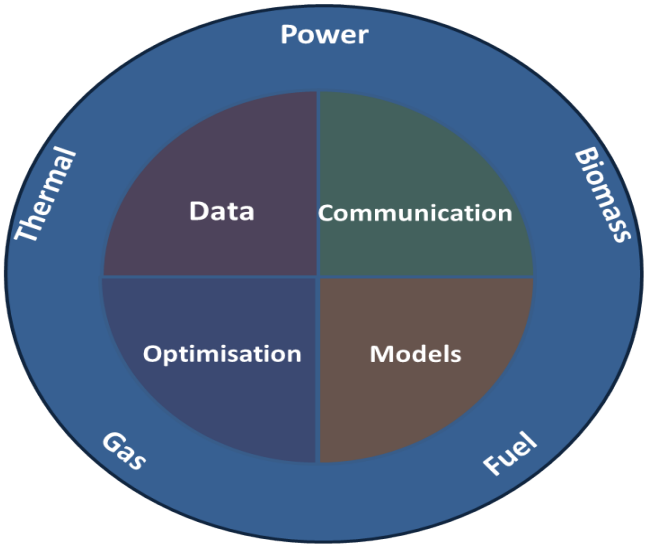
Energy Systems Integration in Cities

Chinese Mayors Training Program



Henrik Madsen, DTU Compute

http://www.henrikmadsen.org

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

http://smartnet-project.eu

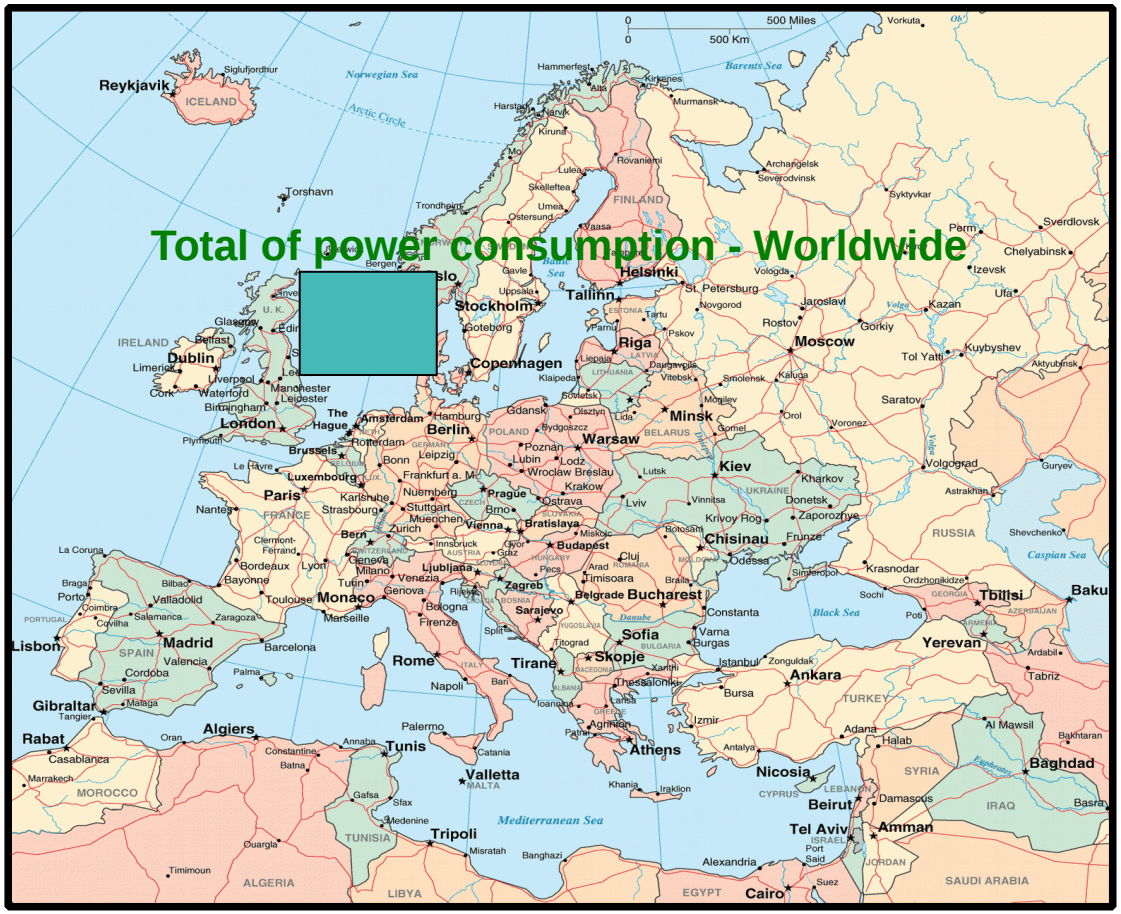
CITIES
Centre for IT Intelligent Energy Systems

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?

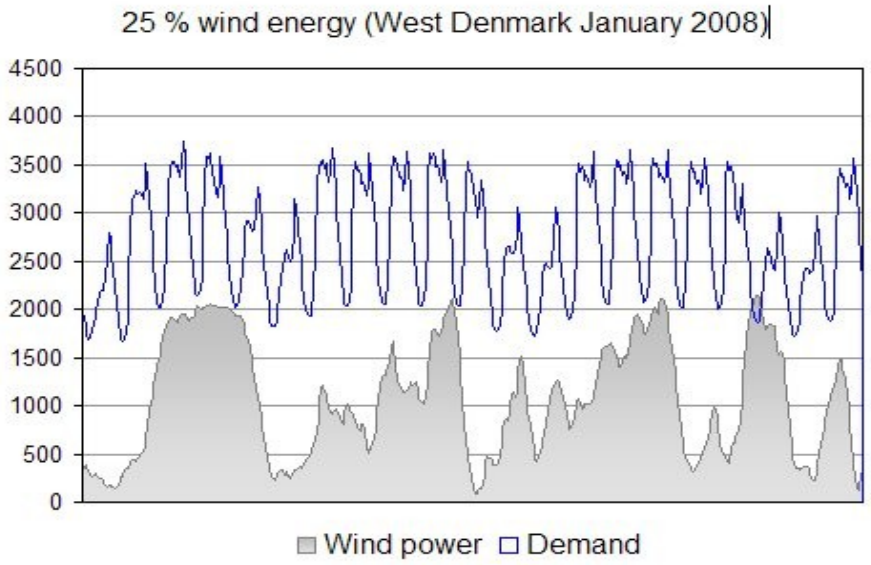
Potentials and Challenges for renewable energy

