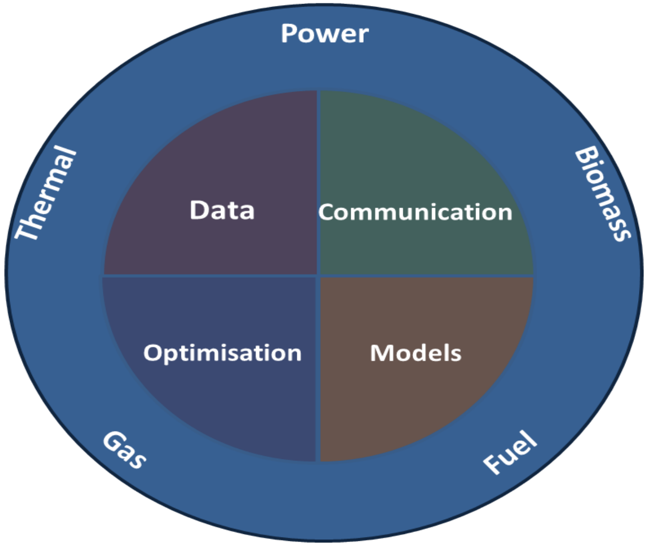
Data-Intelligent Energy Systems Integration in Cities

Chinese Mayors Training Program



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

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

http://smartnet-project.eu

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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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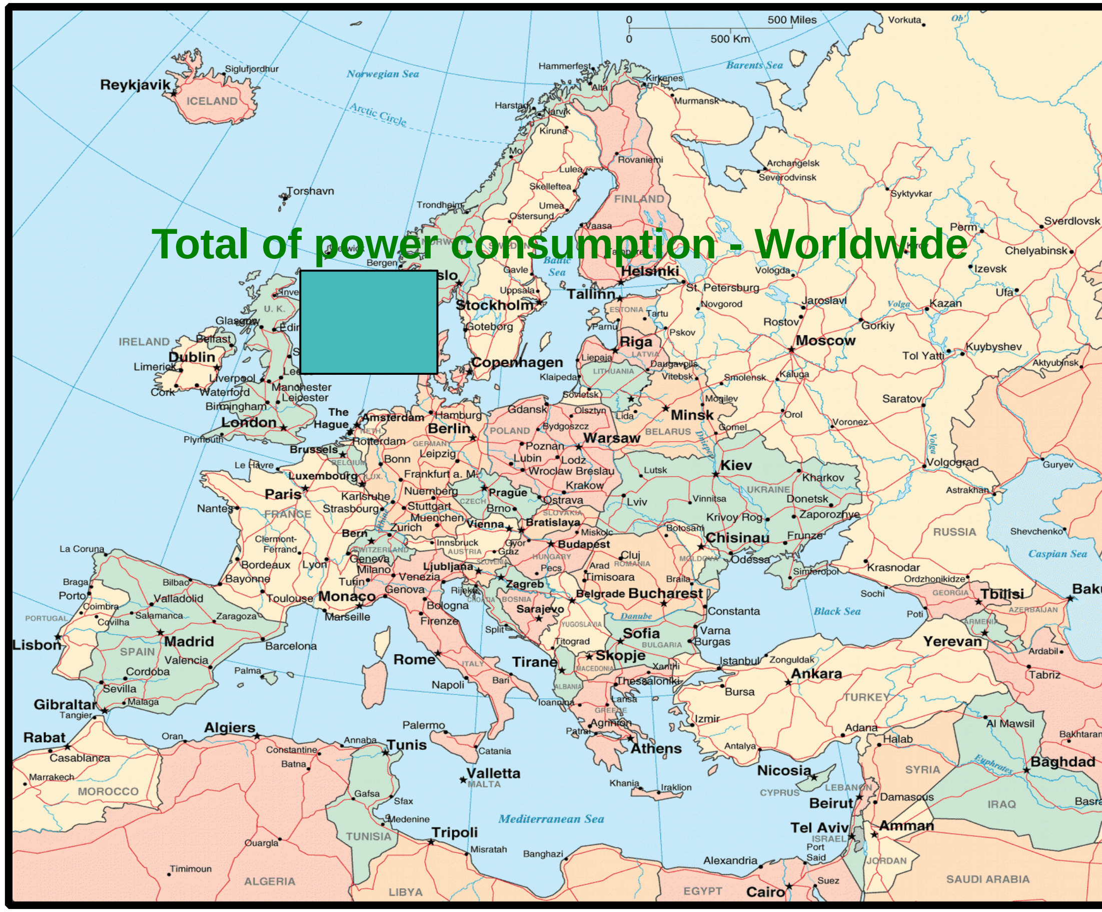
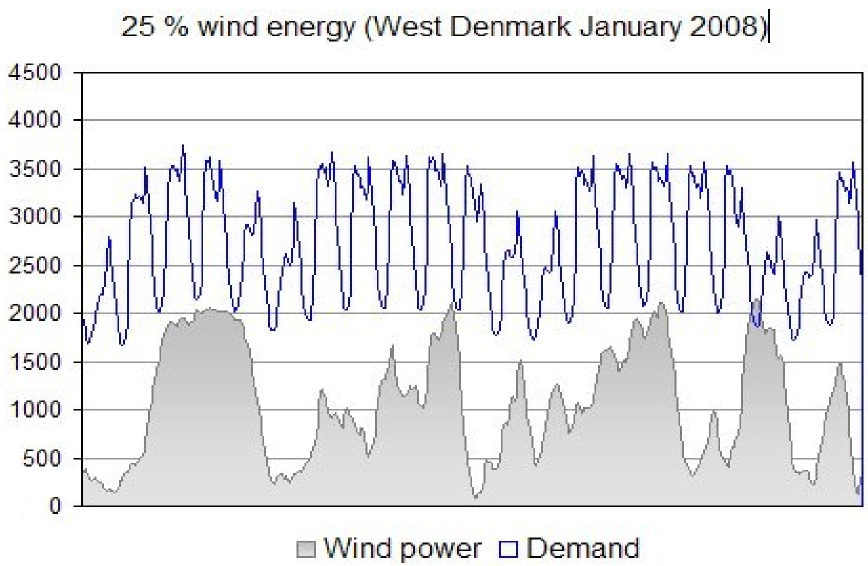
Potentials and Challenges for renewable energy

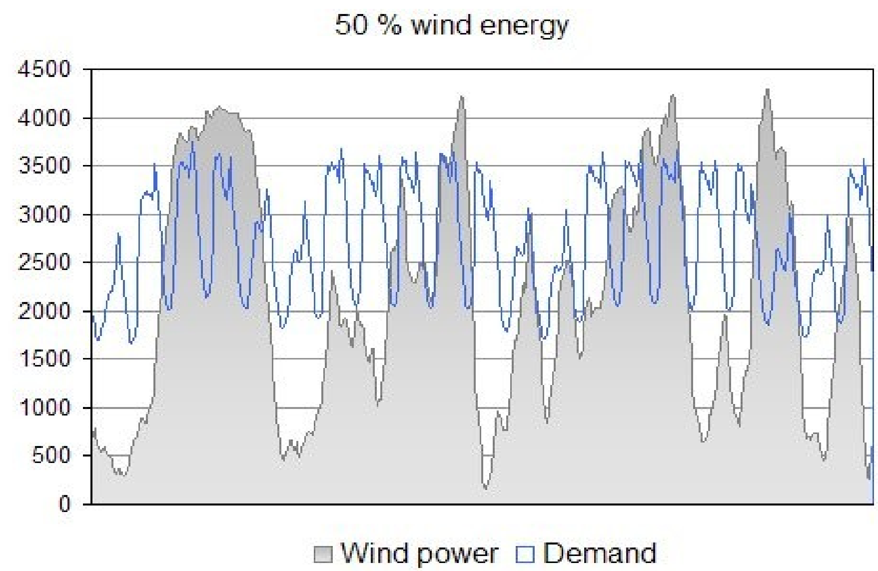
- **Scenario:** We want to cover the worlds entire need for power using wind power
- How large an area should be covered by wind turbines?
- **Conclusion**: Use intelligence ....
- Calls for **IT / Big Data / Smart Cities / Models /** **Energy Systems Integration**



