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Flexible Energy Denmark

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https://www.flexibleenergydenmark.dk/

https://www.centerdenmark.com/

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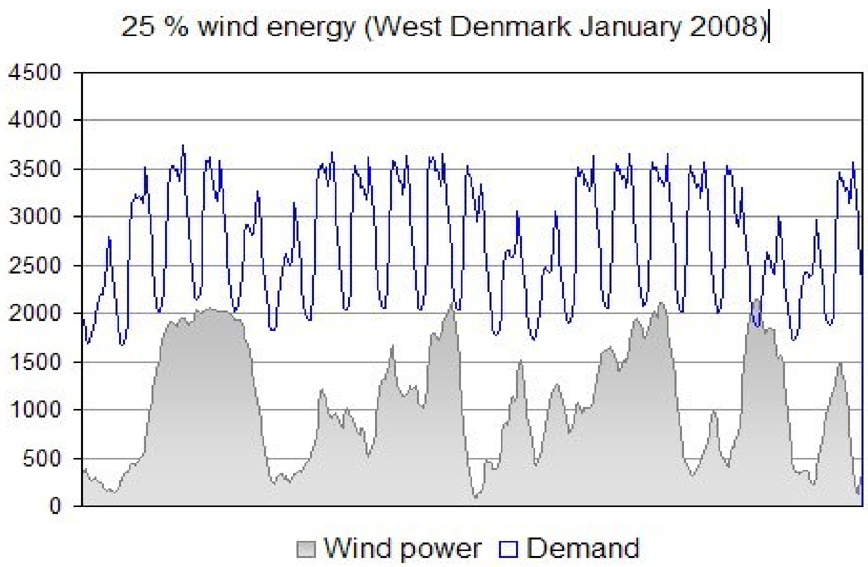
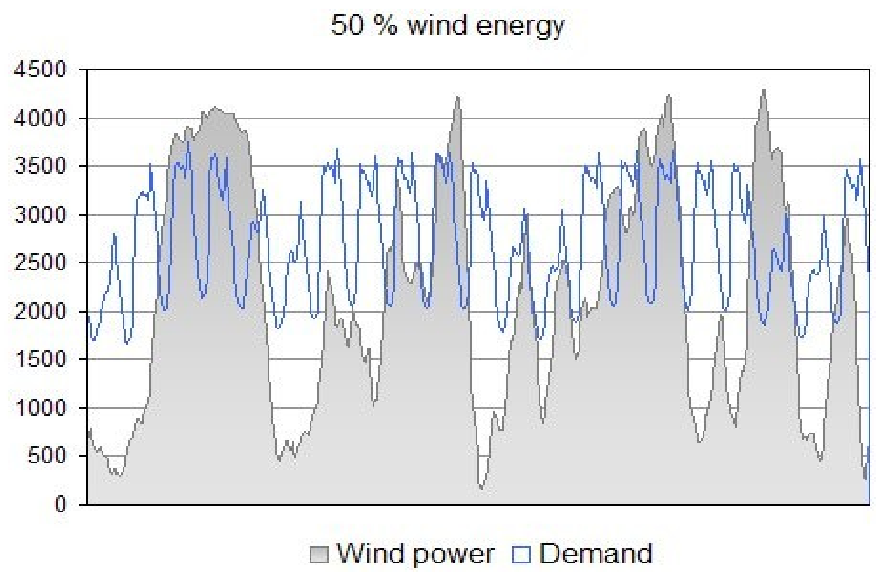
Energy system challenges

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 2020 Forecasting and Flexibility are essential

That's the topics of 'Flexible Energy Denmark'

(For several days the wind power production is more than 100 pct of the power load)

Challenges

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

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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.

Many projects have concluded:

Almost no Flexibility

Data-Intelligent and Flexible Energy Systems

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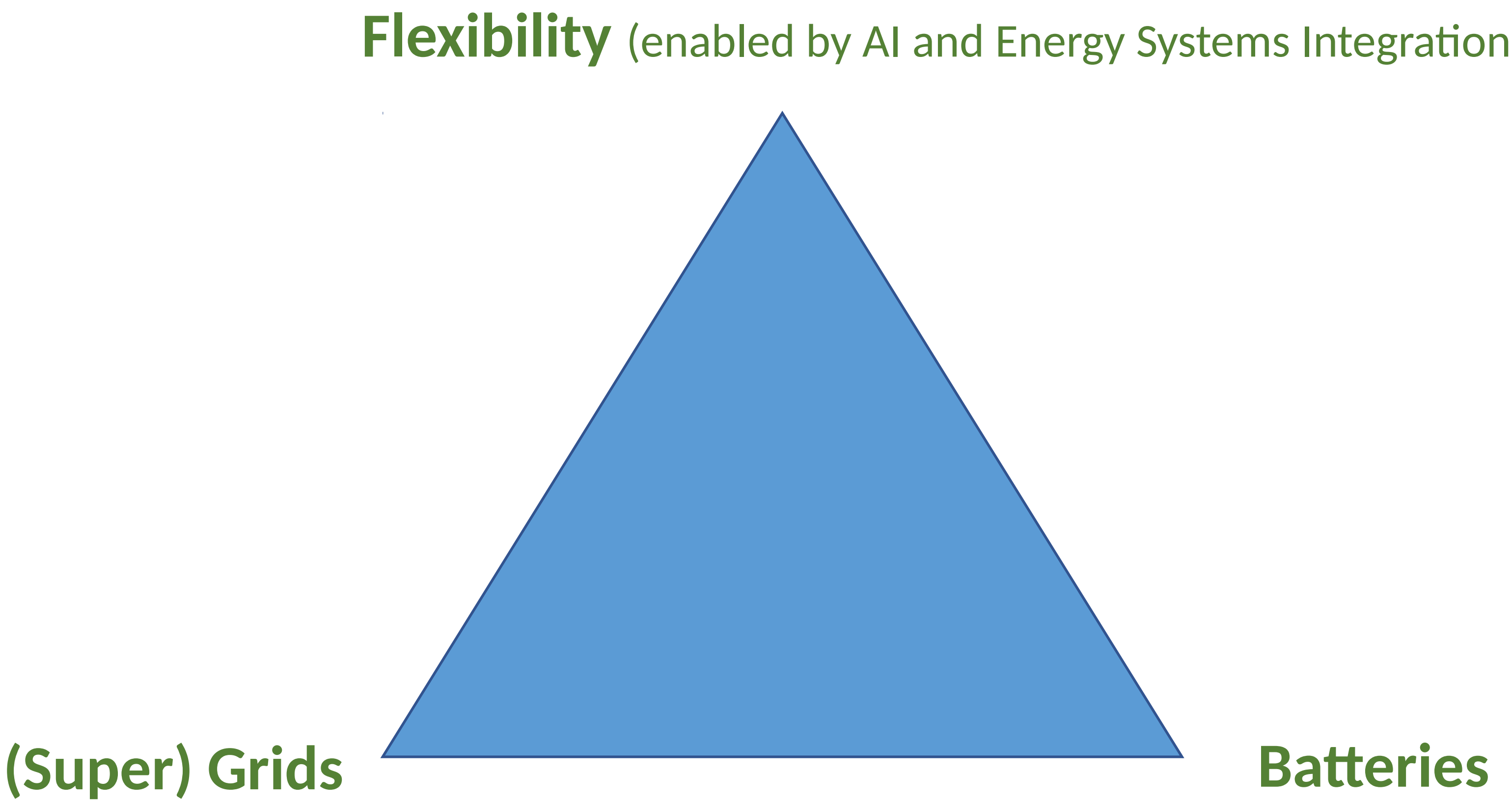
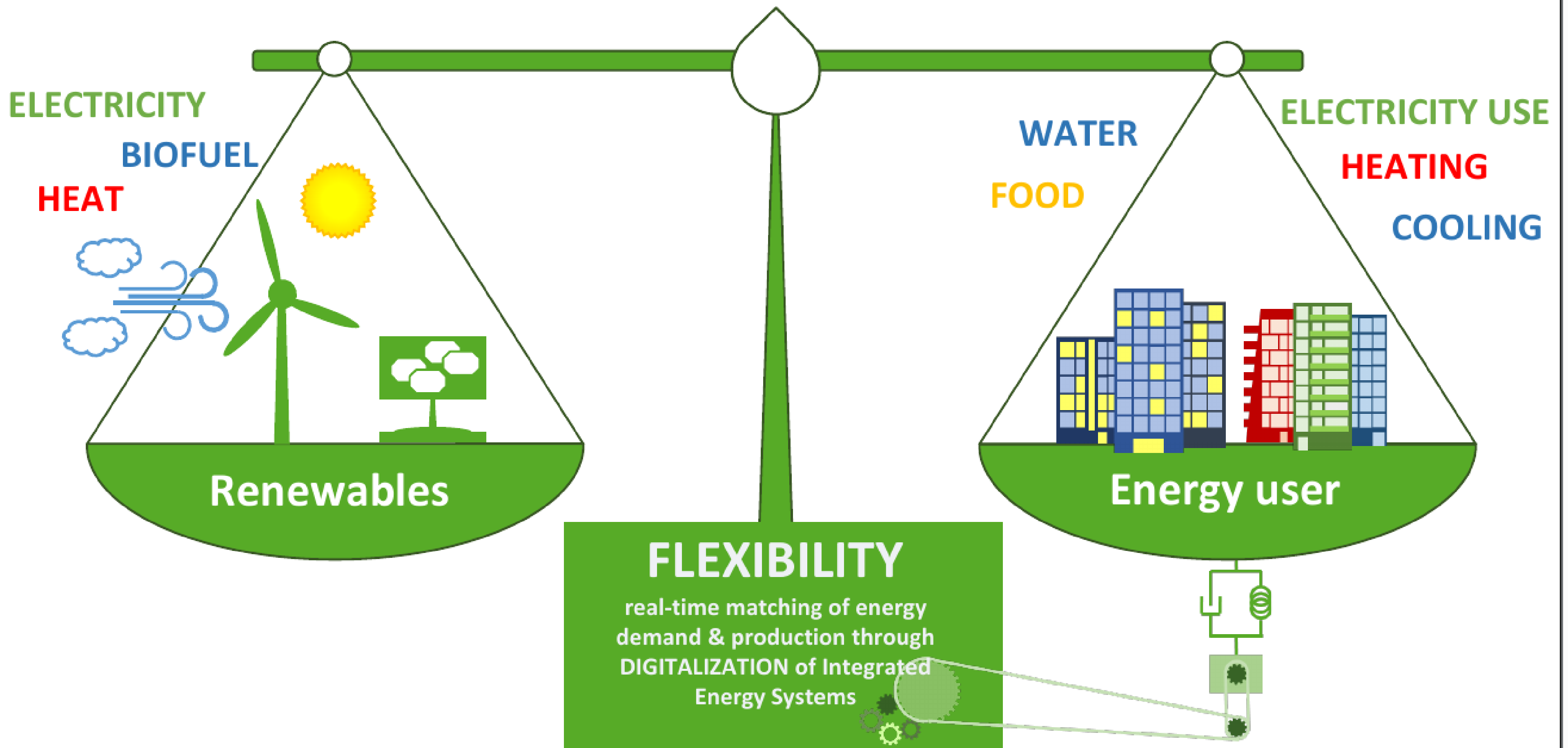
Space of Solutions

