Use of Flexibility in Future Intelligent and Integrated Energy Systems

Henrik Madsen

Dept. Appl. Mathematics and Computer Science, DTU

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

http://www.henrikmadsen.org

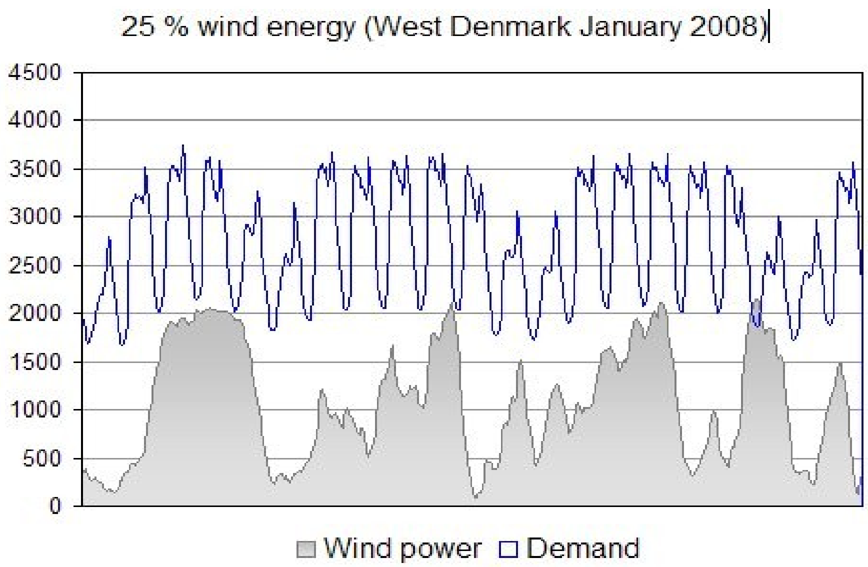
CITIES Centre for IT Intelligent Energy Systems

DI – Meeting, September 5th, 2017

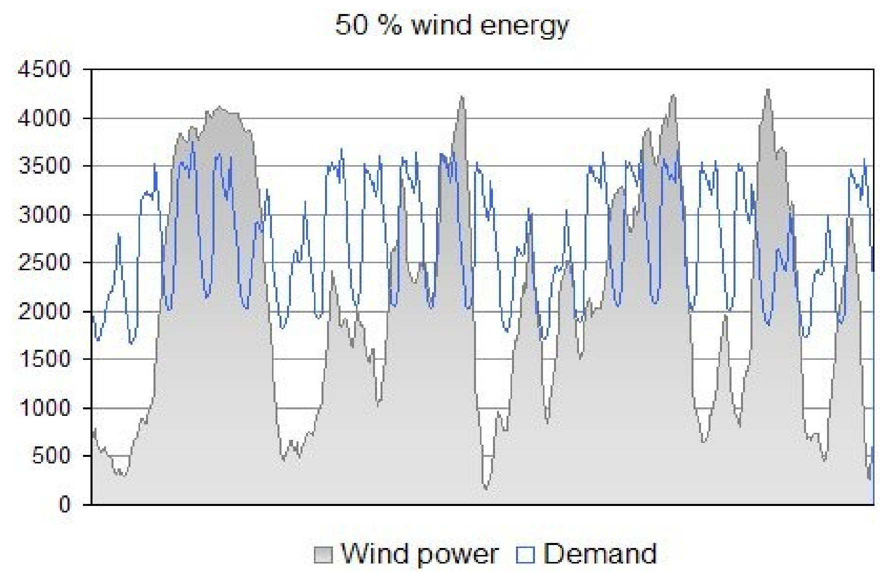
Innovation Fund Denmark

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)



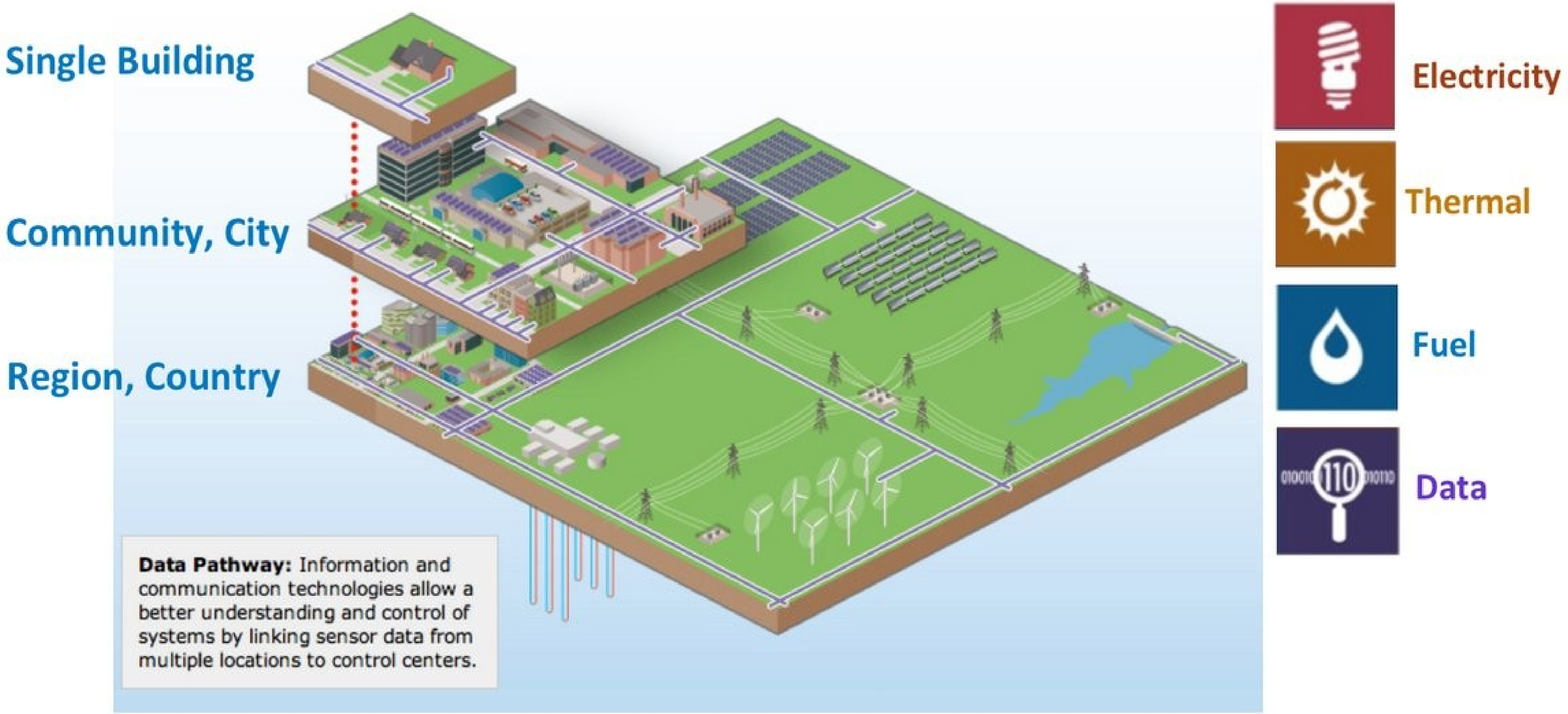
In the first half of 2017 more than 44 pct of electricity load was covered by wind power.

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

Energy Systems Integration

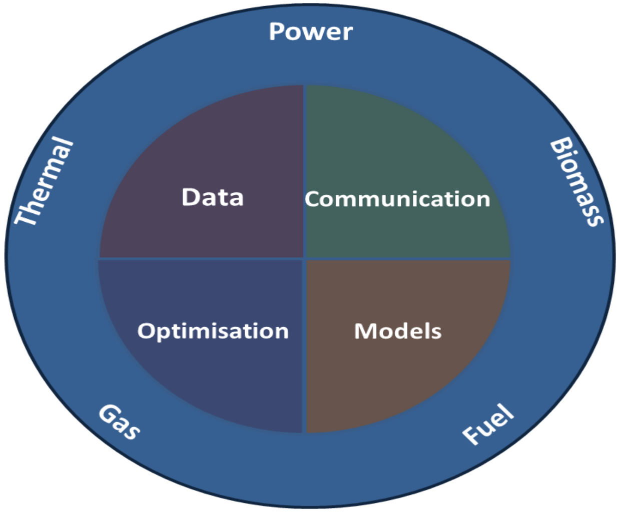
Energy system integration (ESI) = the process of optimizing energy systems across multiple pathways and scales



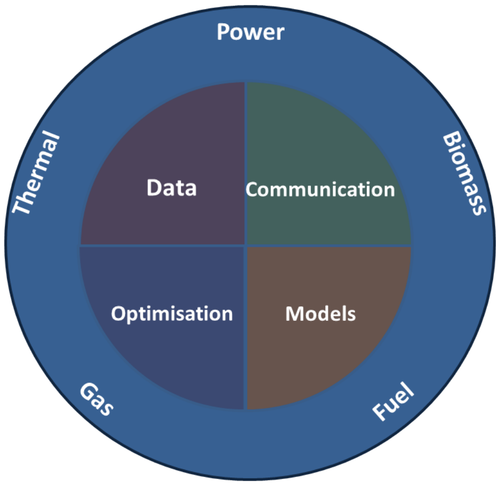
Flexible Solutions and CITIES

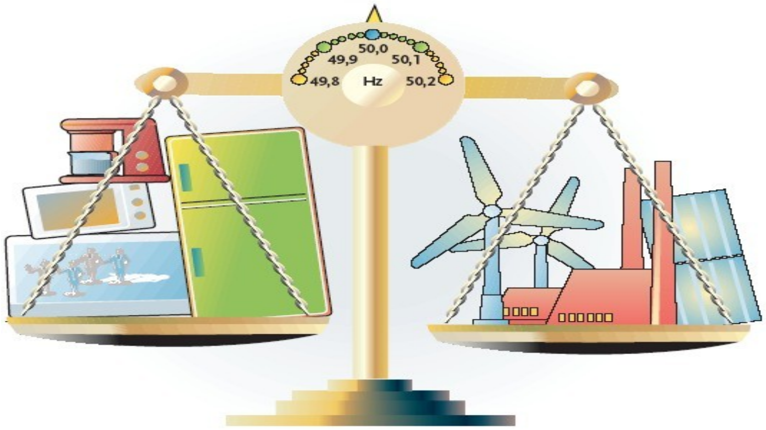
Center for IT-Intelligent Energy Systems in Cities (CITIES) is aiming at establishing methodologies and solutions for design and operation of integrated electrical, thermal, fuel pathways at all scales.

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** 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.

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

Existing Markets - Challenges

- Dynamics
- Stochasticity
- Nonlinearities
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, ...)
- Speed / problem size
- Characterization of flexibility
- Requirements on user installations

Challenges (cont.)

Preparatory study on Smart Appliances

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 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).

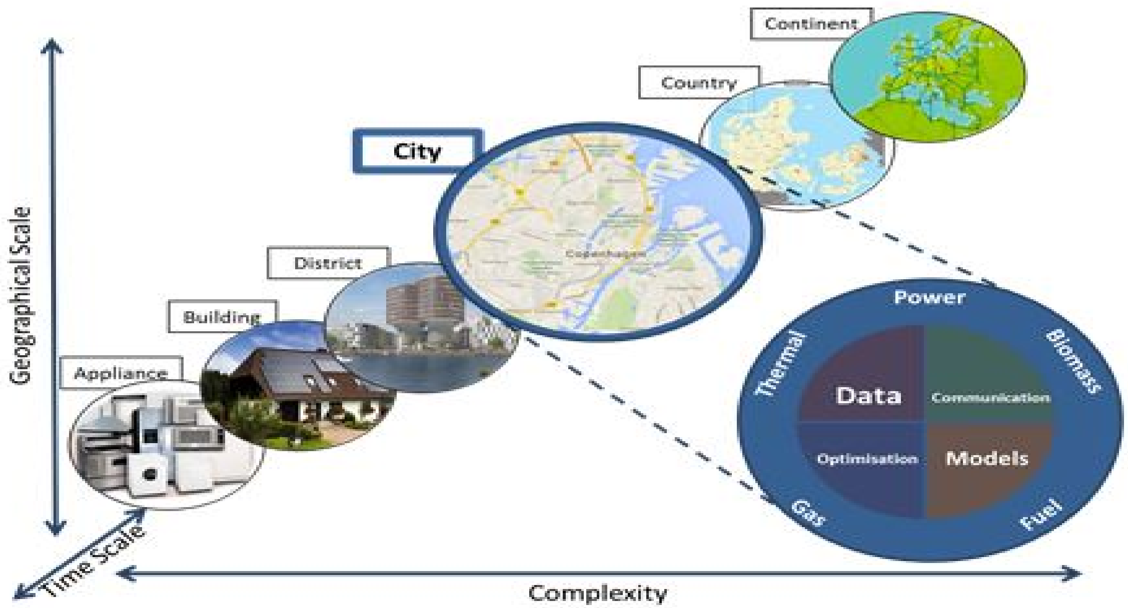
An executive summary of the project results can be downloaded here.