The Danish Wind Power Case

…. balancing of the power system



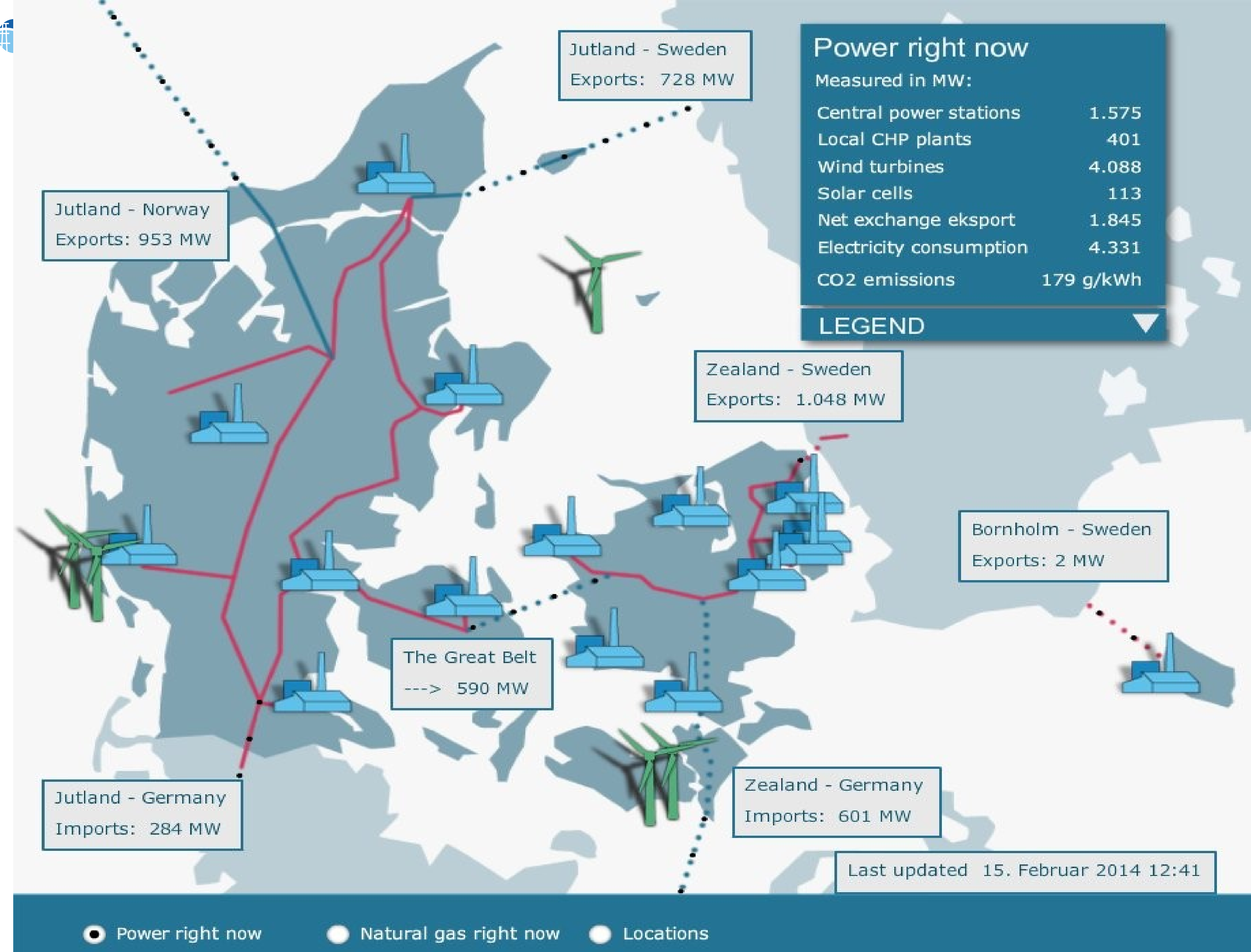


In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)

In 2015 more than 42 pct of electricity load was covered by wind power.

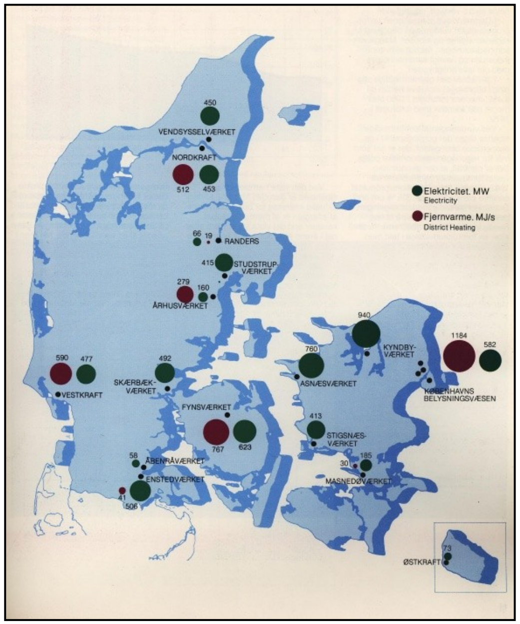
For several days in 2015 the wind power production was more than 120 pct of the power load.

