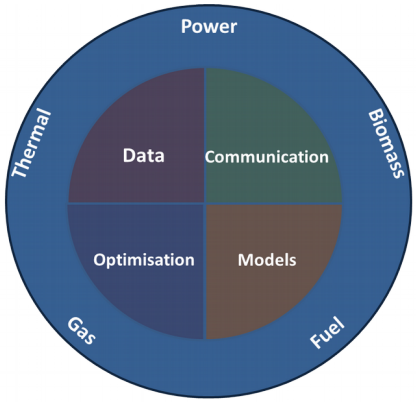
Center Denmark

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

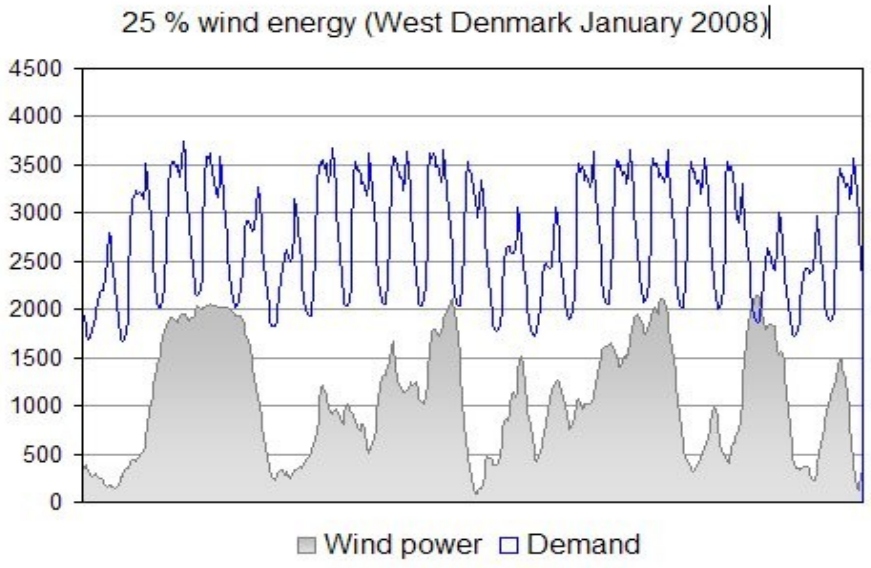
http://www.henrikmadsen.org

CITIES
Centre for IT Intelligent Energy Systems

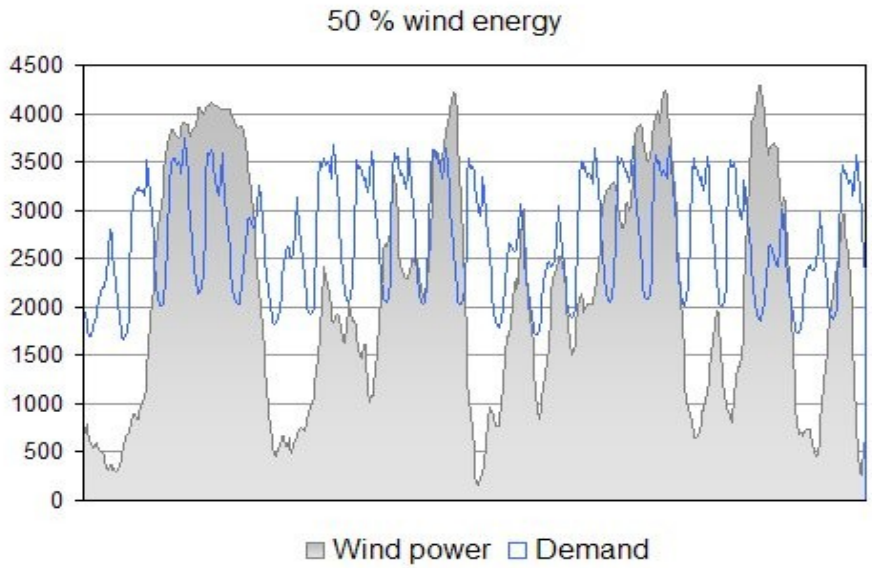
Project Motivation
The challenges

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

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 alternate policy approaches and scenarios.

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.

Report: Almost no flexibility

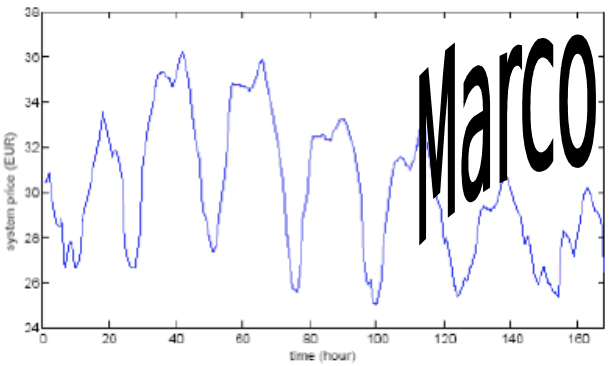
We have seen the same conclusion in almost all previous Danish projects

COMPETITIVE BIDDING AND STABILITY ANALYSIS IN ELECTRICITY MARKETS USING CONTROL THEORY

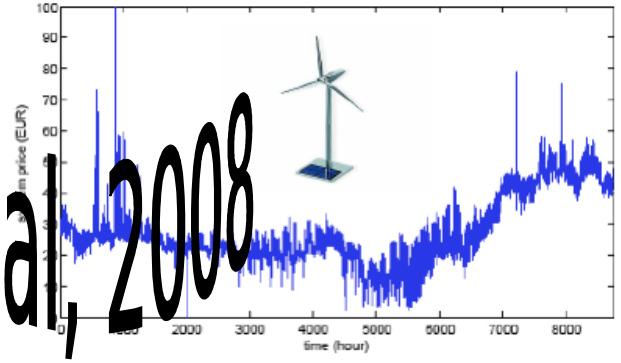
Main idea: **applying control theory to the study of power markets**

Advantages in handling effectively

Dynamics



Uncertainty



Marco Zugno et.al, 2008

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, ...)

↓

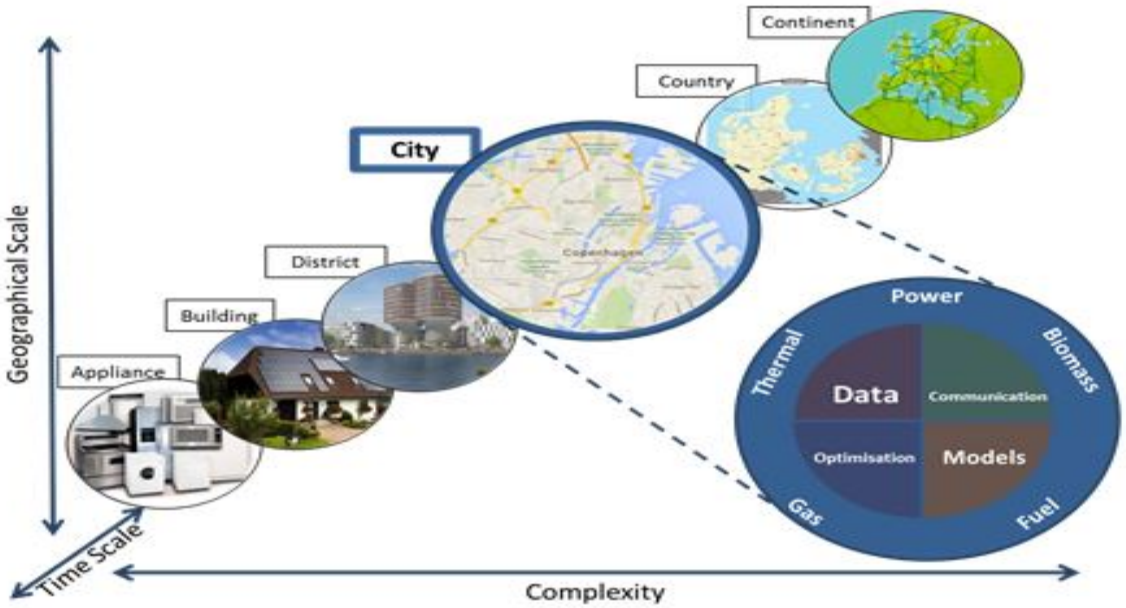
it is possible to develop bidding strategies which are optimal with respect to the stochastic characteristics of the market

