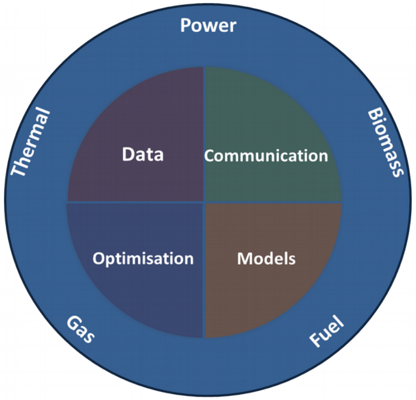
Center Denmark

Data Intelligent Energy Systems

Towards a Smart and Fossil-free Society



Henrik Madsen

Applied Mathematics and Computer Science

Technical University of Denmark

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

http://www.henrikmadsen.org

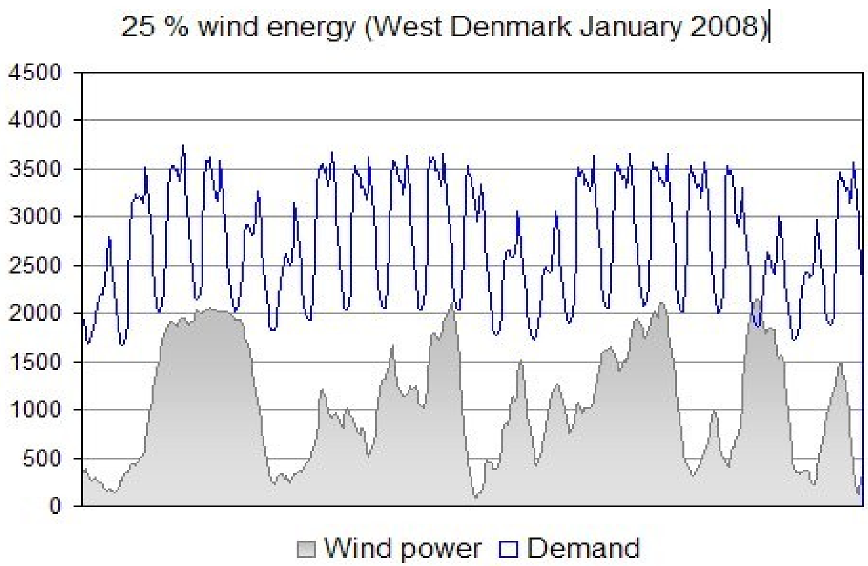
CITIES
Centre for IT Intelligent Energy Systems

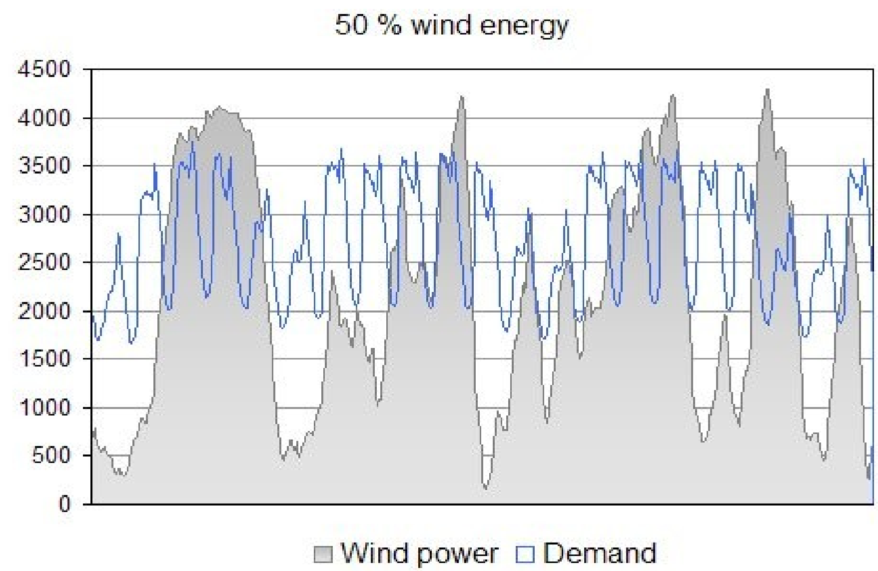
Project Motivation
The challenges

CITIES
Centre for IT Intelligent Energy Systems

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 the first half of 2017 more than 44 pct of electricity load was covered by wind power.

For several days the wind power production was more than 100 pct of the power load.

July 10th, 2015 more than 140 pct of the power load was covered by wind power

CITIES
Centre for IT Intelligent Energy Systems

Challenges (example)

Preparatory study on Smart Appliances

European Commission

Ecodesign Preparatory Study performed for the European Commission

Welcome | Project summary | Planning & Meetings | Documents | Register for website | Register for meeting | Contact & Consortium

Home > Project summary

Report: Almost no flexibility

Project Summary

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) has analysed the technical, economic, market and societal aspects with a view to a broad introduction of smart appliances and to develop adequate policy approaches for such appliances.

We have seen the same conclusion in almost all previous Danish projects

The study deals with Task 1 to 7 of the Methodology for Energy related products (MEErP) as follows:

- Scope, standards and legislation (Task 1, Chapter 1);
- Market analysis (Task 2, Chapter 2);
- User analysis (Task 3, Chapter 3);
- Technical analysis (Task 4, Chapter 4);
- Definition of Base Cases (Task 5, Chapter 5);
- Design options (Task 6, Chapter 6);
- Policy and Scenario analysis (Task 7, Chapter 7).

An executive summary of the project results can be downloaded here.

Throughout the study, new relevant aspects have come up which will be covered in a second phase of the Preparatory Study:

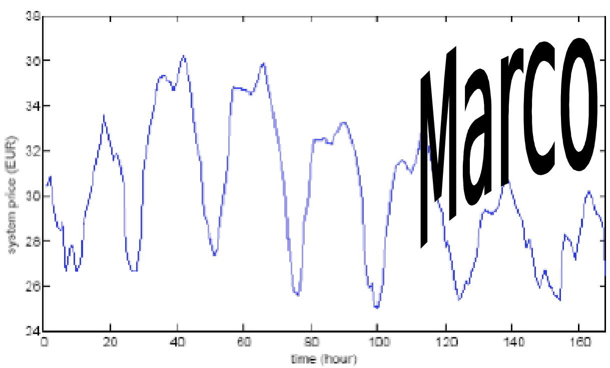
- Chargers for electric cars: technical potential and other relevant issues in the context of demand response.
- The modelling done in the framework of MEErP Task 6 and 7 will be updated with PRIMES data that recently became available, and with the EEA-countries.
- The development and assessment of policy options that were identified in the study will be further elaborated and deepened.

COMPETITIVE BIDDING AND STABILITY ANALYSIS IN ELECTRICITY MARKETS USING CONTROL THEORY

Main idea: **applying control theory to the study of power markets**

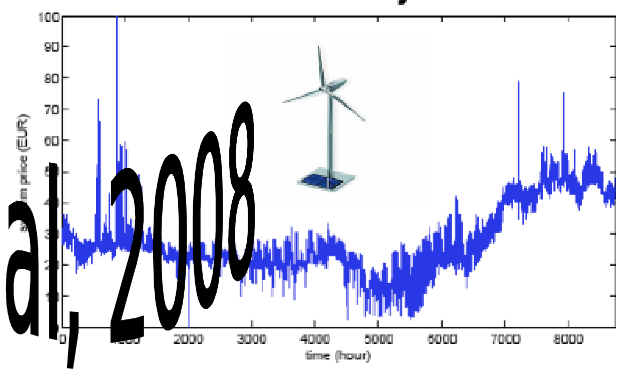
Advantages in handling effectively

Dynamics



Marco Zugno et.al, 2008

Uncertainty



control theory provides ways of modeling the dynamics which is intrinsic in energy markets

↓

it is possible to develop advanced bidding strategies which exploit the inclusion of the dynamics in the model

stochastic control theory allows for taking into account different sources of uncertainty (wind, ...)

↓

it is possible to develop bidding strategies which are optimal with respect to the stochastic characteristics of the market