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

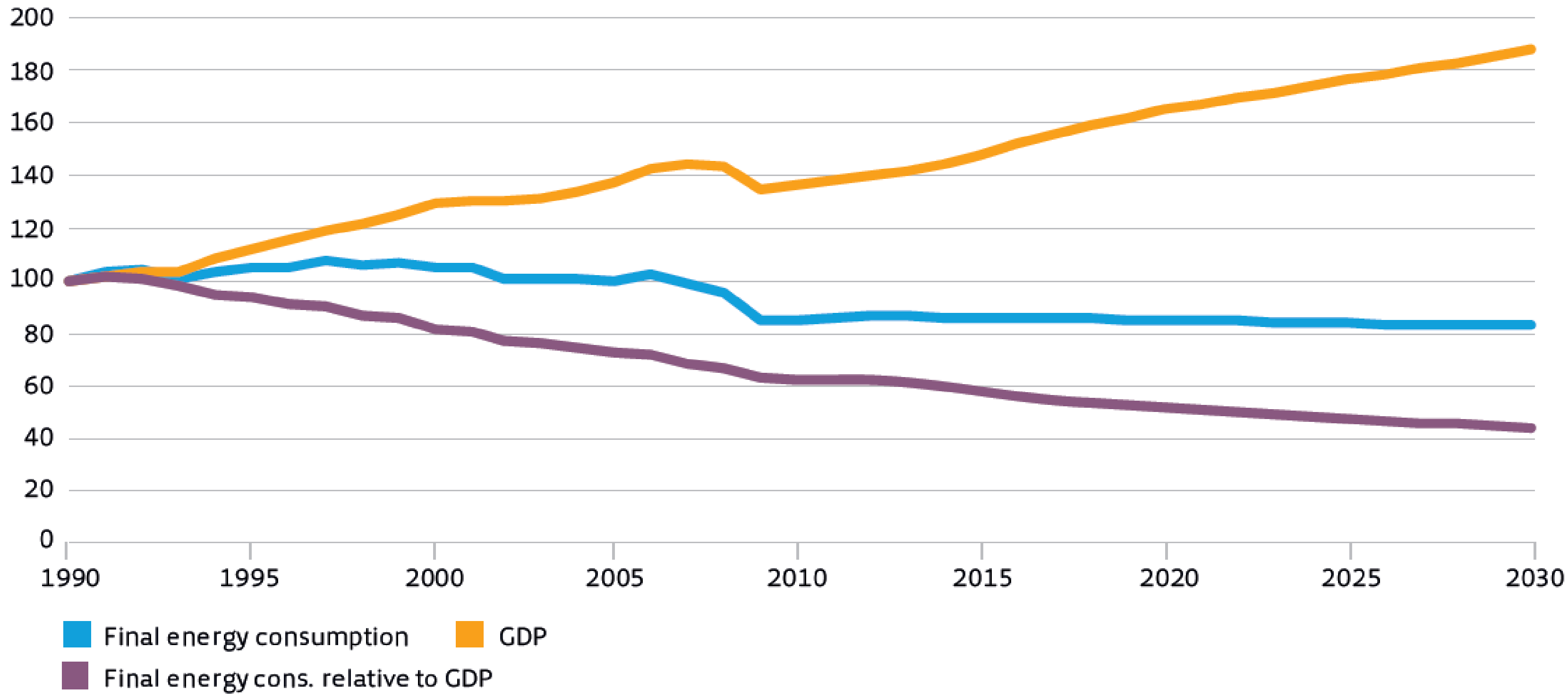
1980



Today

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

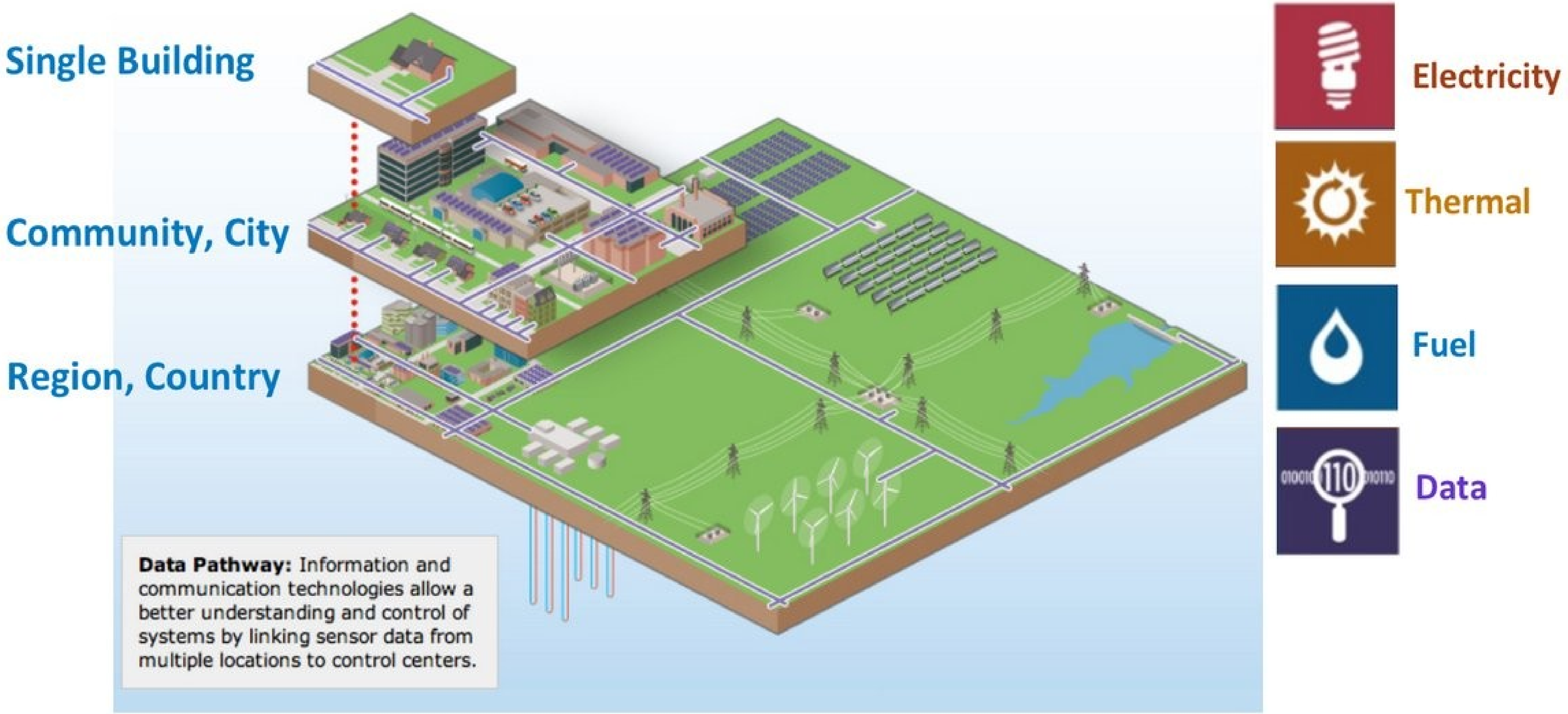
What has since been achieved: De-coupling of consumption and GDP growth



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

Energy Systems Integration in Smart Cities

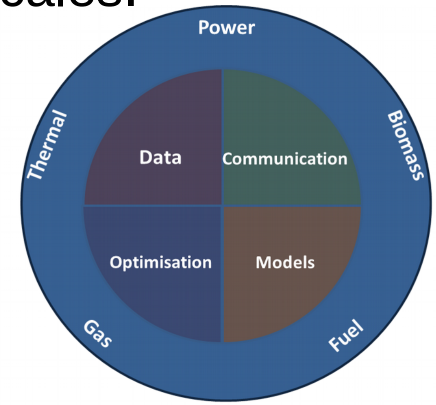
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



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.



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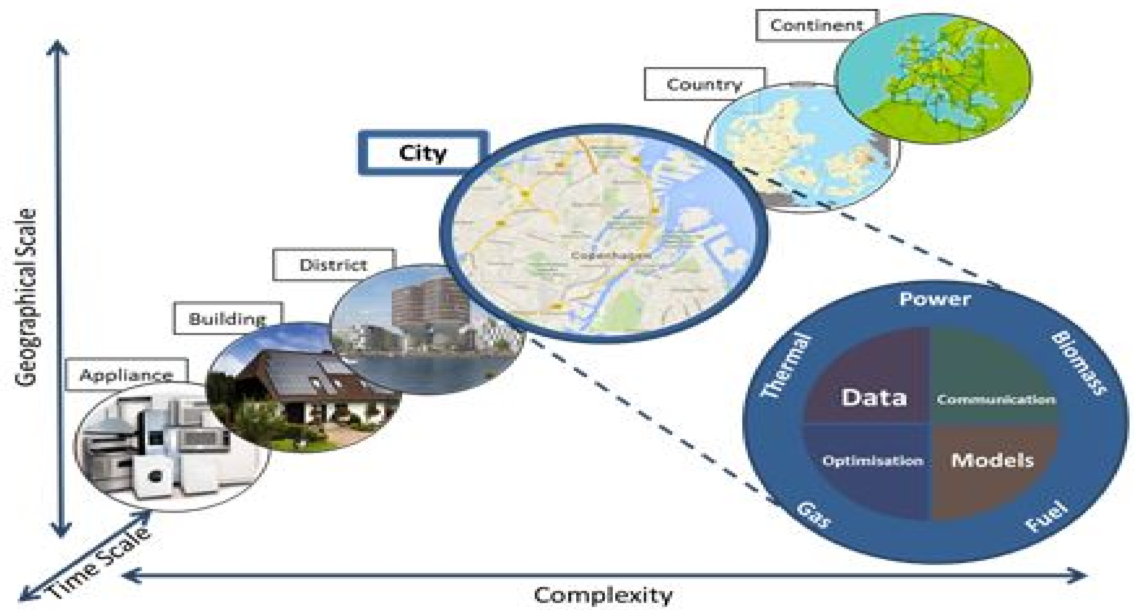
ESI Solutions

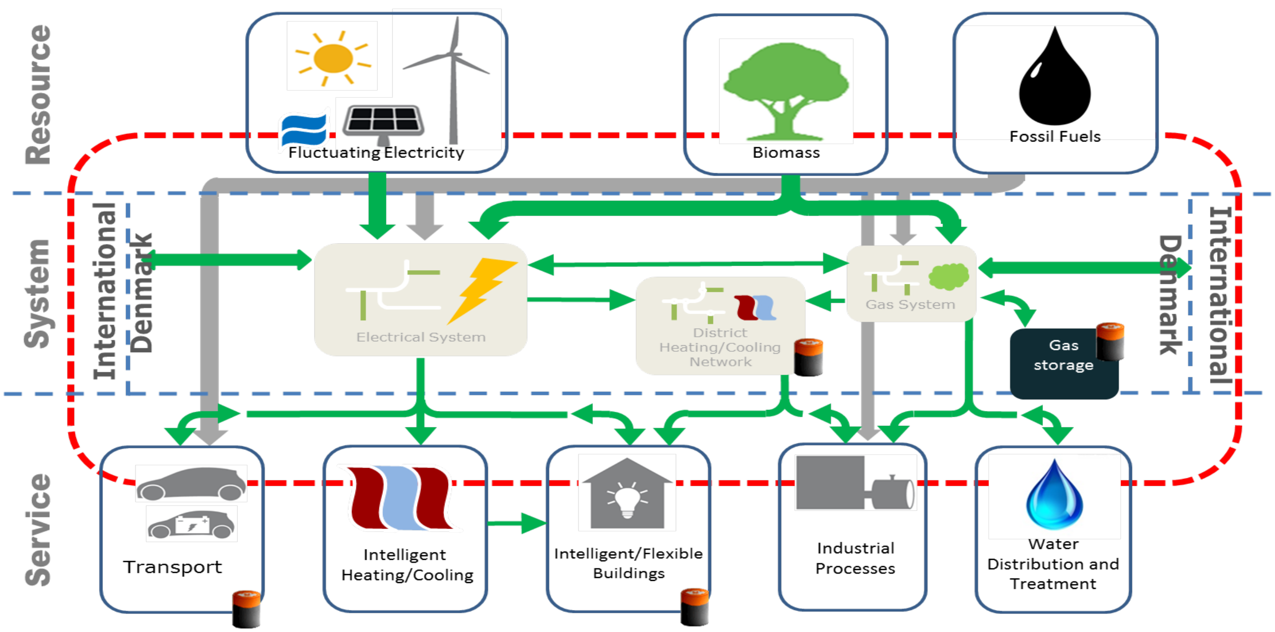
The ***Center for IT-Intelligent Energy Systems in Cities (CITIES)*** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

