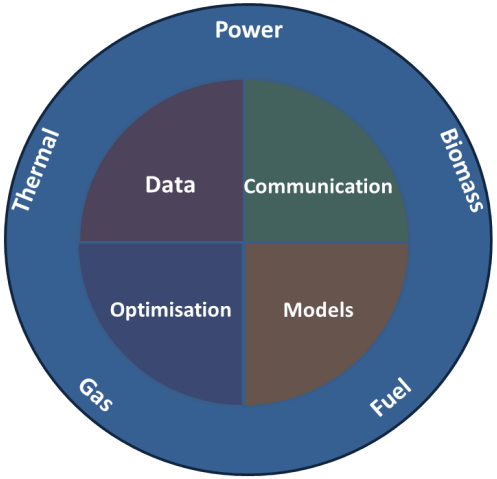
# Methods and new energy taxes paves the way for the future fossil-free energy system

# Results from CITIES




**Henrik Madsen**

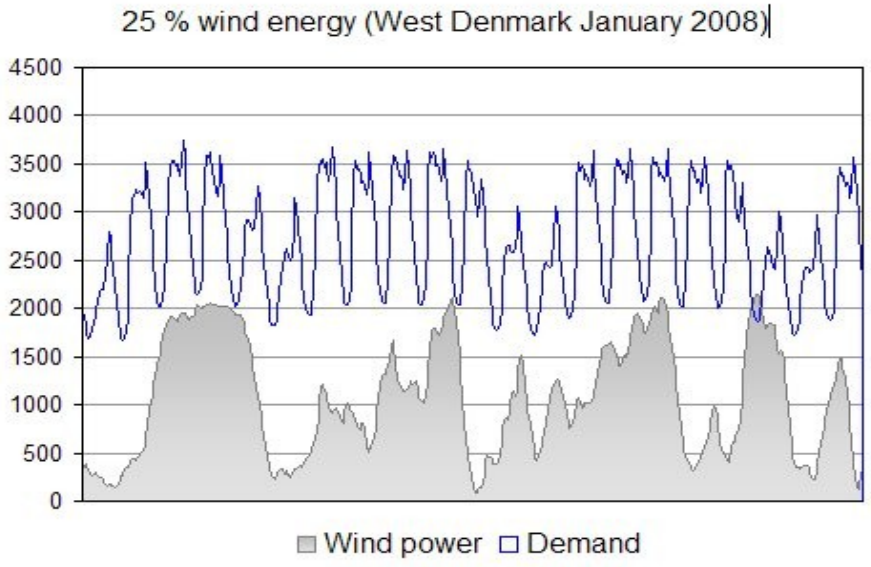
**Matematik og Computer Science, DTU**

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

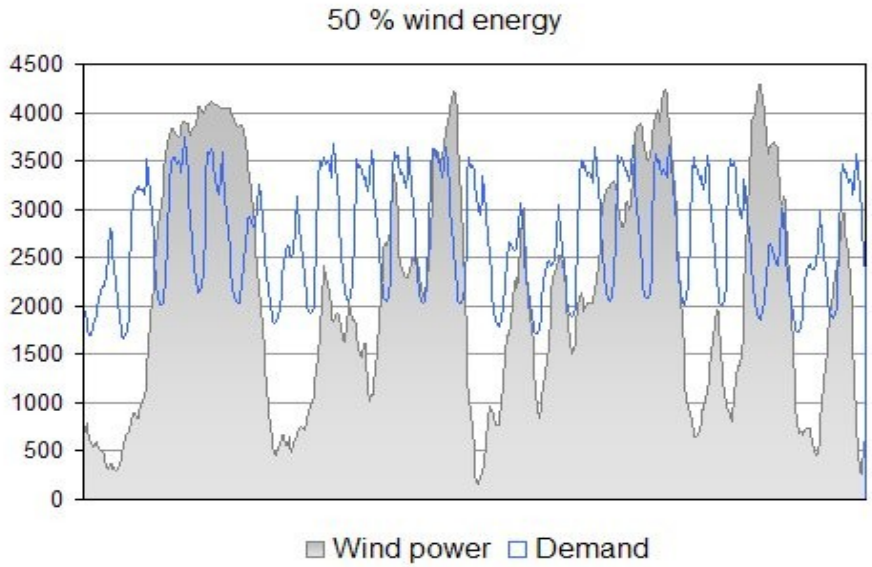
**http://www.henrikmadsen.org**

# 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)

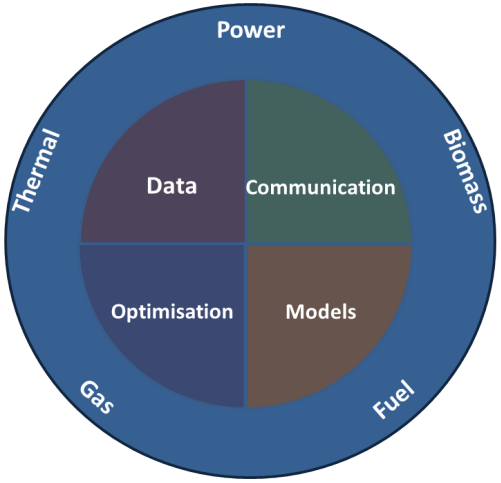



**In the first half of 2017 more than 44 pct of electricity load was covered by wind power.**

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





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.

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

# 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

**Report: Almost no flexibility**

The Ecodesign Preparatory Study on [illegible] has [illegible] 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:

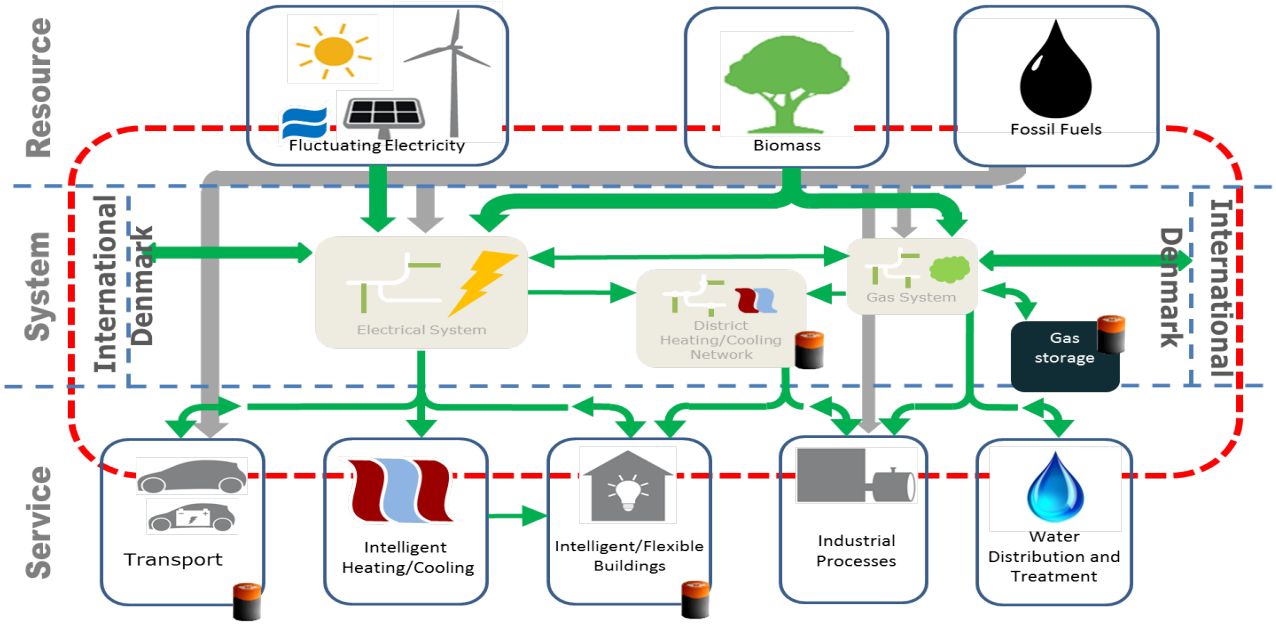
- Chargers for electric cars: technical potential and other relevant issues in the context of demand response.
- The modelling done in the framework of MEErP Task 6 and 7 will be updated with PRIMES data that recently became available, and with the EEA-countries.
- The development and assessment of policy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

