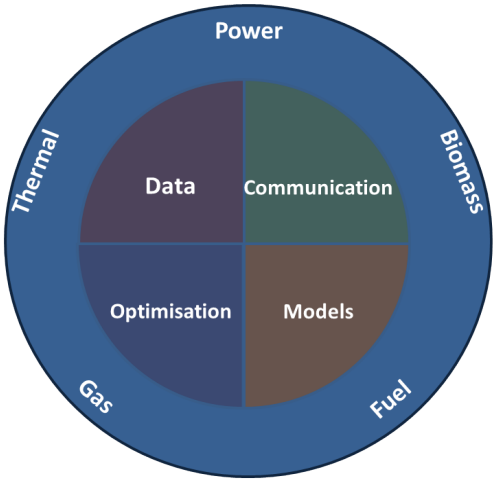
Innovation Fund Denmark

DTU

Characterization and Use of Flexibility for the Future Smart and Integrated Energy System



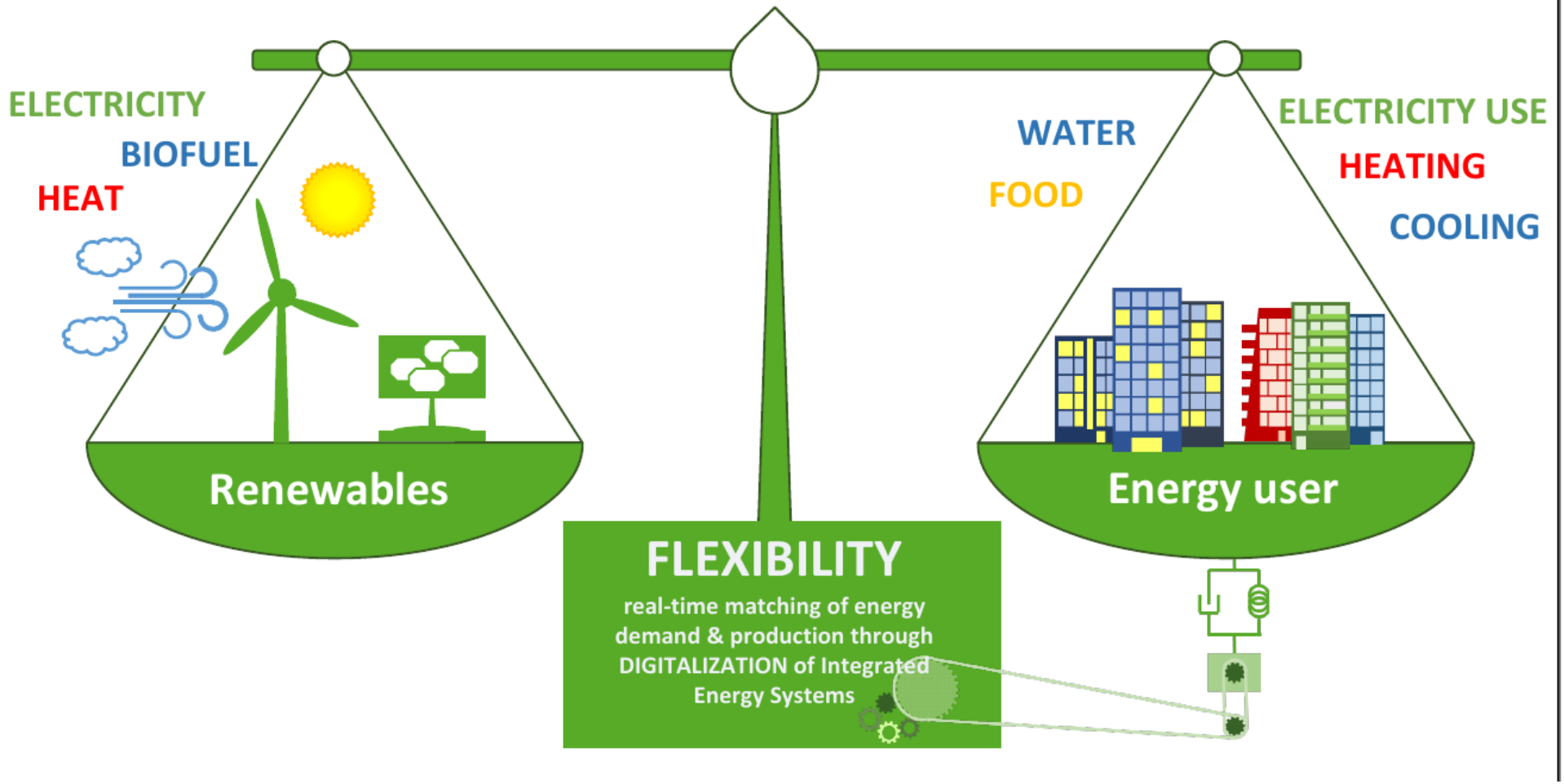
Henrik Madsen (DTU) + many others

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