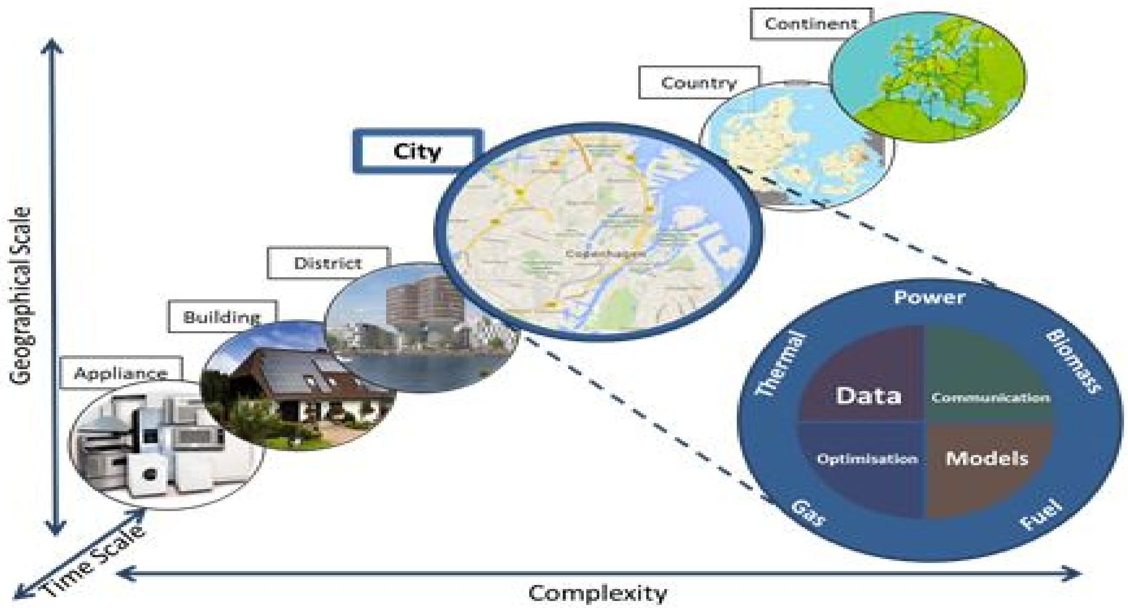
Project Idea

Data Intelligent Energy Systems for a Smart Society

CITIES
Centre for IT Intelligent Energy Systems

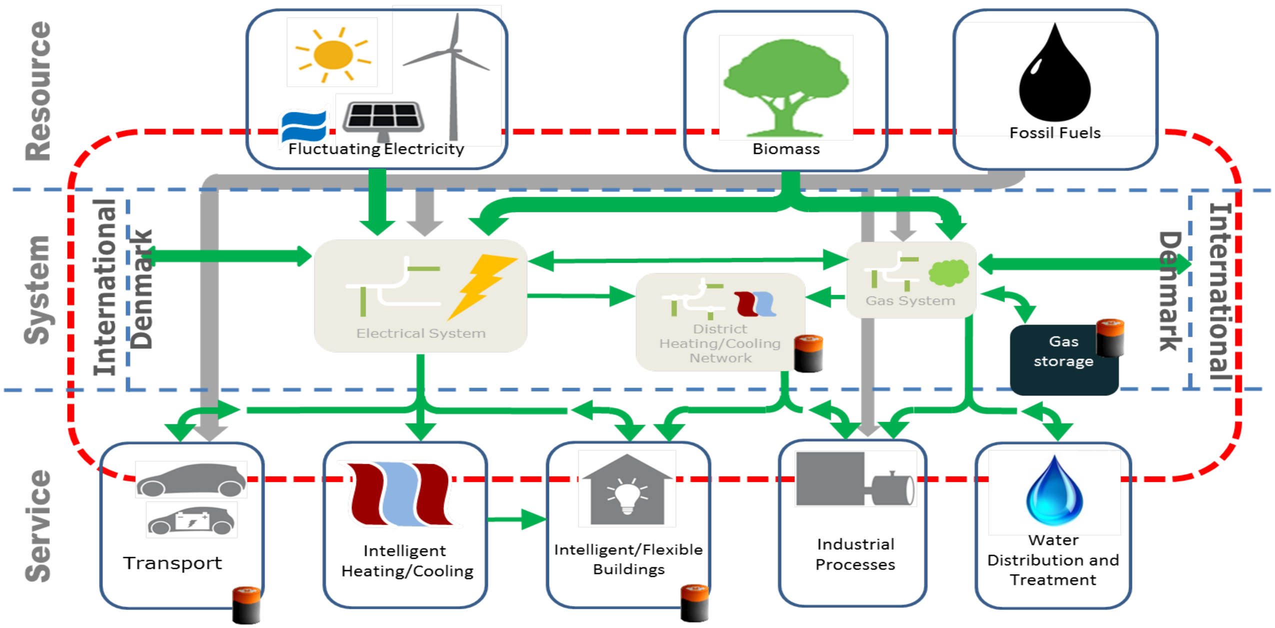
Temporal and Spatial Scales

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



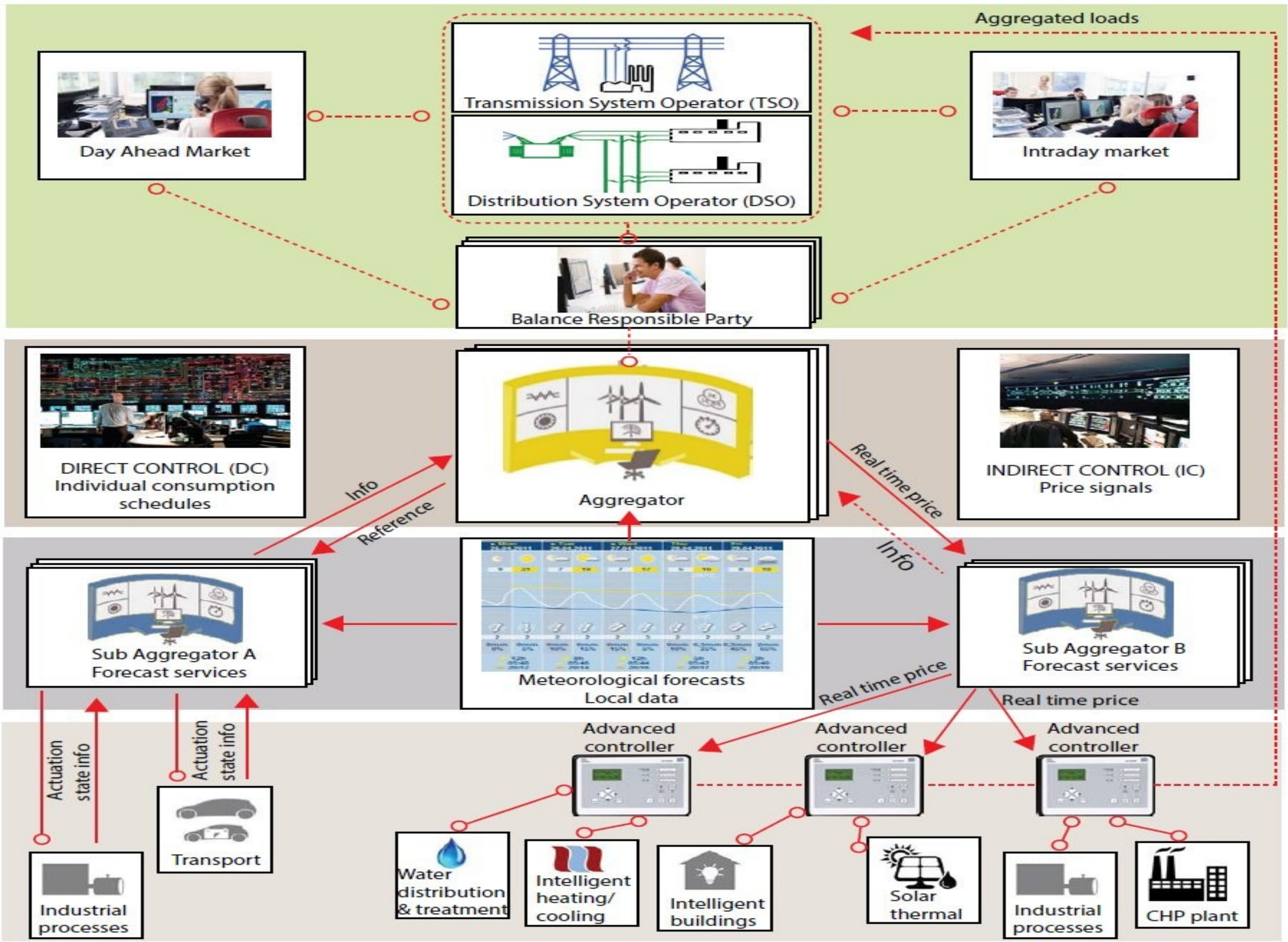
Models for Systems of Systems

Intelligent systems integration using **data and ICT solutions** are based on **models for real-time operation of flexible energy systems**



CITIES
Centre for IT Intelligent Energy Systems

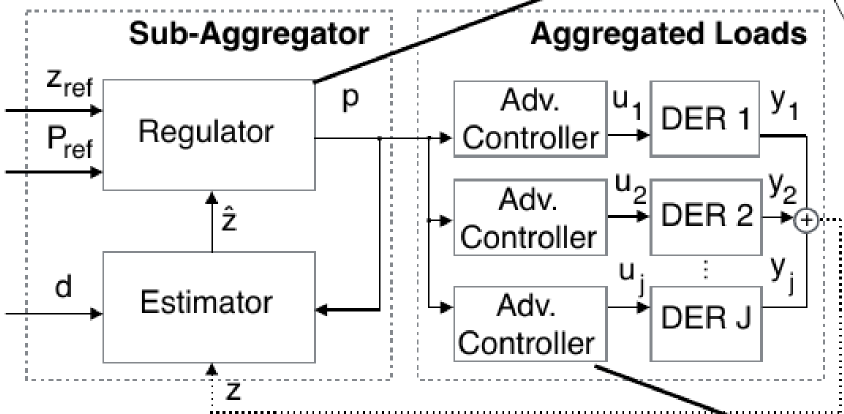
Smart-Energy OS



```
# slow approach, but we are sure things get don
# Try to parallelize anyway
require(multicore)
numcores<-multicore:::detectCores()
mclapply(
  1:N, 
  function(i,data) {
    print(paste(i, "/", N))

    # Find the indices of rows corresponding to
    j <-  which(data$dt_agg %in% aggdata$dt[i])

    # Filter out those who are NA
    j <-  j[!is.na(data$last_one_min_power[j])]

    # Count number of readings
    aggdata$num_readings[i] <-  length(j)
```

Proposed methodology
Control-based methodology

$$\min_{p} \quad \mathrm{E}[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||]$$
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$



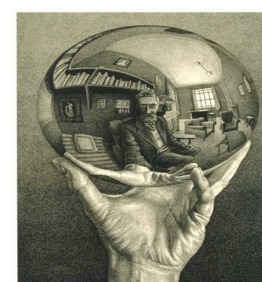
$$\begin{aligned} \min_{u} \quad & \mathrm{E}[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)] \\ \text{s.t.} \quad & x_{k+1} = Ax_k + Bu_k + Ed_k, \\ & y_k = Cx_k, \\ & y_k^{min} \leq y_k \leq y_k^{max}, \\ & u_k^{min} \leq u_k \leq u_k^{max} \end{aligned}$$

