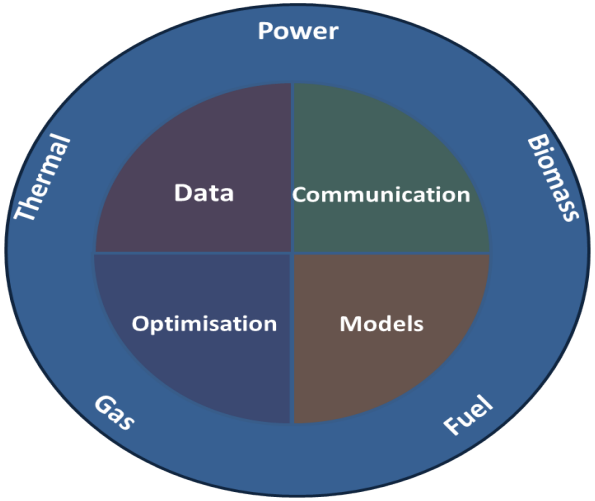
Intelligent Energy Systems Integration

Chinese Mayors Visit on DTU



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

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

http://smartnet-project.eu

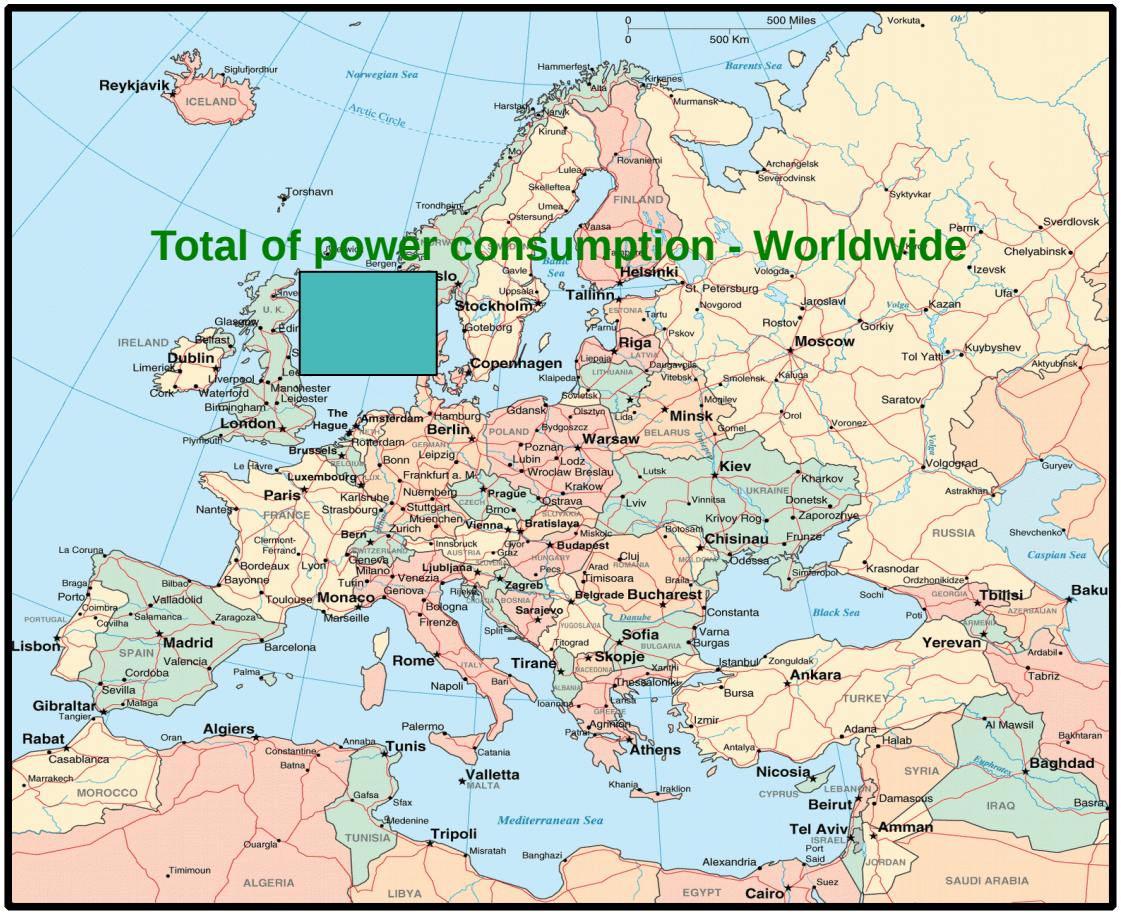
Potentials and Challenges for renewable energy

- **Scenario**: We want to cover the worlds entire need for power using wind power.
- How large an area should be covered by wind turbines?

Reykjavik
ICELAND
Norwegian Sea
Barents Sea
Arctic Circle
Torshavn
Lerwick
Oslo
Stockholm
Helsinki
Tallinn
Riga
Copenhagen
Dublin
London
Amsterdam
Hague
Berlin
Warsaw
Brussels
Paris
Luxembourg
Frankfurt a. M.
Prague
Vienna
Bratislava
Budapest
Kiev
Minsk
Moscow
St. Petersburg
Bern
Zurich
Munchen
Stuttgart
Strasbourg
Milano
Genova
Monaco
Marseille
Lyon
Toulouse
Barcelona
Madrid
Lisbon
Valladolid
Bilbao
Bordeaux
Nantes
Rome
Napoli
Palermo
Tirane
Sarajevo
Belgrade
Bucharest
Sofia
Skopje
Zagreb
Ljubljana
Chisinau
Odessa
Constanta
Istanbul
Ankara
Izmir
Athens
Nicosia
Beirut
Tel Aviv
Amman
Damascus
Baghdad
Cairo
Alexandria
Tripoli
Tunis
Algiers
Rabat
Casablanca
Valletta
Gibraltar
Sevilla
Malaga
Cordoba
Valencia
Mediterranean Sea
Black Sea
Caspian Sea
Volgograd
Yerevan
Tbilisi
Baku
Ankara
Bursa
Izmir
Adana
Halab
Baghdad
Basra
Amman
Tel Aviv
Cairo
Suez
Alexandria
Tripoli
Tunis
Algiers
Rabat
Casablanca
Marrakech
Oran
Constantine
Batna
Gafsa
Sfax
Medenine
Ghadames
Timimoun
Misratah
Banghazi
Khania
Iraklion
Palermo
Catania
Napoli
Bari
Ioannina
Larisa
Thessaloniki
Agrinion
Patras
Split
Titograd
Sarajevo
Zagreb
Ljubljana
Venezia
Genova
Milano
Torino
Bologna
Firenze
Pisa
Nice
Marseille
Toulouse
Montpellier
Perpignan
Barcelona
Zaragoza
Valladolid
Salamanca
Coimbra
Covilha
Porto
Braga
La Coruna
Bilbao
Bayonne
Clermont-Ferrand
Lyon
Geneva
Bern
Zurich
Innsbruck
Munchen
Stuttgart
Karlsruhe
Strasbourg
Nuremberg
Frankfurt a. M.
Luxembourg
Le Havre
Brussels
Rotterdam
Hague
Amsterdam
Hamburg
Berlin
Leipzig
Bonn
Poznan
Lodz
Wroclaw Breslau
Krakow
Ostrava
Brno
Prague
Vienna
Bratislava
Miskolc
Gyor
Budapest
Pecs
Cluj
Arad
Timisoara
Braila
Constanta
Varna
Burgas
Sofia
Skopje
Titograd
Sarajevo
Zagreb
Ljubljana
Split
Rijeka
Trieste
Venezia
Genova
Milano
Torino
Nice
Monaco

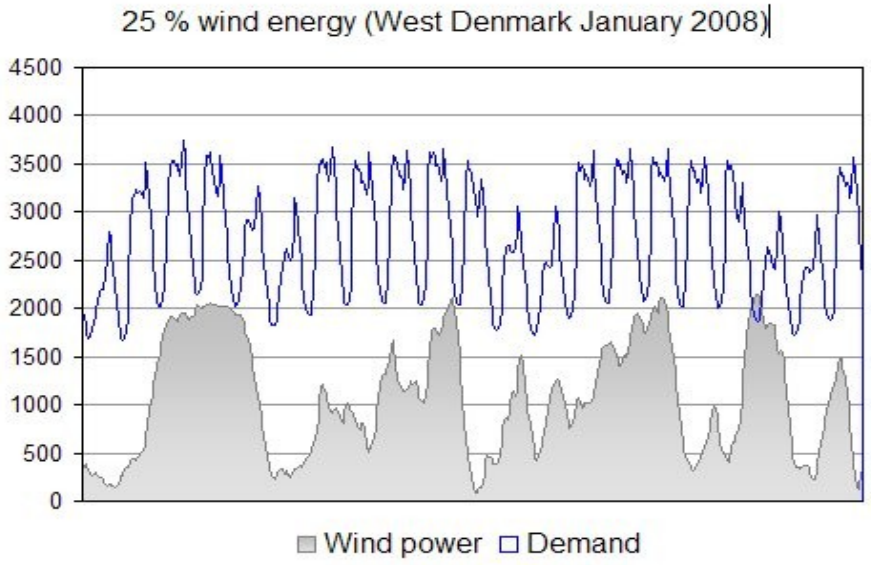
Potentials and Challenges for renewable energy

- **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 Grids / Models / Energy Systems Integration**