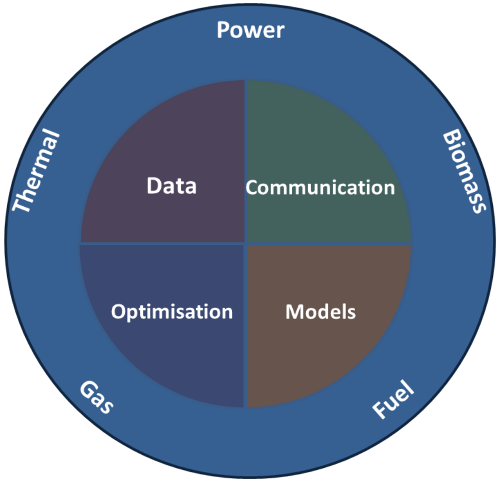
:

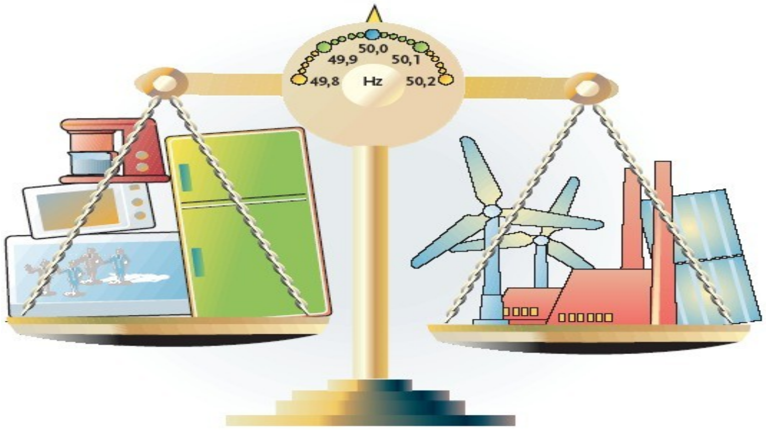


The Challenge: Denmark Fossil Free 2050



Use of AI and Energy Systems Integration

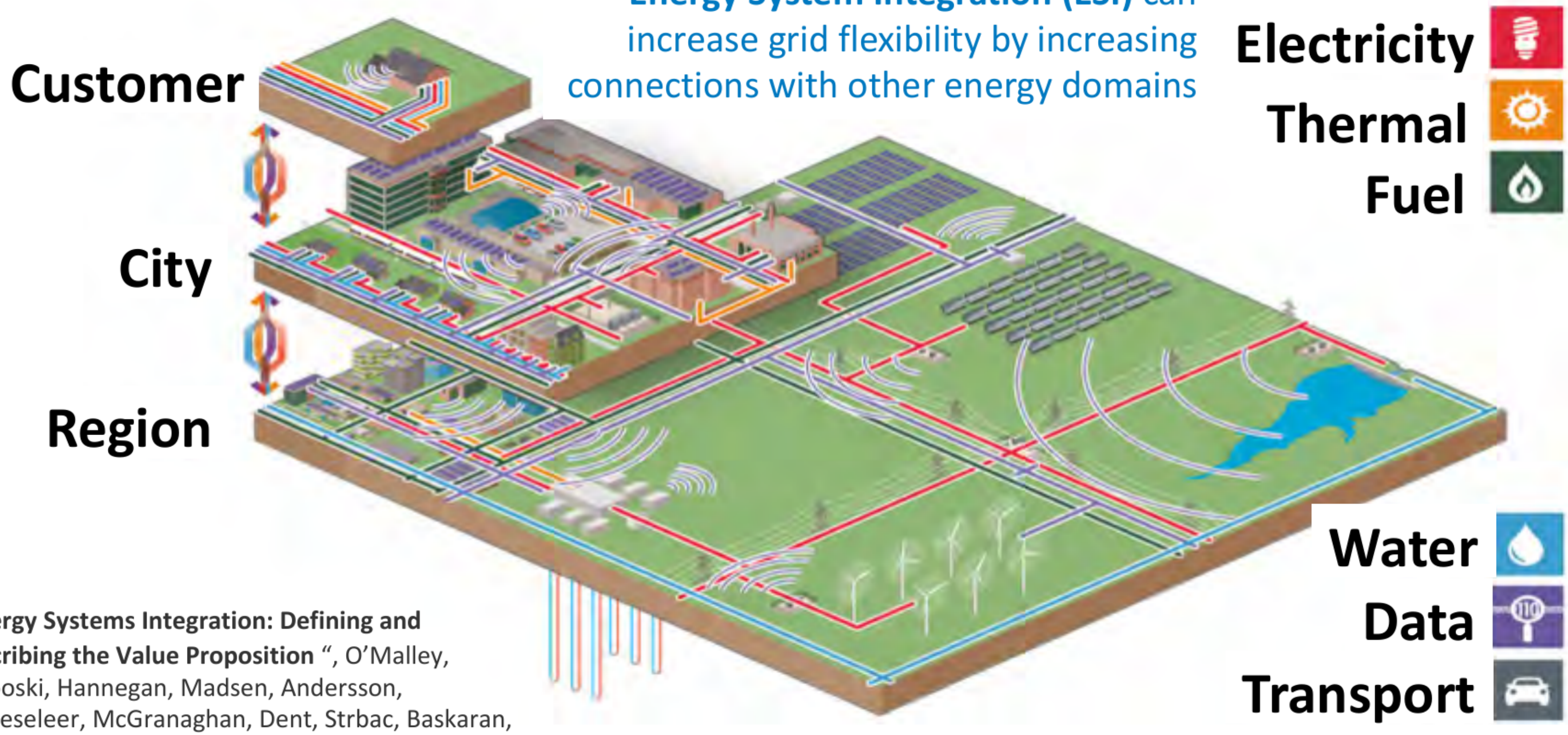




By **intelligently integrating** currently distinct **energy systems** (heat, power, gas and biomass) using **AI and ICT solutions** we can **unlock the flexibility** needed for integrating large shares of fluctuating renewable energy sources

Energy Systems Integration

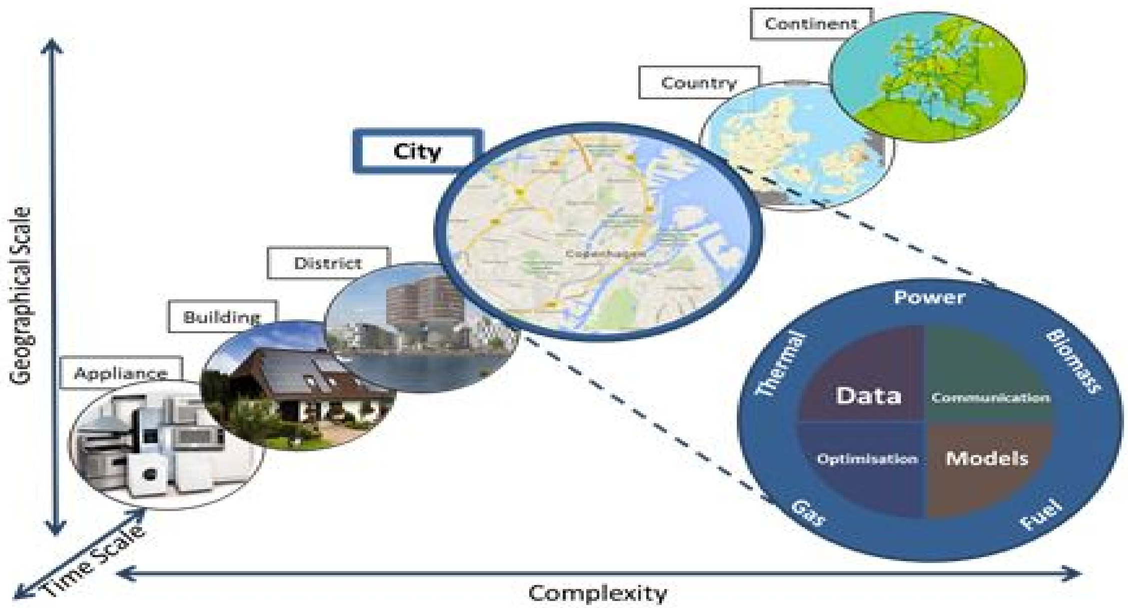
Energy System Integration (ESI) can increase grid flexibility by increasing connections with other energy domains



"**Energy Systems Integration: Defining and Describing the Value Proposition** ", O'Malley, Kroposki, Hannegan, Madsen, Andersson, D'haeseleer, McGranaghan, Dent, Strbac, Baskaran, Rinker., NREL/TP-5D00-66616. June 2016