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

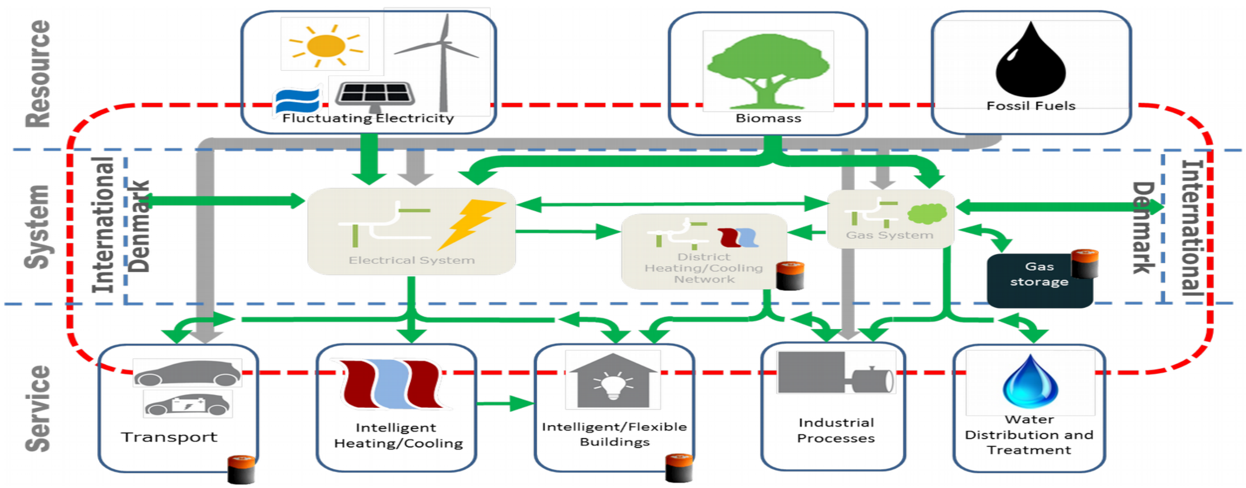


ESI – Concepts

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



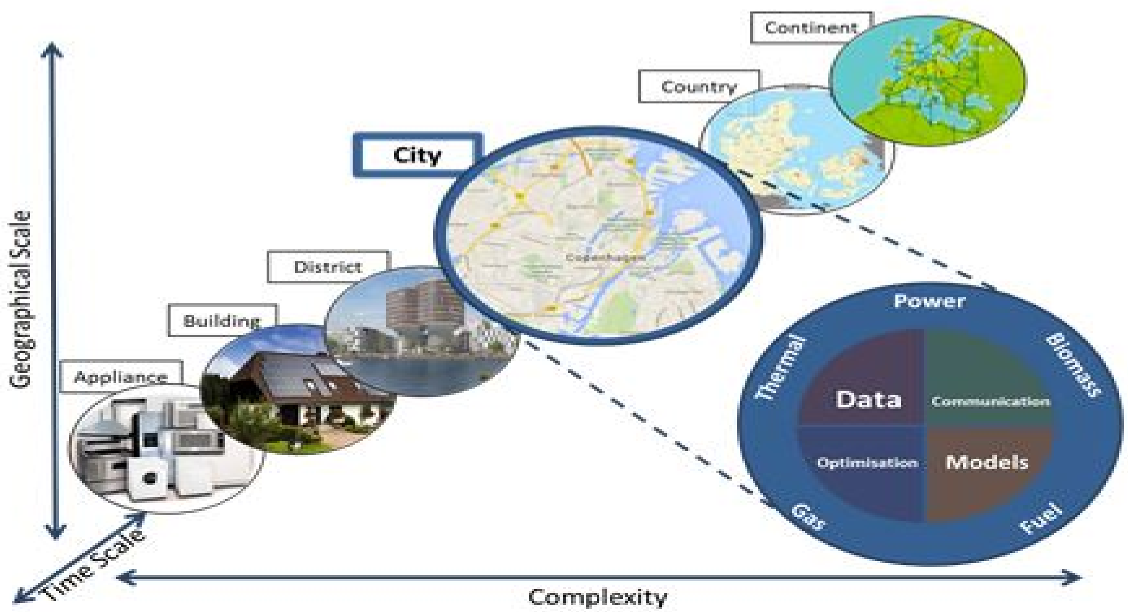
(Virtual) Storage Solutions



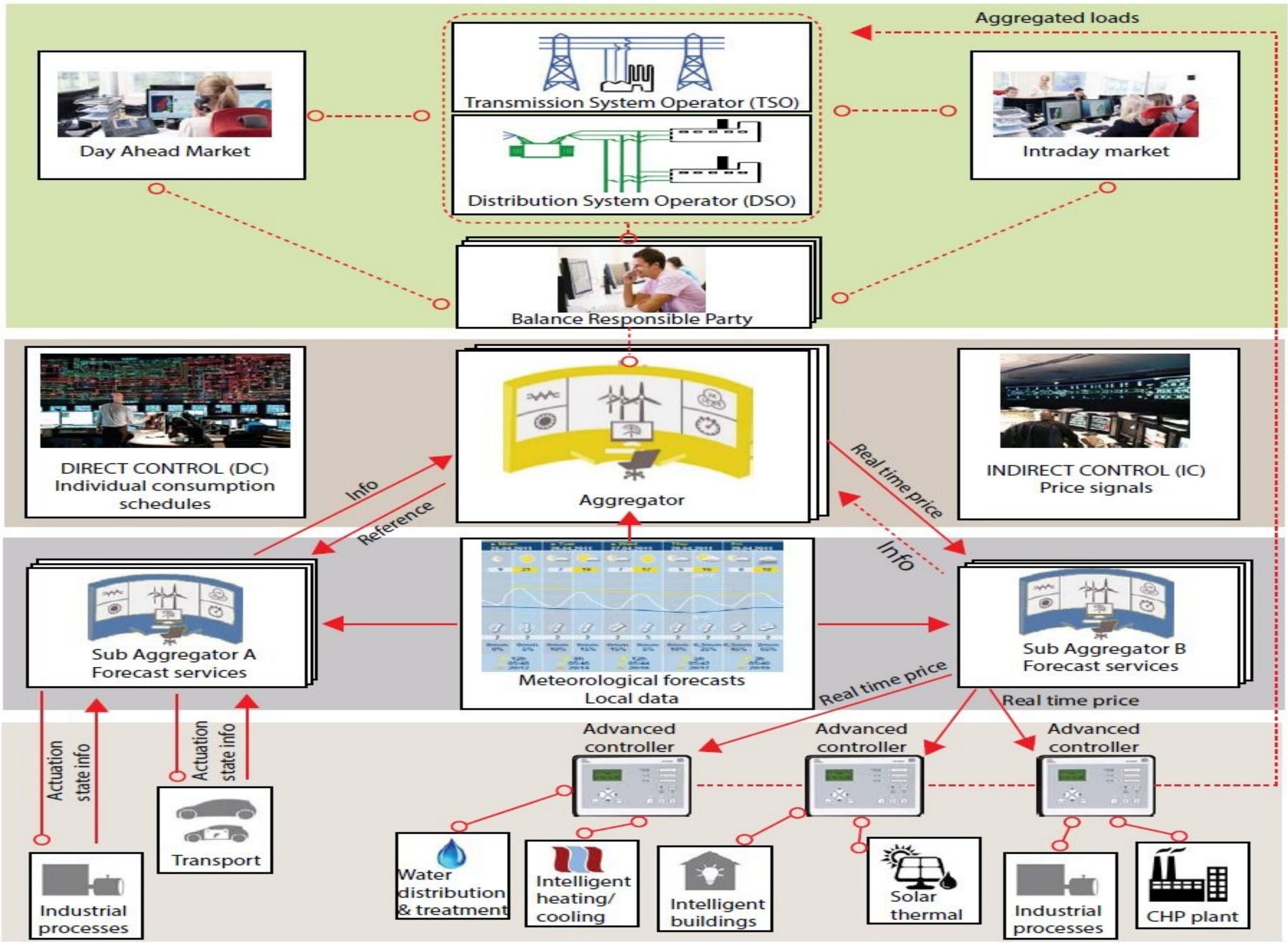
- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - DH systems with thermal solar collectors can often provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions

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**.

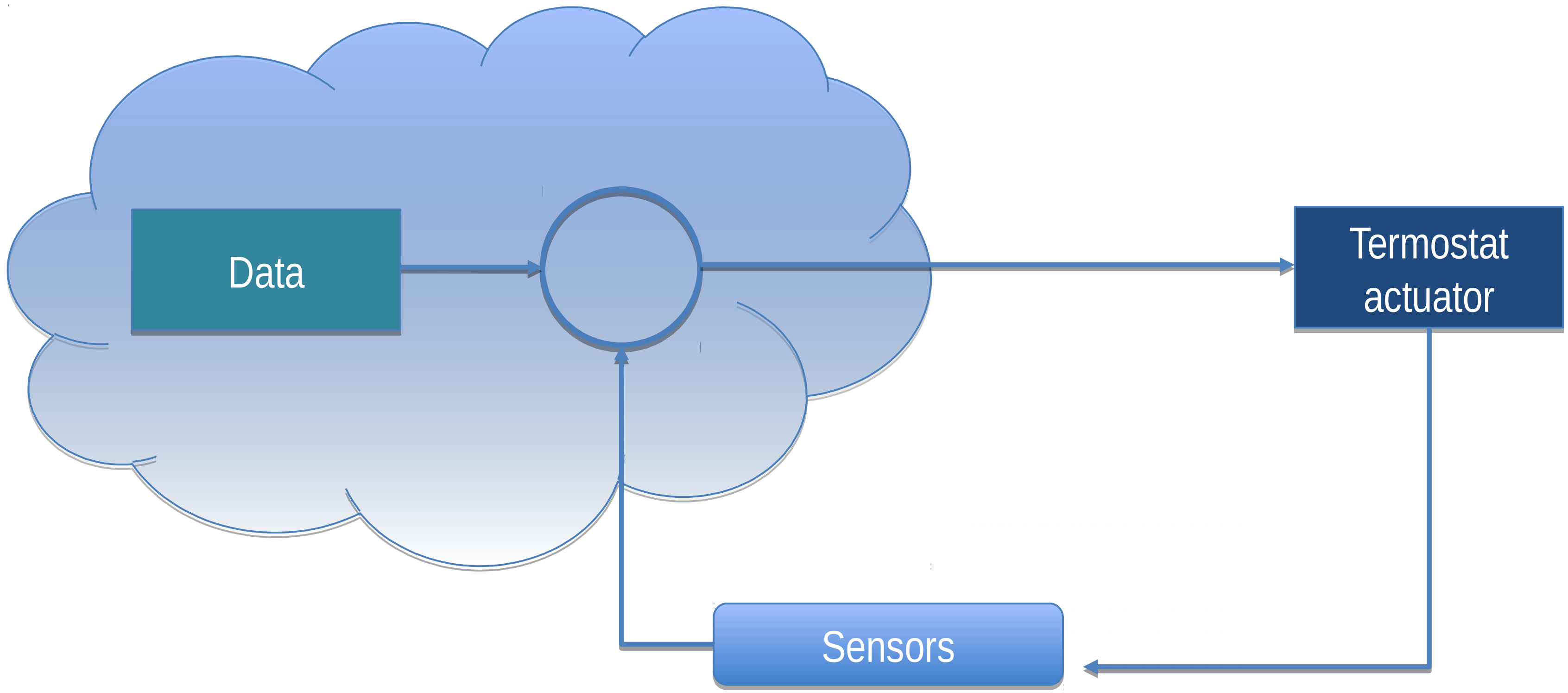


Smart-Energy OS



Maximizes the flexibility – Simple communication – No contracts
Ref: Wiley Book, DTU Annual Report, and several IEEE papers

