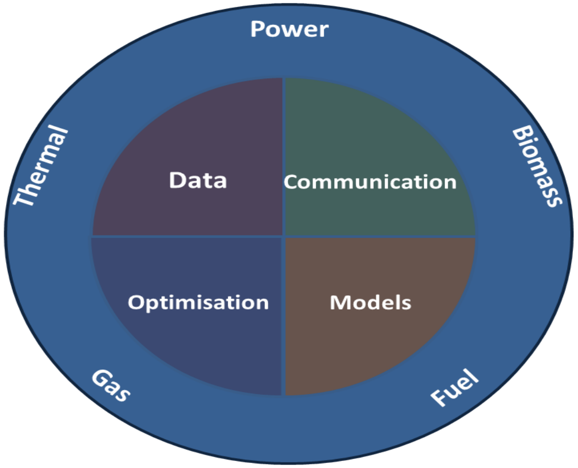
Wind Integration
Research and Practice



Henrik Madsen

Technical University of Denmark (DTU)

https://www.flexibleenergydenmark.dk/

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

http://www.henrikmadsen.org

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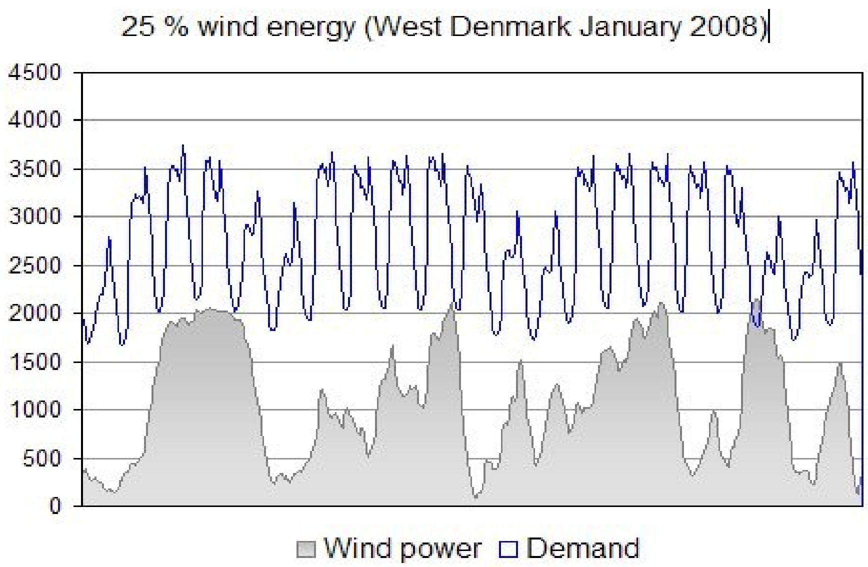
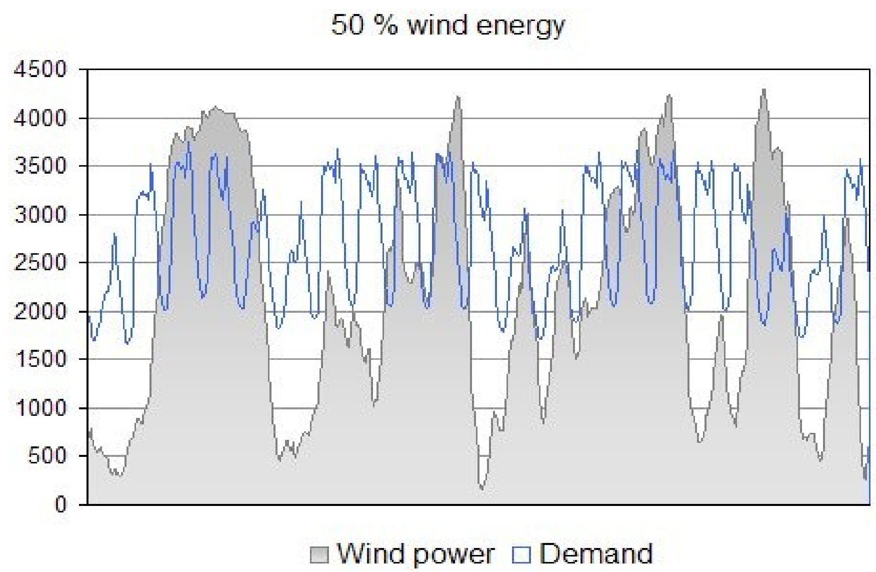
Energy system challenges

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)