# Temporal and Spatial Scales

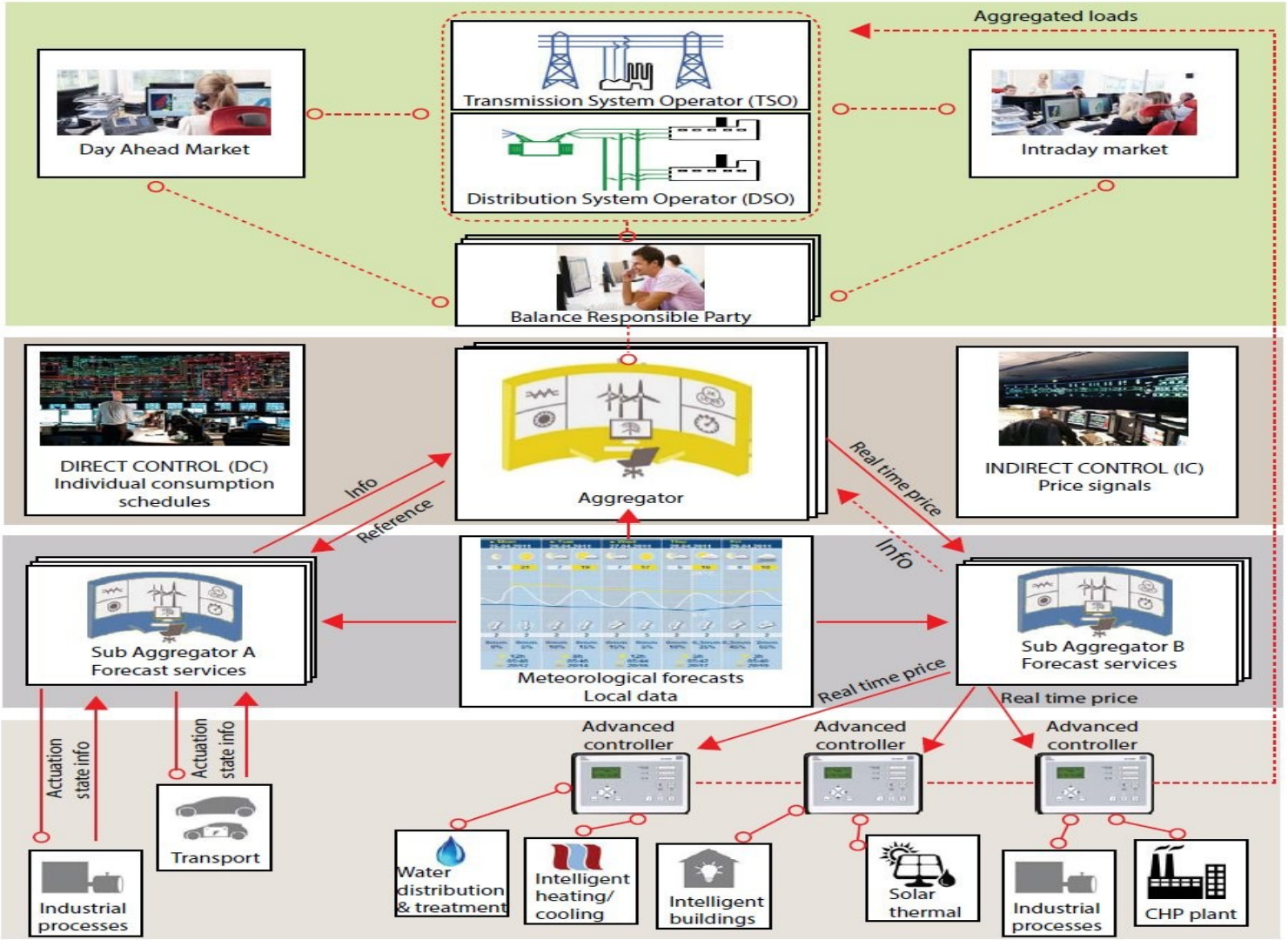
The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems*** at **all scales**.