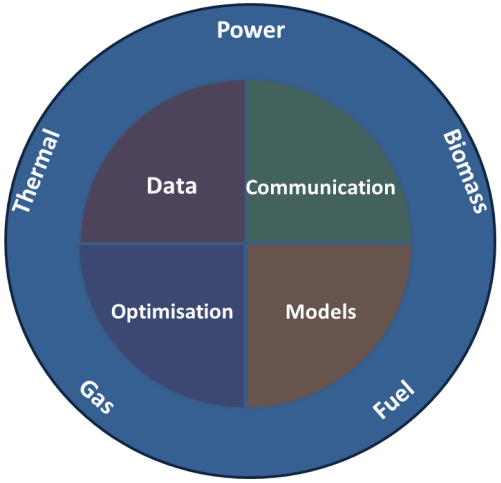
https://www.flexibleenergydenmark.dk

http://www.henrikmadsen.org

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

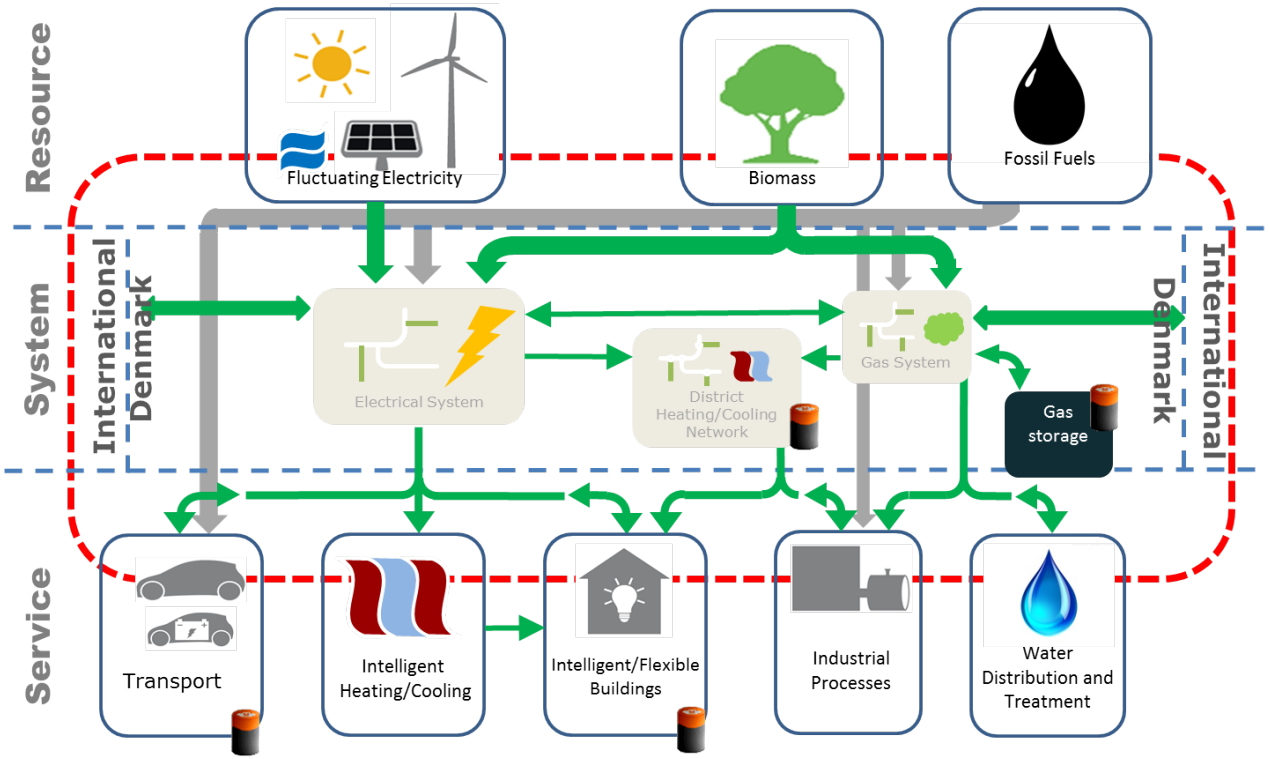
DTU

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 energy energy systems*** at **all scales**.