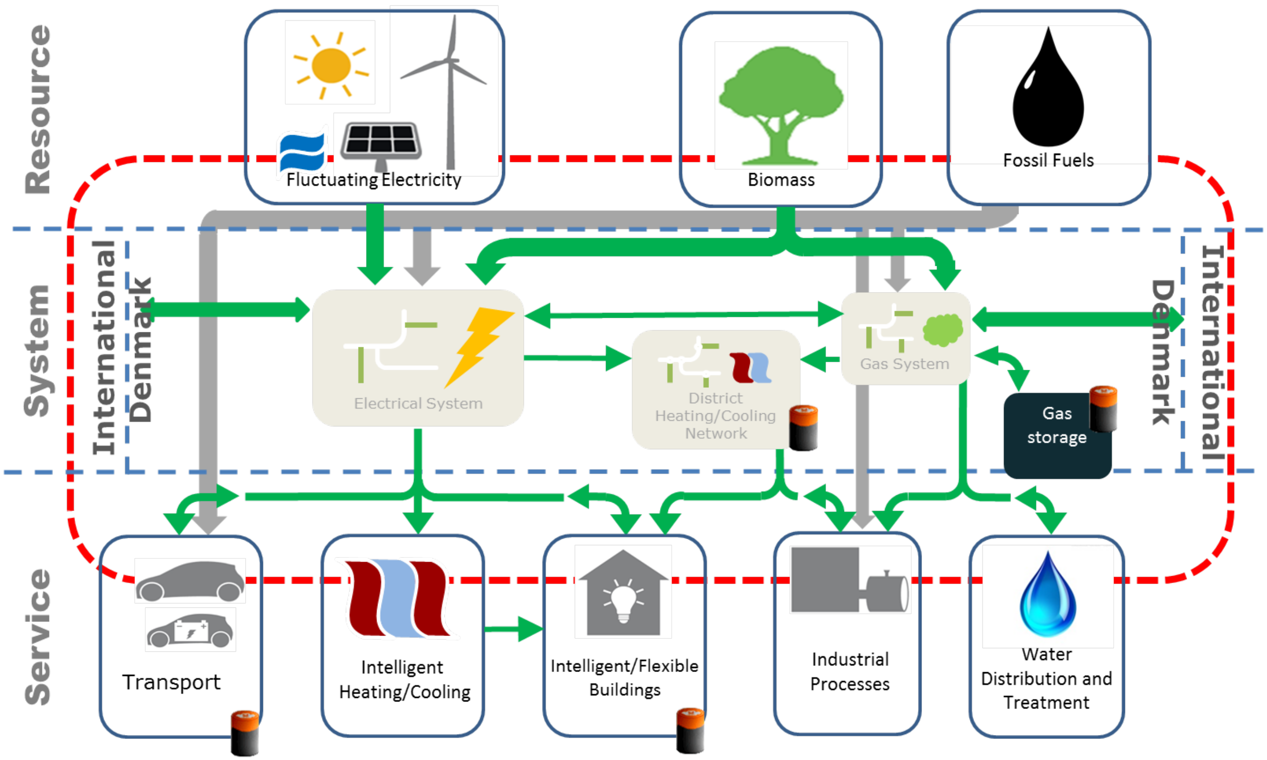
Temporal and Spatial Scales

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

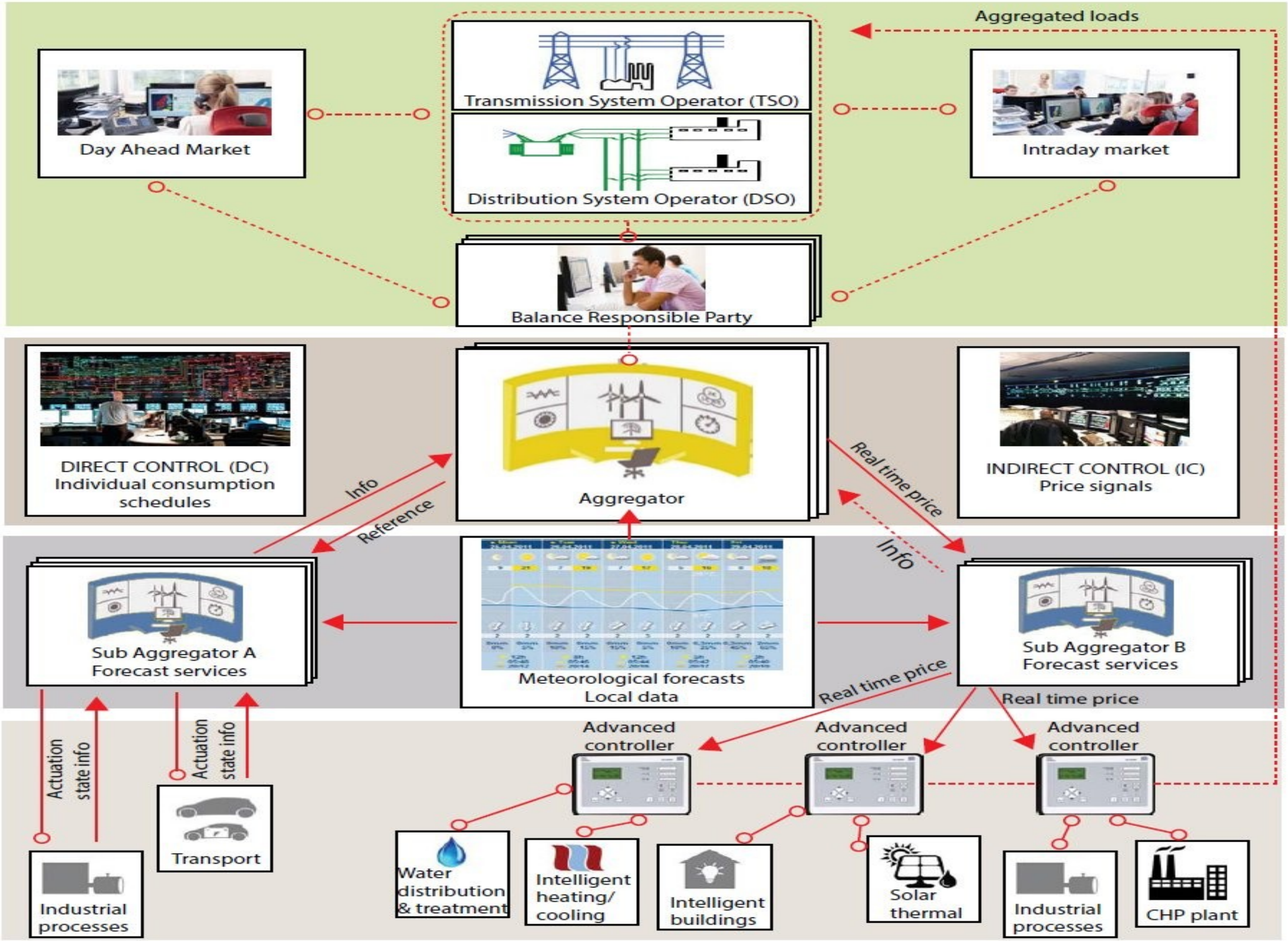


Energy System Models for Real Time Applications and Data Assimilation

- **Grey-box models are simplified models for the individual components facilitating system integration and use of sensor data**



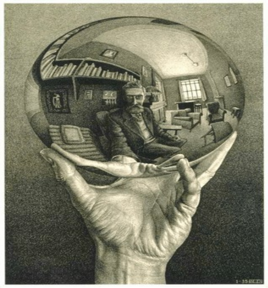
Smart-Energy OS



```
# slow approach, but we are sure things get do
# 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)
```

SE-OS Characteristics

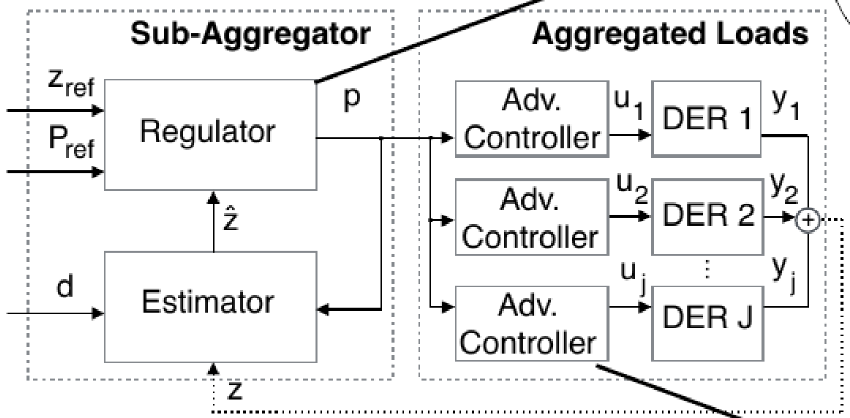
- AI and Grey-Box models for data-intelligence
- Nested sequence of systems – Systems of Systems
- Hierarchy of optimization (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud, Fog, Edge based (IoT, IoS) solutions – eg. for forecasting and control
- Facilitates energy systems integration (power, gas, thermal, ...)



Proposed methodology
Control-based methodology

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

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



$$\min_{u} \quad E[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)]$$

$$\begin{aligned} \text{s.t.} \quad x_{k+1} &= Ax_k + Bu_k + Ed_k, \\ y_k &= Cx_k, \\ y_k^{min} \leq y_k &\leq y_k^{max}, \\ u_k^{min} \leq u_k &\leq u_k^{max} \end{aligned}$$

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

Flexibility Function

Case Study:
Price-based Control of Power Consumption (Peak Shaving)

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Energi- og Forsyningspolitisk Netværk, Sept. 2020