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

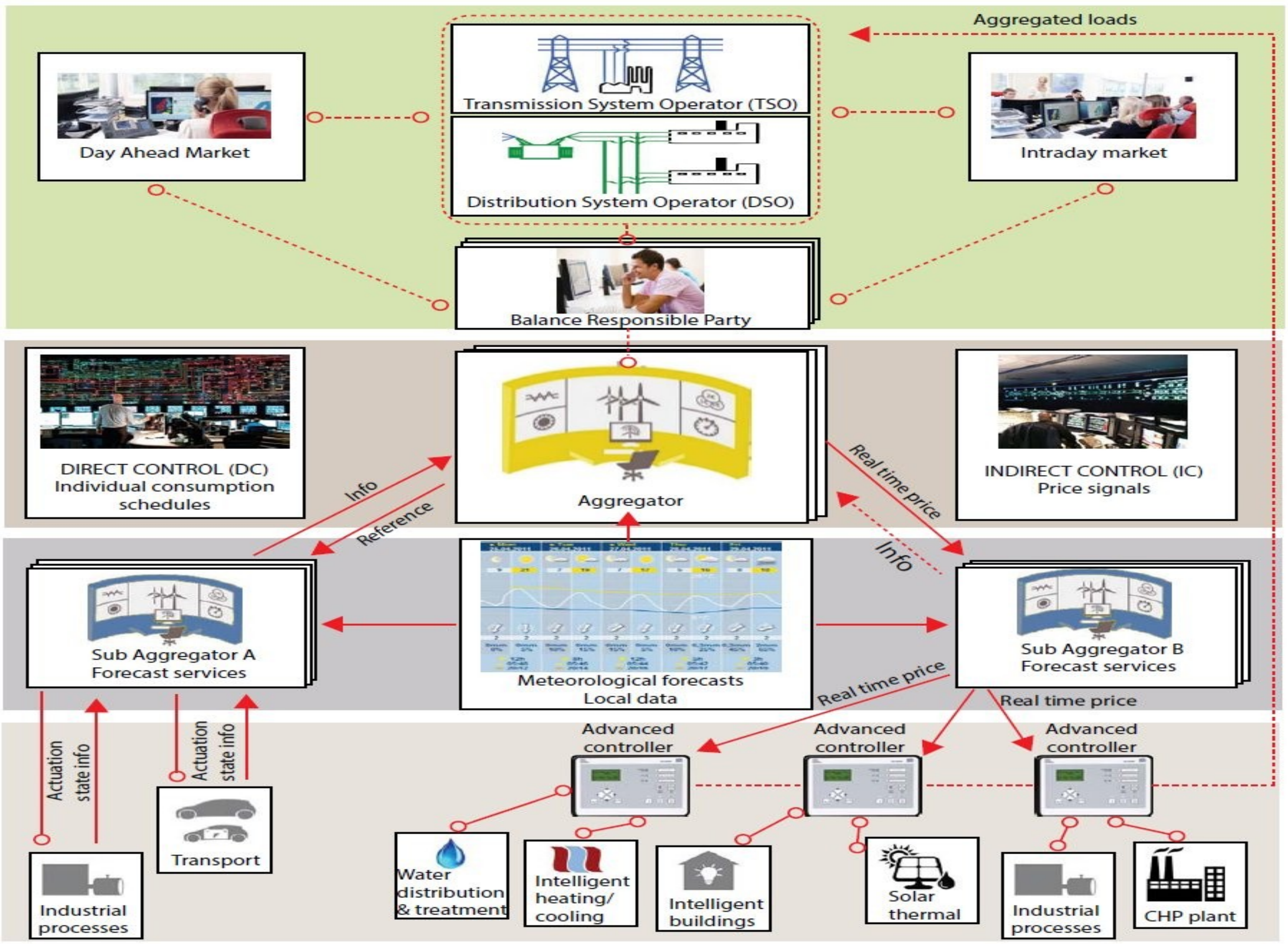
- Chargers for electric cars: technical potential and other relevant issues in the context of demand response.
- The modelling done in the framework of MEErP Task 6 and 7 will be updated with PRIMES data that recently became available, and with the EEA-countries.
- The development and assessment of policy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

Temporal and Spatial Scales

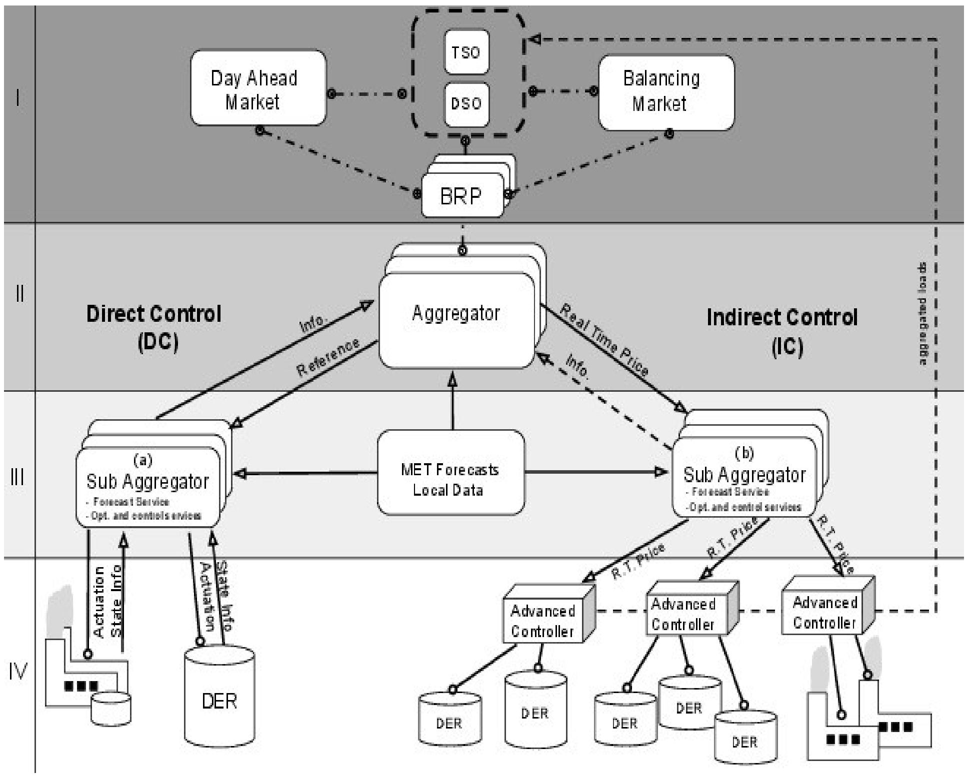
The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems*** at **all scales**.



Smart-Energy OS



Control and Optimization



In New Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

Day Ahead:

Stoch. Programming based on eg. Scenarios

Cost: Related to the market (one or two levels)

Direct Control:

Actuator: **Power**

Two-way communication

Models for DERs are needed

Constraints for the DERs (calls for state est.)

Contracts are complicated

Indirect Control:

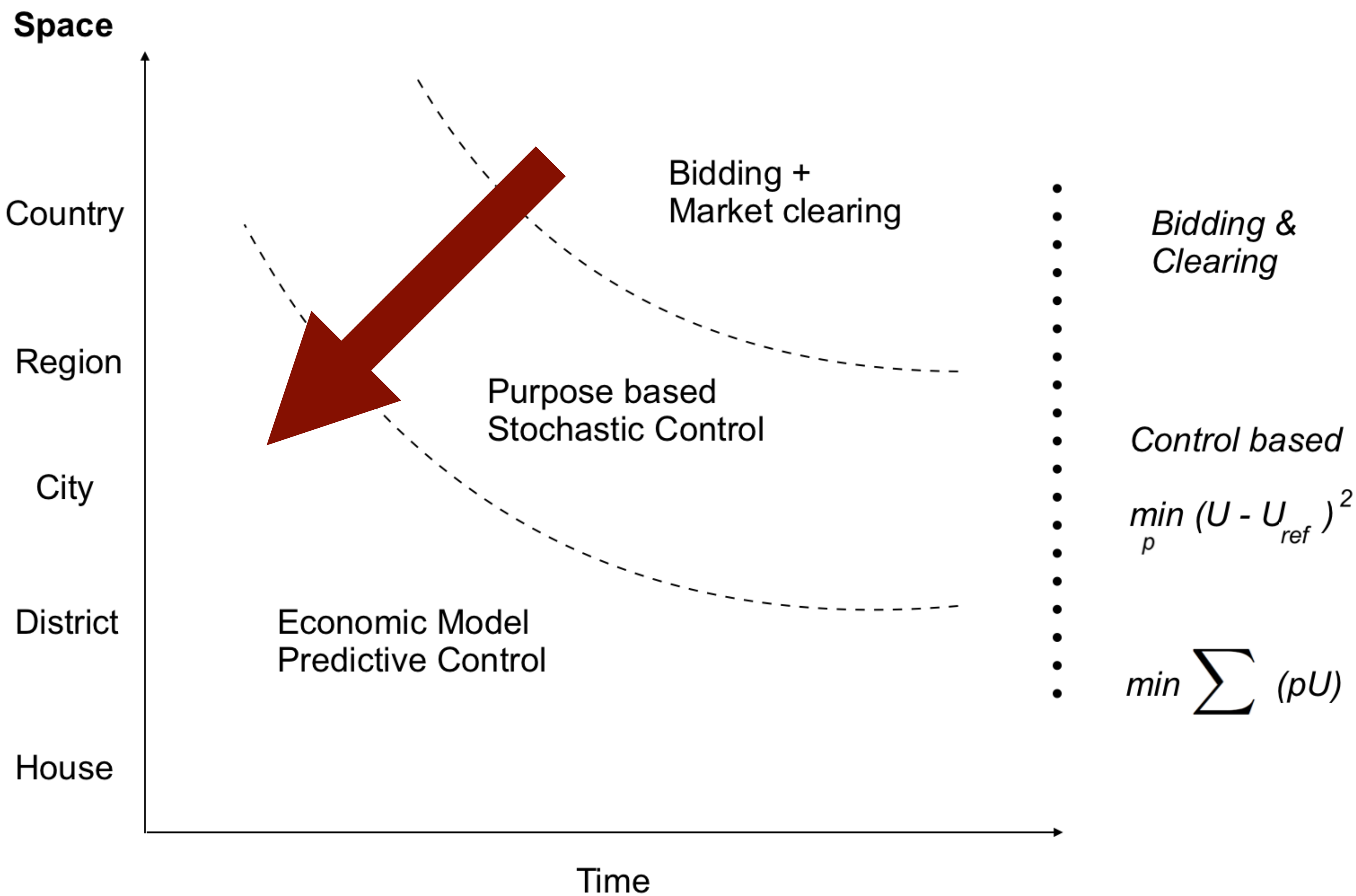
Actuator: **Price**

Cost: E-MPC at **low (DER) level**, One-way communication

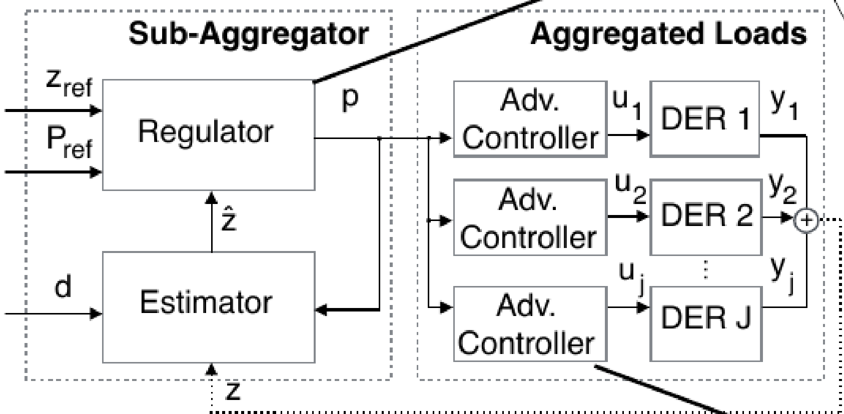
Models for DERs are not needed

Simple 'contracts'

The ‘market’ of tomorrow



Proposed methodology
Control-based methodology



$$\min_{p} \quad \mathrm{E}\Big[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||\Big]$$