Project Idea

Data Intelligent Energy Systems for a Smart Society

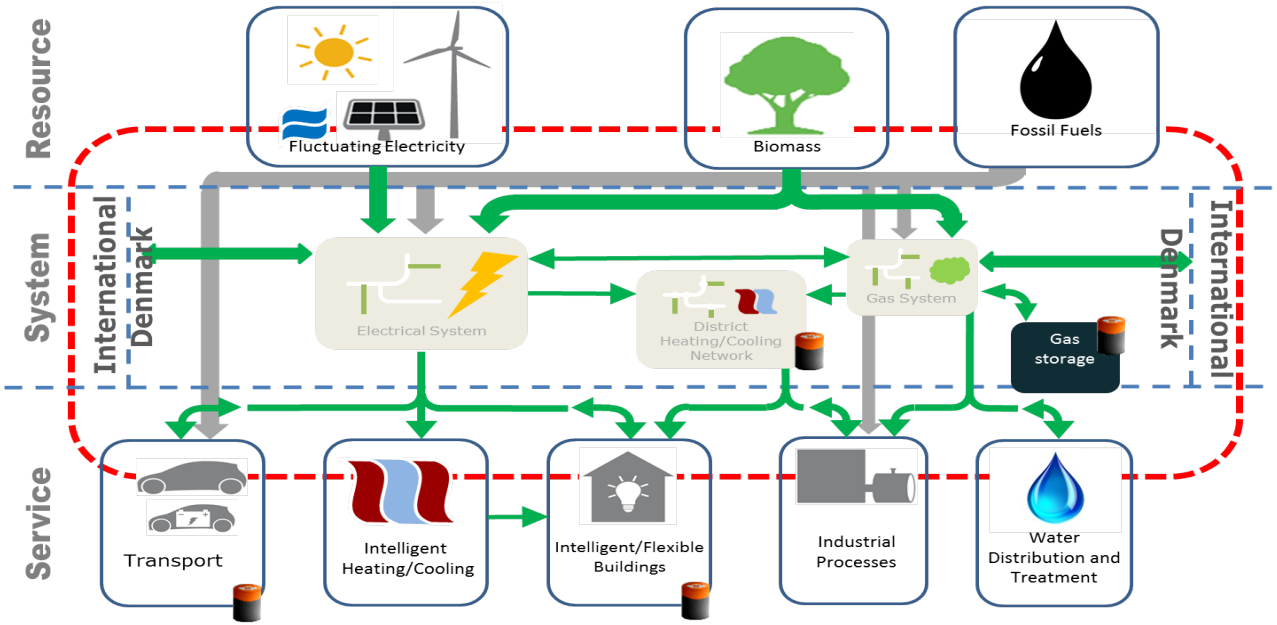
Temporal and Spatial Scales

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**.

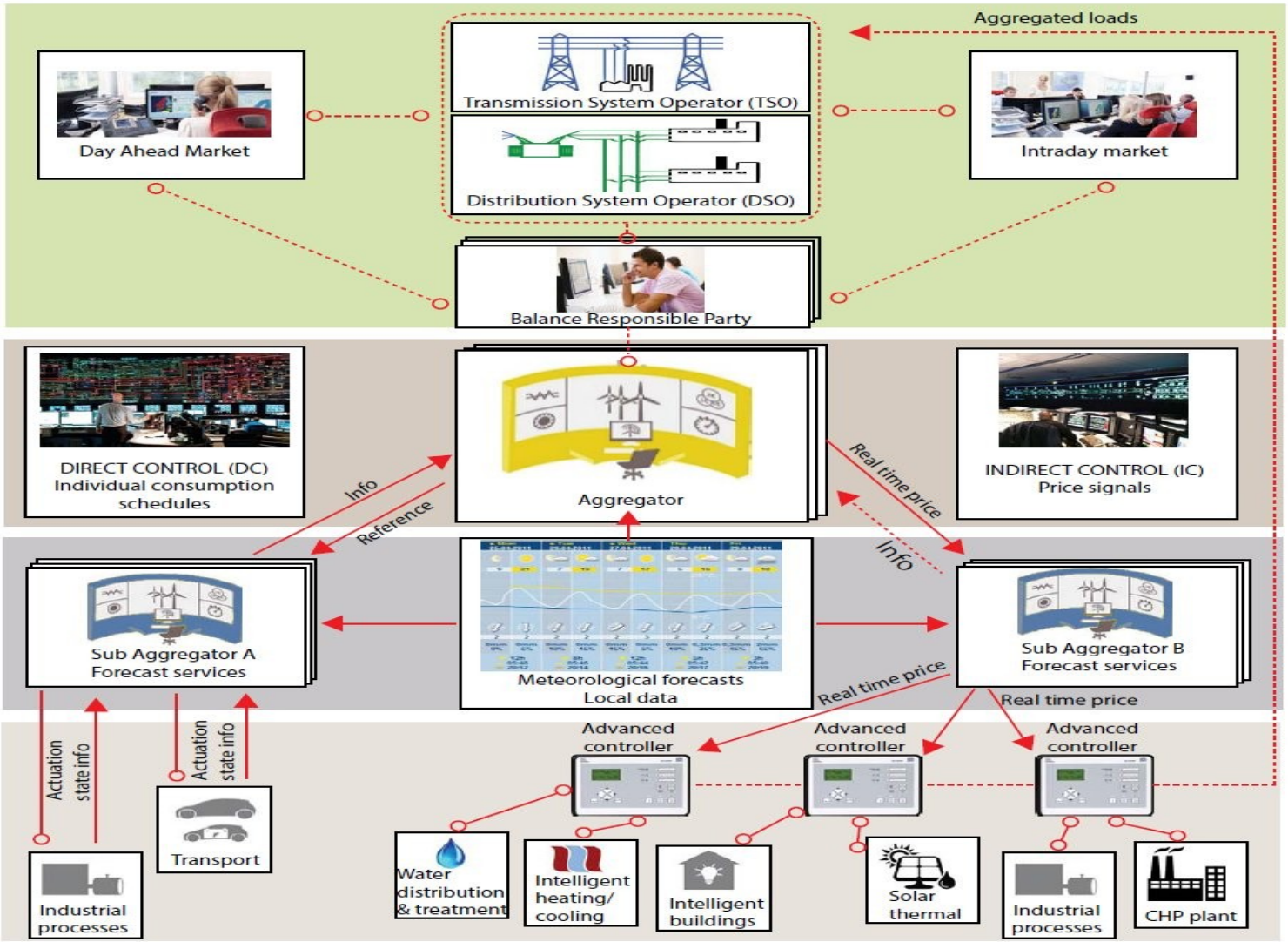


Models for Systems of Systems

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



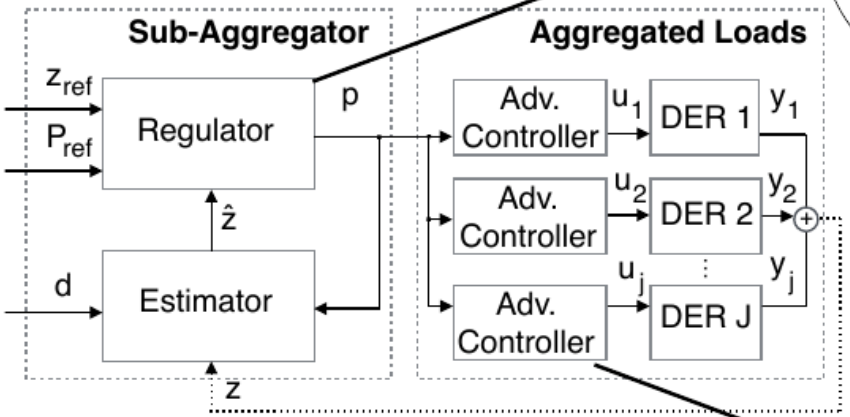
Smart-Energy OS



```
38
39  # Try to parallelize anyway
40  require(multicore)
41  numcores<-multicore:::detectCores()
42  mclapply(
43  ··1:N,·
44  ··function(i,data)·{
45  ····print(paste(i,·"/",·N))
46
47  ····#·Find·the·indices·of·rows·corresponding·to·
48  ····j·<-·which(data$dt_agg·%in%·aggdata$dt[i])
49
50  ····#·Filter·out·those·who·are·NA
51  ····j·<-·j[!is.na(data$last_one_min_power[j])]
52
53  ····#·Count·number·of·readings
    ····aggdata$num_readings[i]·<-·length(j)
```

Proposed methodology
Control-based methodology

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

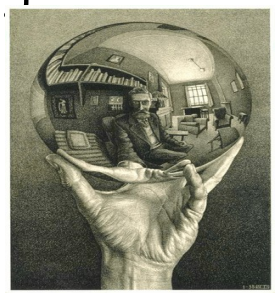


We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

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

Center Denmark:
Data Intelligent Energy Systems

- Automatic and self-cal. methods based on Big Data analytics and AI
- 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