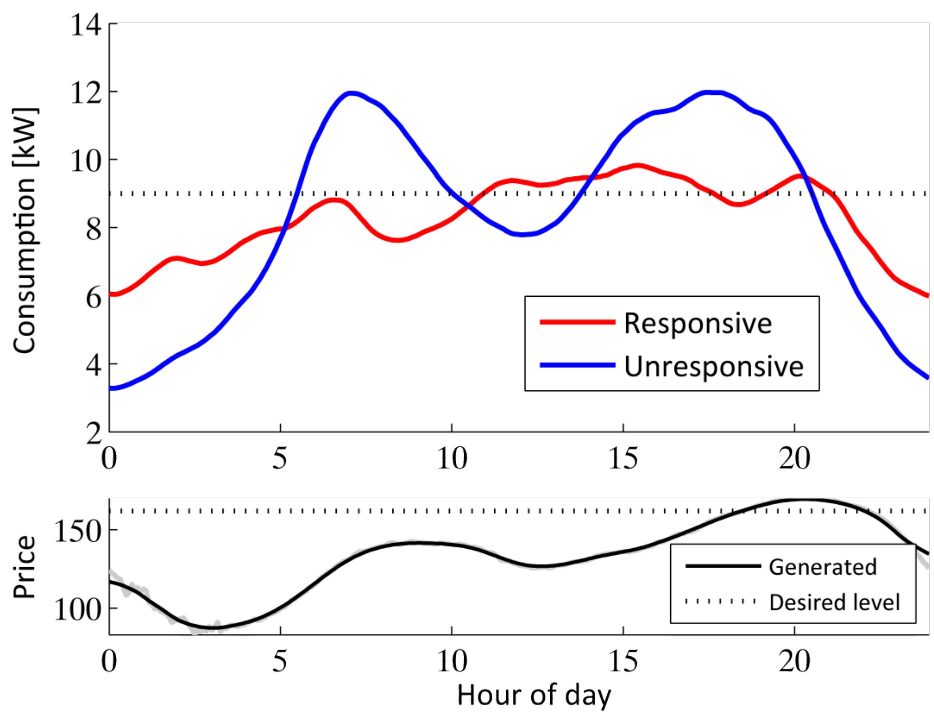
SE-OS
Control loop design – **logical drawing**



Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift



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Case study

Control of Power Consumption Using Summer Houses with a Pool (H2020 SmartNet Project)

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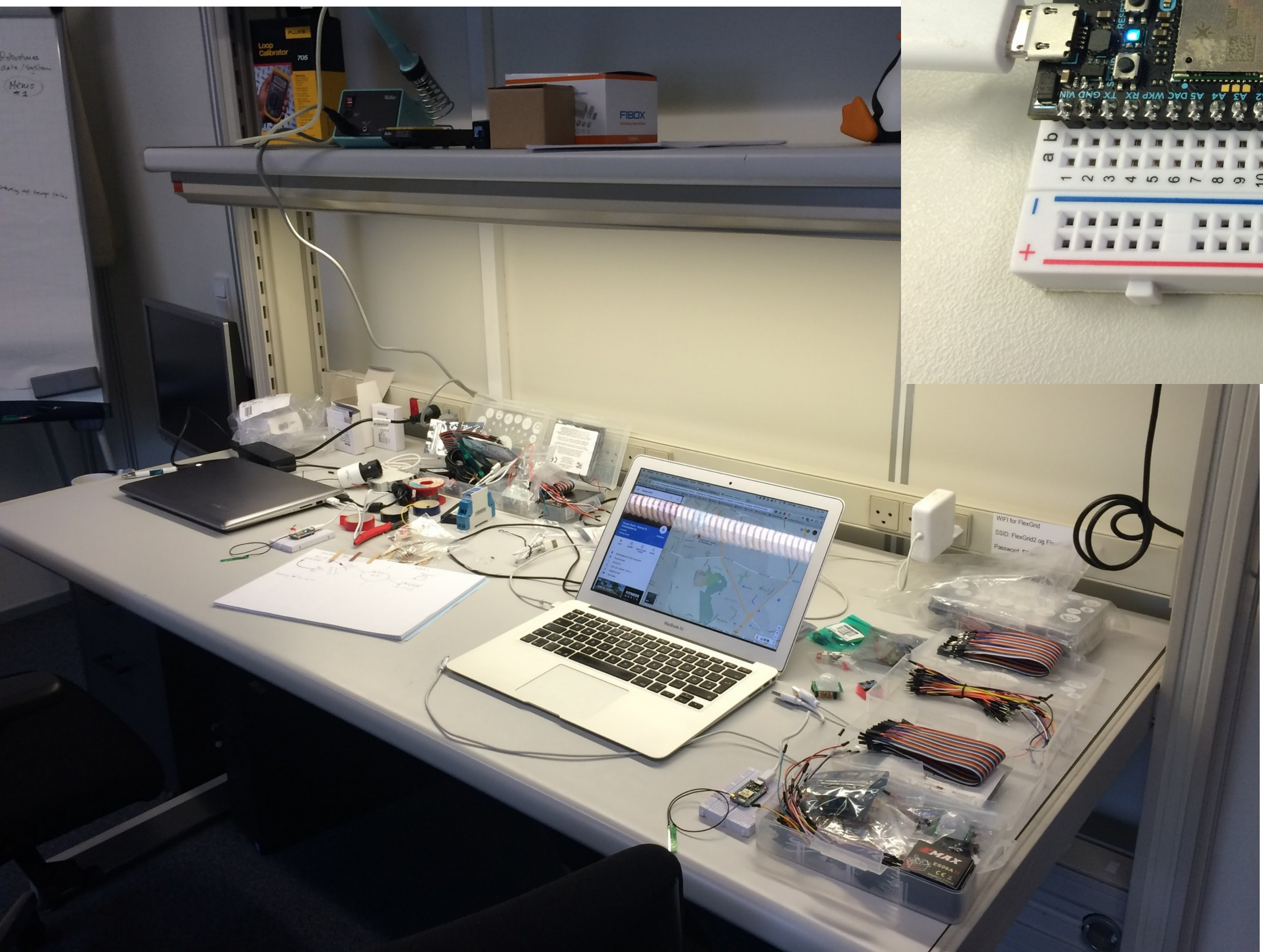
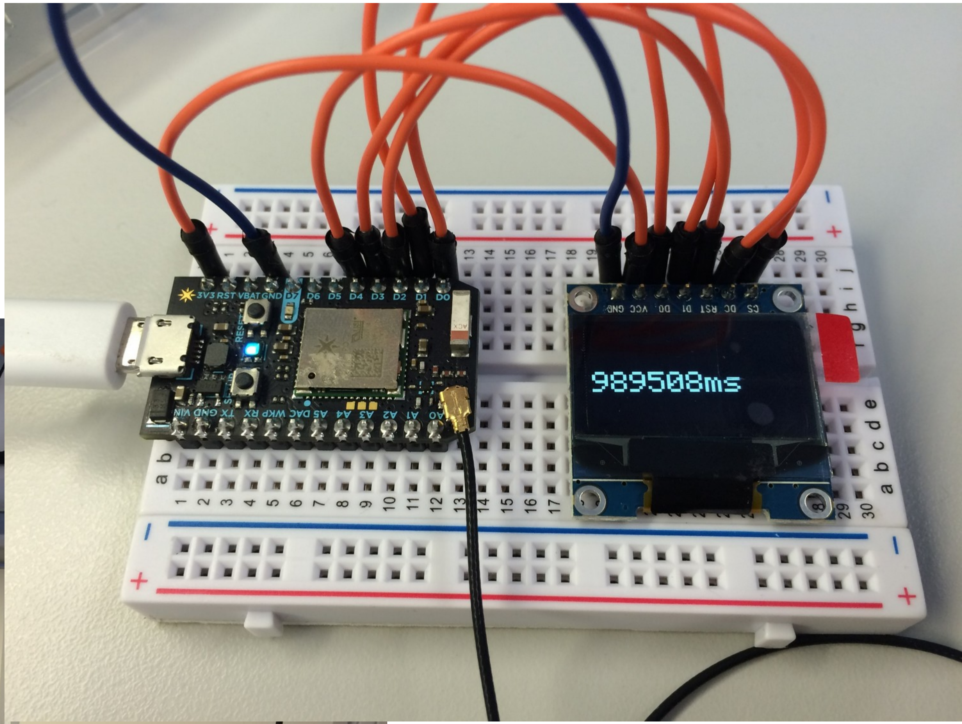
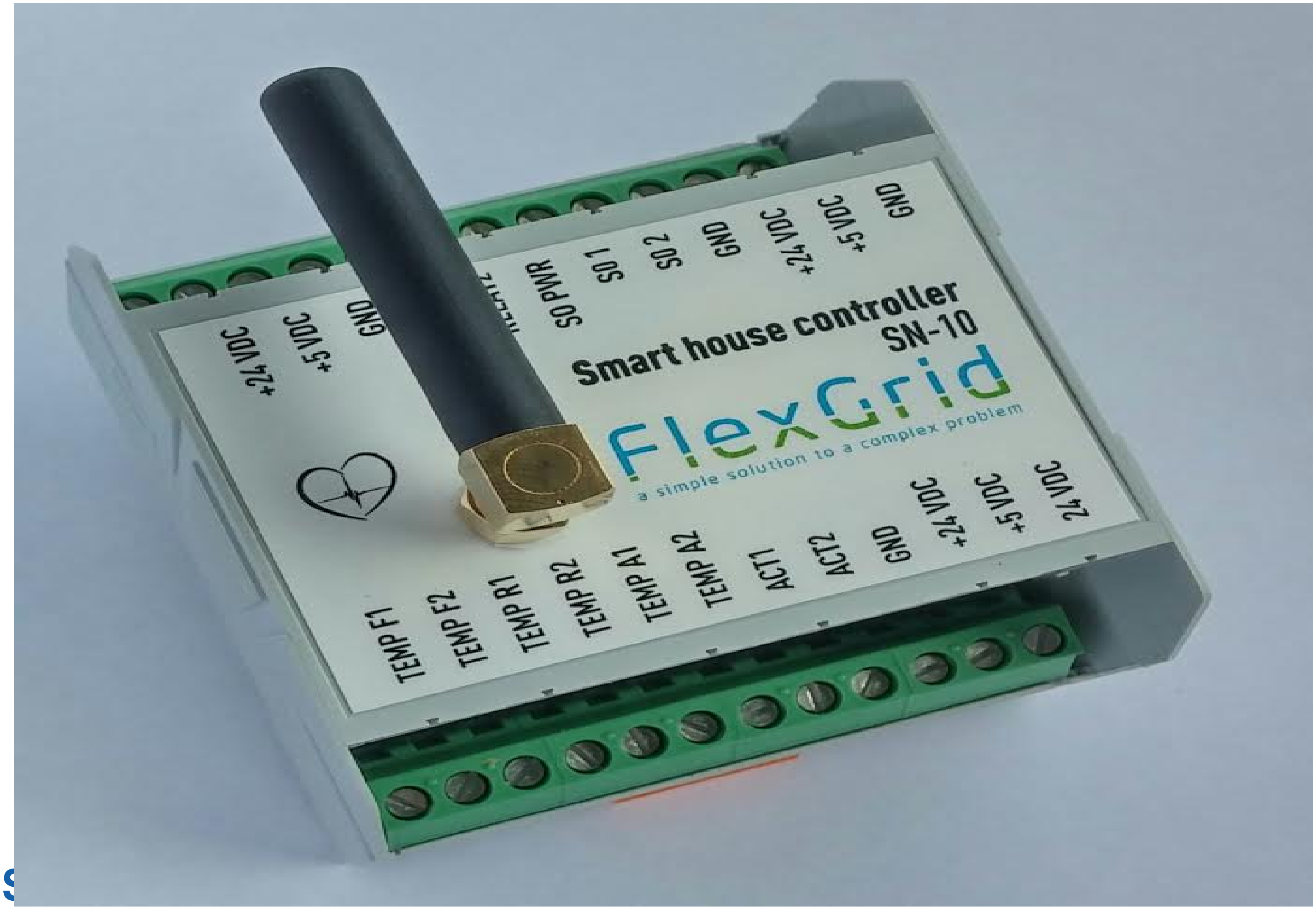
Lab testing ....