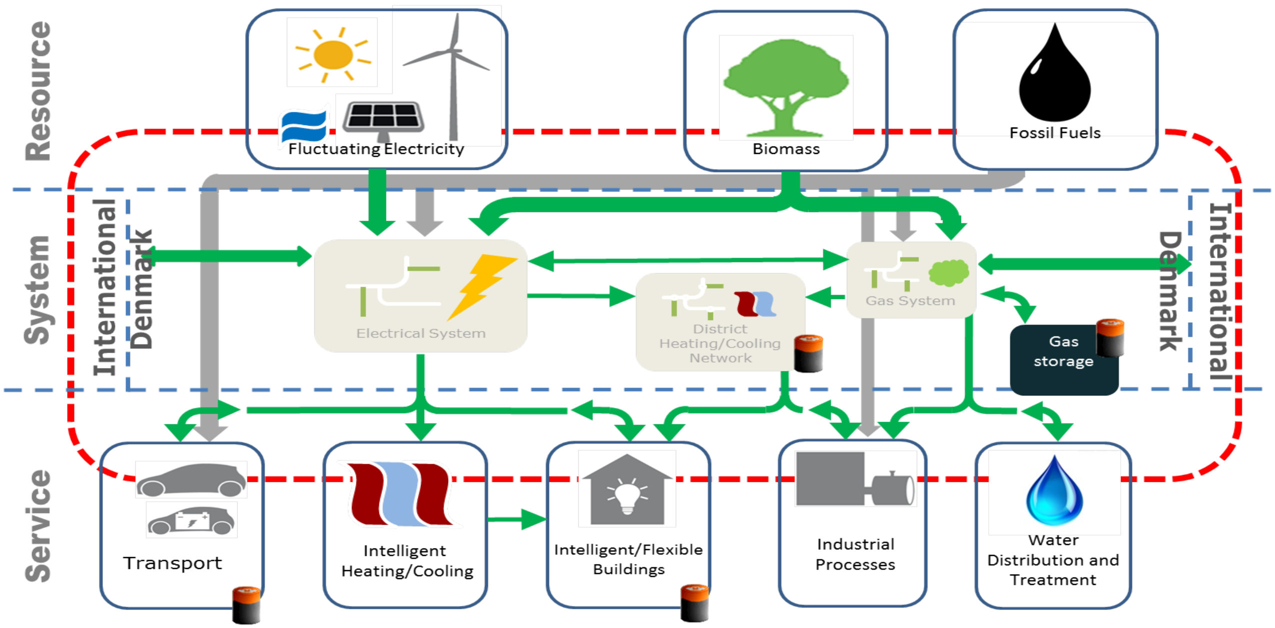
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$

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

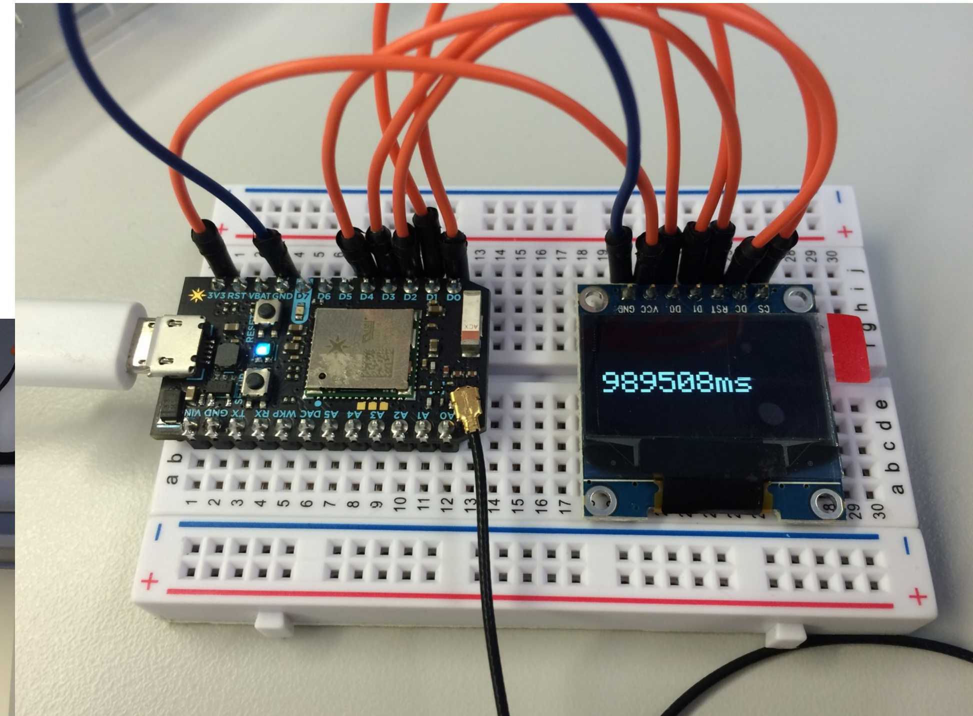
We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

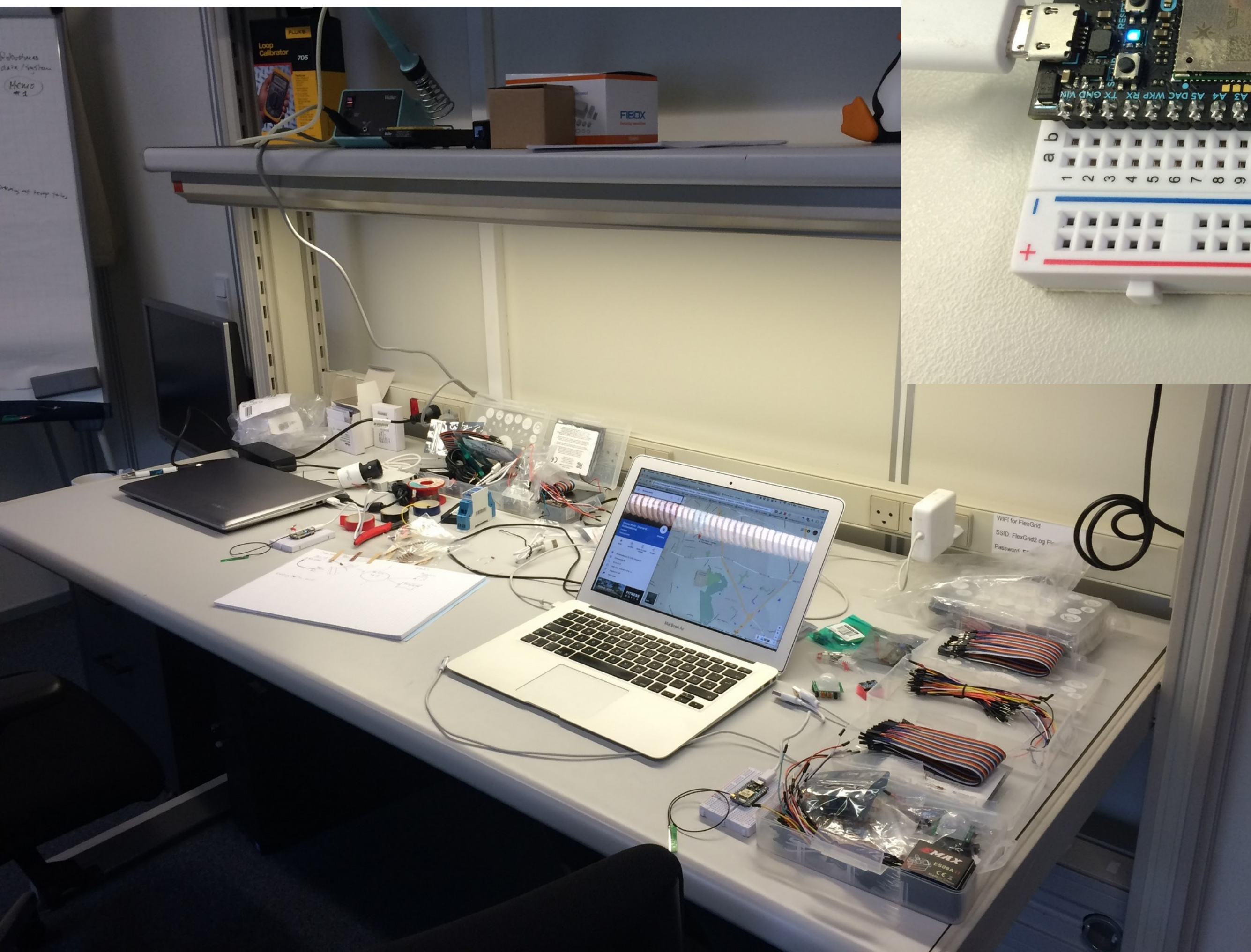
Models for systems of systems

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

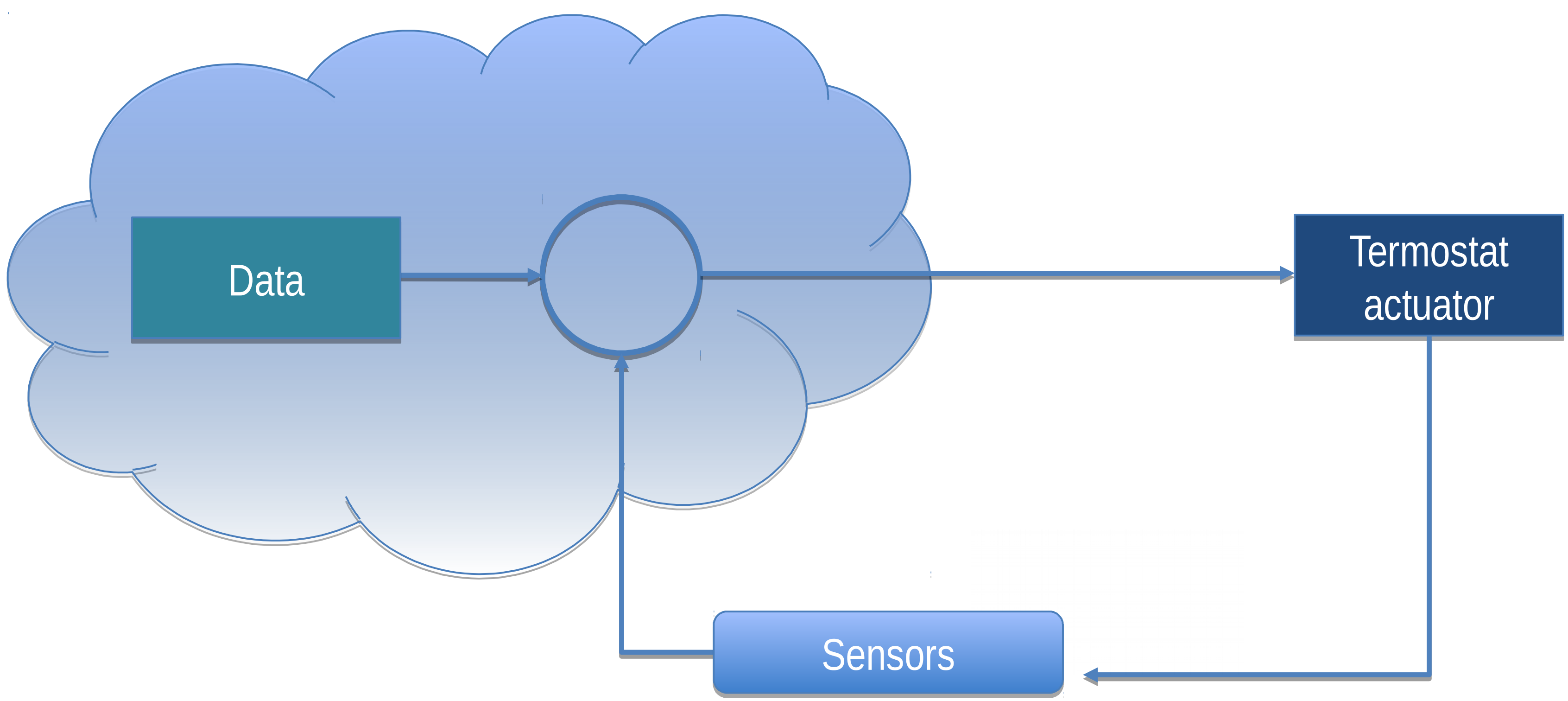


Lab testing ….