# 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**

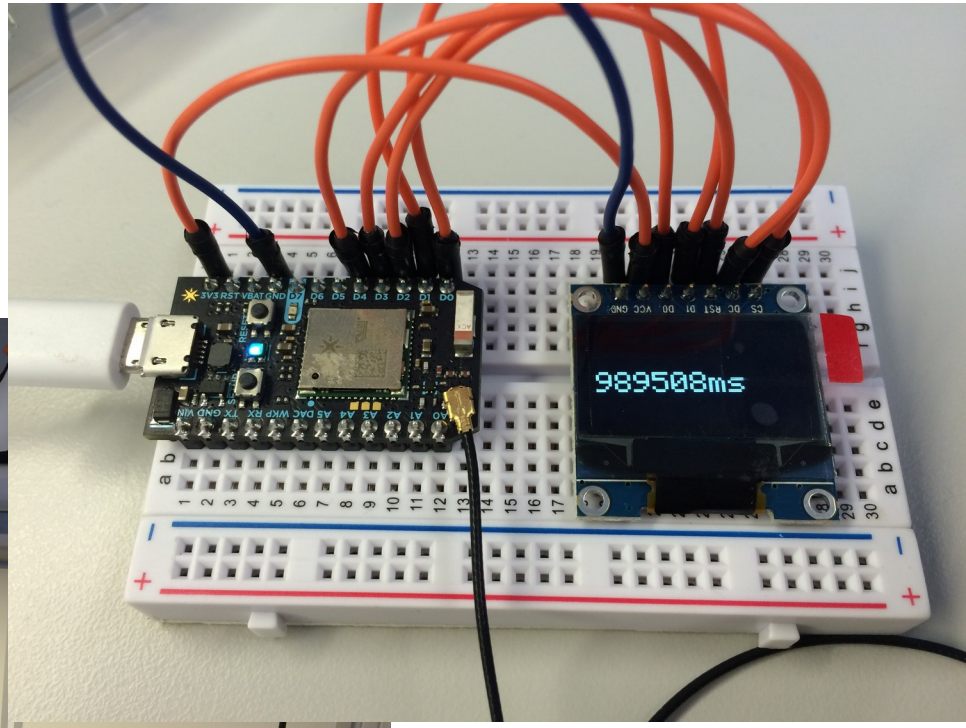


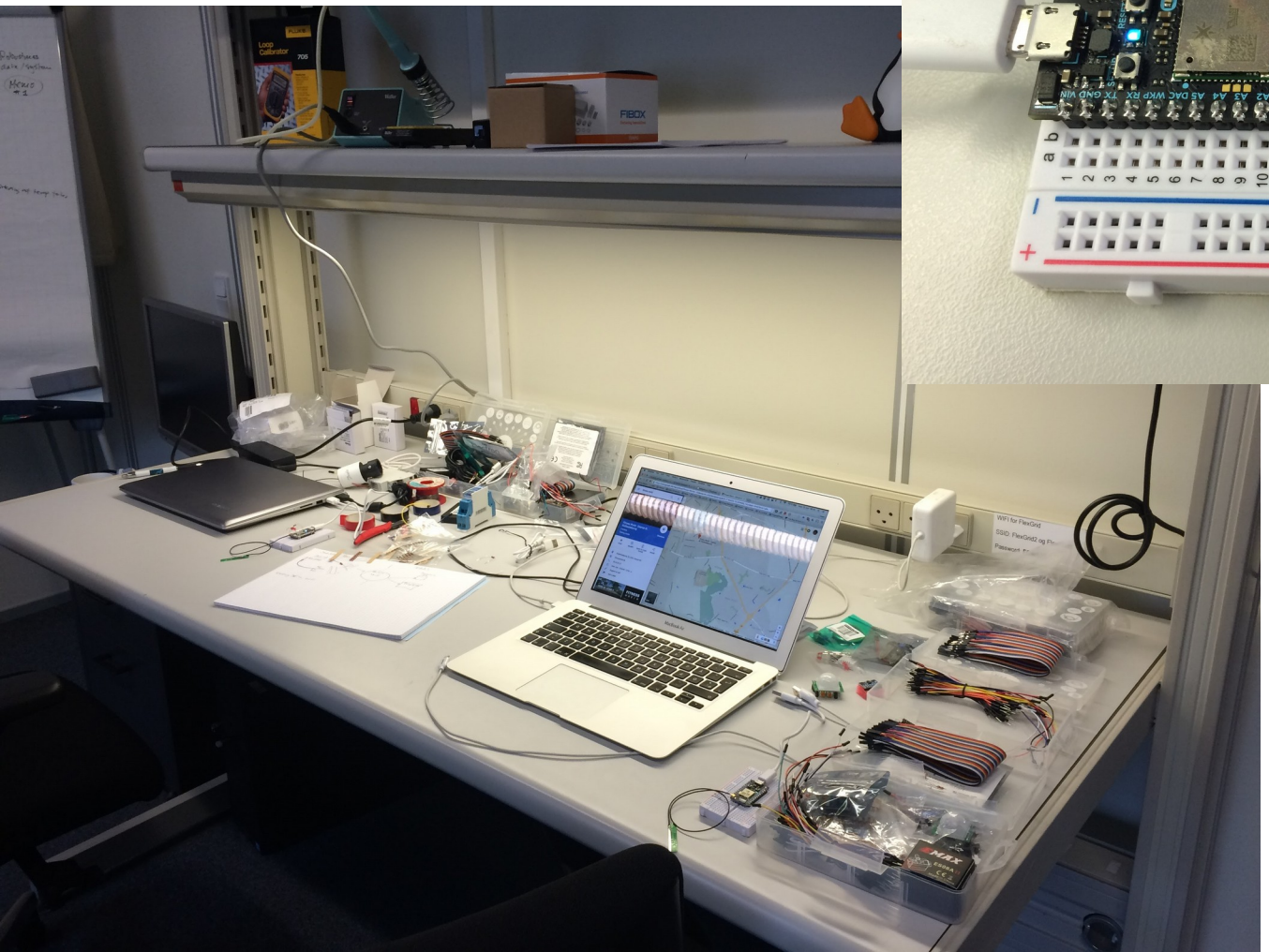
# Smart-Energy OS



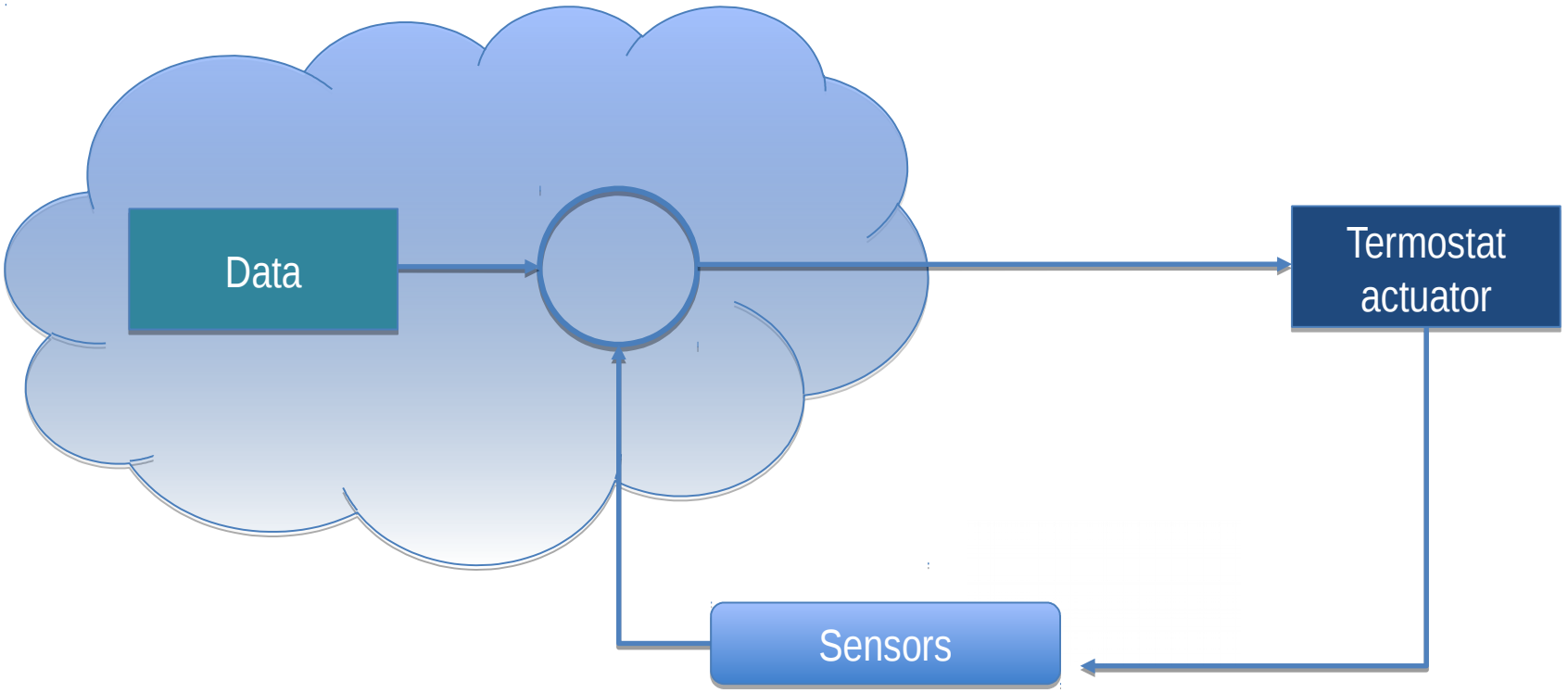
```
38
39  # Try to parallelize anyway
40  require(multicore)
41  numcores<-multicore:::detectCores()
42  mclapply(
43  ··1:N,·
44  ··function(i,data)·{
45  ····print(paste(i,·"/",·N))
46
47  ····#·Find·the·indices·of·rows·corresponding·to·
48  ····j·<-·which(data$dt_agg·%in%·aggdata$dt[i])
49
50  ····#·Filter·out·those·who·are·NA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

# Lab testing ….

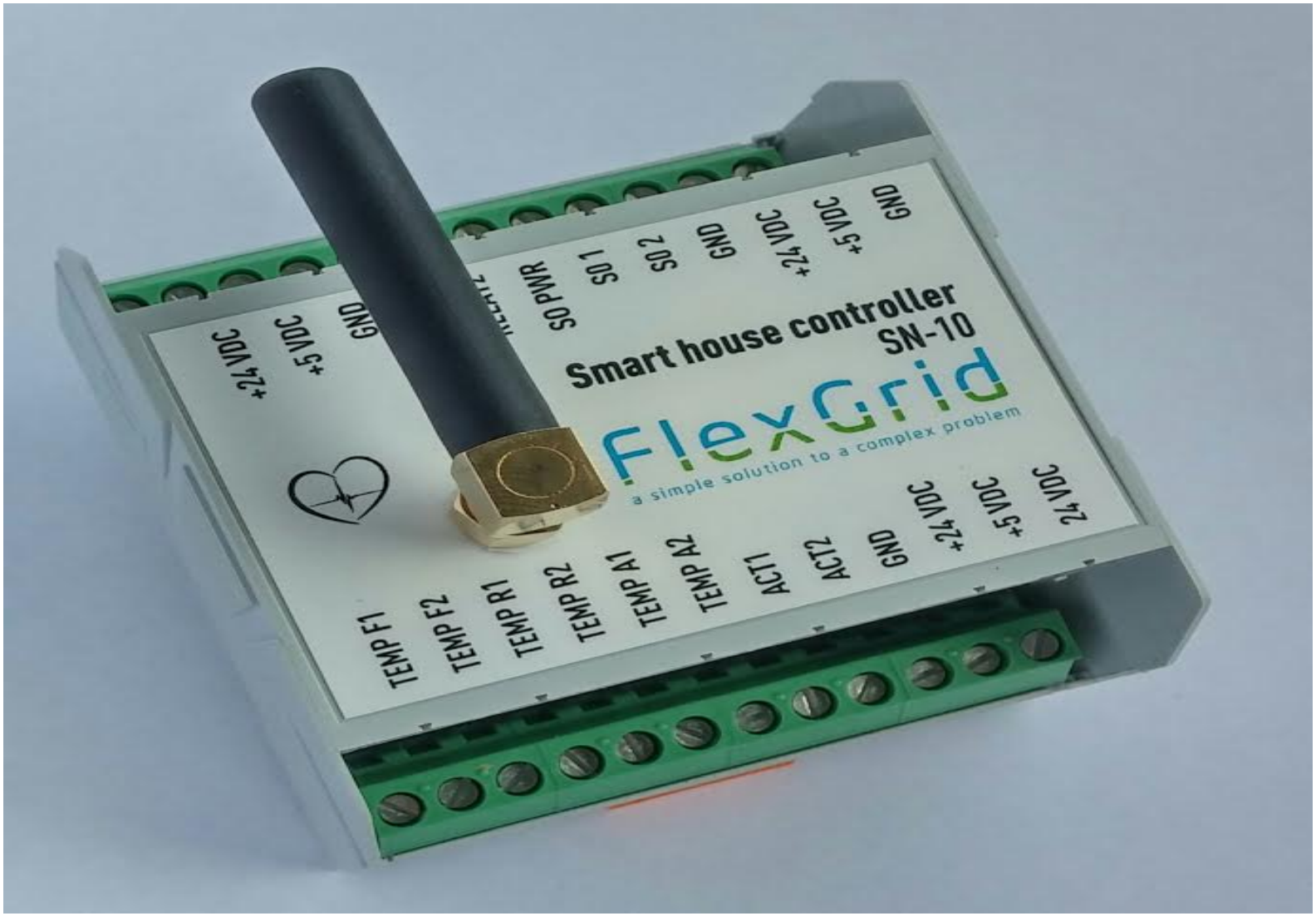


# SE-OS
# Control loop design – **logical drawing**

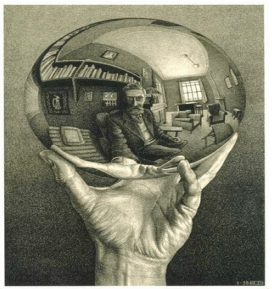


# SN-10 Smart House Prototype



# SE-OS Characteristics

- Automatic and self-calibrated methods based on Big Data analytics and AI