We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

Center Denmark:
Data Intelligent Energy Systems

DTU

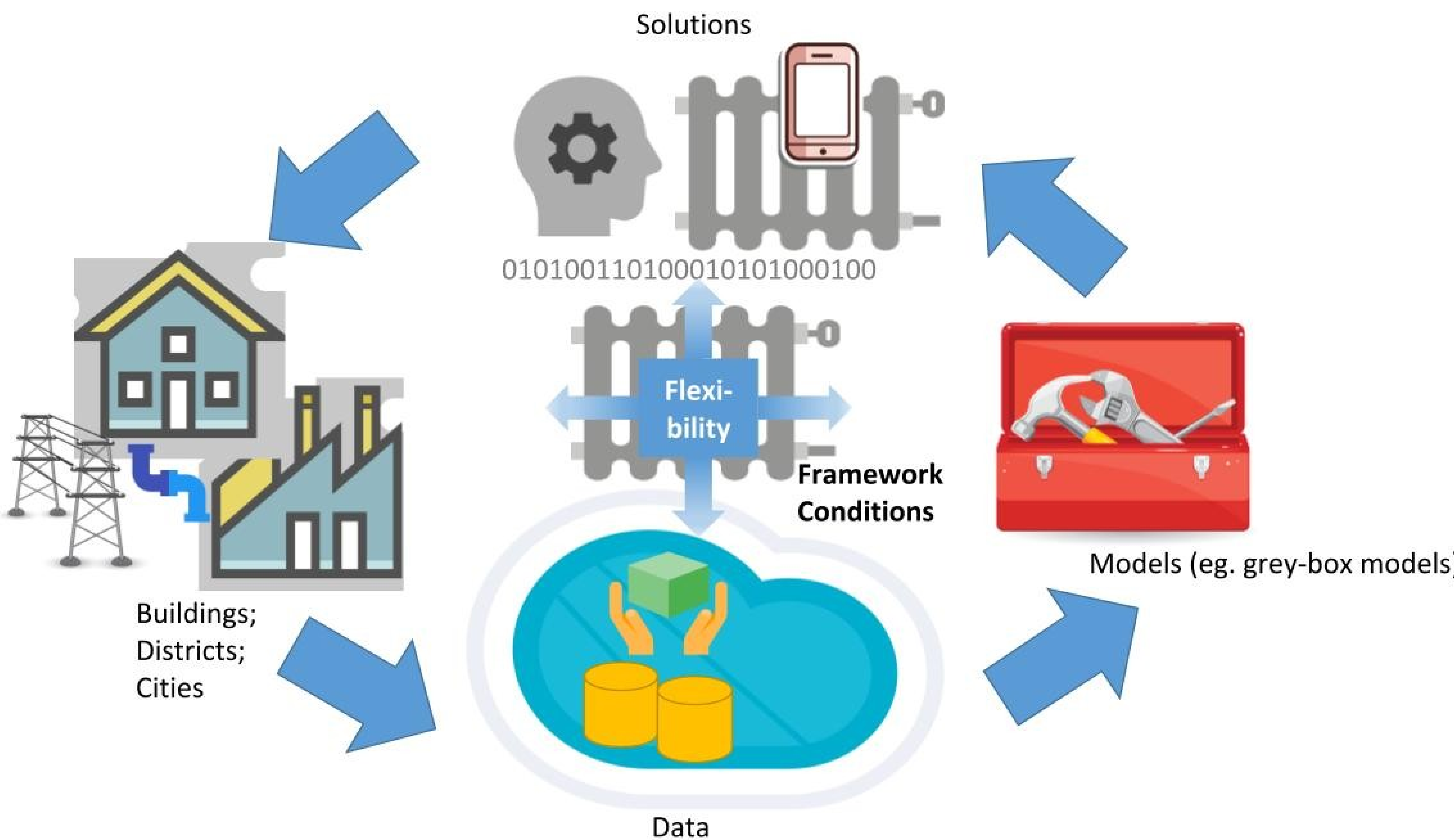
- Automatic and self-cal. methods based on Big Data analytics and AI
- Storage solutions are essential – both batteries and PCM
- Prosumer integration strategy and methodologies
- Labs – Virtual, HiL, Live
- Peer-to-peer communication (incl. blockchain)
- Nested sequence of systems – systems of systems
- Hierarchy of optimization (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud or Fog (IoT, IoS) based solutions – eg. for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, ...)
- Allow for new players (specialized aggregators)
- Simple setup for the communication and contracts
- Harvest flexibility at all levels



The (needed) Transformation

- A procedure for data intelligent control of integrated energy systems (using eg the Smart-Energy OS (SE-OS) setup)
- The test center has to be representative – and scaling is important
- A first very important step would be to establish Center Denmark near Fredericia (10.000 m2 facilities for Research, Education, Development and Testing - plus Dissemination)
- The Societal objective is to establish a realistic and concrete pathway to a fossil-free society
- The Scientific objective is to establish methodologies and solutions for the future intelligent and integrated energy system
- The Commercial perspective is to being able to idenfy and test solutions which can form the background for commercial success stories. We believe that this area has the unique characteristics for being the ultimate live-lab for test and demonstration of future smart energy solutions

Flexibility enabled using data intelligence



CITIES

International Collaboration

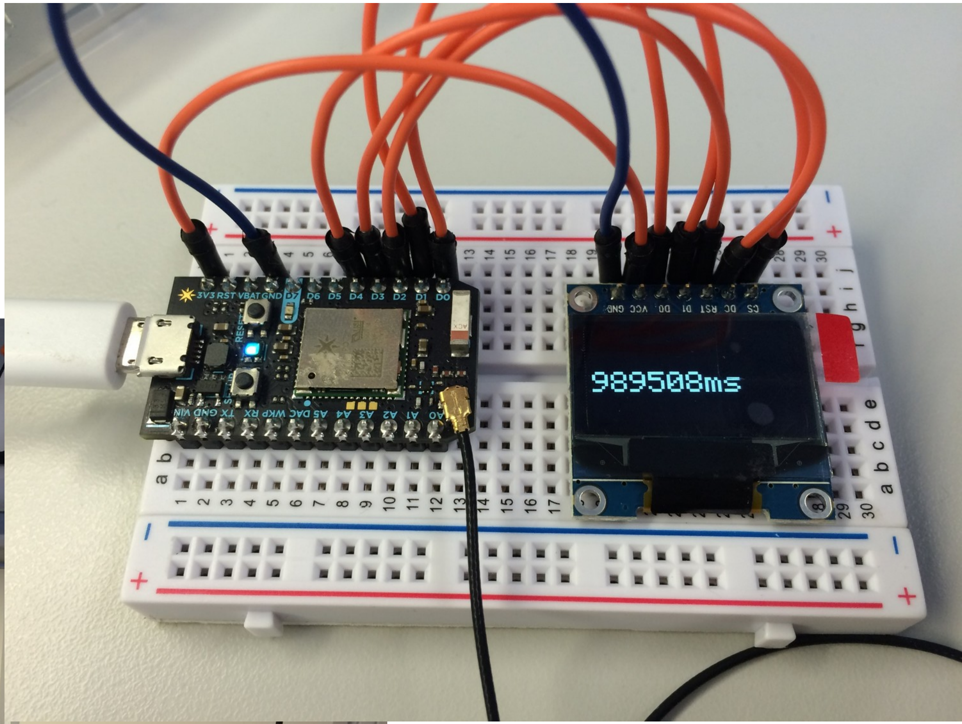
- Our partners – NREL, Berkely Lab, Argonne Nat. Lab, AIT, NTNU, LU, UCD, NTU, Tecnalia, Toyota, Samsung, …
- Close collaboration with many International Projects;

  The largest being:

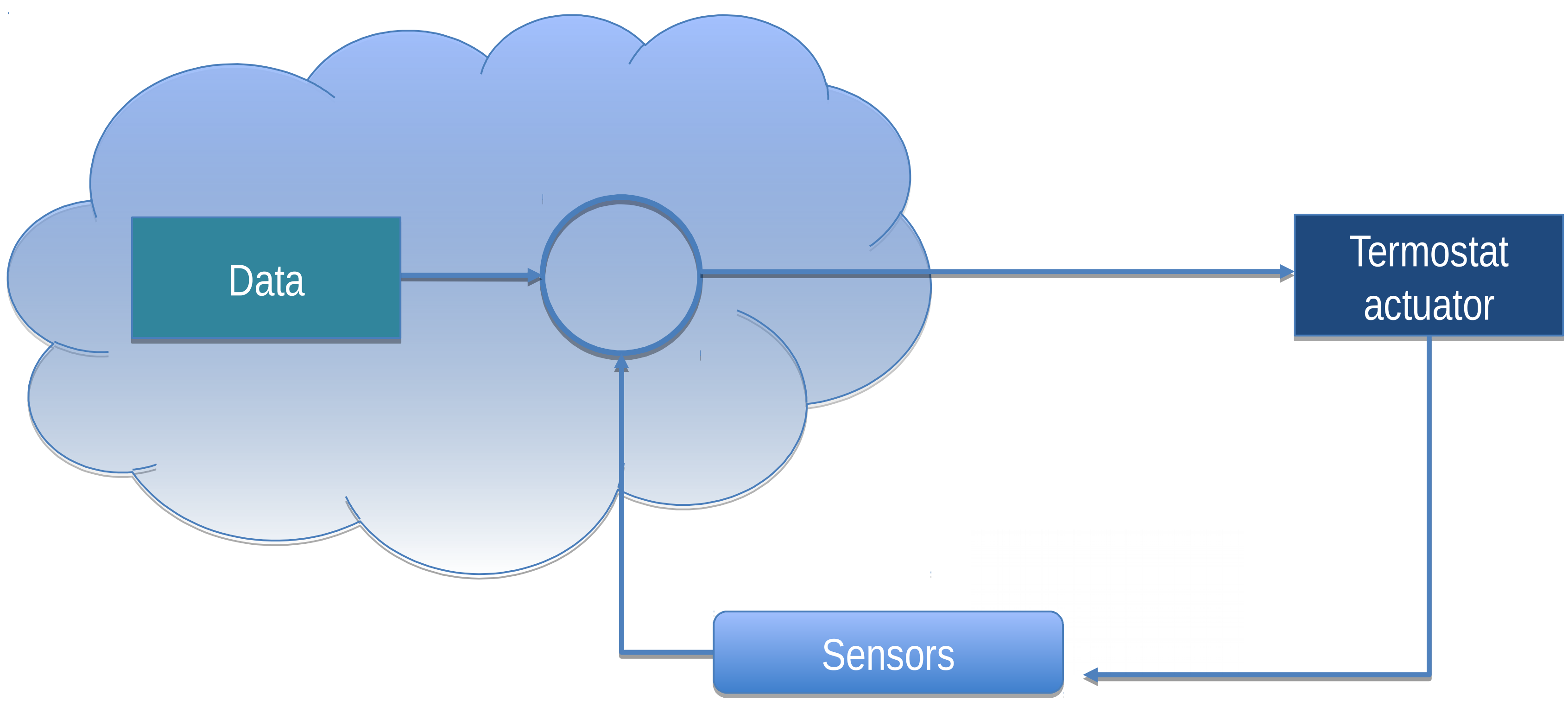
  - Energy Systems Integration Partnership Programme (ESIPP) – Ireland – 120 mill dkr
  - Centre for Energy Systems Integration (CESI) – UK – 300 mill dkr (project partner)
  - Research Centre on Zero Emission Neighb.in Smart Cities (ZEN) – Norway – 400 mill NOK – (partner) Henrik - Prof. II at NTNU
  - 5 EU projects building on results – so far ..
- COST TD1207 'Mathematical Optimization in the Decision Support Systems for Efficient and Robust Energy Networks.