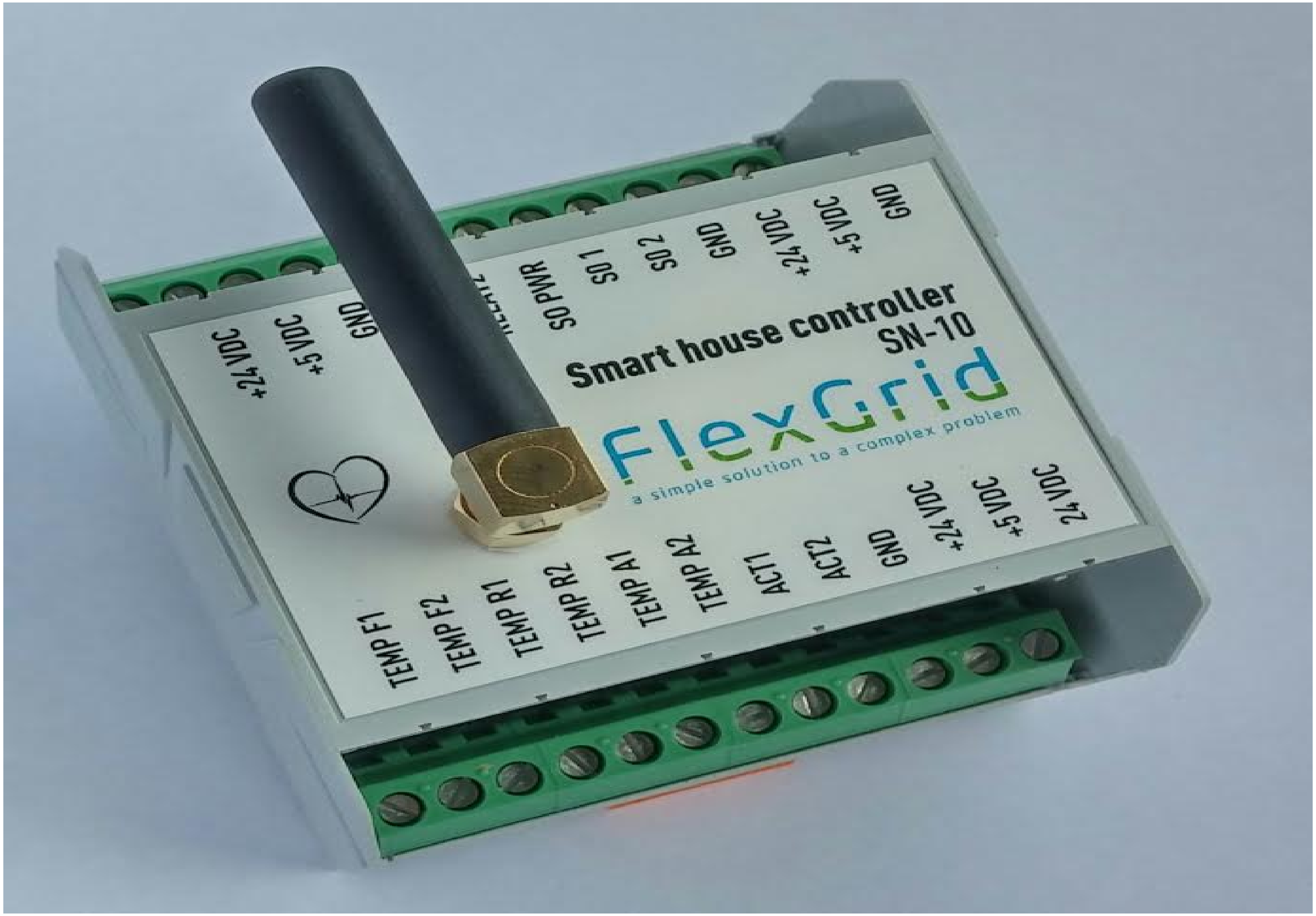




SE-OS
Control loop design – **logical drawing**

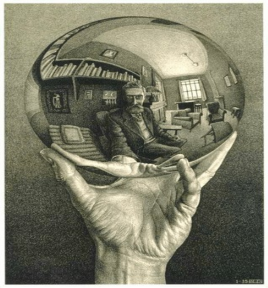


SN-10 Smart House Prototype



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



DTU

Case study No. 1

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

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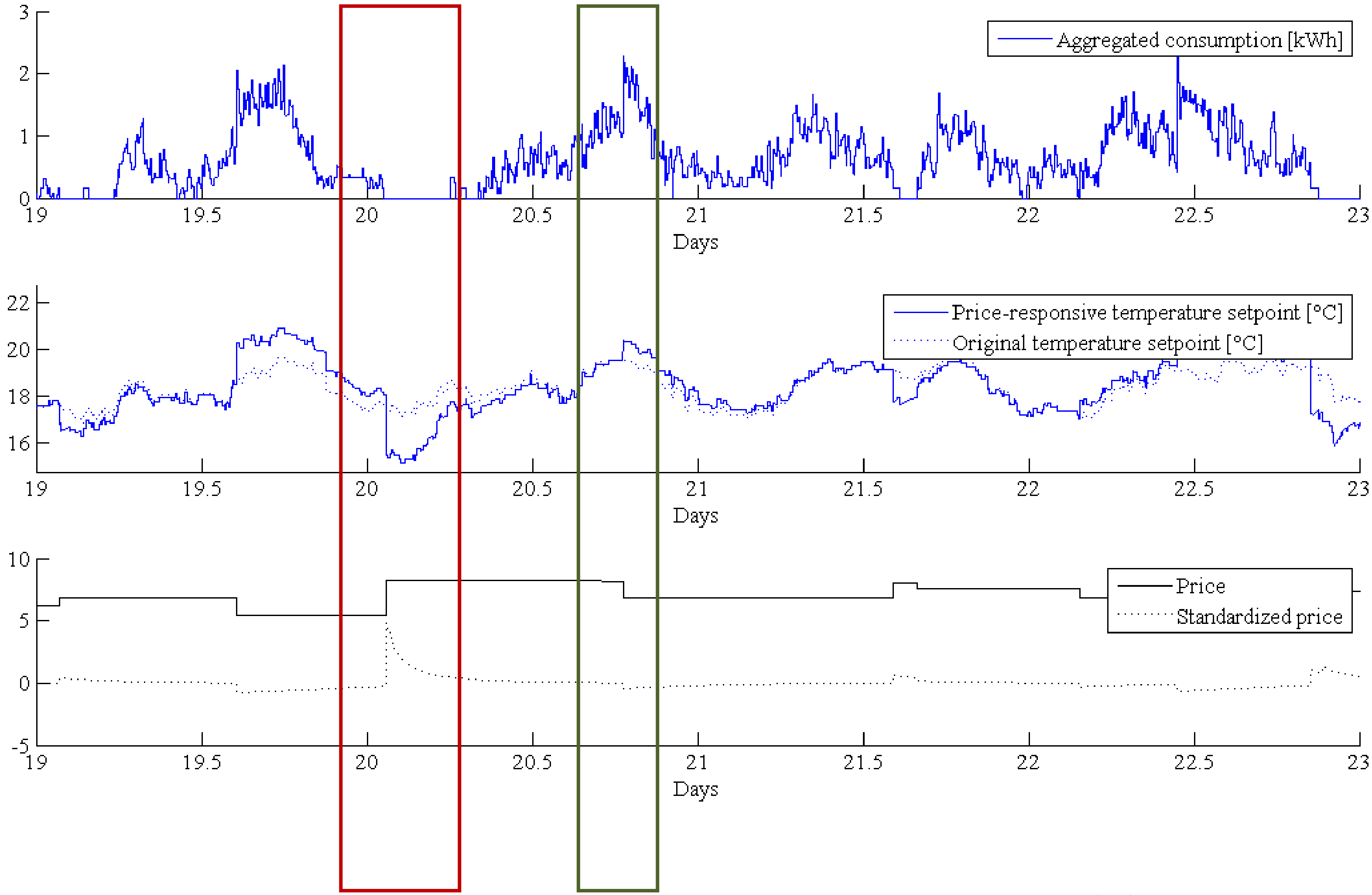
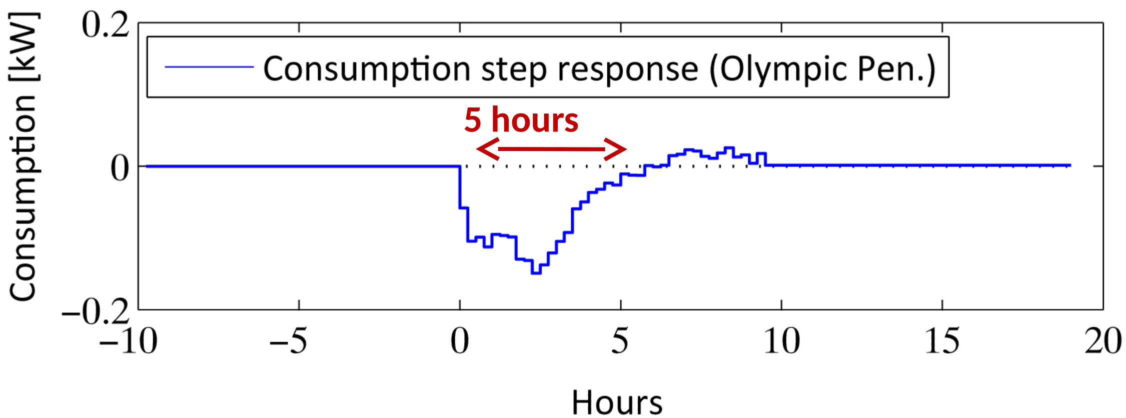
Aggregation (over 20 houses)

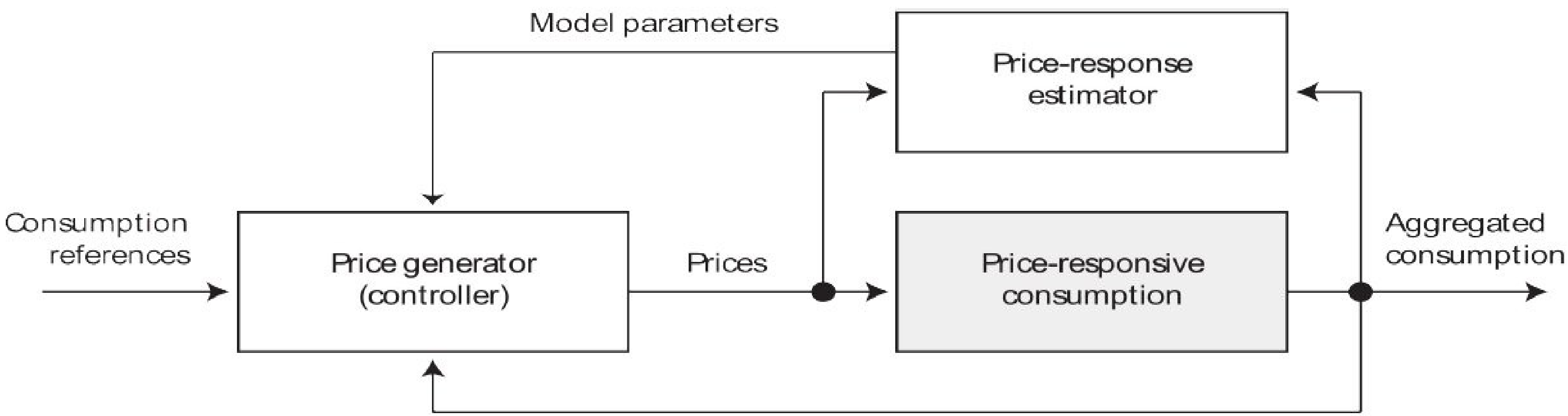


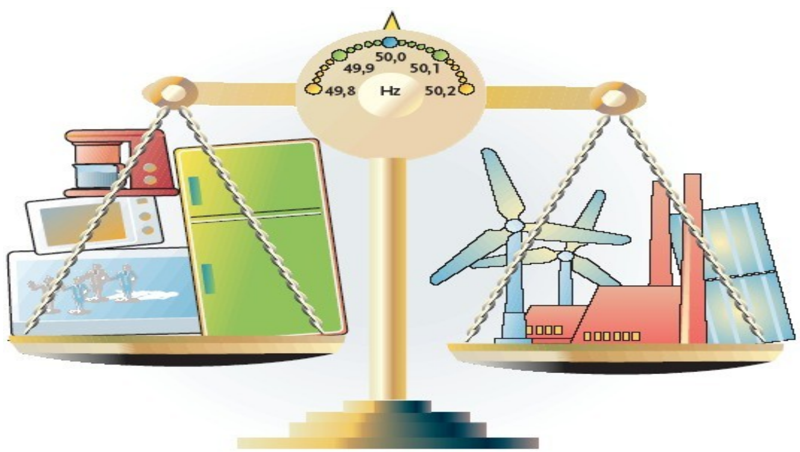
Non-parametric Response on Price Step Change