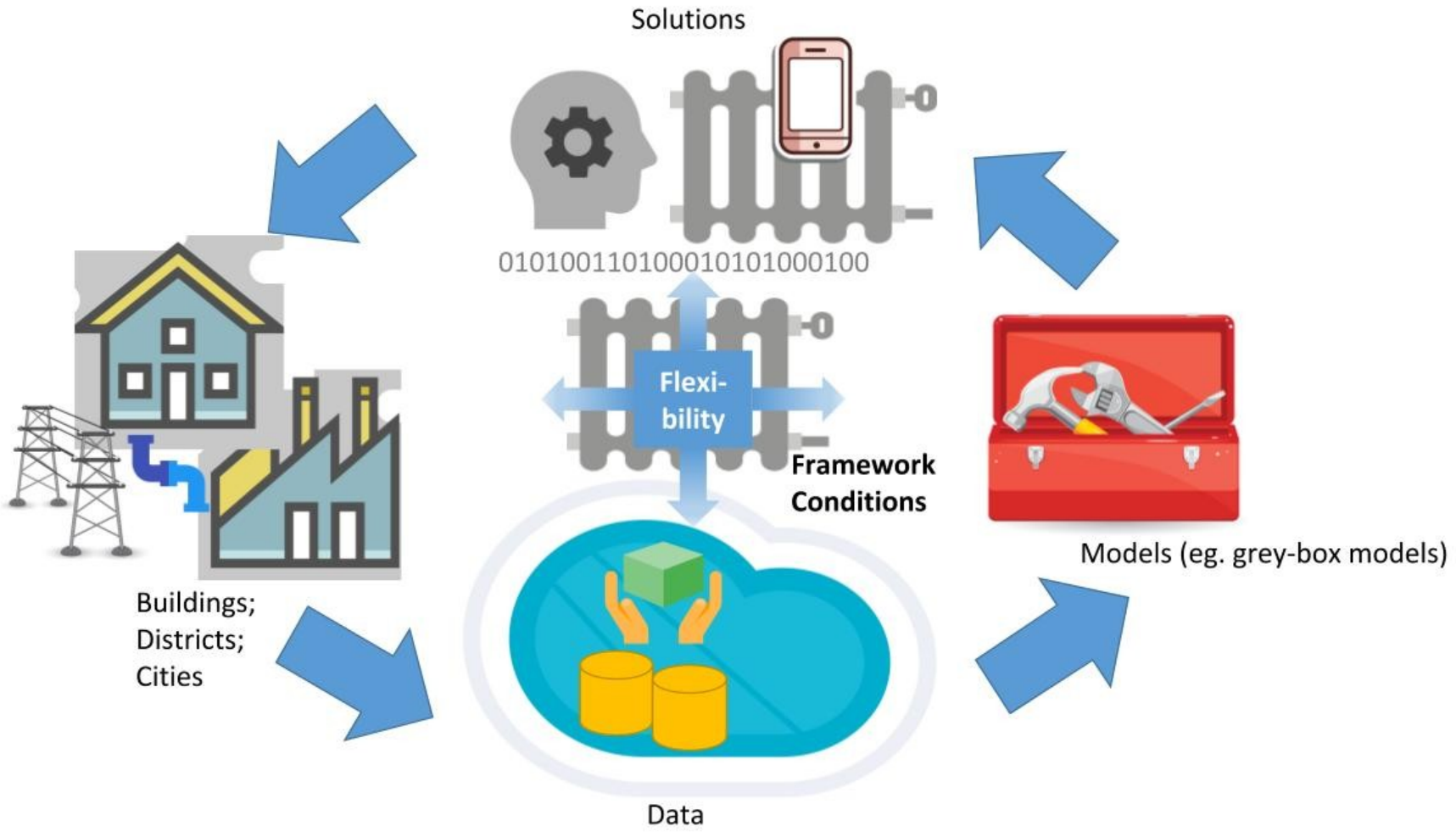


The (needed) Transformation

- 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



International Collaboration

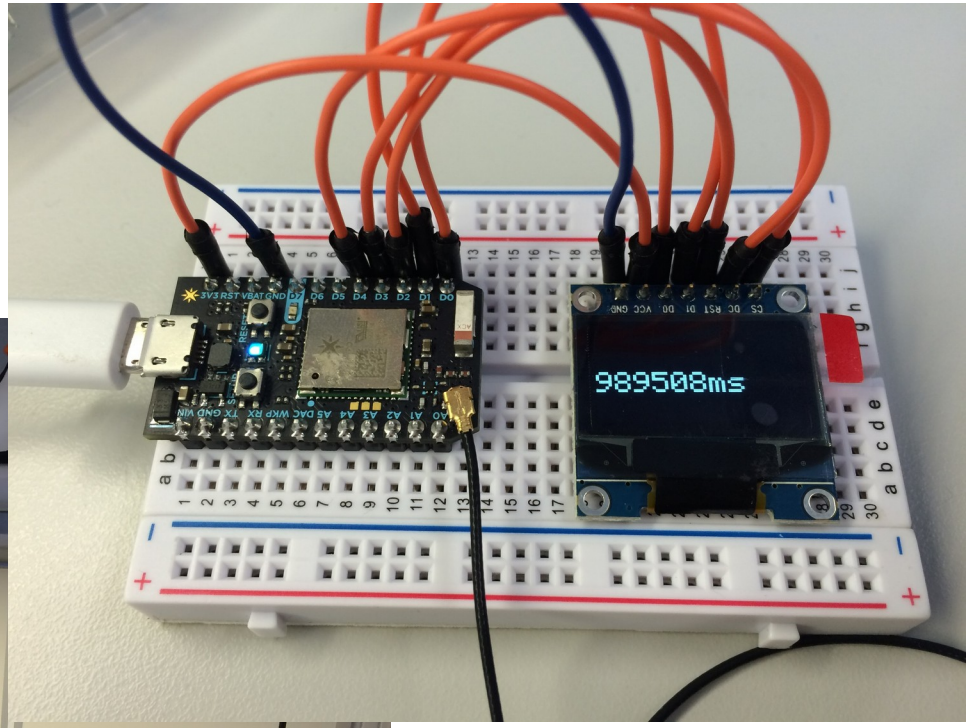
- Our partners – NREL, Berkely Lab, Argonne Nat. Lab, AIT, NTNU, LU, UCD, NTU, Tecnalia, Toyota, Samsung, …
- Close collaboration with many International Projects;

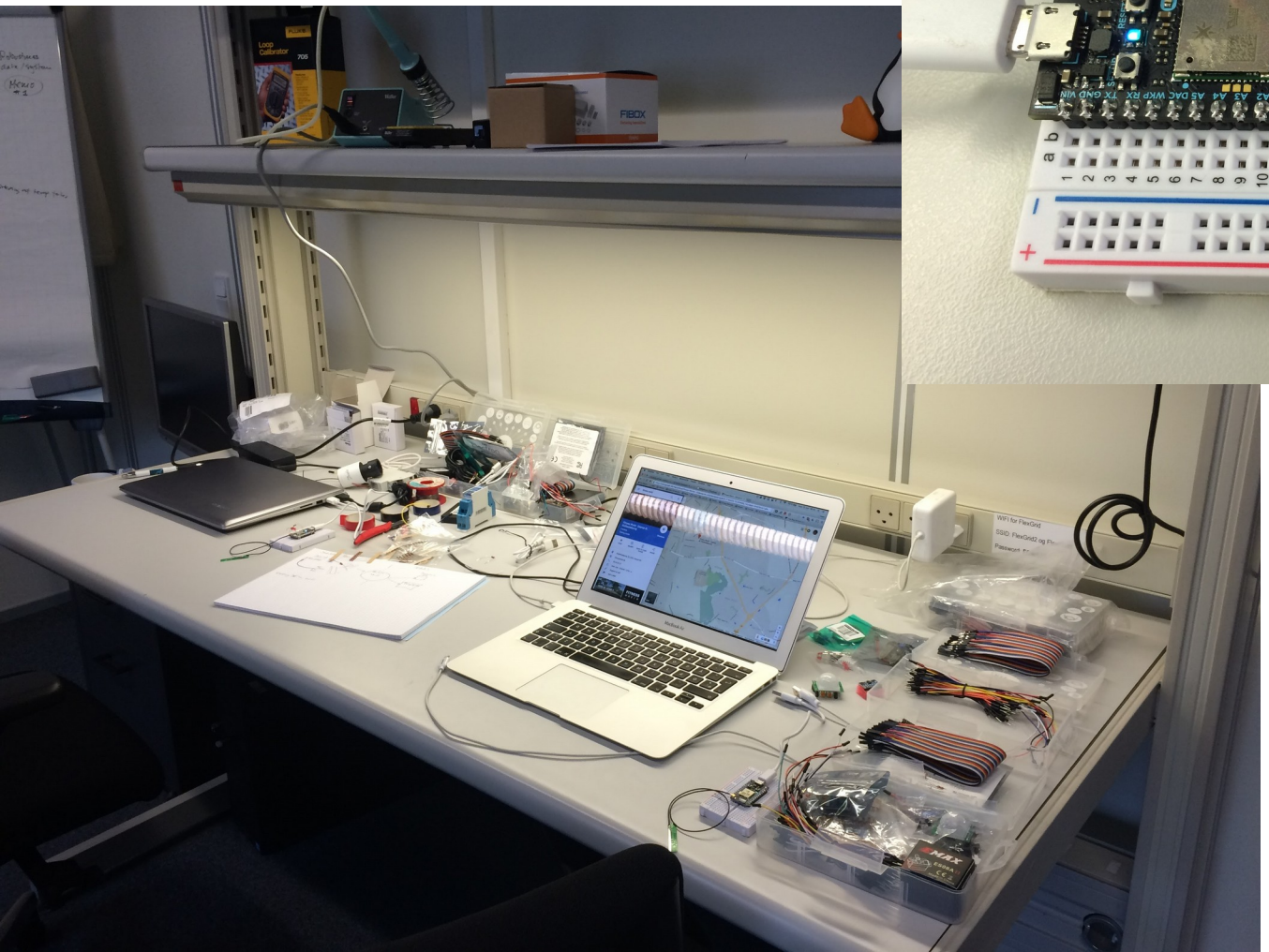
  The largest being:

  - 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.

