems in Cities (CITIES)*** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

This Center is the largest Smart Cities and ESI research project in Denmark – see http://www.smart-cities-centre.org .

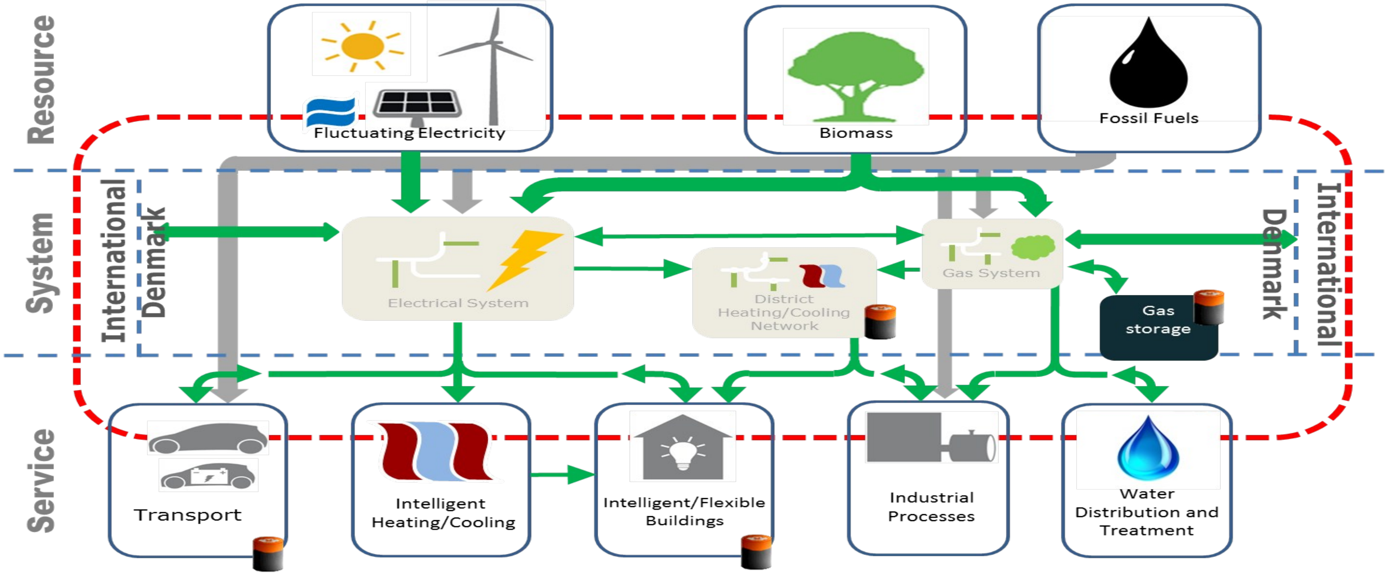


ESI – Concepts

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



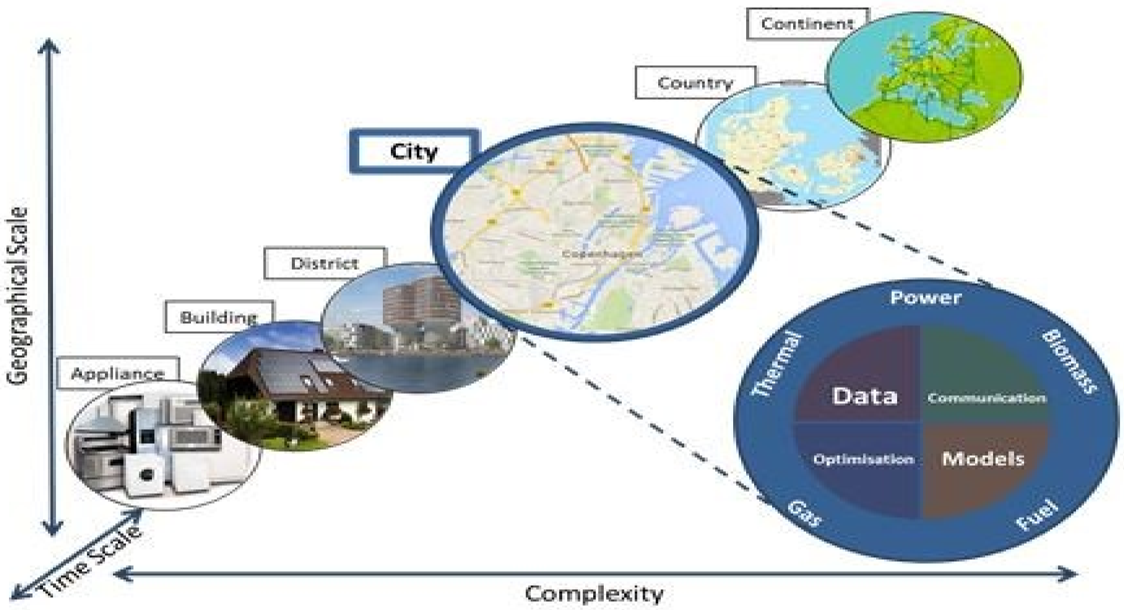
Example: Storage by Energy Systems Integration