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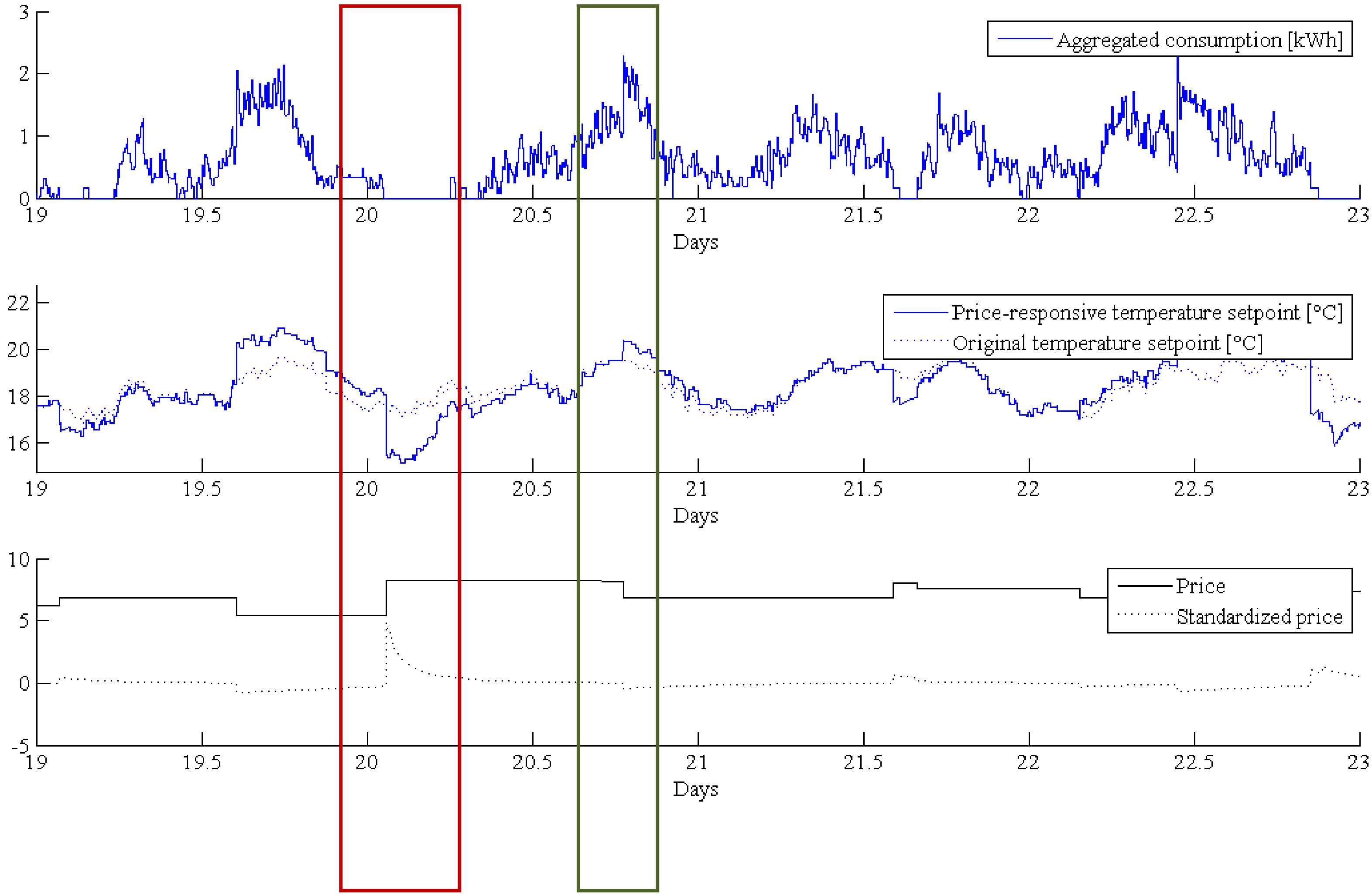
Aggregation (over 20 houses)



Flexibility Function

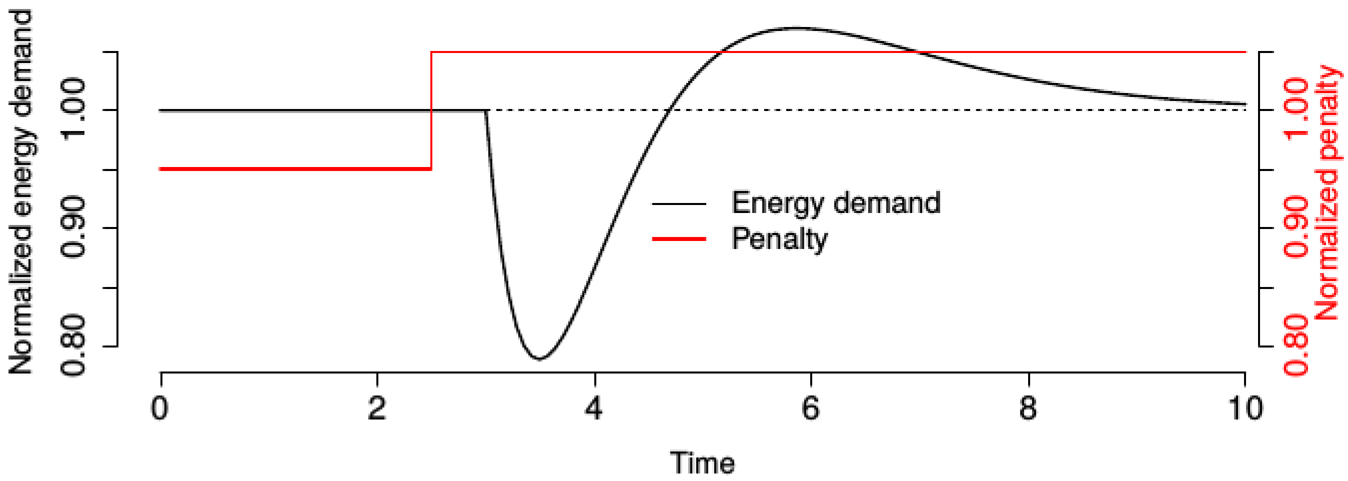
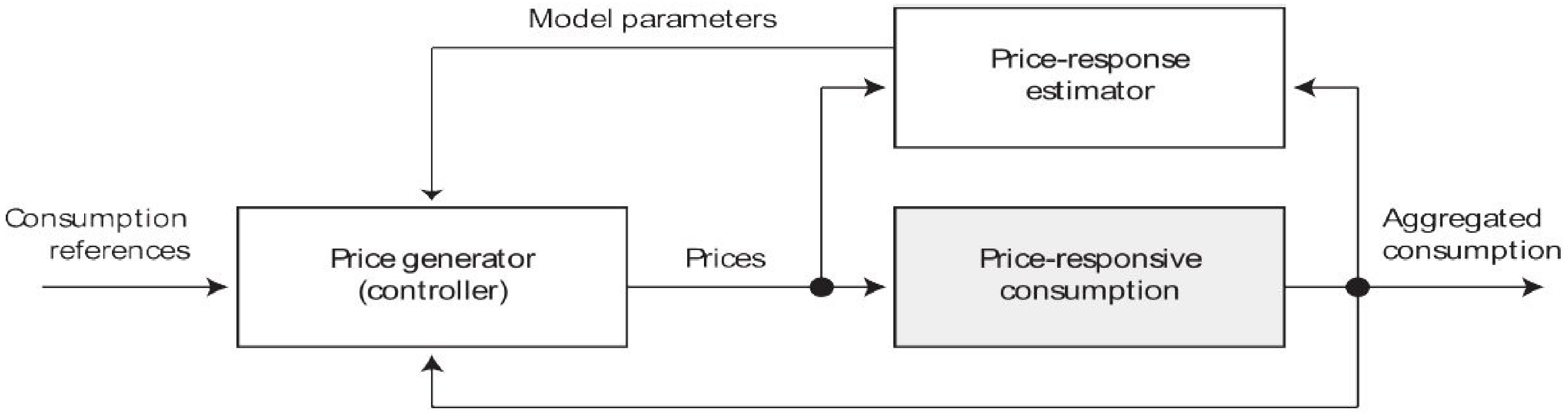
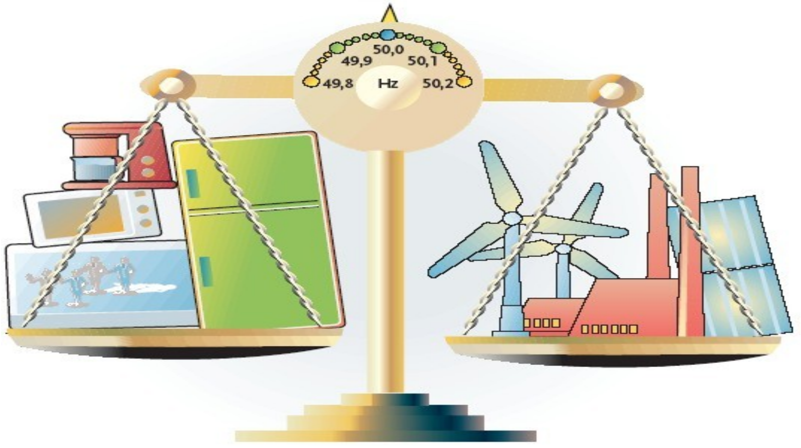


Figure 2: The energy consumption before and after an increase in penalty. The red line shows the normalized penalty while the black line shows the normalized energy consumption. The time scale could be very short with the units being seconds or longer with units of hours. At time 2.5 the penalty is increased,