- 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



CITIES INNOVATION CENTER
Integrated energy systems powered by intelligent data

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# Topics

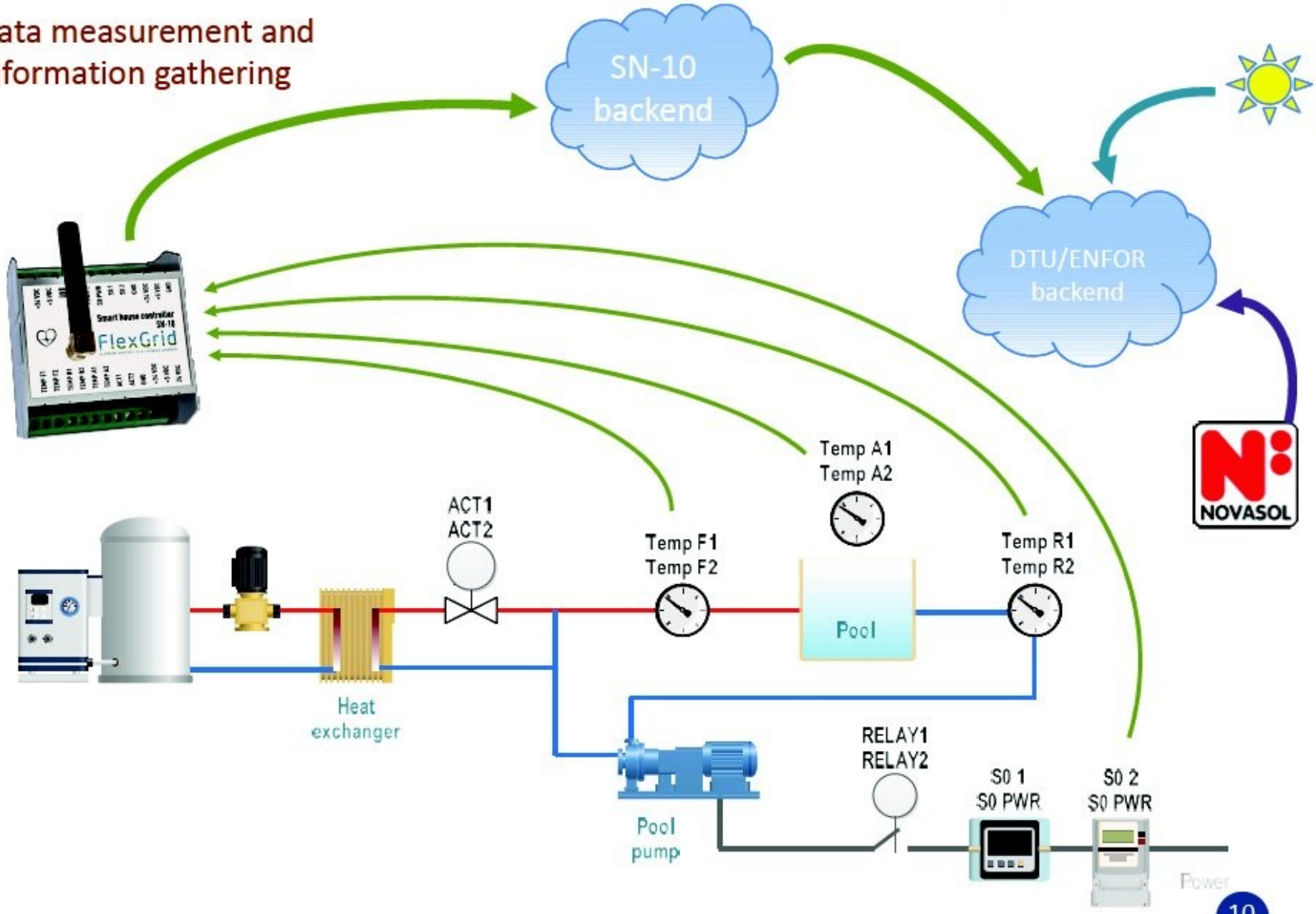
# Case study No. 1

# Control of heat pumps for swimming pools (CO2 minimization)

# How does it work?

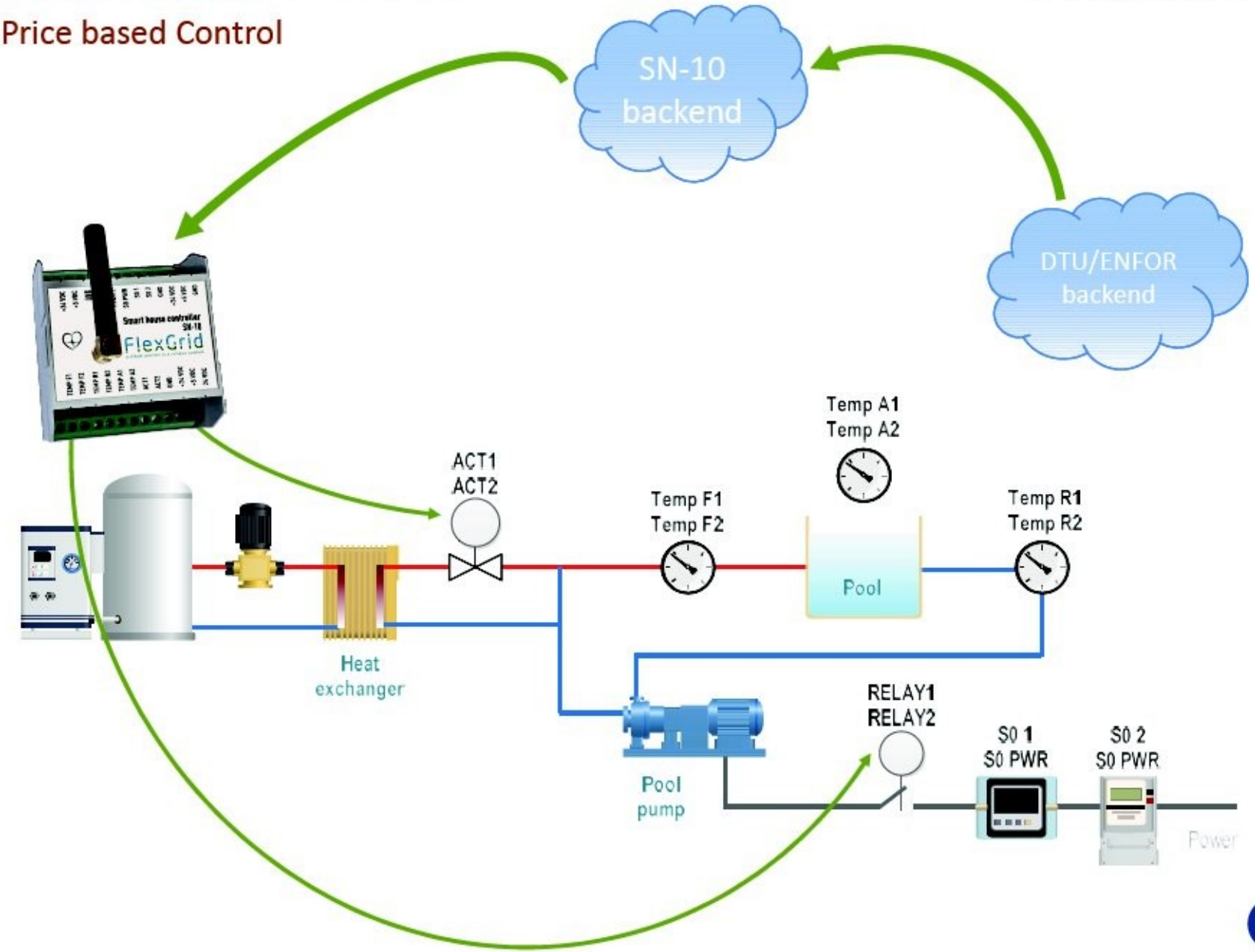
SmartNet

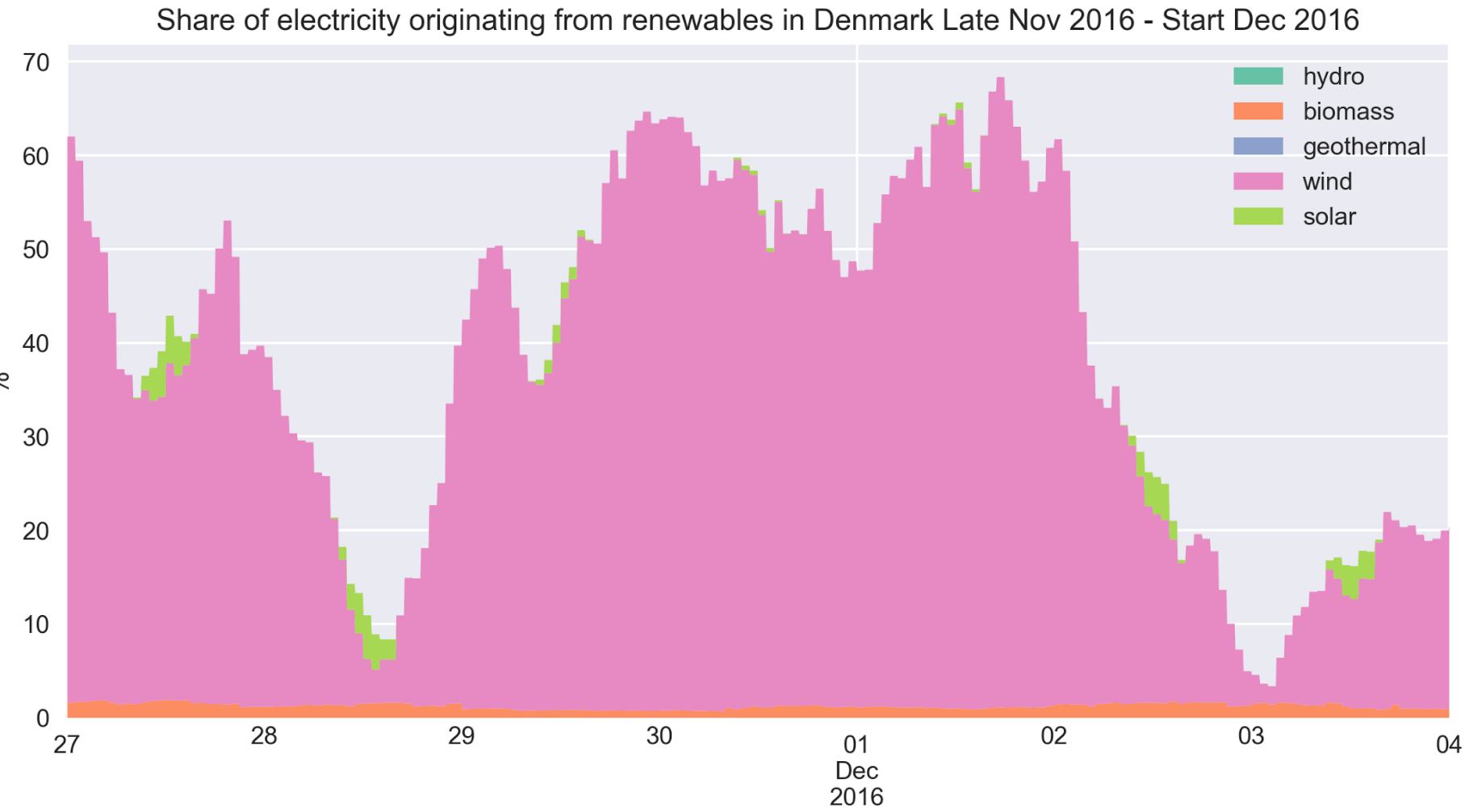
## Data measurement and information gathering



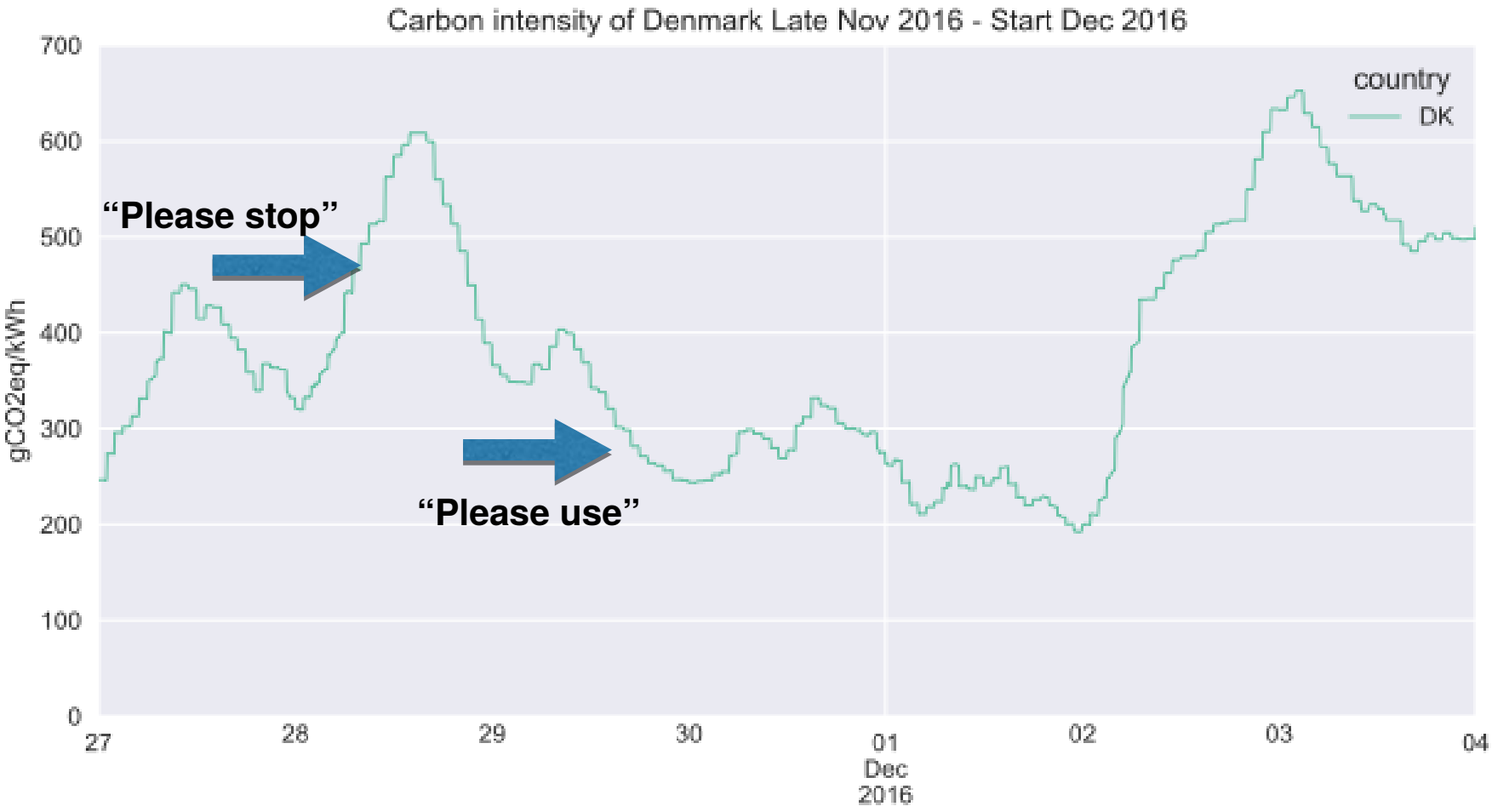
# How does it work?

## Price based Control

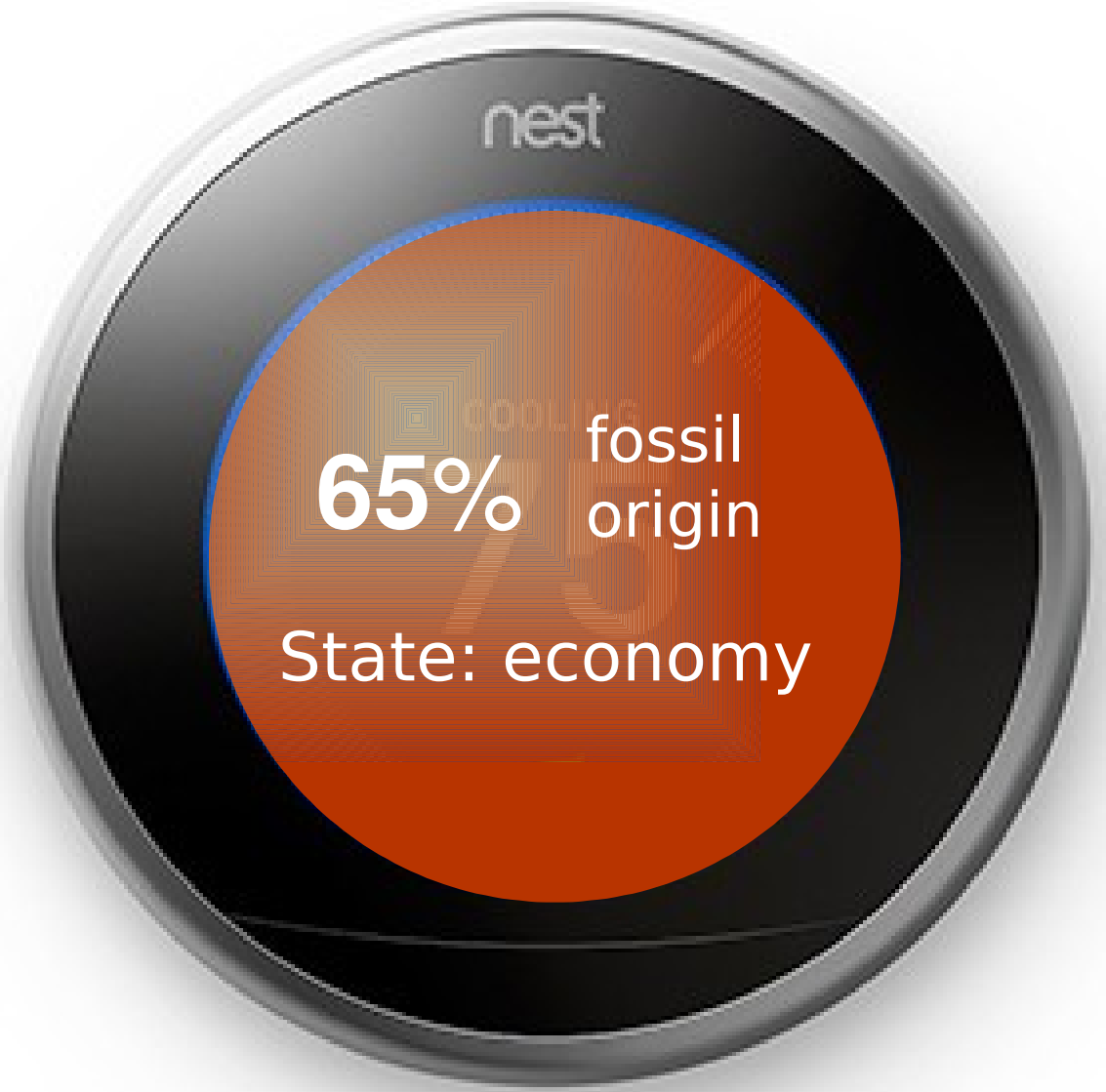




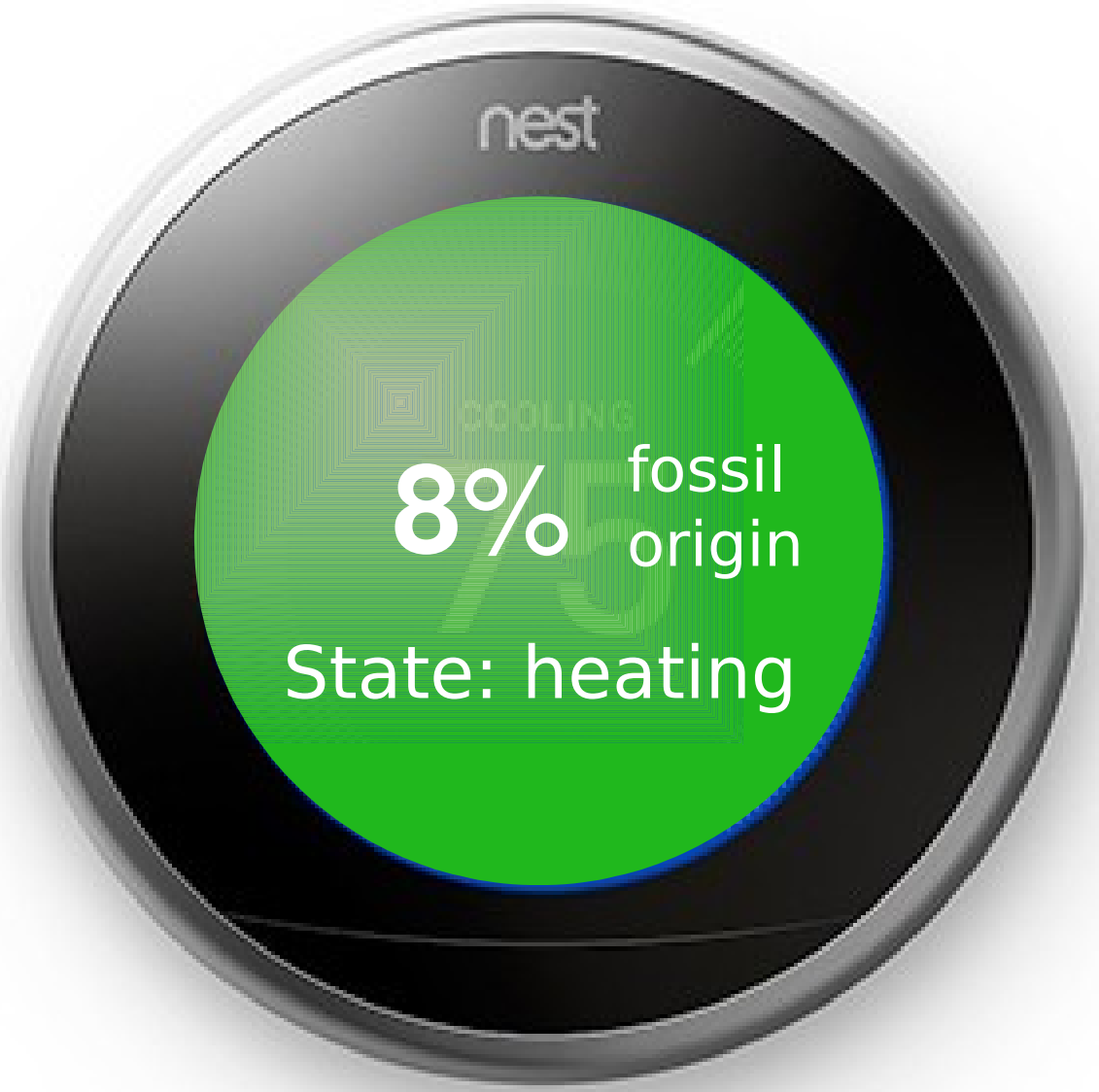

Source: pro.electicitymap.




Source: pro.electicitymap.




www.co2signal.com



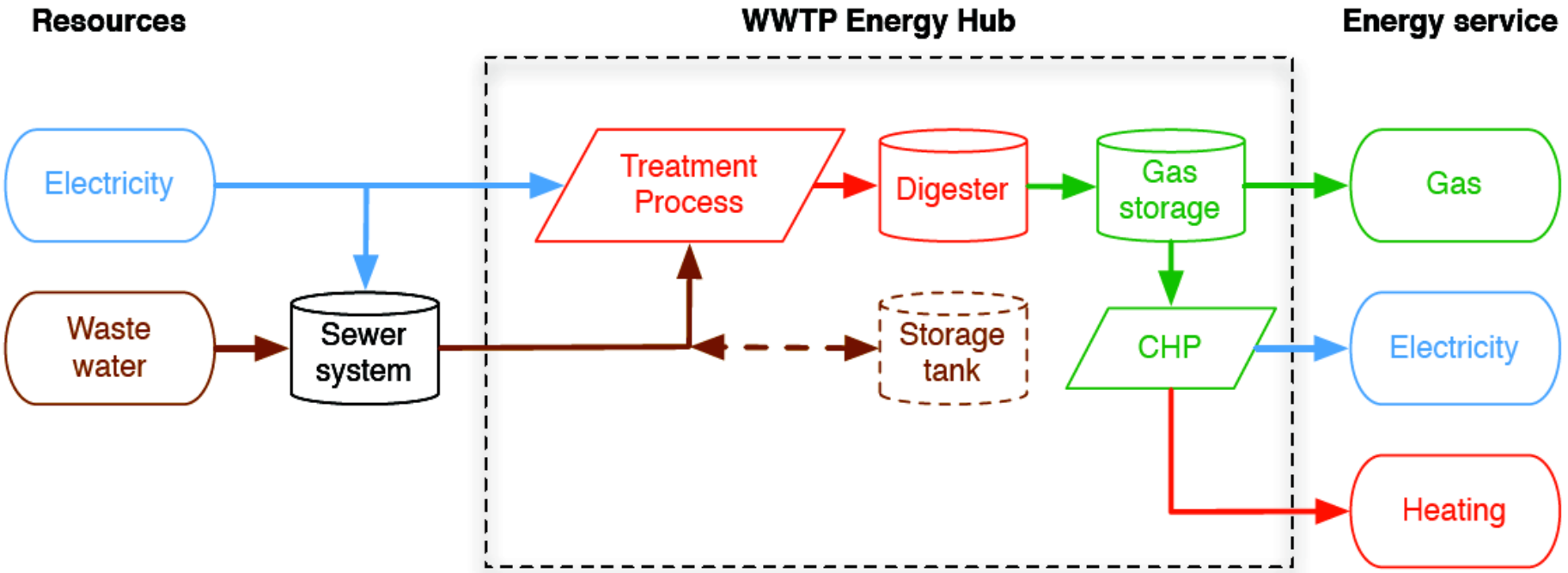

www.co2signal.com

# Case study No. 2

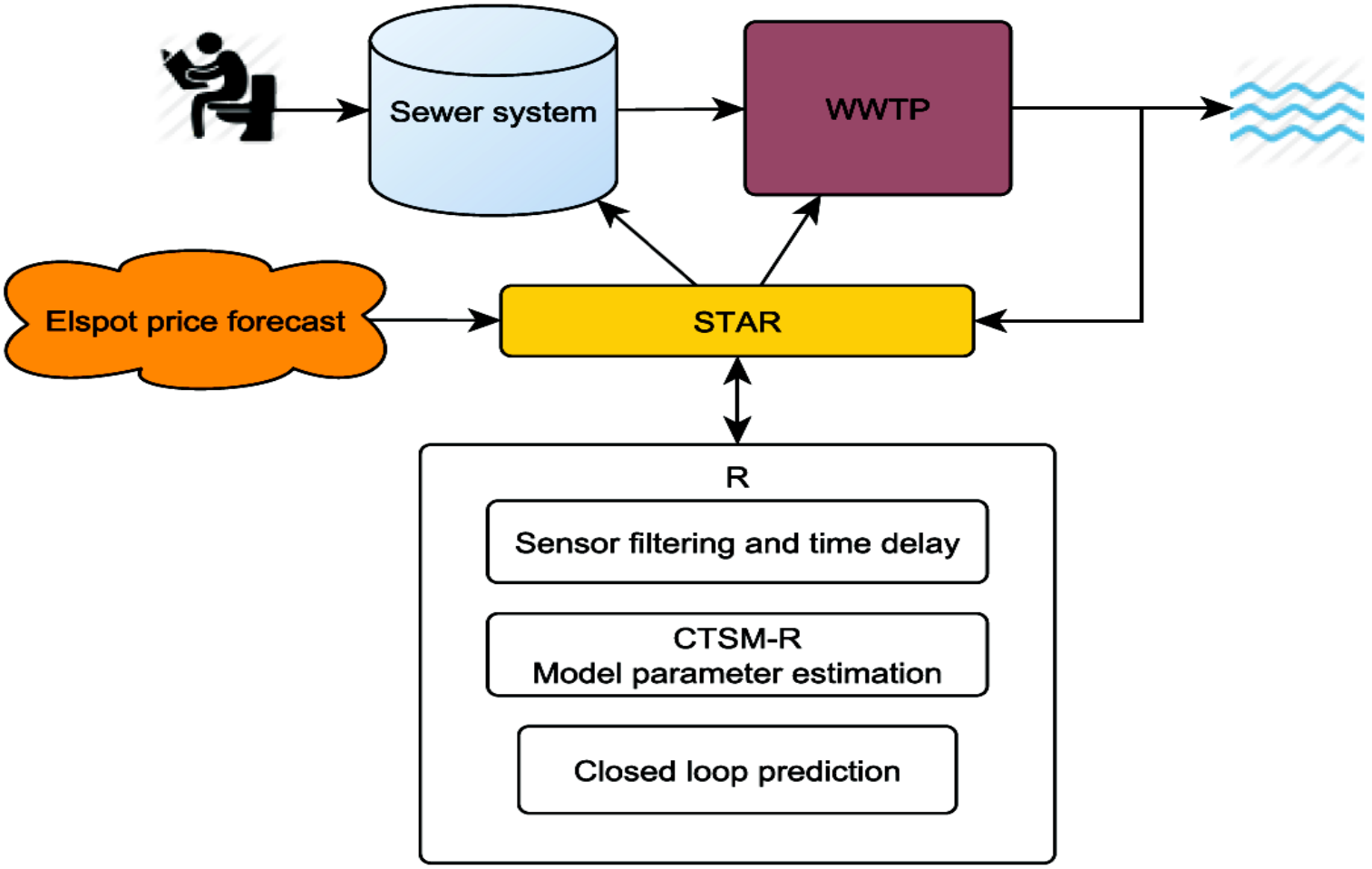
# Wastewater Treatment Plants

# Kolding WWTP

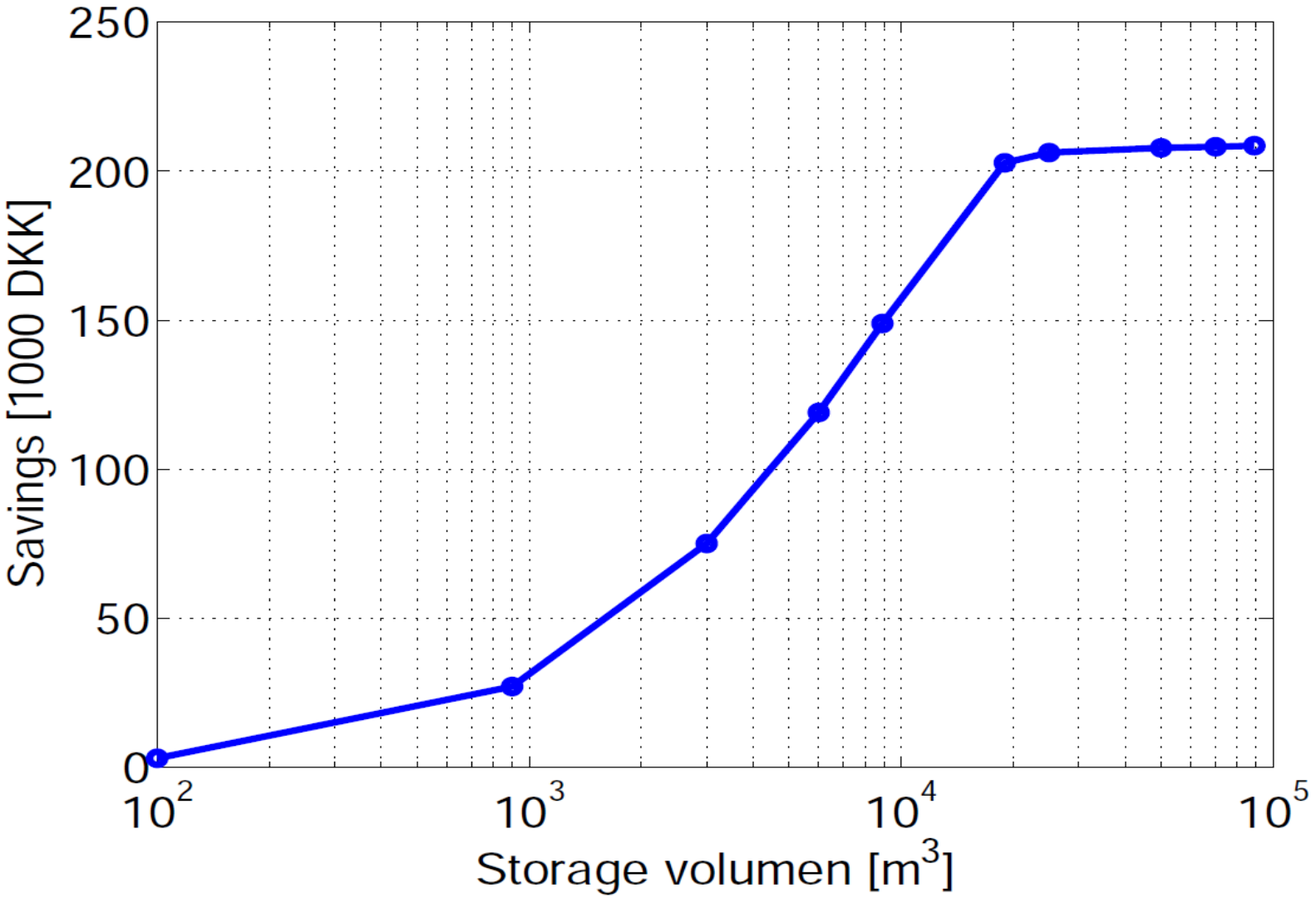