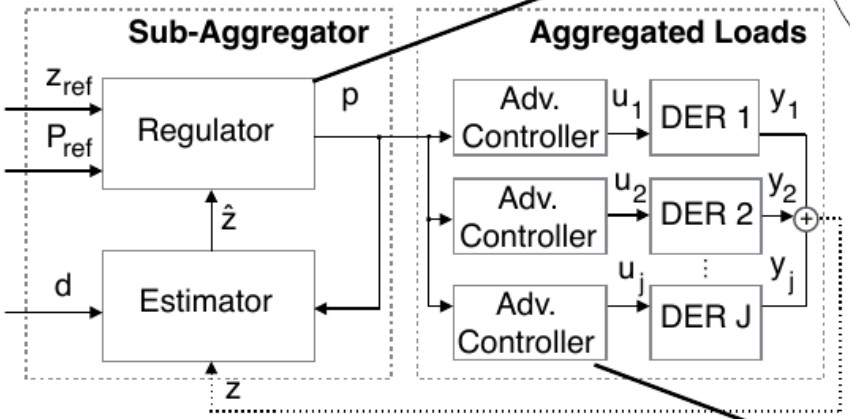
Energy System Models for Real Time Applications and Data Assimilation

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



Proposed methodology
Control-based methodology

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



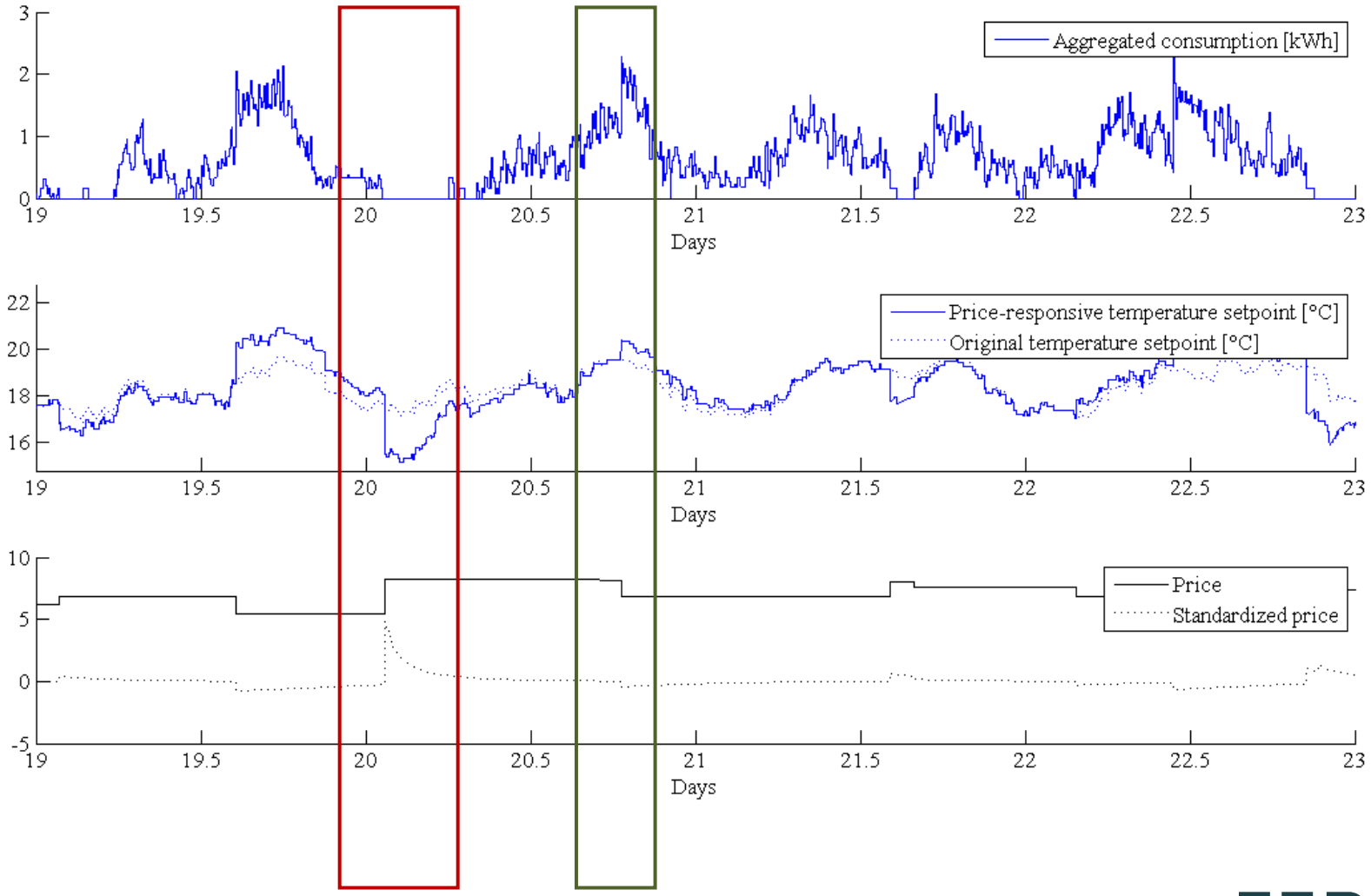
We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