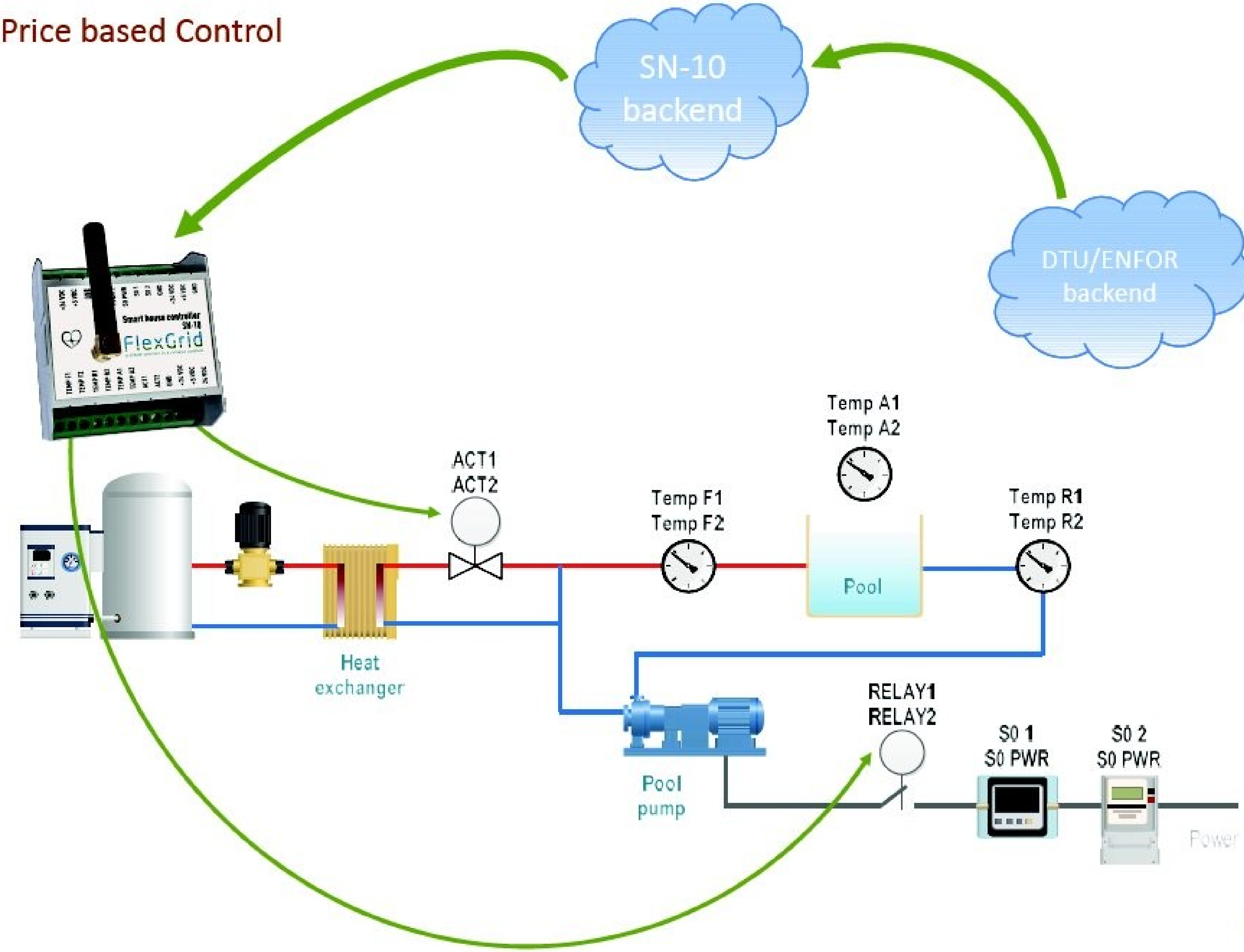


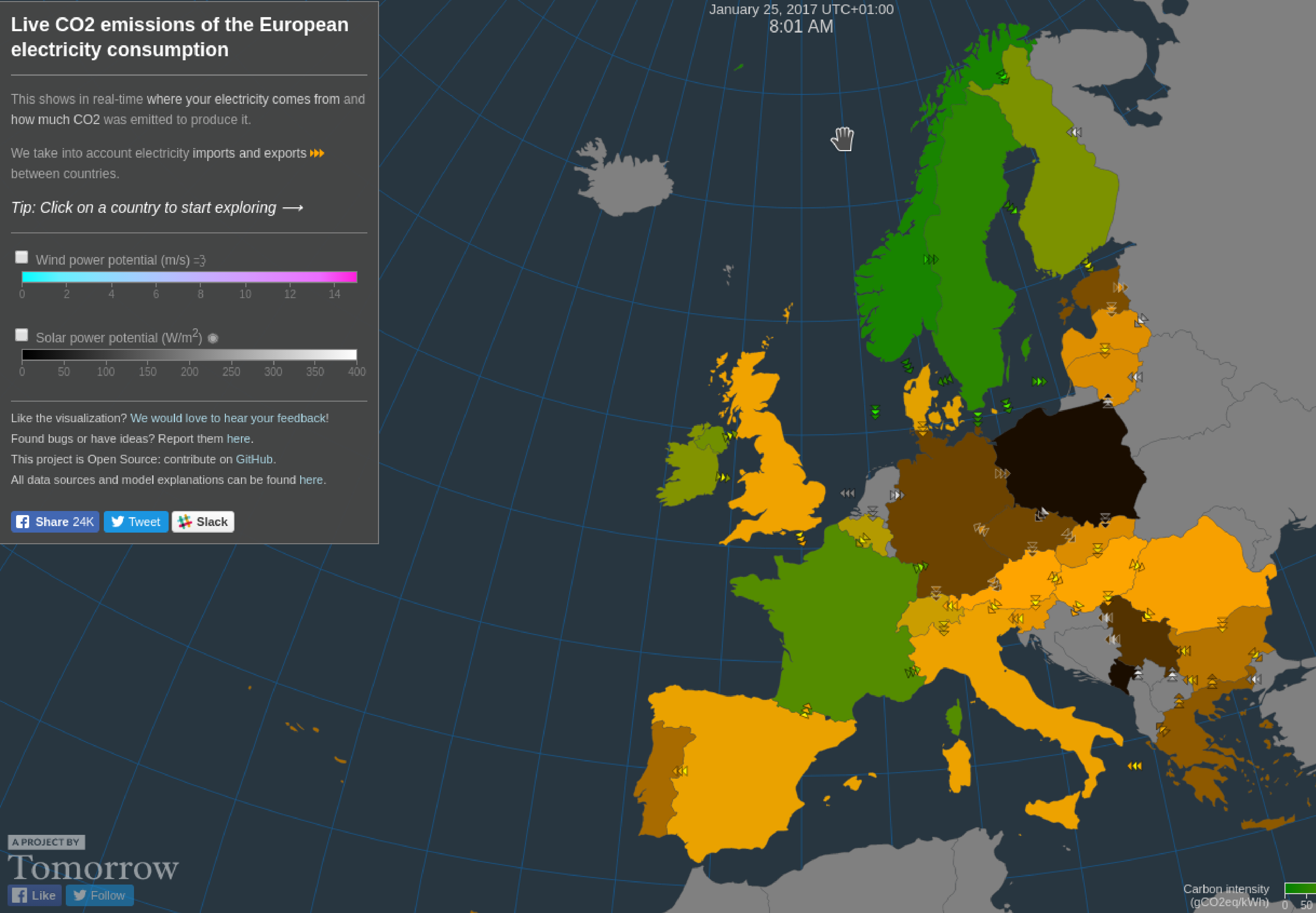
SN-10 Smart House Prototype



How does it work?

Price based Control





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