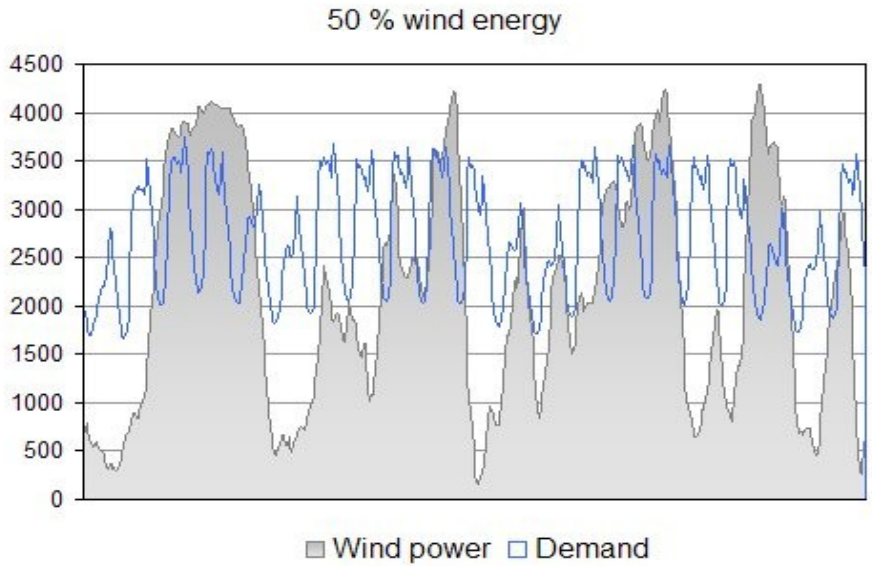


The Danish Wind Power Case

…. balancing of the power system



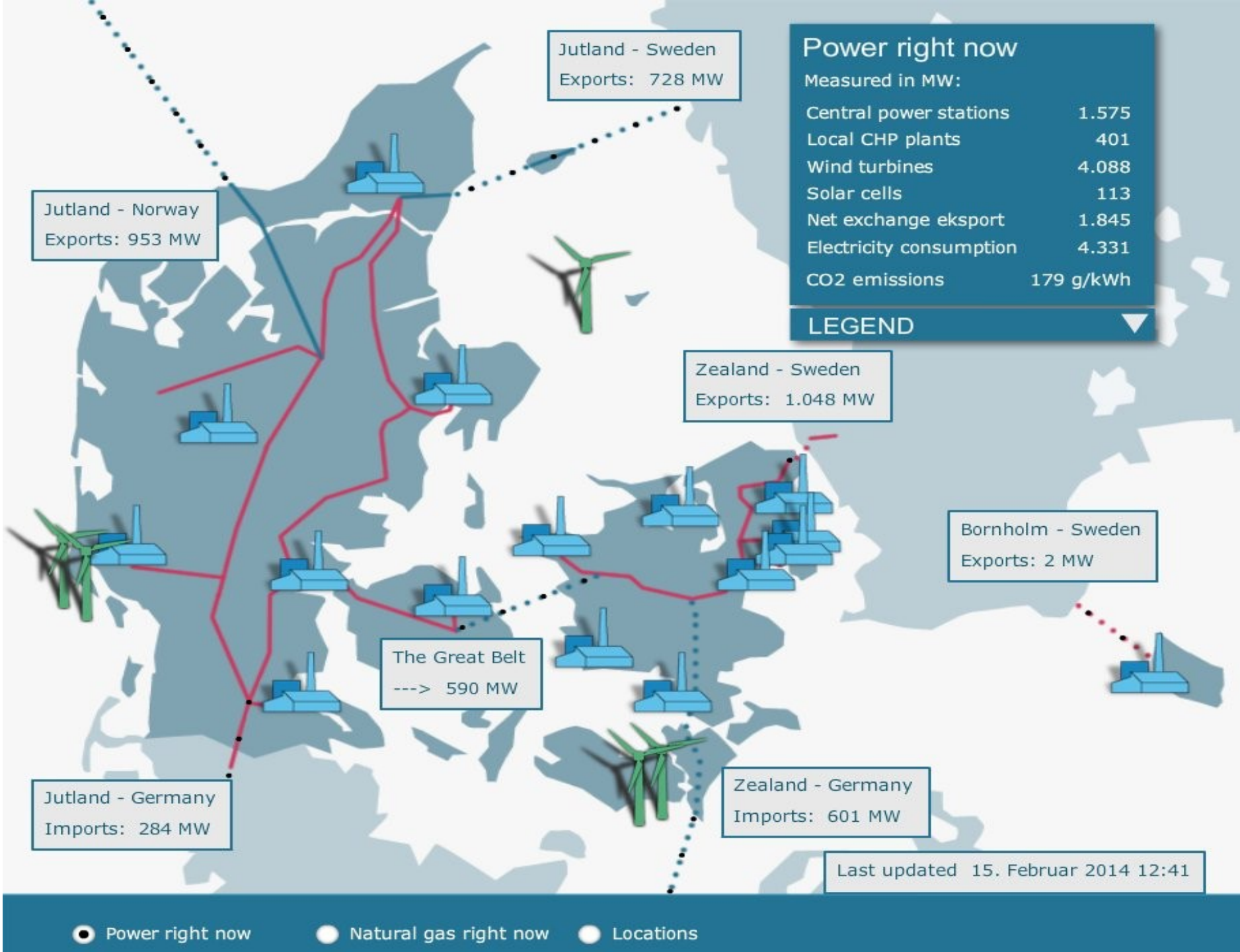
In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)



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

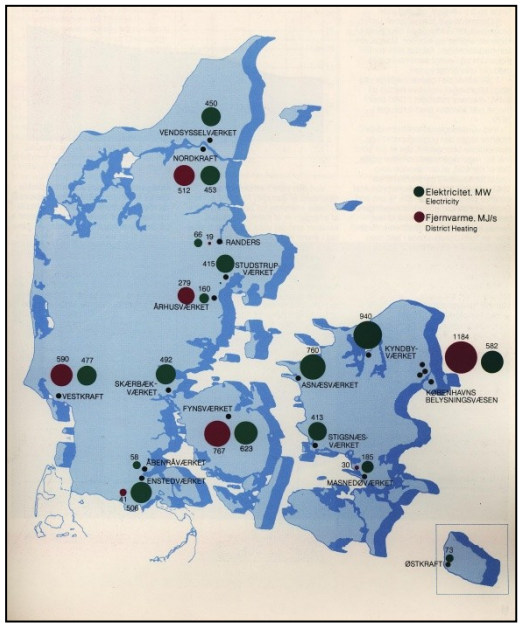
For several days in 2015 the wind power production was more than 120 pct of the power load.

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

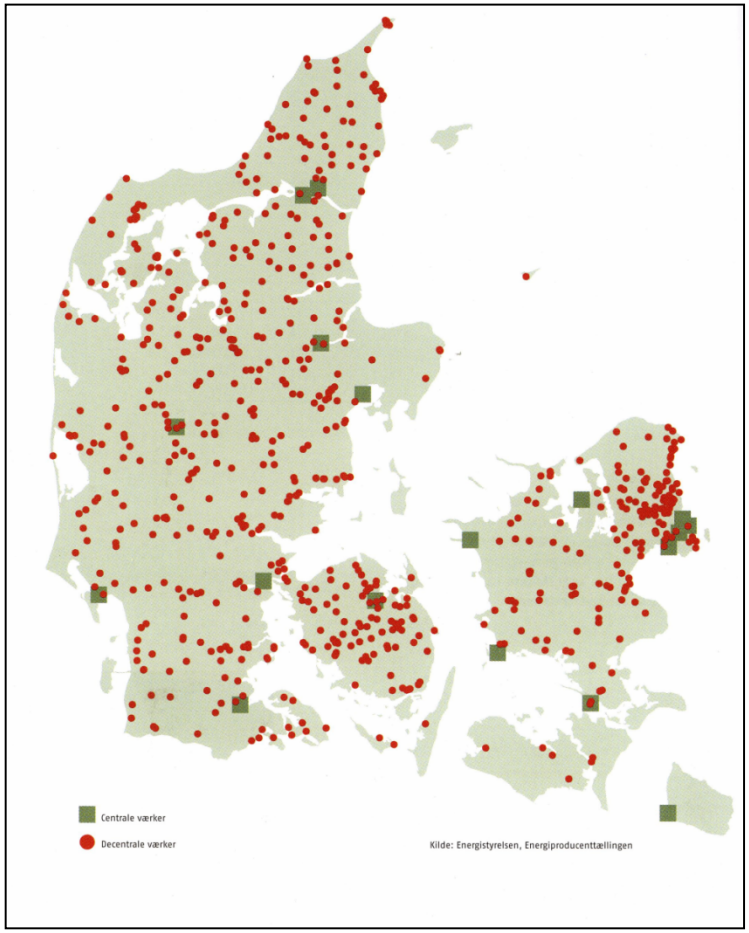

Jutland - Sweden
Exports: 728 MW
Power right now
Measured in MW:
Central power stations 1.575
Local CHP plants 401
Wind turbines 4.088
Solar cells 113
Net exchange eksport 1.845
Electricity consumption 4.331
CO2 emissions 179 g/kWh
LEGEND
Jutland - Norway
Exports: 953 MW
Zealand - Sweden
Exports: 1.048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