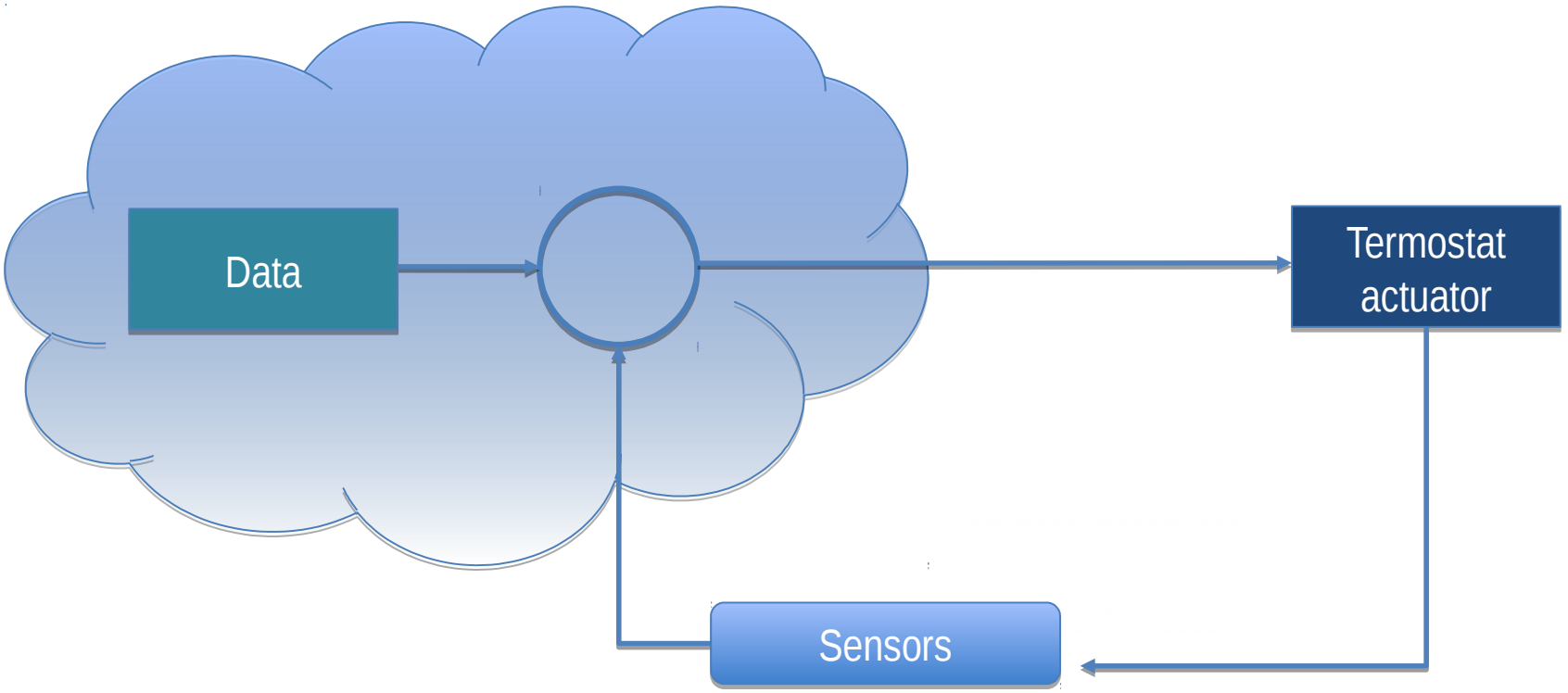
Some results …. (so far)

Lab testing ….