Some results .... (so far)

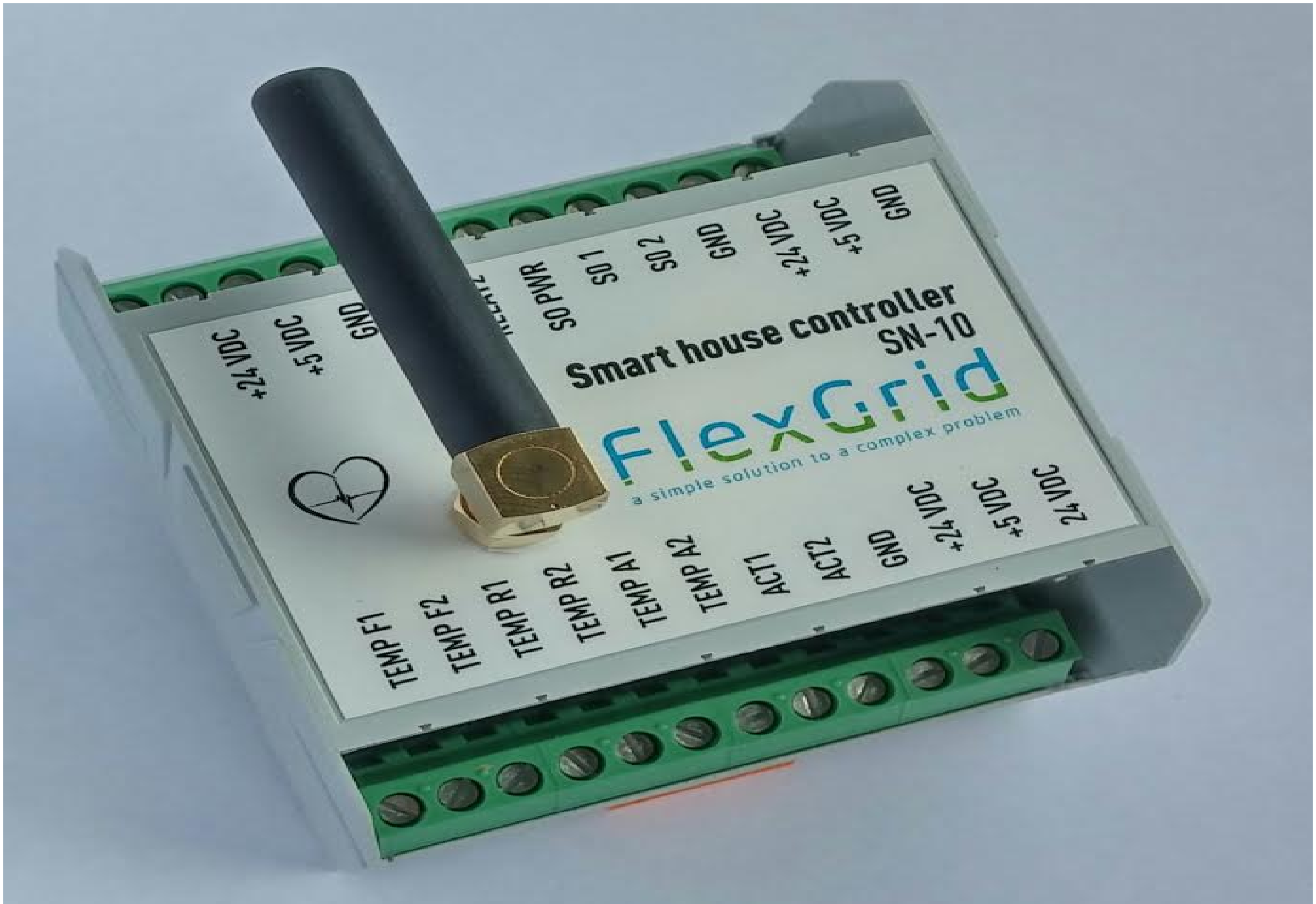
Lab testing ....



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



SN-10 Smart House Prototype



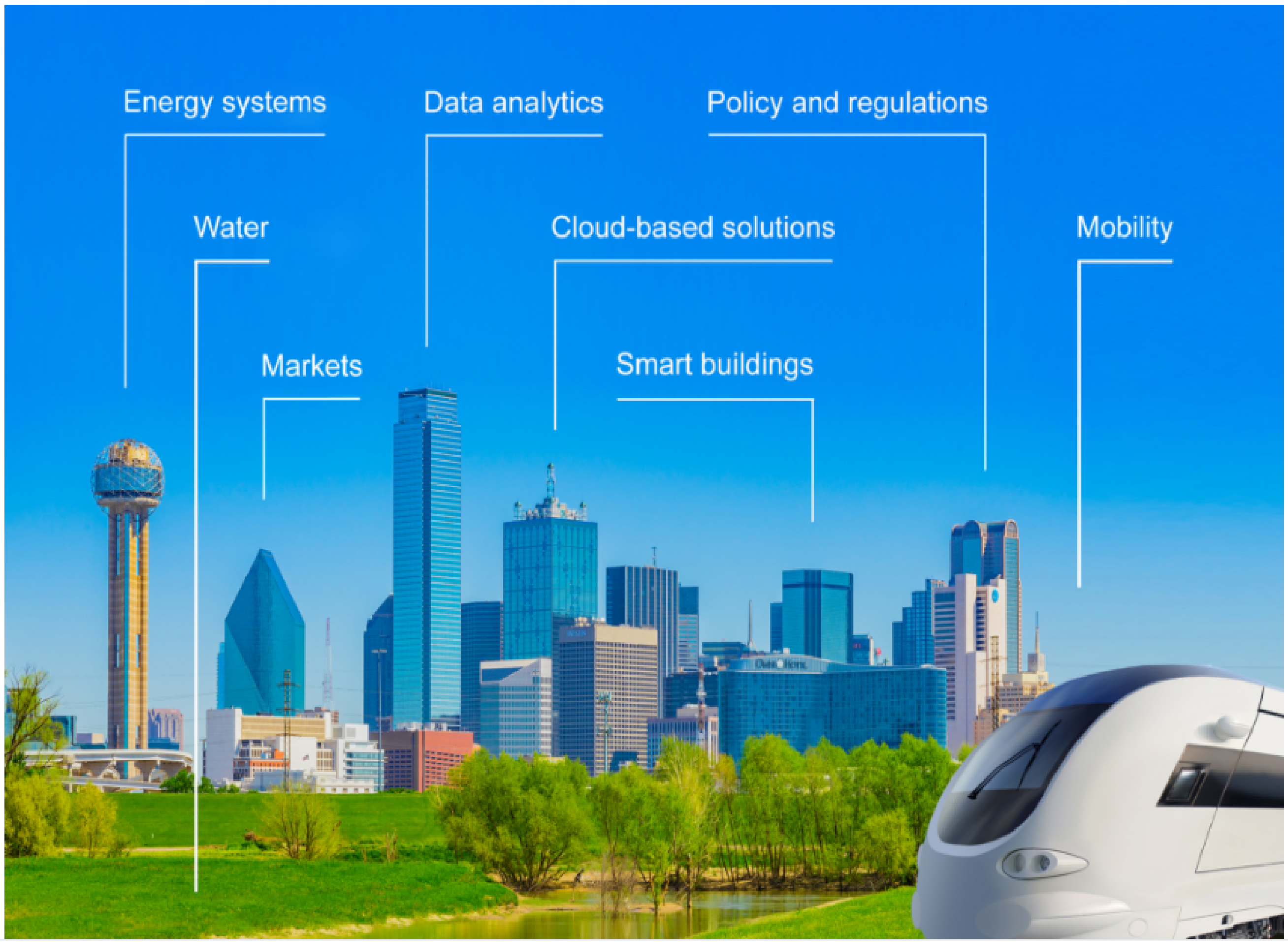
CITIES INNOVATION CENTER

Integrated energy systems powered by intelligent data

Search ...

