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Methodologies for Integrating Energy Flexible Buildings and Districts into the Future Smart Grid

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https://smartcitiesaccelerator.eu

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

http://www.henrikmadsen.org

CITIES
Centre for IT Intelligent Energy Systems

Lyngby-Taarbæk Vidensby, November 2017


RHEINBRAUN
757


KIRA MORRIS/NATIONAL GEOGRAPHIC YOUR SHOT

- Quote by B. Obama at the Climate Summit 2014 in New York:
-
-
- *We are the* ***first generation*** *affected by climate changes,*

and we are the ***last generation*** *able to do something about it!*

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 develo[illegible] such [illegible]

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:

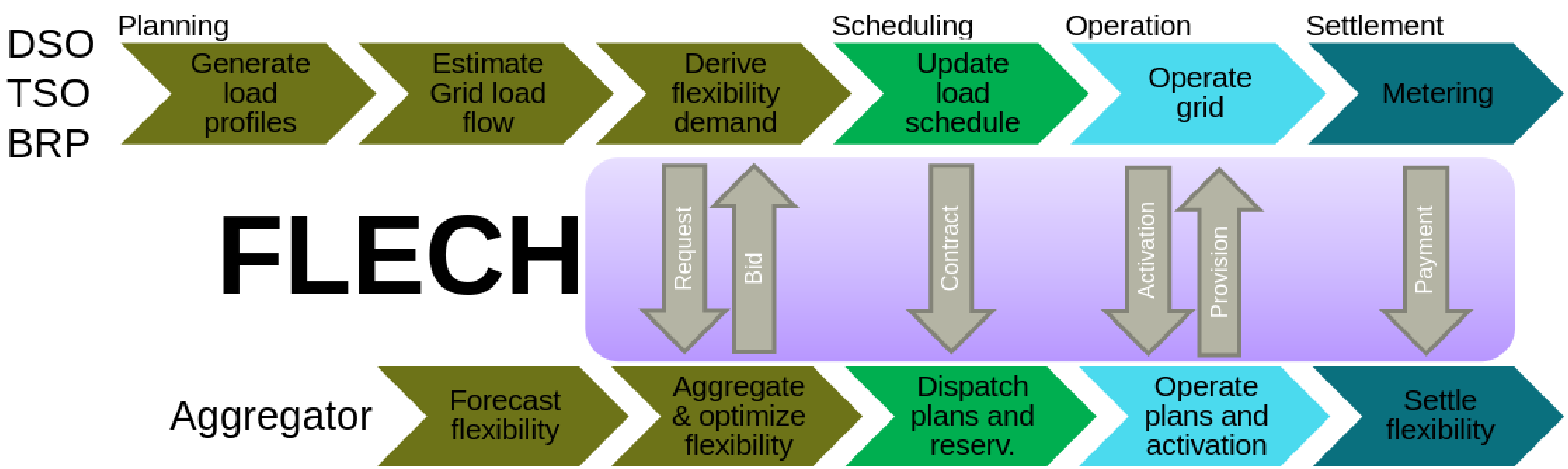
- Scope, standards a[illegible] Chapter [illegible]);
- Market analysis (Task 2, Chapter 2);
- User analysis (Task 3, Chapter 3);
- Technical analysis (Task 4, Chapter 4);
- Definition of Base Cases (Task 5, Chapter 5);
- Design options (Task 6, Chapter 6);
- Policy and Scenario analysis (Task 7, Chapter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

FLECH concept
Interaction between DSO,TSO or BRP and Aggregator



iPower

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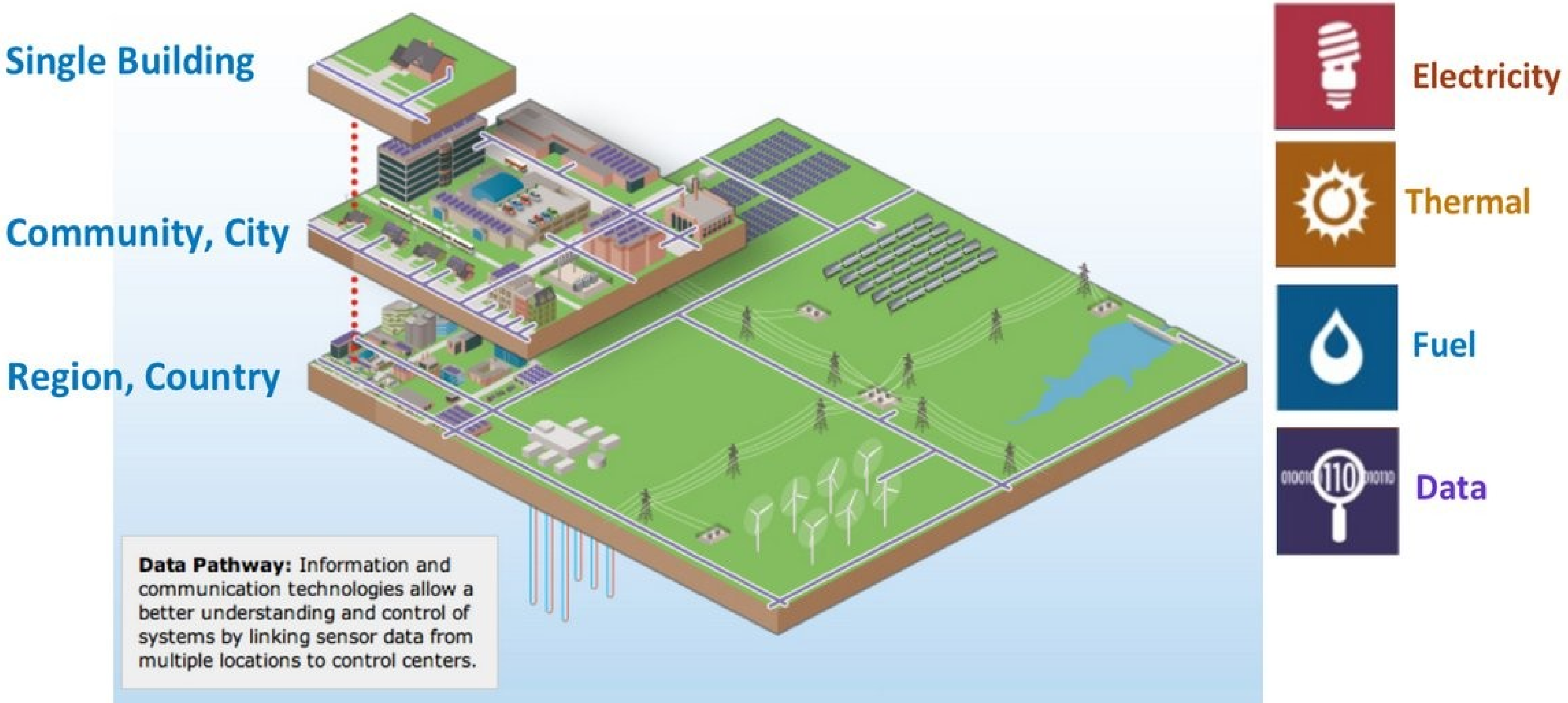
Energy Systems Integration

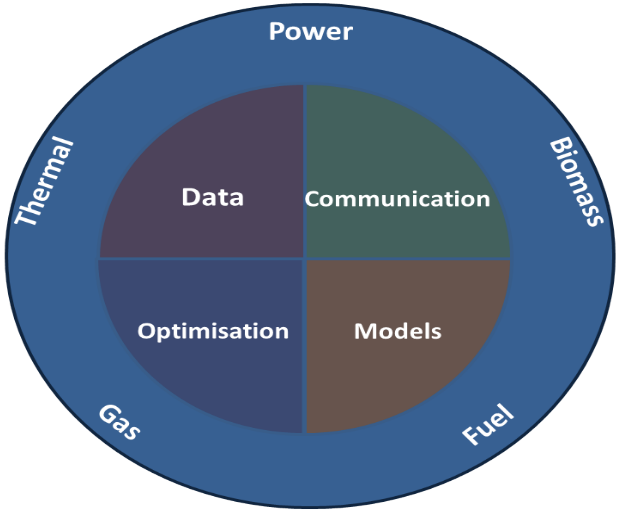
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



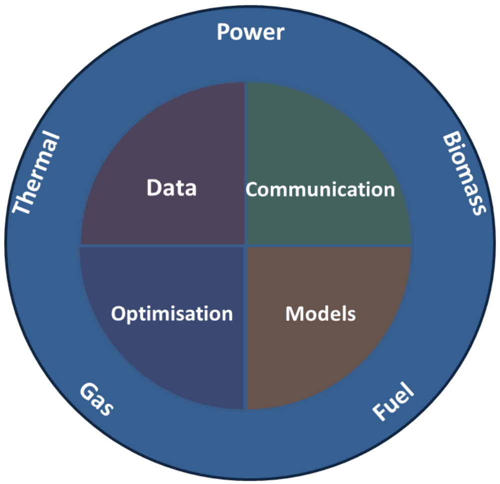
Flexible Solutions and CITIES

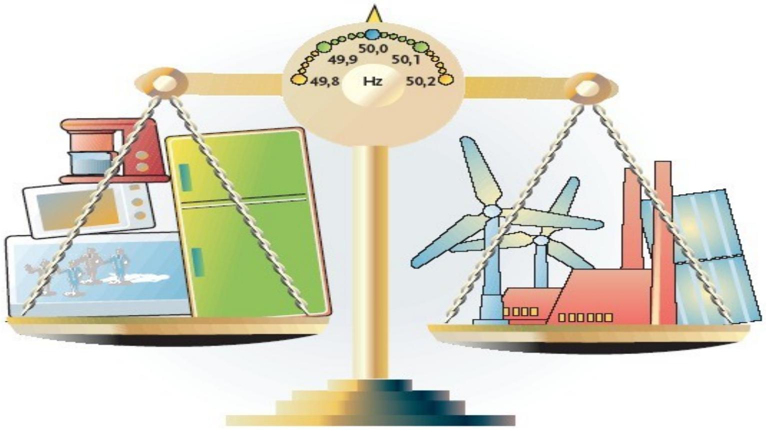
Center for IT-Intelligent Energy Systems in Cities (CITIES) is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

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



Energy Systems Integration





The **central hypothesis in CITIES** is that by **intelligently integrating** currently distinct energy flows (heat, power, gas and biomass) using grey-box models we can balance very large shares of renewables, and consequently obtain substantial reductions in CO2 emissions in Smart Cities.

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

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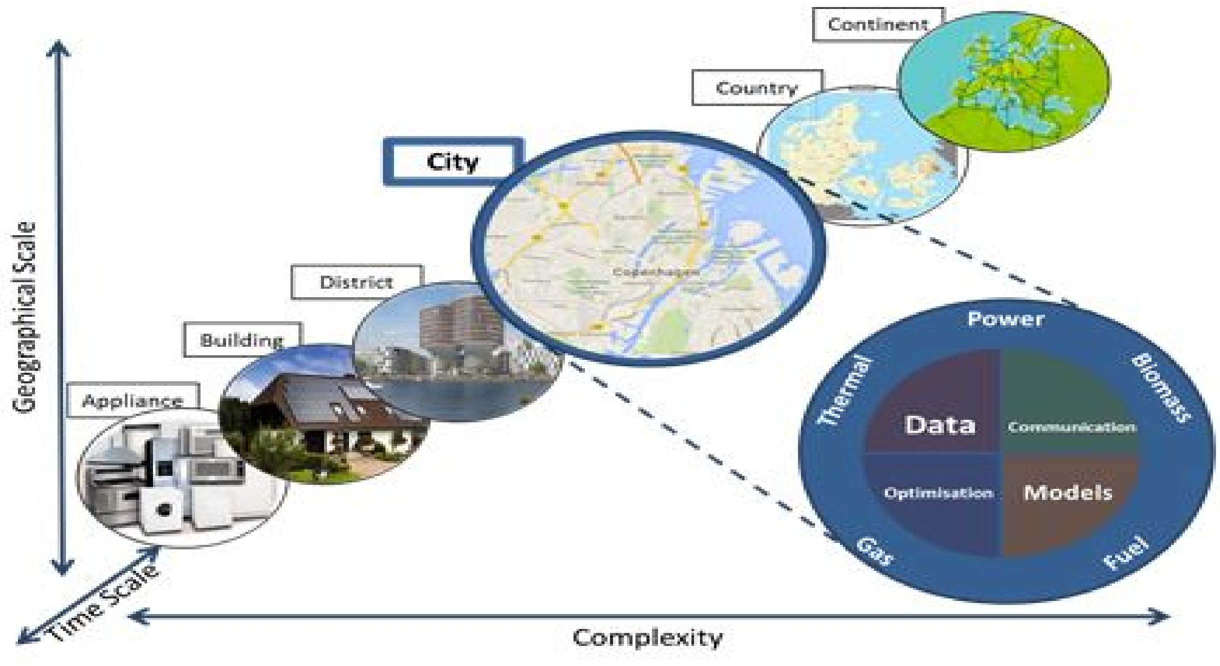
CITIES goals