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

Flexibility Function

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

Aggregation (over 20 houses)



Flexibility Function

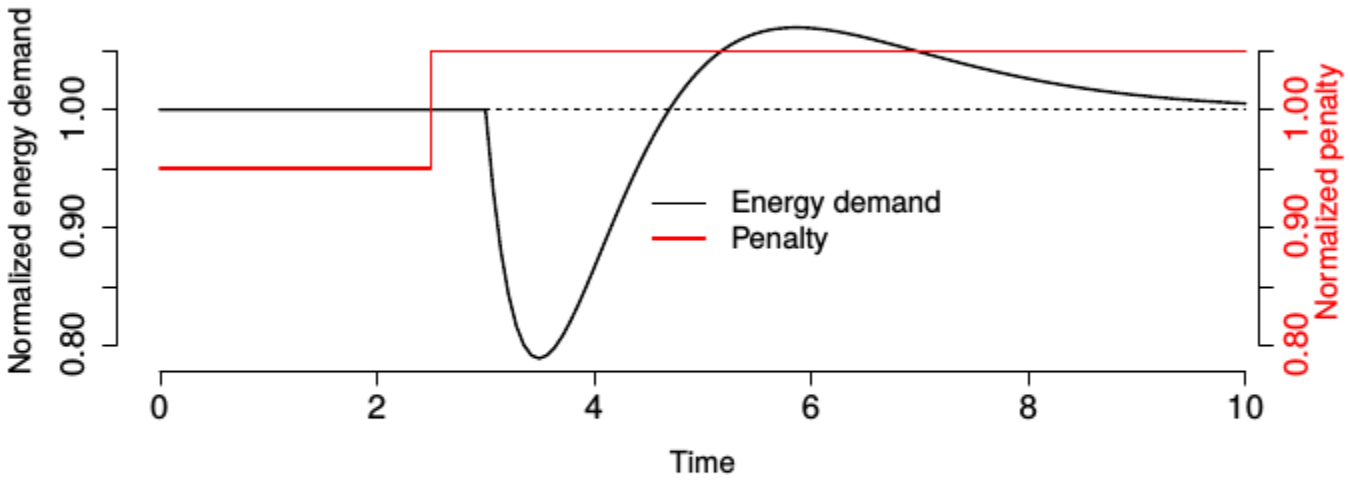
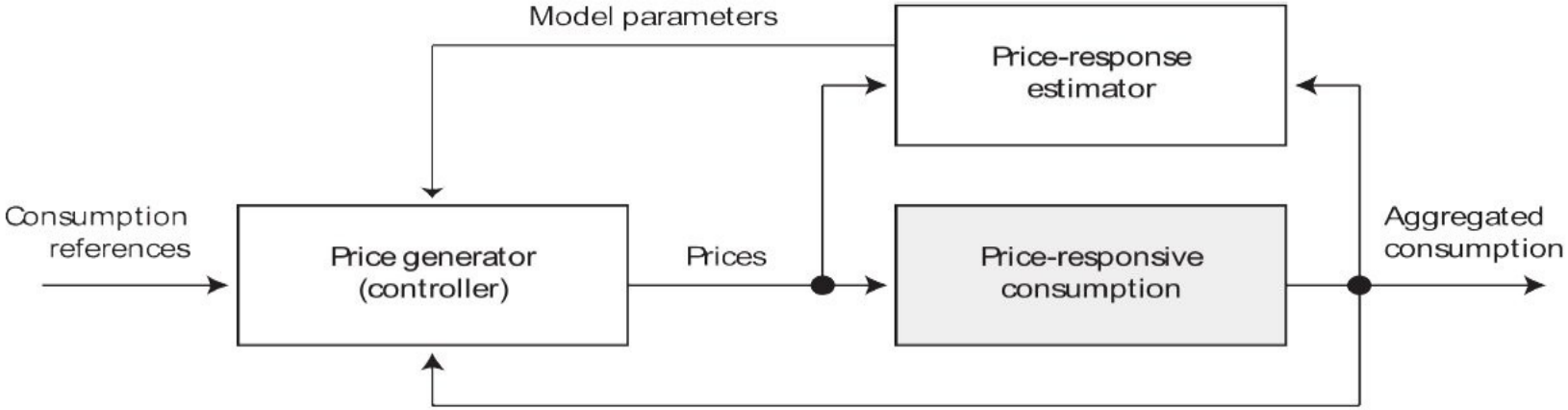
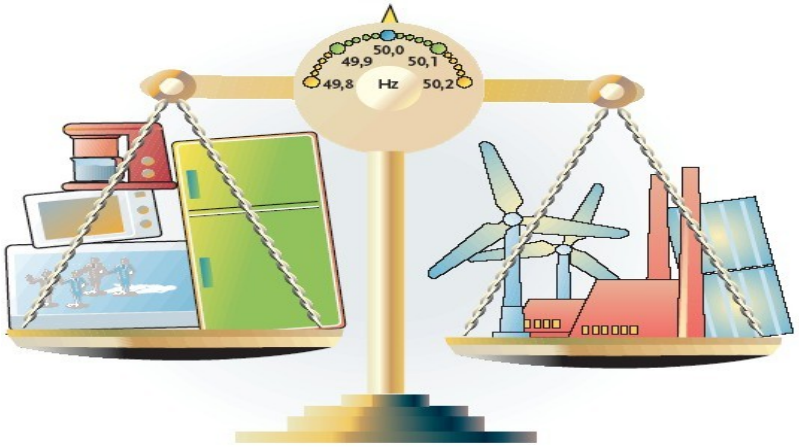