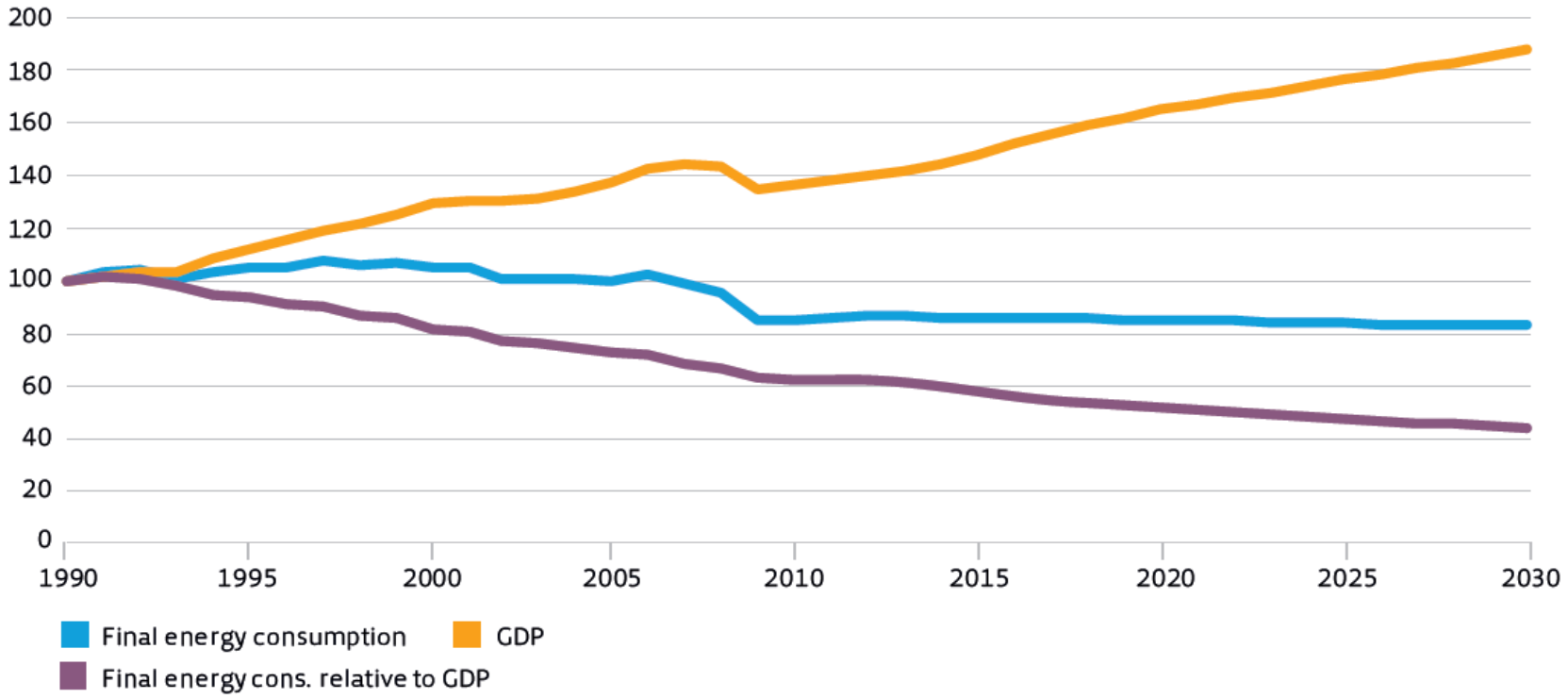


Today



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

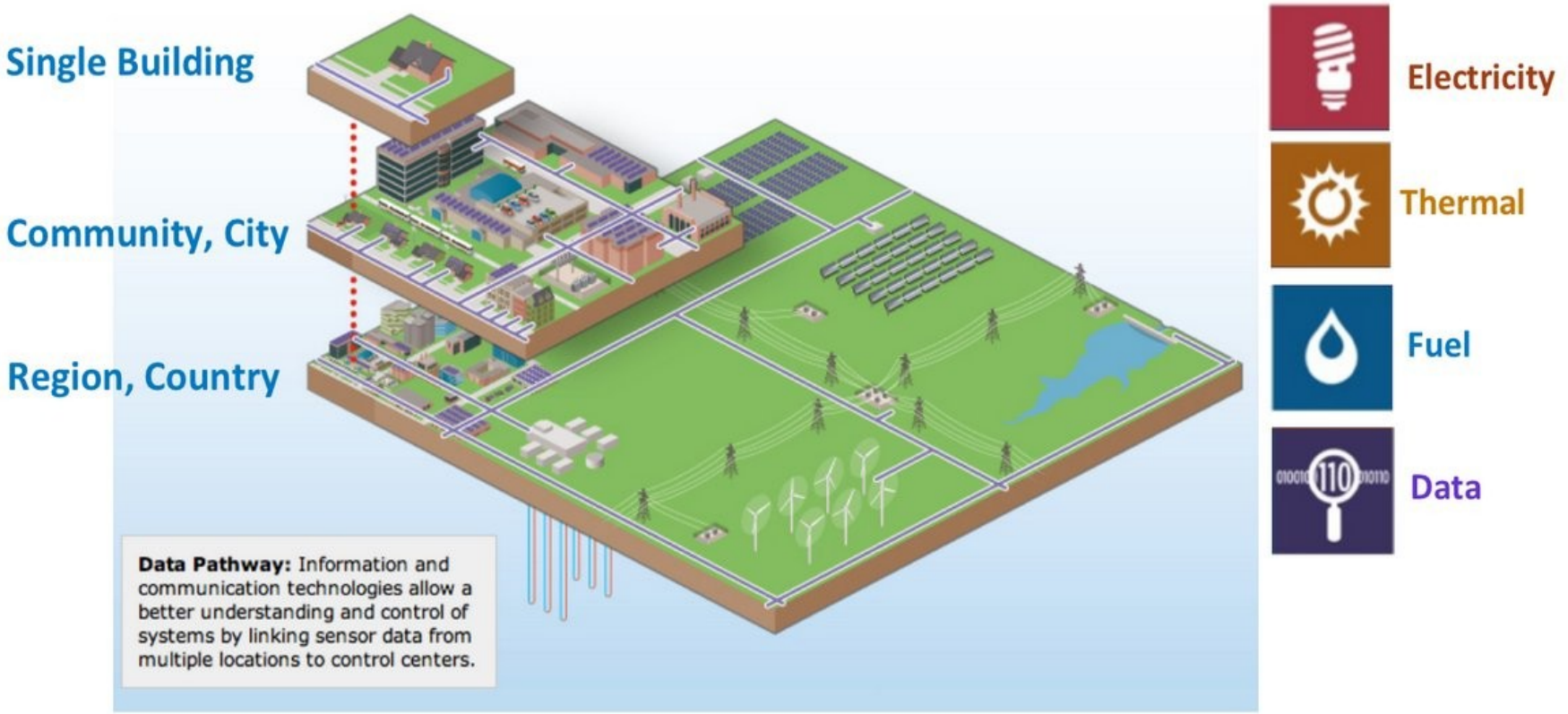
What has since been achieved: De-coupling of consumption and GDP growth



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

Energy Systems Integration in Smart Cities

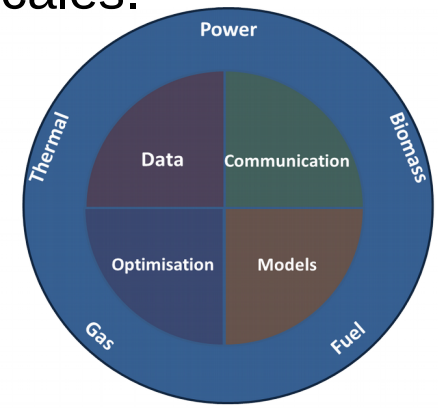
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



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.

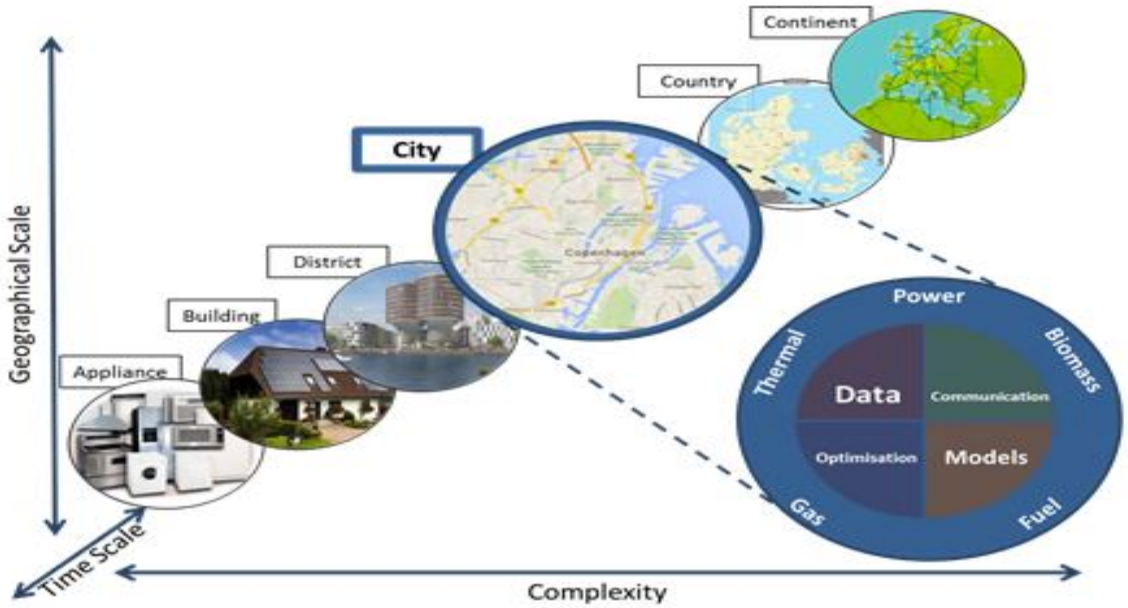
Intelligent integration will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.