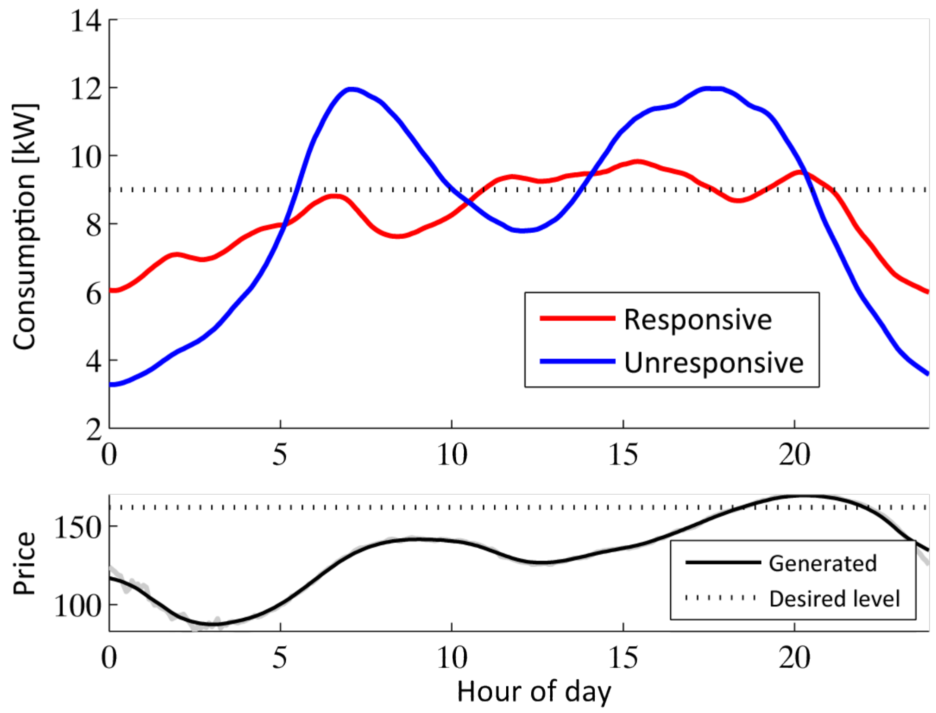
Control of Power Consumption



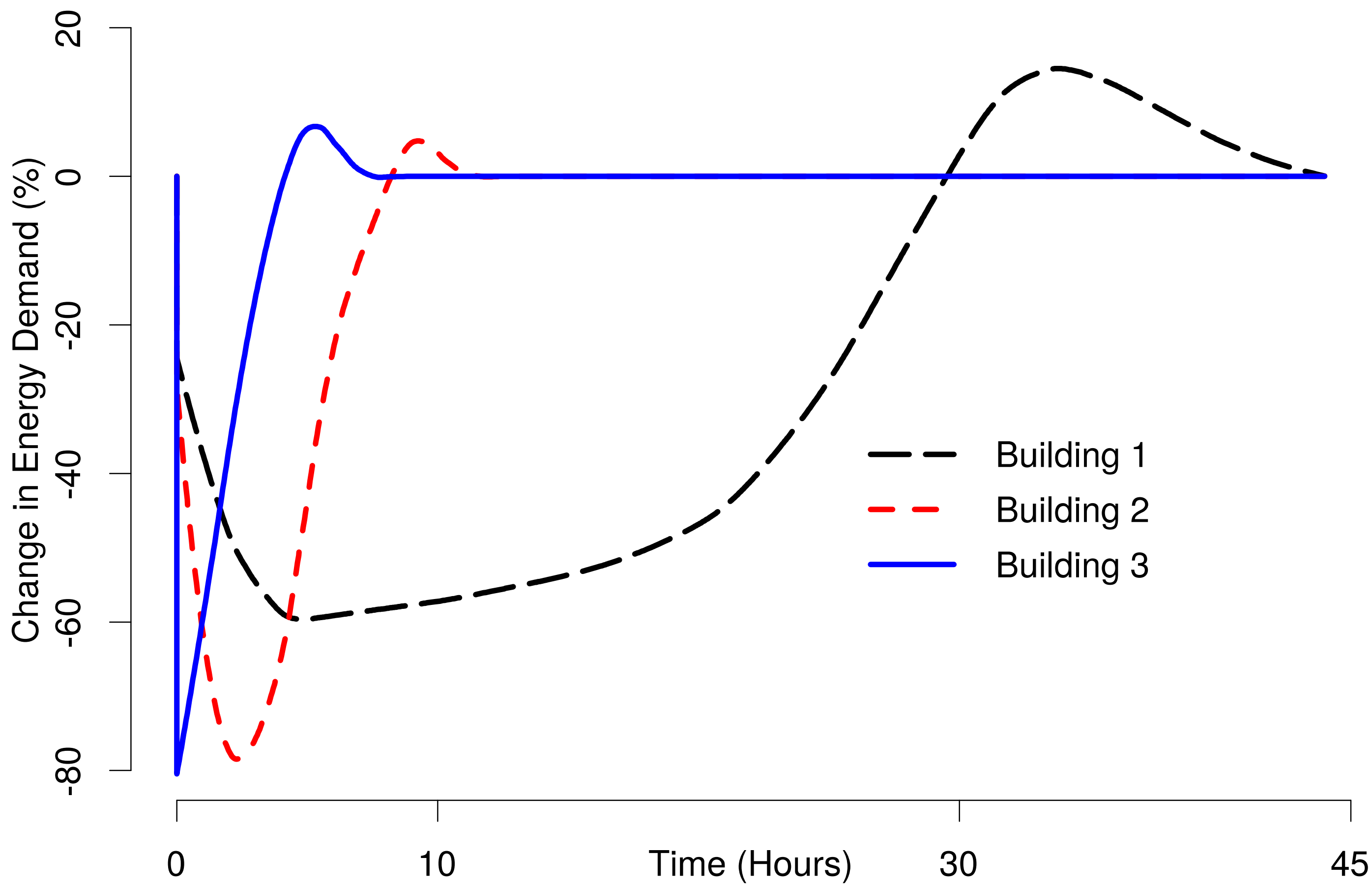


Control performance

Considerable **reduction in peak consumption**



Examples: Flexibility Function



Penalty (examples)

- **Real time CO_2**. If the real time (marginal) CO_2 emission related to the actual electricity production is used as penalty, then, a smart building will minimize the total carbon emission related to the power consumption. Hence, the building will be *emission efficient*.
- **Real time price**. If a real time price is used as penalty, the objective is obviously to minimize the total cost. Hence, the building is *cost efficient*.
- **Constant**. If a constant penalty is used, then, the controllers would simply minimize the total energy consumption. The smart building is, then, *energy efficient*.

Smart Grid Applications

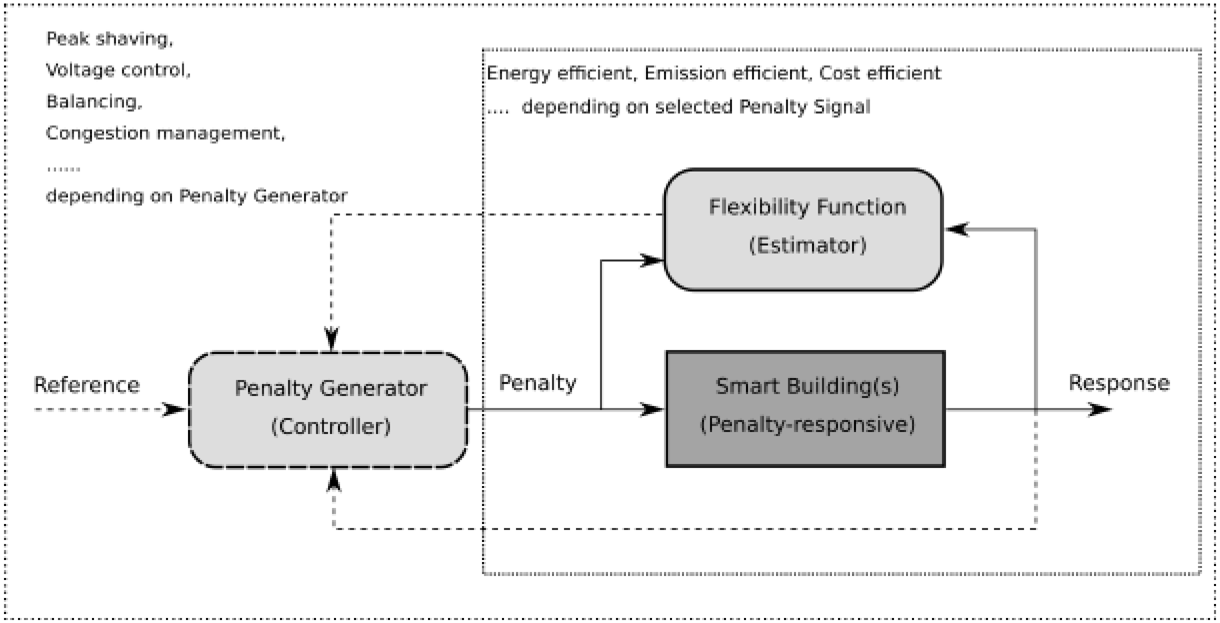
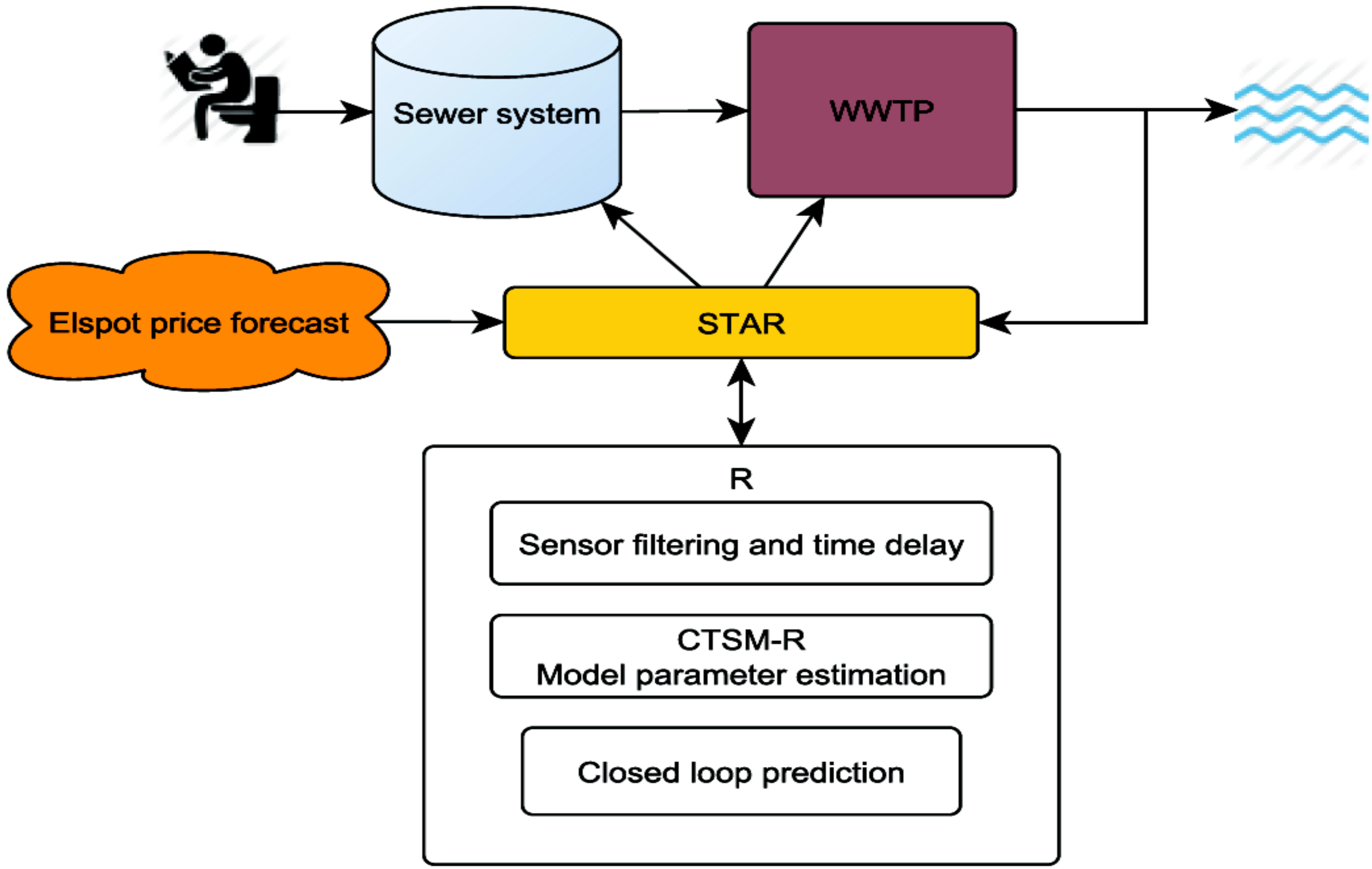
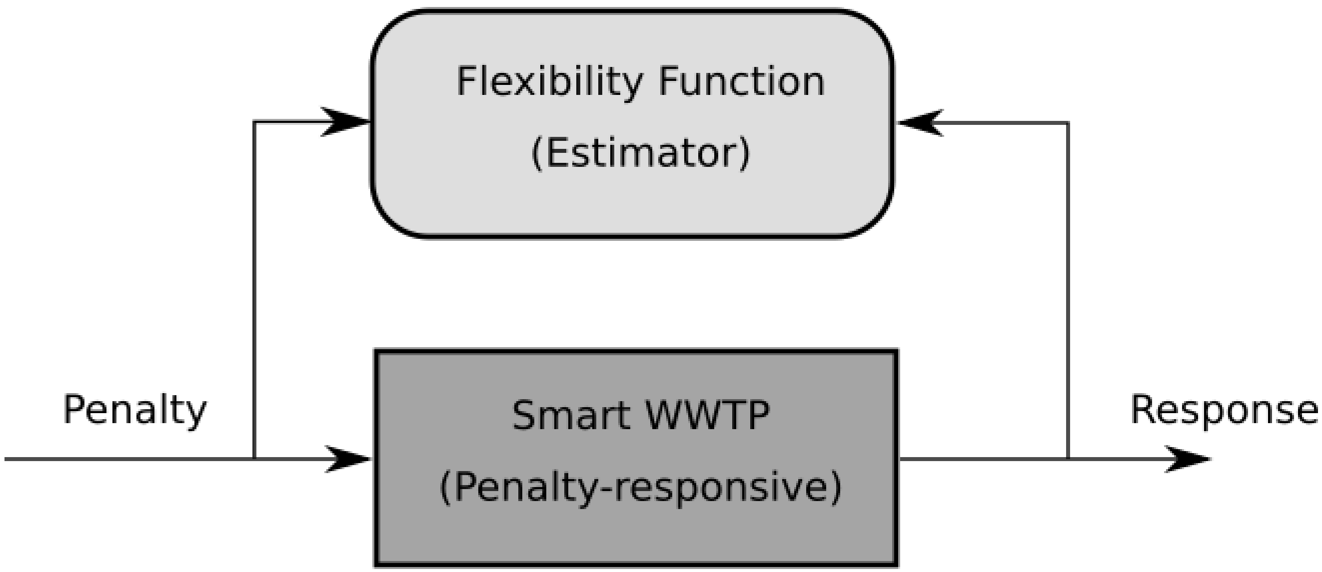


