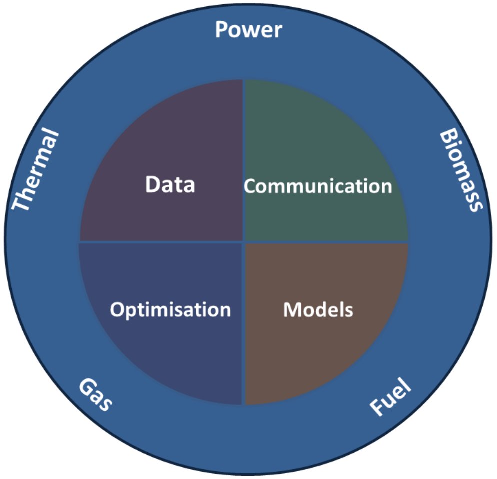
CITIES

(Center for IT-Intelligent Energy Systems)



Henrik Madsen (+ many other people)

Applied Mathematics and Computer Science

Technical University of Denmark

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

http://www.henrikmadsen.org

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The challenges

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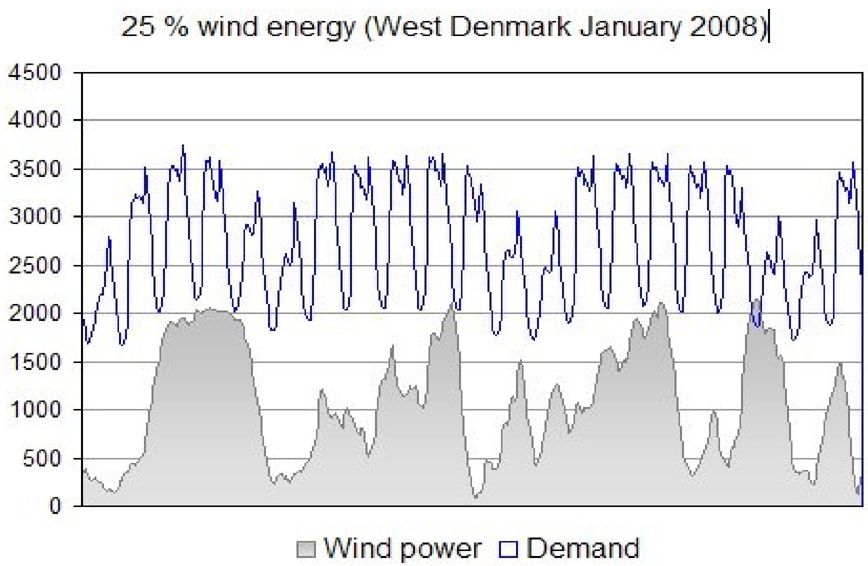
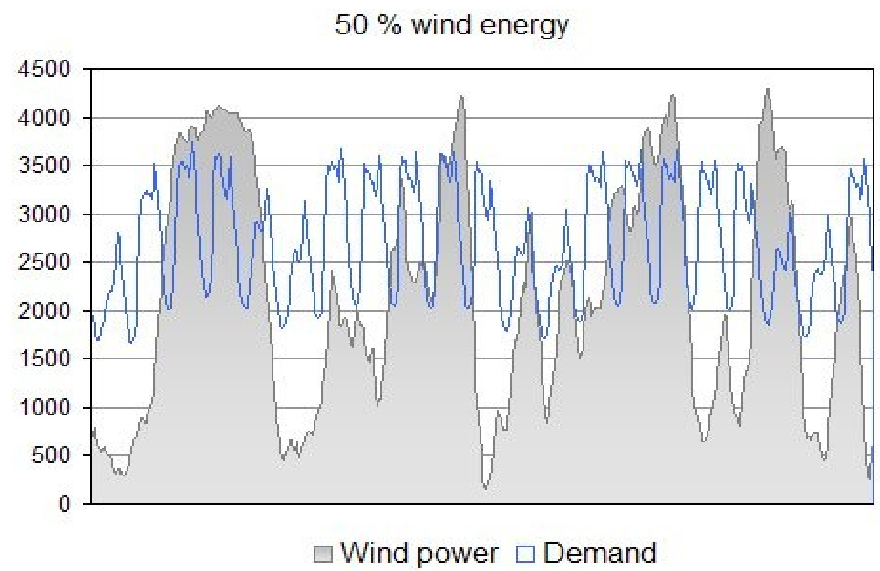
The Danish Wind Power Case

.... 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

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Challenges

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 [...]tal aspects with a view to a broad introduction of smart appliances and to develop adequate policy approaches supporting such uptake.

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.

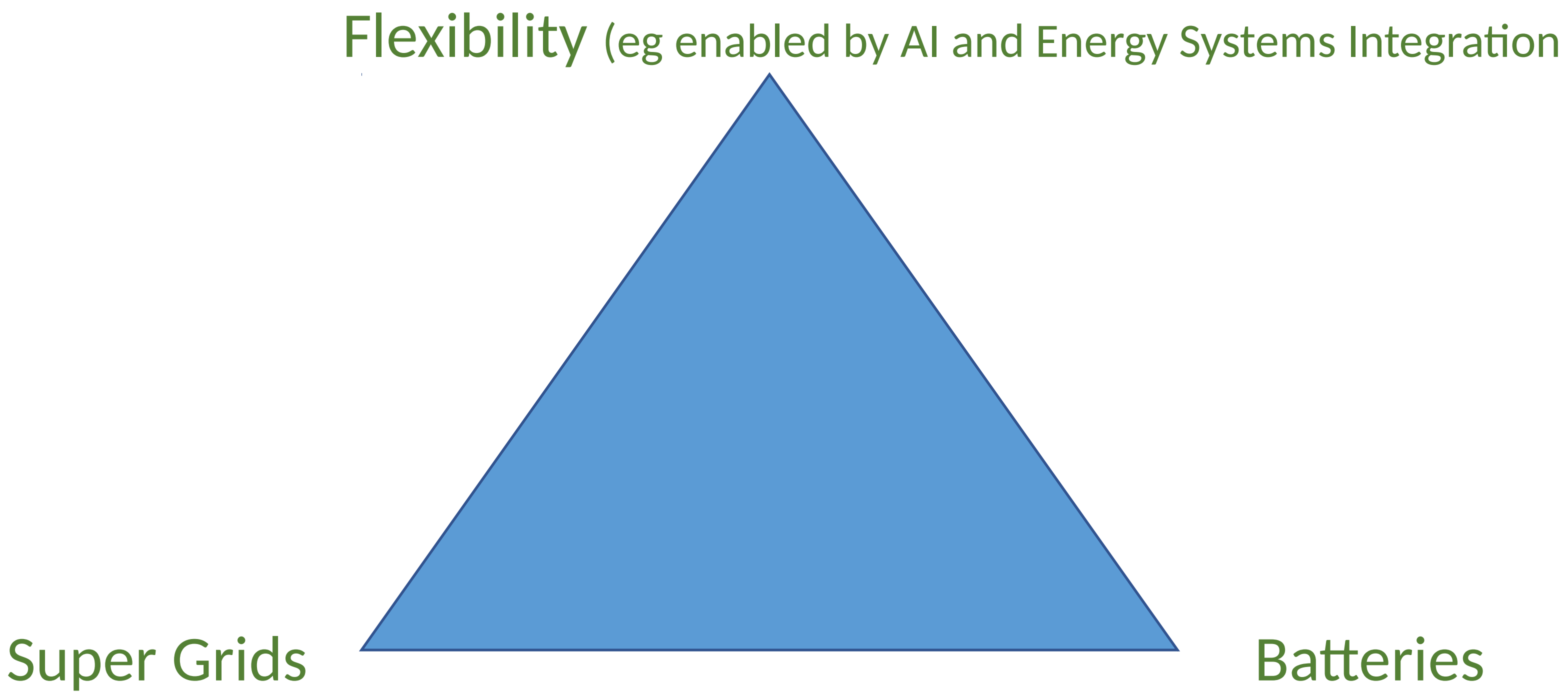
Throughout the study, new relevant aspects have come up which will be covered in a second phase of the Preparatory Study:

- 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.

Almost no Flexibility

Space of Solutions

Ultimately 3 solutions expand the space of solutions:



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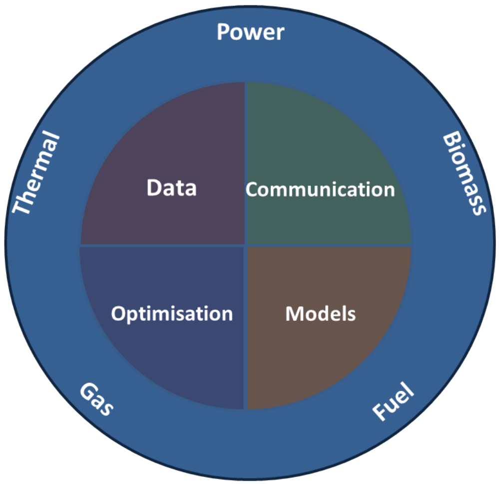
Hypothesis



The **central hypothesis** is that by **intelligently integrating** currently distinct **energy** (heat, power, gas and biomass) and **water** components using **ICT solutions** we can **balance** very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions.