Olympic Peninsula



Control of Energy Consumption

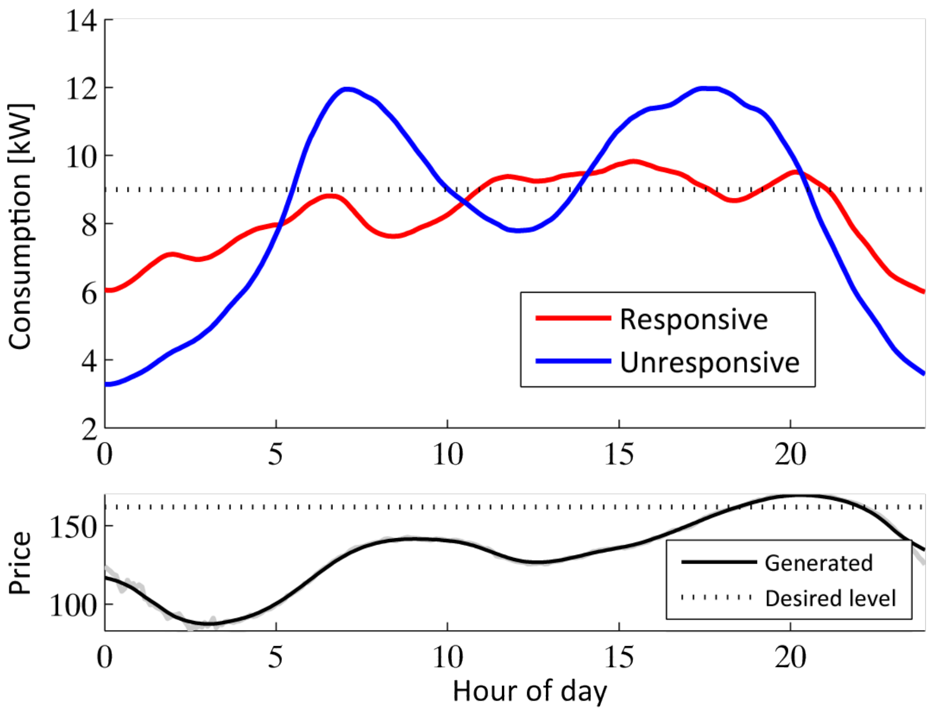




Control performance

Considerable **reduction in peak consumption**

Mean daily consumption shift



Case study No. 2

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

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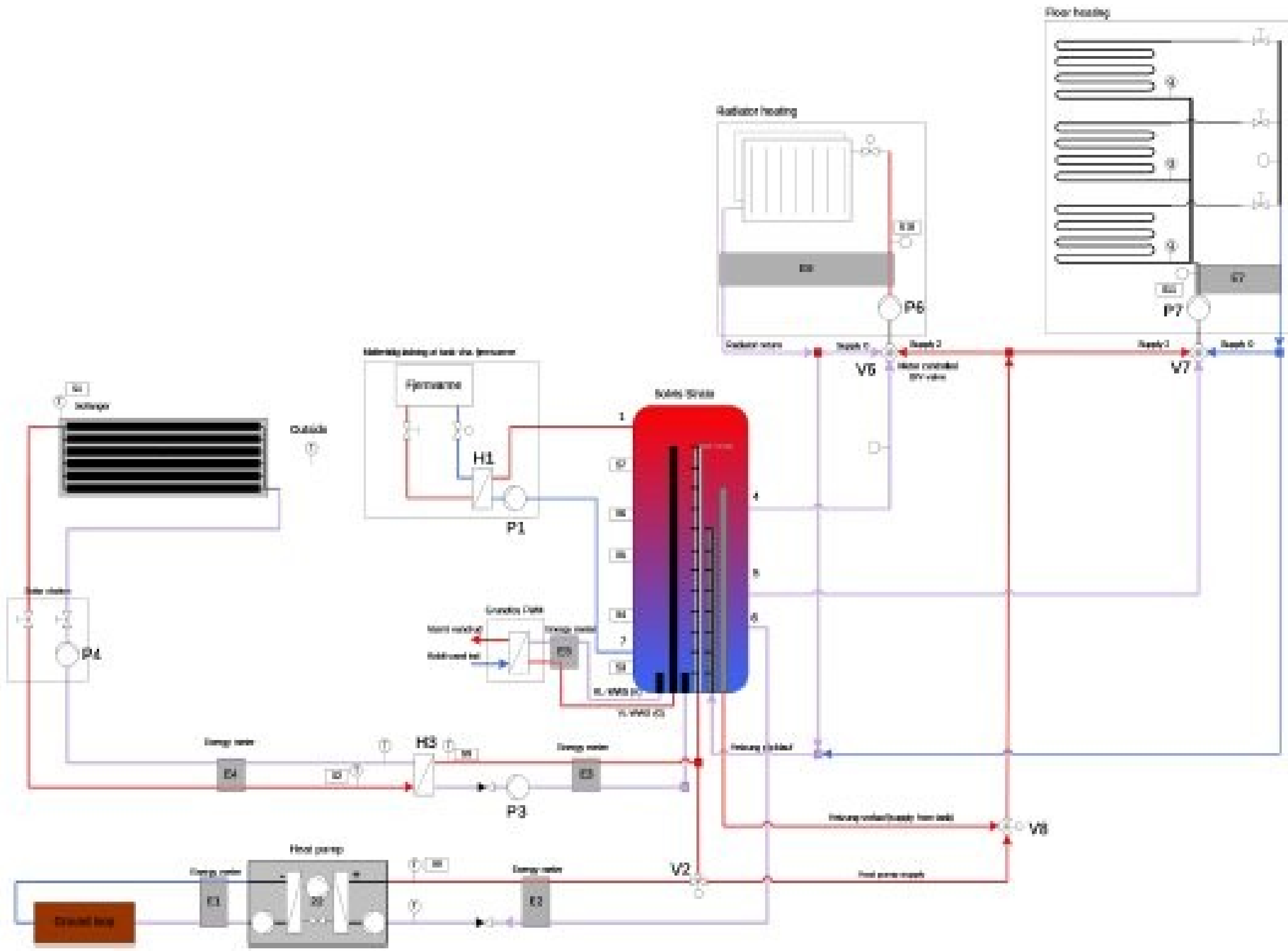
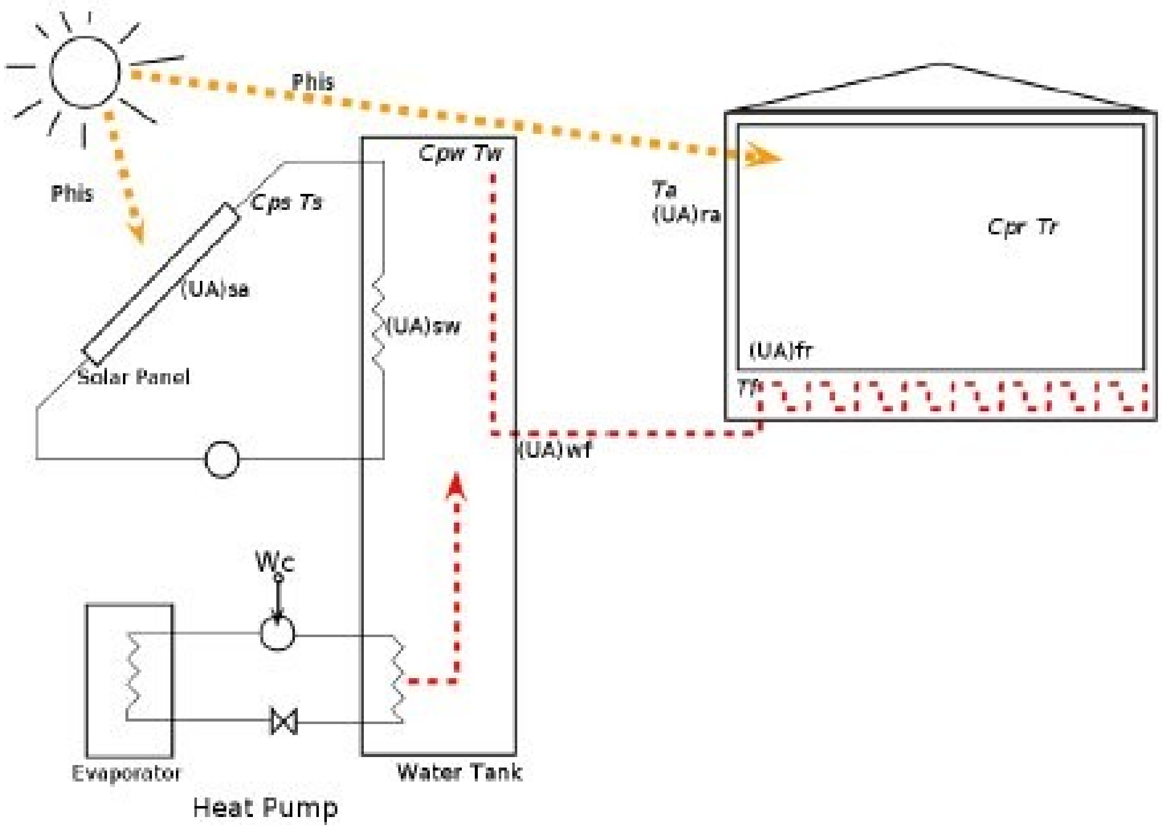
Grundfos Case Study

Schematic of the heating system



Modeling Heat Pump and Solar Collector

Simplified System



Avanced Controller

Economic Model Predictive Control

Formulation

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

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

Subject to

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

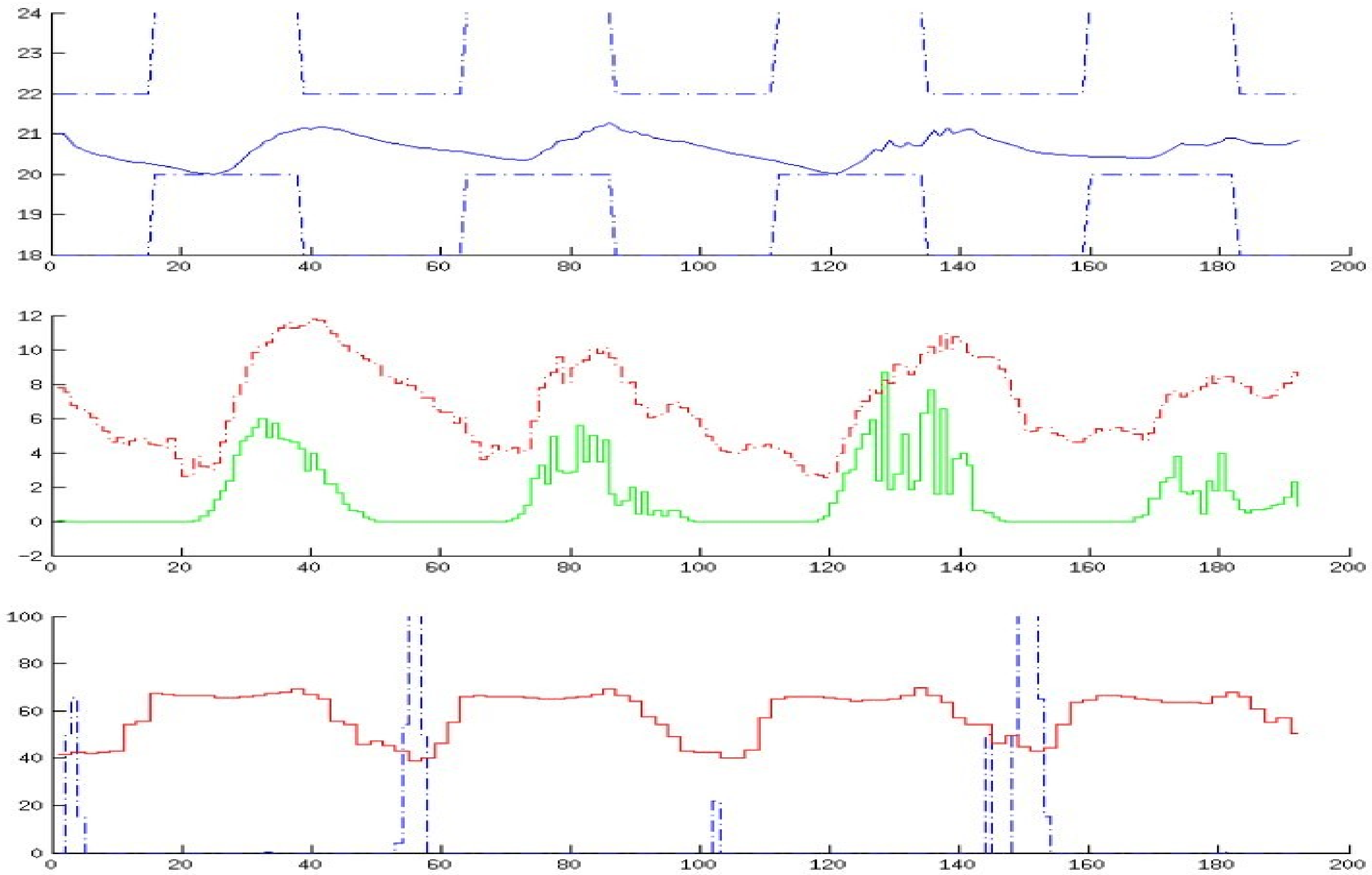
$$y_k = Cx_k \quad k = 1, 2, \ldots, N \tag{4c}$$