ESI Solutions

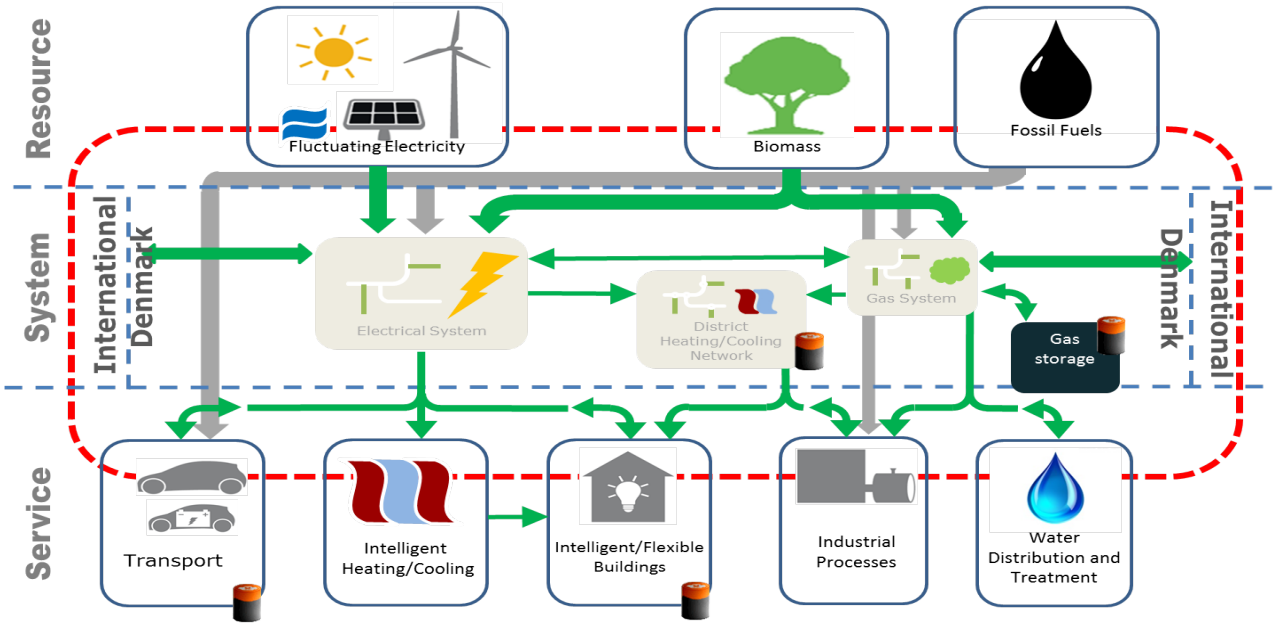
The ***Center for IT-Intelligent Energy Systems in Cities (CITIES)*** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

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

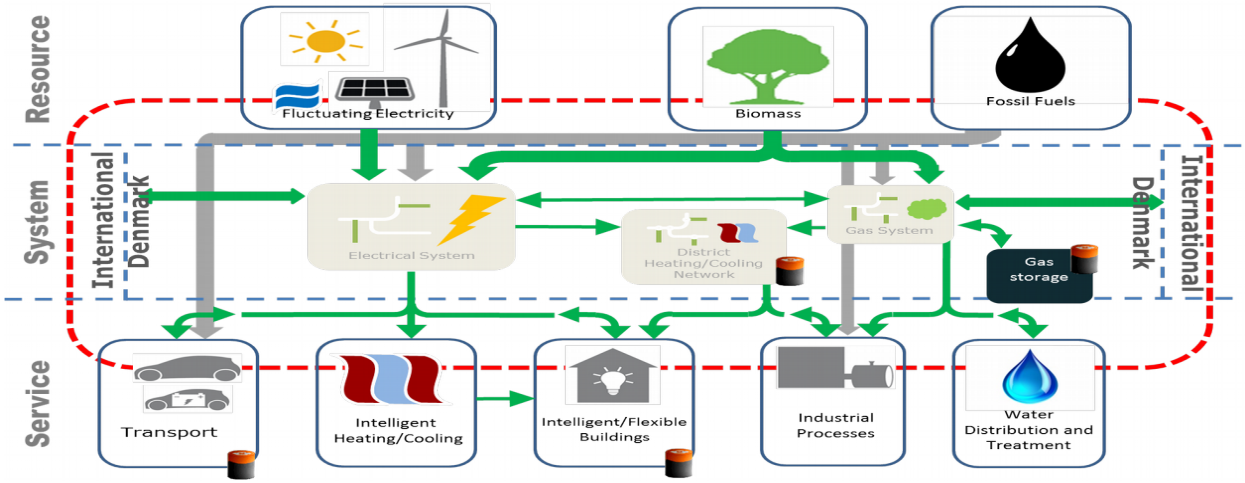


ESI – Concepts

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



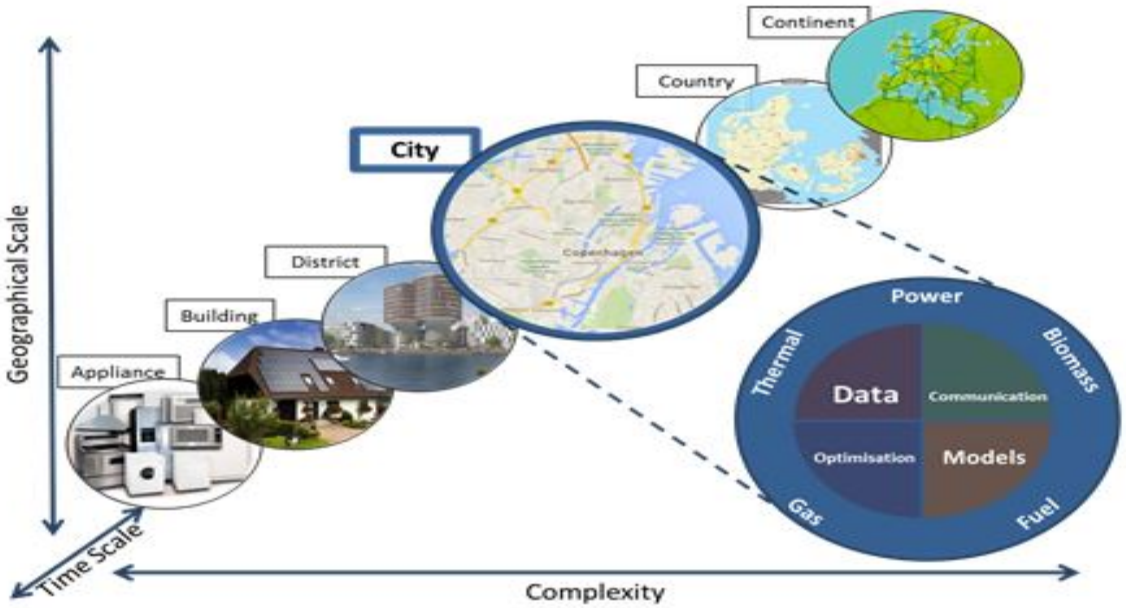
(Virtual) Storage Solutions



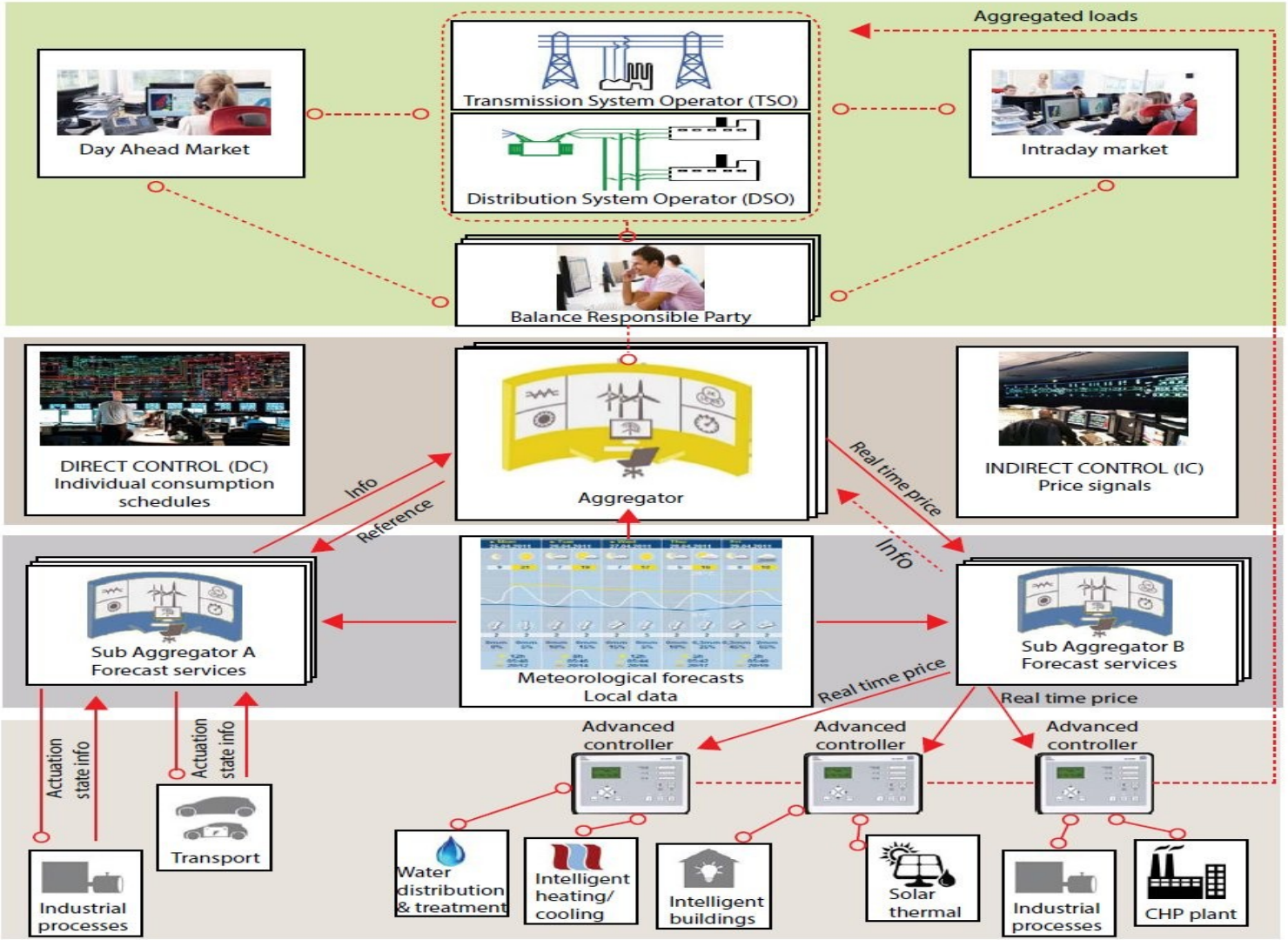
- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
  - District 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