- **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**

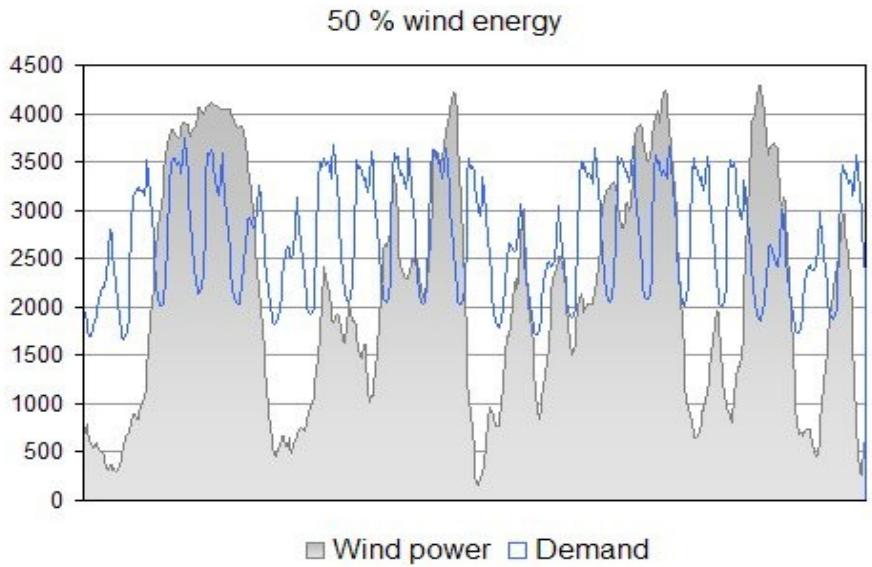

Total of power consumption - Worldwide
Reykjavik
ICELAND
Norwegian Sea
Barents Sea
Arctic Circle
Torshavn
FINLAND
Helsinki
Tallinn
Stockholm
Riga
Moscow
Dublin
Copenhagen
London
Amsterdam
Berlin
Warsaw
Minsk
Kiev
Paris
Brussels
Luxembourg
Prague
Vienna
Budapest
Bucharest
Chisinau
Belgrade
Sarajevo
Sofia
Skopje
Tirane
Rome
Madrid
Lisbon
Barcelona
Monaco
Marseille
Algiers
Tunis
Athens
Ankara
Istanbul
Izmir
Nicosia
Beirut
Tel Aviv
Amman
Damascus
Baghdad
Tripoli
Valletta
Cairo
Alexandria
Gibraltar
Rabat
Casablanca
Black Sea
Caspian Sea
Mediterranean Sea
Yerevan
Tbilisi
Baku
Volgograd
Saratov
Kazan
Ufa
Perm
Yekaterinburg
Chelyabinsk
Sverdlovsk
Izevsk
Kuybyshev
Krasnodar
Sochi
Donetsk
Kharkov
Zaporozhye
Krivoy Rog
Odessa
Constanta
Varna
Burgas
Bursa
Adana
Halab
Al Mawsil
Baghdad
Basra
Damascus
Amman
Beirut
Tel Aviv
Cairo
Alexandria
Suez
Port Said
Tripoli
Tunis
Algiers
Rabat
Casablanca
Marrakech
Fez
Oran
Annaba
Constantine
Batna
Gafsa
Sfax
Medenine
Ouargla
Timimoun
Misratah
Banghazi
Palermo
Catania
Napoli
Bari
Milano
Venezia
Genova
Torino
Lyon
Bordeaux
Toulouse
Bilbao
Valladolid
Salamanca
Zaragoza
Valencia
Palma
Cordoba
Sevilla
Malaga
Tangier
Porto
Coimbra
Covilha
Braga
Bayonne
Nantes
Le Havre
Plymouth
Glasgow
Belfast
Limerick
Cork
Waterford
Liverpool
Manchester
Leicester
Birmingham
Edinburgh
Aberdeen
Inverness
Hull
Hamburg
Bremen
Hannover
Leipzig
Dresden
Nuremberg
Stuttgart
Munchen
Frankfurt a. M.
Bonn
Koln
Duisburg
Rotterdam
The Hague
Utrecht
Groningen
Eindhoven
Antwerpen
Gent
Liege
Luxembourg
Metz
Nancy
Strasbourg
Karlsruhe
Zurich
Bern
Geneva
Innsbruck
Graz
Linz
Salzburg
Wien
Bratislava
Brno
Ostrava
Krakow
Wroclaw Breslau
Lodz
Poznan
Lublin
Lutsk
Lviv
Vinnitsa
Bydgoszcz
Gdansk
Olsztyn
Lida
Grodno
Pskov
Tartu
Parnu
Riga
Liepaja
Daugavpils
Vitebsk
Smolensk
Kaluga
Tula
Moskva
Yaroslavl
Rostov
Gorkiy
Vologda
Novgorod
St. Petersburg
Murmansk
Kirkenes
Hammerfest
Alta
Harstad
Narvik
Kiruna
Lulea
Skelleftea
Umea
Ostersund
Vaasa
Rovaniemi
Archangelsk
Severodvinsk
Syktyvkar
Trondheim
Bergen
Stavanger
Kristiansand
Oslo
Gavle
Uppsala
Goteborg
Jonkoping
Malmo
Aalborg
Aarhus
Odense
Esbjerg
Kolding
Vejle
Herning
Viborg
Skagen
Roskilde
Copenhagen
Helsingor
Kaliningrad
Klaipeda
Siauliai
Kaunas
Vilnius
Grodno
Minsk
Mogilev
Orsha
Vitebsk
Gomel
Pripyat
Chernobyl
Kiev
Zhytomyr
Vinnitsa
Khmelnytskyi
Ternopil
Lviv
Ivano-Frankivsk
Chernivtsi
Uzhhorod
Lutsk
Rivne
Zhytomyr
Kharkov
Donetsk
Dnipropetrovsk
Zaporozhye
Krivoy Rog
Simferopol
Sevastopol
Yalta
Kerch
Feodosiya
Mariupol
Berdyansk
Melitopol
Kherson
Mykolayiv
Odessa
Izmail
Bilhorod-Dnistrovskyi
Chisinau
Balti
Tiraspol
Bendery
Cahul
Ungheni
Soroca
Edinet
Briceni
Orhei
Hincesti
Cimislia
Comrat
Ceadir-Lunga
Vulcanesti
Taraclia
Basarabeasca
Causeni
Dubasari
Rezina
Floresti
Drochia
Glodeni
Riscani
Ocnita
Donduseni
Soldanesti
Sangerei
Nisporeni
Ialoveni
Straseni
Anenii Noi
Calarasi
Stefan Voda
Leova
Cantemir
Ungheni
Iasi
Botosani
Suceava
Bacau
Piatra Neamt
Vaslui
Galati
Braila
Focsani
Buzau
Ploiesti
Bucharest
Giurgiu
Calarasi
Slobozia
Constanta
Tulcea
Sulina
Sfantu Gheorghe
Brasov
Sibiu
Targu Mures
Cluj
Oradea
Arad
Timisoara
Resita
Drobeta-Turnu Severin
Craiova
Pitesti
Targoviste
Ramnicu Valcea
Slatina
Caracal
Alexandria
Turnu Magurele
Zimnicea

The Danish Wind Power Case

…. balancing of the power system



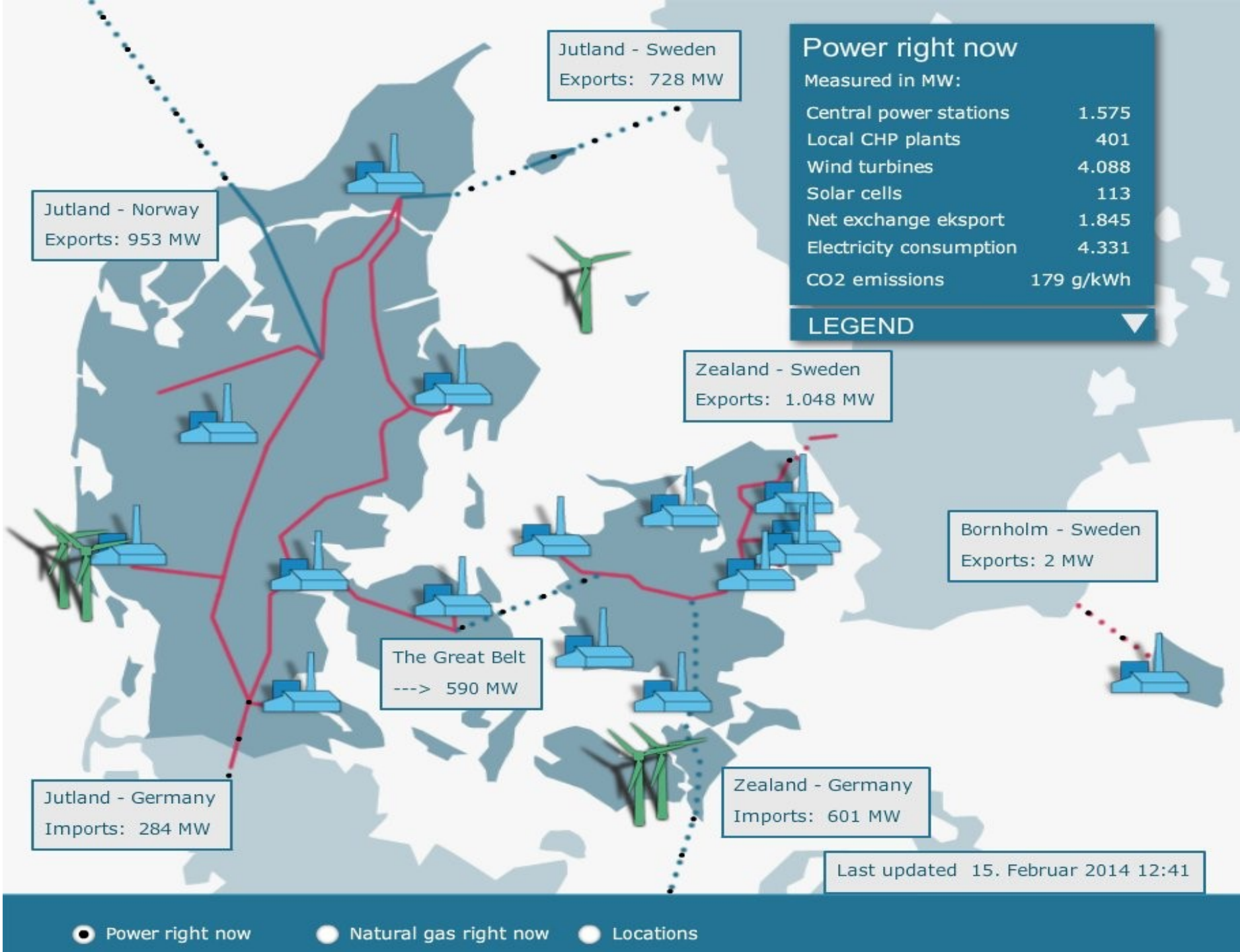
In 2008 wind power did cover the entire demand of electricity in 200 hours (West DK)



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

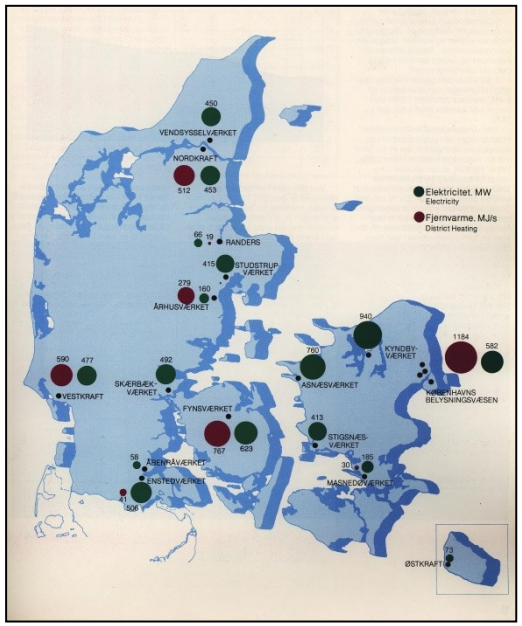
For several days in 2015 the wind power production was more than 120 pct of the power load.