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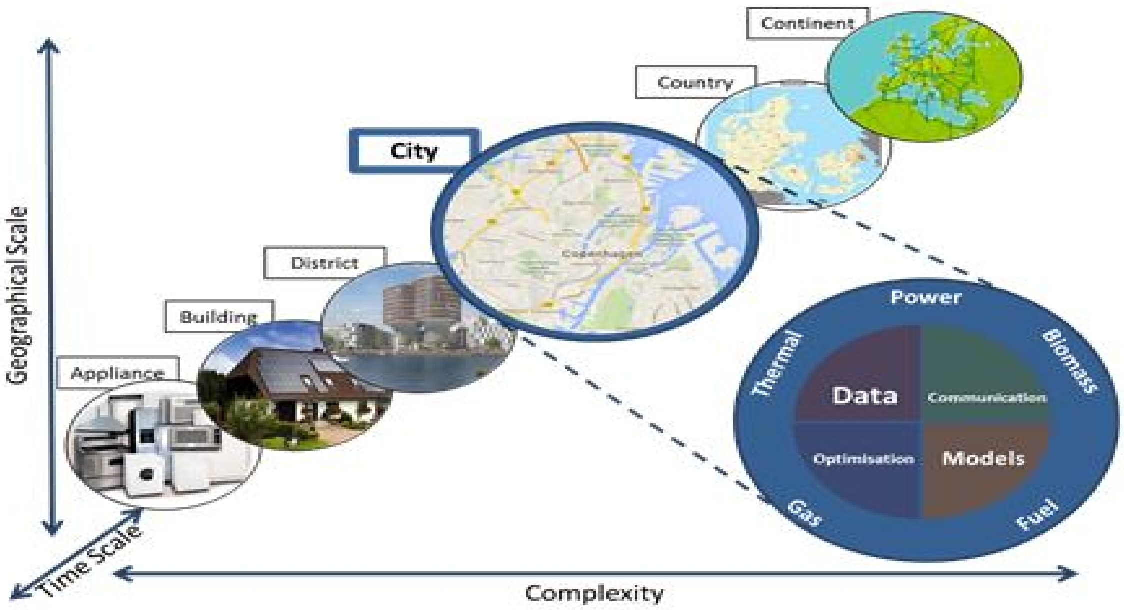
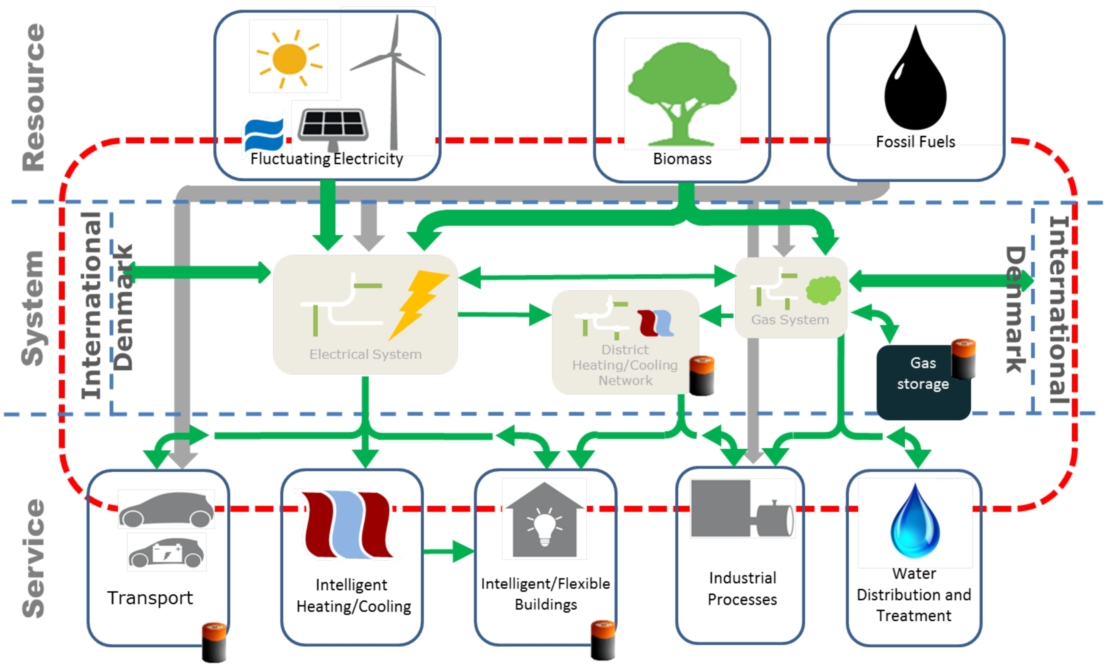
Temporal and Spatial Scales

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**.

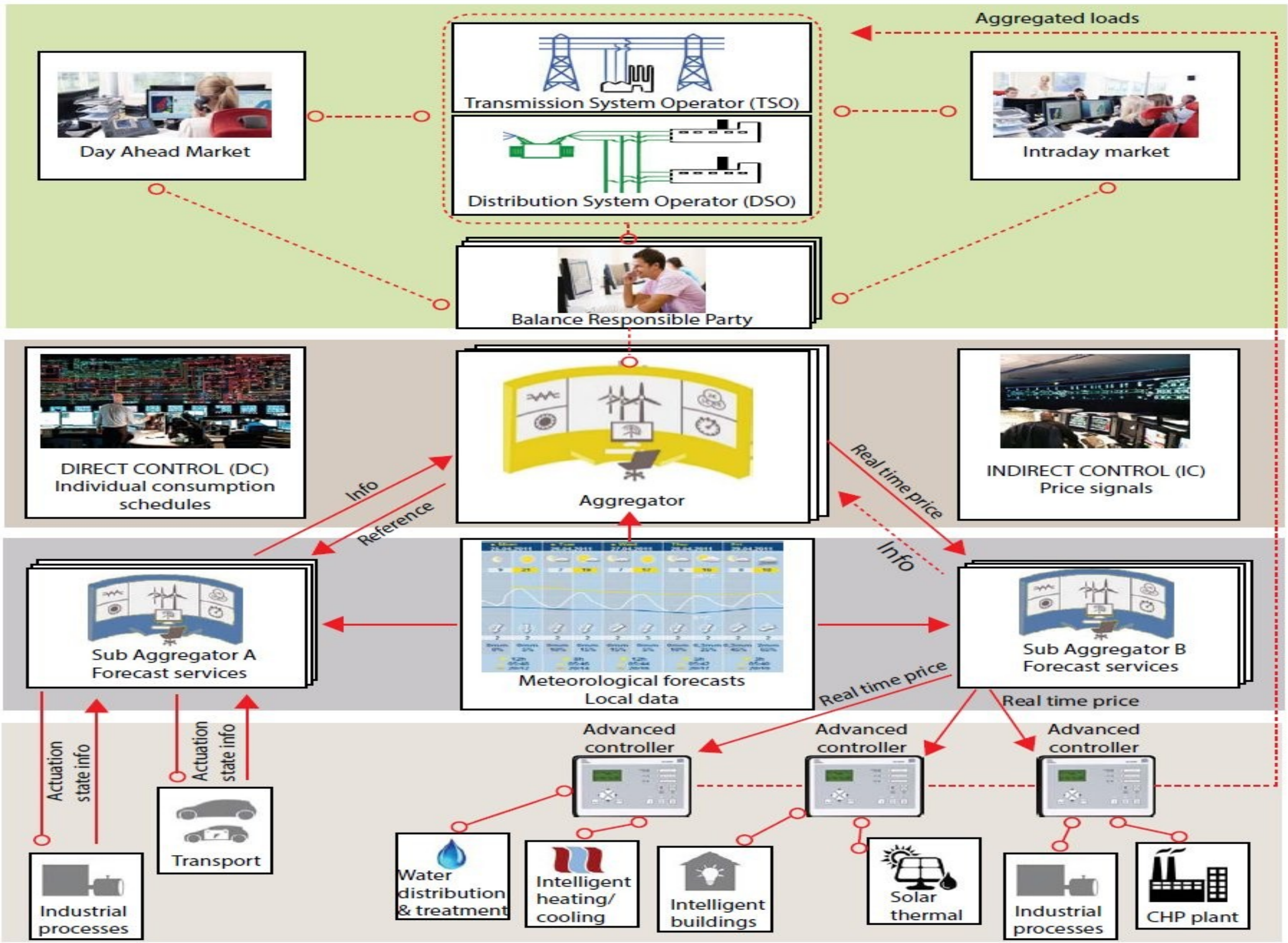


Concepts

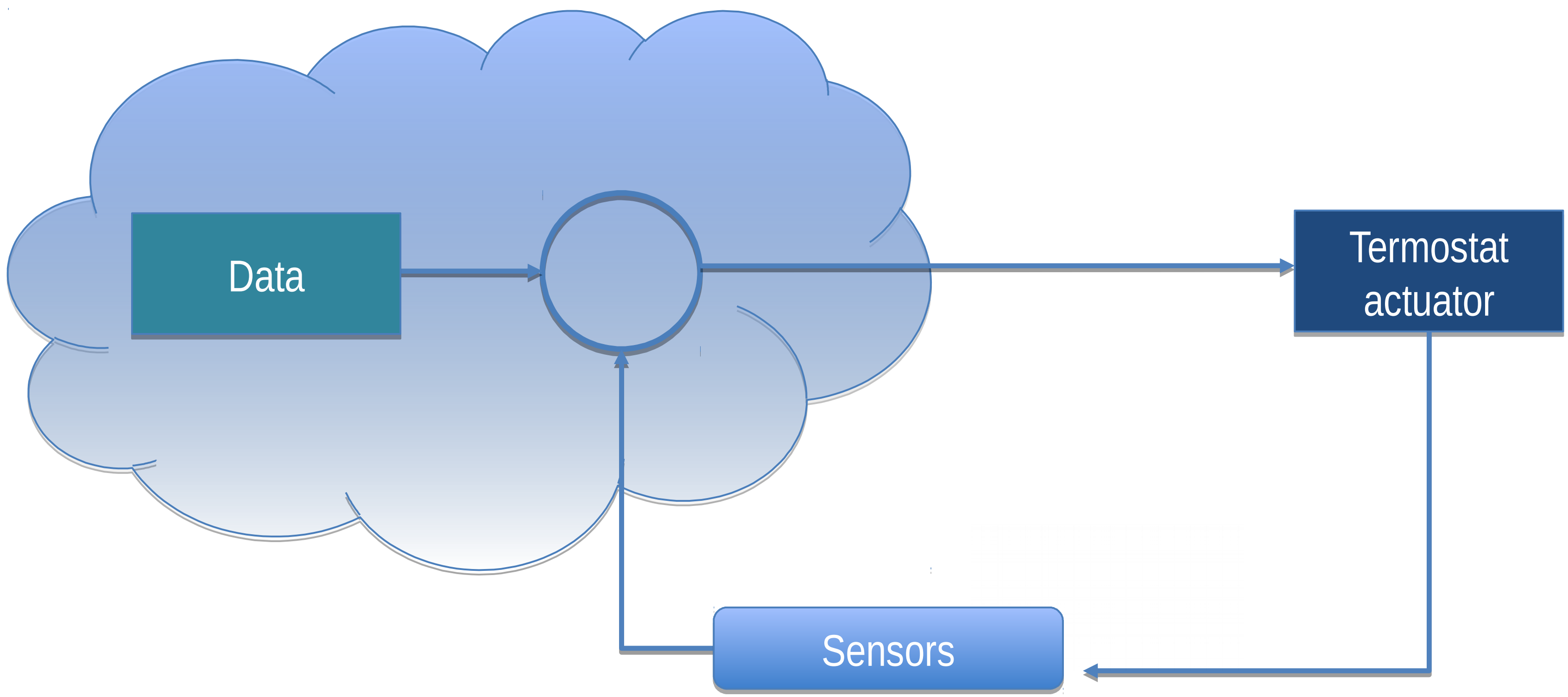
Integration based on **ICT solutions** (Data Analytics, Cyber Physical Models, Forecasting, Control, IoT, IoS, AI, automated learning, ..) leading to methods for **operation** and **planning** of future energy systems