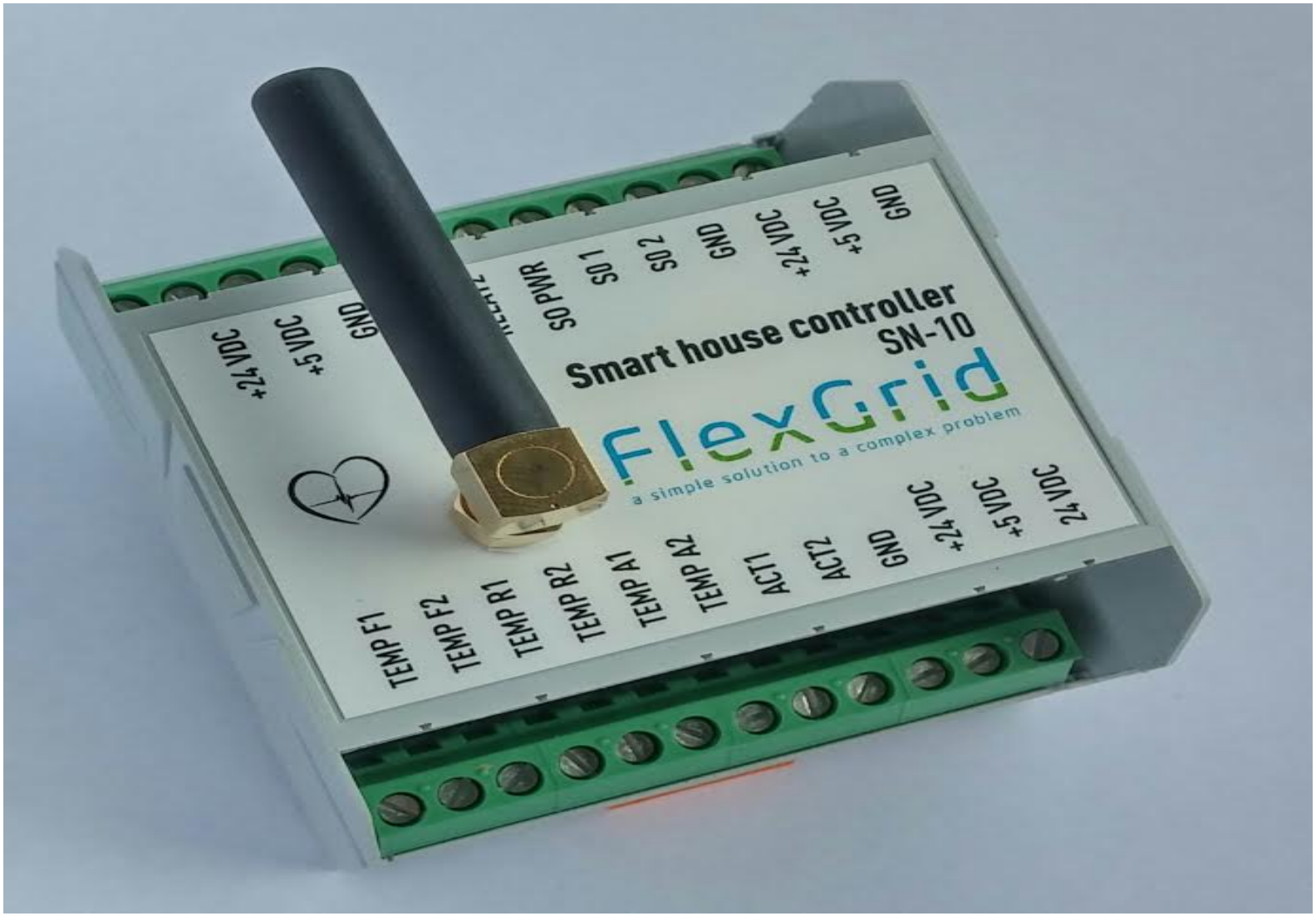




SE-OS
Control loop design – **logical drawing**



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

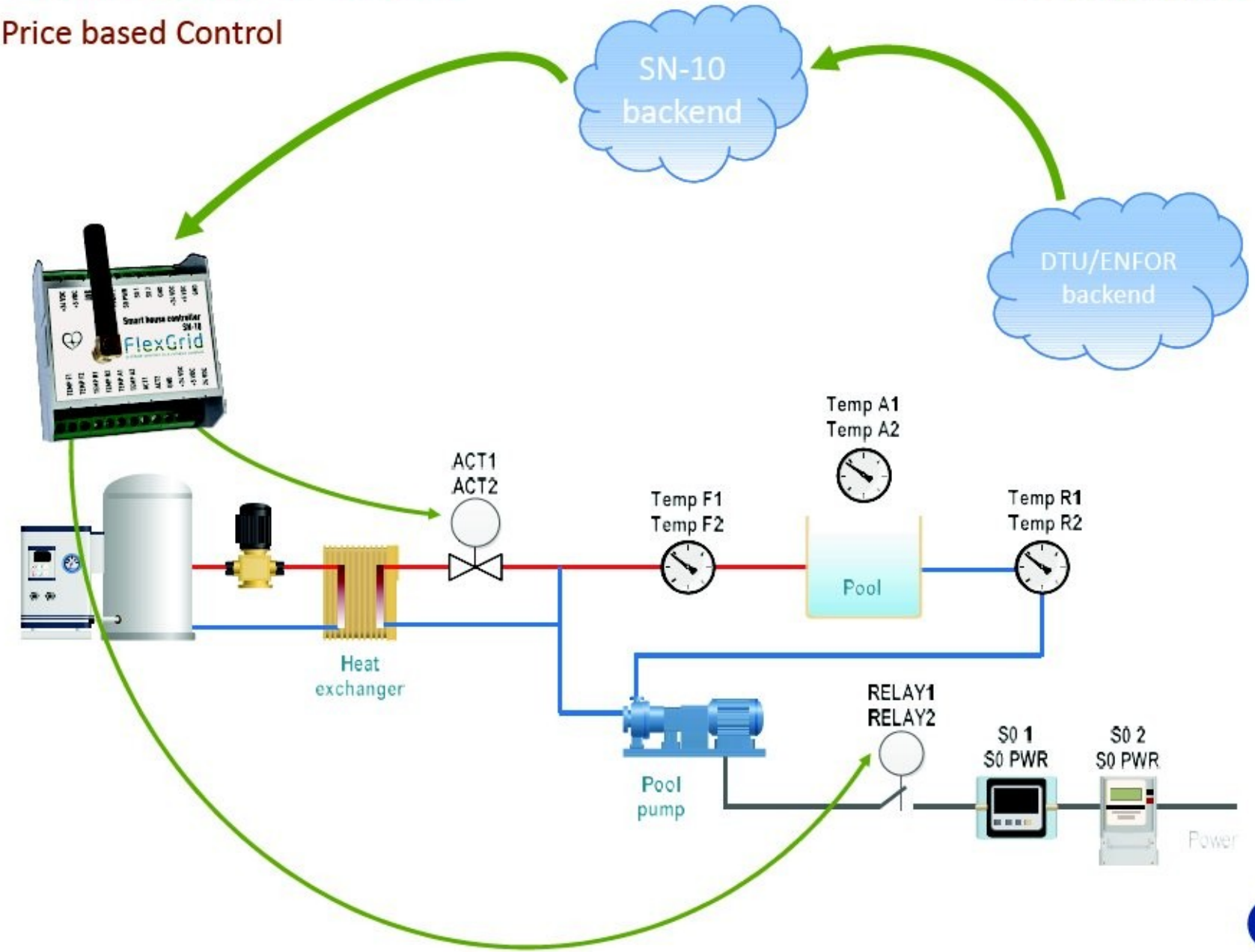
Topics

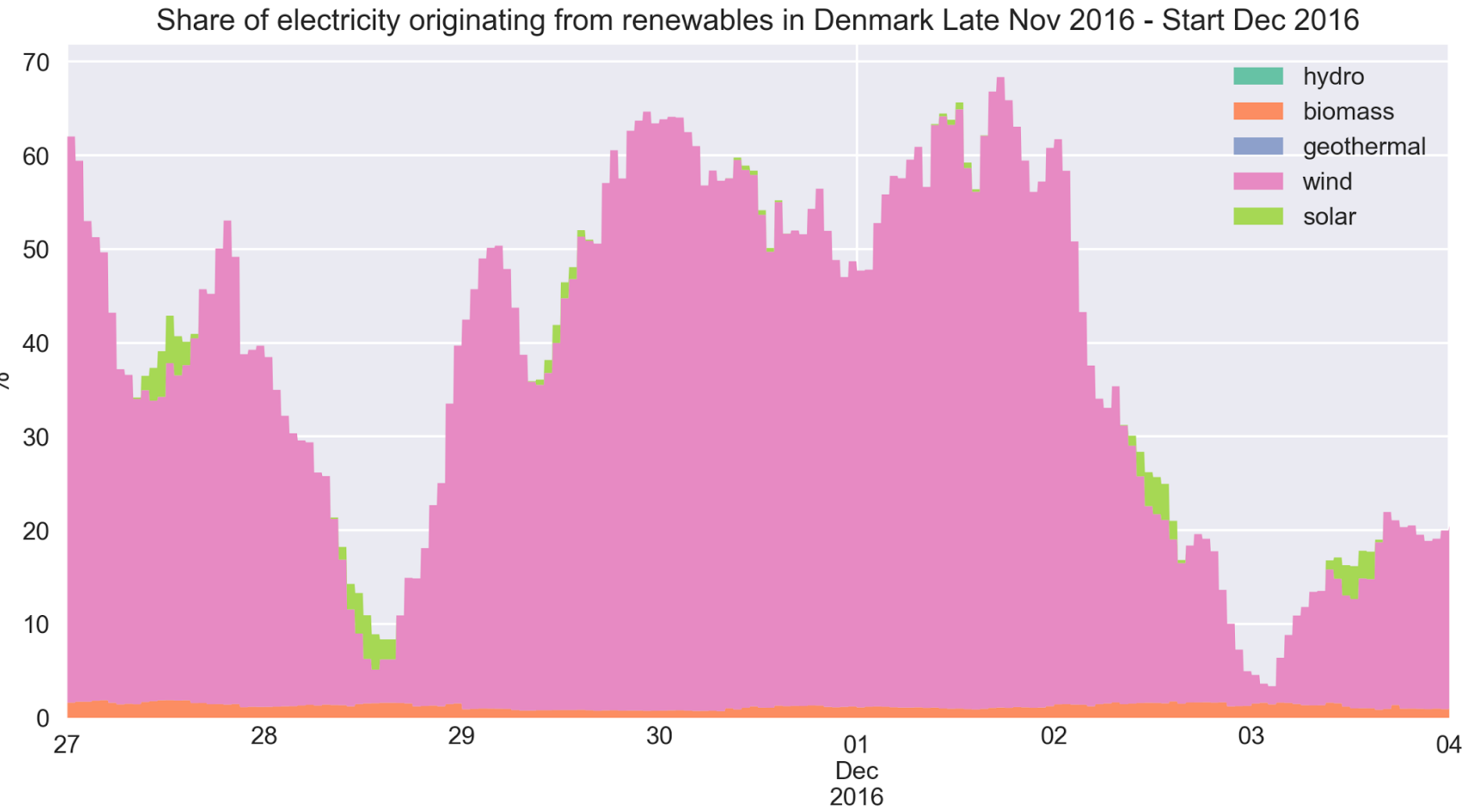
Case study No. 1

Control of heat pumps for swimming pools (CO2 minimization)