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

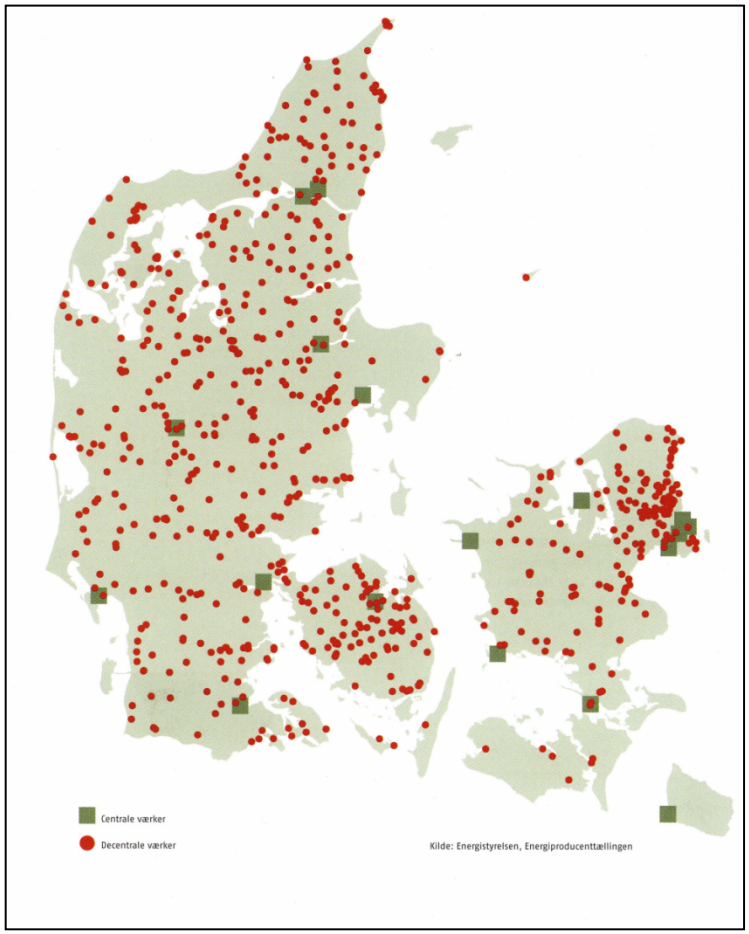

Jutland - Sweden
Exports: 728 MW
Power right now
Measured in MW:
Central power stations 1.575
Local CHP plants 401
Wind turbines 4.088
Solar cells 113
Net exchange eksport 1.845
Electricity consumption 4.331
CO2 emissions 179 g/kWh
LEGEND
Jutland - Norway
Exports: 953 MW
Zealand - Sweden
Exports: 1.048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

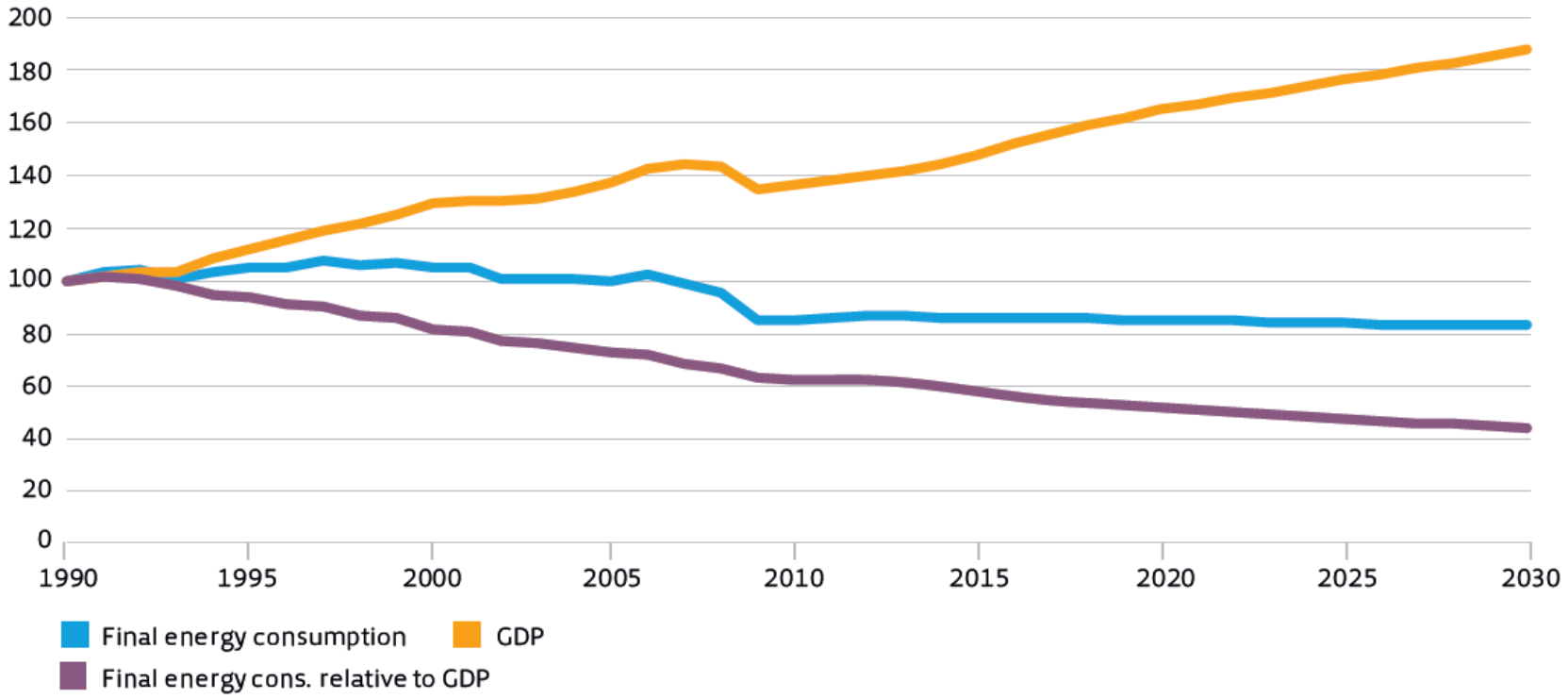


Today



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

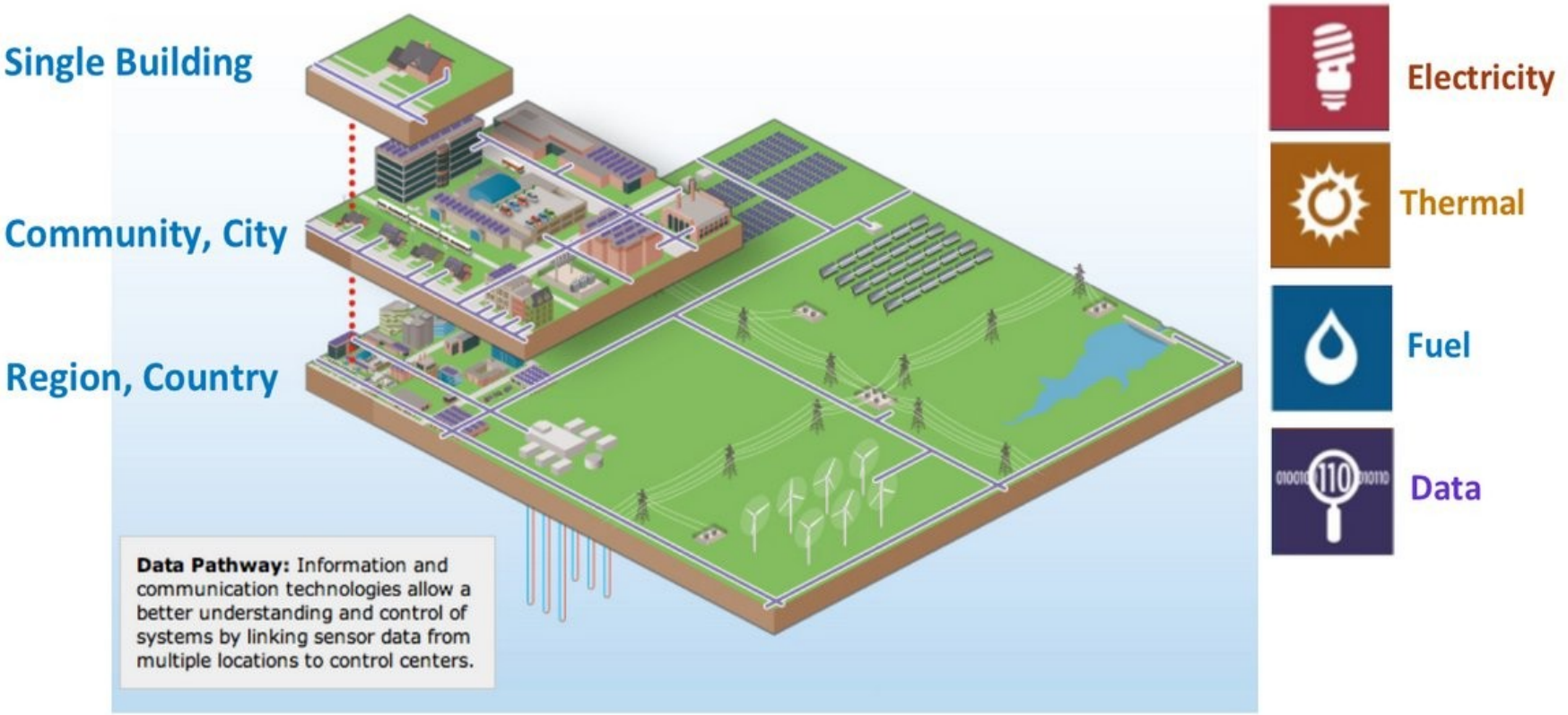
What has since been achieved: De-coupling of consumption and GDP growth



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

Energy Systems Integration in Smart Cities

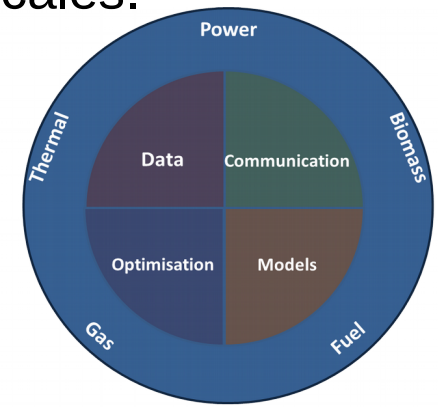
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



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.