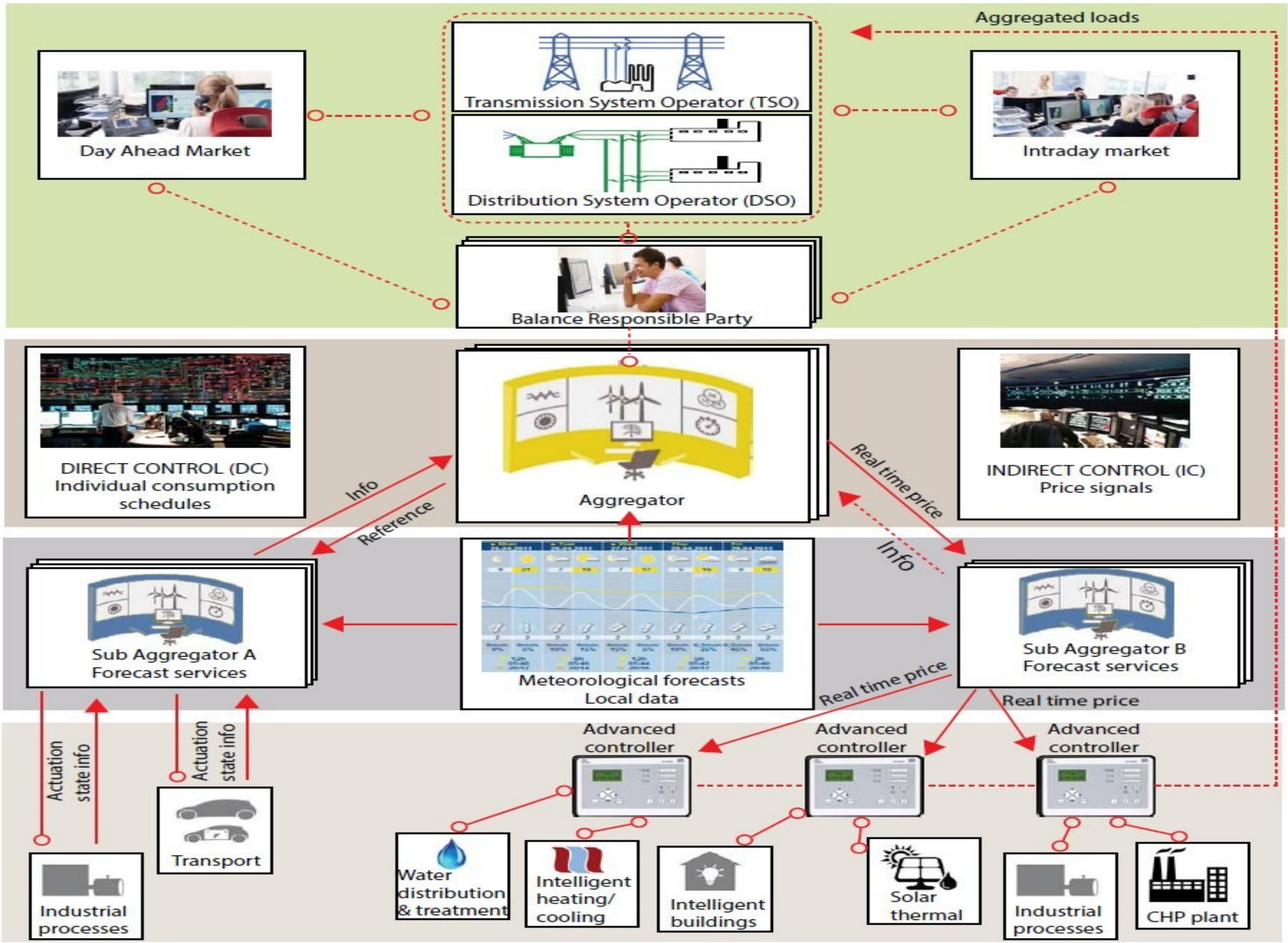
- **Denmark (2014) : 48 pct of power load by renewables (> 100 pct for some days in January)**
- **(Virtual) storage principles:**
  - Buildings can provide storage up to, say, 5-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - Gas systems can provide seasonal storage