To establish methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales in **Smart Cities**



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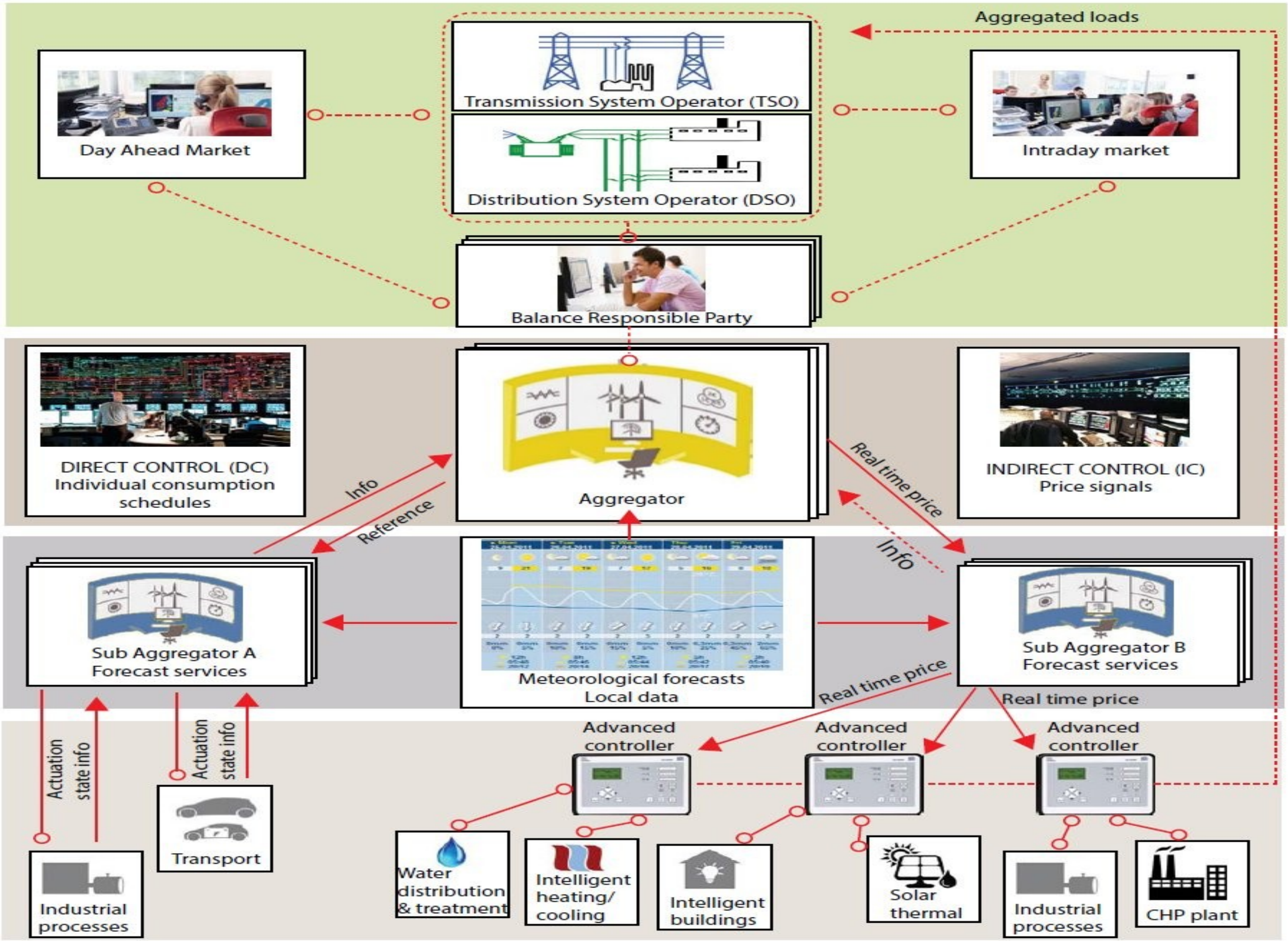
Smart-Energy OS



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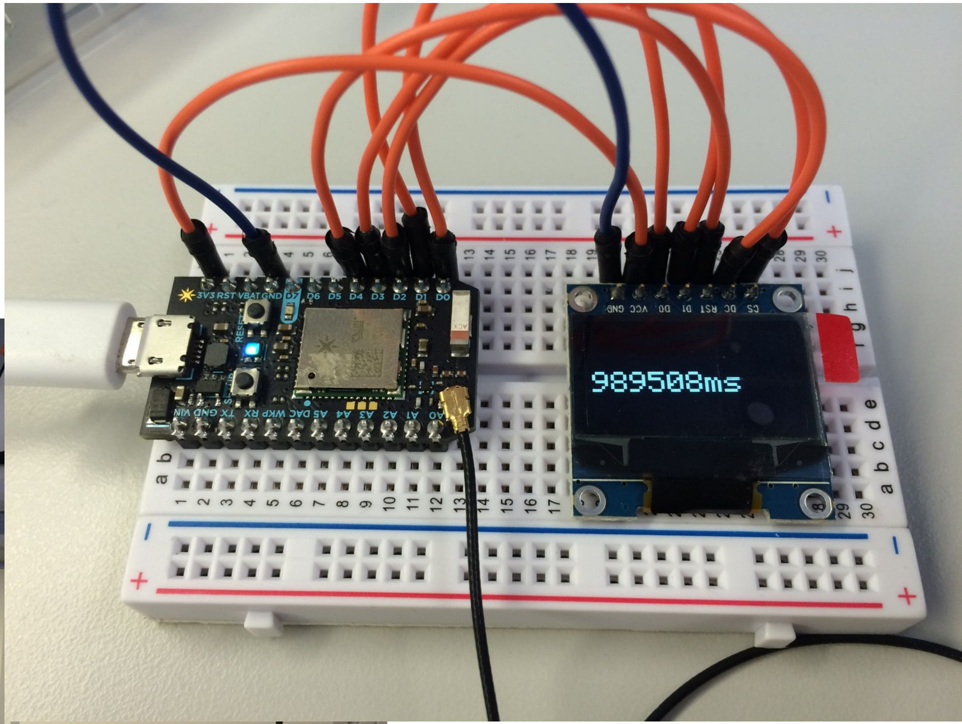
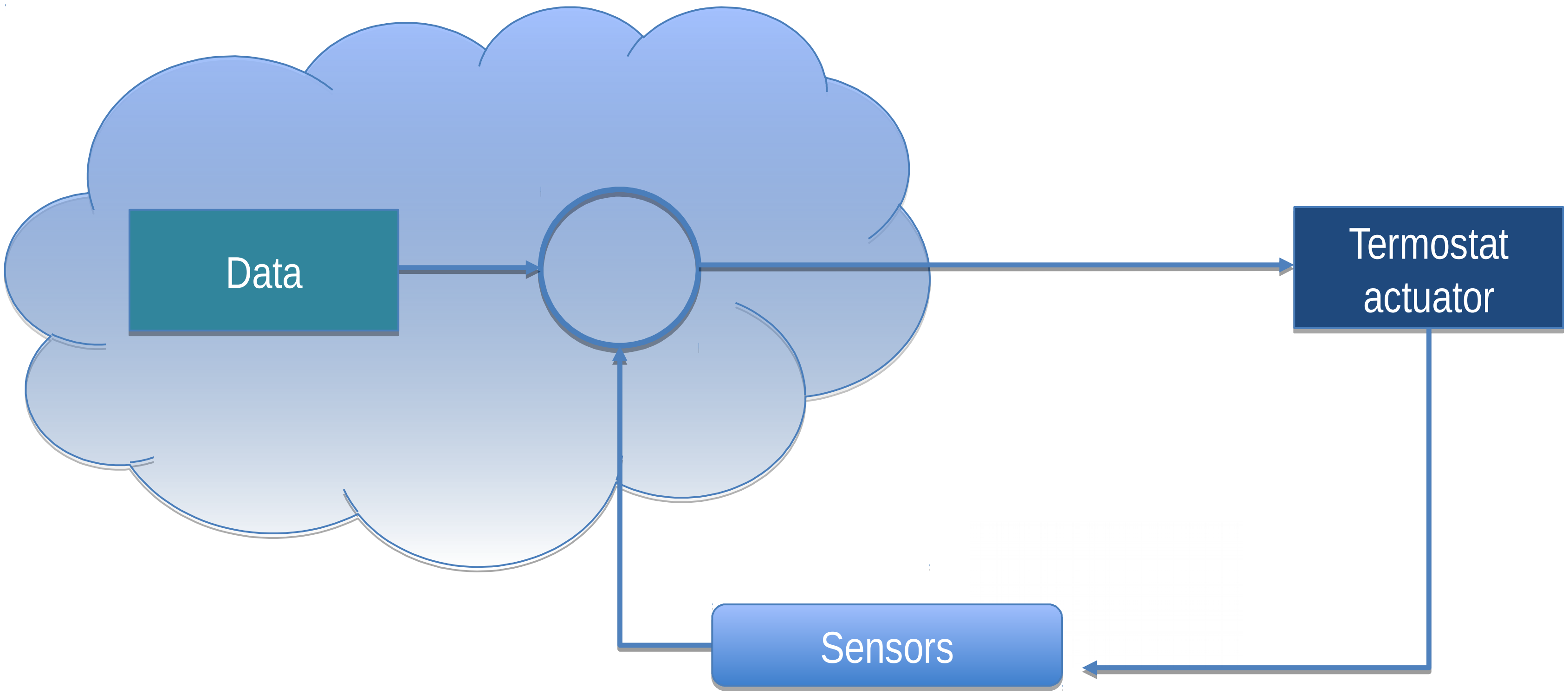
```
# slow approach, but we are sure things get don
# Try to parallelize anyway
require(multicore)
numcores<-multicore:::detectCores()
mclapply(
  1:N, 
  function(i,data) {
    print(paste(i, "/", N))

    # 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)
```

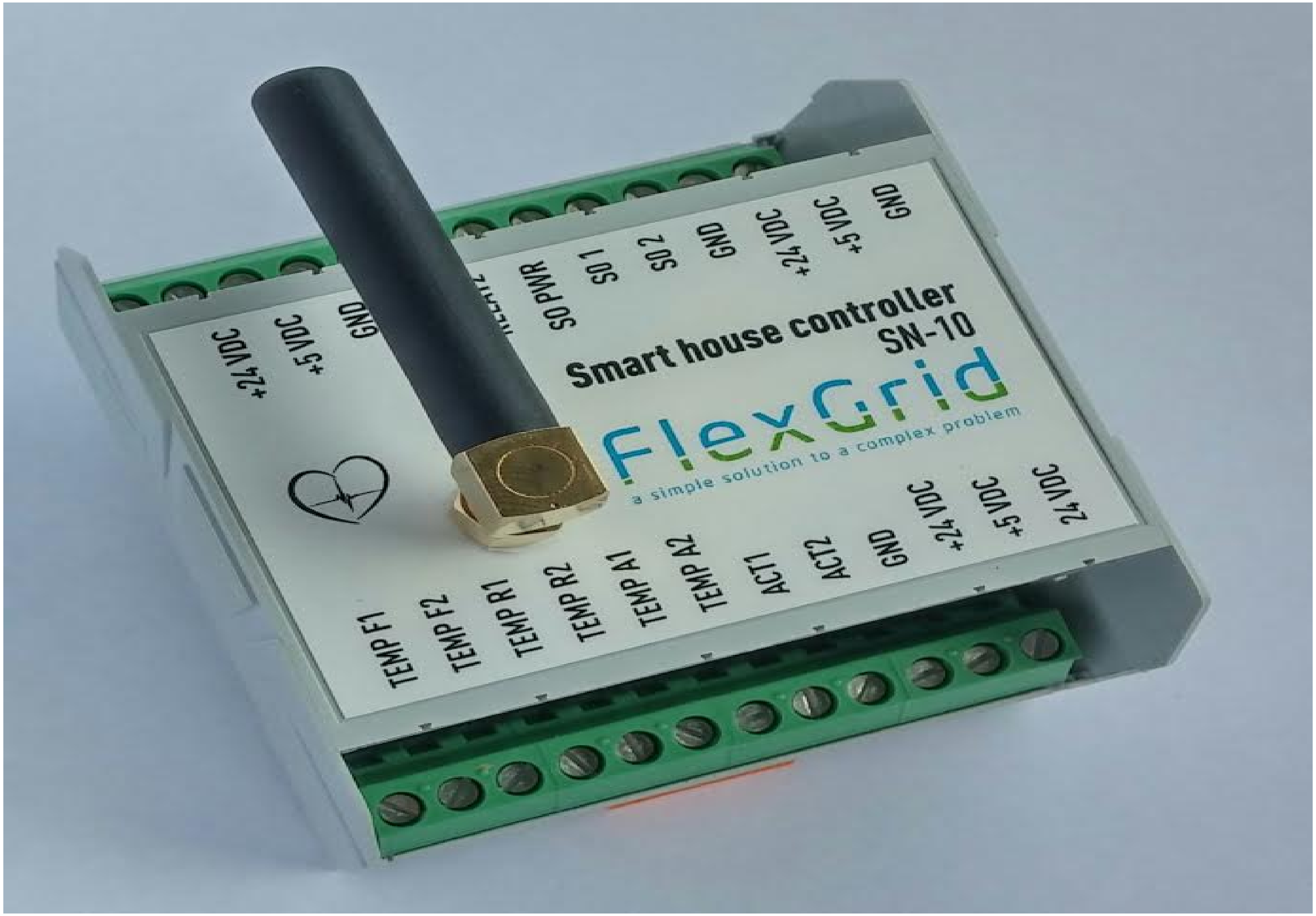
Lab testing ….