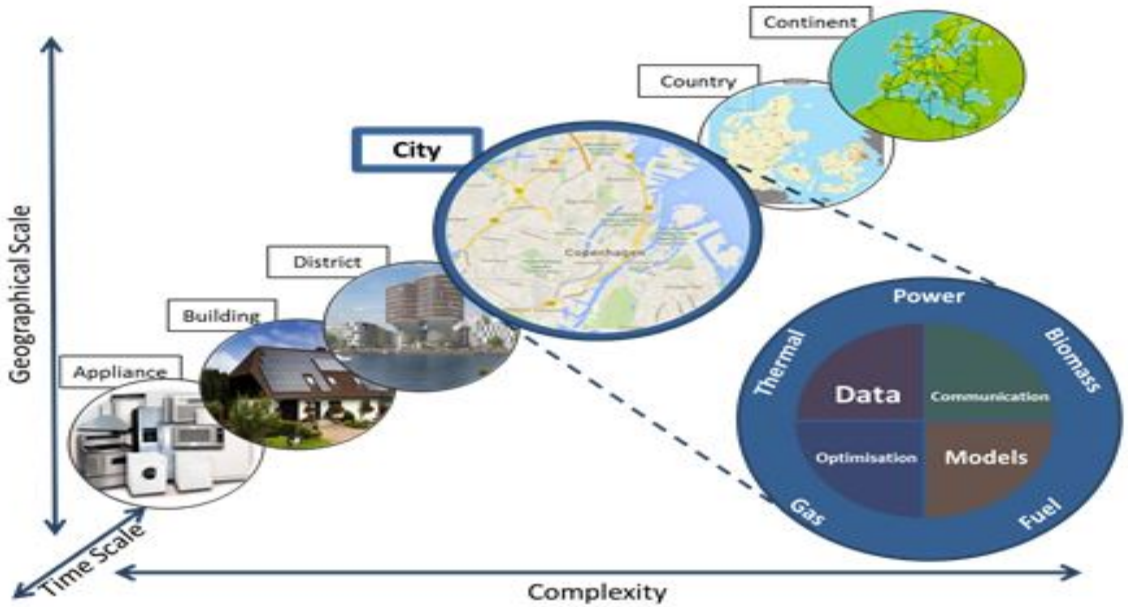
Intelligent integration will (for instance) enable lossless ‘virtual’ storage on a number of different time scales.



ESI Solutions

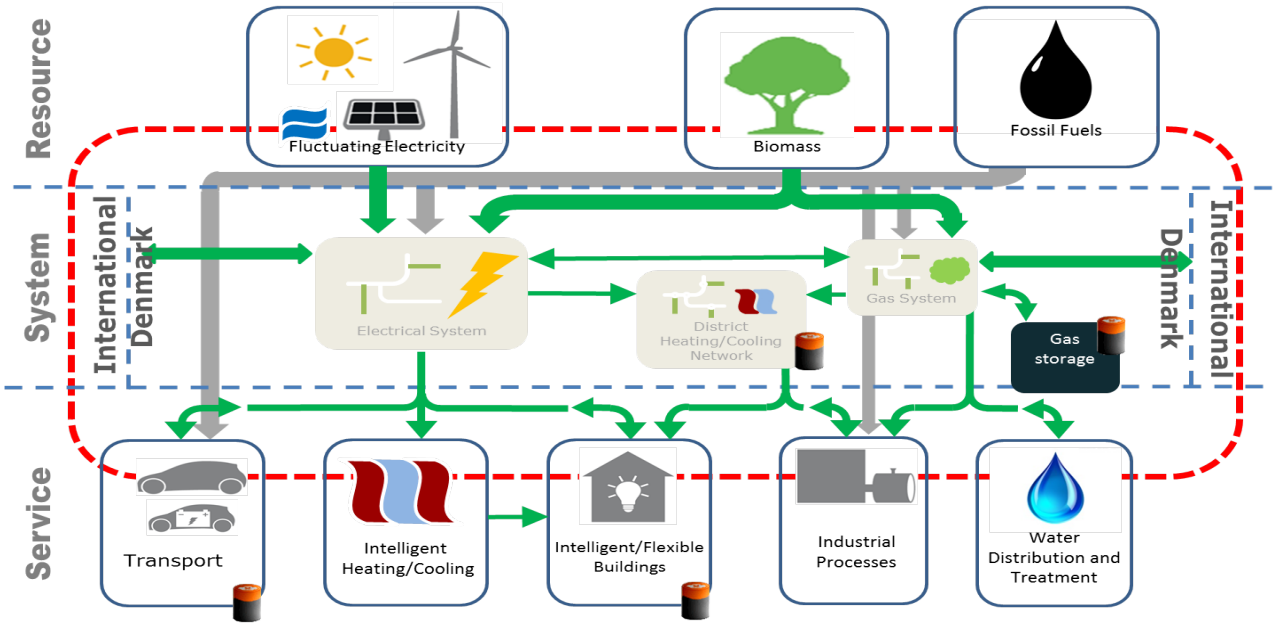
The ***Center for IT-Intelligent Energy Systems in Cities (CITIES)*** is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