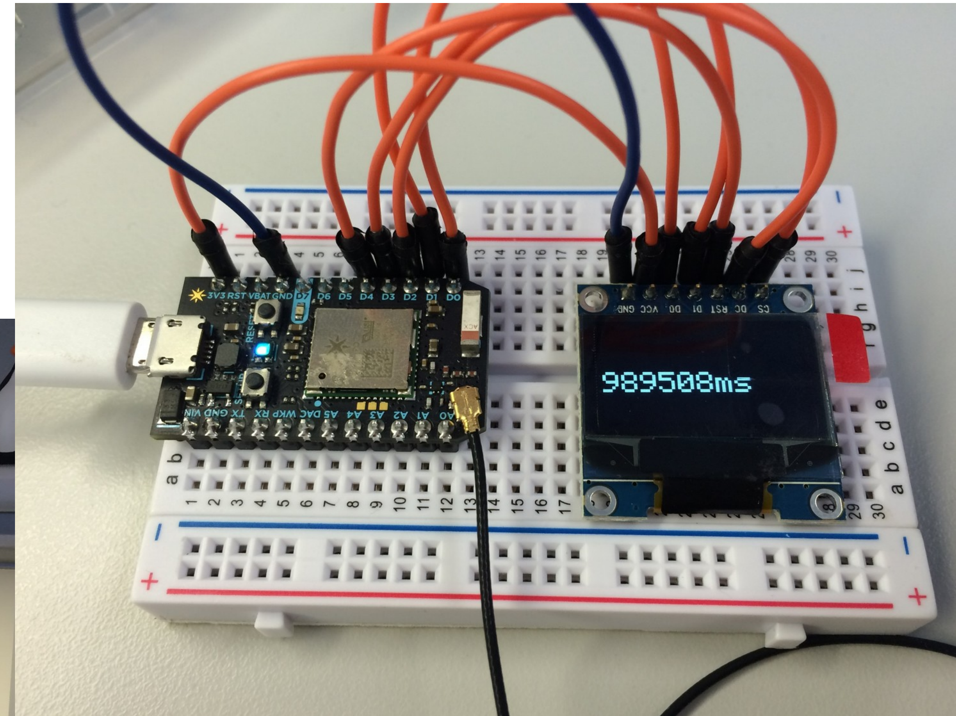
Smart-Energy OS

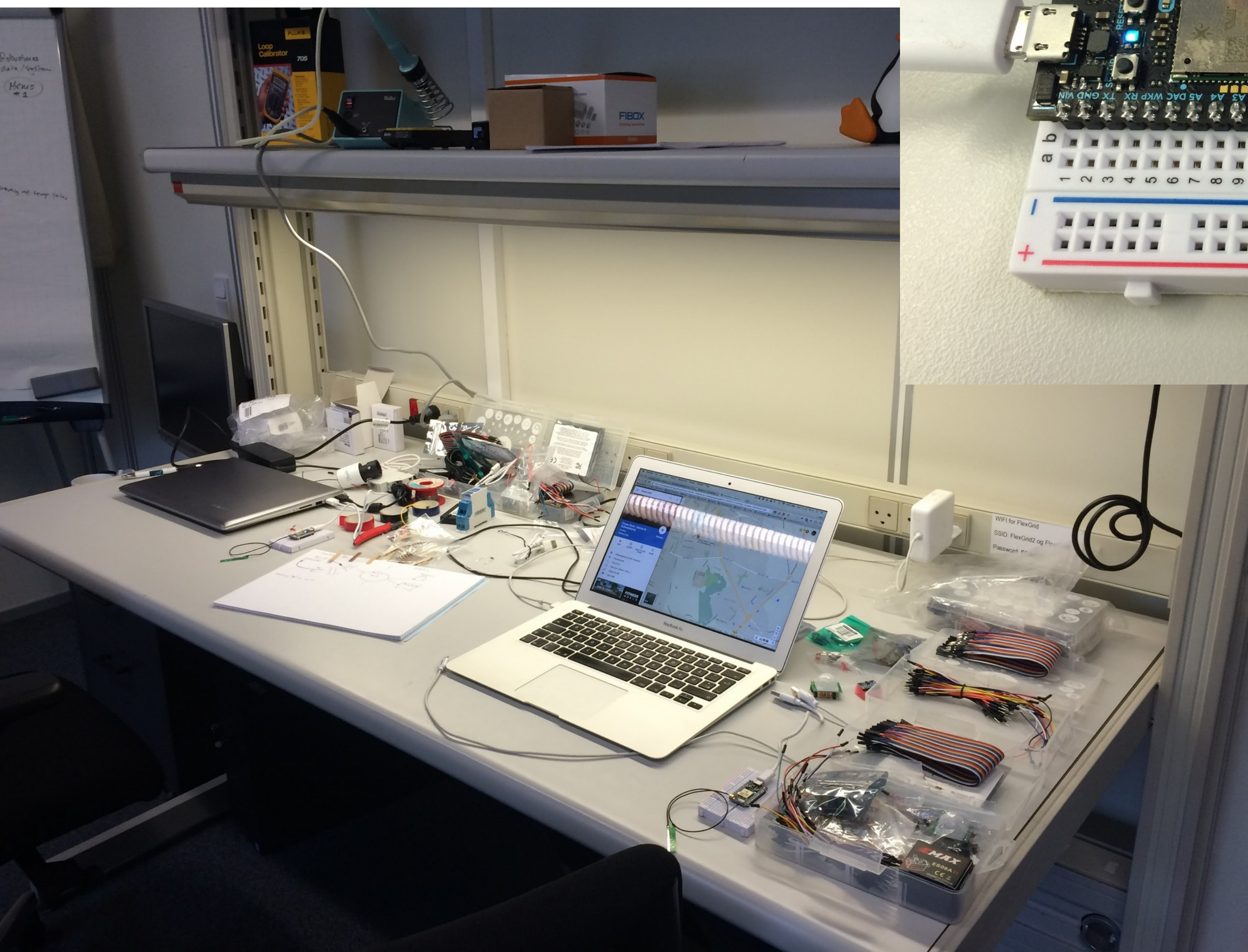


SE-OS
Control loop design – **logical drawing**

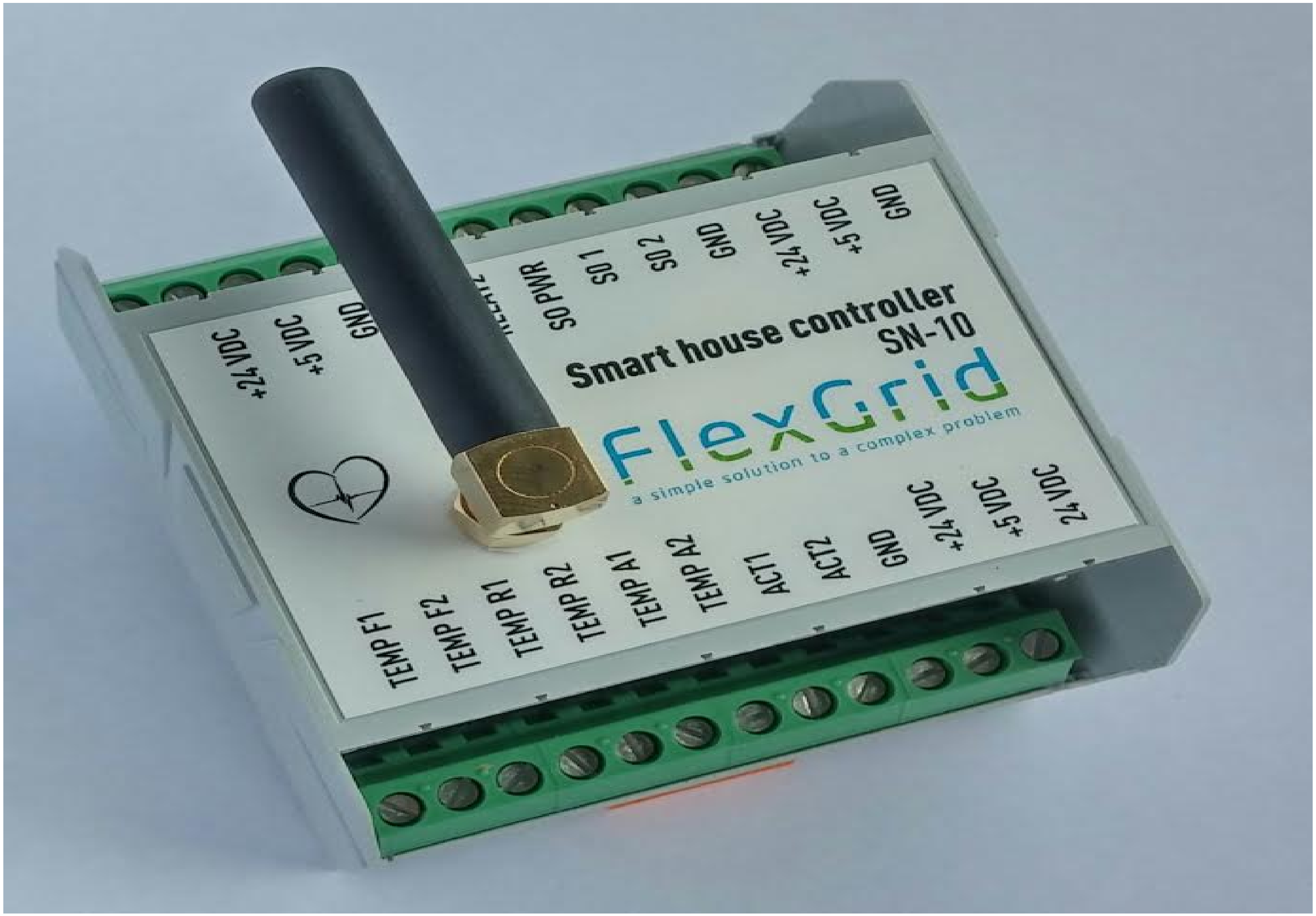


Lab testing ....