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



SN-10 Smart House Prototype



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Case study No. 1

Control of Power Consumption using the Thermal Mass of Buildings (Peak shaving)

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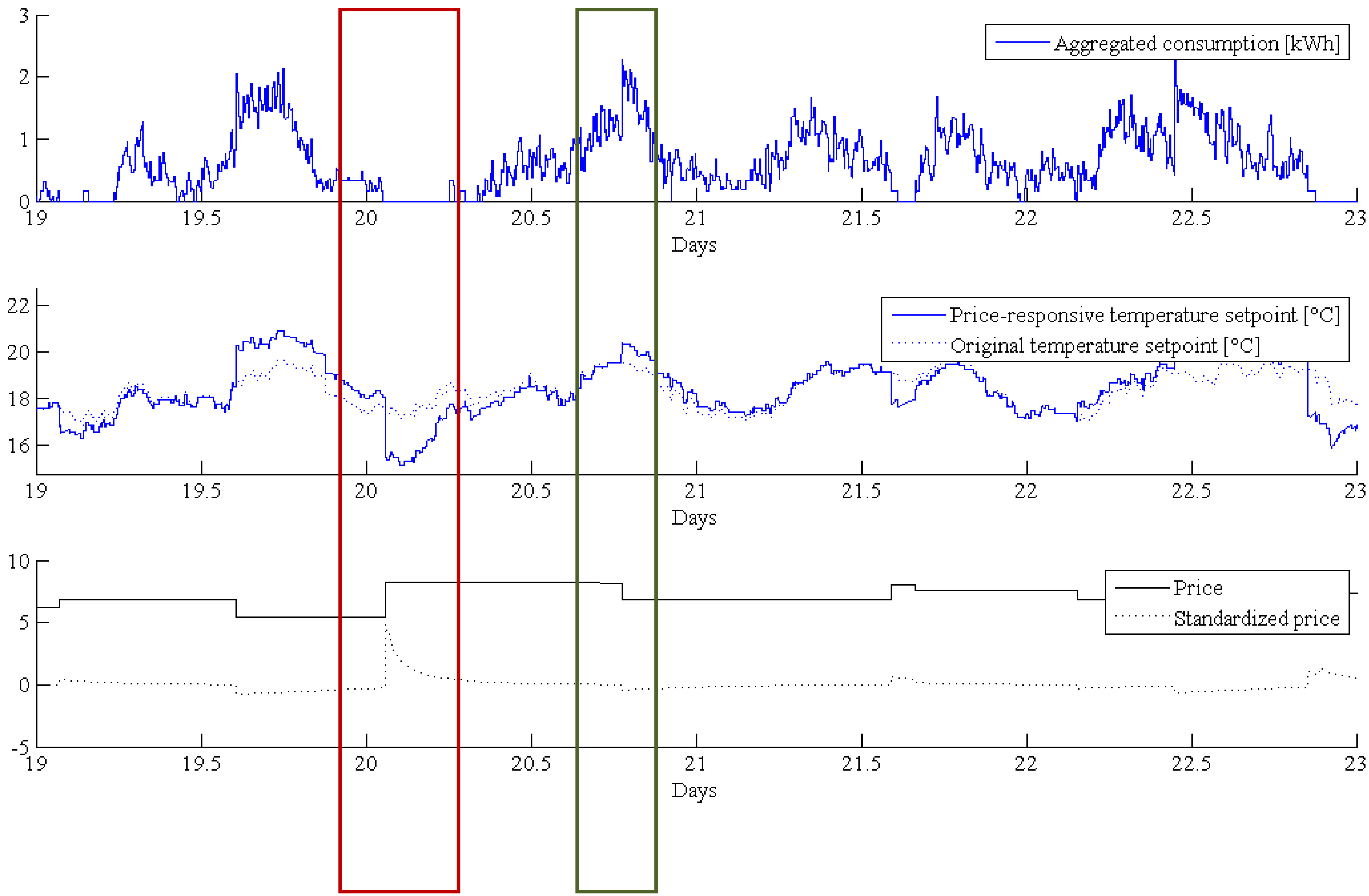
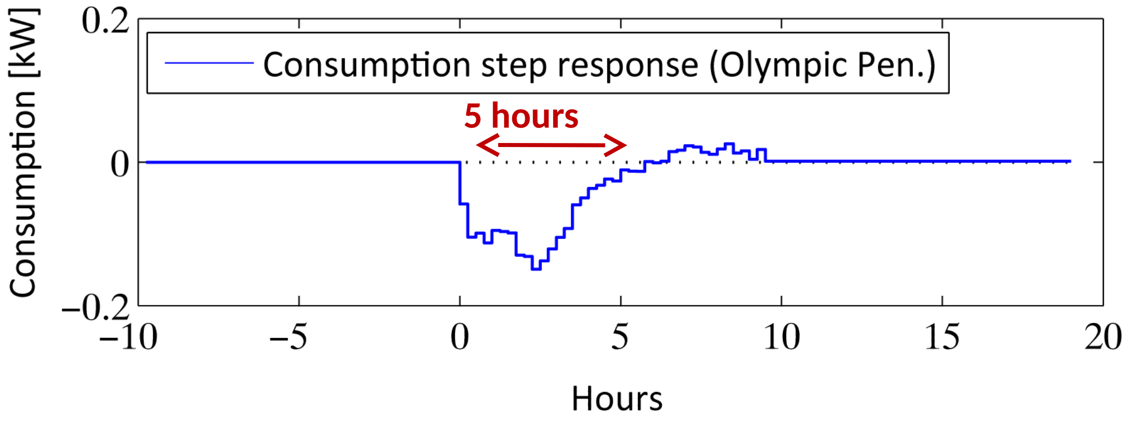
Lyngby-Taarbæk Vidensby, November 2017

Aggregation (over 20 houses)

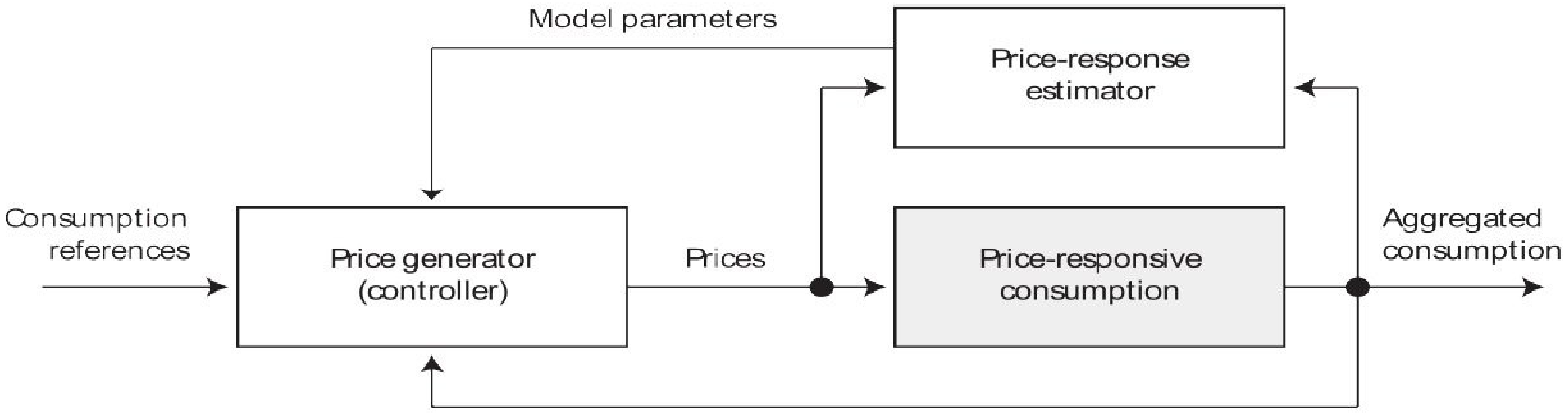


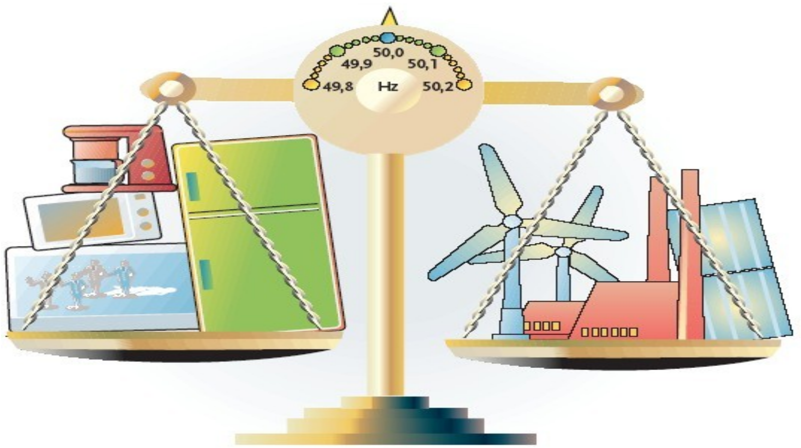
Non-parametric Response on Price Step Change

Olympic Peninsula



Control of Energy Consumption

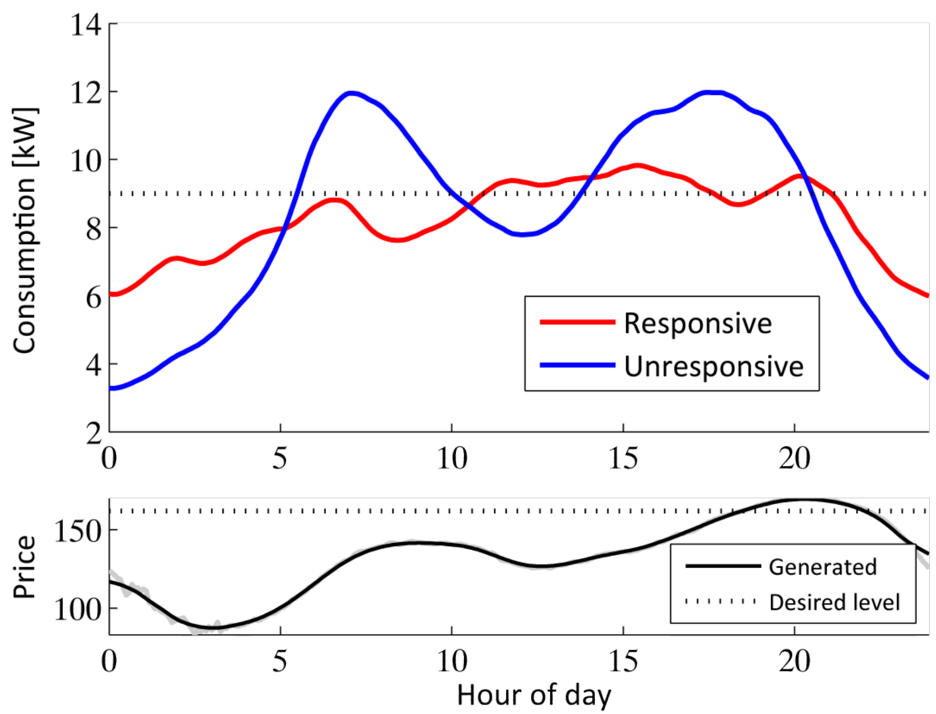




Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift



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Case study No. 2

Control of Heat Pumps for buildings with a thermal solar collector (minimizing cost)