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

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

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

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



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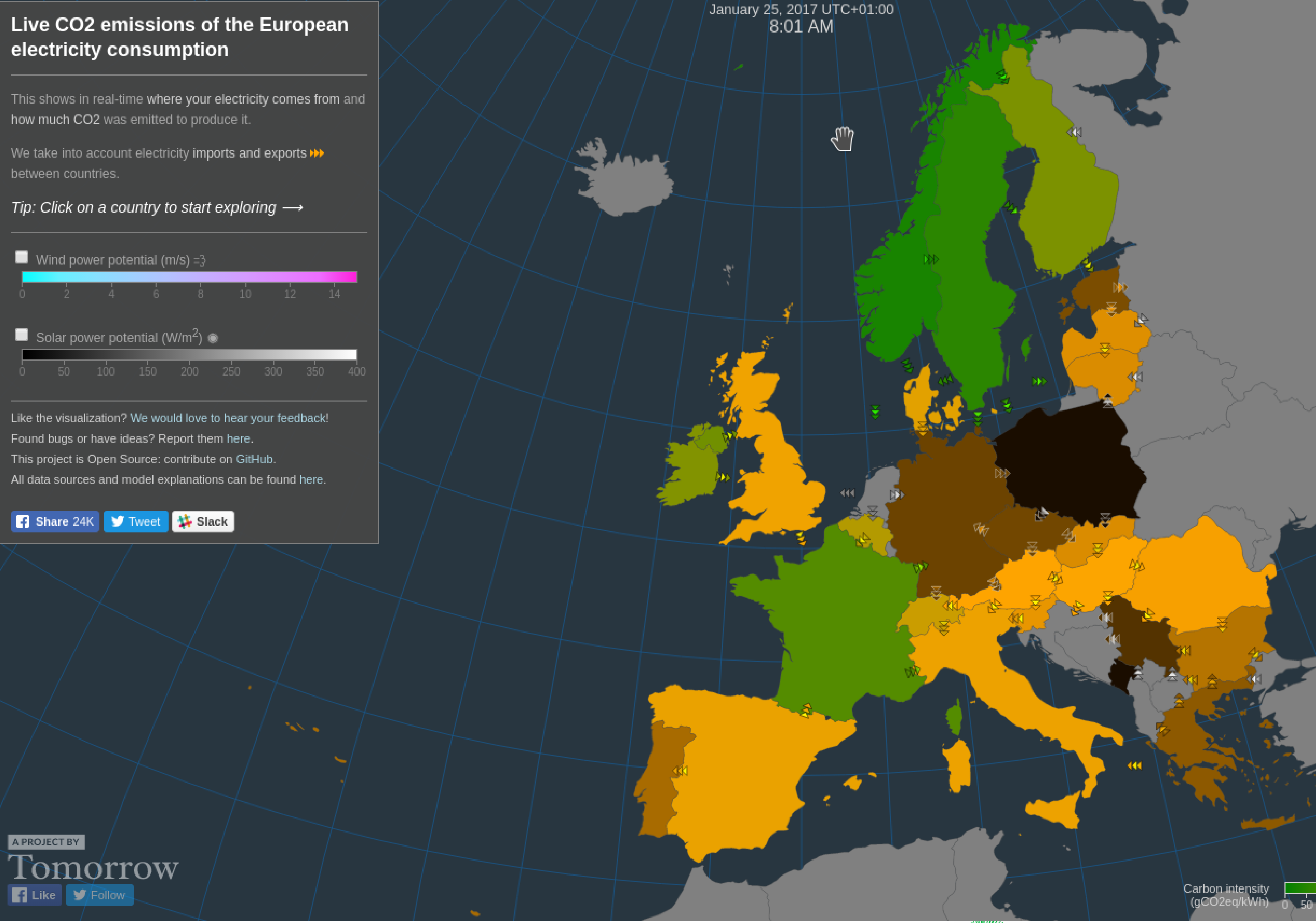
Case study No. 3

Control of heat pumps for swimming pools (CO2 minimization)



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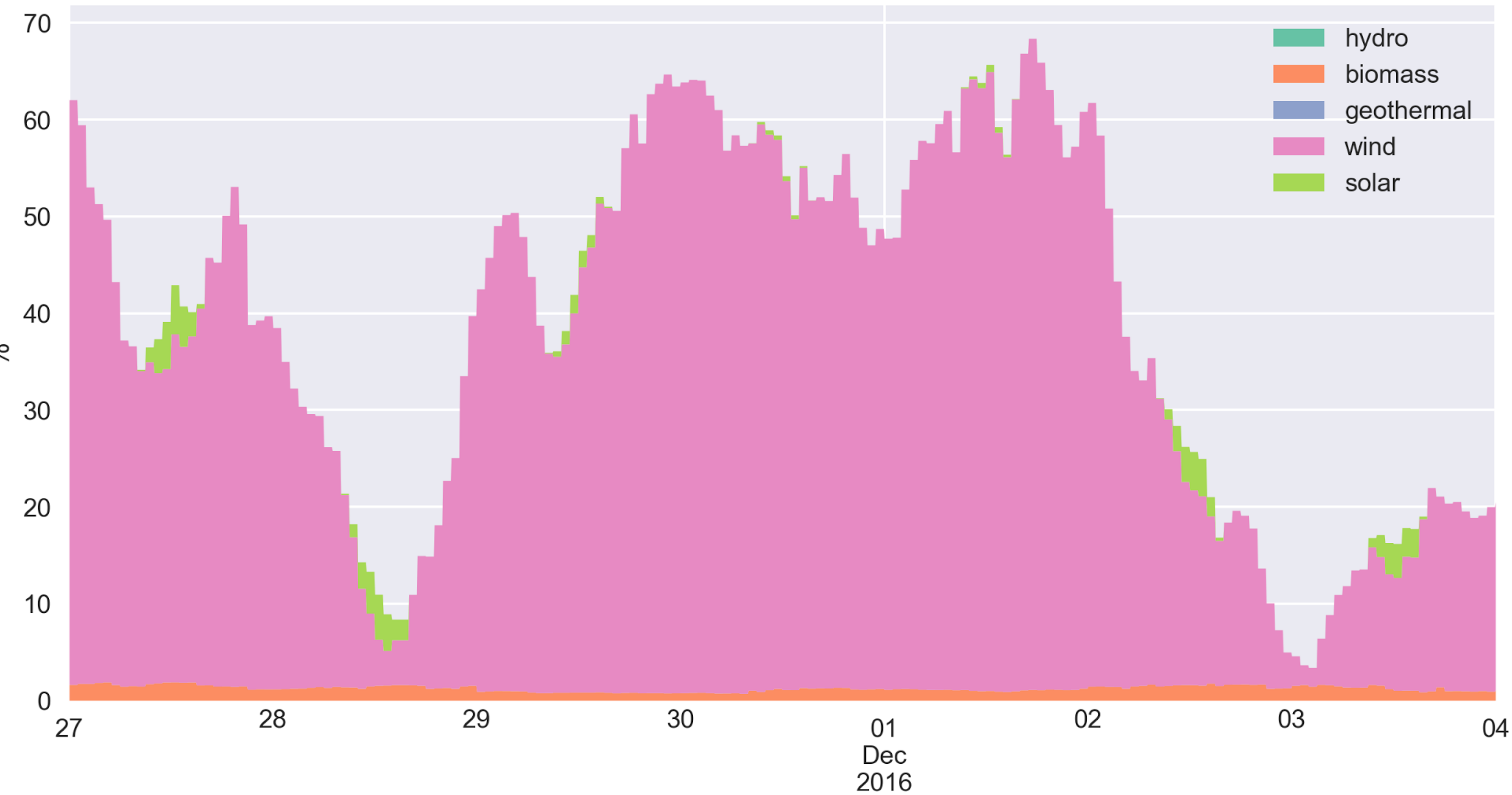
Share of electricity originating from renewables in Denmark Late Nov 2016 - Start Dec 2016



Source: pro.electicitymap.

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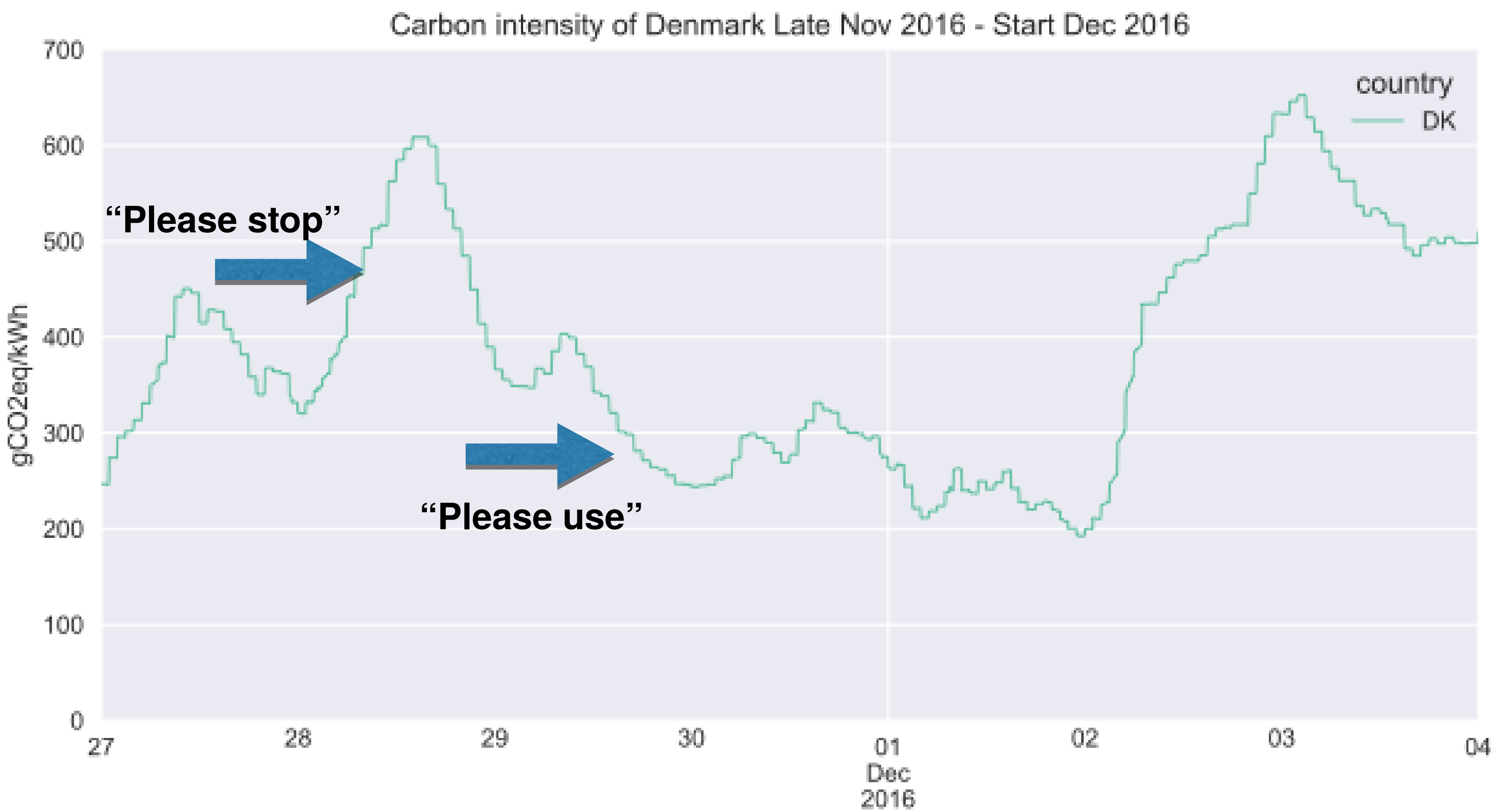
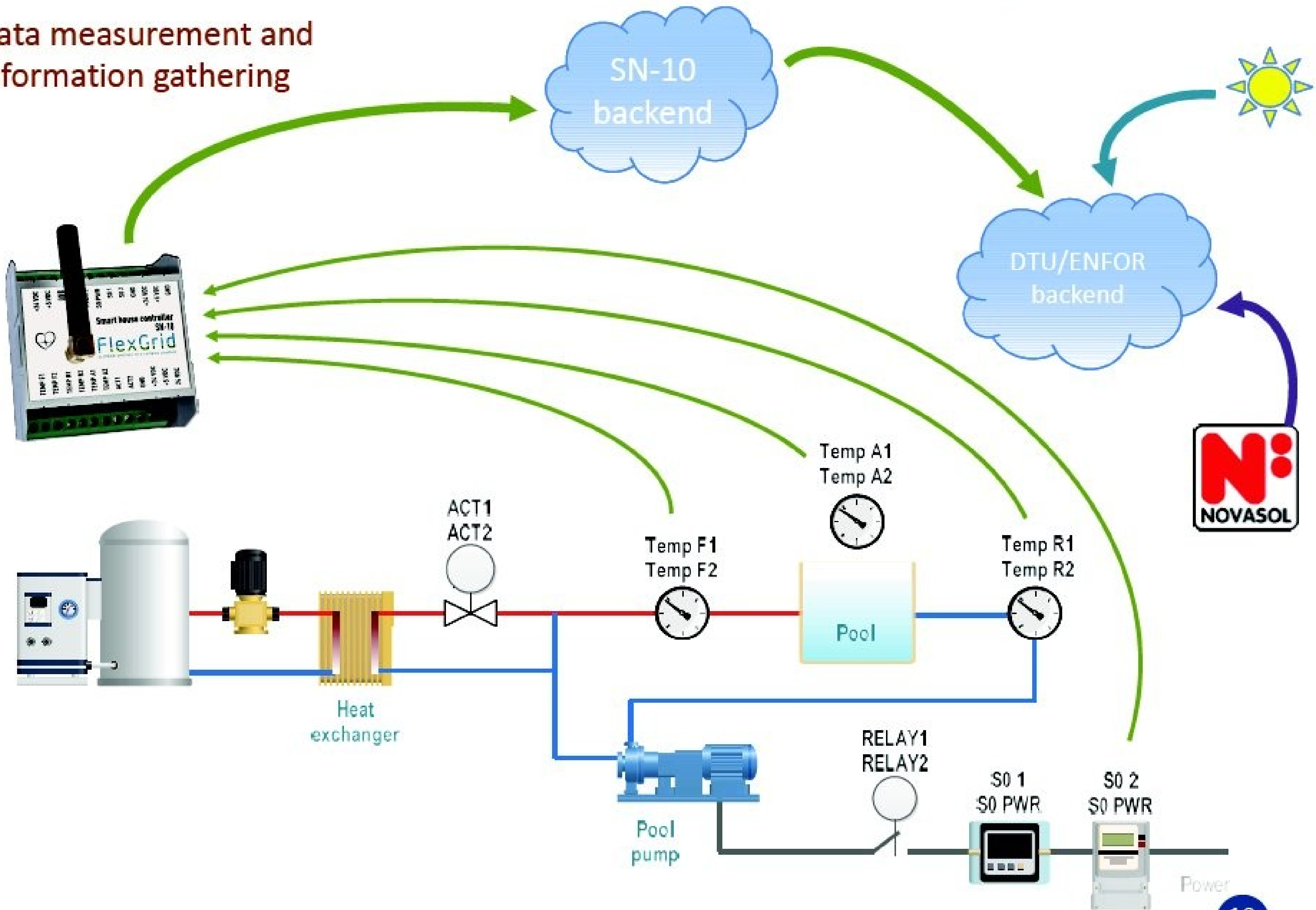


Source: pro.electicitymap.