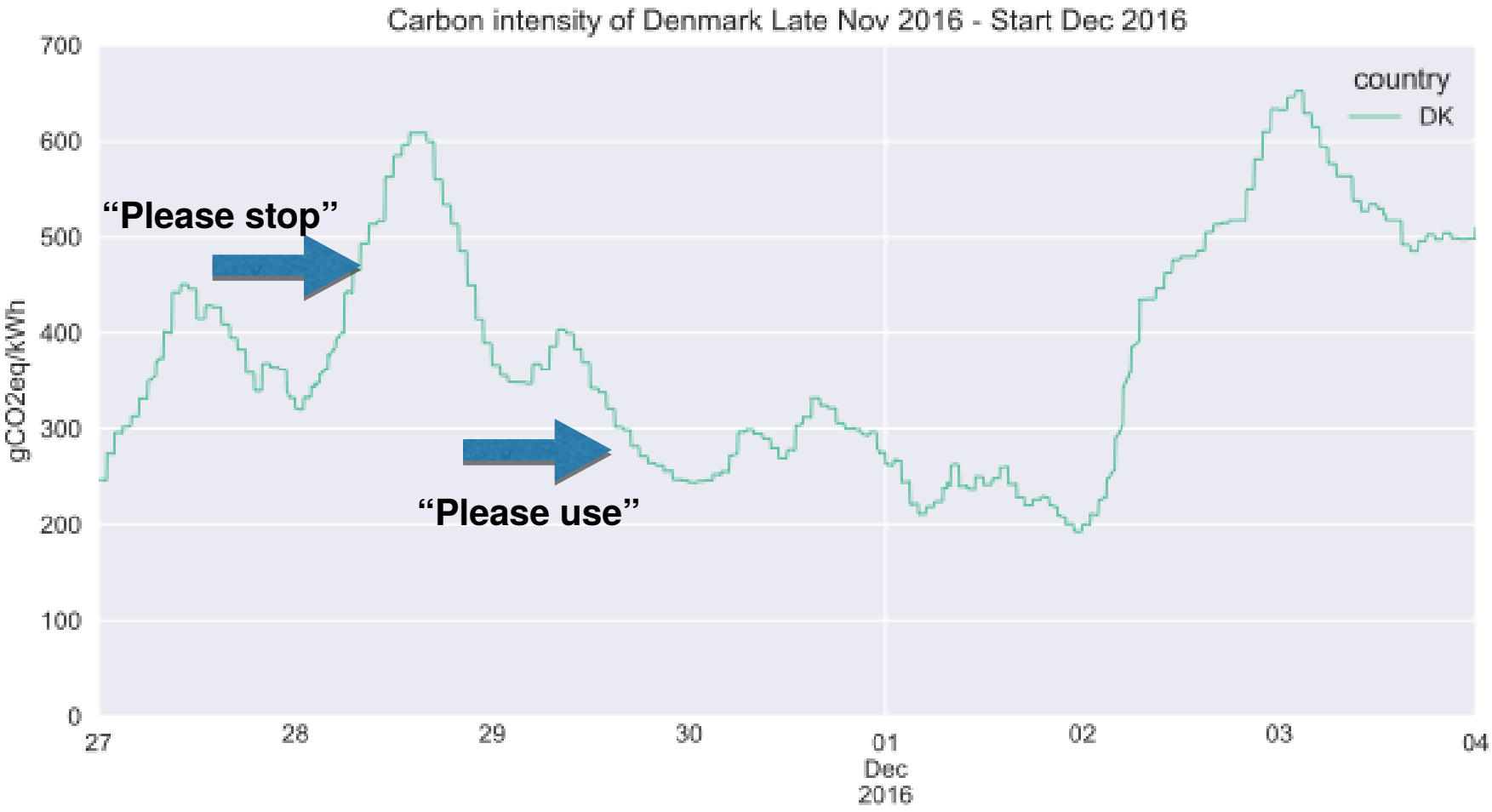
How does it work?

Price based Control

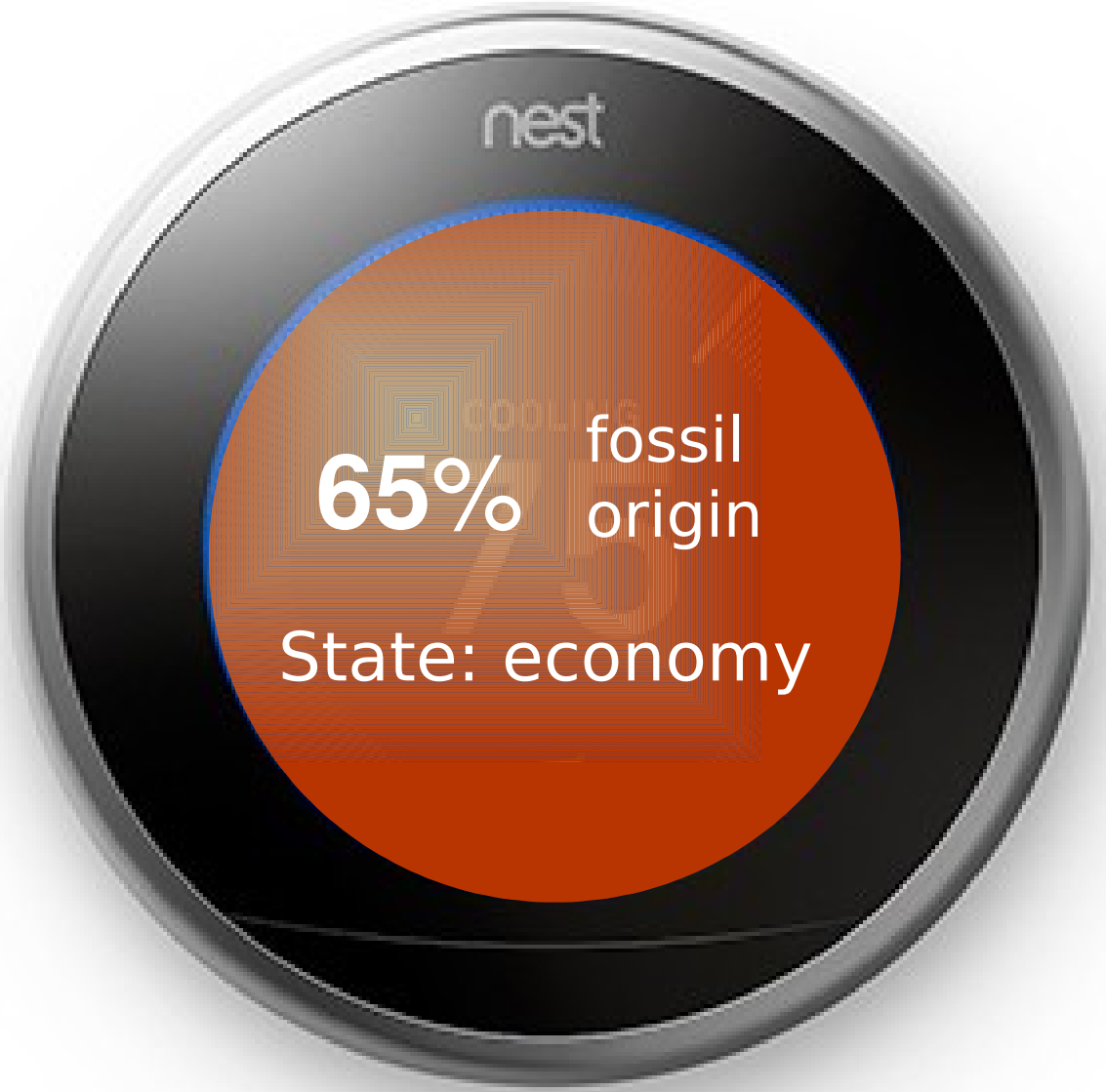




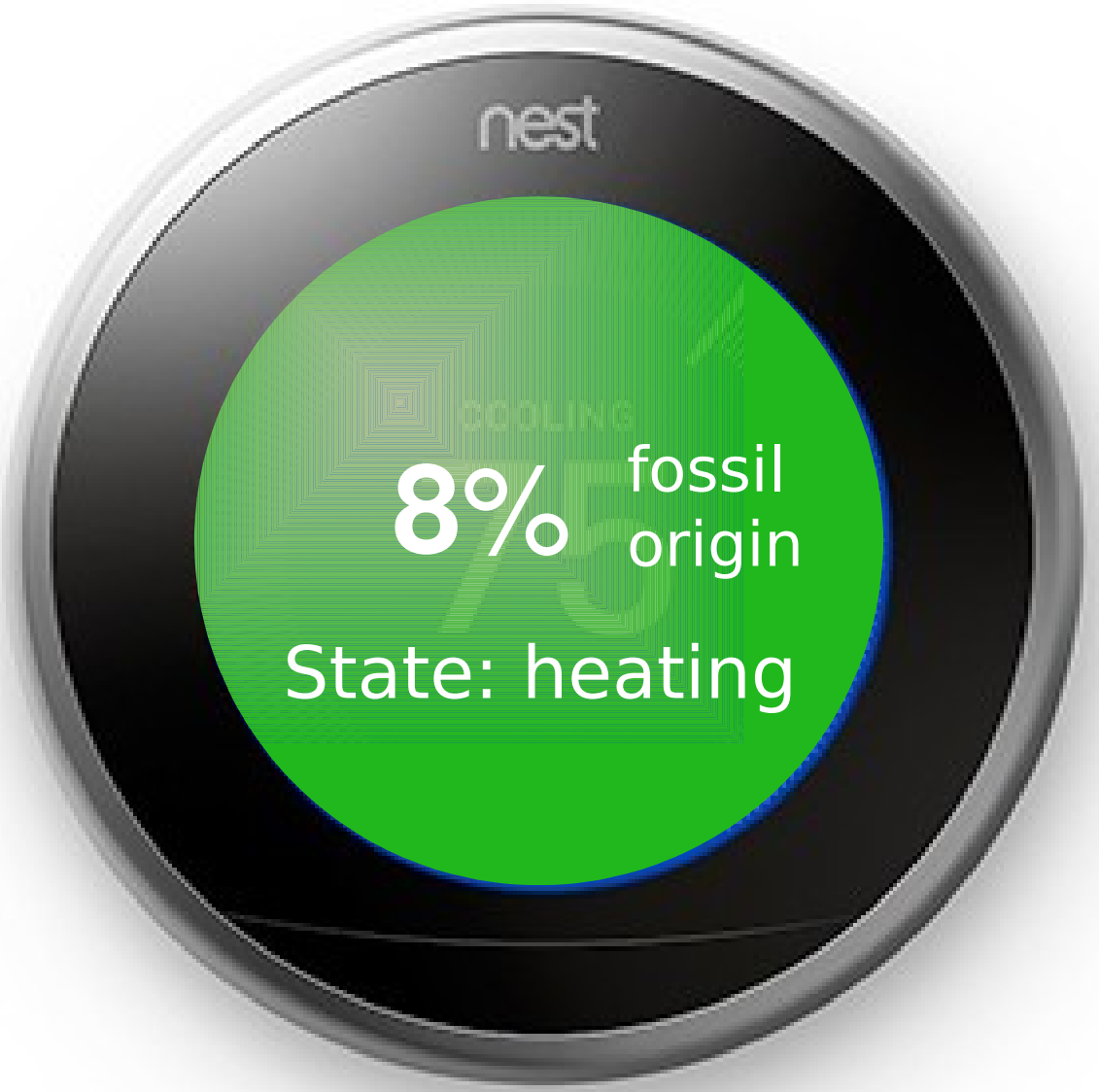
Source: pro.electicitymap.