Temporal and Spatial Scales

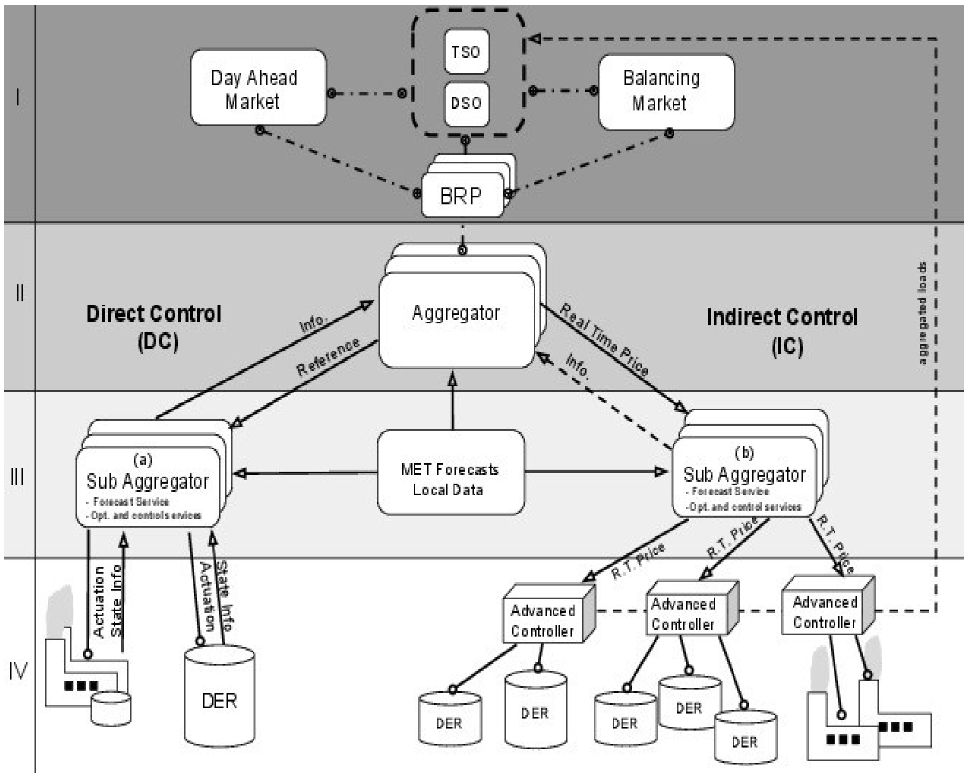
The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems*** at **all scales**.