Figure 8: Smart buildings and penalty signals.

Energy Flexibility in Wastewater Treatment



Flexibility Function



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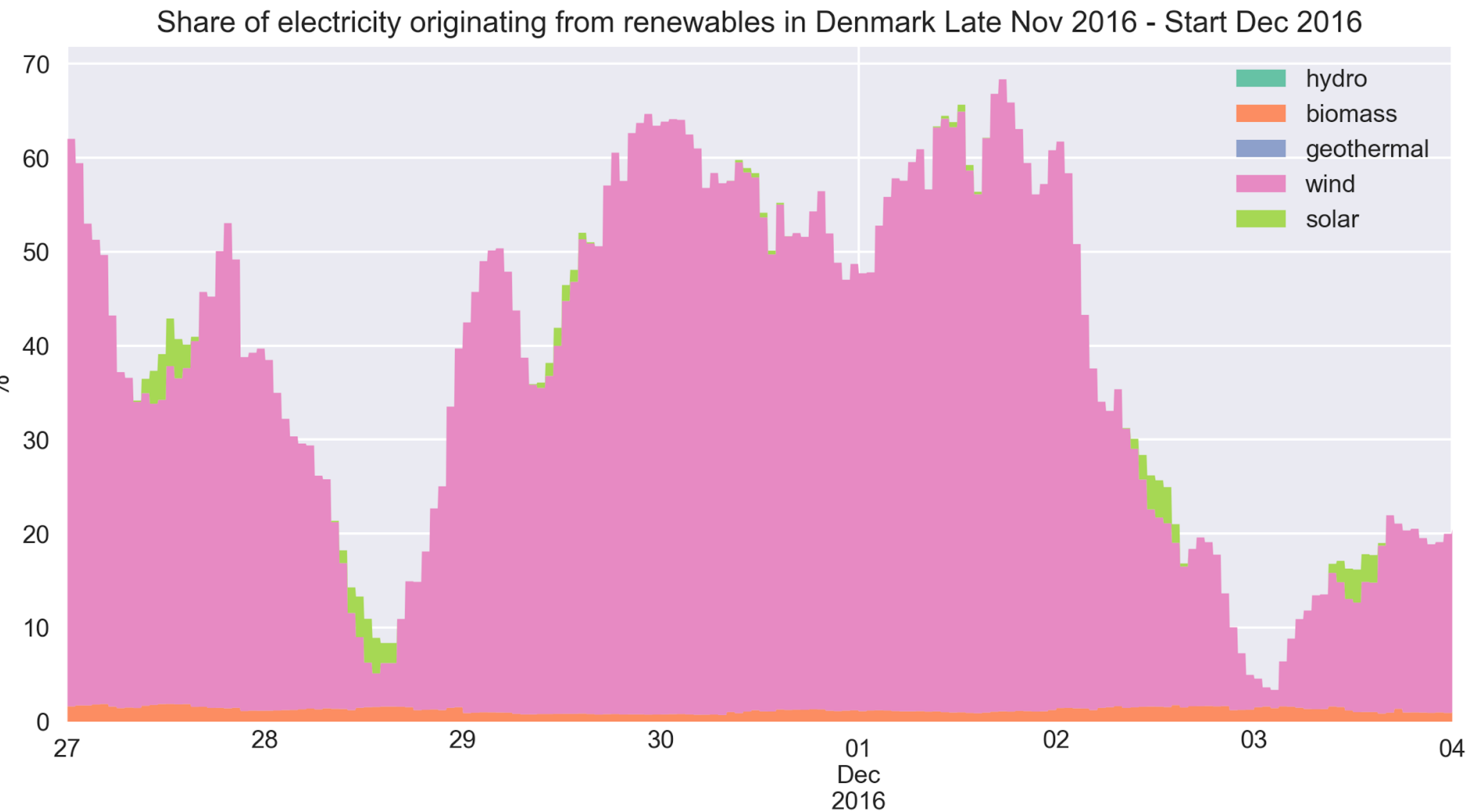
Case study

Storage of Wind Energy in Swimming Pools (Cost/CO2 minimization)

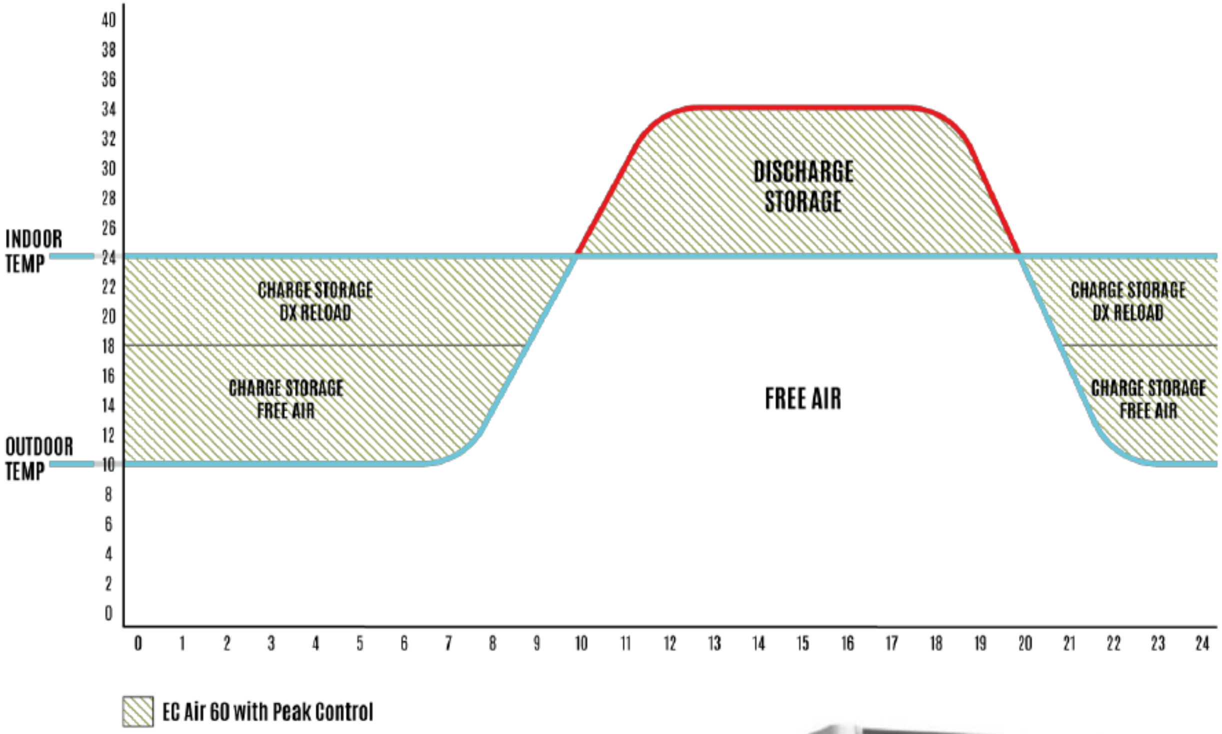


Source: pro.electicitymap.org

Example: CO2-based control (10-20 pct CO2 reduction)

Data Centers and Data-Intelligent Operation

Large savings (90-95 pct) related to cooling of data centers using PCM (Center Denmark/EnergyCOOL)



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Integrated energy systems powered by intelligent data