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

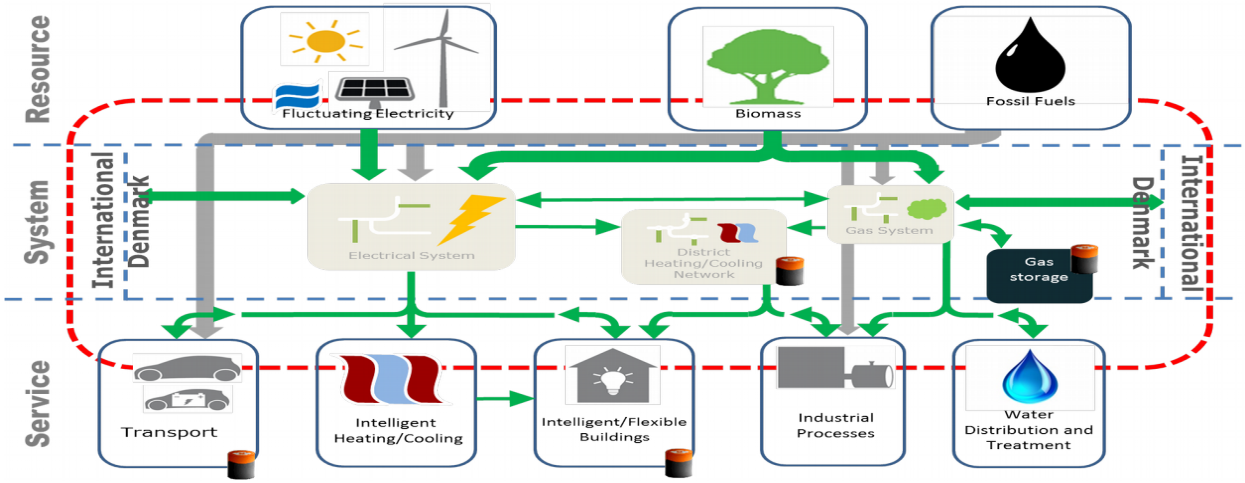


ESI – Concepts

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



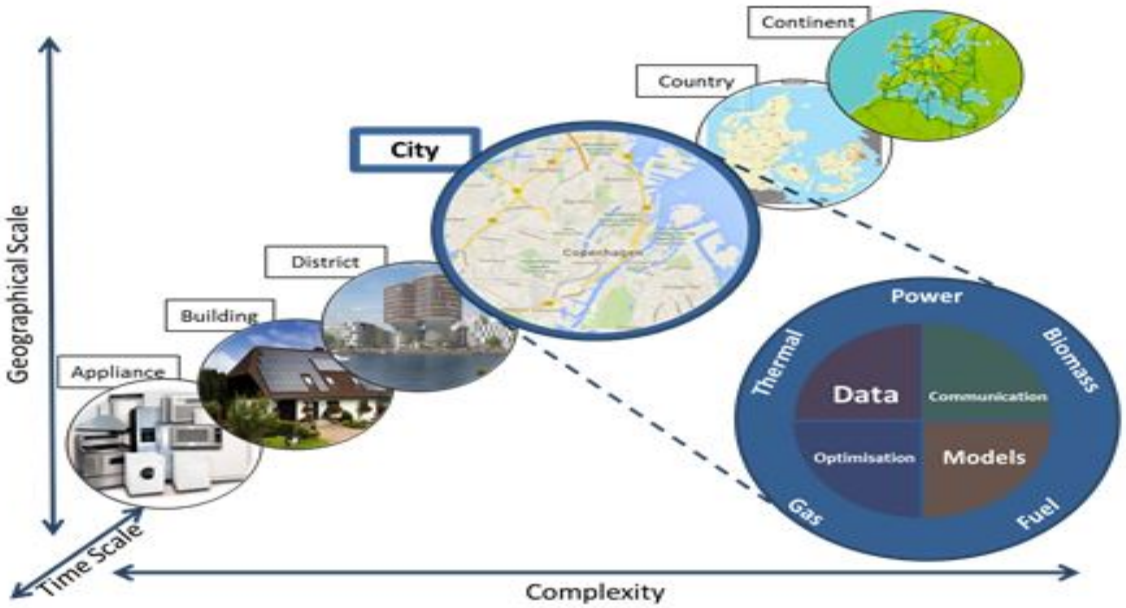
(Virtual) Storage Solutions



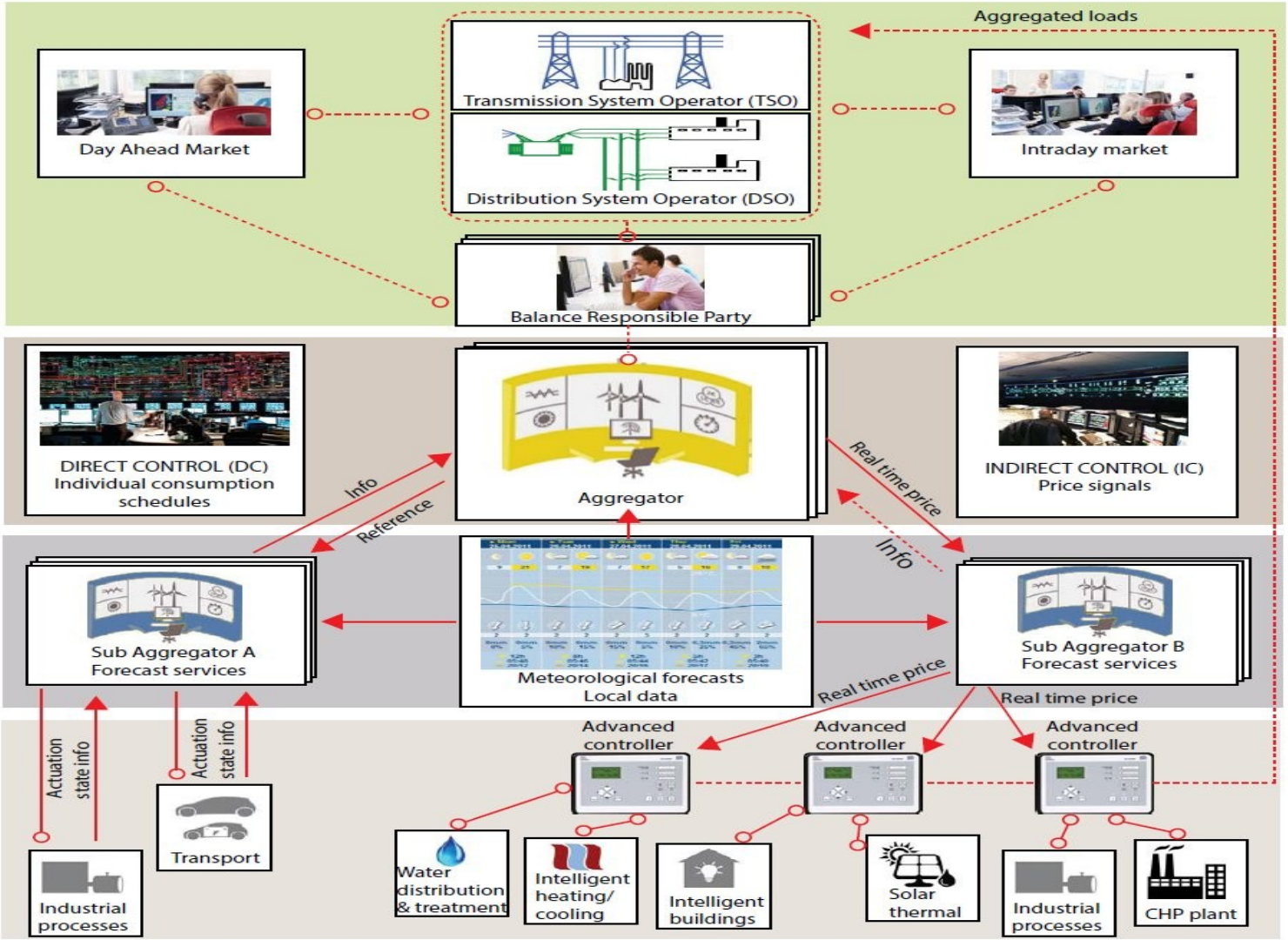
- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-12 hours ahead
  - District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



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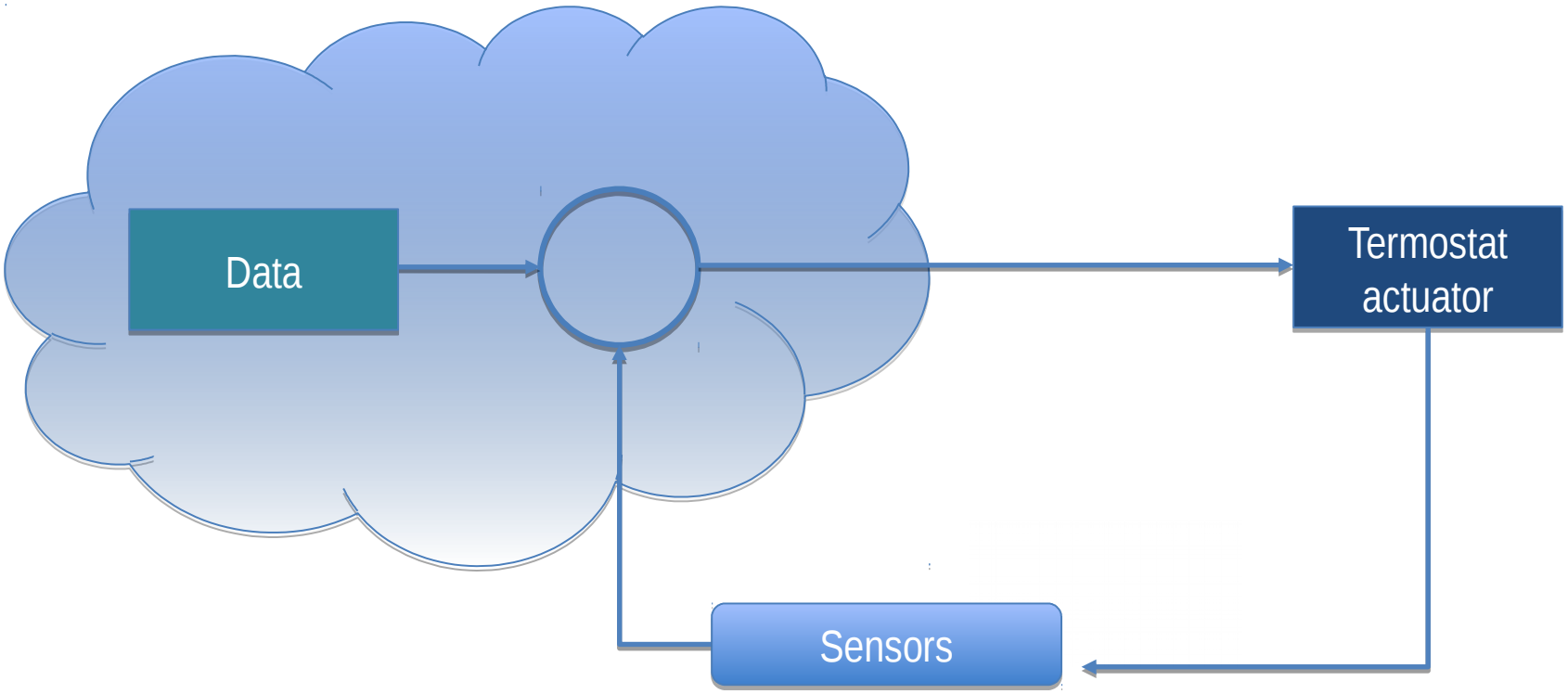
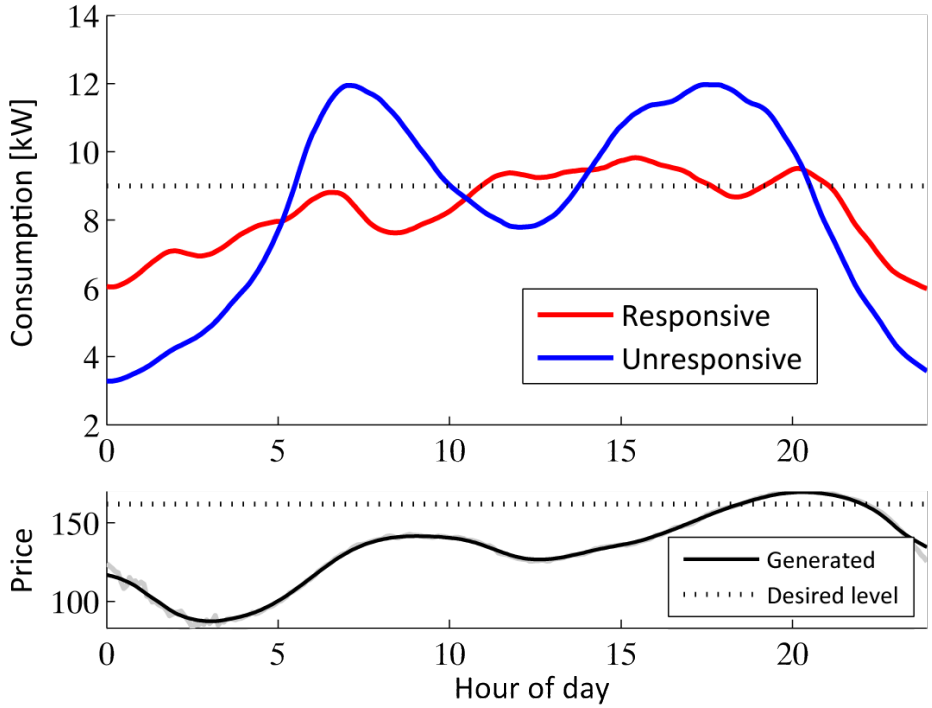
SE-OS
Control loop design – **logical drawing**