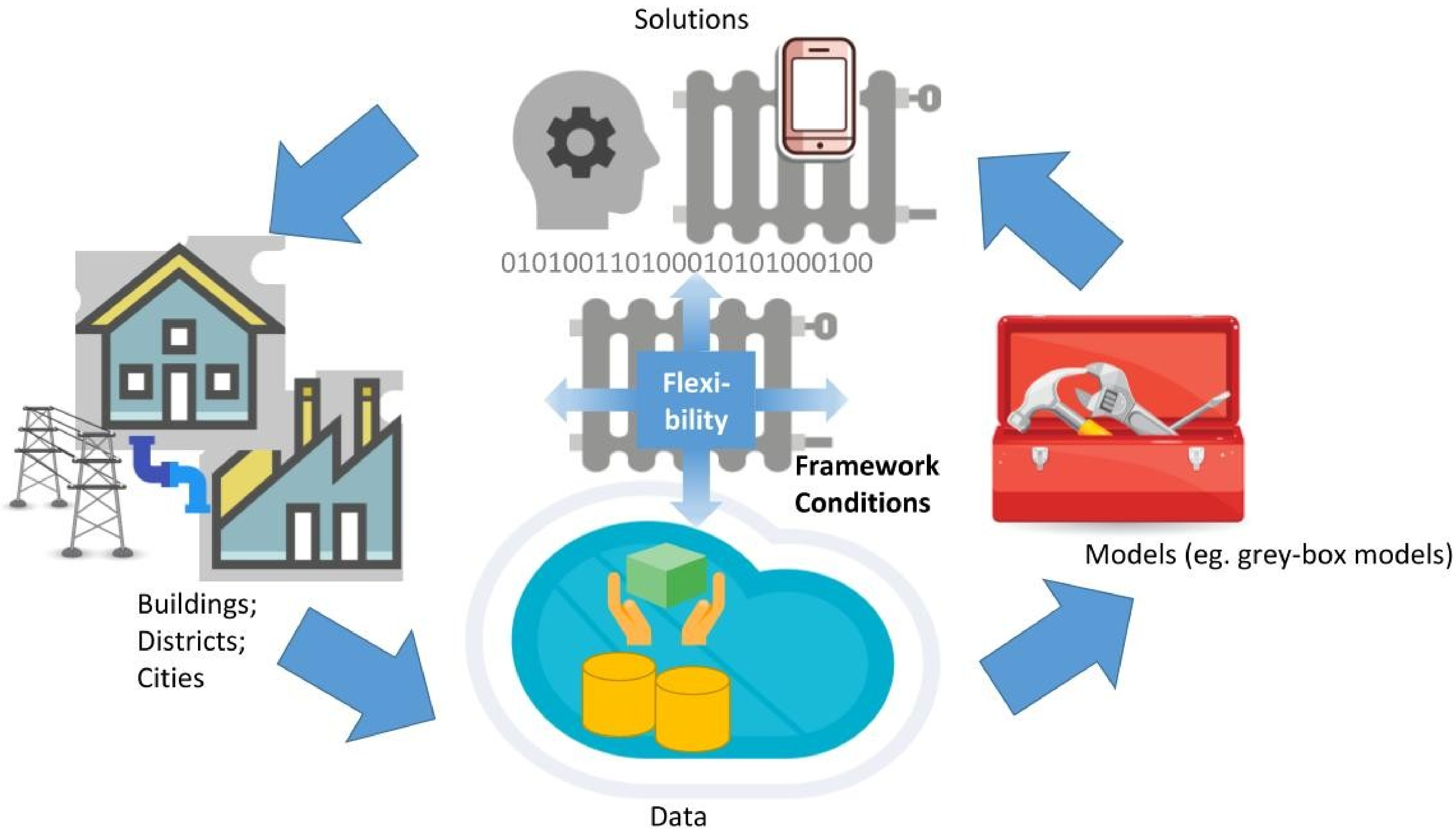




SN-10 Smart House Prototype

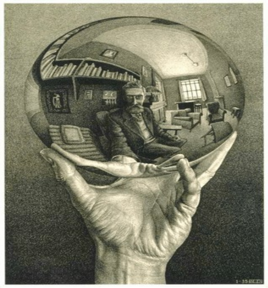


Flexibility enabled using data intelligence (AI)



SE-OS Characteristics

- ‘Bidding – clearing – activation’ at higher levels
- 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
- Provides a solution for all ancillary services
- Harvest flexibility at all levels -> max. Virtual storage



Some Highlights

- New planning tools
- A number of new software, hardware and cloud based solutions
- Large flexibility potentials demonstrated - in particular for **IT-Intelligent Integ. Energy Systems**
- Smart-Energy Operating-System (SE-OS) (Big Data, IA, IoT, Controllers,..)
- Energy/power markets (new solutions/design)
- AS4.0 – a control based approach for smart grids (incl. Ancillary services)
- Storage solutions (virtual by integrated energy systems, physical)
- Flexibility Function – A new approach for characterizing the flexibility
- Flexibility Index – A method for calculation the flexibility (with/without Framework conditions)
- New controllers for smart energy systems - implemented also as a cloud solution
- Methodologies and tools for optimal operation under uncertainty (also bidding..)
- Digitilization of District Heating (District Heating v.4.0)
- Science Cloud for CITIES
- CITIES Innovation Centre
- Center Danmark (under establishment)

Case study

Control of heat pumps
(Energy or/and CO2 efficient control)

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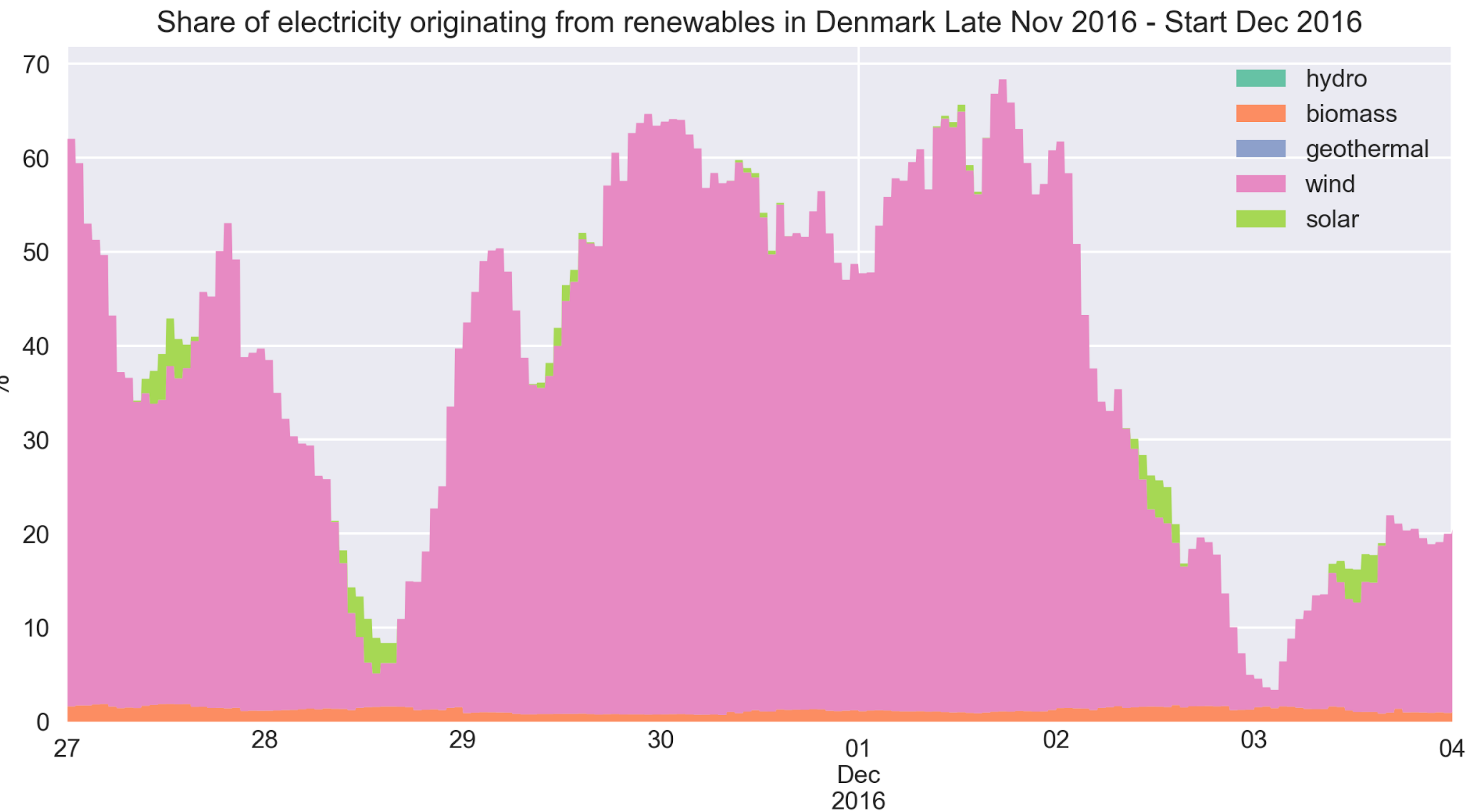

Source: pro.electicitymap.

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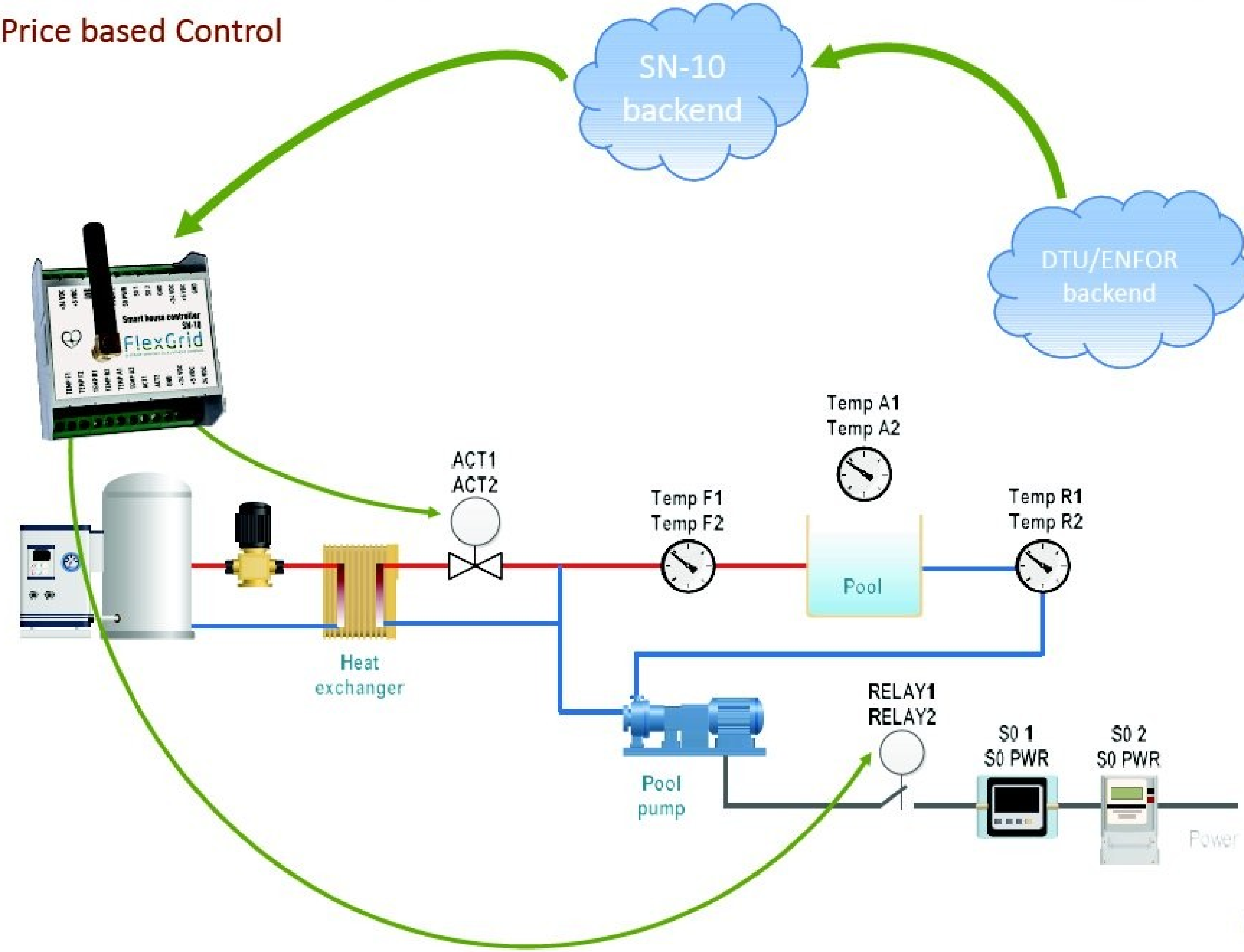
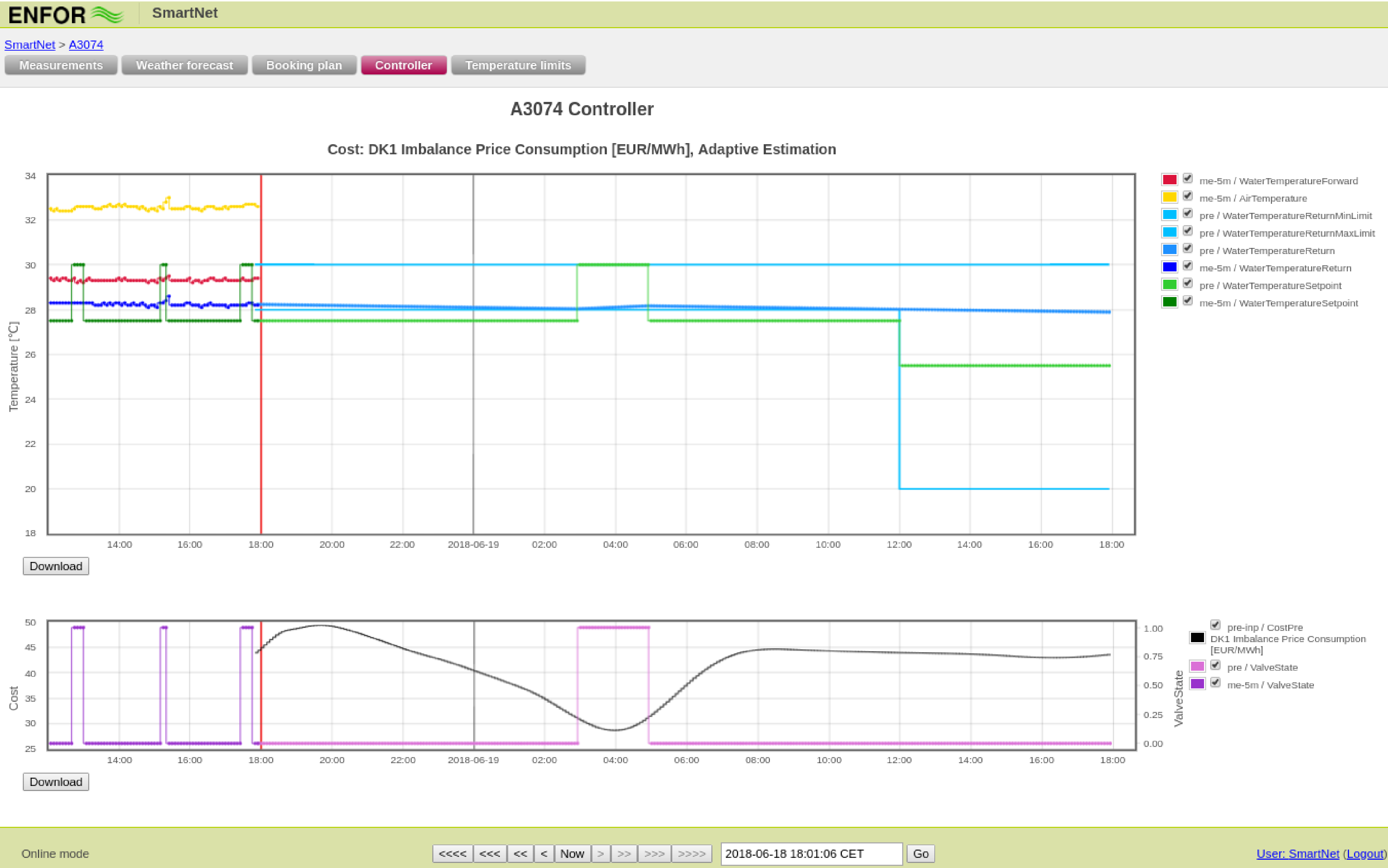
How does it work?