Source: pro.electicitymap.



www.co2signal.com



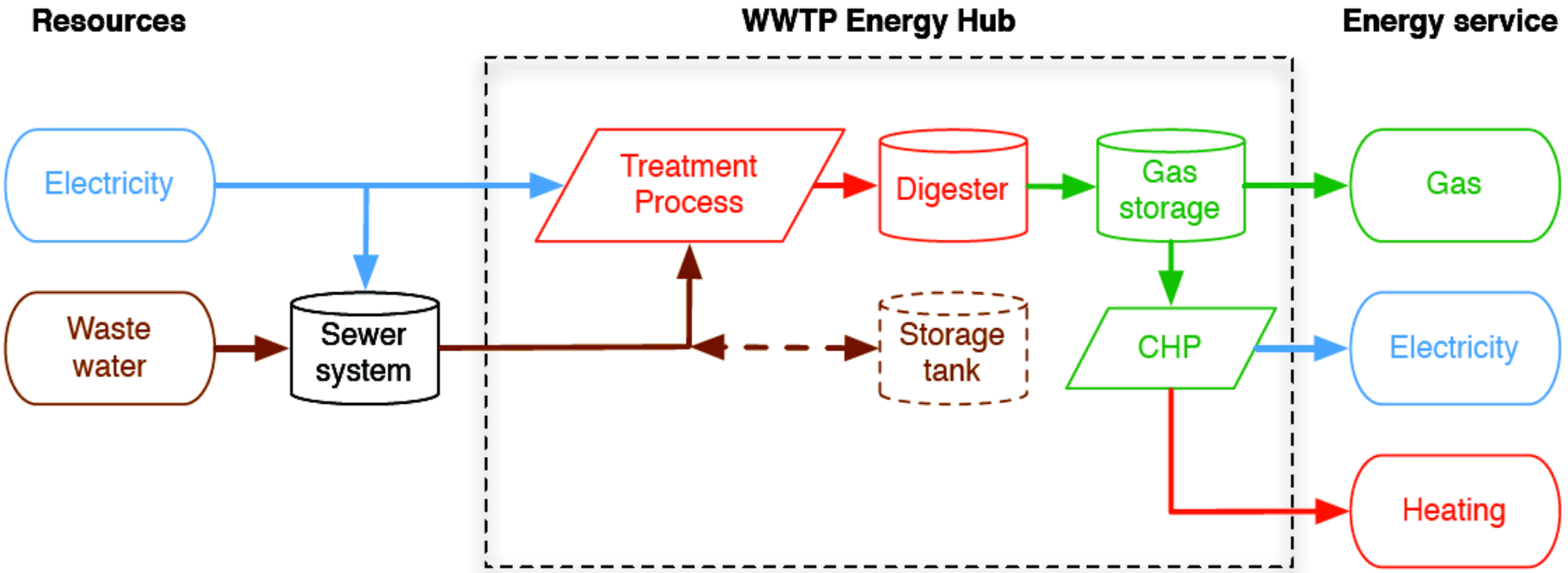
www.co2signal.com

Case study No. 2

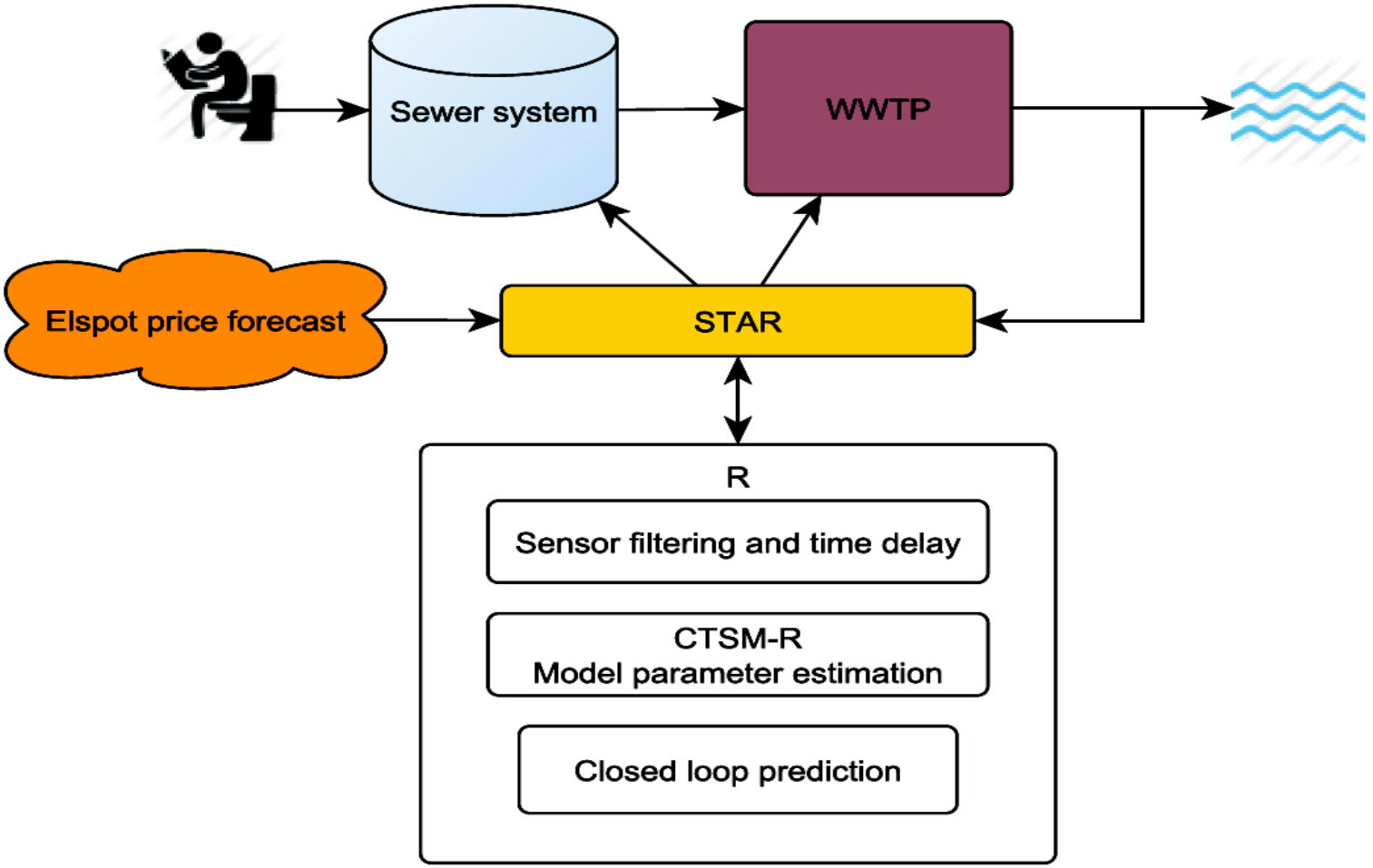
Wastewater Treatment Plants

Kolding WWTP

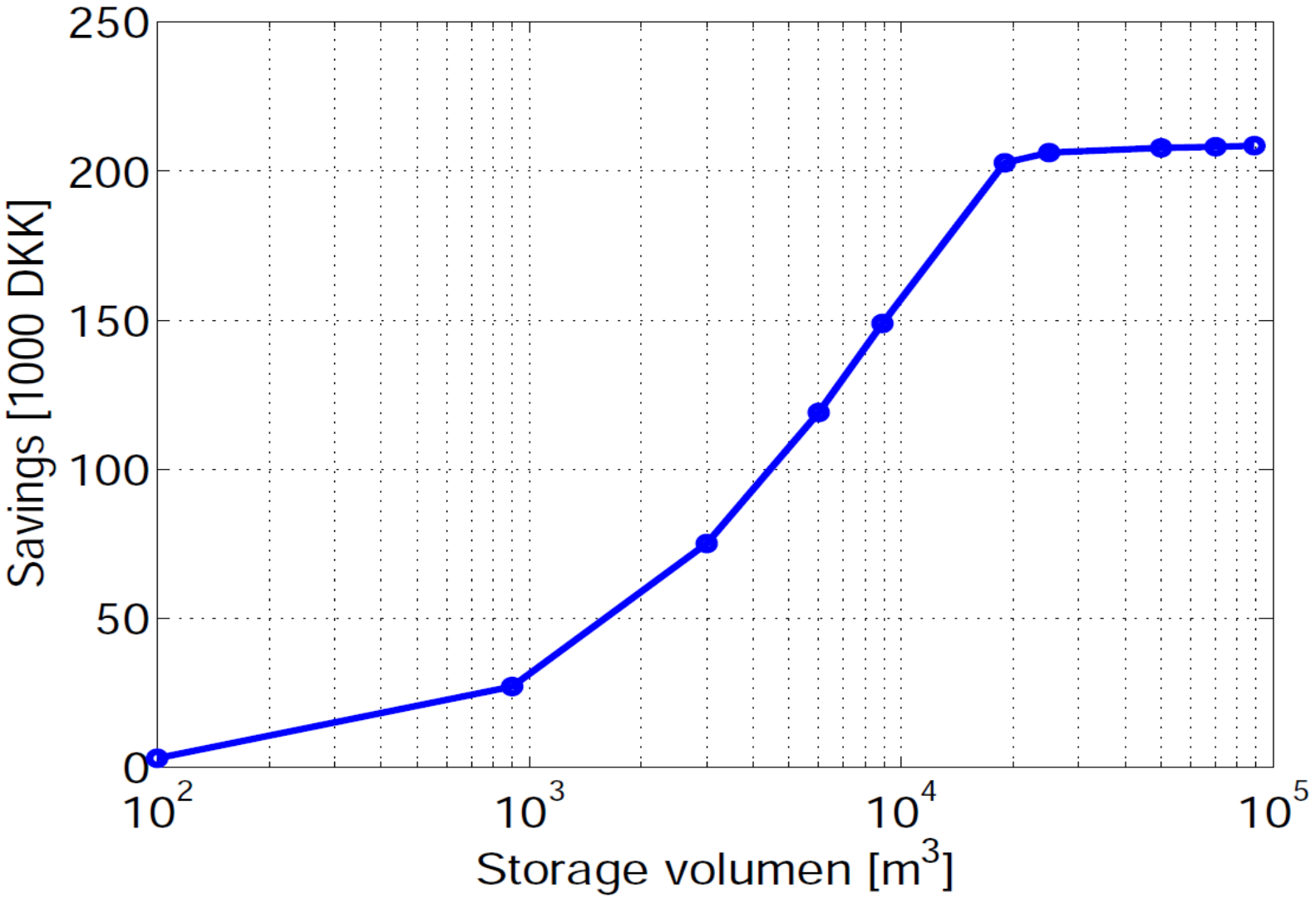
Waste-2-Energy



Energy Flexibility in Wastewater Treatment



Sewer System Annual Elspot Savings

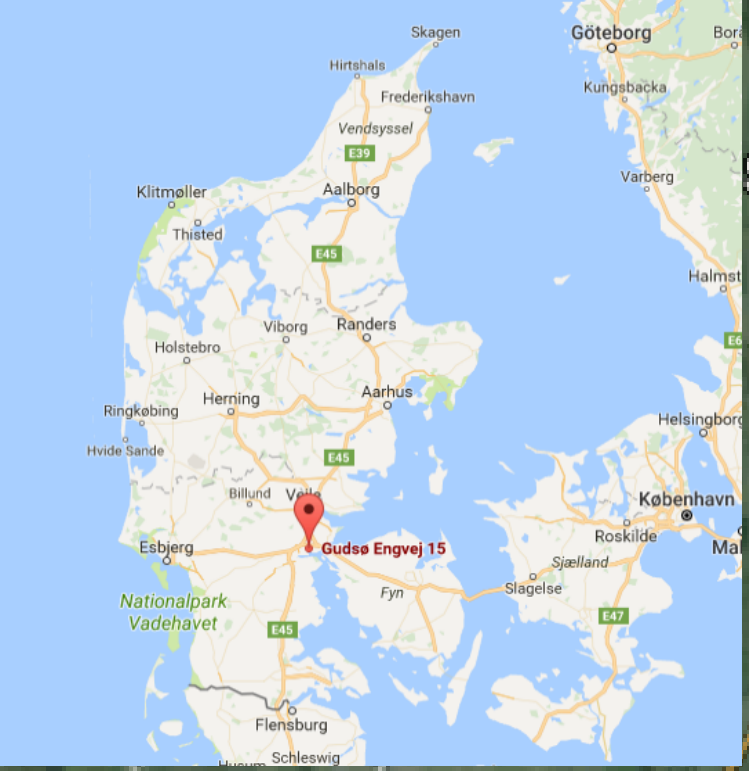


CITIES
Centre for IT Intelligent Energy Systems

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



Smidstrup

E45

Raffinade

Bryggeriet

Frede

E20

Google

Fredericia

Spildevand

Erritsø

Taulov

TVIS

Arla

EWii

E20

Dansk
Fjernvarme

Center
Danmark

EnergiNet.dk

Ørsted