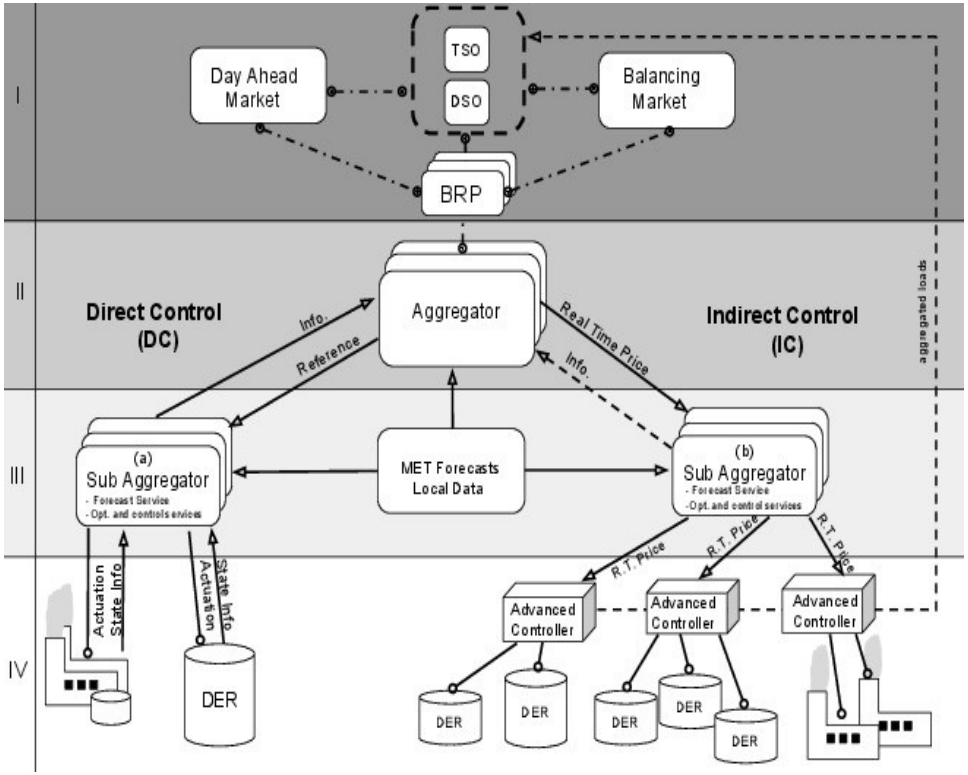
The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems*** at **all scales**.



Smart-Energy OS



Control and Optimization



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**

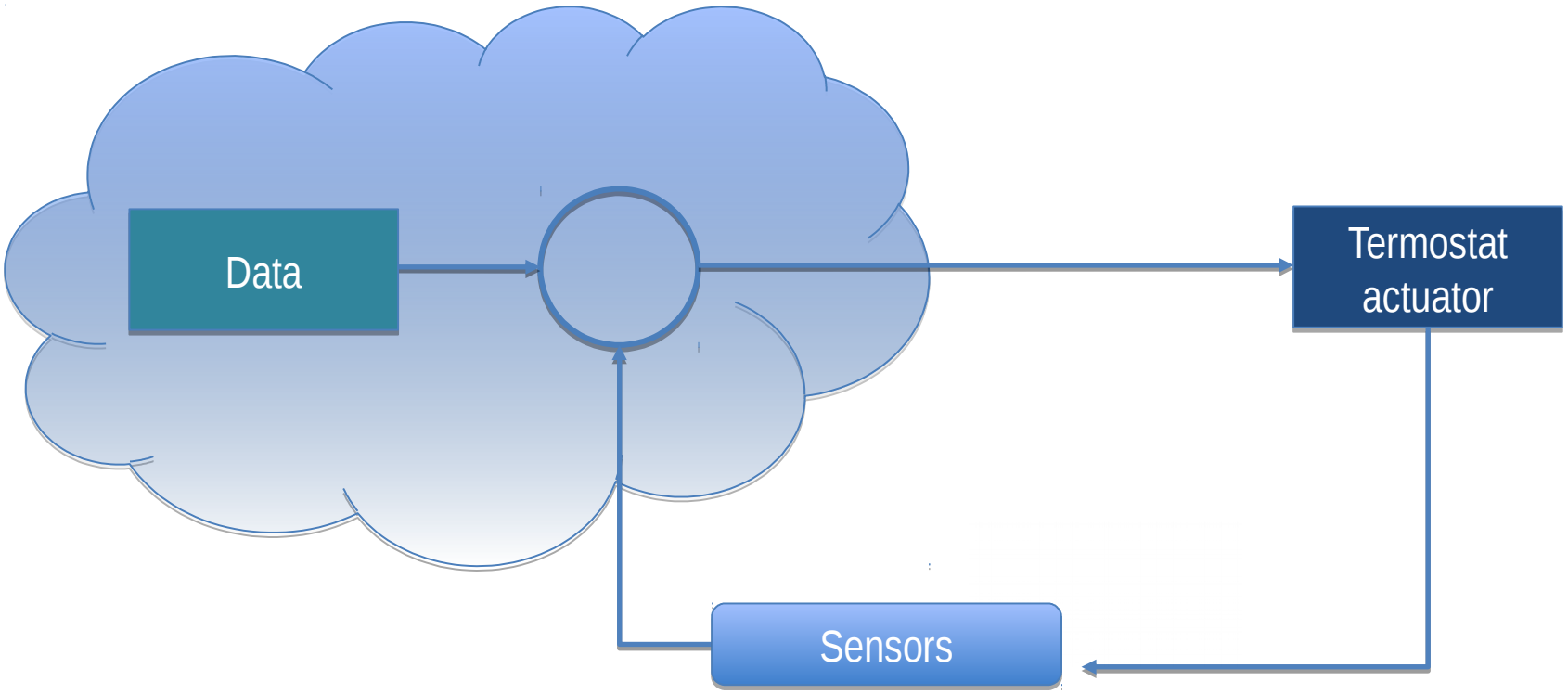
Cost: E-MPC at **low (DER) level**, One-way communication

Models for DERs are not needed

Simple 'contracts'

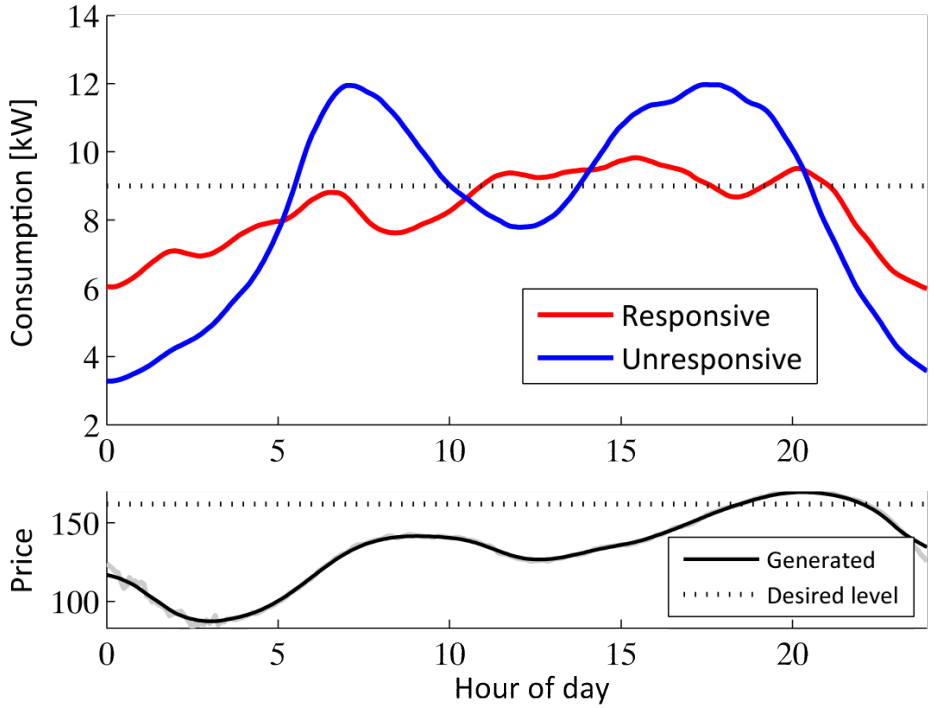
New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