HOME | 100% BY 2050 | ABOUT US | TOPICS | PROJECTS | EVENTS | PARTNERS

Topics



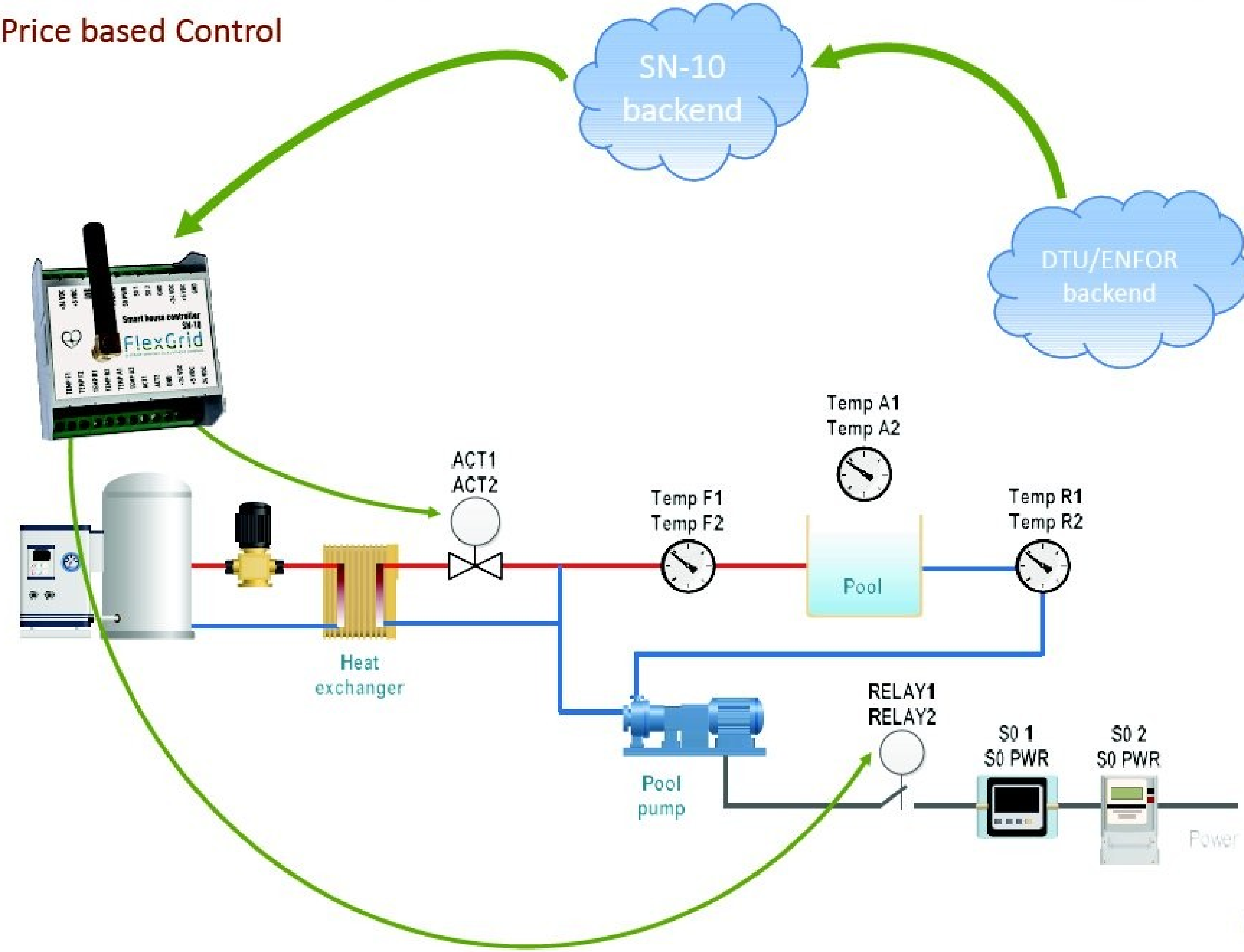
Case study No. 1

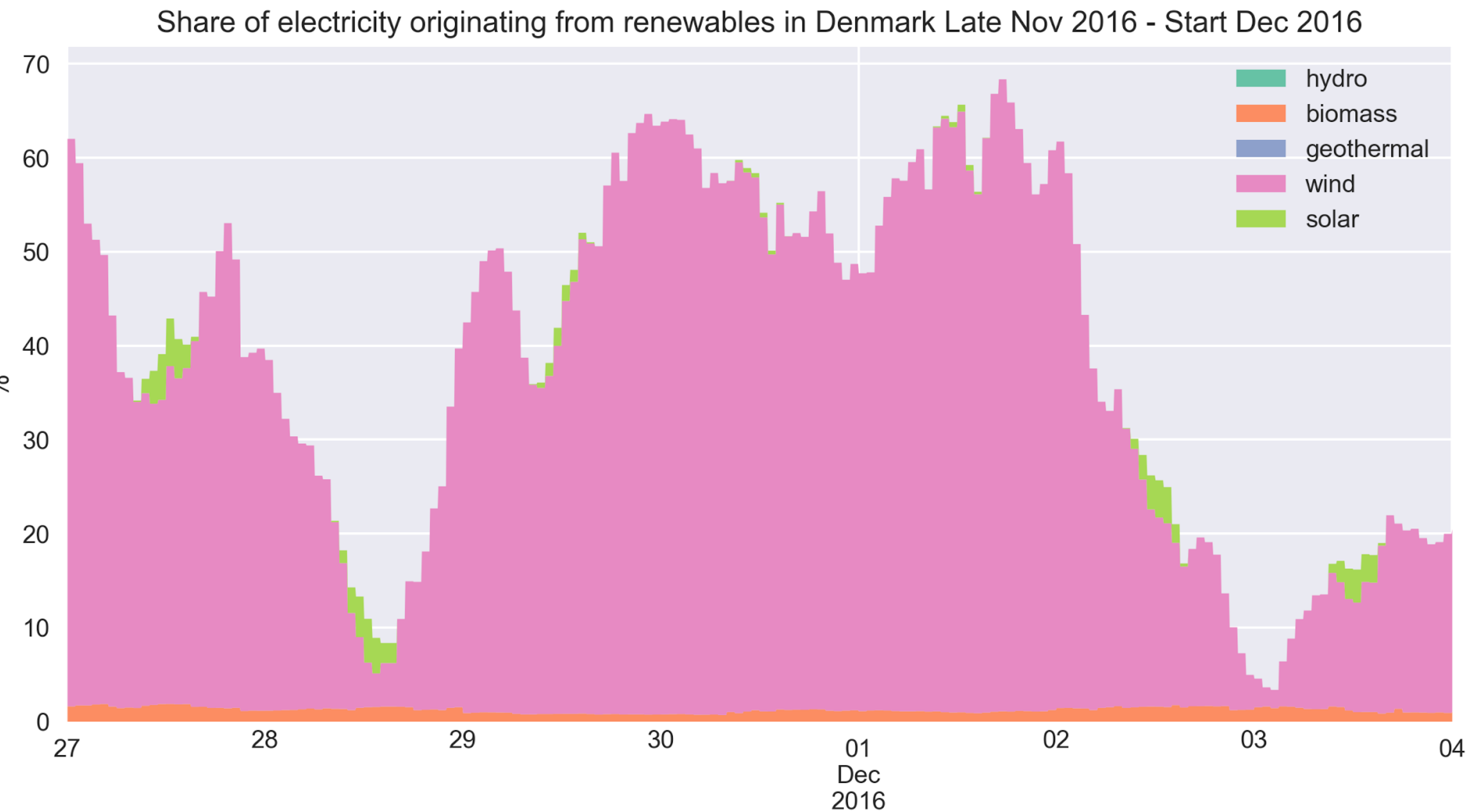
Control of heat pumps for swimming pools (CO2 minimization)

CITIES
Centre for IT Intelligent Energy Systems

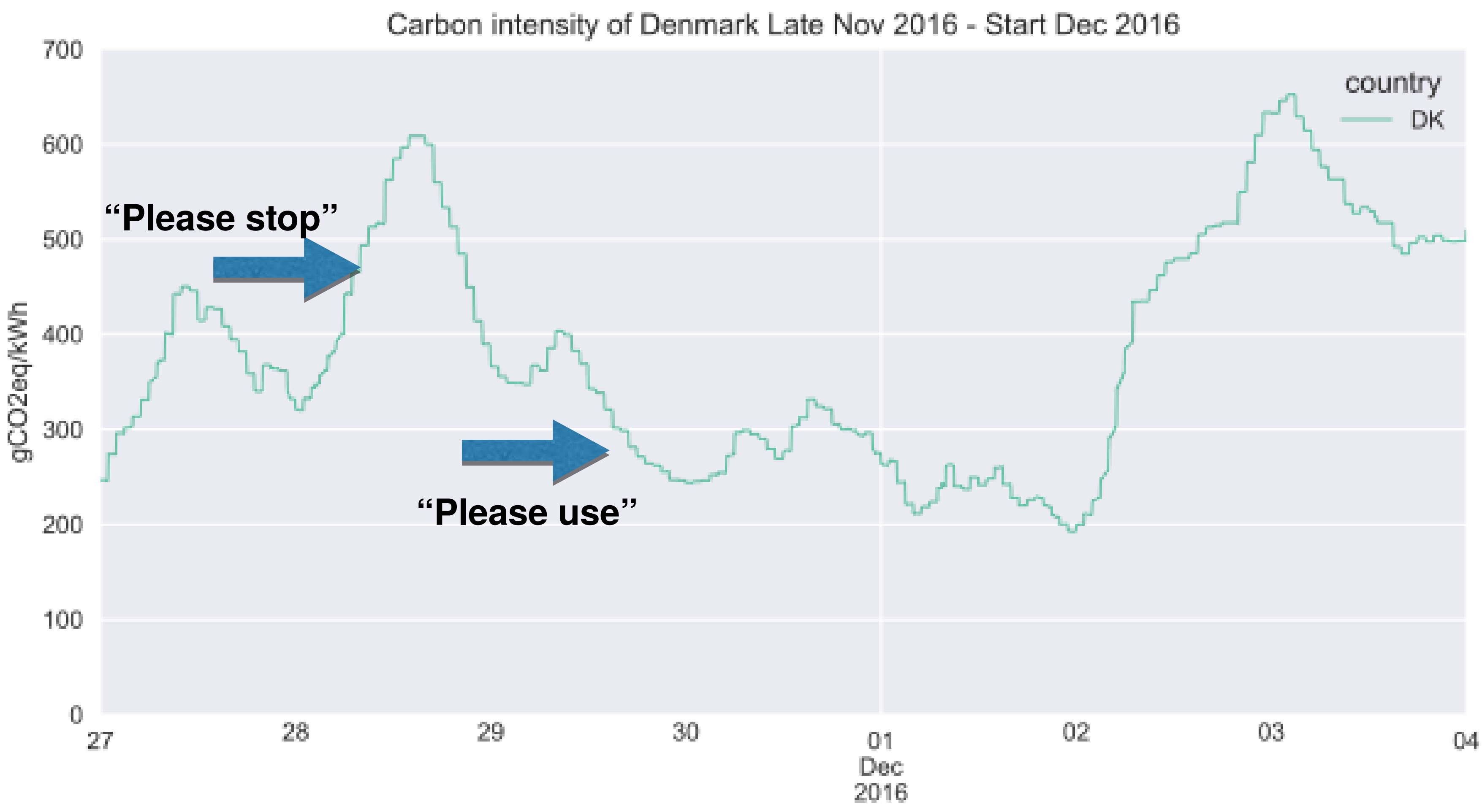
How does it work?