Smart-Energy OS



Control and Optimization



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:

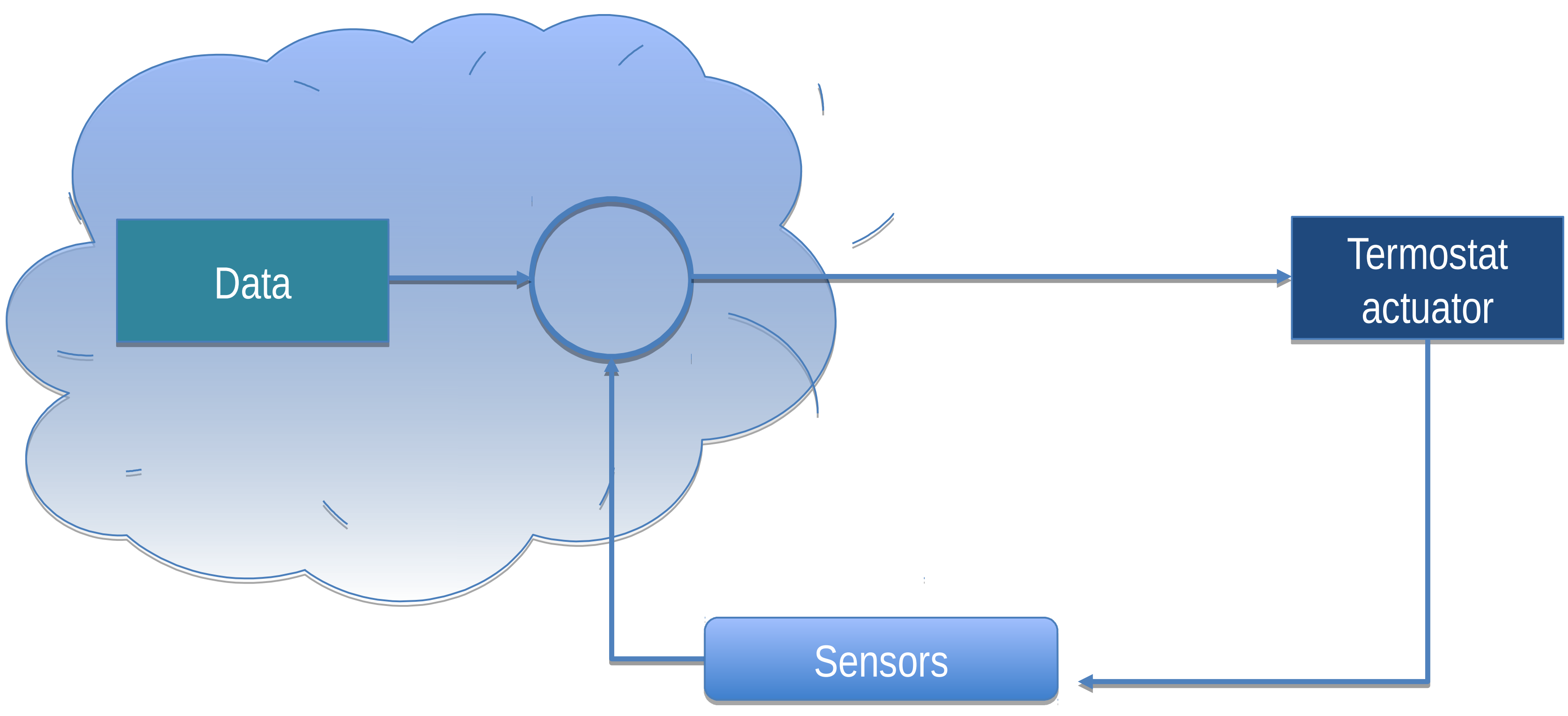
Actuator: **Price**