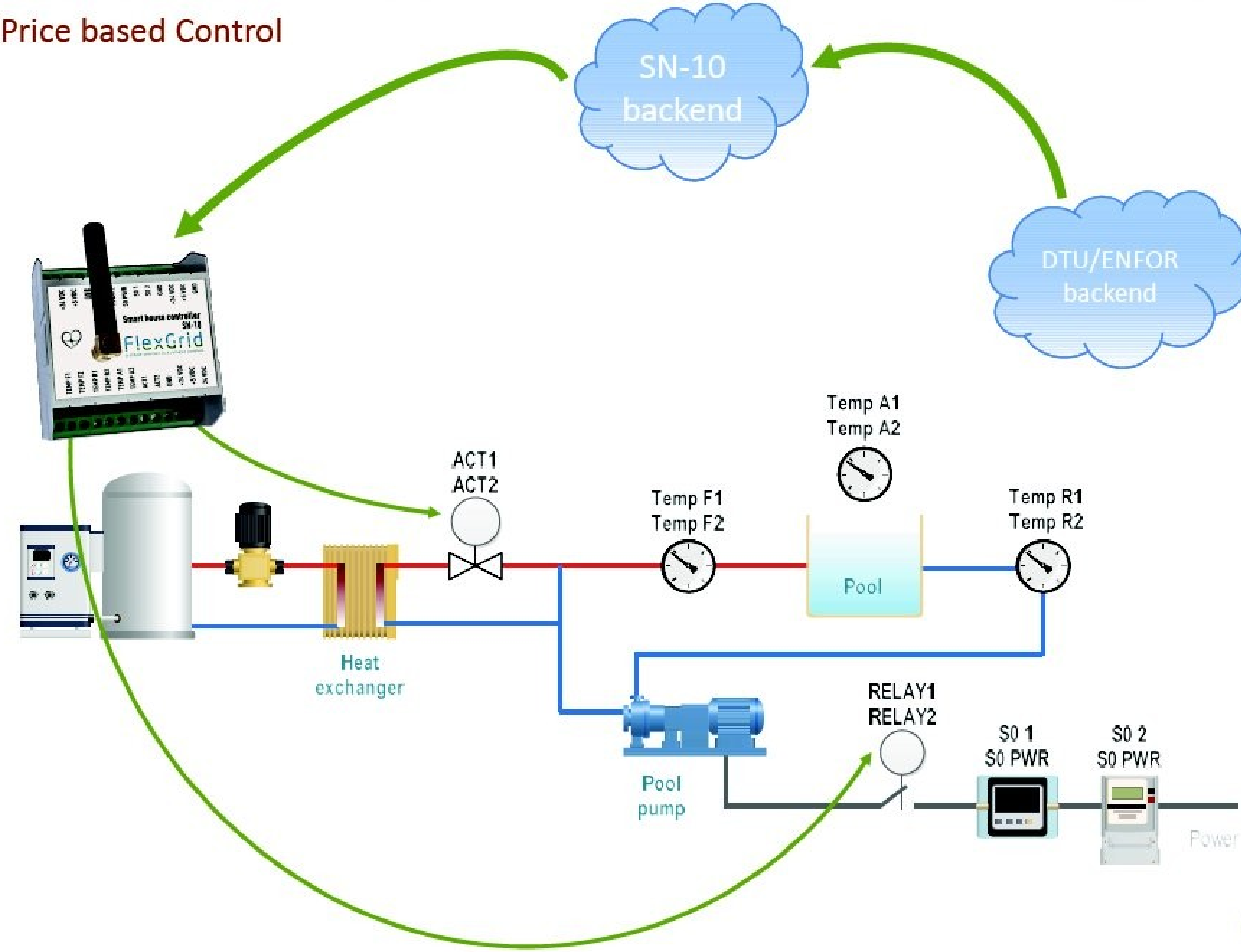
How does it work?

Data measurement and information gathering

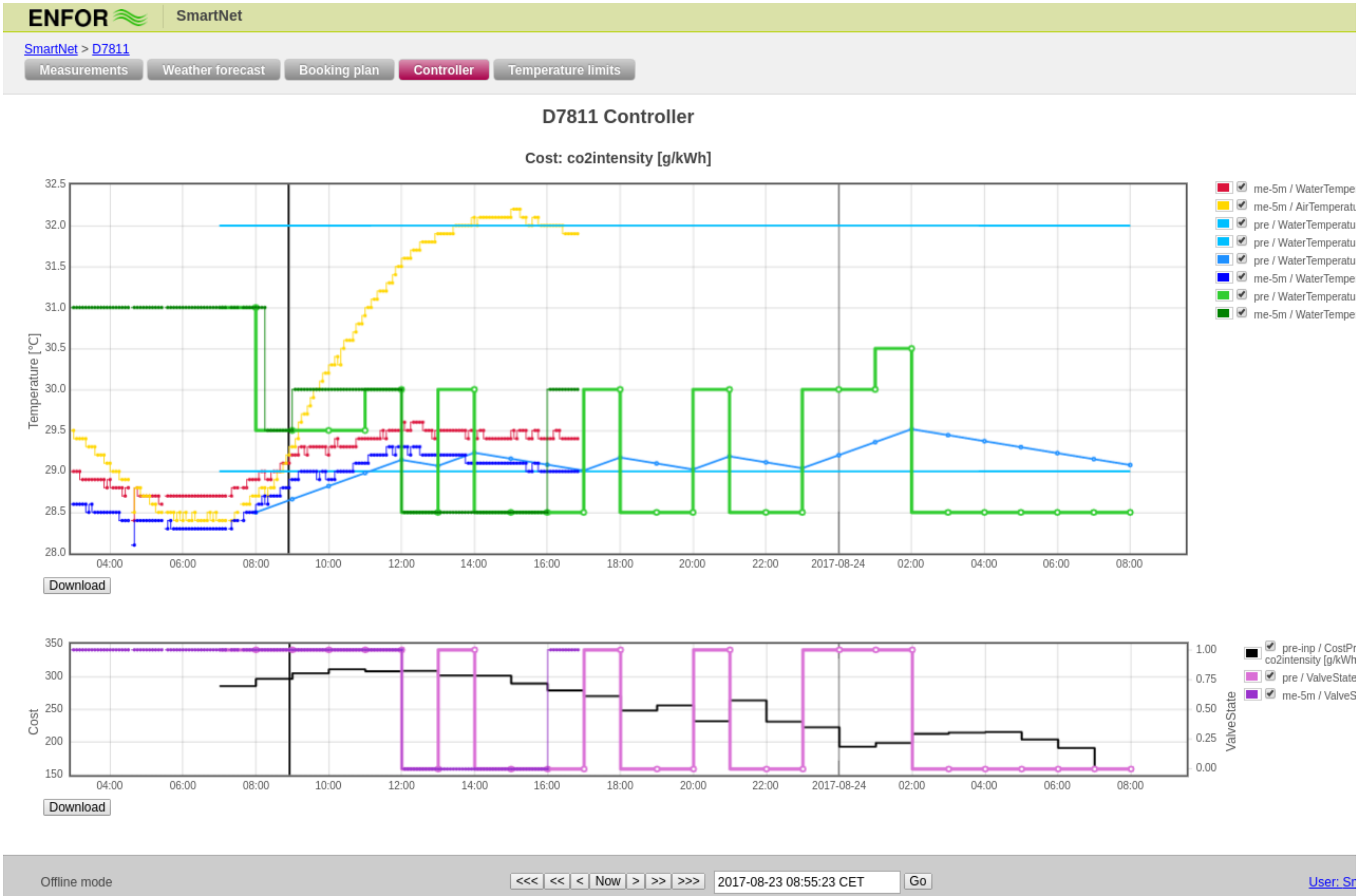


How does it work?

Price based Control



Example: CO2-based control



Ingeniøren
TEKNOLOGI • NATURVIDENSKAB • SAMFUND
18. AUGUST 2017

MARKANTE FAGFOLK TIL POLITIKERNE:

Her er vejen til smarte energiafgifter

Prisen på energi skal afspejle, hvilken forurening den medfører. Det er nødvendigt for at fremme den grønne omstilling, mener en gruppe fagfolk bag nyt udspil.

ENERGIPOLITIK

Af **Sanne Wittrup** sw@ing.dk

Følg fysikken. Det er hovedprincippet i et forslag til en ny model for energiafgifter fra en perlerække af store danske virksomheder, forskningsinstitutioner og forsyningsvirksomheder.

Gruppen foreslår, at de enkelte brændsler skal pålægges en 'forureningsafgift', der afspejler, hvad det koster at neutralisere forureningen fra brændslet. Hvad enten det så er CO_2, partikler eller svovl. Afgiften skal lægges på energien, når den går ind i værket, bilen eller fyret.

Samtidig skal også selve værket, bilen eller vindmøllen pålægges en afgift, der afspejler anlæggets miljøeffekt fra fremstilling til og med nedtagning i et livscyklusperspektiv – og hvad det koster at neutralisere denne effekt.

Ideen er så, at stærkt varierende forbrugerpriser på energi skal opmuntre forbrugerne til at flytte deres energiforbrug.

Med forslaget blander fagfolk med indsigt i dynamikken i energisektoren sig nu i debatten om, hvordan fremtidens energiafgifter skal indrettes. En debat, som Skatteministeriet tog hul på her i sommer med et såkaldt 'fagligt oplæg' til en ny afgiftsmodel.

Gruppen mener, at en ny afgiftsmodel er helt nødvendig for at få fremmet et meget mere fleksibelt energiforbrug, som ifølge dem er nøglen til en effektiv grøn omstilling, og som vil kunne åbne for at realisere masser af innovative, danske styringsmodeller og systemløsninger på energiområdet.

Professor Henrik Madsen fra Institut for Matematik og Computer Science på DTU, der taler på vegne af gruppen, synes nemlig ikke, at Skatteministeriet har gjort sit arbejde færdigt, blandt andet fordi anbefalingerne ikke tager tilstrækkelig højde for dynamikken i energisystemet.

»Den rigtige omkalfatring af energiafgifter og -tilskud vil kunne bringe Danmark helt i front med fleksible løsninger og forretningsmodeller. Vi oplever, at både firmaer og private investorer står i kø for at komme i gang med at udvikle og demonstrere kommercielle løsninger, der kan udnytte strømmen, når den er grøn og billig,« forklarer Henrik Madsen og understreger, at virksomhederne gør det, fordi de er overbeviste om, at de kan tjene store penge på at kunne udvikle og demonstrere løsninger i Danmark og senere tilbyde dem til andre lande.

Gruppen er dannet af deltagere i et stort forskningsprojekt ved navn 'Cities', hvor man har udviklet styringer og systemløsninger til forskellige elementer i fremtidens intelligente og integrerede energisystem.

Disse demonstrationsprojekter har vist, at der rent teknisk findes mange muligheder for at integrere store mængder vind- og solenergi, hvis man på en intelligent måde kan udnytte den dynamik og fleksibilitet, der er i et energisystem, hvor produktion og forbrug af el, varme, vand, affald og transport er tænkt sammen.

Danfoss er en af virksomhederne bag den nye model. Leder af Danfoss' eksterne aktiviteter Torben Funder-Kristensen peger på, at Danmark har en unik mulighed for at udvikle disse nye løsninger, fordi vi har teknologien, knowhow og en moderne og samarbejdsvillig forsyningssektor.

»Men vi har kun et vindue på fem til ti år, før andre lande kommer ind og tager over, så det haster med at få omlagt energiafgifterne, der reelt dræber mange demonstrationsprojekter. Vi kan ikke vente!« siger han.