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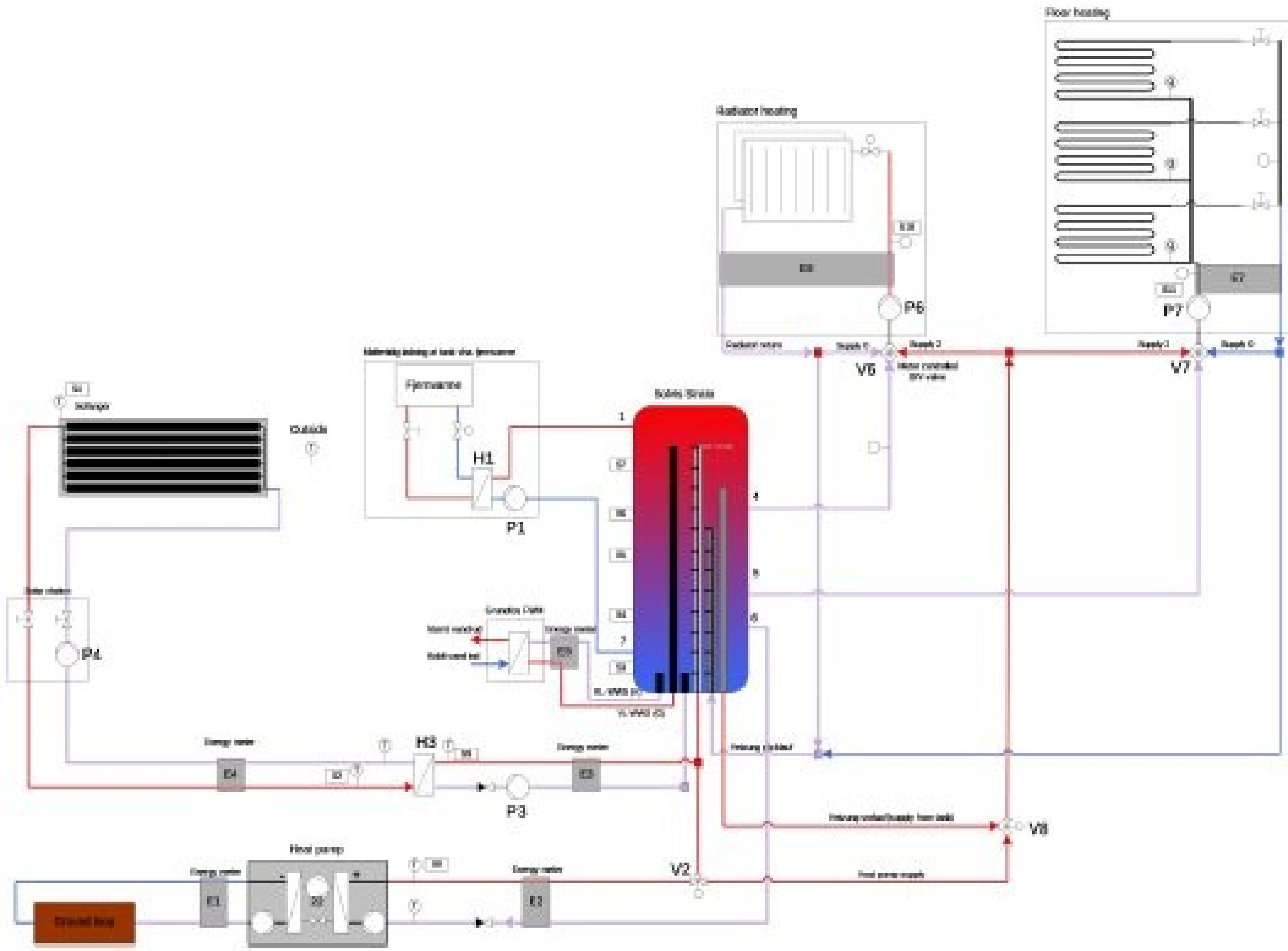
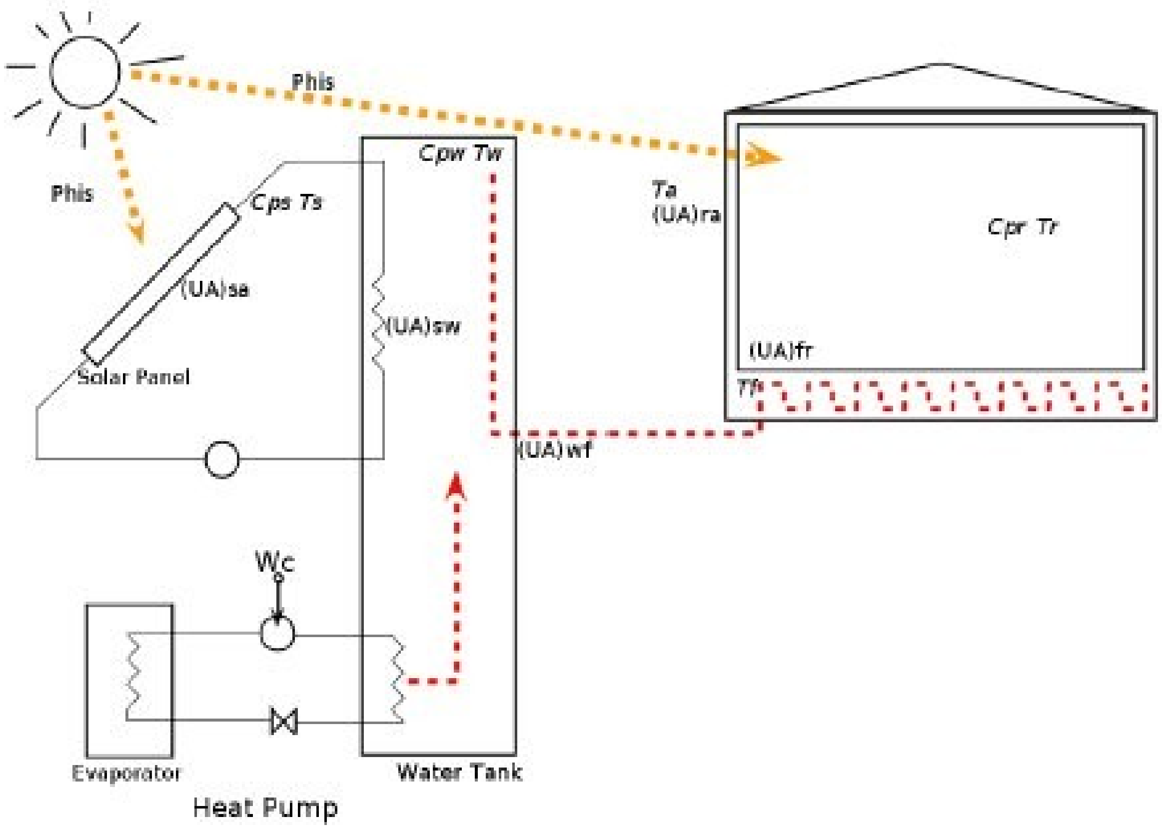
Grundfos Case Study

Schematic of the heating system



Modeling Heat Pump and Solar Collector

Simplified System



Formulation

The Economic MPC problem, with the constraints and the model, can be summarized into the following formal formulation:

$$\min_{\{u_k\}_{k=0}^{N-1}} \phi = \sum_{k=0}^{N-1} c' u_k \tag{4a}$$

$$\text{Subject to} \quad x_{k+1} = Ax_k + Bu_k + Ed_k \quad k = 0, 1, \ldots, N-1 \tag{4b}$$

$$y_k = Cx_k \quad k = 1, 2, \ldots, N \tag{4c}$$

$$u_{min} \leq u_k \leq u_{max} \quad k = 0, 1, \ldots, N-1 \tag{4d}$$

$$\Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} \quad k = 0, 1, \ldots, N-1 \tag{4e}$$

$$y_{min} \leq y_k \leq y_{max} \quad k = 0, 1, \ldots, N \tag{4f}$$

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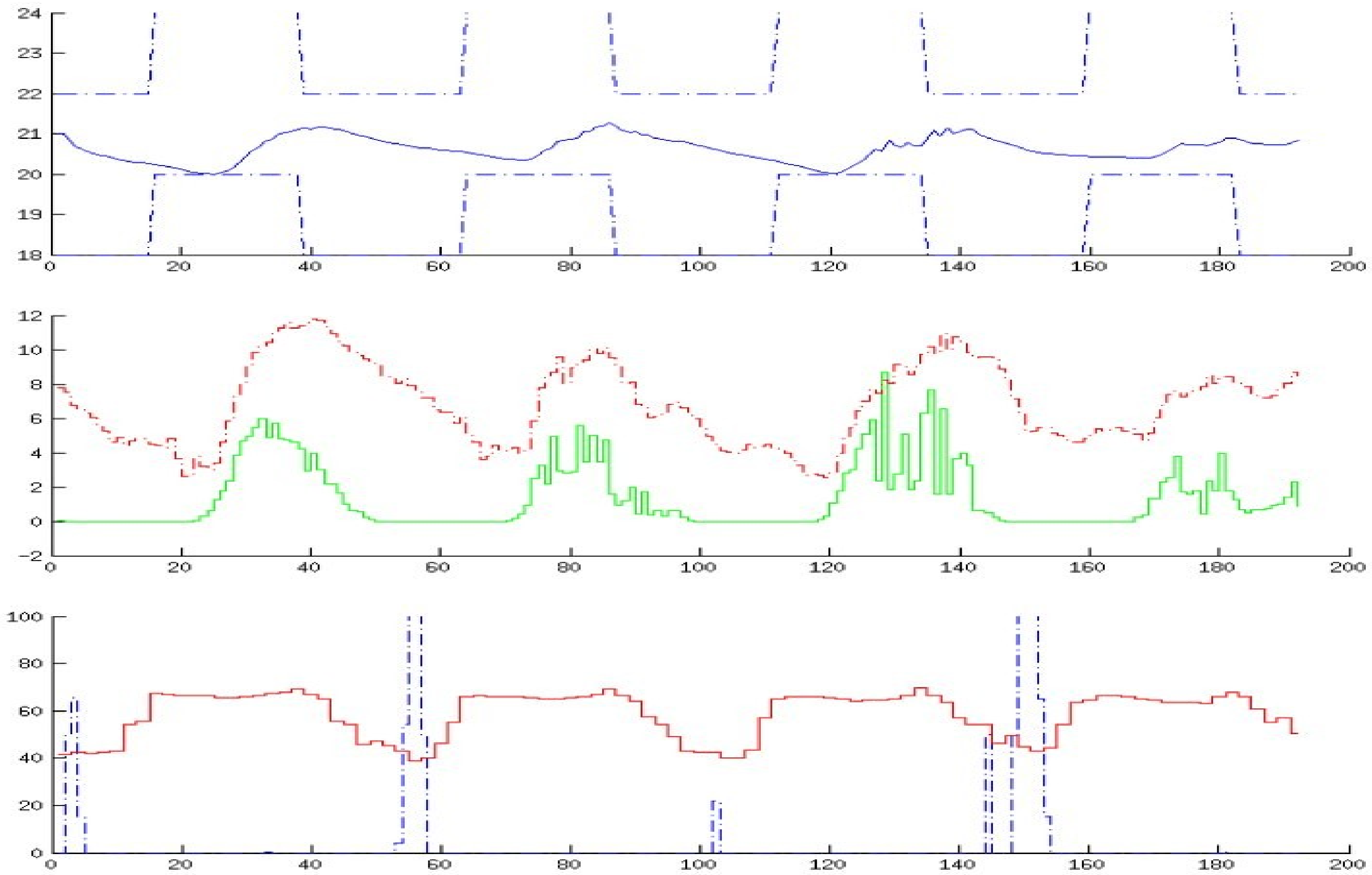
EMPC for heat pump with solar collector (savings 35 pct)