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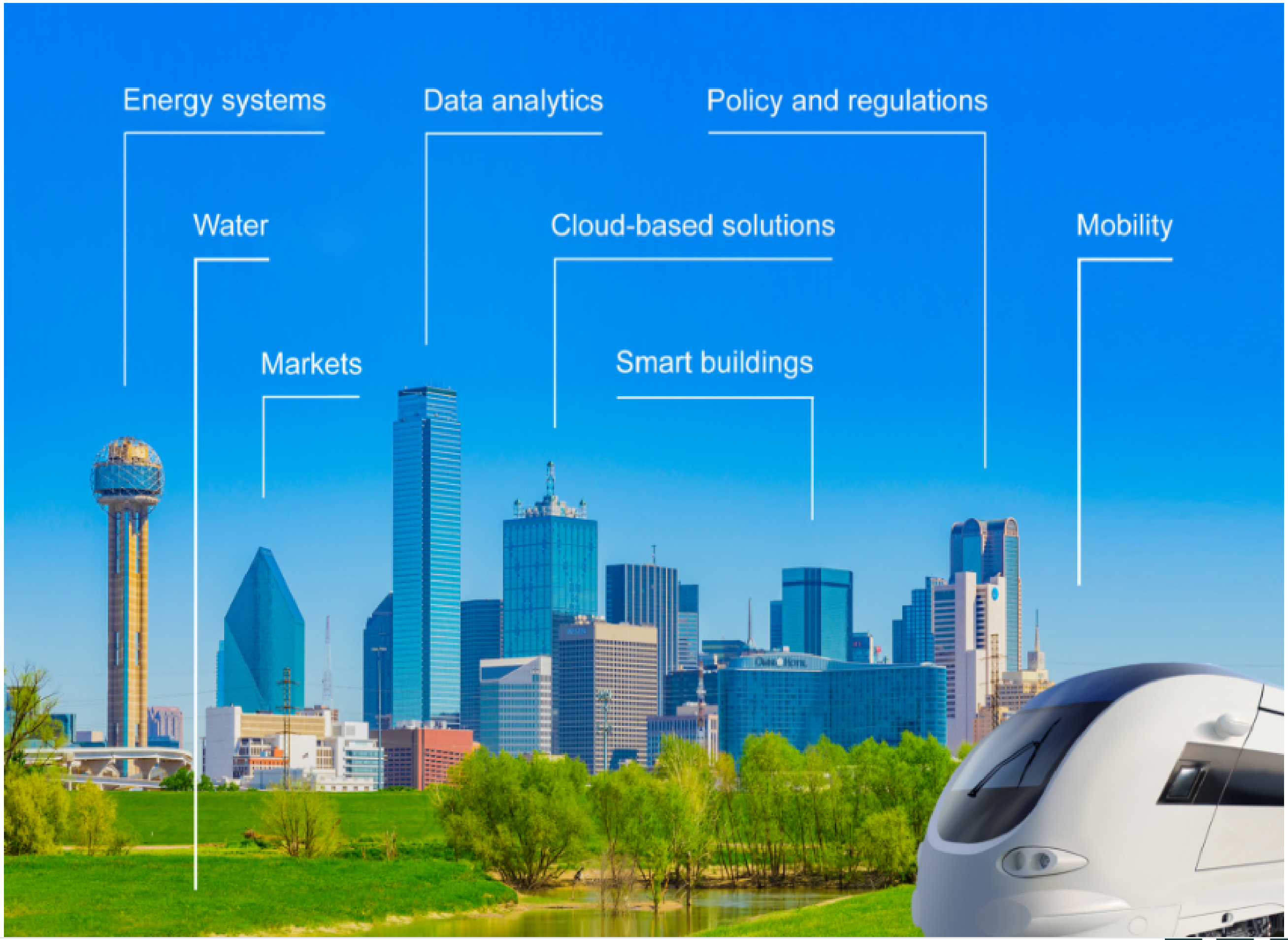

Center Denmark

National Digitalization Hub for Accelerating the Green Transition by Green Innovation

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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
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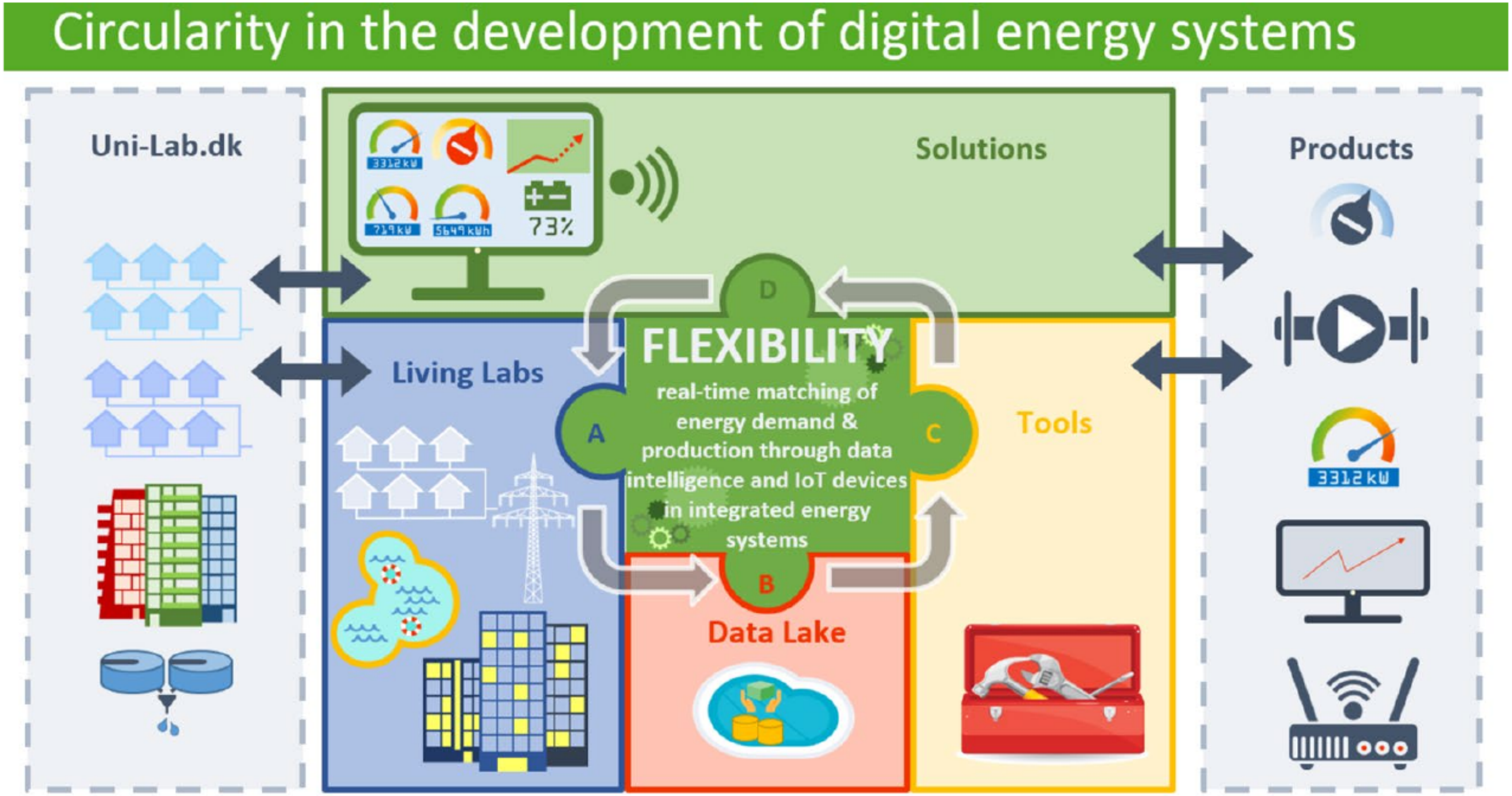
DTU


FORECAST
BYGNING INTELLIGENS
INTERFACE
AI
FORECAST
FORECAST
FORECAST

Center Danmark – Digitaliserings Hub



Uni-Lab.dk

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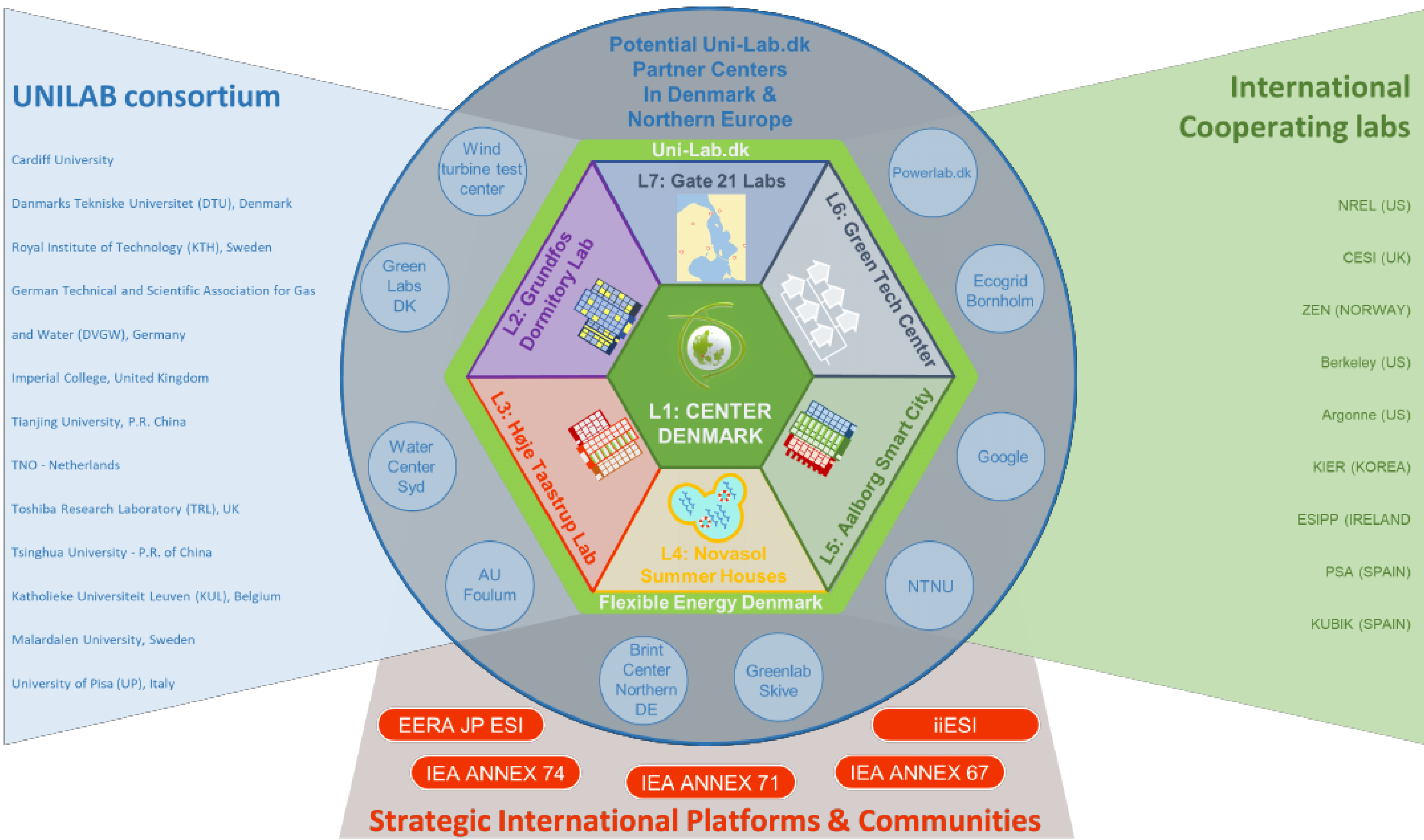
Center Denmark, Living Labs, Partnerships