Price based Control

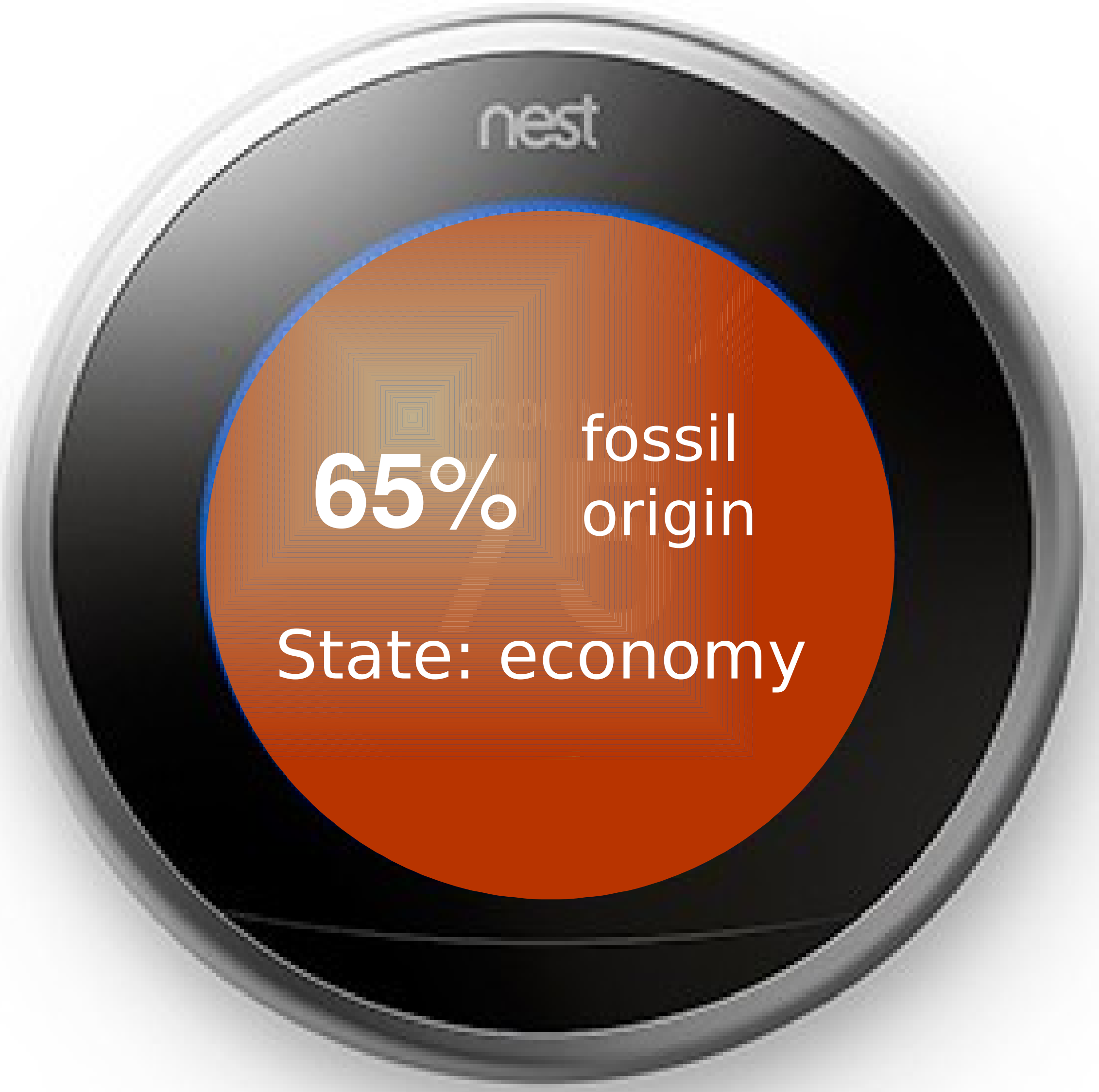




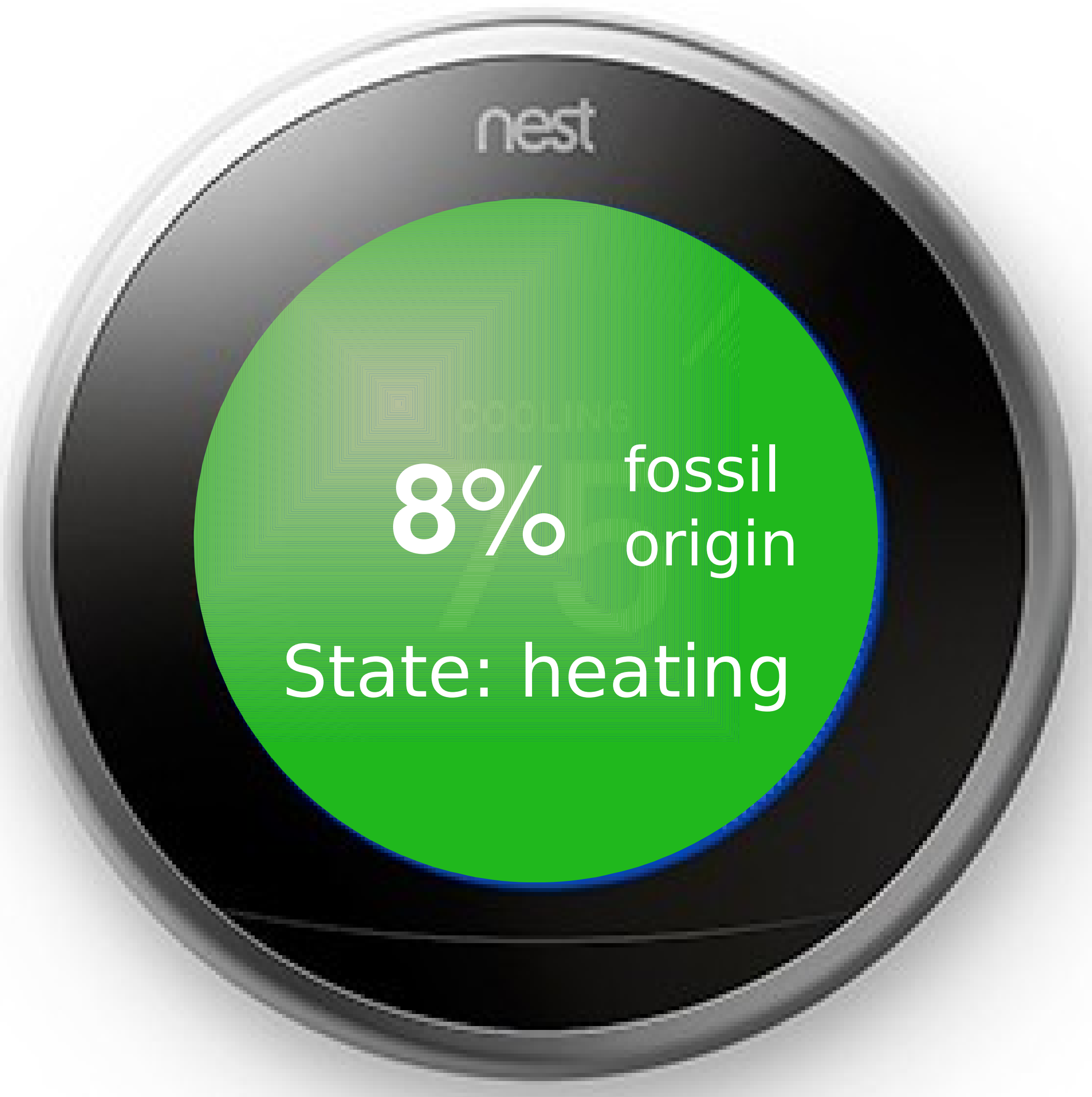
Source: pro.electicitymap.



Source: pro.electicitymap.