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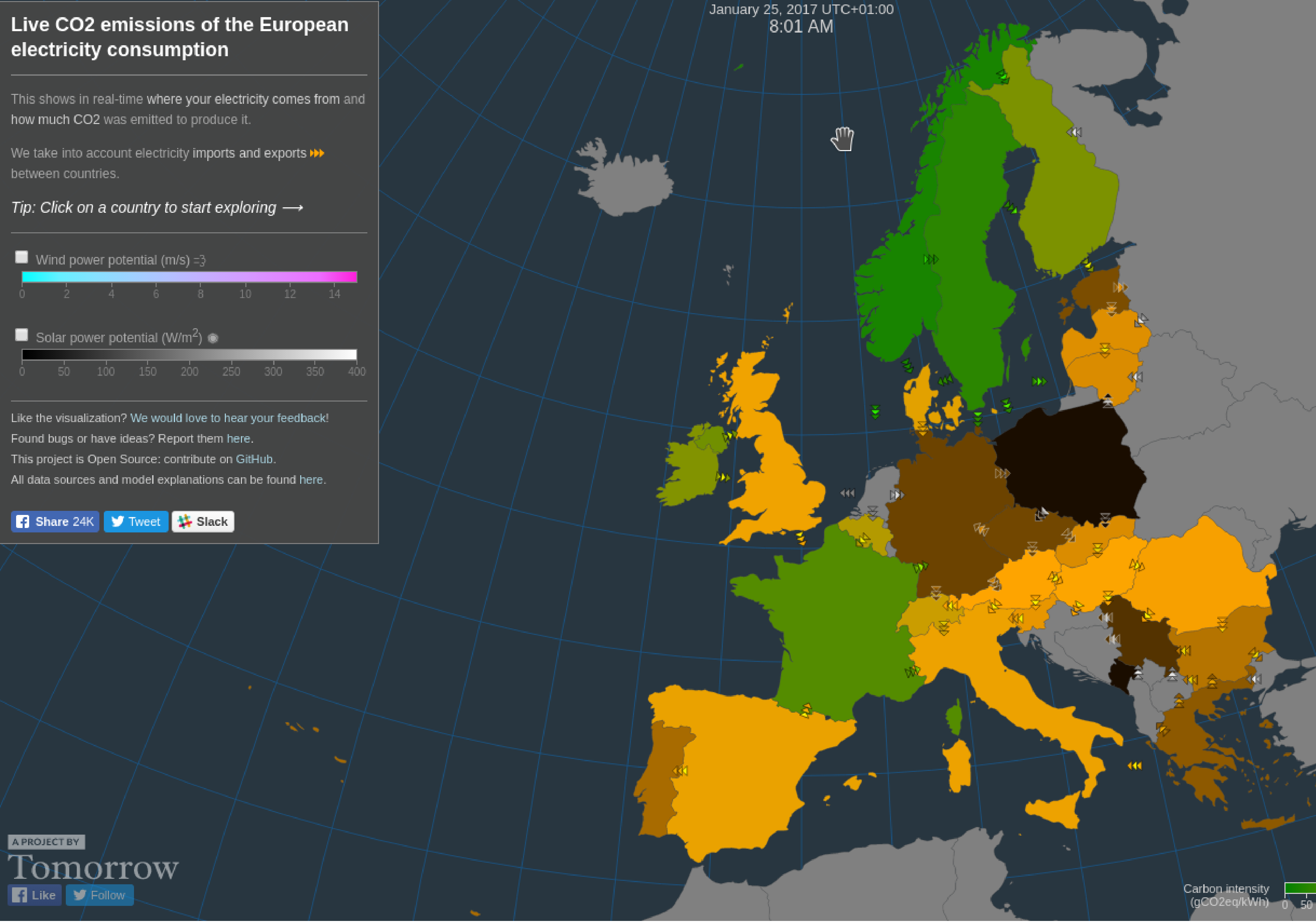
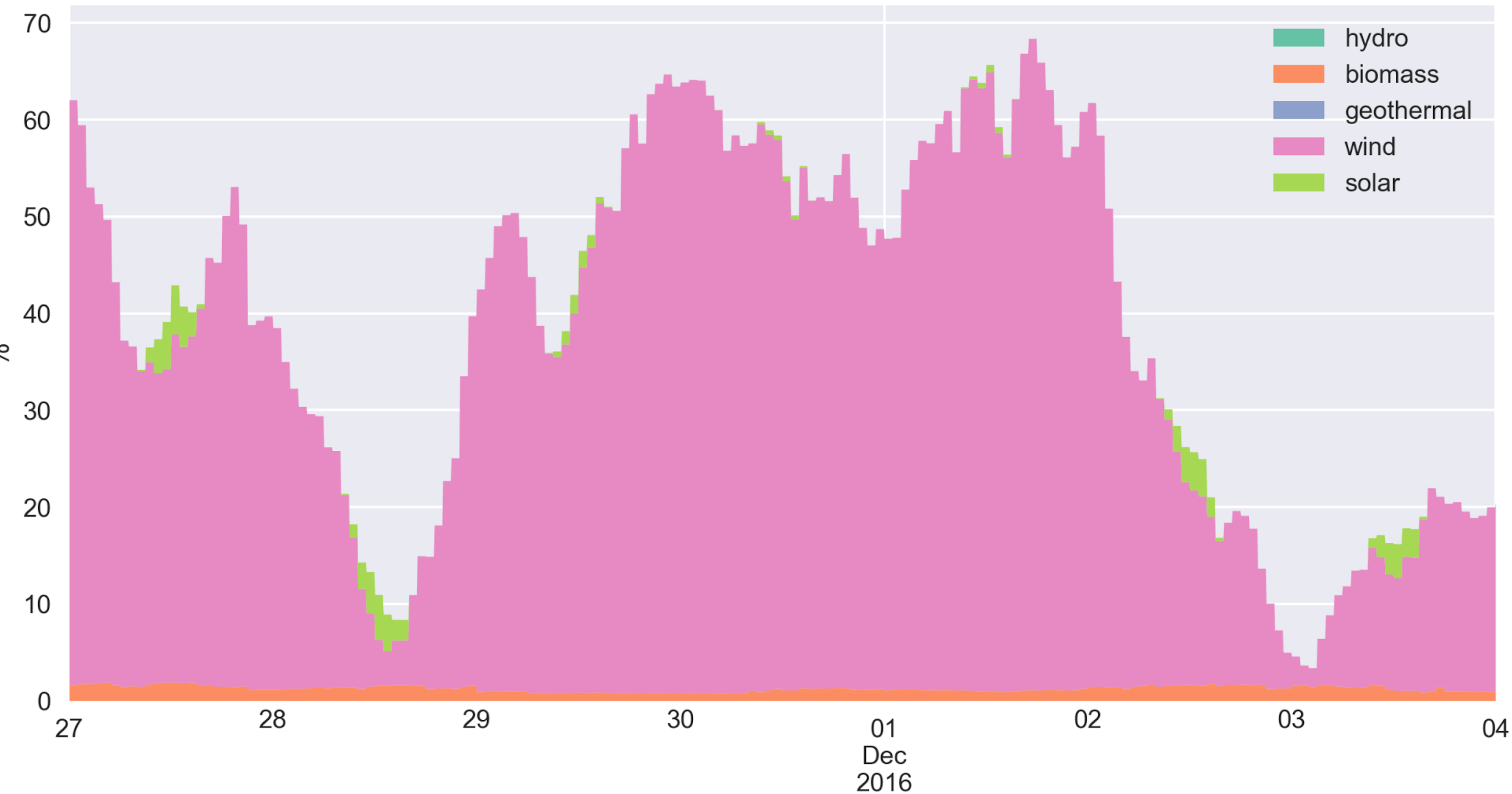
Case study No. 3

Control of heat pumps for swimming pools (CO2 minimization)

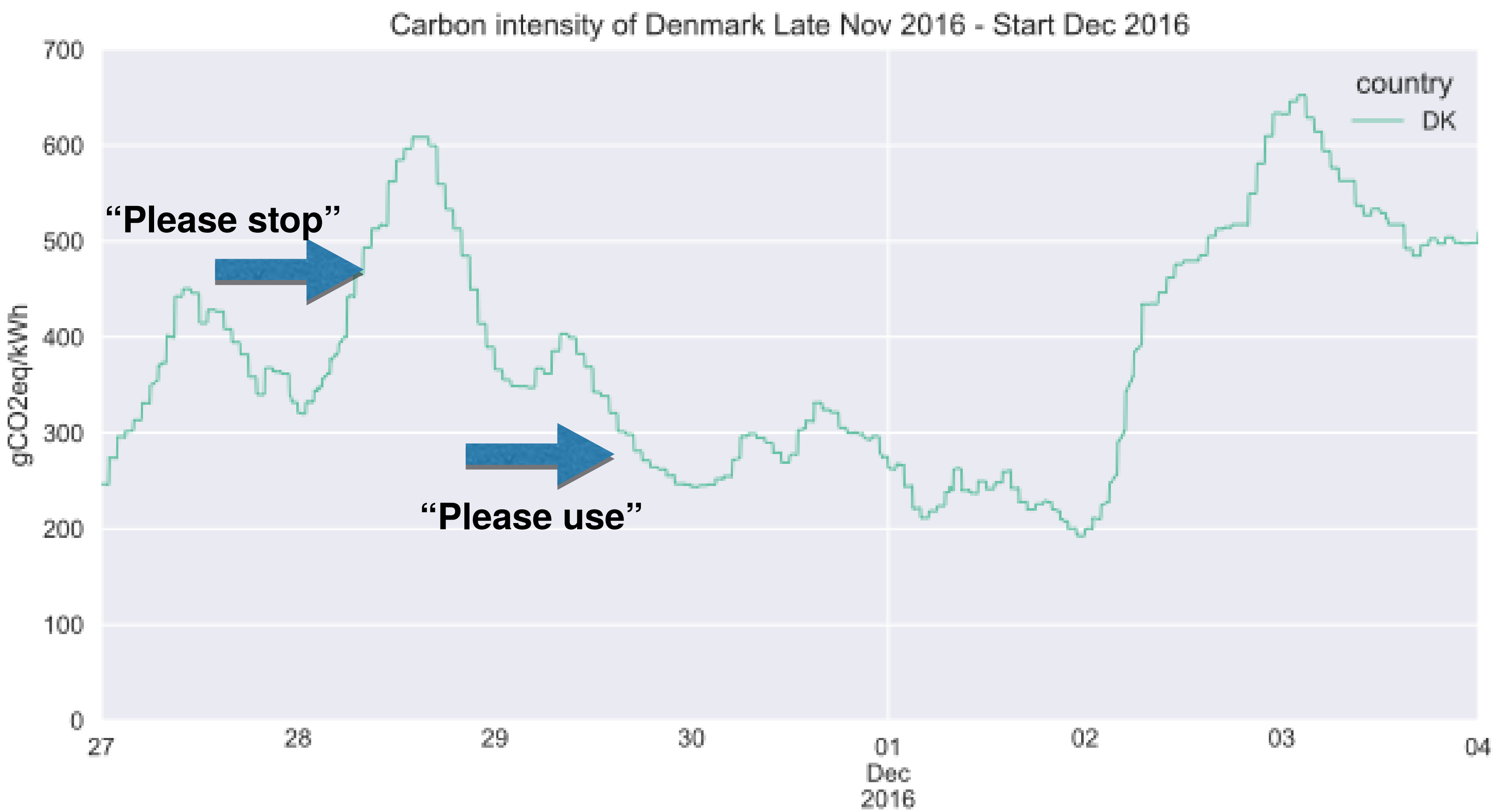
Lyngby-Taarbæk Vidensby, November 2017


January 25, 2017 UTC+01:00
8:01 AM
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
A PROJECT BY
Tomorrow
Like
Follow
Carbon intensity (gCO2eq/kWh)
0 50

Share of electricity originating from renewables in Denmark Late Nov 2016 - Start Dec 2016