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



Control performance

Considerable **reduction in peak consumption**
Mean daily consumption shift



DTU

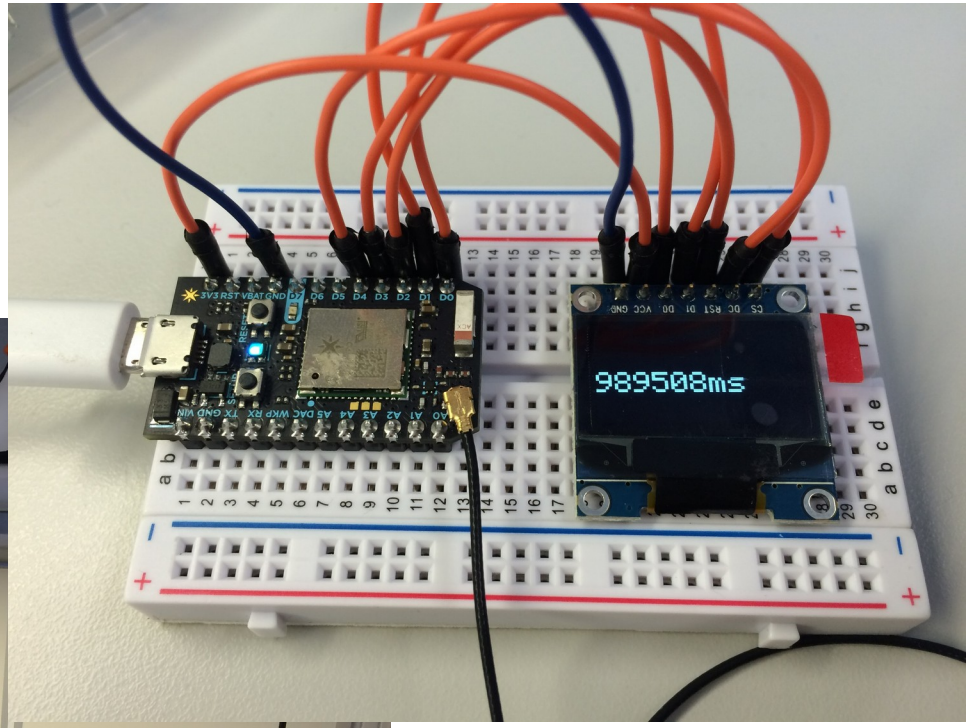
Case study

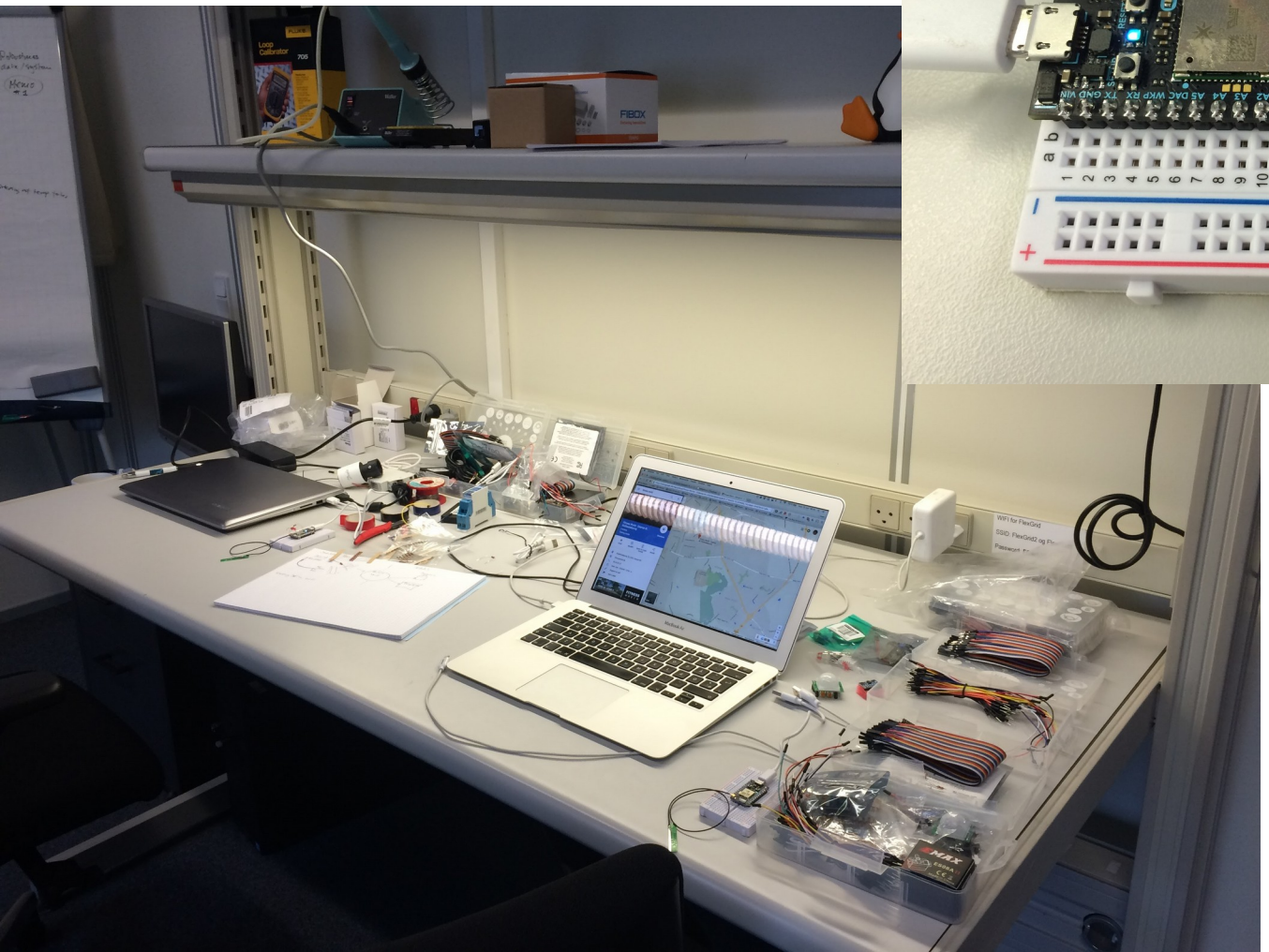
Control of Power Consumption Using Summer Houses with a Pool (H2020 SmartNet Project)

SmartNet

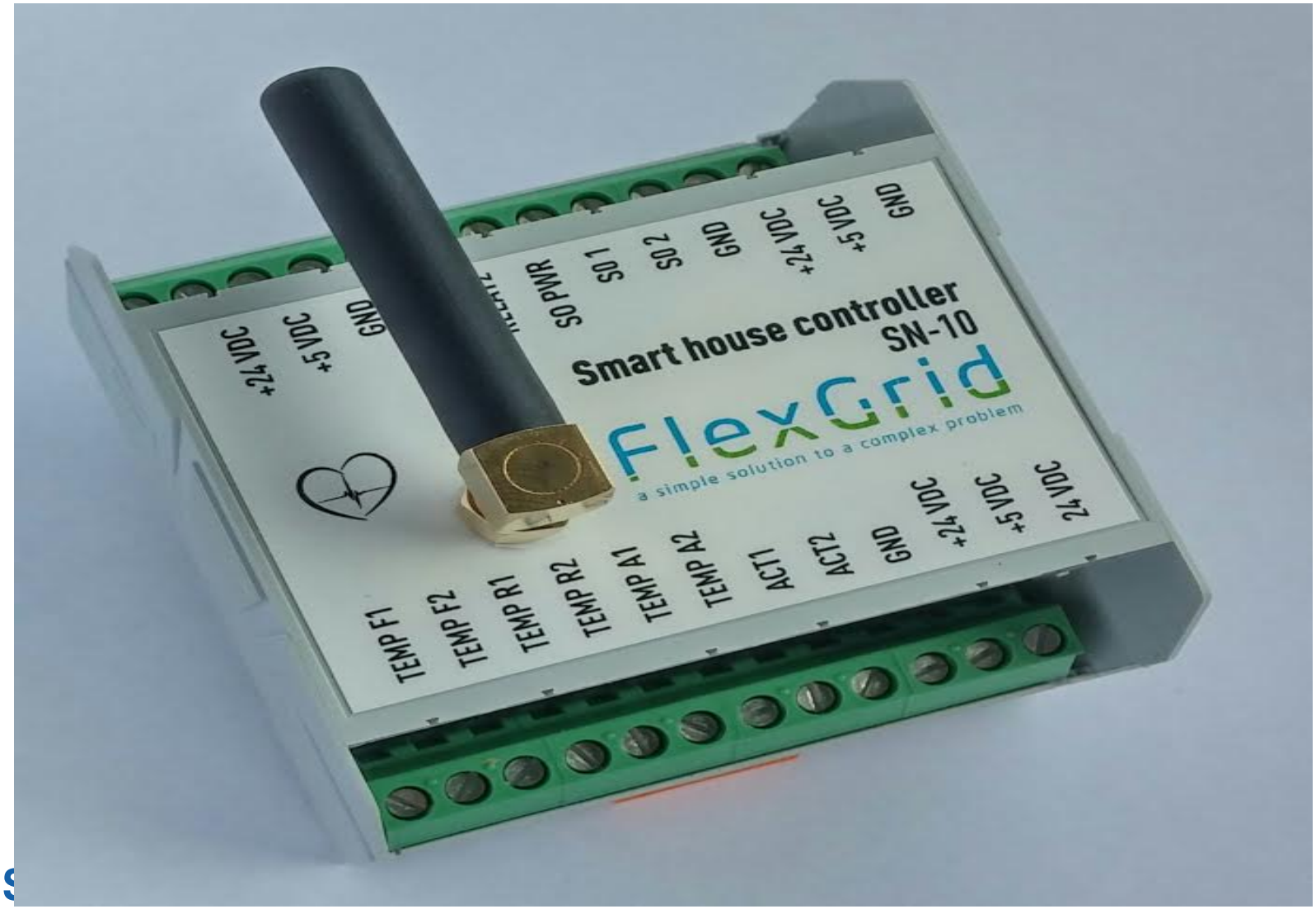
CITIES
Centre for IT Intelligent Energy Systems

Lab testing ….