Skærbæk
værket

Kolding

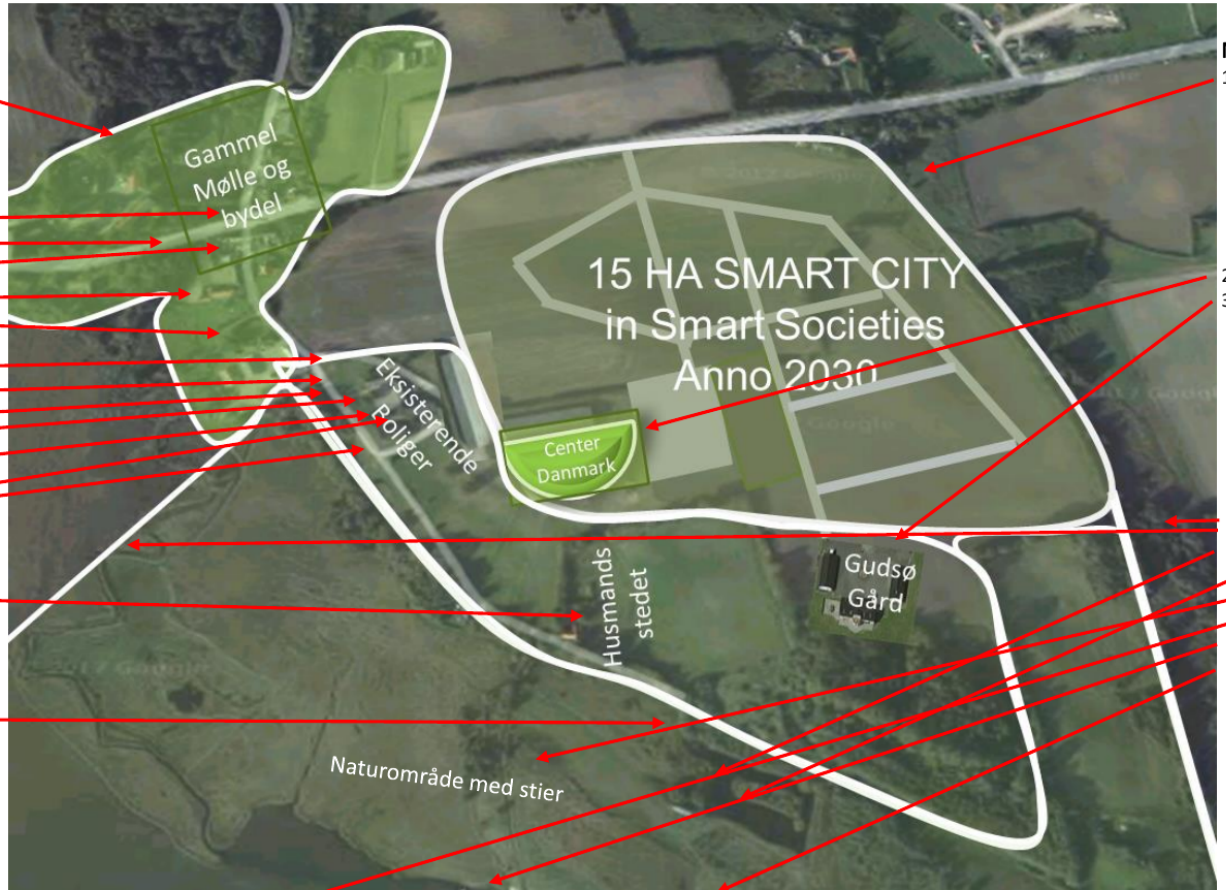
Midde


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



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 m^2
3. Ny Gudsøgård 2600 m^2
    1. Privat hus 280 m^2
    2. Erhverv 280 m^2
    3. Stald 280 m^2

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/

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

Lars Bøtker-Rasmussen
Bygningskonstruktør
BØTKERS TEGNESTUE ApS

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

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

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

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