Professor i ressourceøkonomi på KU Peder Andersen – som sidder i referencegruppen for Skatteministeriets afgiftsrapport – finder, at gruppens afgiftsforslag ser interessant ud, men at det samtidig er lidt svært at gennemskue, om de økonomiske incitamenter rammer rigtigt:

»Når man primært lægger afgift på input af brændslet, risikerer man, at der ikke er incitamenter for virksomhederne til at undgå forurening, f.eks. ved at rense effektivt eller bruge ren teknologi. Det går imod korrekt økonomisk tænkning,« siger han.

Samtidig påpeger han, at den foreslåede afgift på selve produktionsanlæggene kan blive en meget tung ordning at administrere.

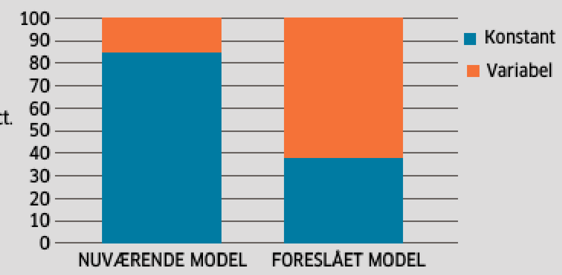
»Det vigtige er jo, at der gives klare økonomiske incitamenter til, at både økonomien og miljøet tilgodeses,« siger han.

Det nye forslag er baseret på møder og diskussioner med markante personer fra Danfoss, Grundfos, Kamstrup, Dansk Fjernvarme, Eniig, AffaldVarme Aarhus, Teknologisk Institut, DTU, KU, ProjectZero og Aarhus Kommune.

I den kommende tid vil gruppen gå videre med sit forslag til de relevante ministerier og har allerede en aftale i Energi-, Forsynings- og Klimaministeriet. ■

ELPRISEN SKAL VÆRE DYNAMISK

I dagens elpris er afgifter og tariffer faste, og kun selve elmarkedsprisen varierer. I den nye afgiftsmodel vil størstedelen af prisen kunne variere, da afgifterne skal variere på de brændselstyper, der kan levere strømmen.



Kilde: Henrik Madsen, DTU Grafik: LGJ

LÆS SIDE 4-5

CITIES

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,

CITIES INNOVATION CENTER

Integrated energy systems powered by intelligent data

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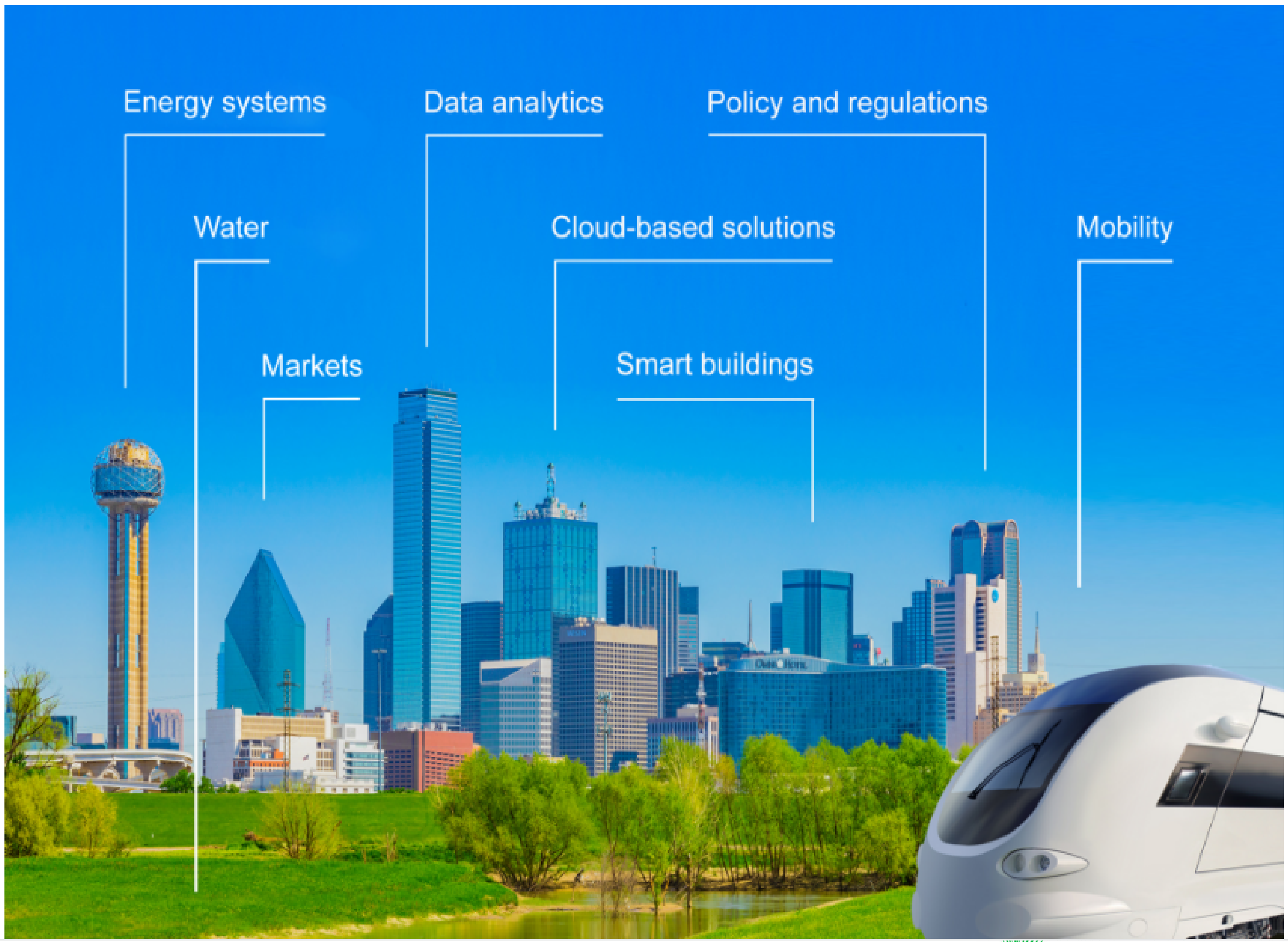
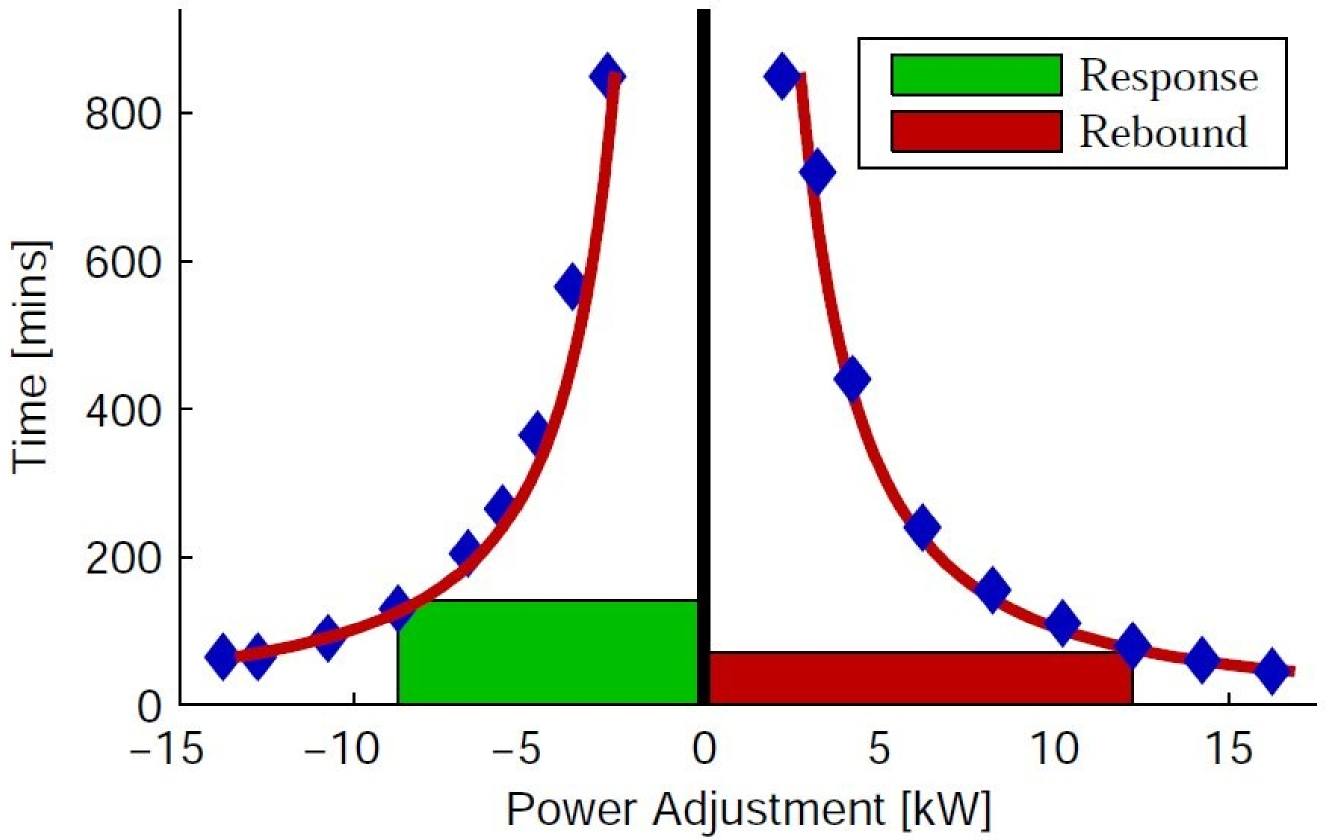


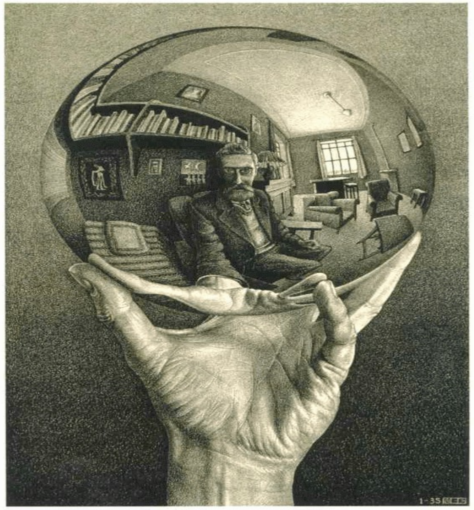
Further Aspects

Flexibility Represented by Saturation Curves
(for market integration using block bids)

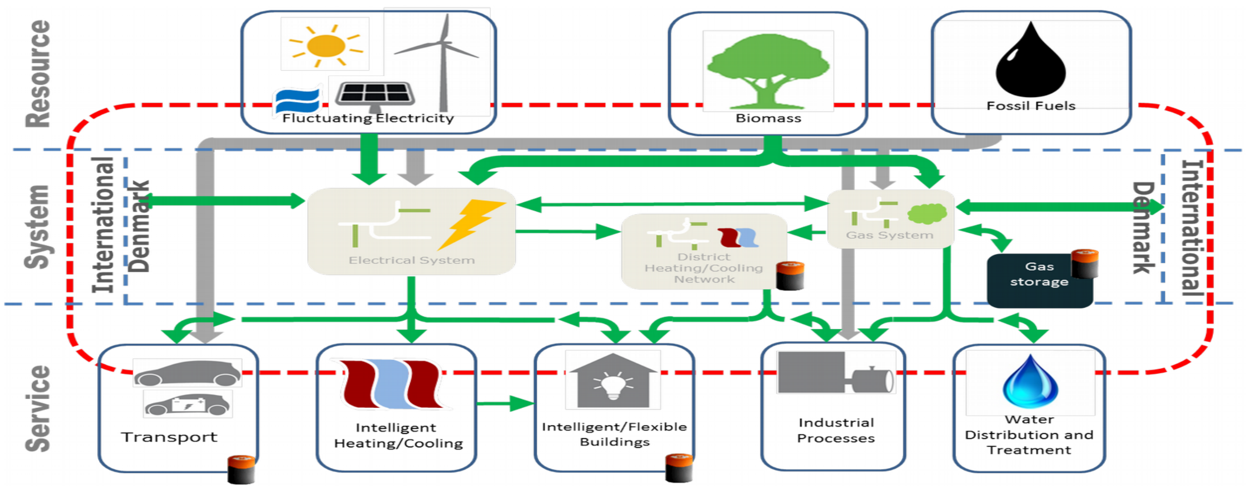


Understanding Power/Energy Flexibility
Some Demo Projects in CITIES:

- 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, ...)
- ....



(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

Summary

- A procedure for data intelligent control of power load, using the Smart-Energy OS (SE-OS) setup, is suggested.
- 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).
- 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)

For more information ...

See for instance

www.smart-cities-centre.org

...or contact

– Henrik Madsen (DTU Compute)

hmad@dtu.dk

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