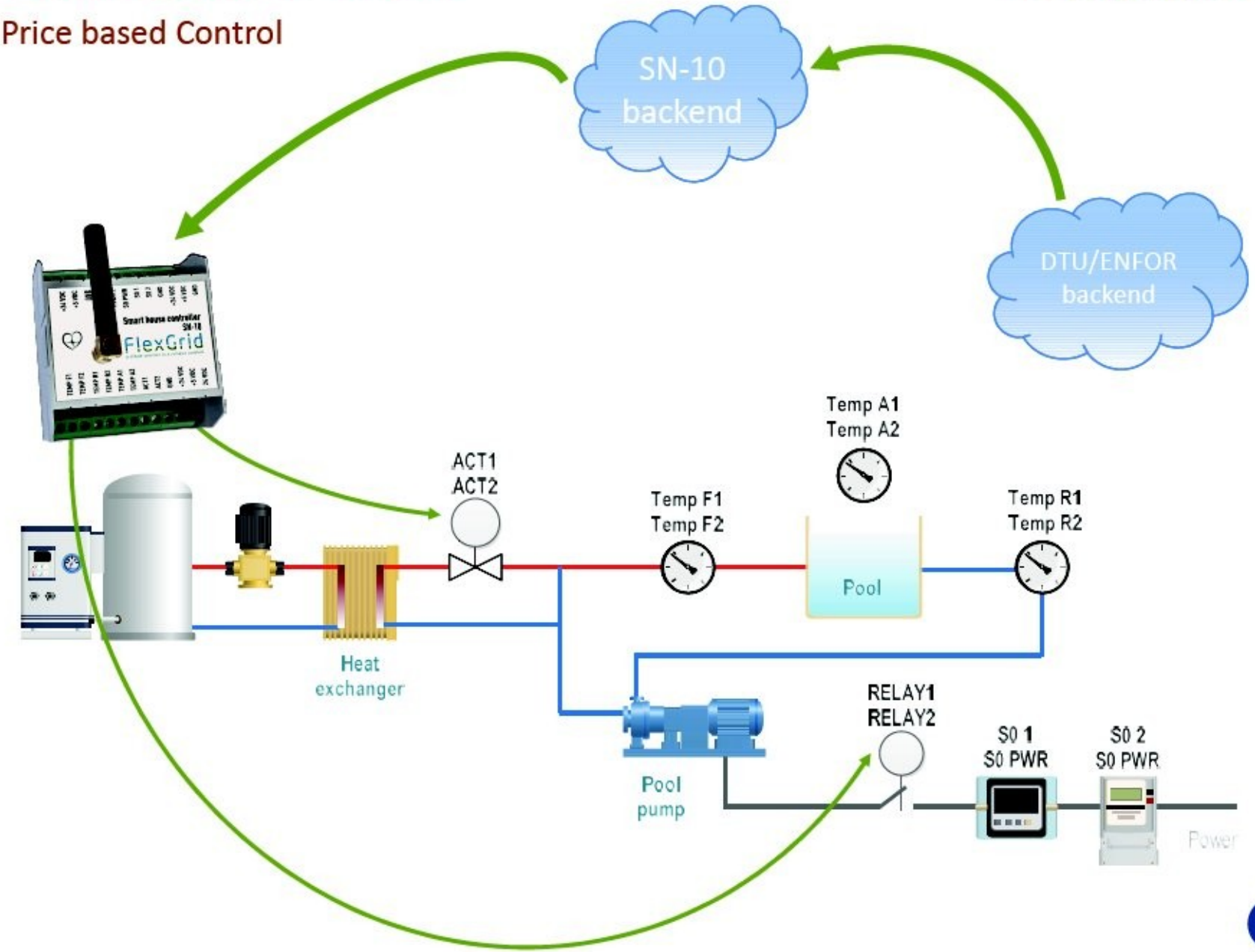


SN-10 Smart House Prototype

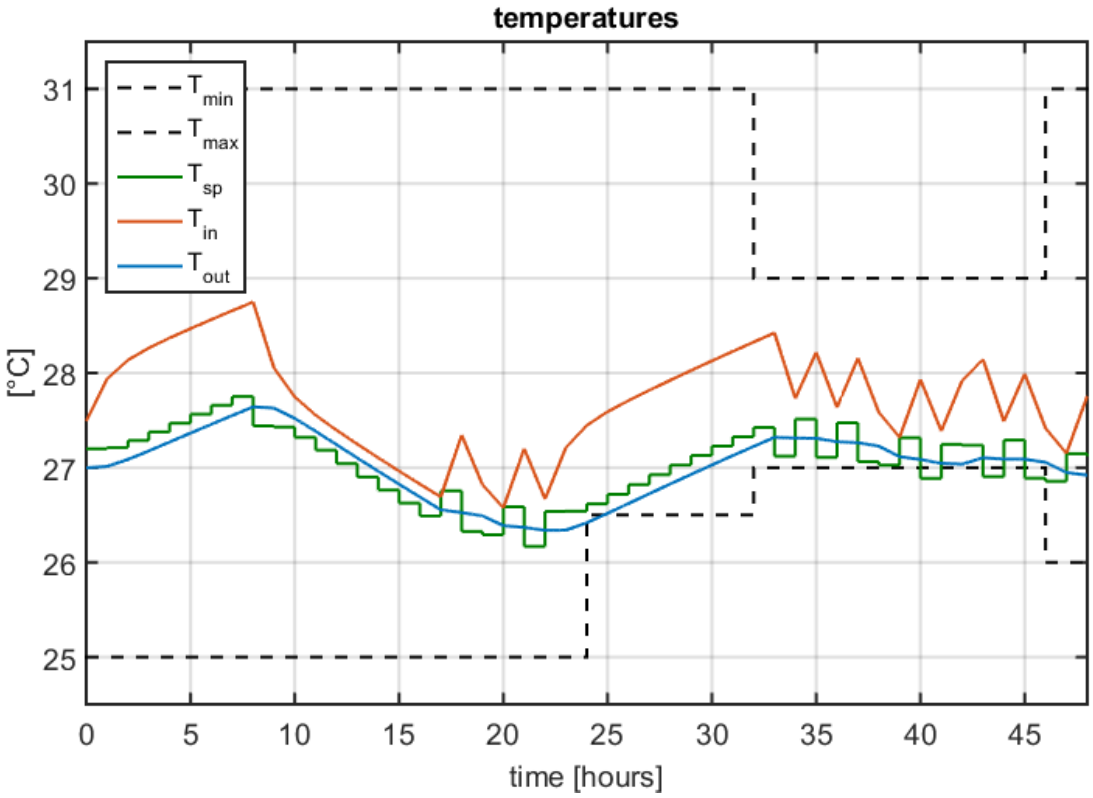


How does it work?

Price based Control



Results


temperatures
T_min
T_max
T_sp
T_in
T_out
[°C]
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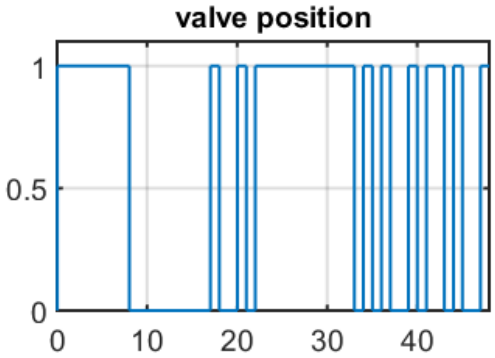
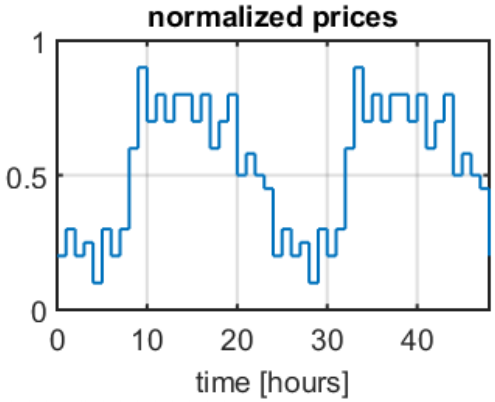
35
40
45
time [hours]