www.co2signal.com



www.co2signal.com

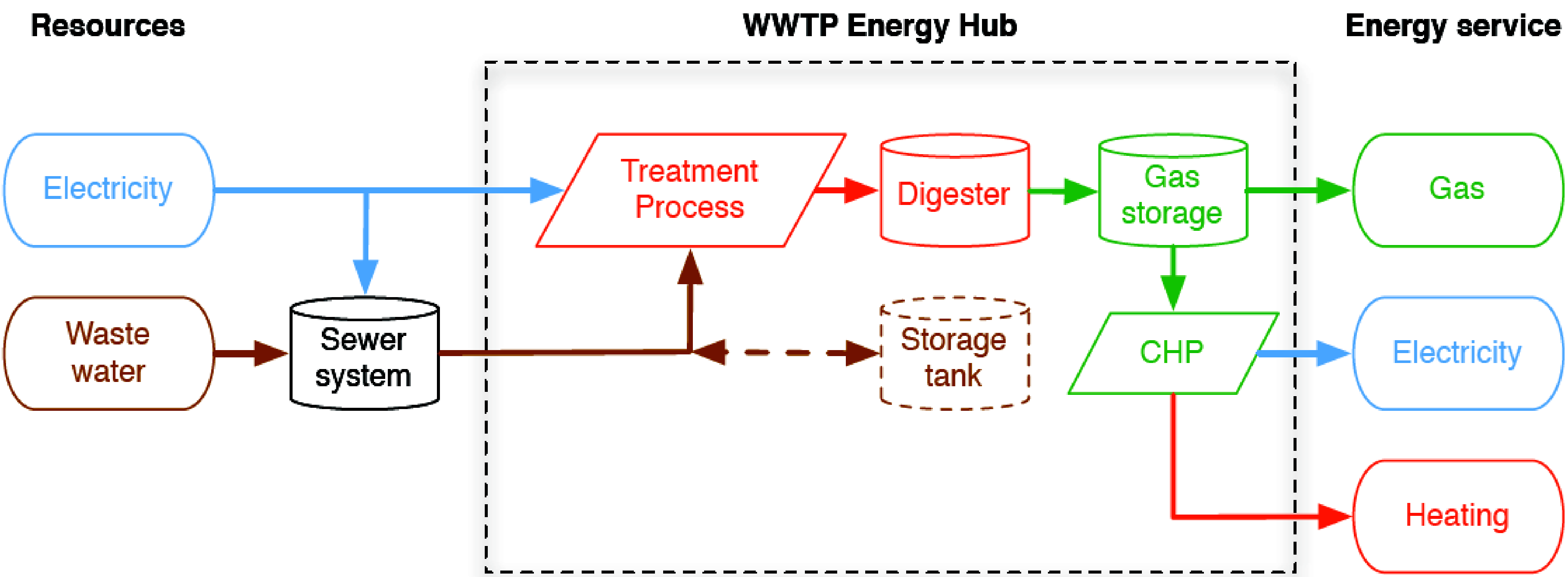
Case study No. 2

Wastewater Treatment Plants

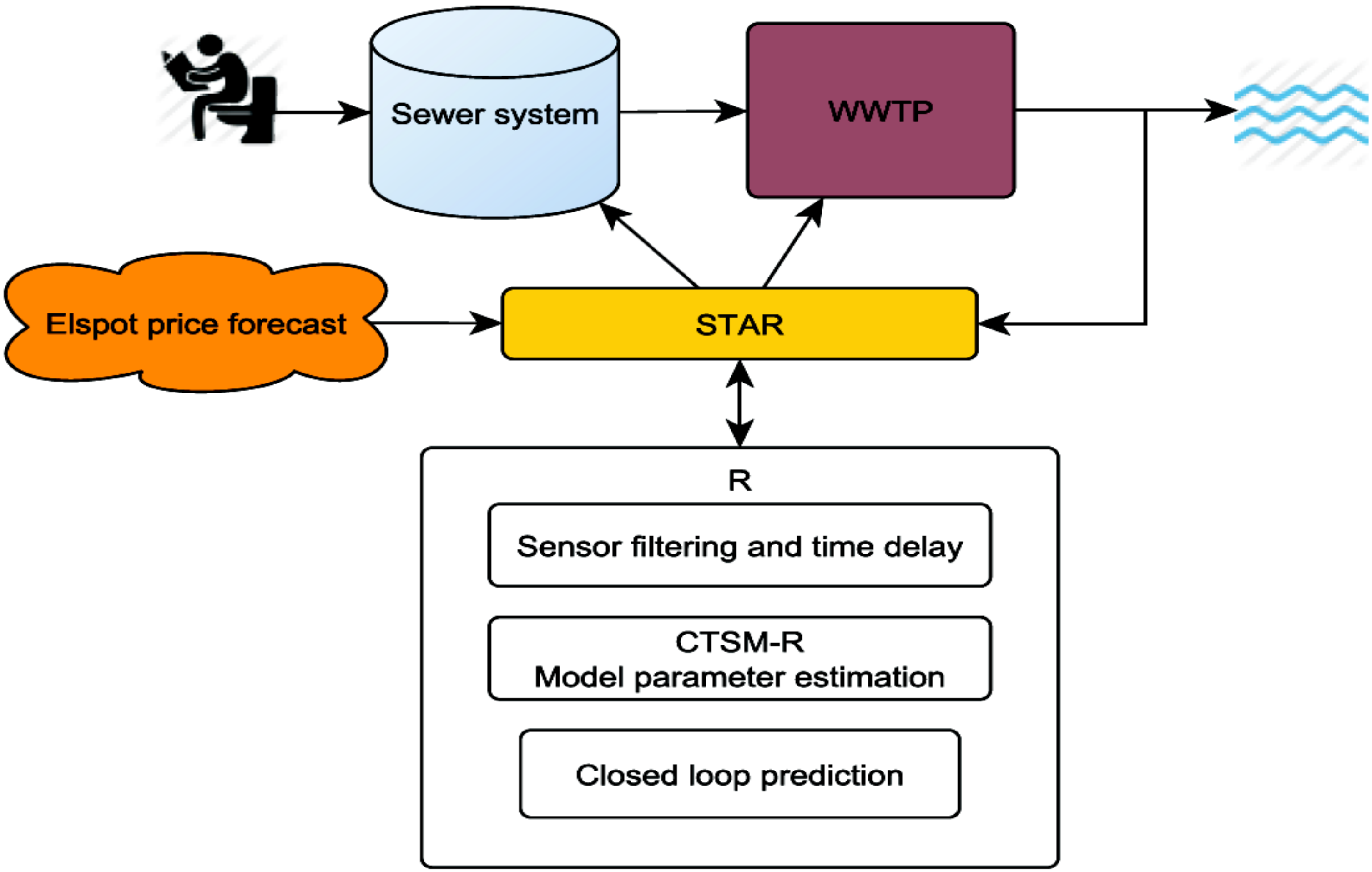
CITIES
Centre for IT Intelligent Energy Systems

Kolding WWTP

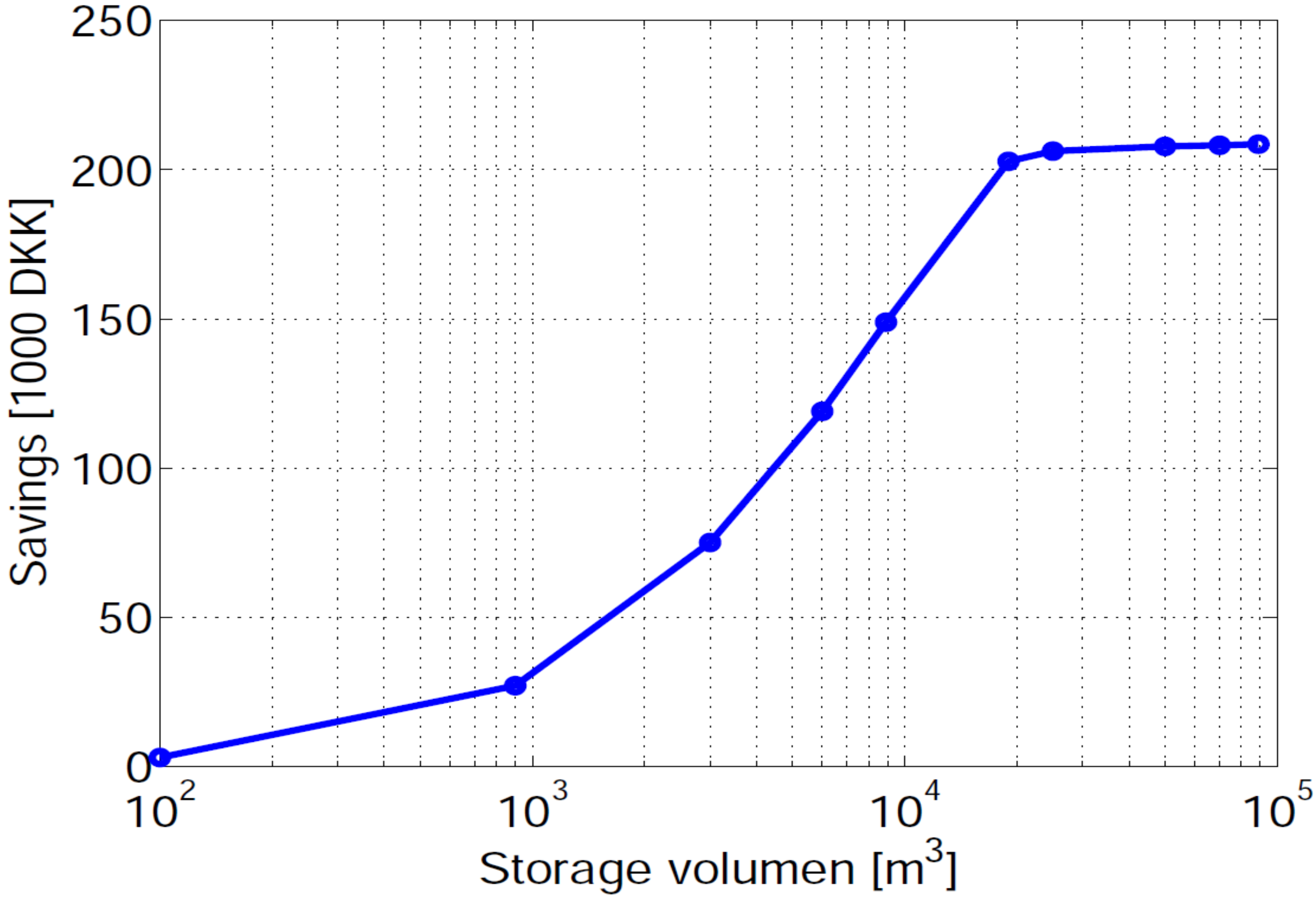
Waste-2-Energy



Energy Flexibility in Wastewater Treatment



Sewer System Annual Elspot Savings



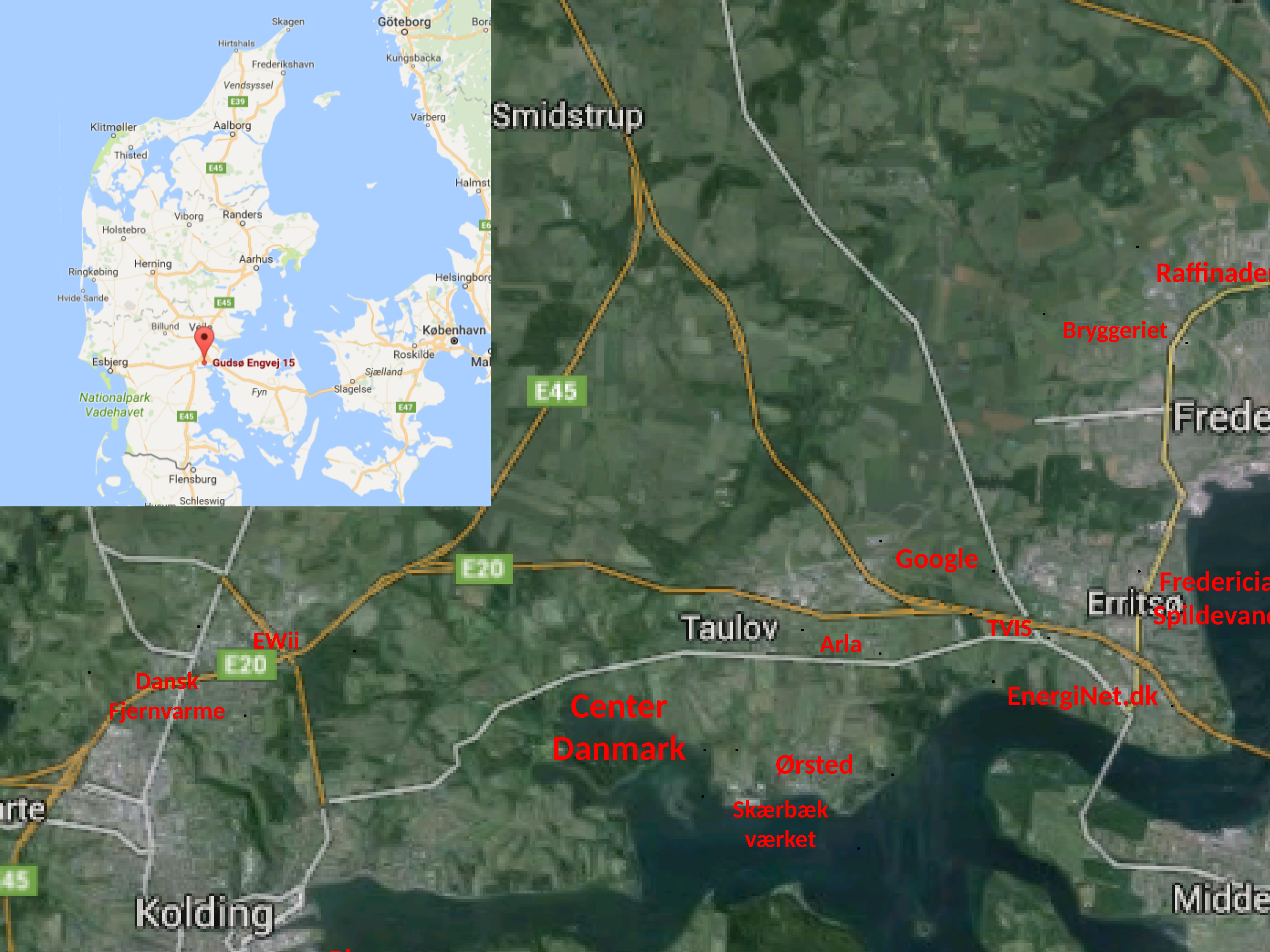
CITIES
Centre for IT Intelligent Energy Systems