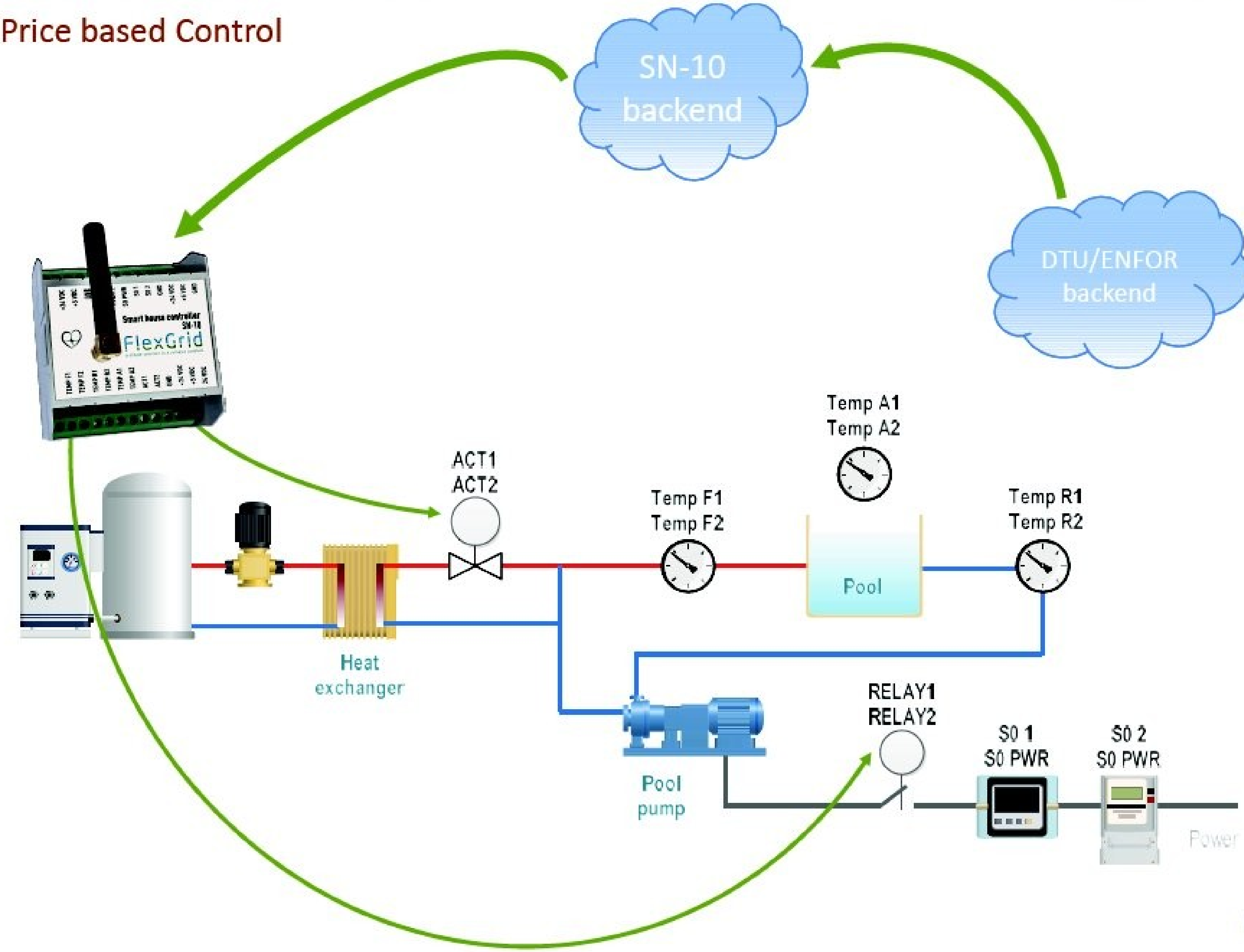
Source: pro.electicitymap.



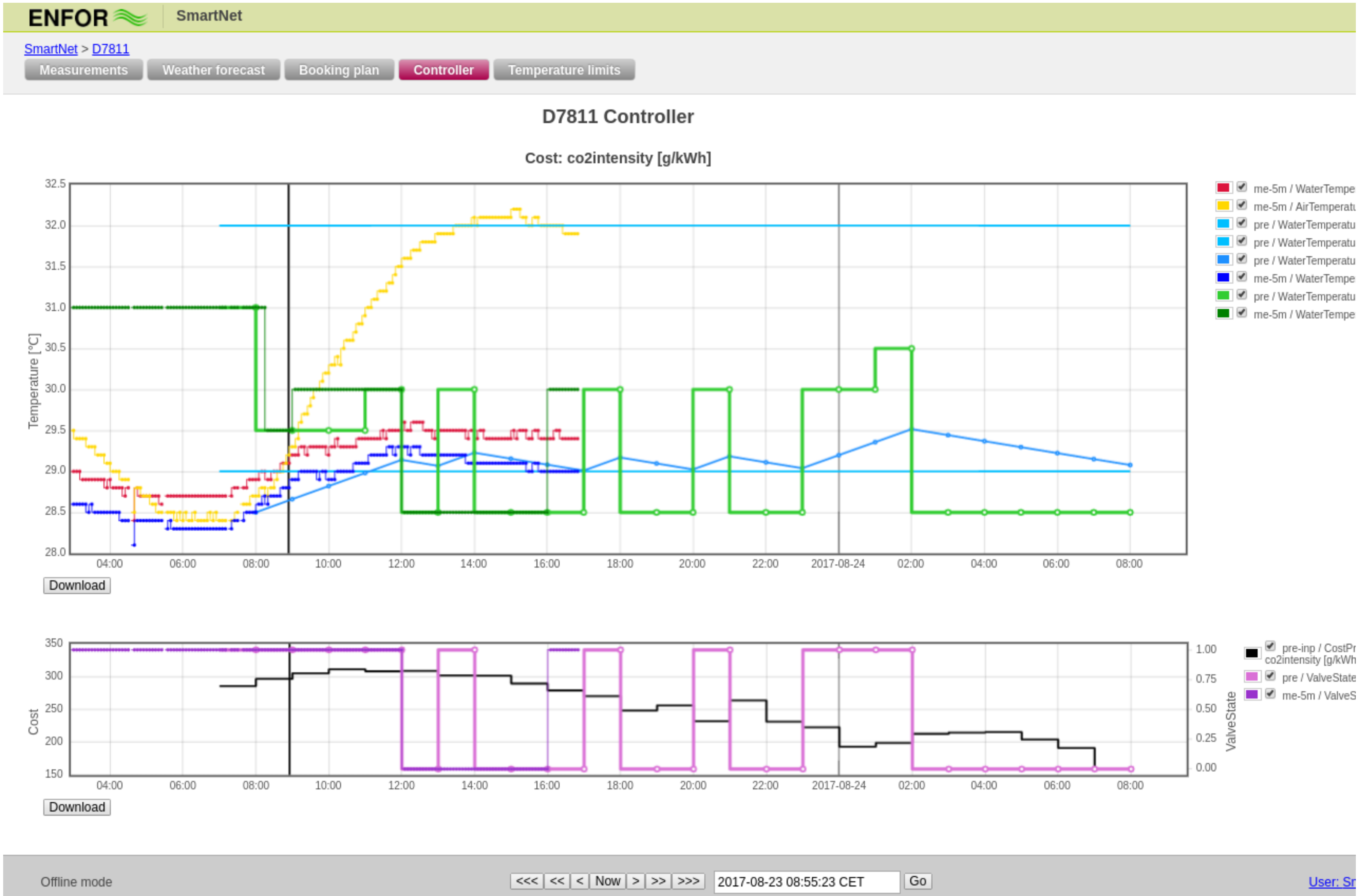
Source: pro.electicitymap.

How does it work?

Price based Control



Example: CO2-based control



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Centre for IT-Intelligent Energy Systems in cities

Demo projects | Software solutions | Work Packages | Partners | Events | Communications | Publications | Vacant positions | Contacts

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 at GitHub.

Search ...

Latest news

Ambassador Louise Bang Jespersen visited CITIES, October 29th 2015

CITIES Korean International Workshop – KIER, Daejeon, Korea, October 22nd 2015

Workshop on Mathematical Sciences Collaboration in Energy Systems Integration – DTU, Innovation Fu

CITIES INNOVATION CENTER

Integrated energy systems powered by intelligent data

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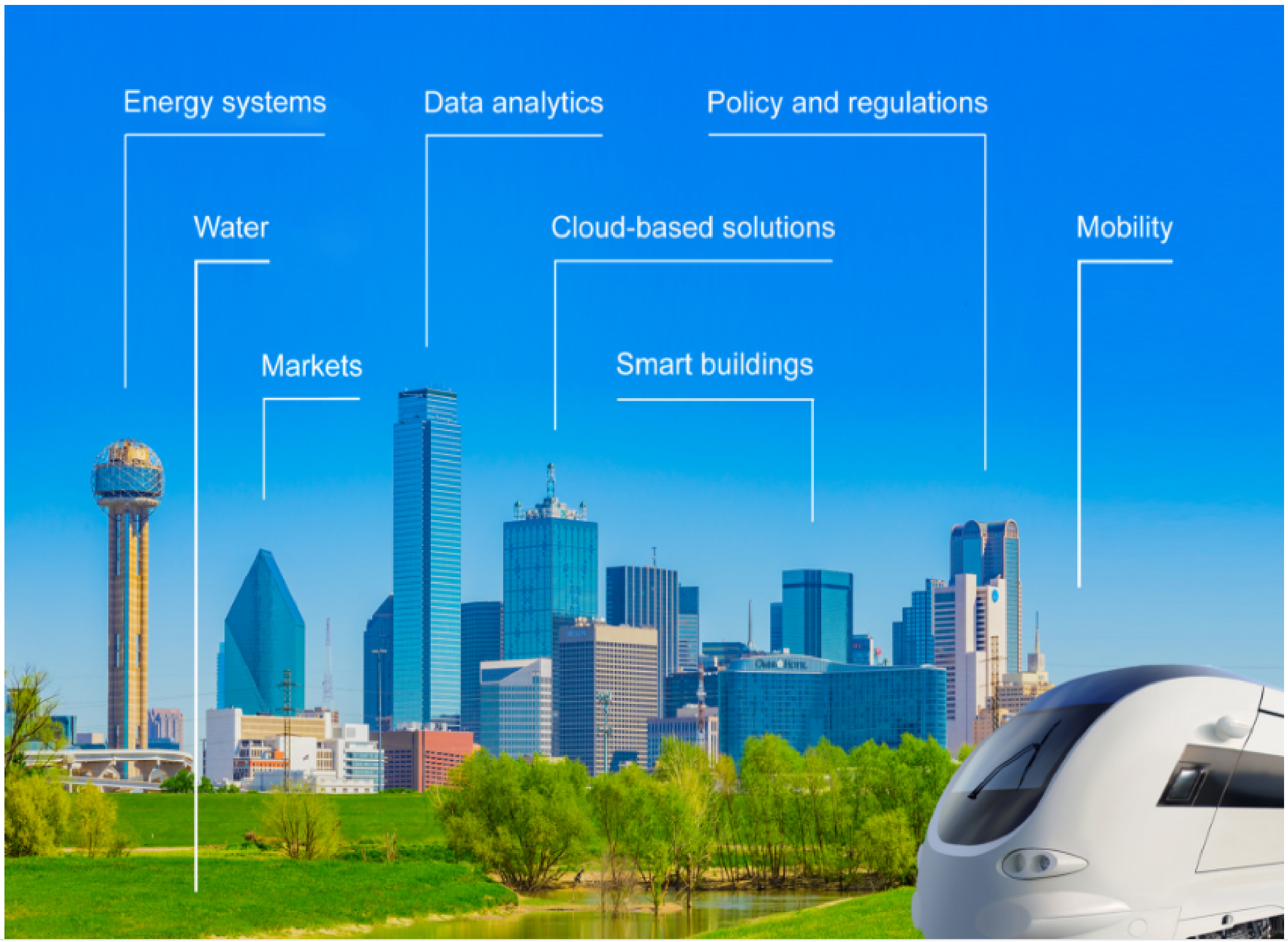
Topics