Price based Control

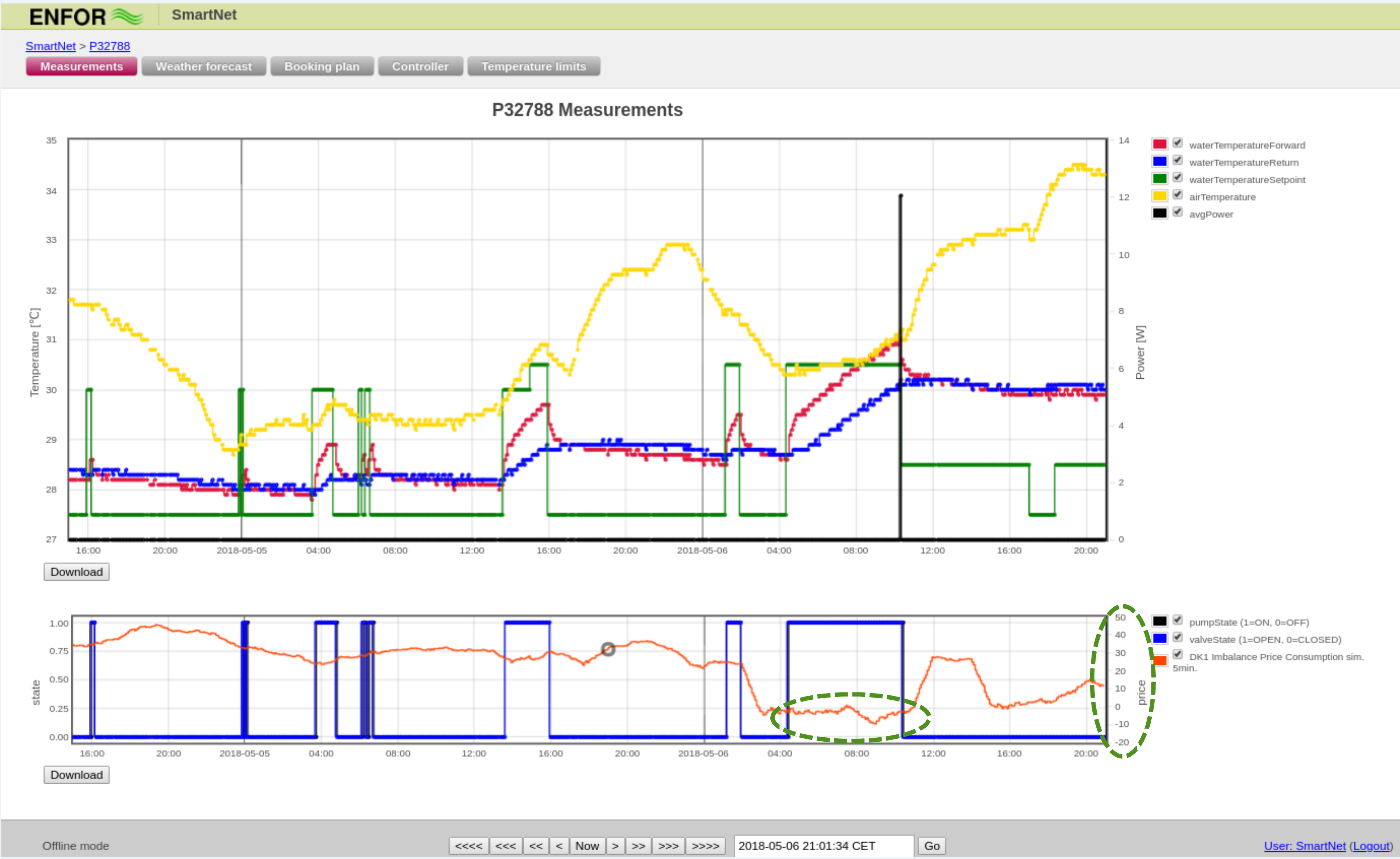


Example: Price-based control



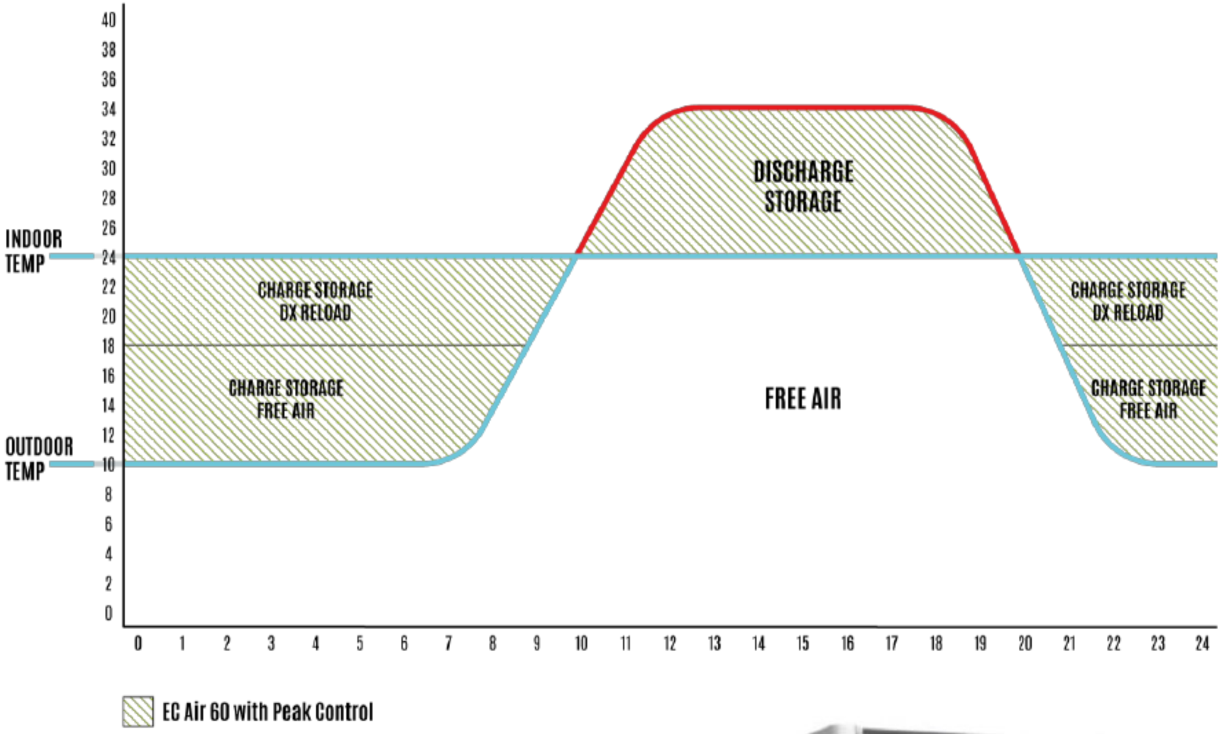
Example: CO2-based control (savings: min 10 pct)