# Waste-2-Energy



# Energy Flexibility in Wastewater Treatment

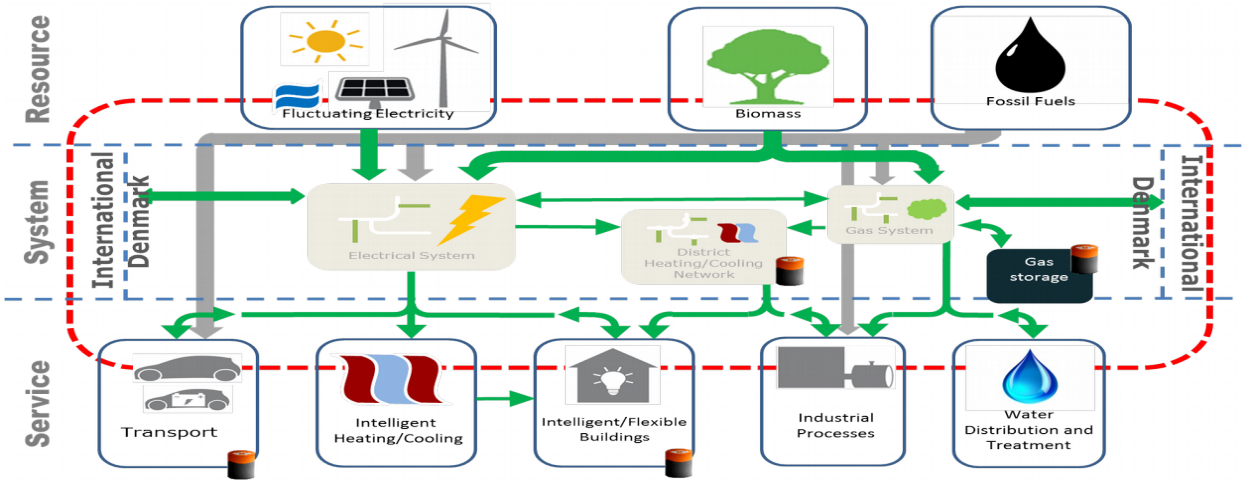


# Sewer System Annual Elspot Savings



# Further Aspects

# (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

Ingeniøren
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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.

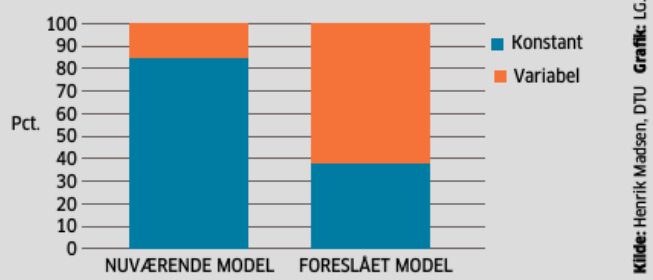
Det nye forslag er baseret på møder og diskussioner med markante personer fra Danfoss, Grundfos, Kamstrup, Dansk Fjernvarme, Eniig, AffaldVarme Aarhus, Teknologisk Institut, DTU, KU, Project-Zero og Aarhus Kommune.

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. ■

LÆS SIDE 4-5

## 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

# New Energy Taxes

## Working group linked to CITIES (Board members)

- Contrary to other studies we have seen a large potential in Demand Response