Control performance

Considerable **reduction in peak consumption**

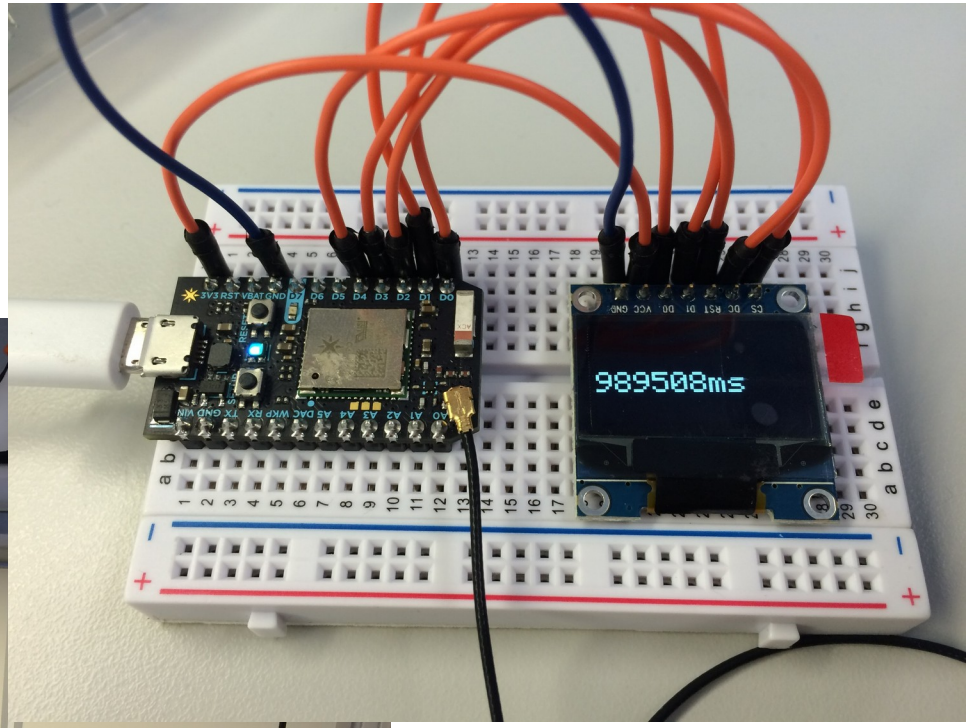
Mean daily consumption shift

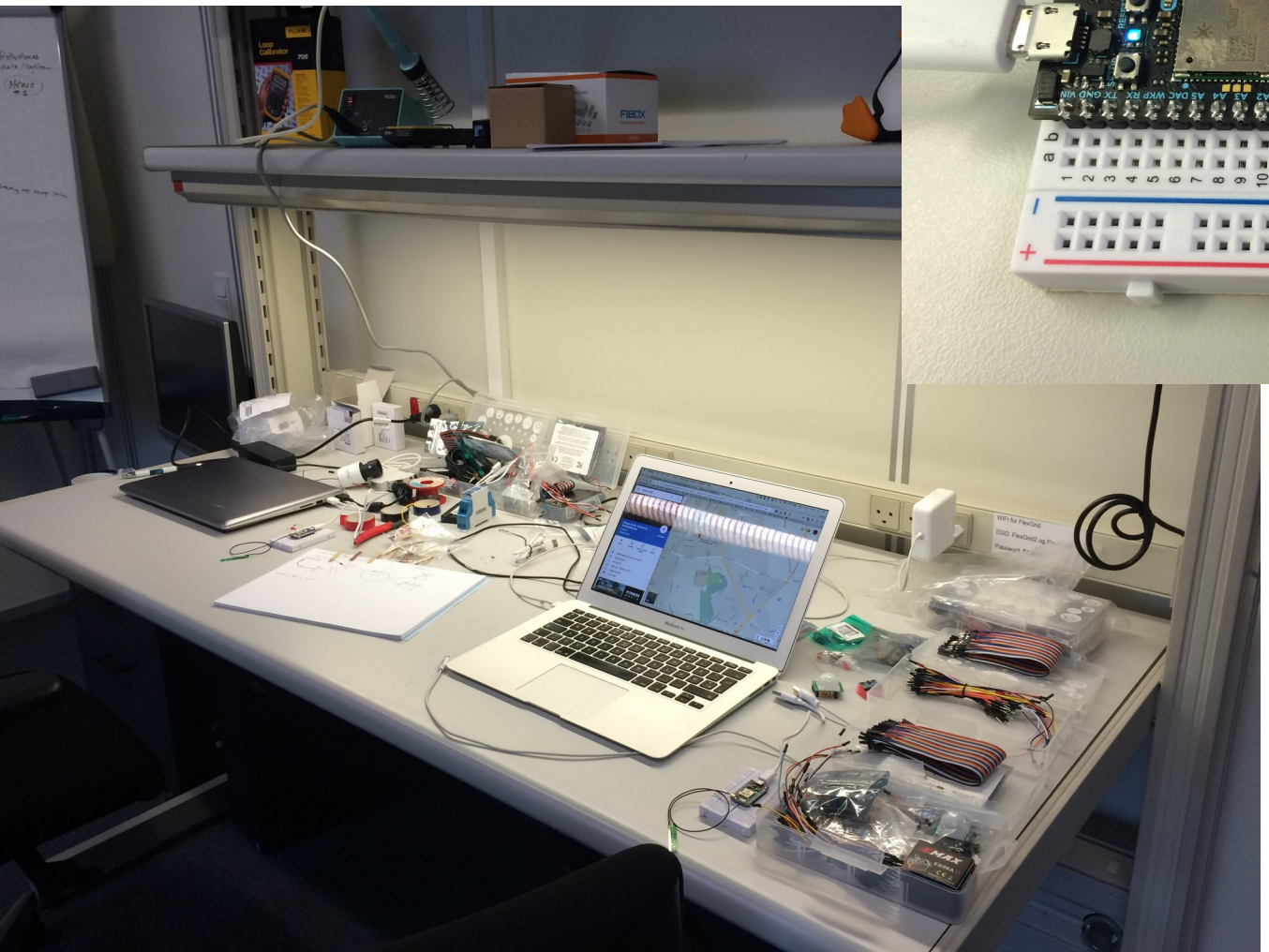


Case study

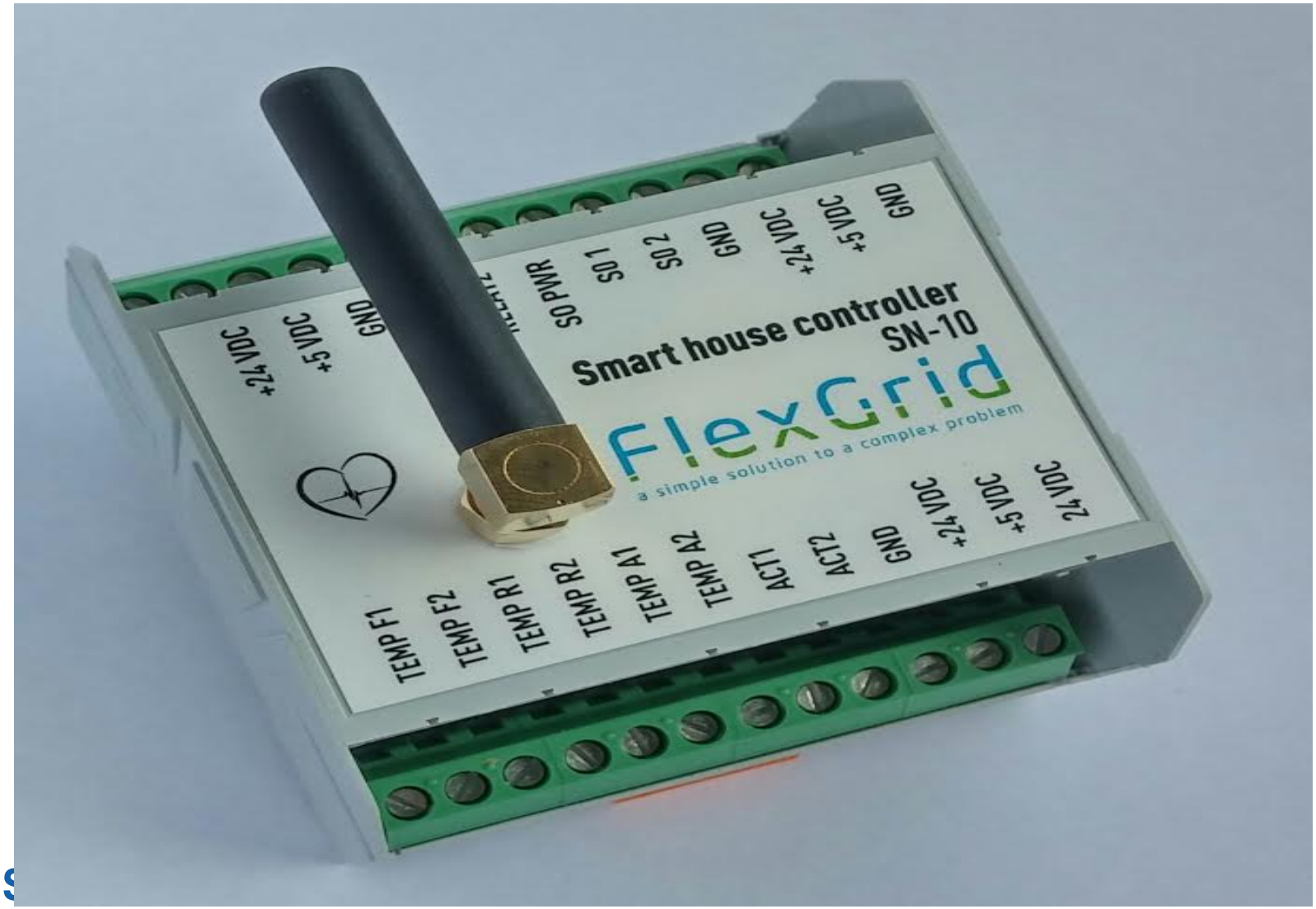
Control of Power Consumption Using Summer Houses with a Pool (H2020 SmartNet Project)

Lab testing ….