Example with negative power prices

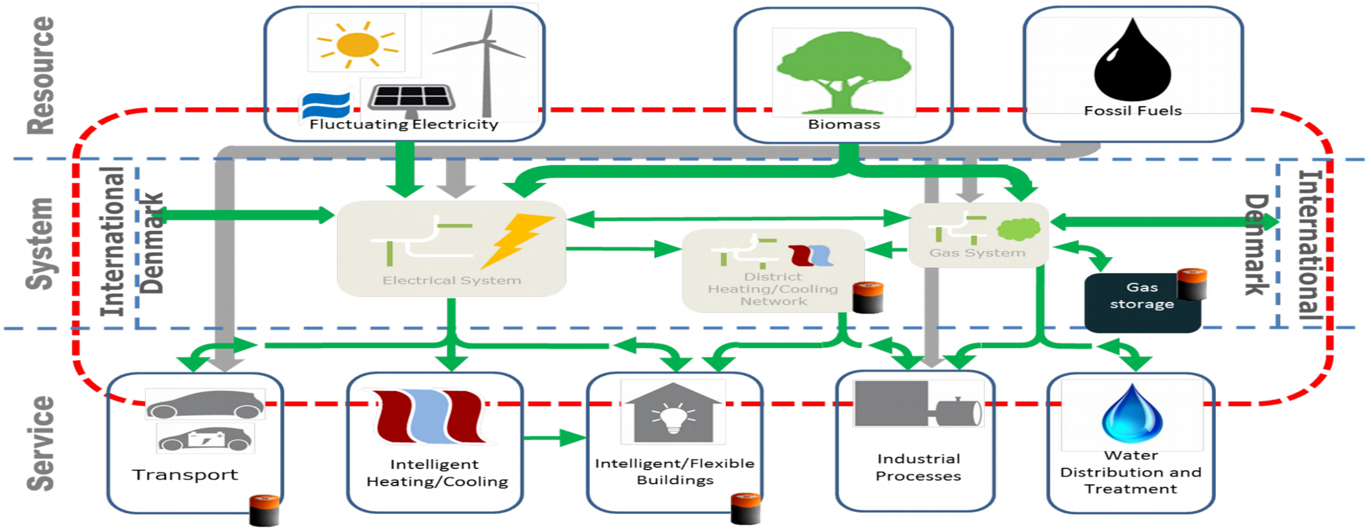


Data Centers

Large savings (90-95 pct) related to cooling for data centers using PCM (from Center Denmark)



(Virtual) Storage Solutions



- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.2-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 2-12 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-18 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - DH/DC systems with pit / bore hole storage can often provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions

CITIES INNOVATION CENTER

Integrated energy systems powered by intelligent data

Search ...

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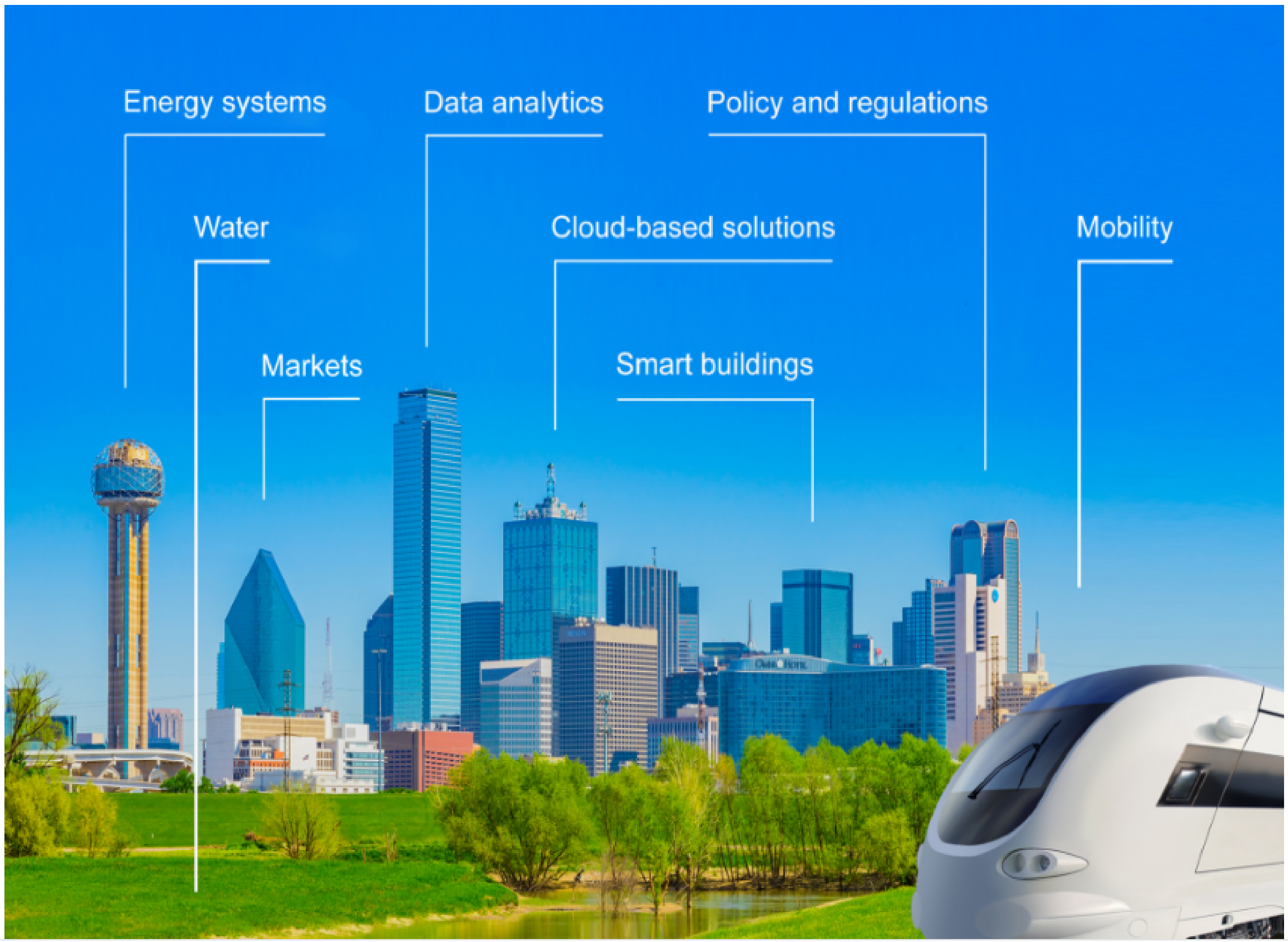
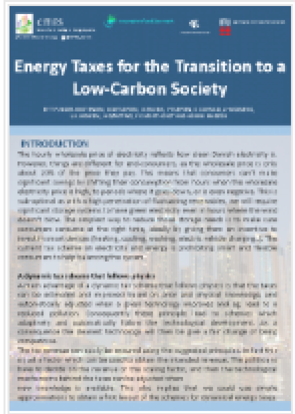
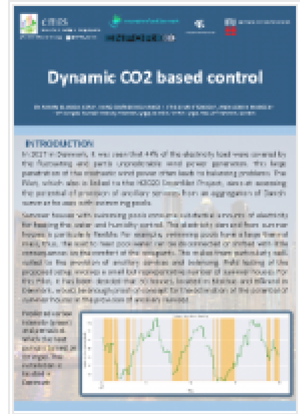
Topics



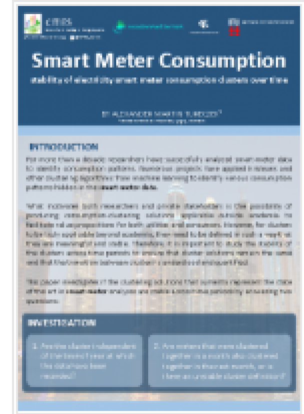
CITIES Solutions Brochures



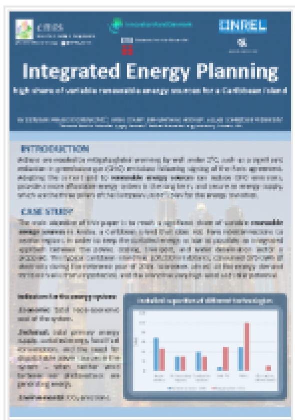
Energy taxes for the transition to a low-carbon society



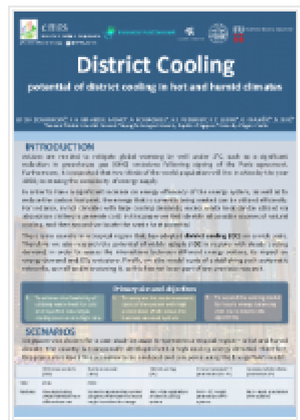
Dynamic CO2 based control



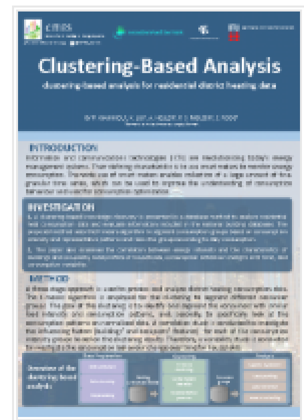
Stability of electricity smart meter clusters



Integrated energy planning for a carribean island



Potential of district cooling



Clustering based analysis of residential district heating data

Summary

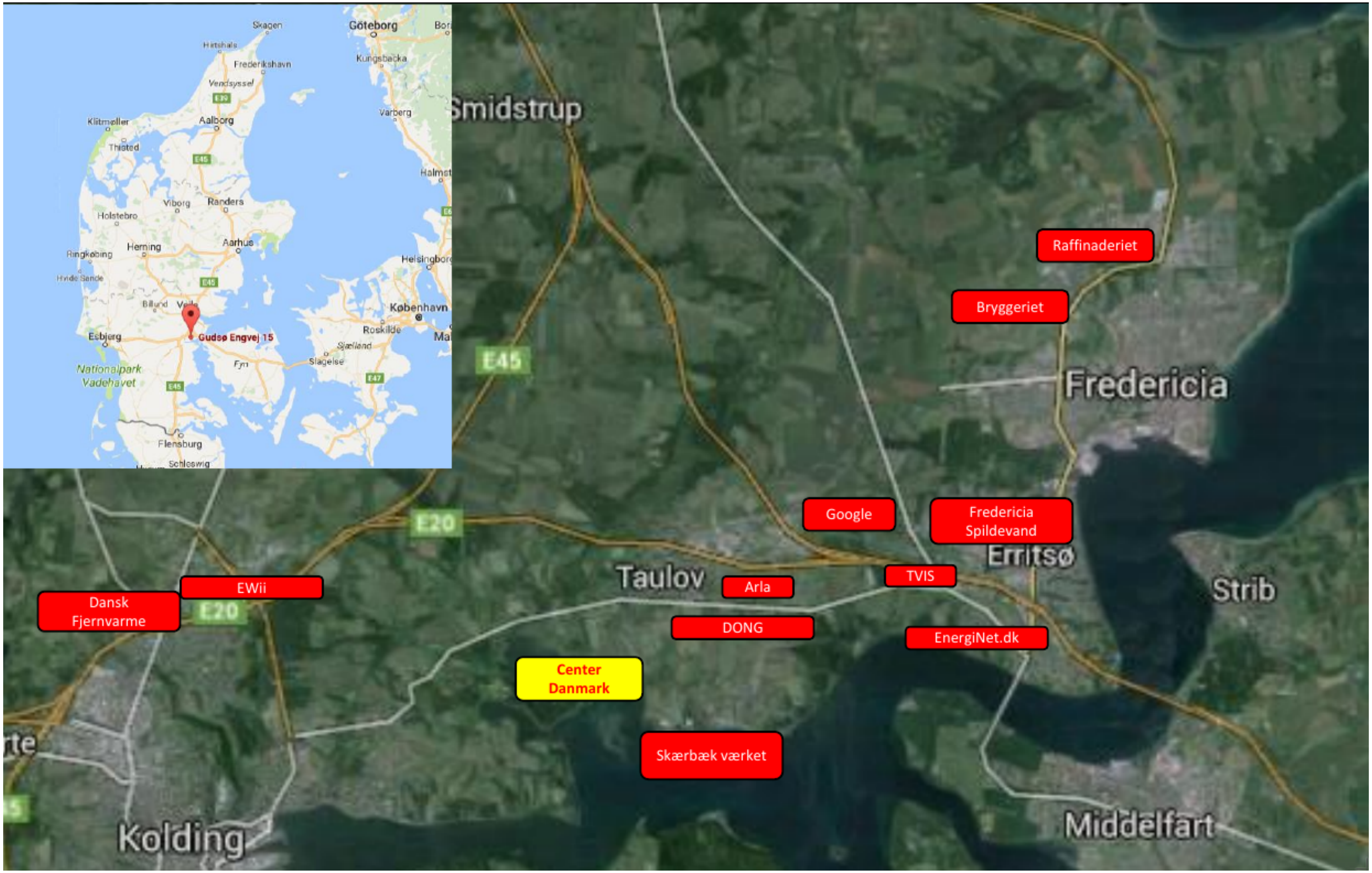
- We have demonstrated a large potential in Demand Response. Automatic solutions and consumer acceptance are important
- We have a strong team – Goal: From application 30-40 journal papers (2014-2020). Status: About 120 journal papers published now (March 2019)
- Controllers developed in CITIES can focus on
  - Peak shaving
  - Smart Grid demand (like ancillary services needs, ...)
  - Energy Efficiency
  - Cost Minimization
  - Emission Efficiency
- We see large problems with tax and tariff structures in many countries (eg. Denmark)
- New HEAT 4.0 project will take us further ahead with digitalization
- Center Denmark is (will be) established as a National Digitalization Hub for Smart Energy and Water systems. Main purpose to unlock the flexibility needed for the green transition