Figure 2: The energy consumption before and after an increase in penalty. The red line shows the normalized penalty while the black line shows the normalized energy consumption. The time scale could be very short with the units being seconds or longer with units of hours. At time 2.5 the penalty is increased,

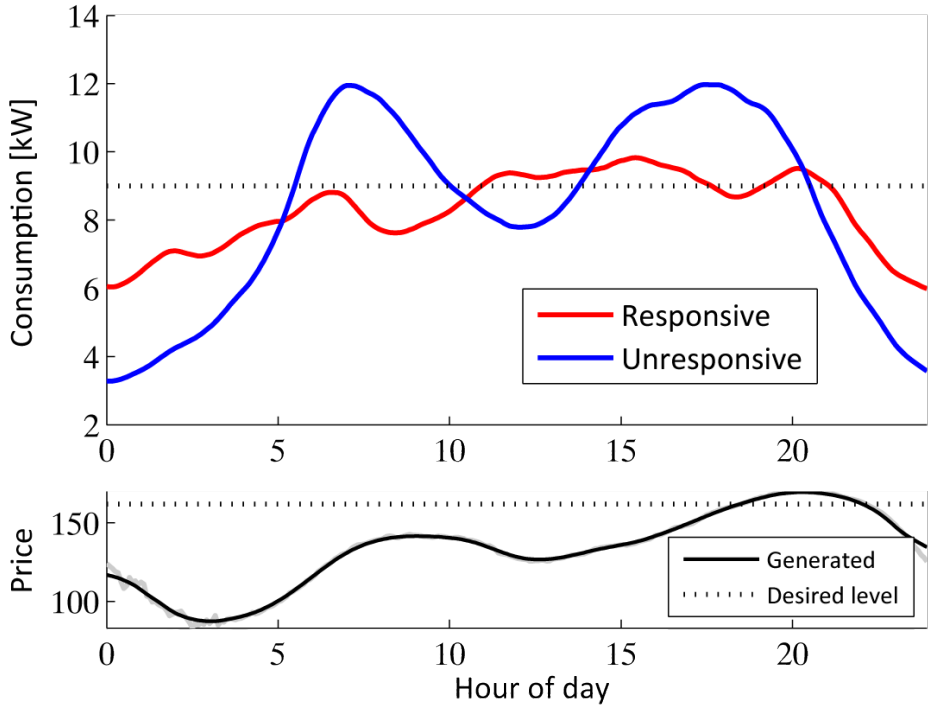
Control of Power Consumption





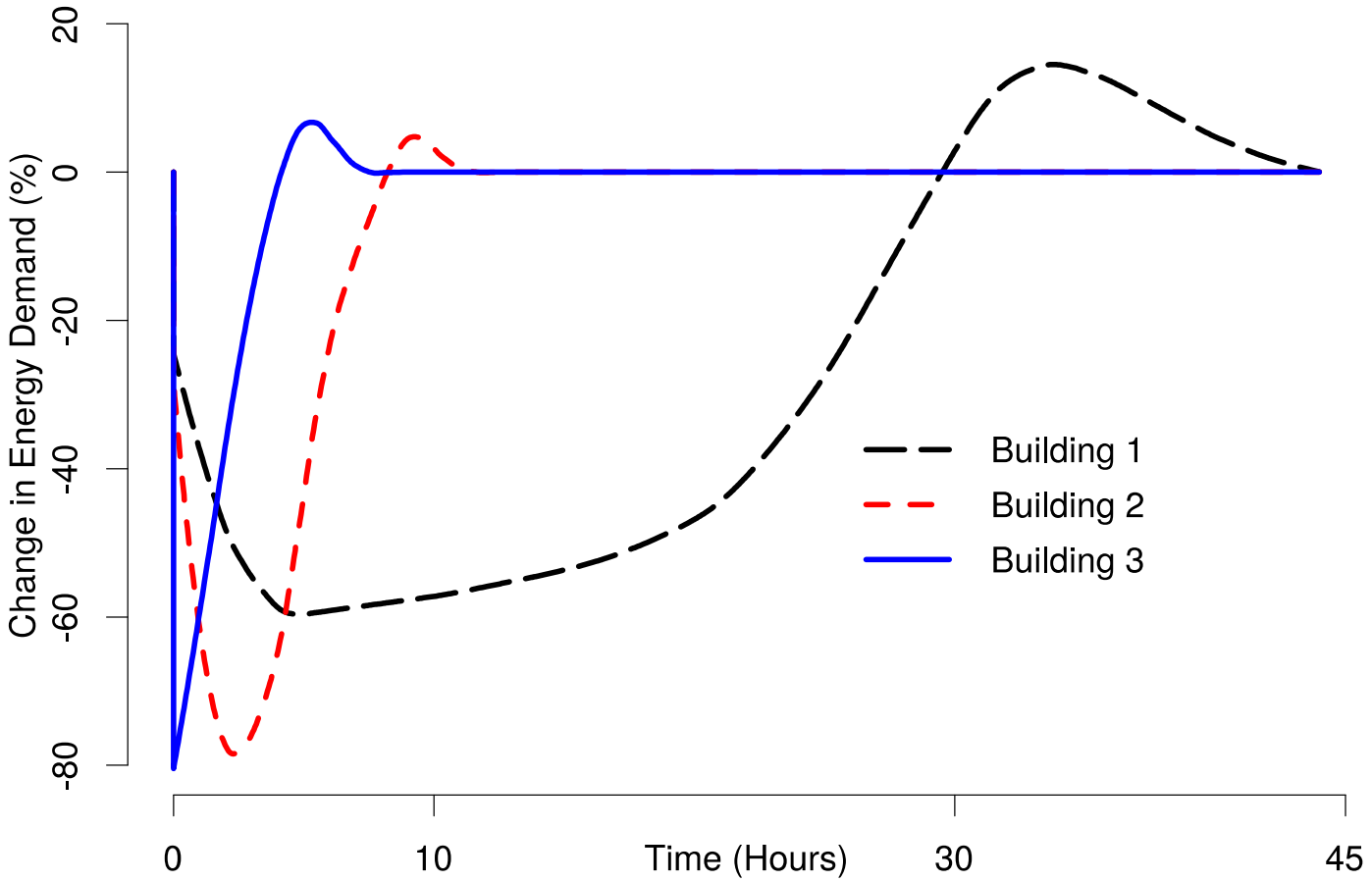