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

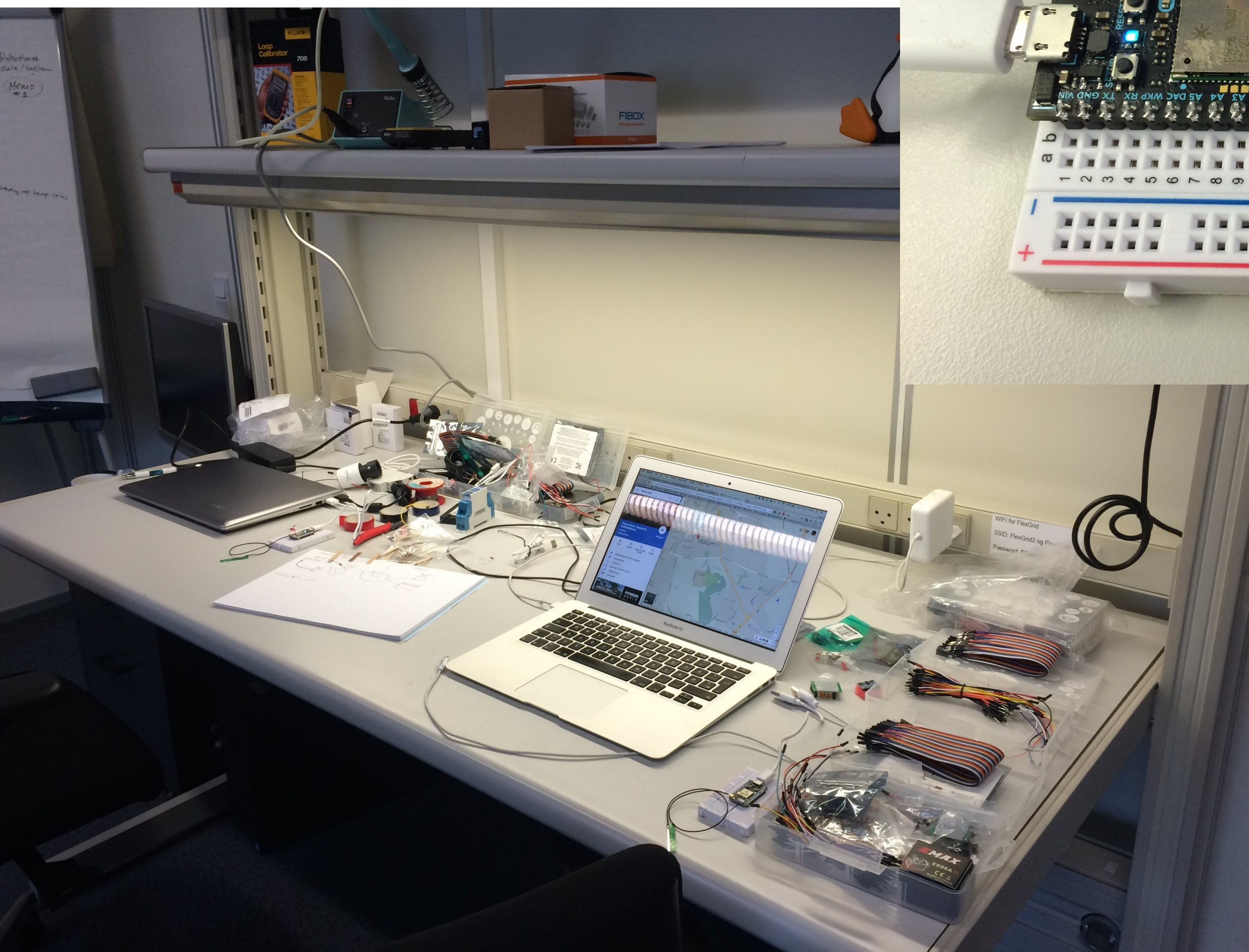
Models for DERs are not needed

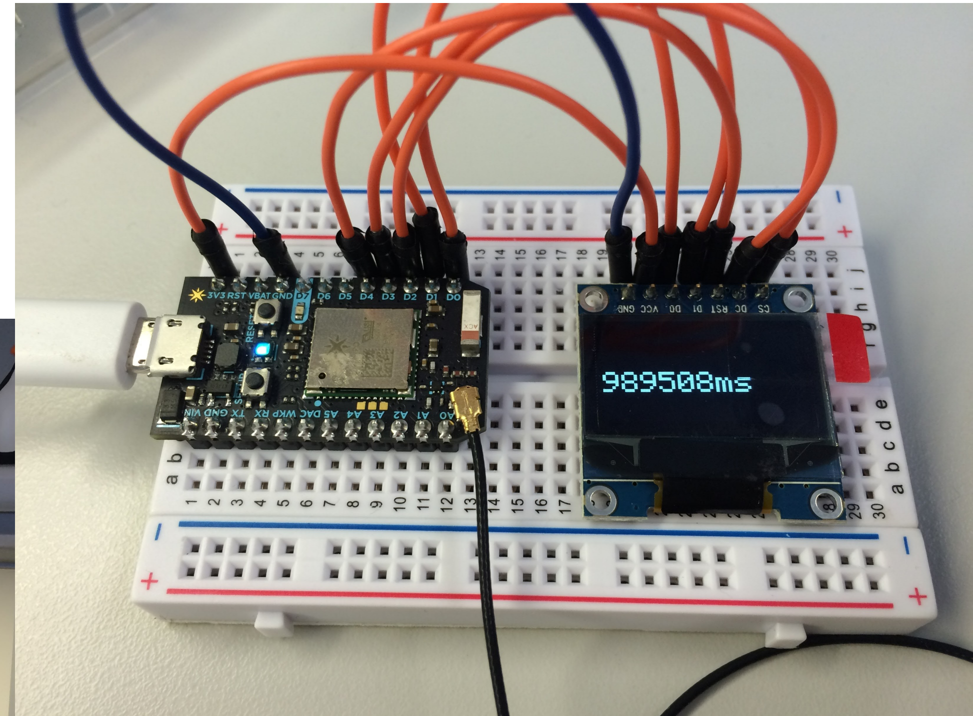
Simple 'contracts'