- We need a better coupling between energy vectors (power, thermal, gas)
- Automatic solutions - and end-user focus important
- Dynamics prices – should be linked to eg the actual CO2 content
- Taxes should be related to the costs of removing the polution (eg. Prices for carbon capture)
- Various ‘products’ should be offered (like fixed price, varying, high cap, …)
- Taxes should be added once and similarly - when imported to the energy system
- Taxes must be adaptive to changes in the technology
- Important to include LCA based costs (fra vugge til grav analyser)
- 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)

# Taxes and the Transformation

- A procedure for data intelligent control of power load, using the Smart-Energy OS (SE-OS) setup, is suggested.
- We would like to test and demonstrate solutions in a large Transformation Zone and Period close to many of the leading energy companies – Region Midtjylland (plus maybe Region Syddanmark) is ideal.
- The zone has to be representative – and the scale is important
- We would like to establish Testcenter Denmark near Kolding (10.000 m2 facilities for research, 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

centerdanmark
intelligent energi

- Fra Forskning til kommercialisering i real-life test miljø

MASTER PRÆSENTATION


Gudsø Engvej 15
Dansk Fjernvarme
EWii
Taulov
DONG
Center Danmark
EnergiNet.dk
Skærbæk værket
Smidstrup
Fredericia
Kolding
Middelfart
E45
E20

# Test i et mini samfund beliggende på 30 Hektar naturgrund

- Test i et fungerende driftsmiljø bestående af 16 forskellige typer bygninger, Total 9963 m²

centerdanmark
intelligent energi

1. Privathus, 183 m².
2. Privathus, 153 m²
3. Privathus, 166 m²
4. Gård 140 m²
5. Gård 4-længet 231 m²
6. Rækkehus 140 m²