Control performance

Considerable **reduction in peak consumption**



DTU

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

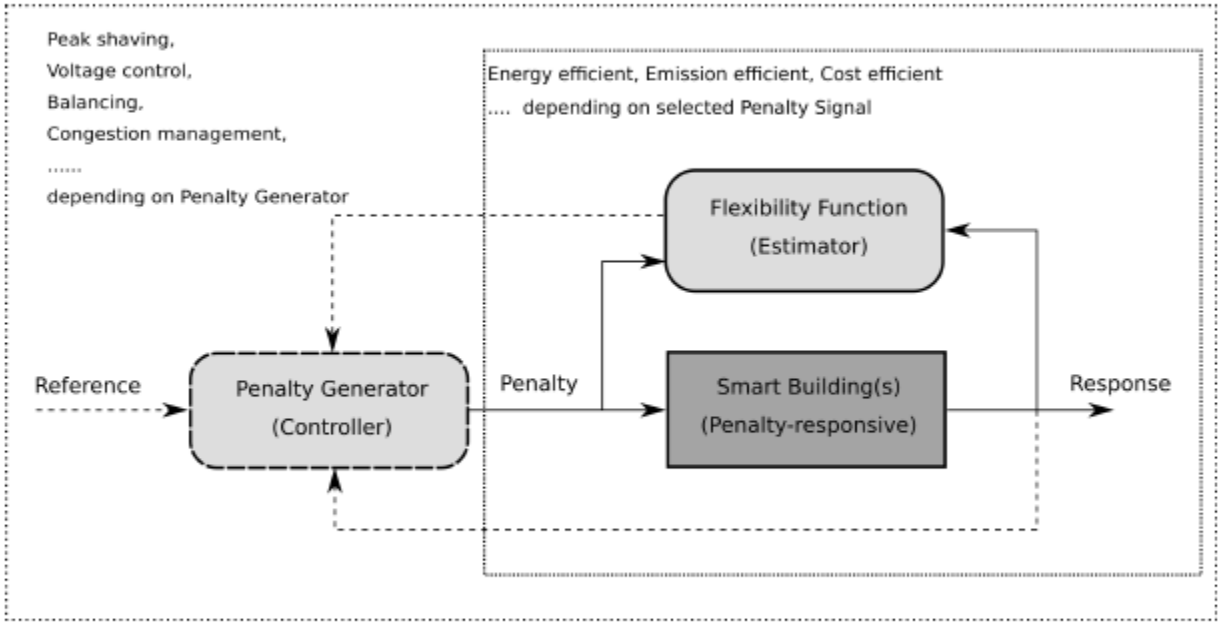
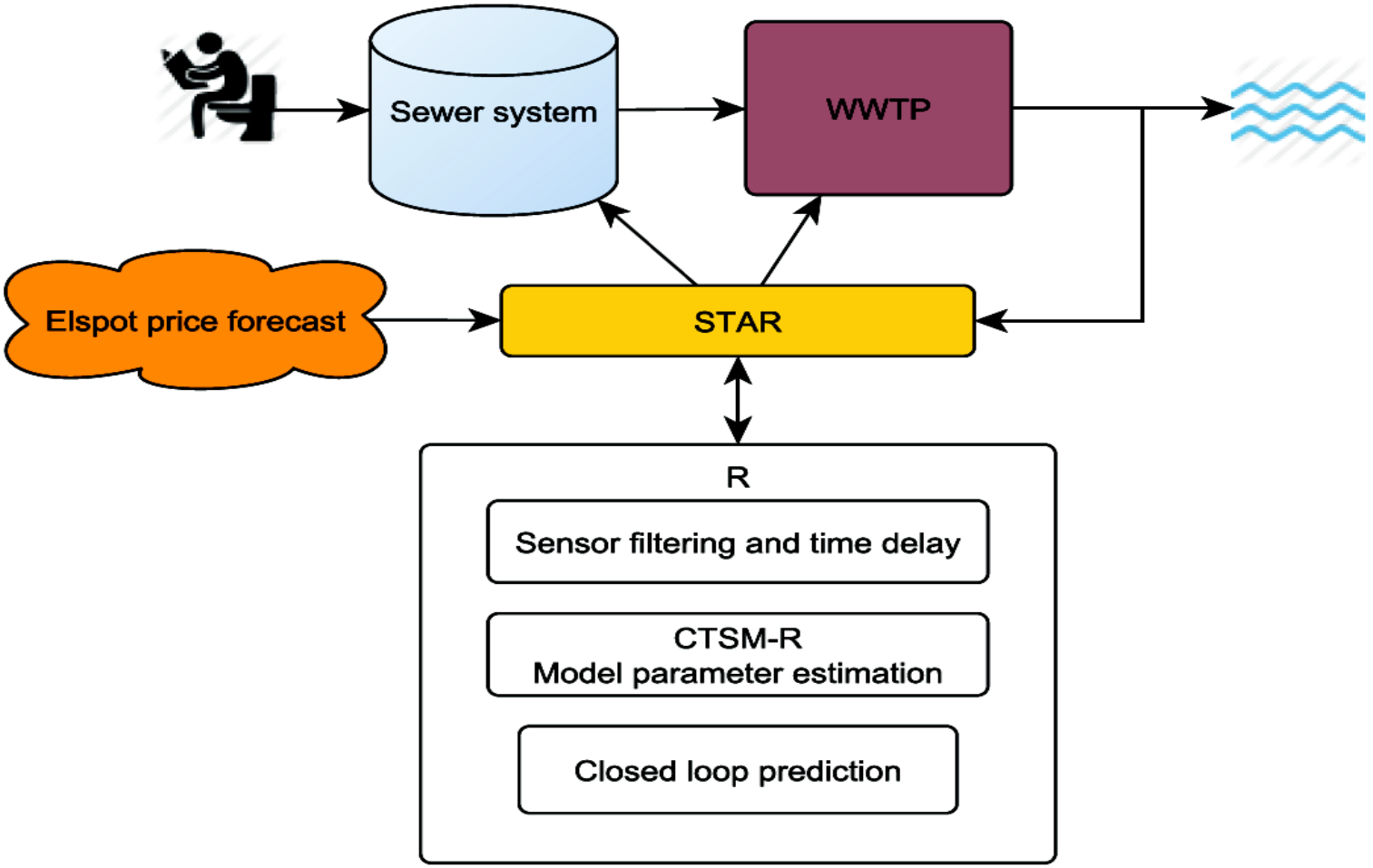
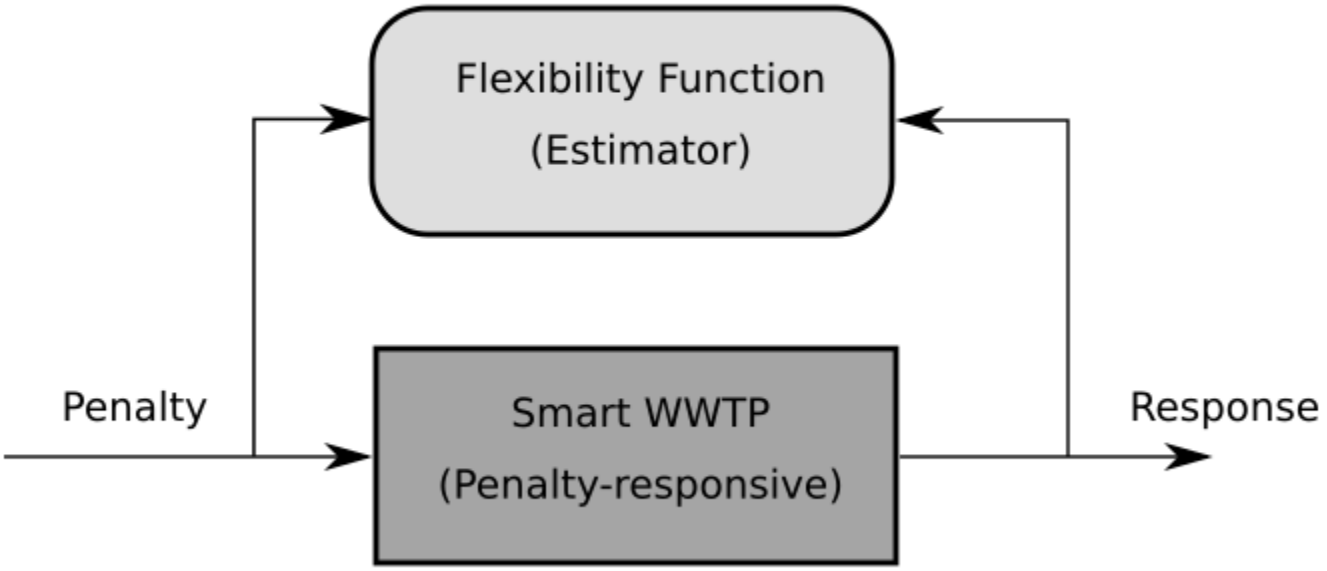


Figure 8: Smart buildings and penalty signals.

Energy Flexibility in Wastewater Treatment



Flexibility Function



Summary

- We have demonstrated a large potential in unlocking the flexibility in integrated energy systems using the FF and the Smart-Energy OS
- The Smart-Energy OS Controllers can focus eg. 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)
- We need new digitalized markets (based on AI and control)
- Center Denmark is established as a National Digitalization Hub for Smart Energy and related systems (water and food primarily). Main purpose is 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.

Innovation Fund Denmark

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

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**

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, Fog, Edge based (IoT, IoS) 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 problems
- Harvest flexibility at all levels -> max. Virtual storage