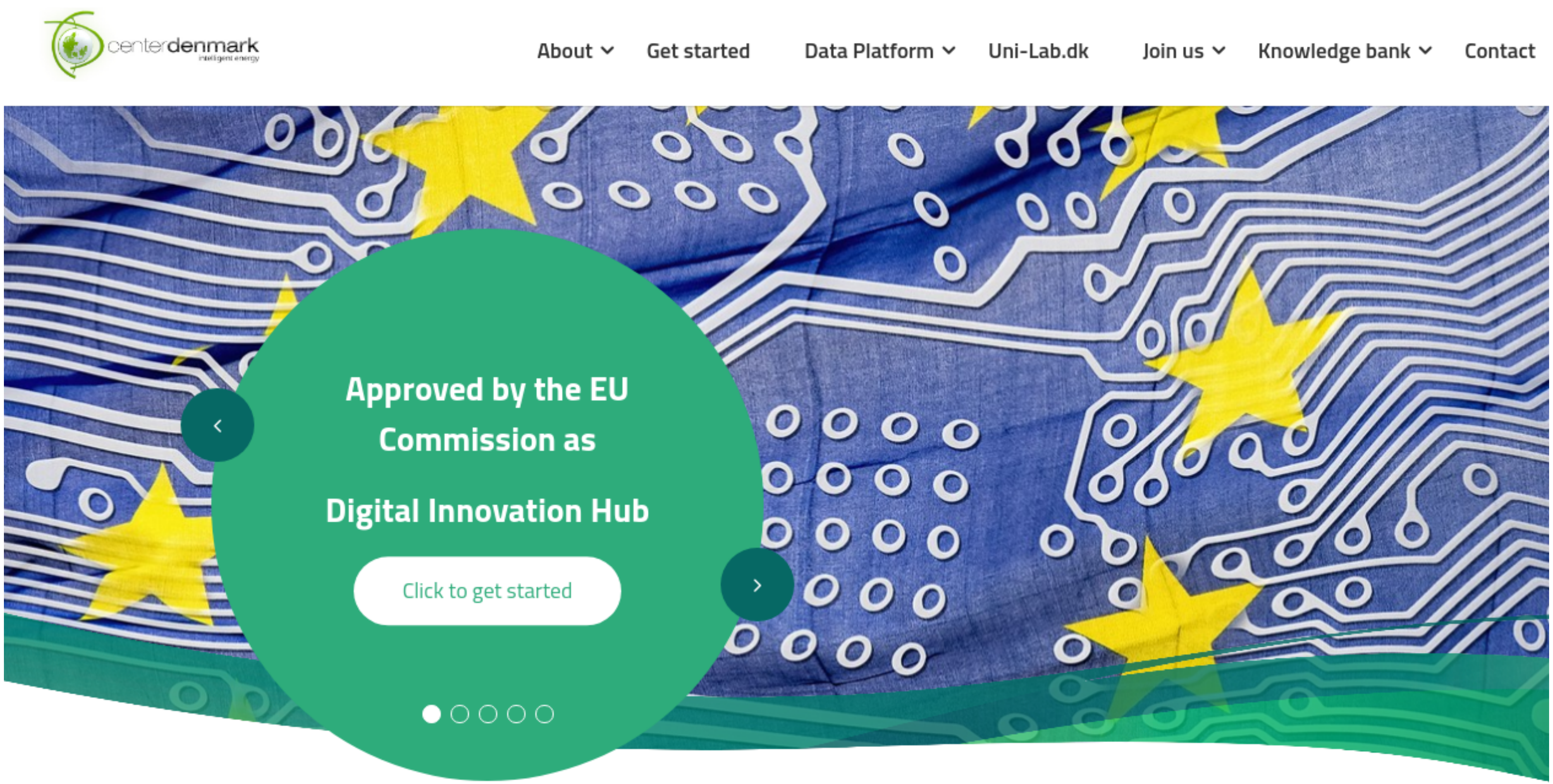
Digitalization Hub - Center Denmark

DTU

- A digitalization hub for data intelligent operation of integrated energy systems (electricity, thermal, gas, water)
- A national hub for unlocking the flexibility potential for large scale integration of fluctuating renewable energy
- Tests on framework conditions have to be representative – and scaling is important
- The new national smart energy hub is Center Denmark (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 using digitalization and a smart energy hub
- 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 setup has the unique characteristics for being the ultimate smart energy hub for test and demonstration of future smart energy solutions

Center Denmark

- Become a partner – it's free (see www.centerdenmark.com)
- It will increase possibilities for eg. EU projects and support – also since Center Denmark is approved by the Commission



Center Denmark is an independent and non-profit national research center with the aim to unify and embed research results within the field of digitalization of energy systems and put

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Need for Regulatory Changes – Now!

Need for Regulatory Changes

- **Today there are no incentives for being smart**. We must ensure an 'intelligent' time varying price signal (SmartEn Europe - Bruxelles)
- Average electricty price (15 pct – energy, 20 pct tariffs, 65 pct energy tax). We pay more for transport than for the energy
- Taxes are constant -> Should be linked to CO2 emission in real time. This would incentivice a smart energy system.
- Tariffs are constant -> Should be linked to energy (kWh) and capacity (kW)
- Excess heat is often not used ->

  We should harmonize the taxes

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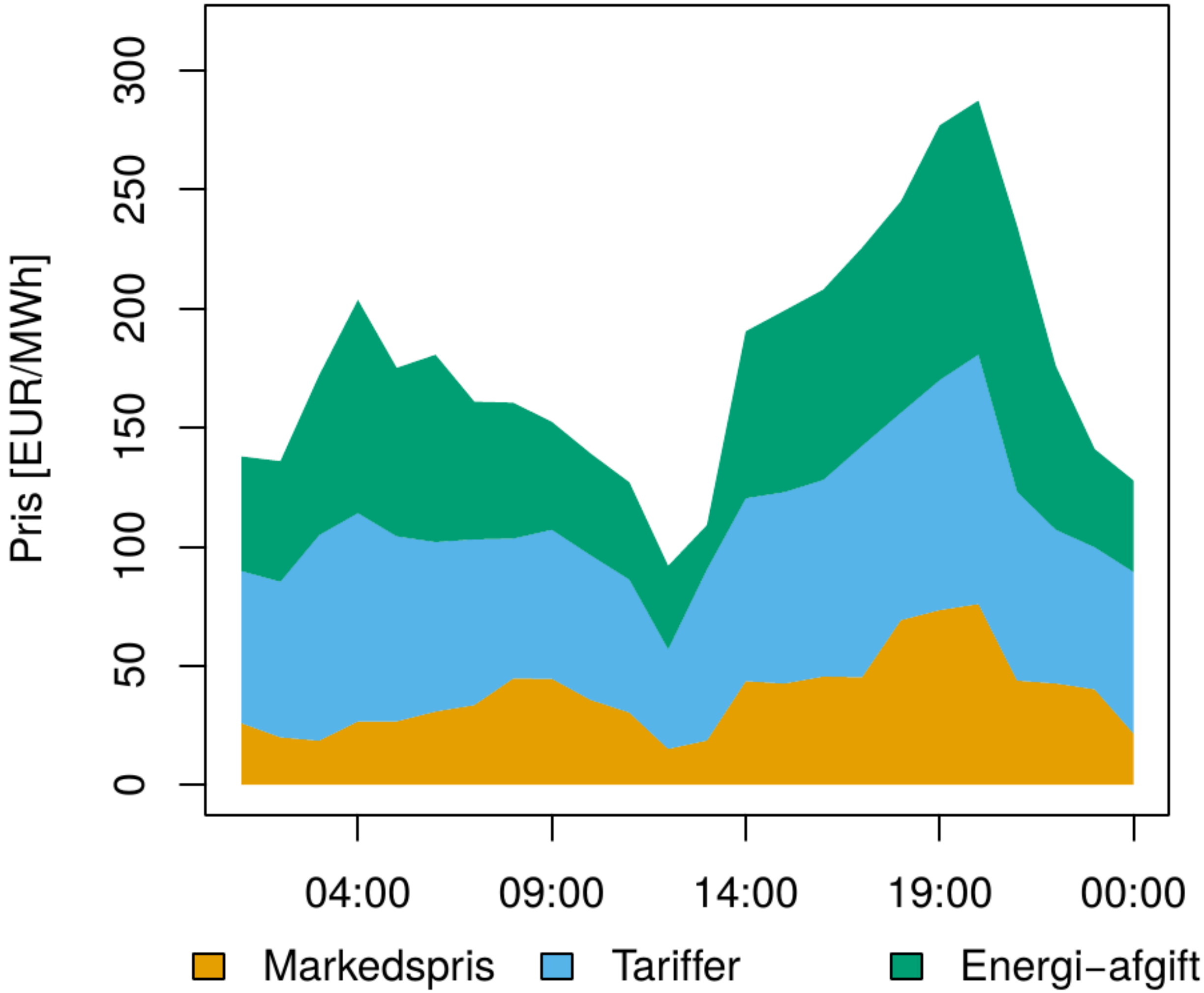
Intelligent price-signals



Markets – Needed changes

- Static -> **Dynamic**
- Deterministic -> **Stochastic**
- Linear -> **Nonlinear**
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, ...) -> **Coordination + Hierarchy**
- Speed / problem size -> **Decomposition + Control Based Solutions**
- Characterization of flexibility (bids) -> **Flexibility Functions**
- Requirements on user installations -> **One-way communication**