Some Smart Cities Collaborators

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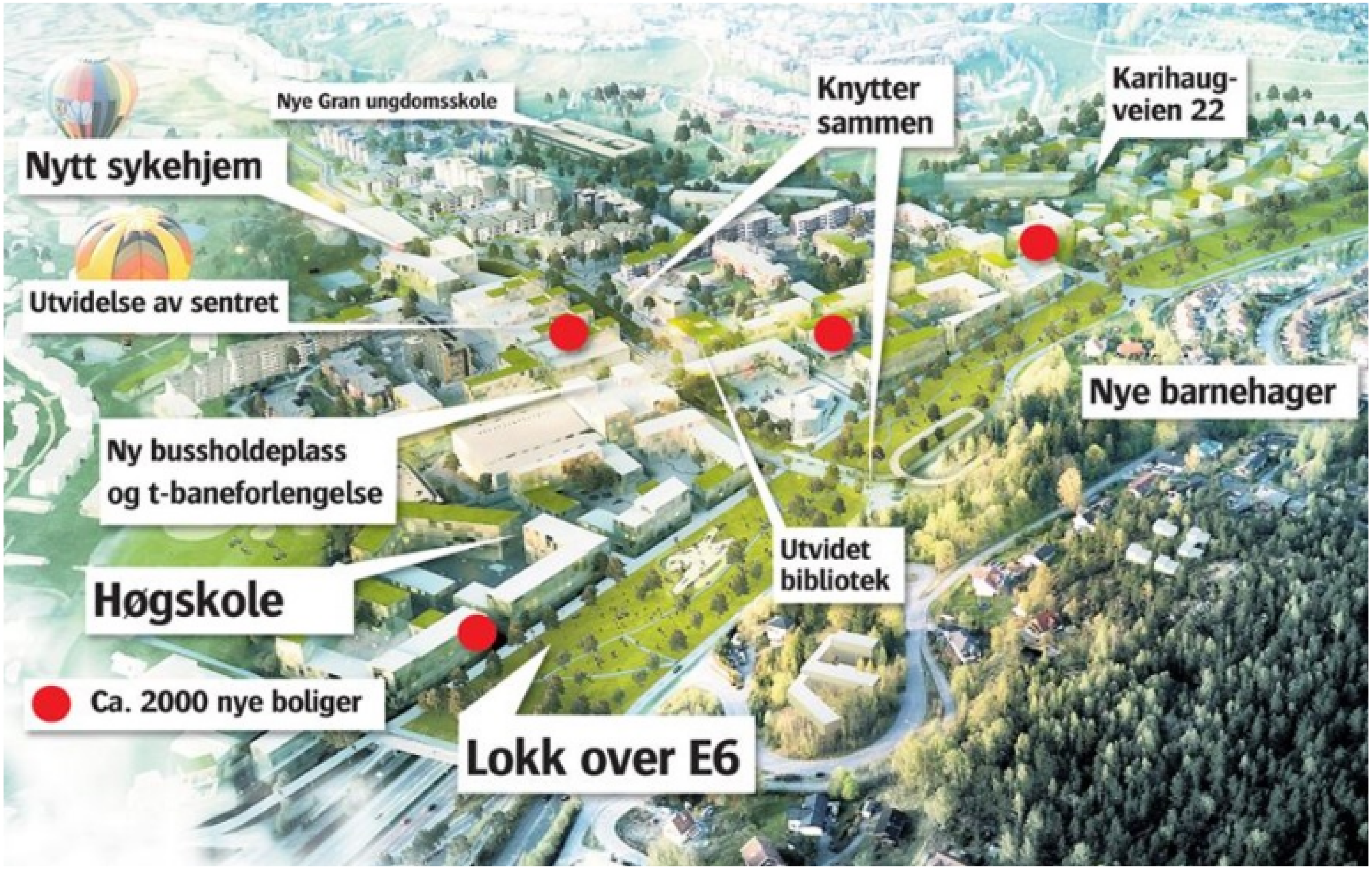
Oslo Municipality: Furuset



The project will include building upgrades and new builds, a smart thermal micro-grid and both public and private actors.

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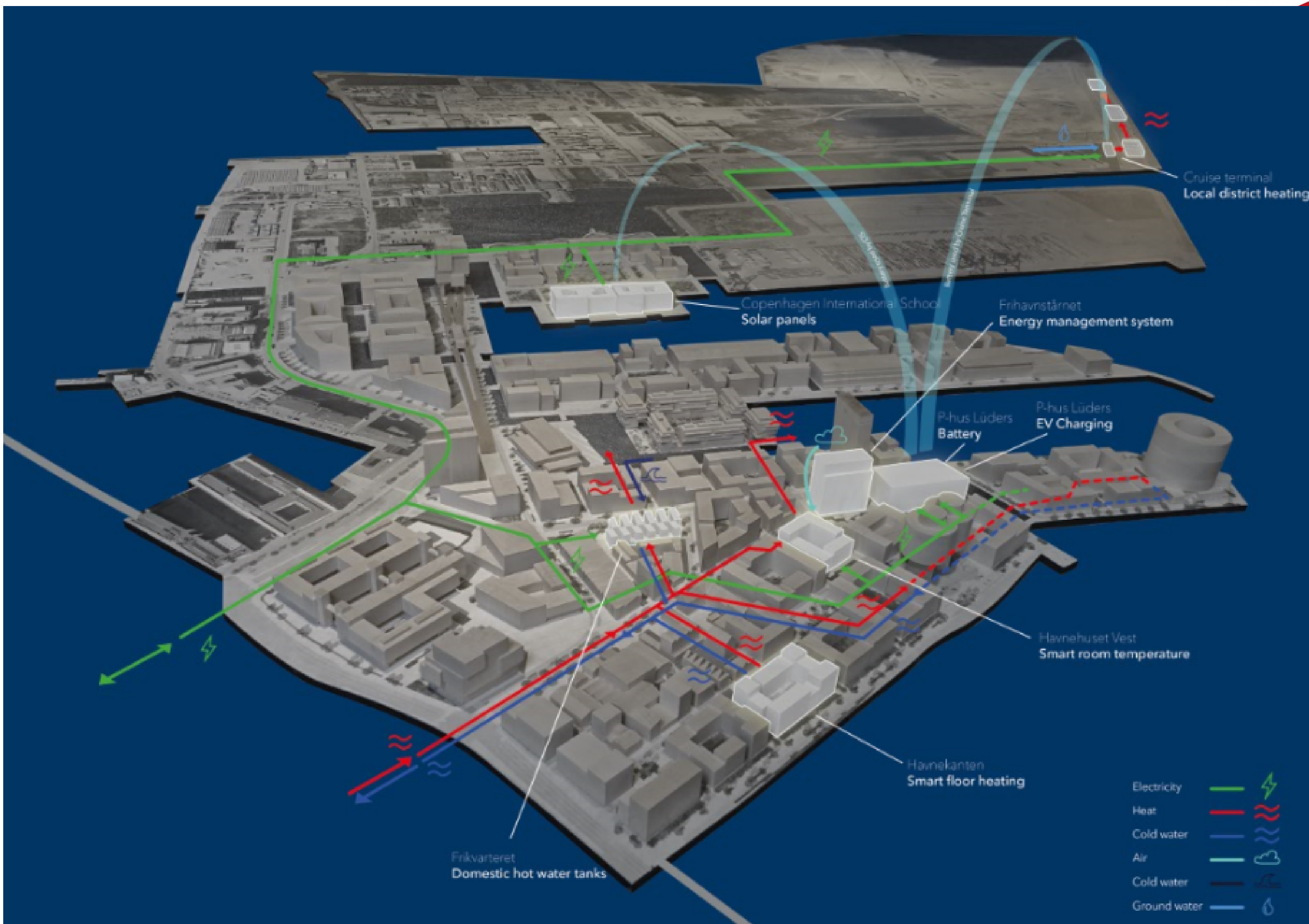
EnergyLab Nordhavn

DTU



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Media

For media inquiries, use our contact form for fastest response. If you are writing about our Youth-Led Tech program, contact Interim Executive Director Kyla Williams at (312) 565-2933 or kwilliams@cct.org

Here's the Smart Chicago logo in jpg and eps formats.

The name of the organization is "Smart Chicago Collaborative" ("Smart Chicago" for short). It's never abbreviated to "SCC".

Here are hundreds of photos of the work we do: Civic User Testing Group, OpenGov Chicago meetups, Connect Chicago meetups, hackathons, and #CivicSummer. All of these photos are licensed as Creative Commons— free for you to use for any purpose, with attribution.

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Elverum Municipality: Ydalir

A new neighbourhood that will include approximately 1000 homes will be developed over a 10-15 year period. A school and kindergarten will be built in the neighbourhood. Elverum tomteselskap is the property owner. Plans for the area include the extensive use of wood, and smart mobility.

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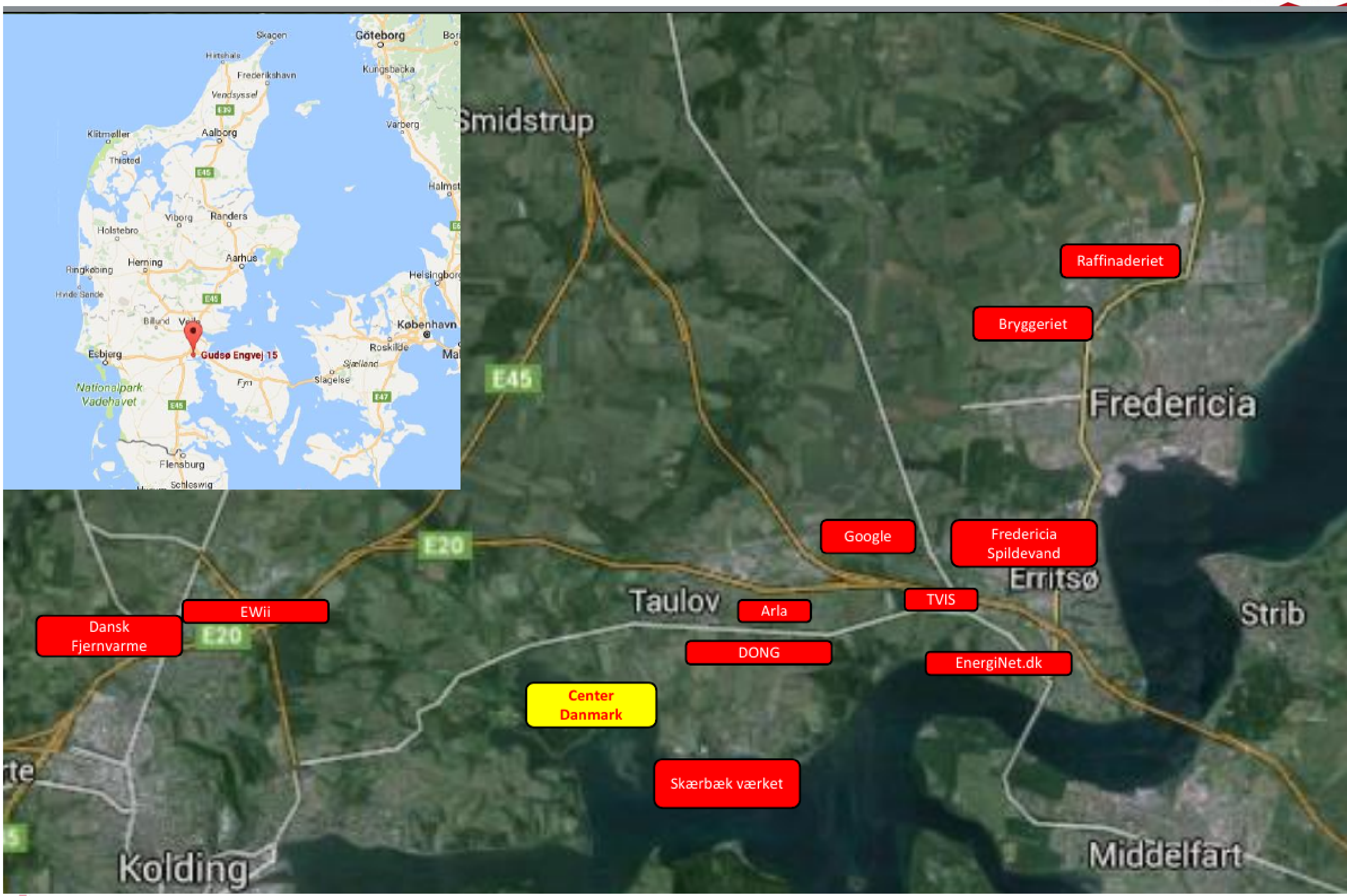
Testcenter Denmark