valve position
1
0.5
0
0
10
20
30
40


normalized prices
1
0.5
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0
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30
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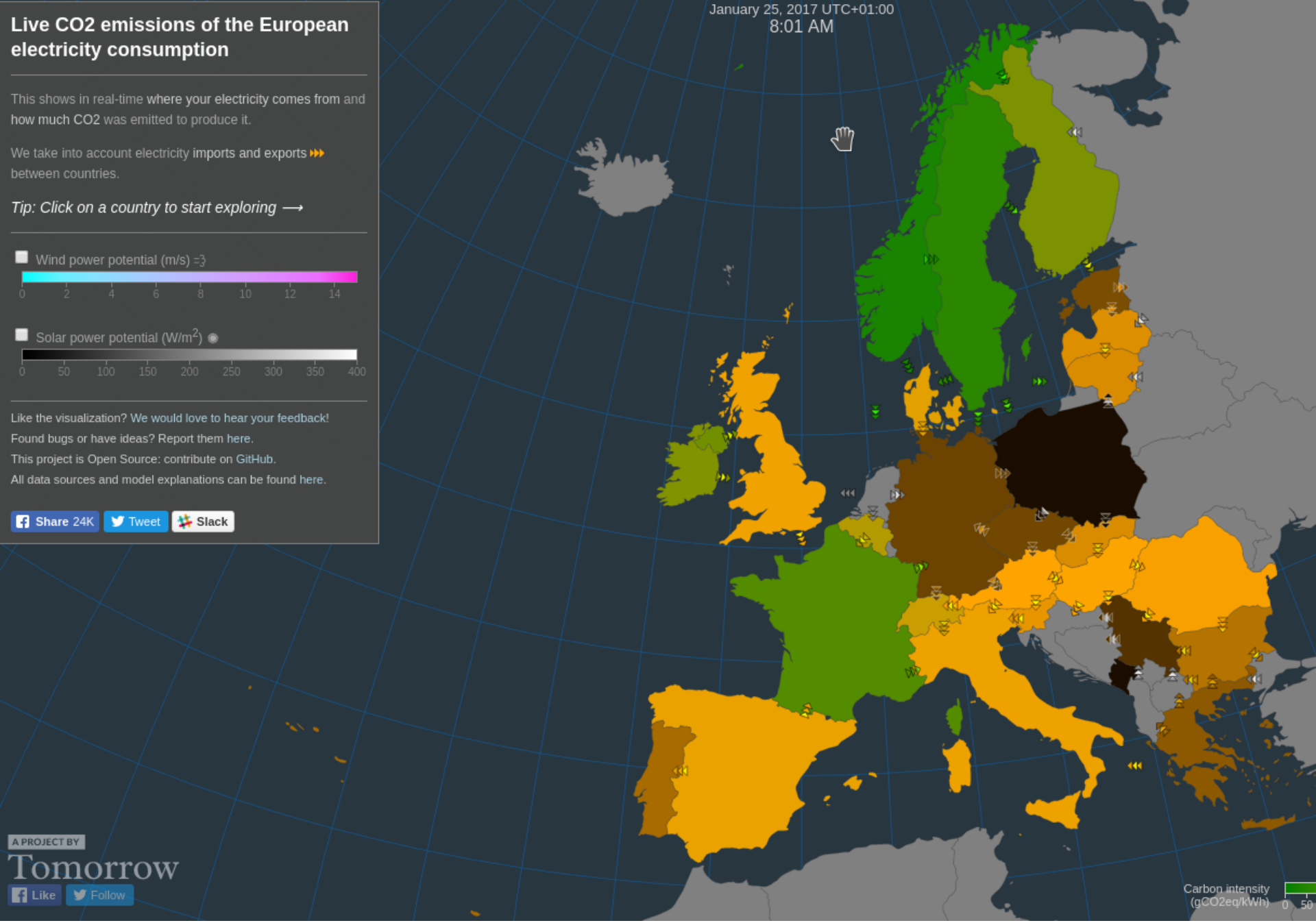
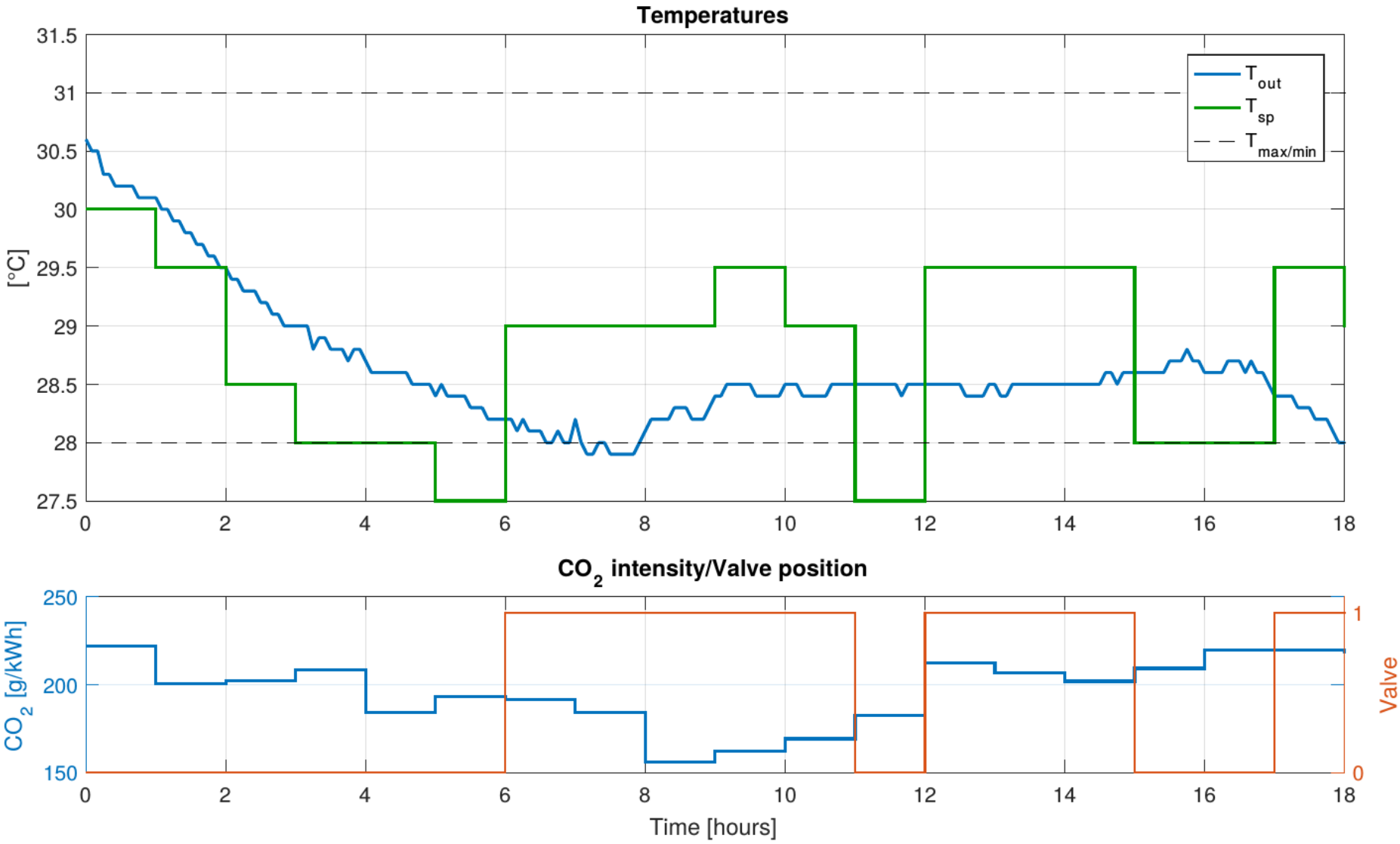
time [hours]


Live CO2 emissions of the European electricity consumption
This shows in real-time where your electricity comes from and how much CO2 was emitted to produce it.
We take into account electricity imports and exports between countries.
Tip: Click on a country to start exploring ⟶
Wind power potential (m/s)
0 2 4 6 8 10 12 14
Solar power potential (W/m2)
0 50 100 150 200 250 300 350 400
Like the visualization? We would love to hear your feedback!
Found bugs or have ideas? Report them here.
This project is Open Source: contribute on GitHub.
All data sources and model explanations can be found here.
Share 24K
Tweet
Slack
January 25, 2017 UTC+01:00
8:01 AM
A PROJECT BY
Tomorrow
Like
Follow
Carbon intensity (gCO2eq/kWh)
0 50


Temperatures
31.5
31
30.5
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27.5
[°C]
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2
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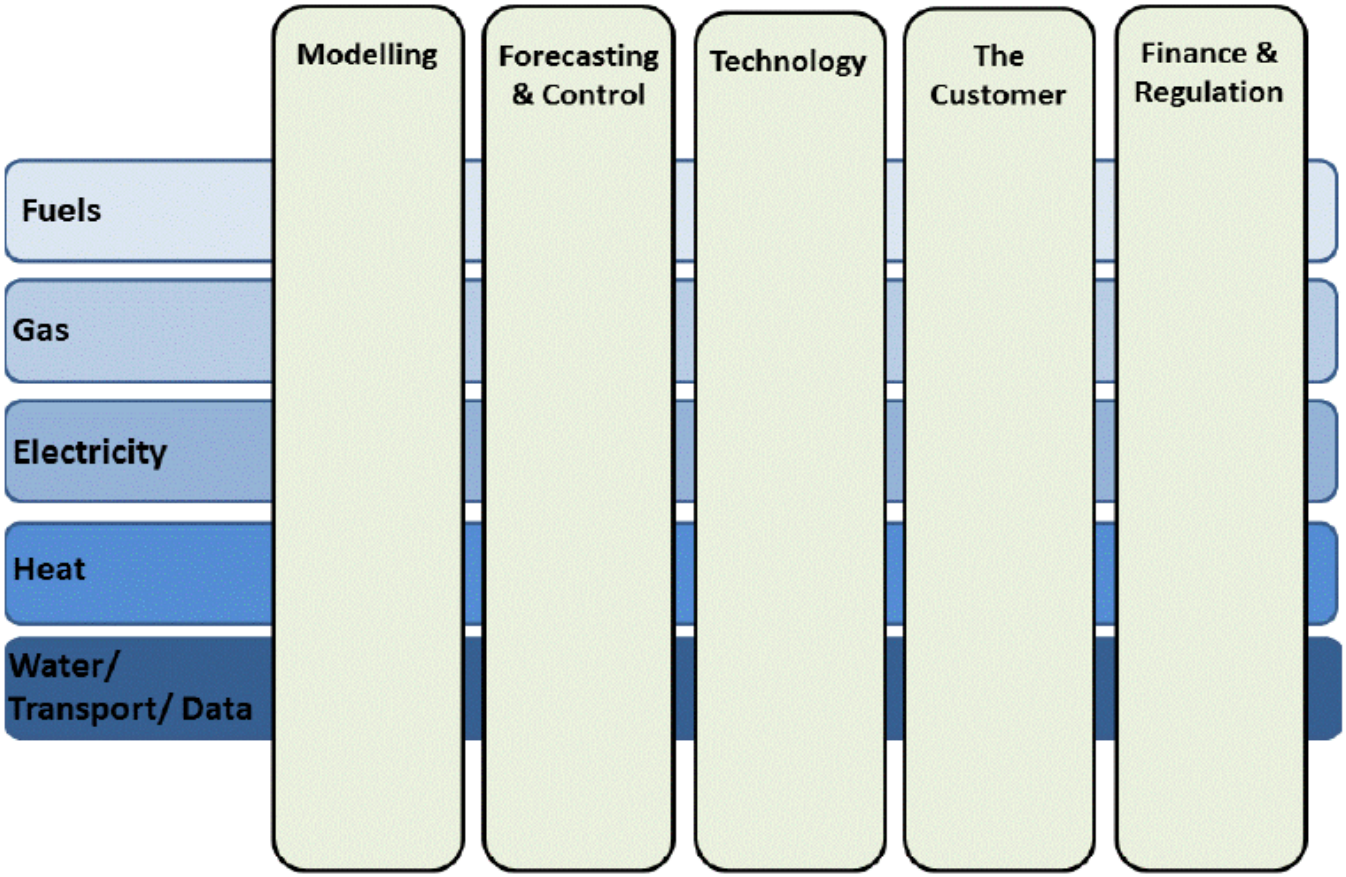
12
14
16
18
T out
T sp
T max/min
CO2 intensity/Valve position
250
200
150
CO2 [g/kWh]
1
0
Valve
Time [hours]

(UCD, DTU, KU Leuven):

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



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)