Center Denmark

Green transition paved by green innovation


CENTER
DENMARK
Connect networks and data
for a green world
Danmarks
nationale Center
Fremme den grønne omstilling.
Samle og bygge bro, mellem
forskning, teknologi, natur og formidling,
på tværs af interesseorganisationer,
virksomheder, skoler og
universiteter.

Center Danmark
Test Center for Intelligent and Integrated Energy Systems

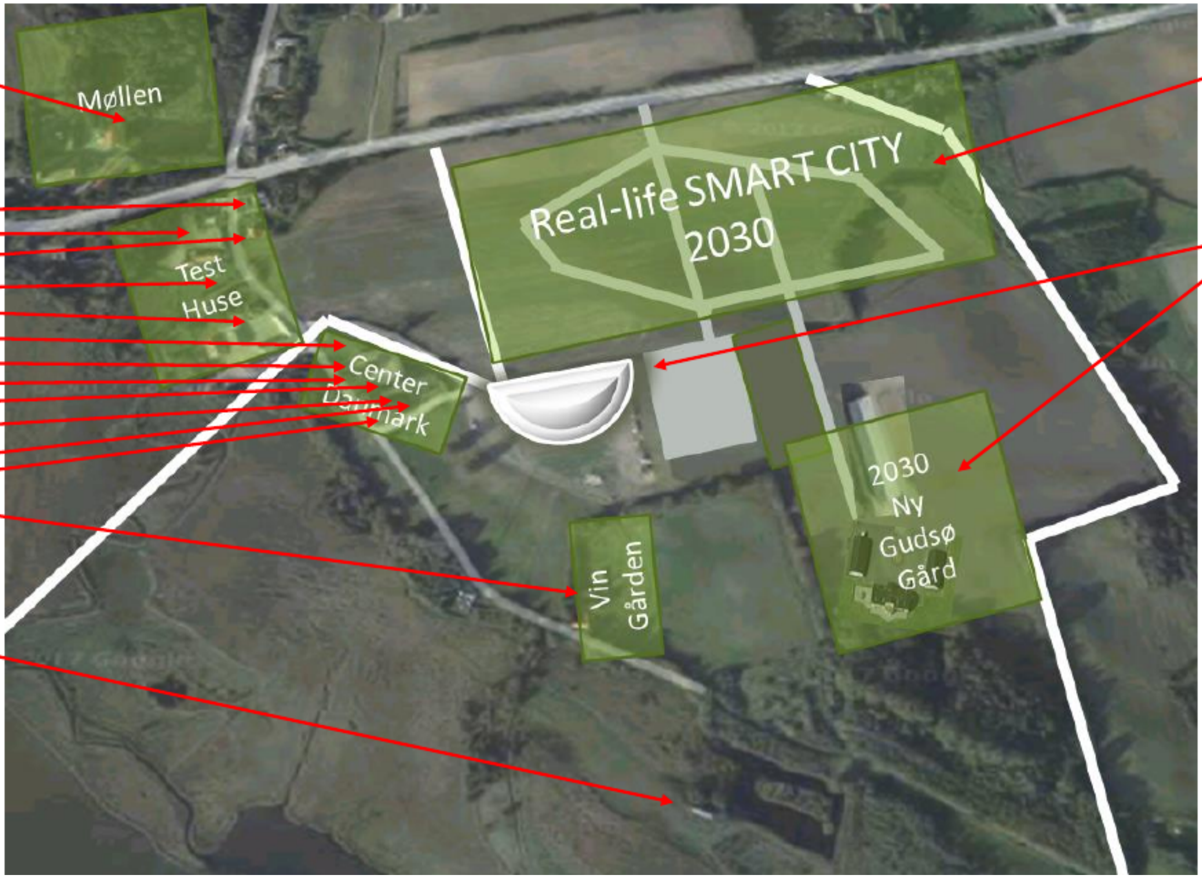


Test i et mini samfund beliggende på 40 Hektar naturgrund

- Test i et fungerende driftsmiljø bestående af mange forskellige typer bygninger

Ældre bygninger :

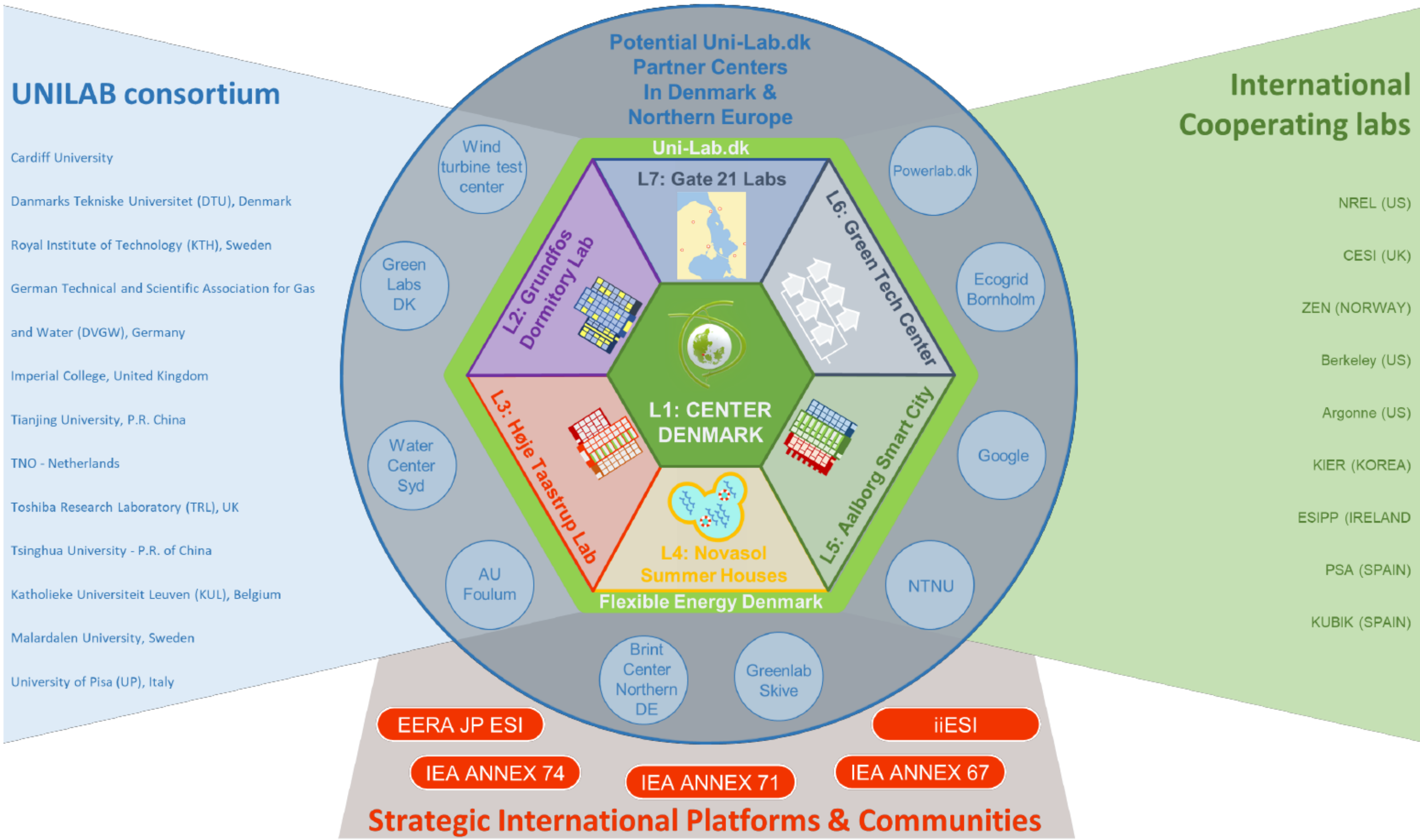
1. Møllen: Urban Farmning
   1. Bygning 228 m²
   2. Bygning 590 m²
   3. Bygning 290 m²
   4. Bygning 230 m²
   5. Bygning 155 m²
2. Privathus, 183 m².
3. Privathus, 153 m²
4. Privathus, 166 m²
5. Gård 140 m²
6. Gård 4-længet 231 m²
7. Rækkehus 140 m²
8. Rækkehus 130 m²
9. Depot 140 m²
10. Kontor 110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