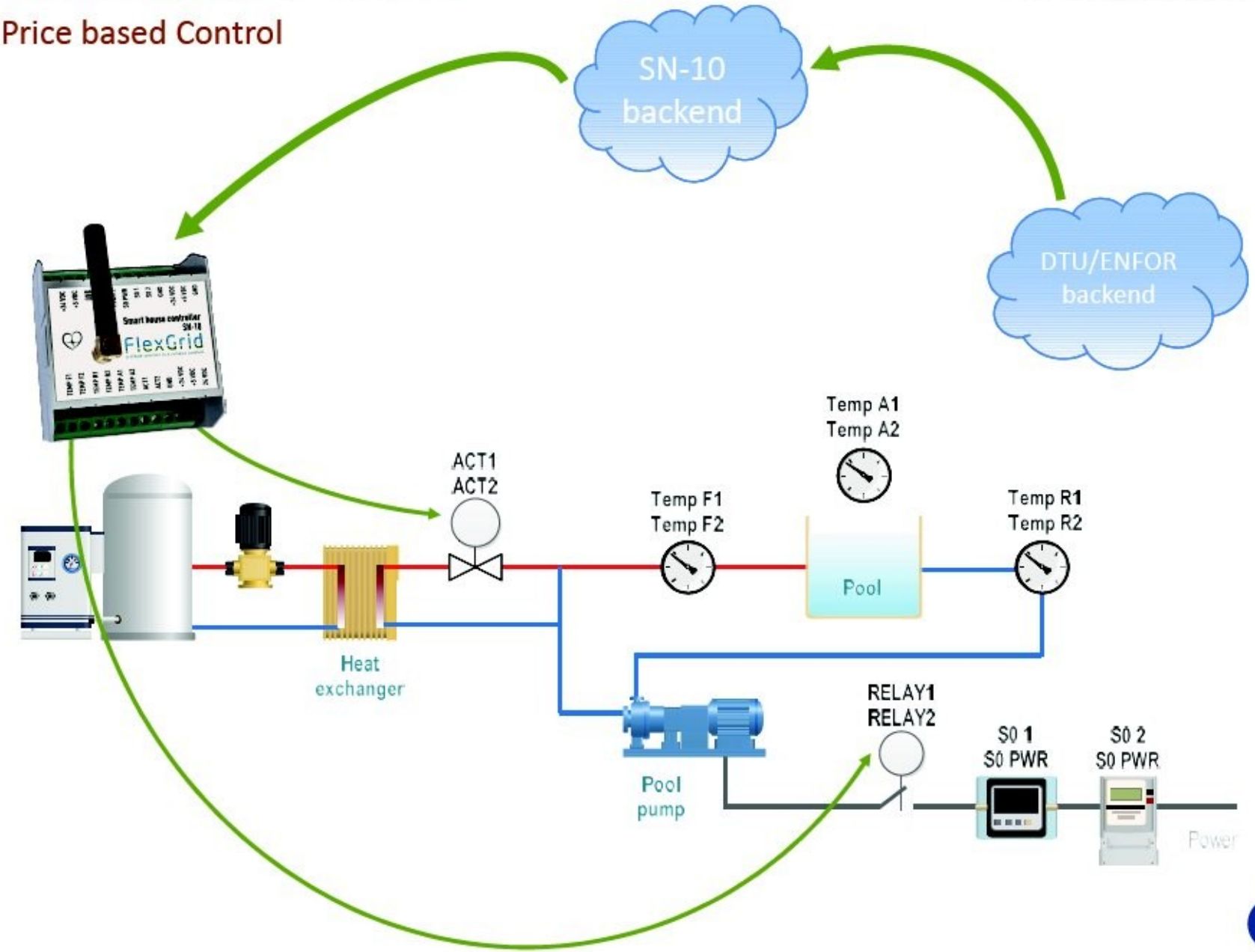


SN-10 Smart House Prototype

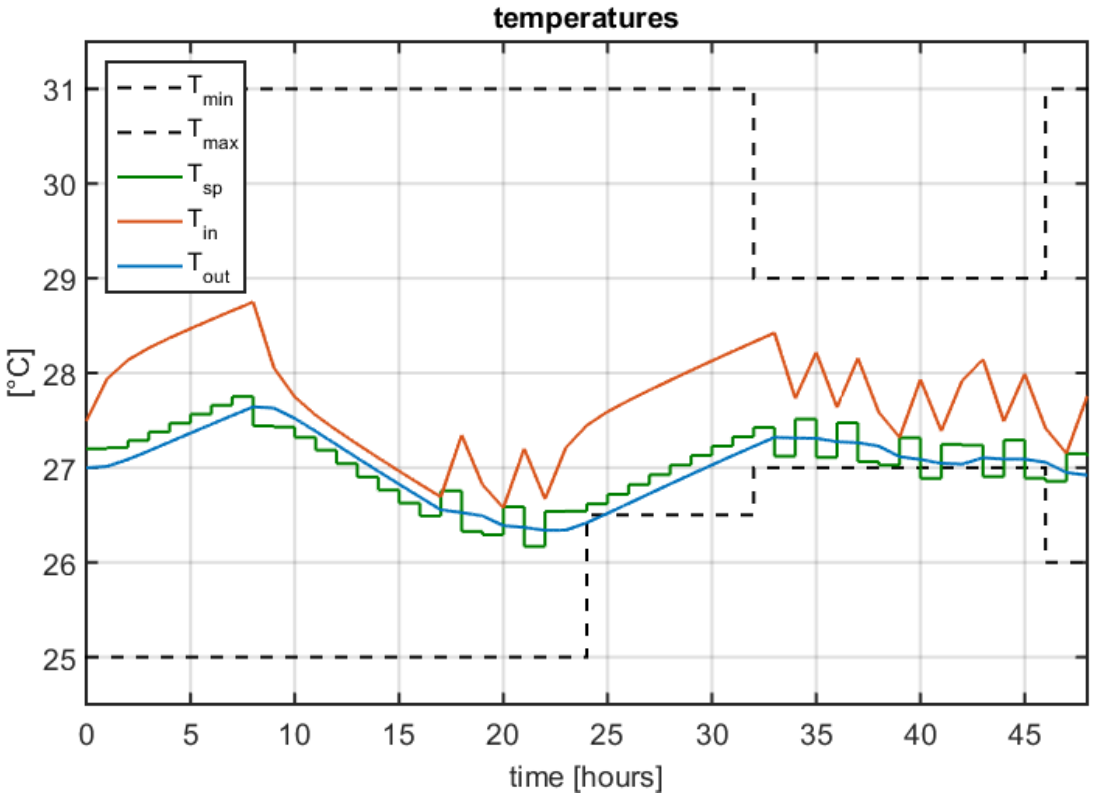


How does it work?