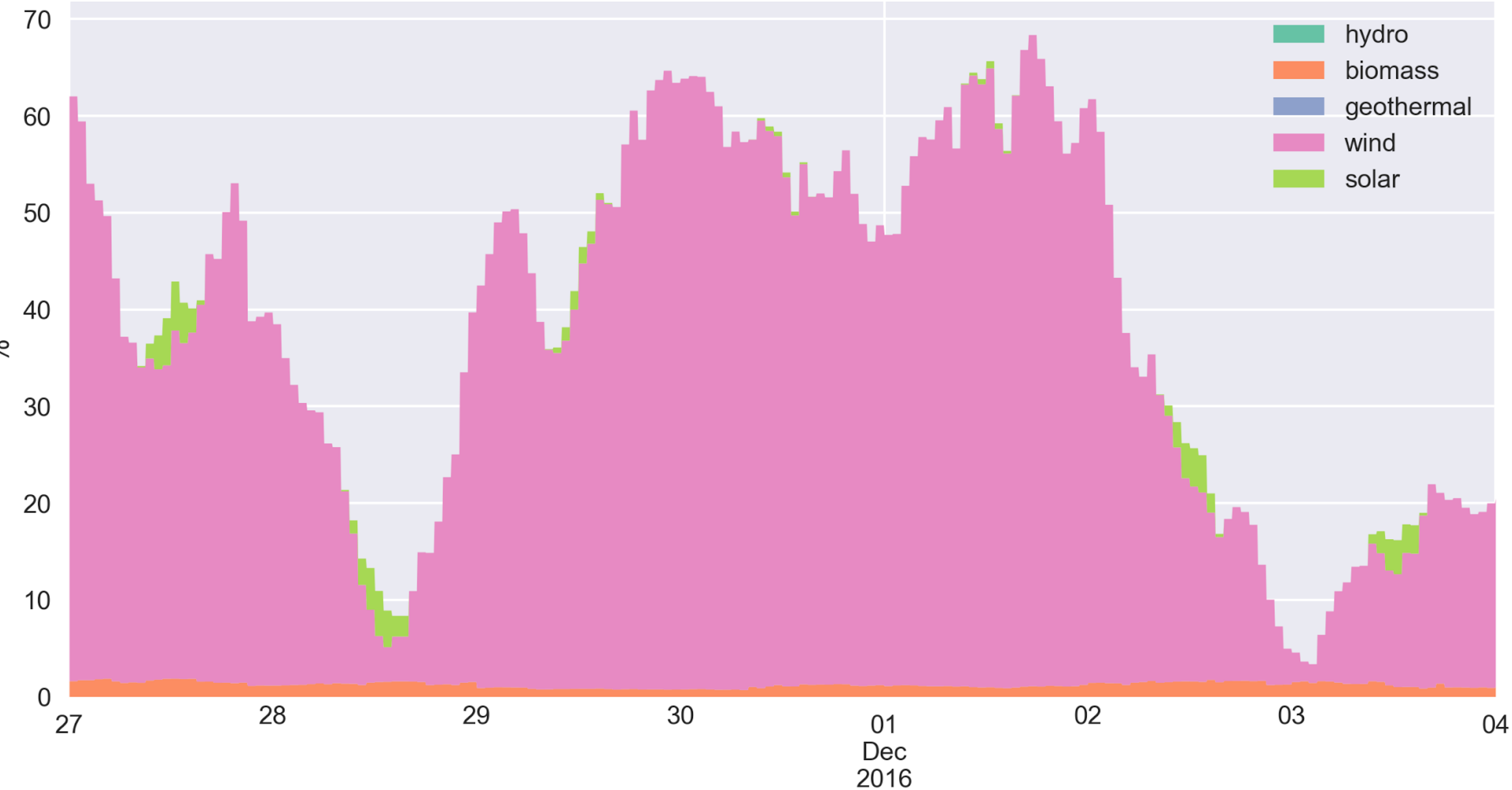
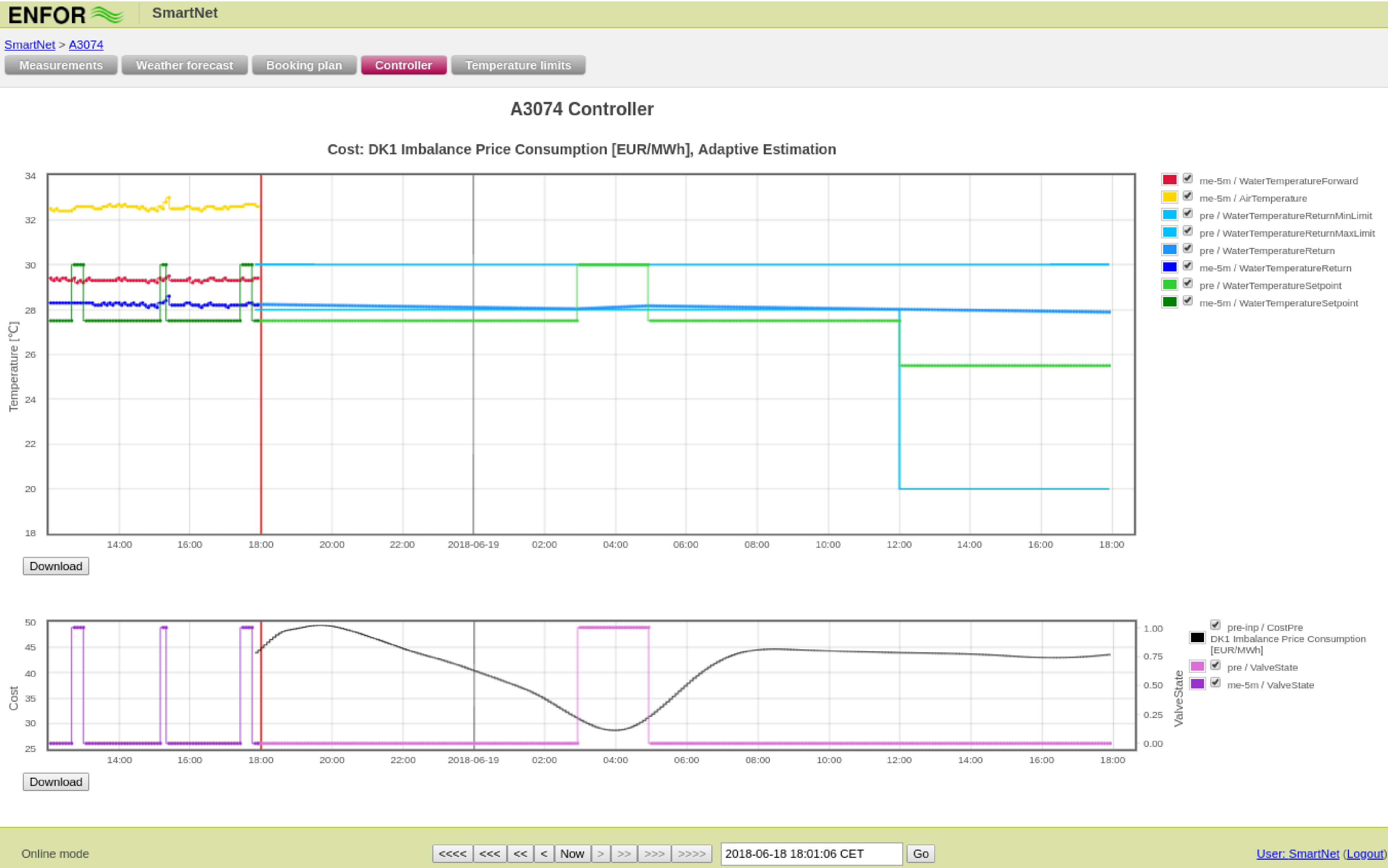
Share of electricity originating from renewables in Denmark Late Nov 2016 - Start Dec 2016