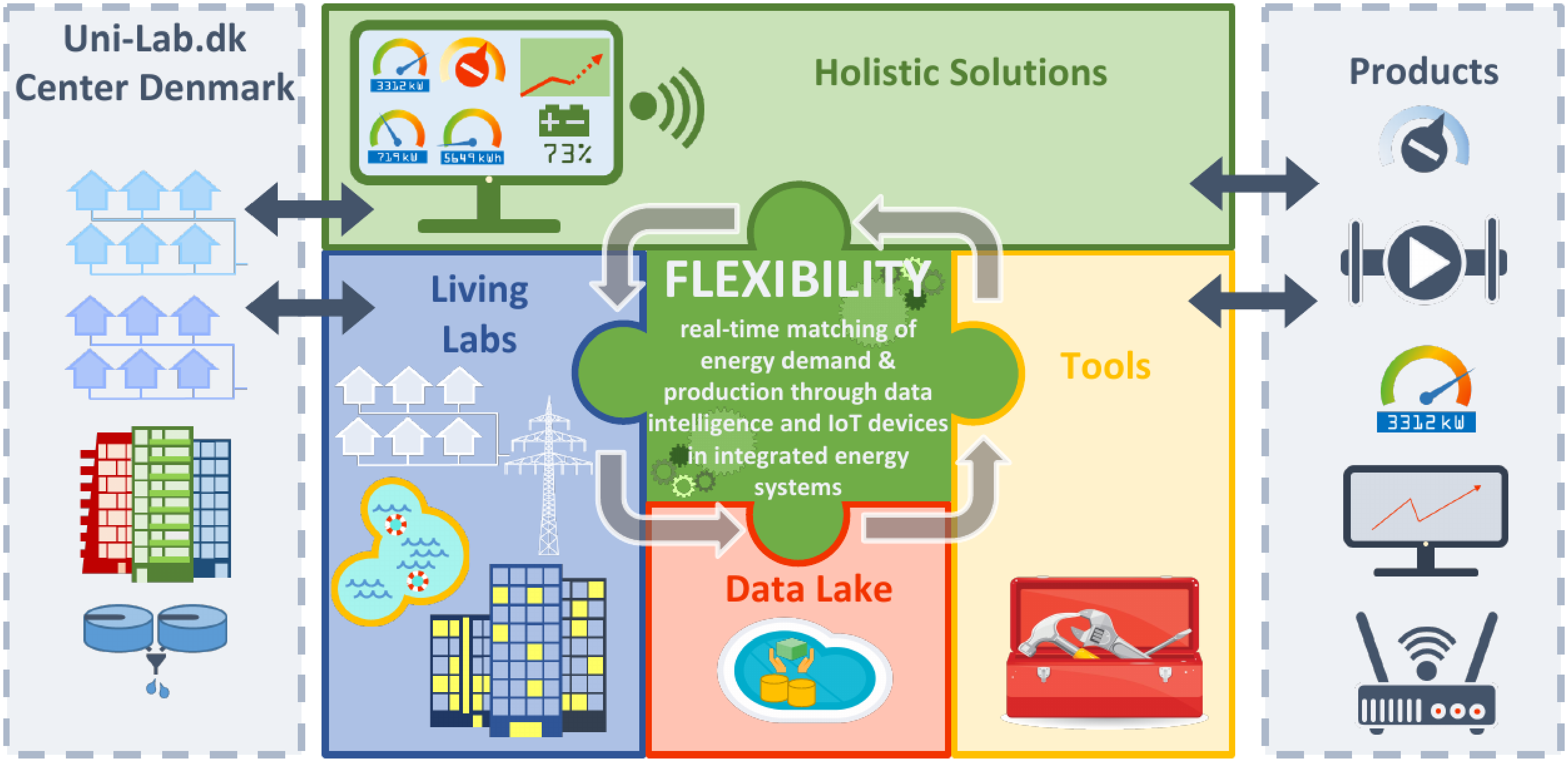
Nye bygninger :

1. Smart City 2030
   1. Urban Farmning
   2. Rækkehuse
   3. Parcel huse
   4. Kollegie værelser
   5. Undervisningsbygning
   6. Laboratorier
2. Center Danmark 4800 m²
3. Ny Gudsøgård 2600 m²
   1. Privat hus 280 m²
   2. Erhverv 280 m²
   3. Stald 280 m²
   4. Ridehal 1700 m²
   5. Produktion Gødning

Center Denmark, Living Labs, Partnerships

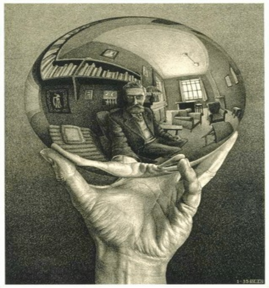


A Danish Path to a Fossil Free Society



Center Denmark:
Data Intelligent Energy Systems

- Automatic and self-cal. methods based on Big Data analytics and AI
- Storage solutions are essential – both physical and virtual storage
- 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 (virtual storage) at all levels



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EERA
European Energy Research Alliance

Coordinating energy research for a low carbon Europe

Energy Systems Integration

THE EERA JOINT PROGRAMME IN ENERGY SYSTEMS INTEGRATION

This Joint Programme in Energy Systems Integration seeks to bring together research strengths across Europe to optimize our energy system, in particular by benefiting from the synergies between heating, cooling, electricity, renewable energy and fuel pathways at all scales. The energy elements of the water and transport system are also included as is the enabling data and control network that enables the optimization.

The Joint Programme in Energy Systems Integration is designed to develop the technical and economic framework that government and industries will need to build the future efficient and sustainable European energy system. It is fully aligned with the recently published SET Plan Integrated Roadmap and potential impact include increased reliability and performance, minimisation of cost and environmental impacts and, in particular, increased penetration of renewable energy sources.

STRUCTURE

The Joint Programme is organised in 5 Sub-Programmes (SP) that target different aspects of Energy Systems Integration. Given the nature of Energy Systems Integration, the SPs are strongly interlinked.

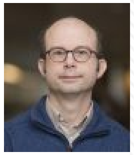
- **SP1**: Modelling, coordinated by Dr. Juha Kiviluoma, VTT (FI)
- **SP2**: Forecasting, aggregation & control, coordinated by Prof. Henrik Madsen, DTU (DK)
- **SP3**: Technology, coordinated by Peter Breuhaus, IRIS (NO)
- **SP4**: Consumer, coordinated by Kristiane Lindland, IRIS (NO)
- **SP5**: Finance & regulation, coordinated by Erik Delarue, KU Leuven (BE)

News of this program

Useful documents

Coordinator

Laurens de Vries
e-mail

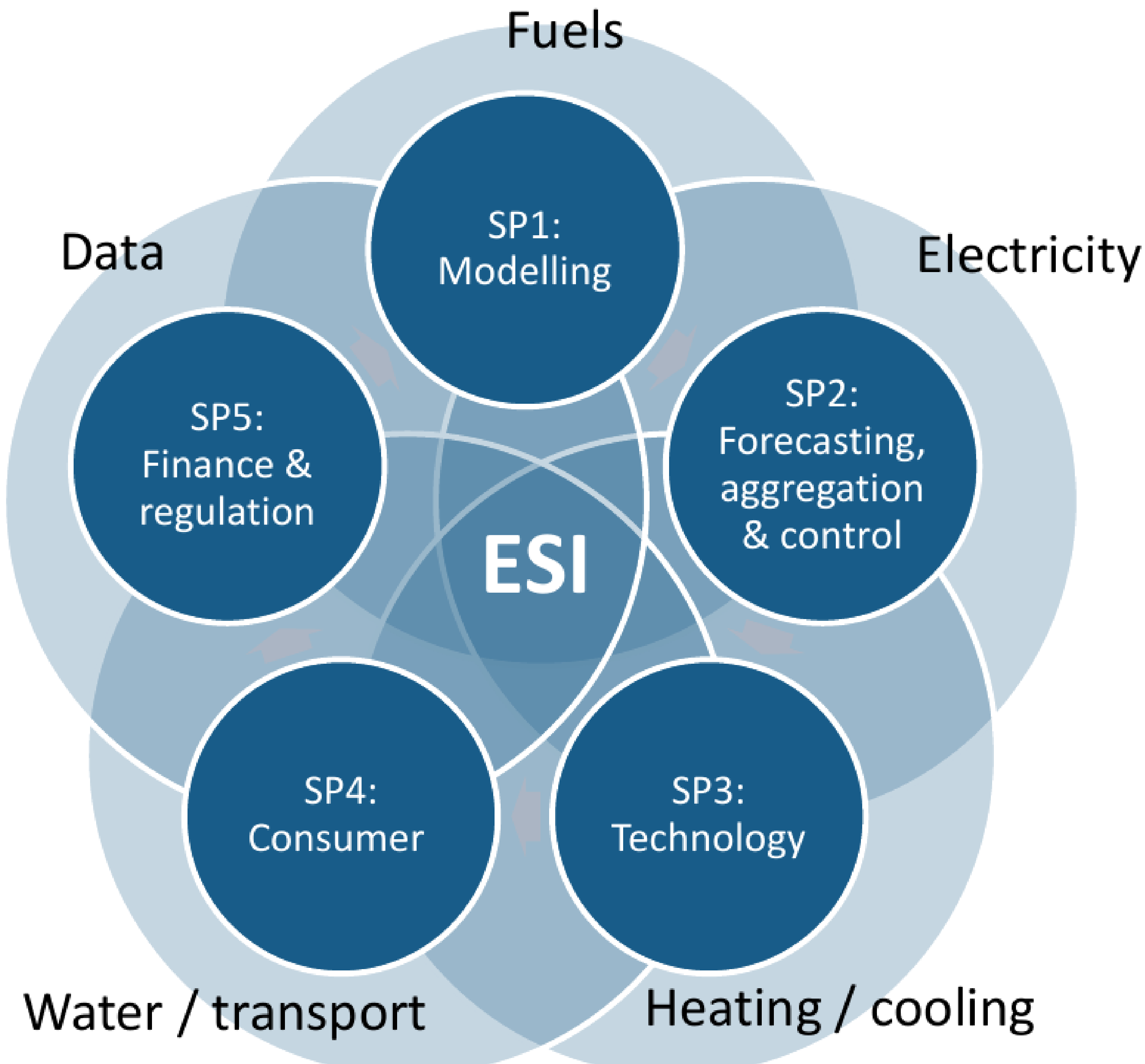


JP Vice-Coordinator, William D'haerseleer | KU Leuven
e-mail

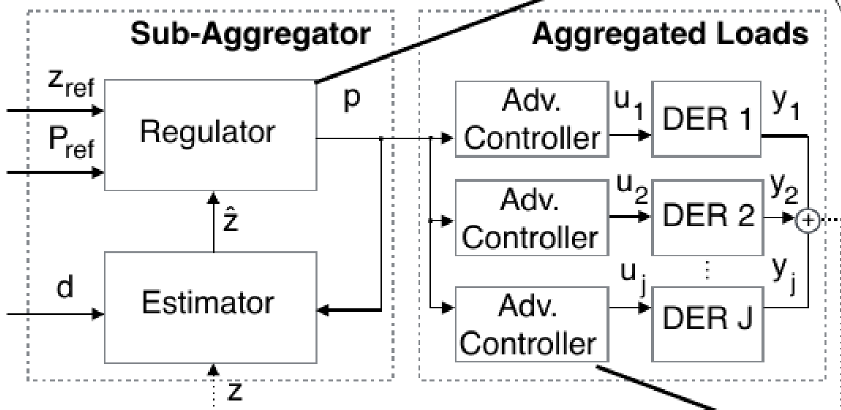
Contact at EERA

Elena Guarneri
e-mail

DESCRIPTION OF WORK



Proposed methodology
Control-based methodology



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

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

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

For more information ...

See for instance

www.smart-cities-centre.org

...or contact

– Henrik Madsen (DTU Compute)
  hmad@dtu.dk

Acknowledgement - DSF 1305-00027B