Price based Control



Results


temperatures
T_min
T_max
T_sp
T_in
T_out
[°C]
31
30
29
28
27
26
25
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5
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15
20
25
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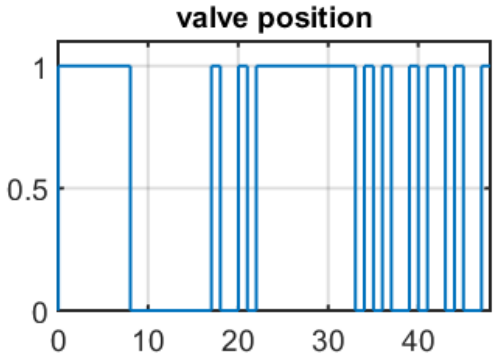
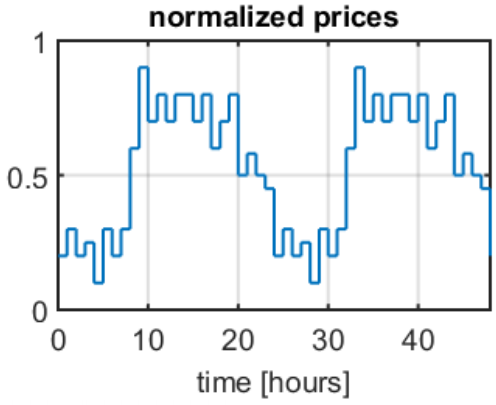
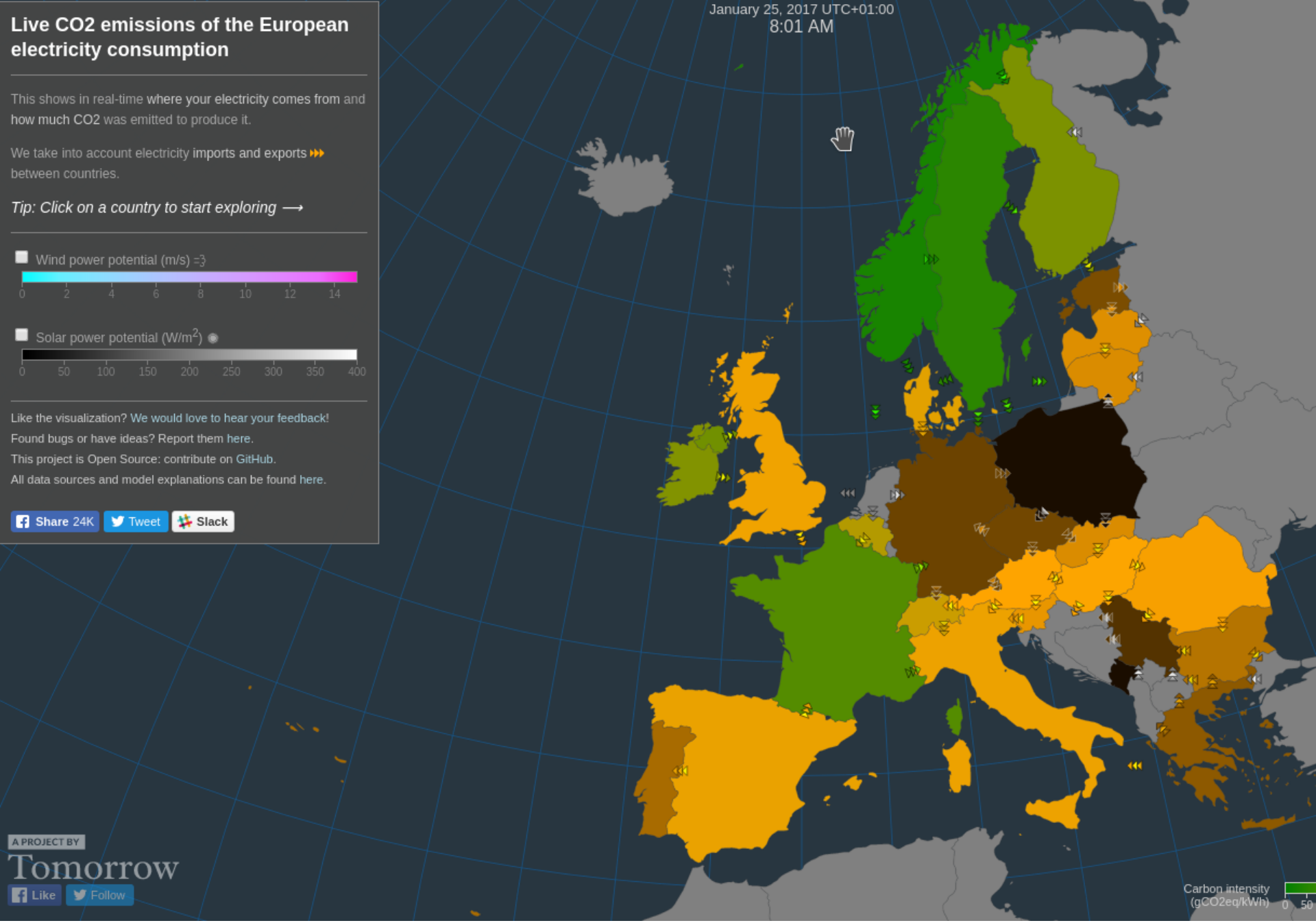
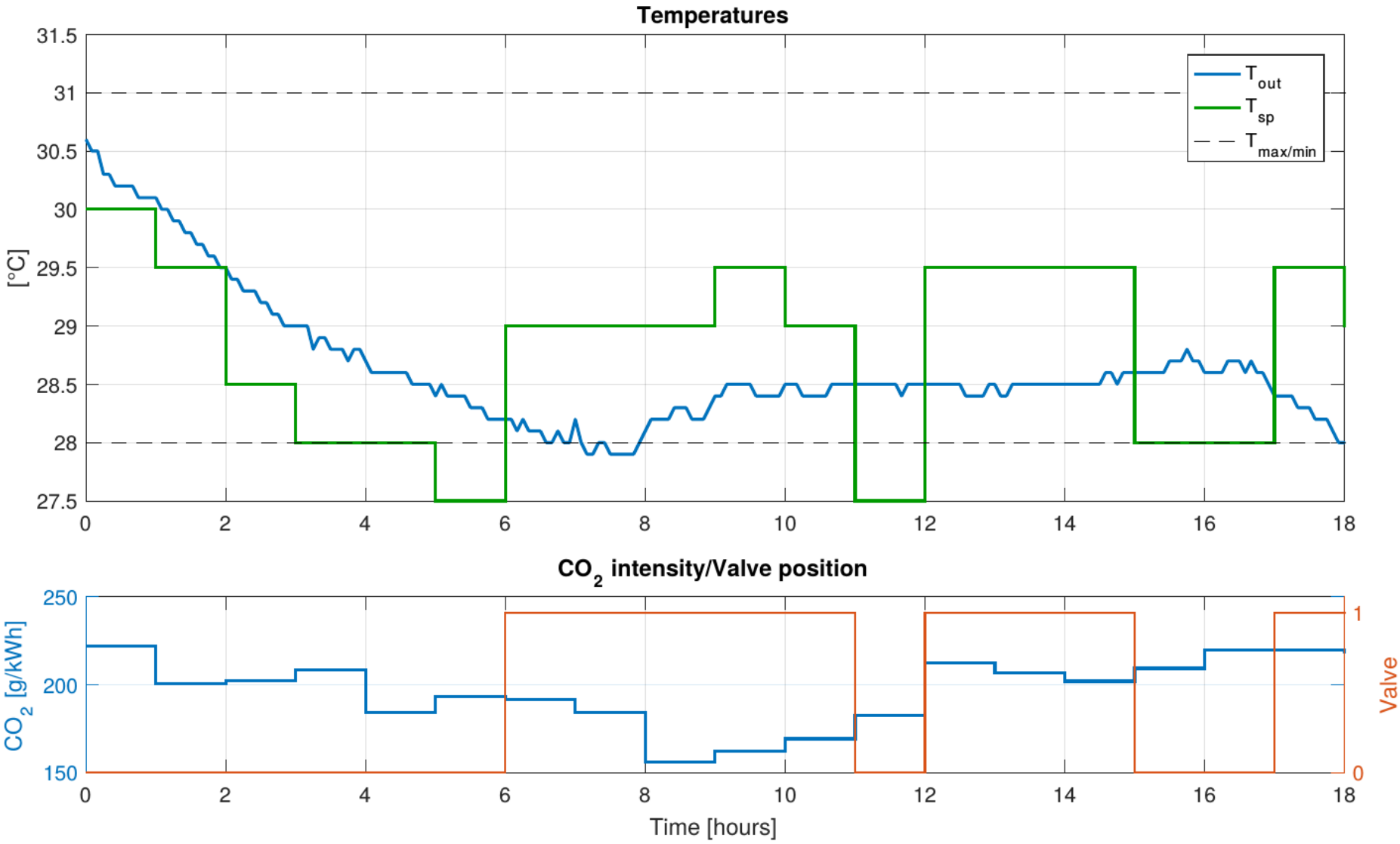
35
40
45
time [hours]


valve position
1
0.5
0
0
10
20
30
40

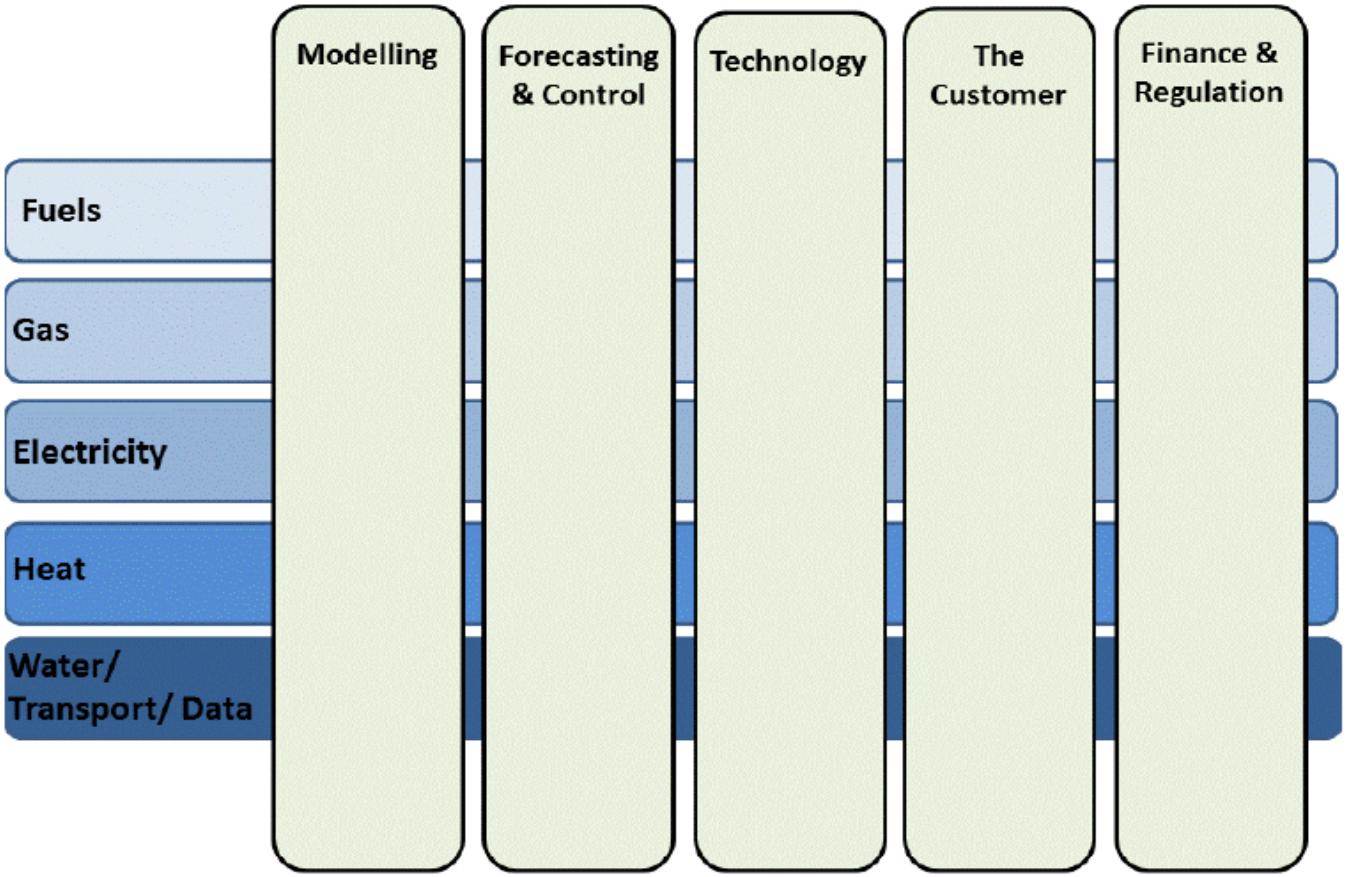

normalized prices
1
0.5
0
0
10
20
30
40
time [hours]


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
30
29.5
29
28.5
28
27.5
[°C]
0
2
4
6
8
10
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)



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

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)