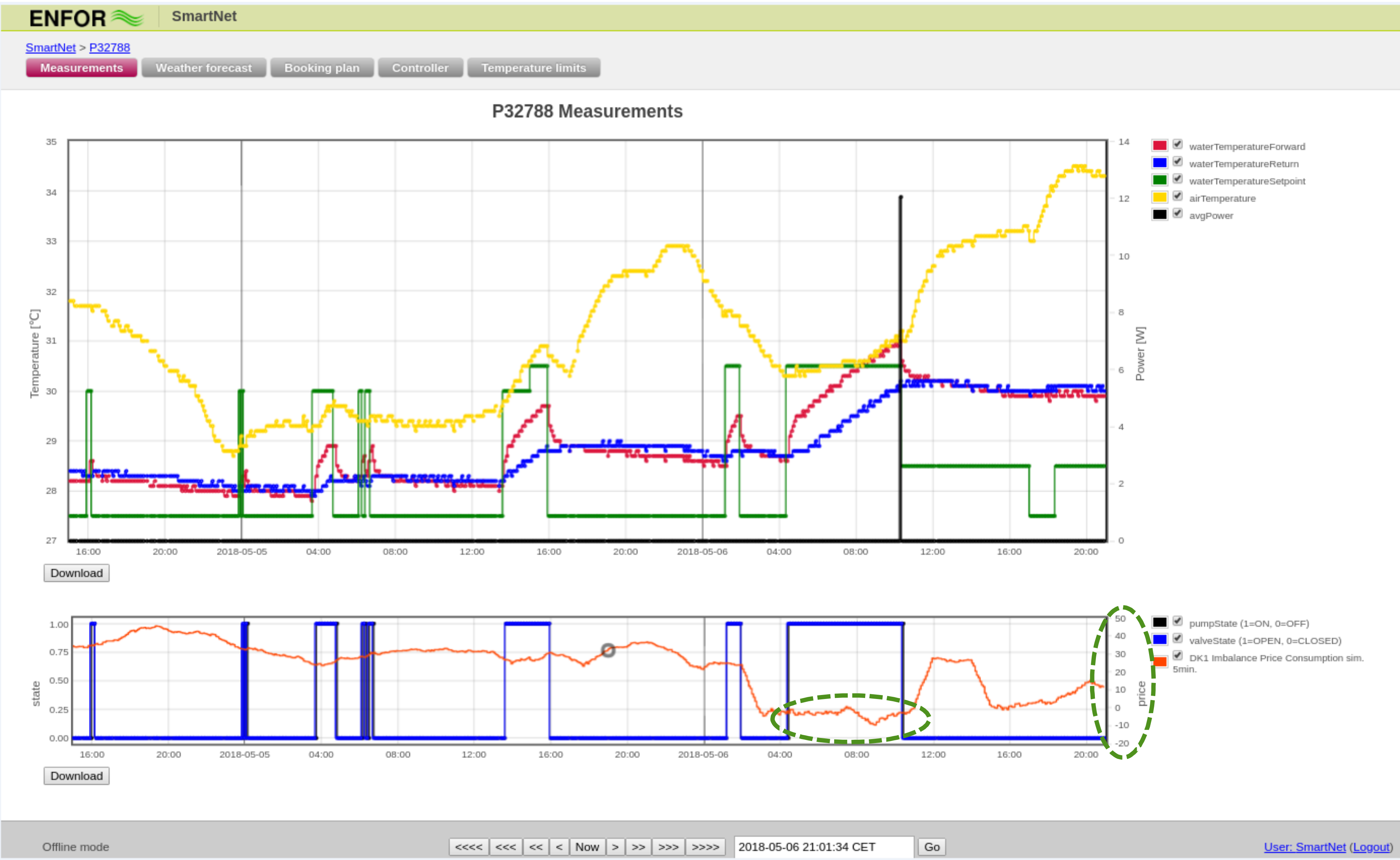
Source: pro.electicitymap.org

Example: Price-based control



Example: CO2-based control

Example with negative power prices



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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

CITIES INNOVATION CENTER

Integrated energy systems powered by intelligent data

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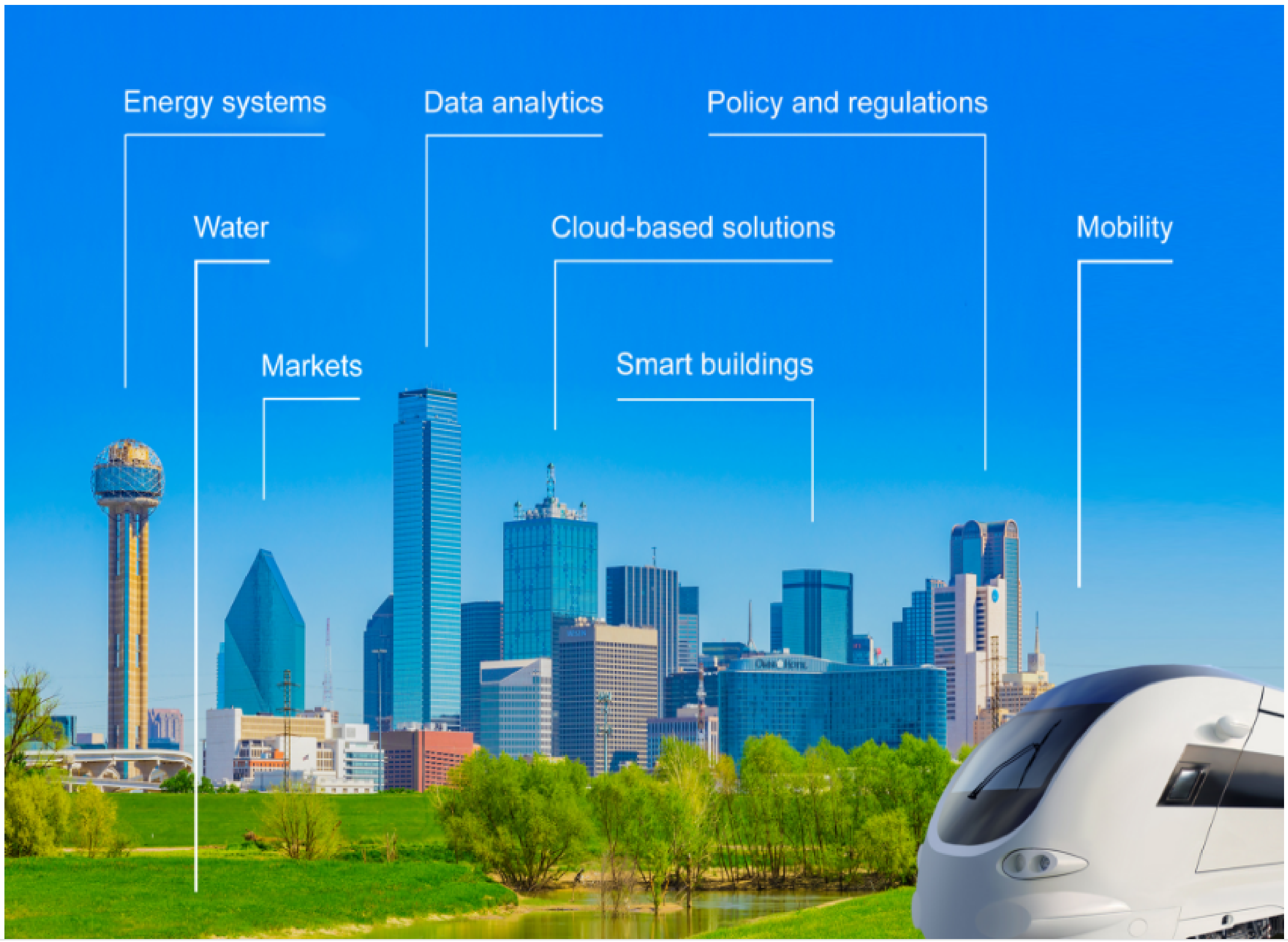
Topics



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)