SE-OS
Control loop design – **logical drawing**

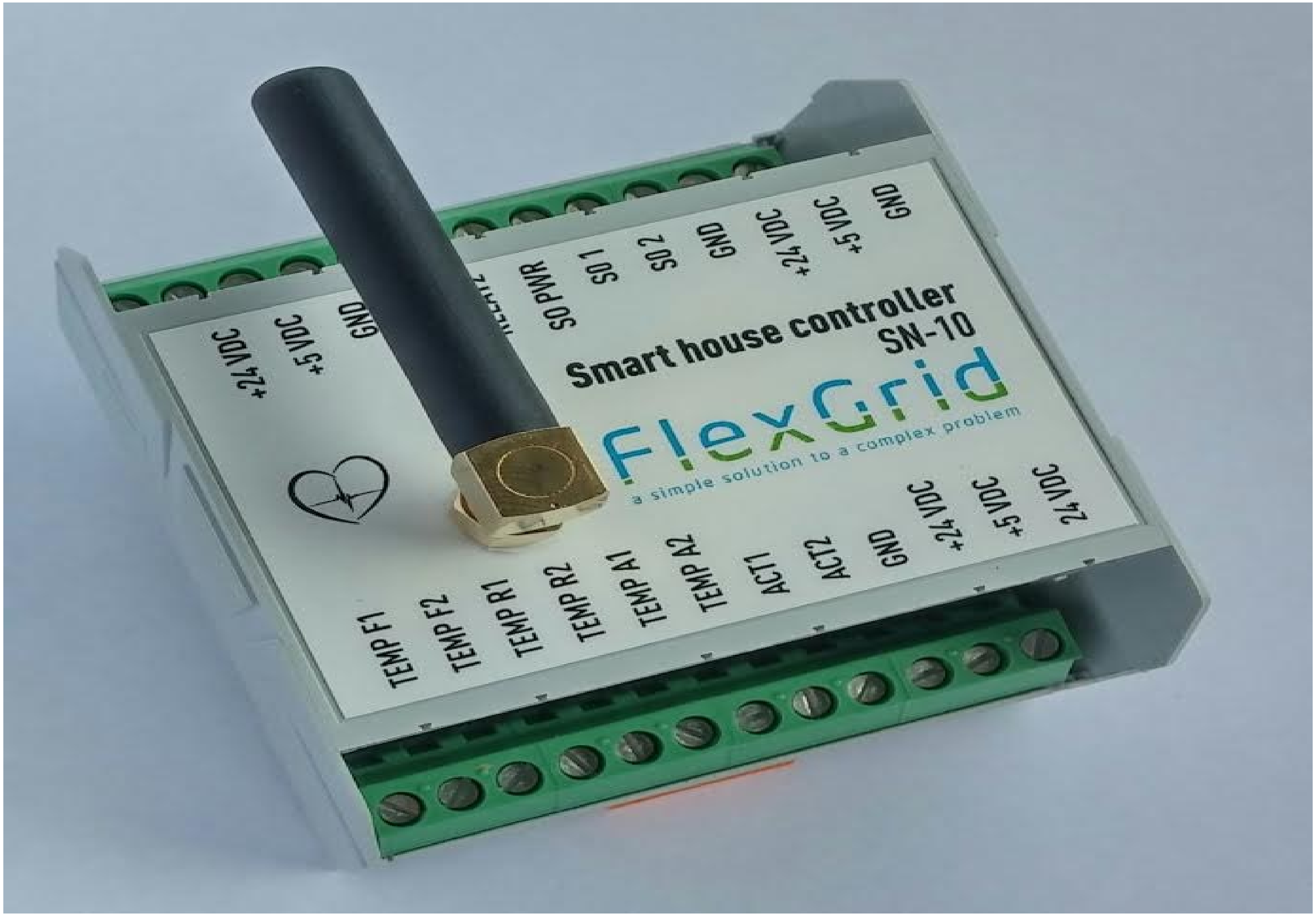


Lab testing ....





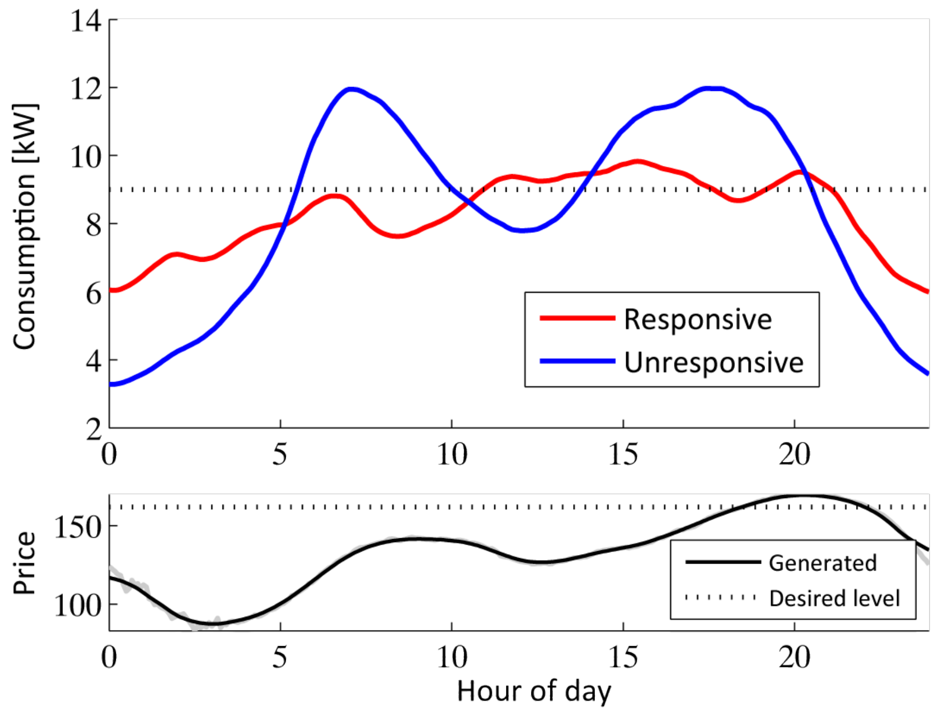
SN-10 Smart House Prototype



Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift



CITIES

Centre for IT-Intelligent Energy Systems in cities

Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available on GitHub.

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R . The software is available on GitHub.