DTU

centerdanmark
intelligent energi

- National Centre for Research, Education, Innovation, Test and Demonstration with a focus on data intelligent and integrated energy systems, physical and virtual storage, and water and food systems coupling

- From research to business in a real-life test environment with a main focus on the environment, people and nature



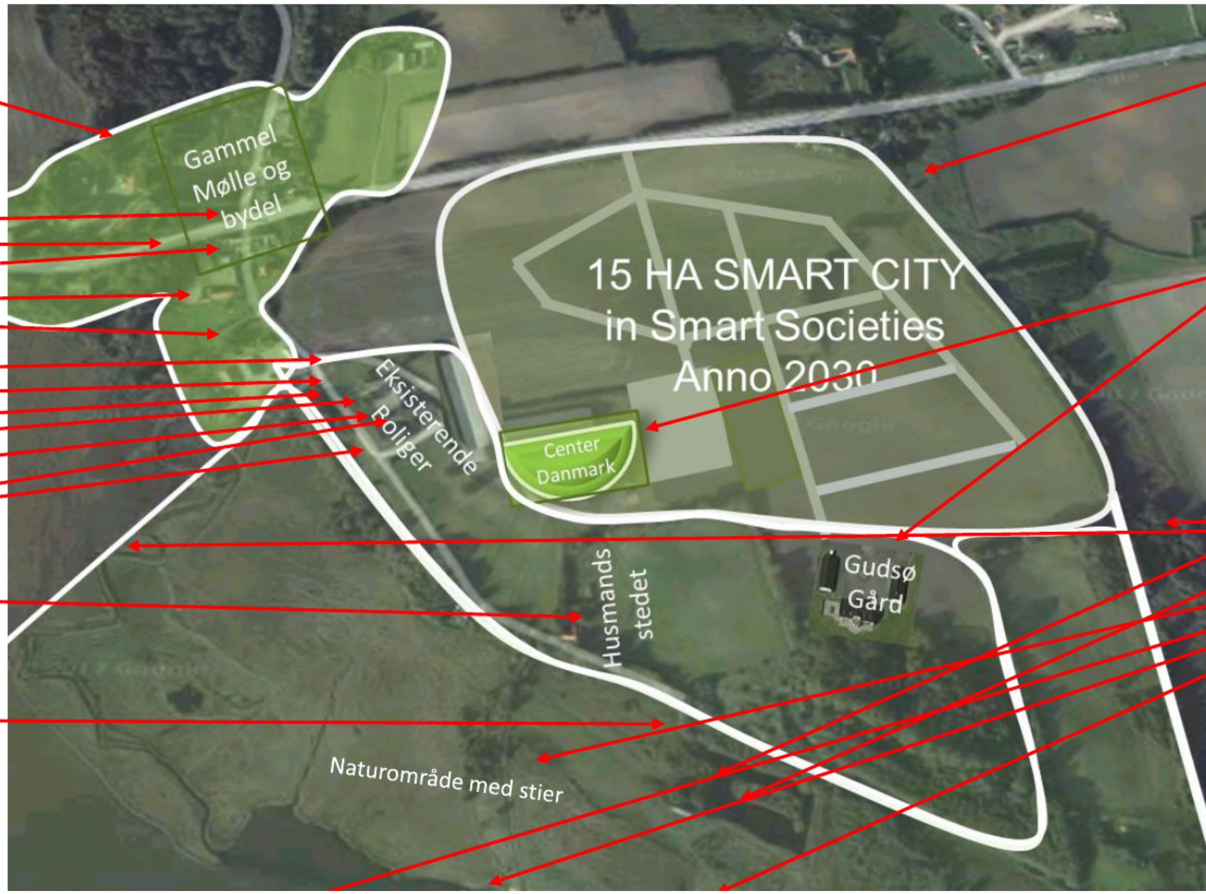
Skagen
Göteborg
Hirtshals
Frederikshavn
Kungsbacka
Vendsyssel
E39
Varberg
Klitmøller
Aalborg
Thisted
E45
Viborg
Randers
Holstebro
Aarhus
Herning
Ringkøbing
Helsingborg
Hvide Sande
E45
Billund
København
Roskilde
Esbjerg
Gudsø Engvej 15
Sjælland
Fyn
Slagelse
Nationalpark Vadehavet
E45
E47
Flensburg
Schleswig
Smidstrup
E45
Raffinader
Bryggeriet
Frede
E20
Google
Fredericia
Erritsø
Spildevand
Taulov
TVIS
Arla
EWii
E20
Dansk Fjernvarme
Center Danmark
EnergiNet.dk
Ørsted
Skærbæk værket
Kolding
Midde


Taulov
Gammel Mølle og bydel
161
SMART CITY in Smart Societies Anno 2030
Center Danmark
Eksisterende Boliger
Husmands stedet
Gudsø Gård
Oddersted
Naturområde med stier
Kort
Google

A mixture of old and new buildings (smart city anno 2030)

Ældre bygninger :

1. Møllen: Urban Farmning
    1. Bygning 228 m²
    2. Bygning 590 m²
    3. Bygning 290 m²
    4. Bygning 230 m²
    5. Bygning 155 m²
2. Privathus, 183 m².
3. Privathus, 153 m²
4. Privathus, 166 m²
5. Gård 140 m²
6. Gård 4-længet 231 m²
    1. Udbygninger 1200 m²
7. Rækkehus 140 m²
8. Rækkehus 130 m²
9. Depot 140 m²
10. Kontor 110 m²
11. Lager 450 m²
12. Erhverv produktion 450 m²
13. Ridehal 1700 m²
14. Produktion Øko Gødning
15. Privat hus 160 m²
16. Husmandssted 110 m²
    1. Erhverv 70 m²
    2. Produktion 25 m²
    3. Kølerum 5 m²
    4. Klimarum 10 m²
17. Shelter 60 m²



Nye bygninger :

1. Smart City 2030
    1. Urban Farmning
    2. Rækkehuse
    3. Parcel huse
    4. Kollegie værelser
    5. Undervisningsbygning
    6. Laboratorier
    7. Mini Industri
2. Center Danmark 4800 m²
3. Ny Gudsøgård 2600 m²
    1. Privat hus 280 m²
    2. Erhverv 280 m²
    3. Stald 280 m²

Natur, miljø & Dyreliv:

1. Åer
2. Sø
3. Skov
4. Eng
5. Hav
6. Natursti
7. Shelters

The old mill - Old Danish Energy System

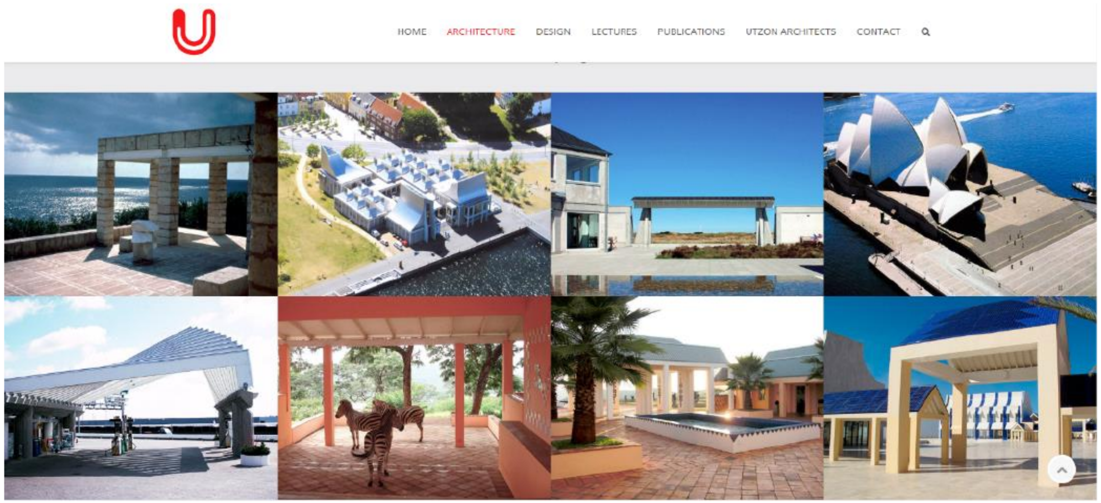
The project team - Architect and Construction

Jan Utzon
Arkitekt
https://utzon.dk/architecture/

Jørgen Hansen
Arkitekt MMA, 3D
http://www.3dform.dk

Klaus Bøgeholt-Laursen
Landinspektør, Partner
https://www.lifa.dk/

Karin Niemann-Christensen
Byplanrådgiver, Arkitekt MAA
https://www.lifa.dk/



Lars Bøtker-Rasmussen
Bygningskonstruktør
BØTKERS TEGNESTUE ApS

Søren Jeppe Pedersen
Arkitekt M.A.A
http://sjpdar.dk

- Planlægning
- Budgettering
- Skitsering/projektering
- Udbud
- Prisindhentning
- Kontrahering
- Bygherreleverancer
- Byggemøder
- Kvalitetskontrol
- Økonomistyring
- Aflevering
- Opfølgning