7. Rækkehus 130 m²
8. Depot 140 m²
9. Kontor 110 m²
10. Lager 450 m²
11. Erhverv produktion 450 m²
12. Privat hus 160 m²
13. Center Danmark 4800 m²
14. Ny Gudsøgård 2600 m²
    1. Privat hus 280 m²
    2. Erhverv 280 m²
    3. Stald 280 m²
    4. Ridehal 1700 m²
    5. Produktion Gødning
15. Vingården 110 m²
    1. Erhverv 70 m²
    2. Produktion Vin 25 m²
    3. Kølerum 5 m²
    4. Klimarum kaffe 10 m²
16. Shelter 60 m²

# For more information …

See for instance

www.smart-cities-centre.org

…or contact

- Henrik Madsen (DTU Compute)

  hmad@dtu.dk

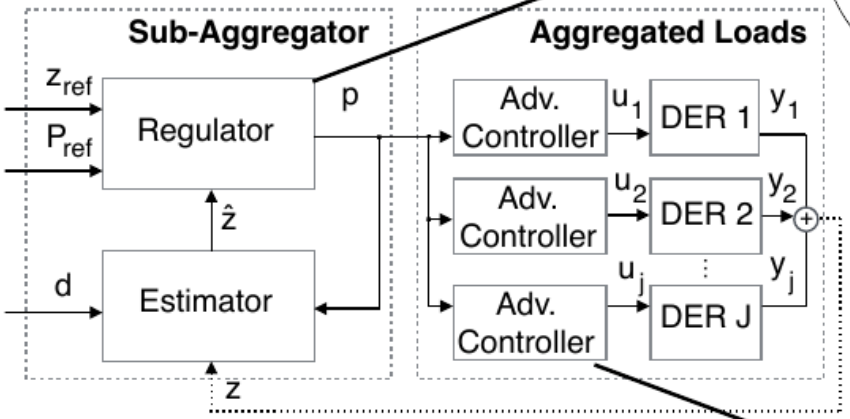
Acknowledgement - DSF 1305-00027B


Your global warming impact
Electricity
Car
Vegetables
Meat
Airplanes

Tomorrow

# 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.

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

# 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, ...)
- .....