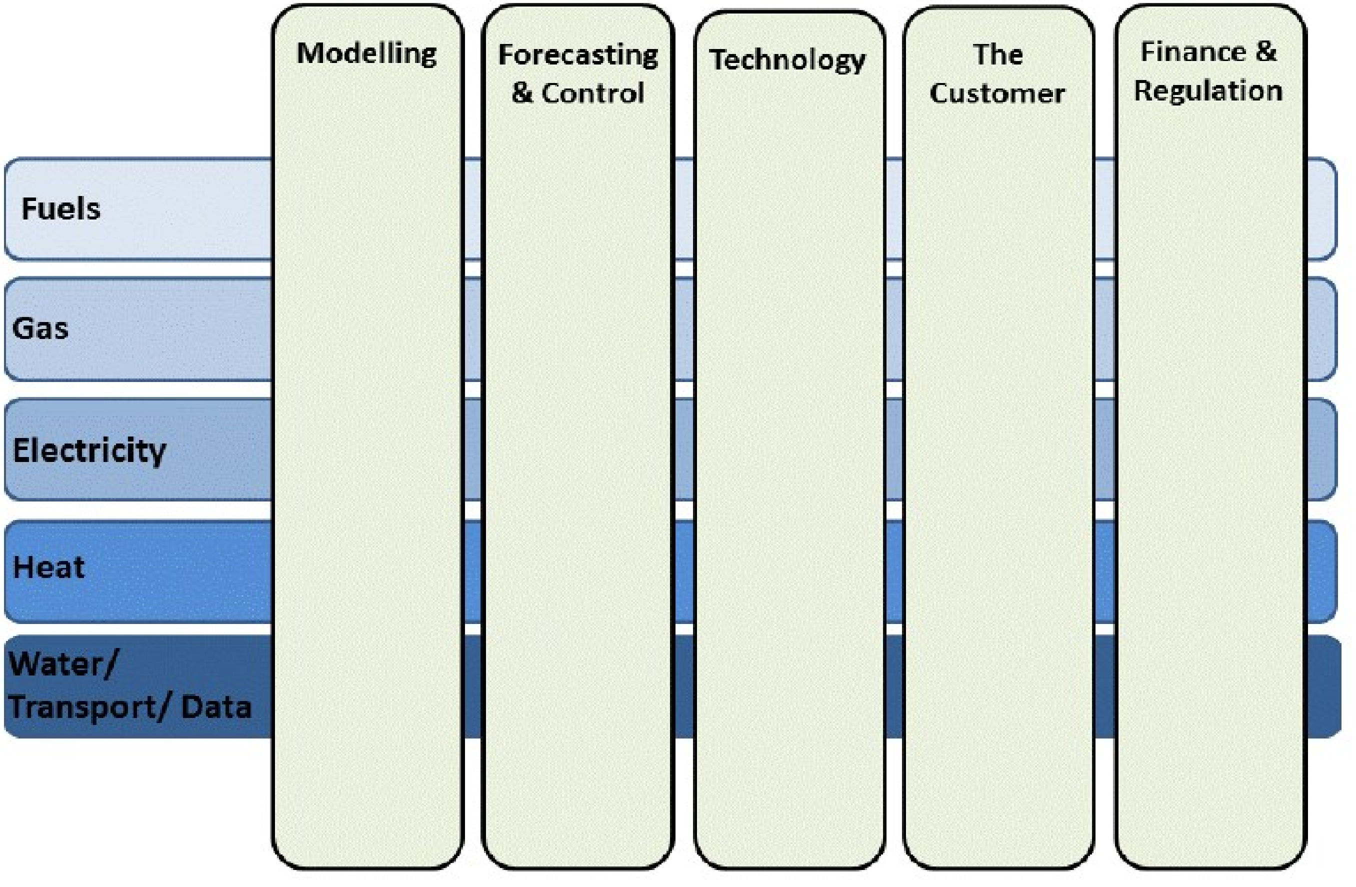
Search ...

Latest news

- Summer School at DTU, Lyngby, Denmark – July 4th-8th 2016
- Summer School – Granada, Spain, June 19th-24th 2016
- Third general consortium meeting – DTU, May 24th-25th 2016
- Smart City Challenge in Copenhagen – April 20th 2016
- Guest lecture by Pierluigi Mancarella at DTU, April 6th

Proposal (UCD, DTU, KU Leuven):

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



Conclusions

- Energy Systems Integration in Cities can provide virtual and lossless storage solutions (so maybe we should put less focus on physical storage solutions)
- Intelligent Energy Systems Integration in Cities using ICT is the key to enable large shares of wind and solar power
- Focus on zero emission buildings – and less on zero energy buildings (the same holds supermarkets, wastewater treatment plants, etc.)
- District heating (or cooling) provides virtual storage on the essential time scale (up to a few days)
- We see a large potential in Demand Side Management in Cities. 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)