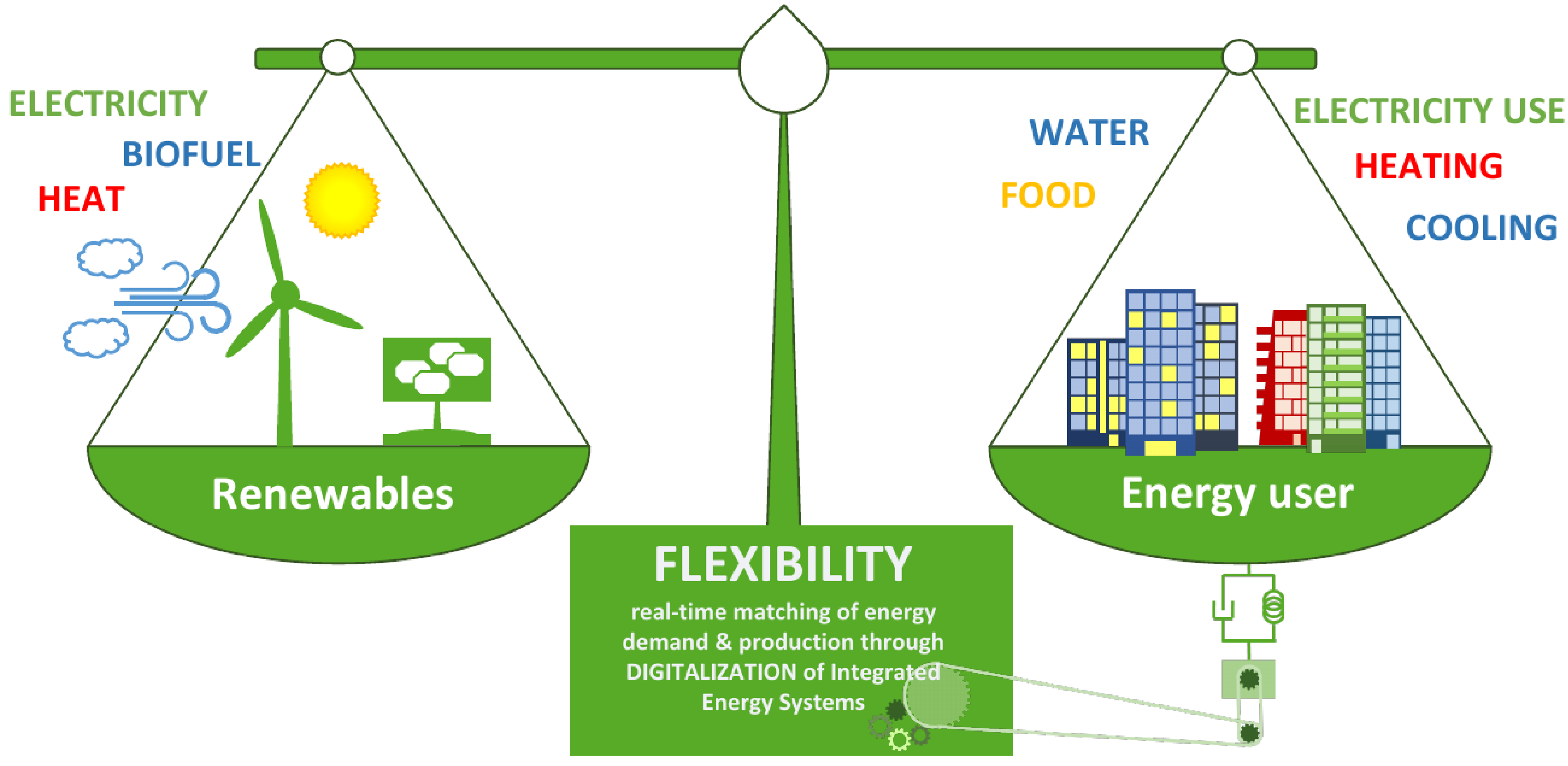


In 2020 Forecasting and Flexibility are essential

That's the topics of 'Flexible Energy Denmark'

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

The Challenge: Denmark Fossil Free 2050

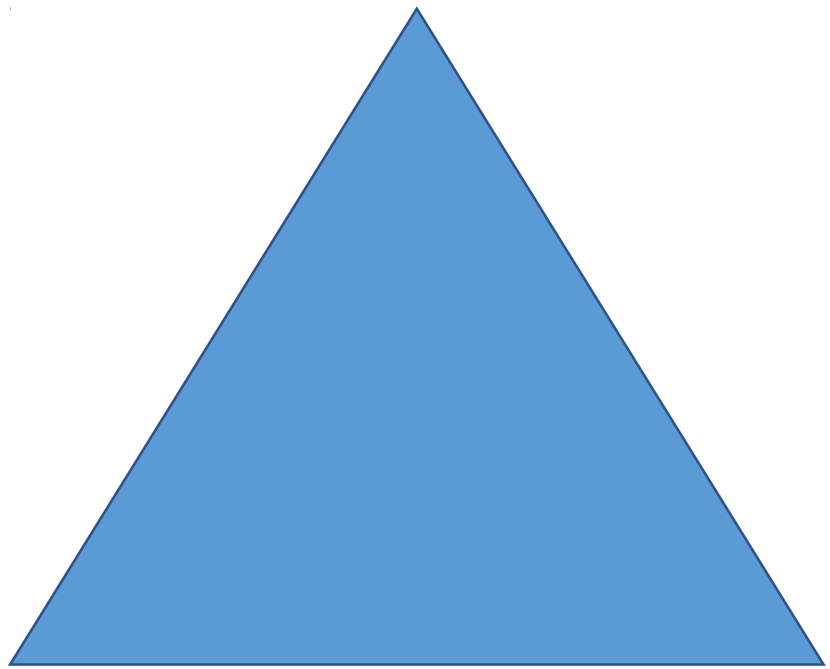


Data-Intelligent and Flexible Energy Systems

Space of Solutions

Flexibility / Virtual Storage

(enabled by Digitalisation and Energy Systems Integration)