DTU



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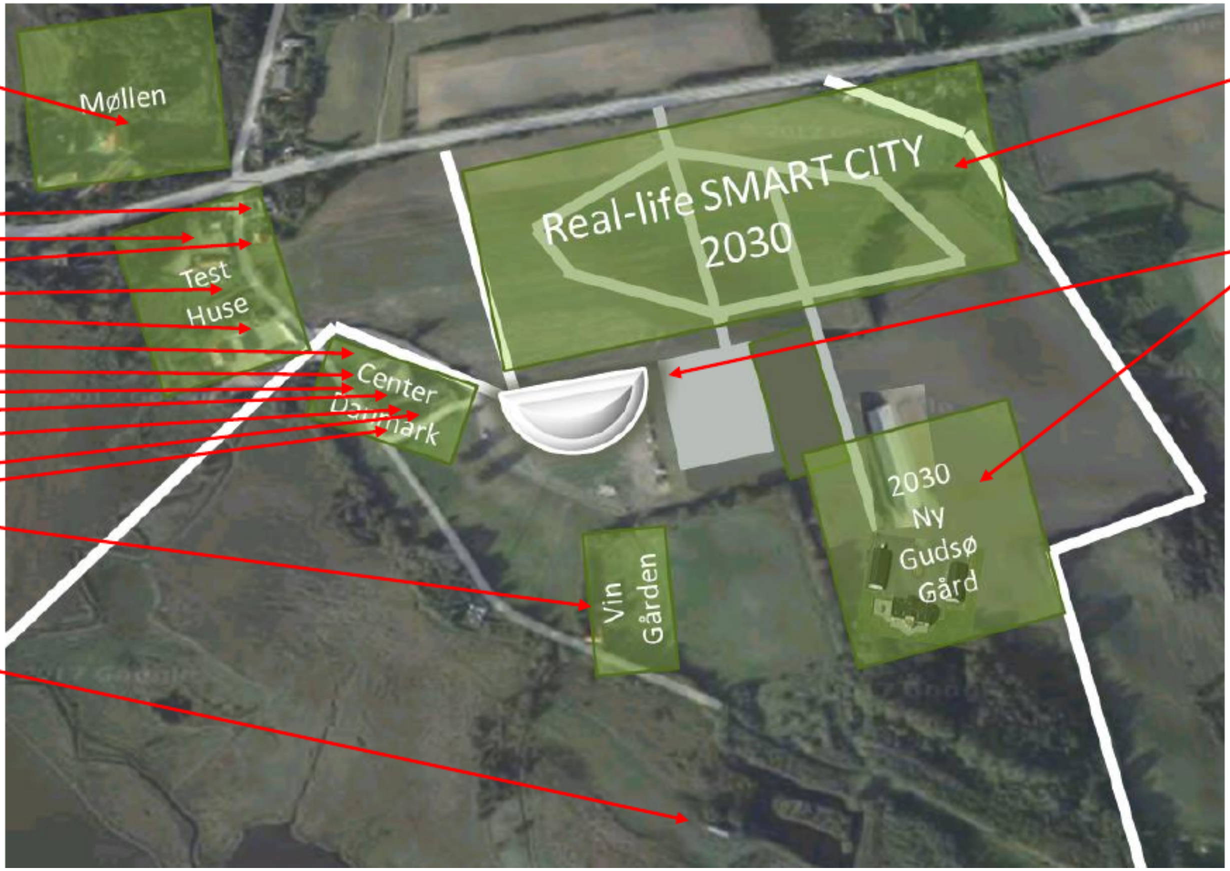
Test i et mini samfund beliggende på 40 Hektar naturgrund

- 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

Summary

- A procedure for data intelligent control of power load, using the Smart-Energy OS (SE-OS) setup, is suggested.
- Built on ICT solutions, Cloud Computing, Edge Computing, IoT, IoS, DMS, Forecasting and Control
- Energy communities, Blockchain, Transactive Energy, Agents
- The SE-OS controllers can focus on
  - Peak Shaving
  - Smart Grid demand (like ancillary services needs, ...)
  - Energy Efficiency
  - Cost Minimization
  - Emission Efficiency
- We have demonstrated a large potential in Demand Response. Automatic solutions, and end-user focus are important
- We see large problems with the tax and tariff structures in many countries (eg. Denmark).

For more information ...

See for instance

www.smart-cities-centre.org

...or contact

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

Acknowledgement - DSF 1305-00027B

Further Aspects

Some references

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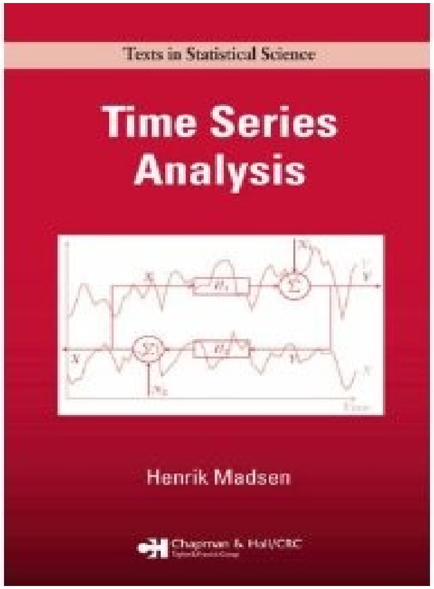
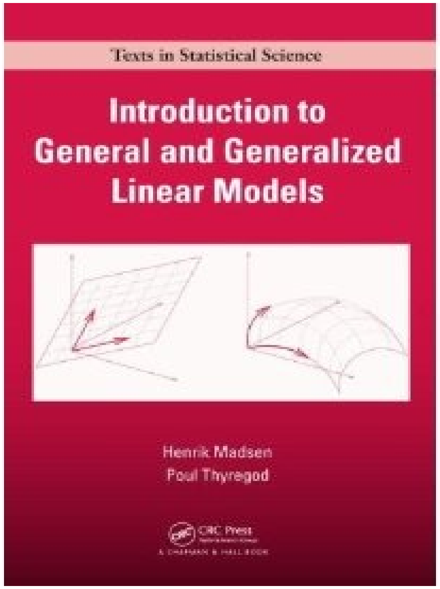
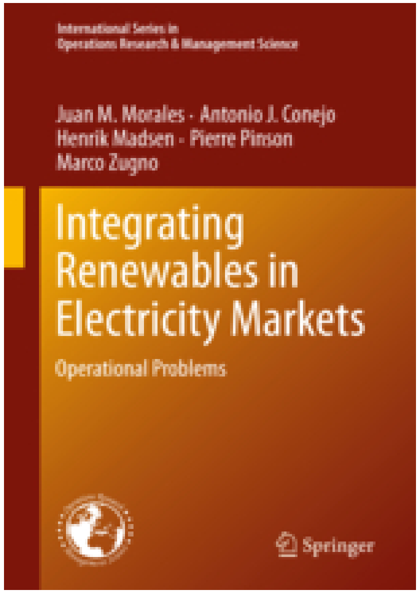
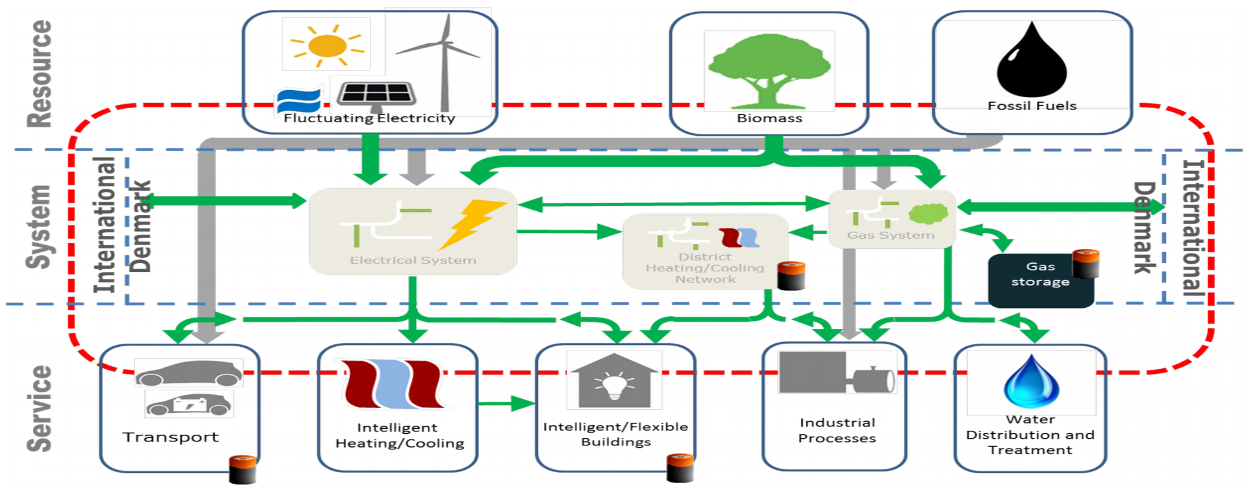
Some 'randomly picked' books on modeling ....







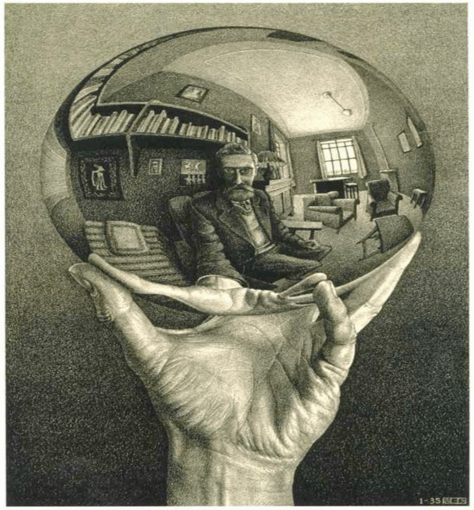
(Virtual) Storage Solutions



- **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

Understanding Energy Flexibility
Some Demo Projects in CITIES:

- Control of WWTP (ED, Kruger, ..)
- Heat pumps (Grundfos, ENFOR, ..)
- Supermarket cooling (Danfoss, TI, ..)
- Summerhouses (DC, ENDK, Nyfors, ..)
- Green Houses (NeoGrid, ENFOR, ….)
- CHP (Dong Energy, EnergiFyn, …)
- Industrial production
- EV (Eurisco, Enfor, …)
- ………….



Characteristics

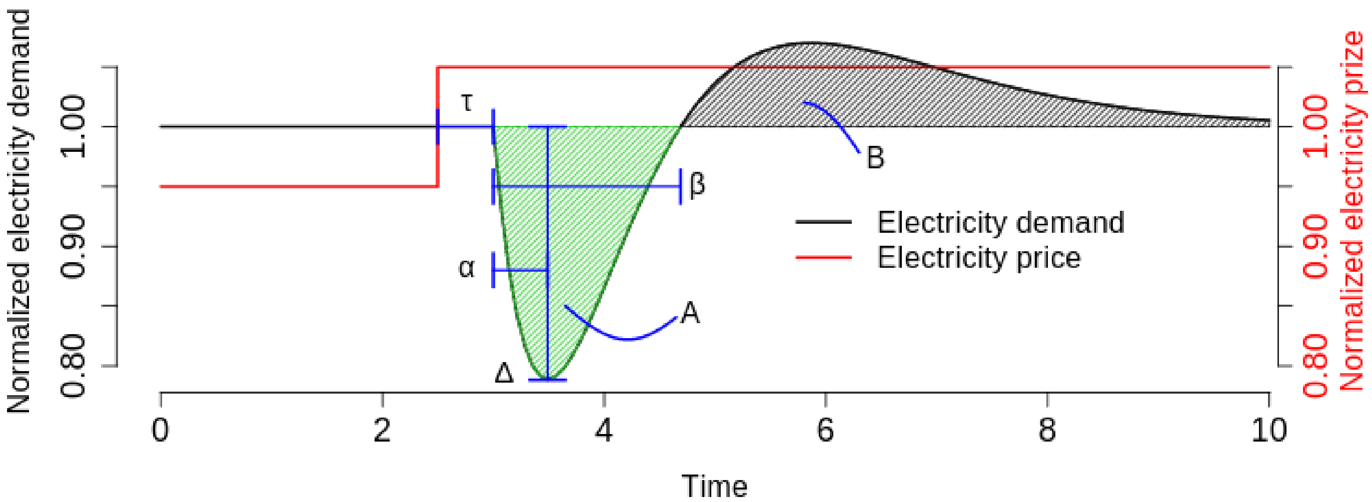


Figure 4: Six characteristics of the demand response to a step increase in electricity price. τ: The delay from adjusting the electricity prize and seeing an effect on the electricity demand, equal to approximately 0.5 here. Δ: The maximum change in demand following the price change, in this case close to 0.2. α: The time it takes from the change in demand starts until it reaches the lowest level, approximately equal to 0.5 here. β: The total time of decreased electricity demand, roughly equal to 2 here. A: The total amount of decreased energy demand, given by the green-shaded area. B: The total amount of increased energy demand, given by the grey-shaded area.

Innovation Fund Denmark

Labelling proposal

for energy, price and emission based labelling

DTU

The test consists of the following steps:

1. Let λ_t be the price of electricity at time t.
2. Simulate the control of the building *without considering* the price, and let u_t^0 be the electricity consumption at time t.
3. Simulate the control of the building *considering* the price, and let u_t^1 be the electricity consumption at time t.
4. The total operation cost of the price-ignorant control is given by $C^0 = \sum_{t=0}^{N} \lambda_t u_t^0$.
5. Similarly the operation cost of the price-aware control is given by $C^1 = \sum_{t=0}^{N} \lambda_t u_t^1$.
6. $1 - \frac{C^1}{C^0}$ is the result of the test, giving us the fractional amount of saved money.

This test is inspired by minimizing total costs for varying electricity prices, but in general λ_t could just represent ones desire to reduce electricity demand at time t.

Flexibility Represented by Saturation Curves

(for market integration using block bids)