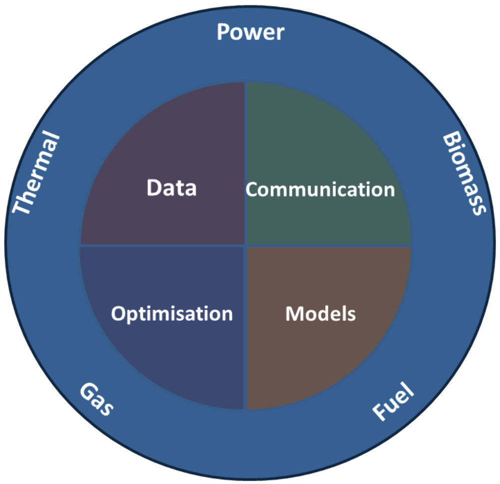


(Super) Grids

Batteries

DTU

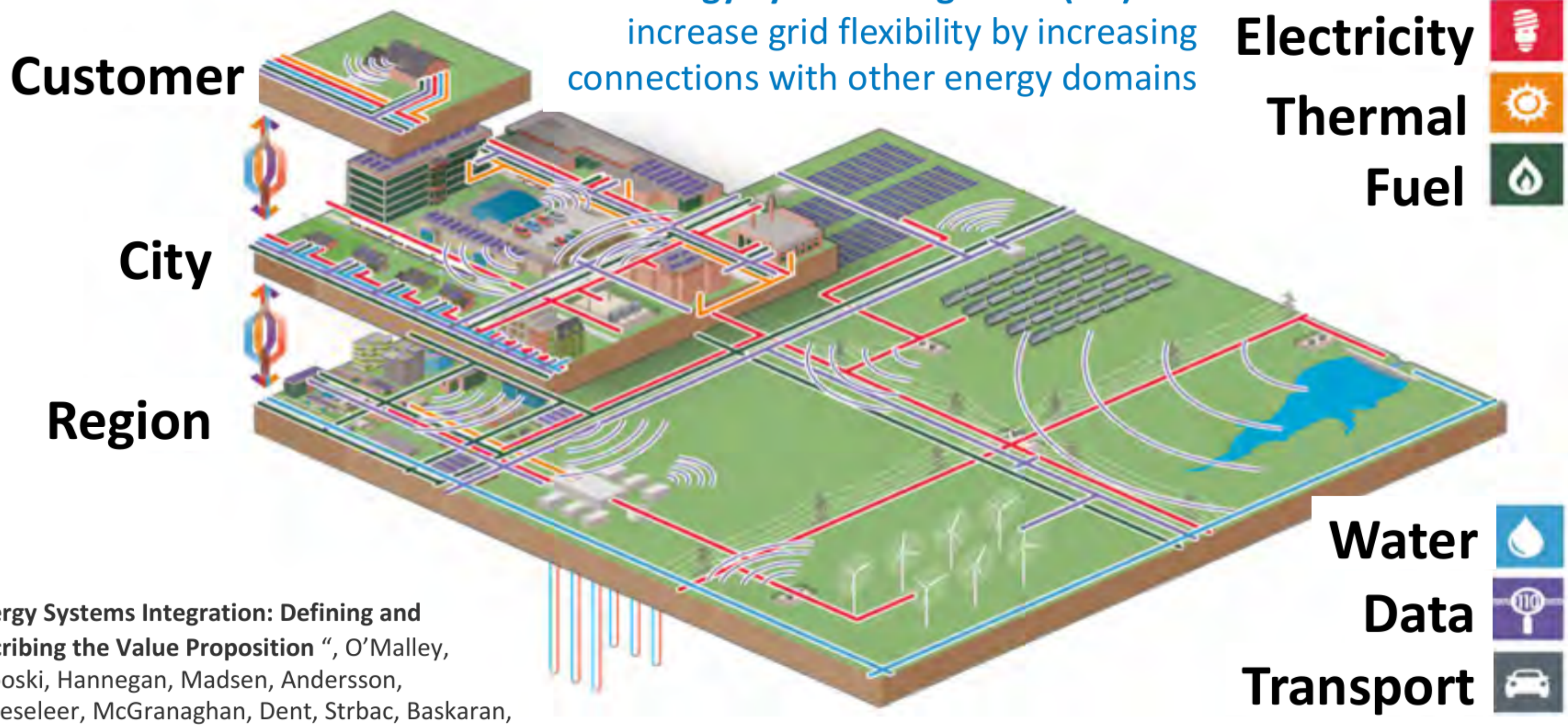
Use of Digitalization and Energy Systems Integration



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

Energy Systems Integration

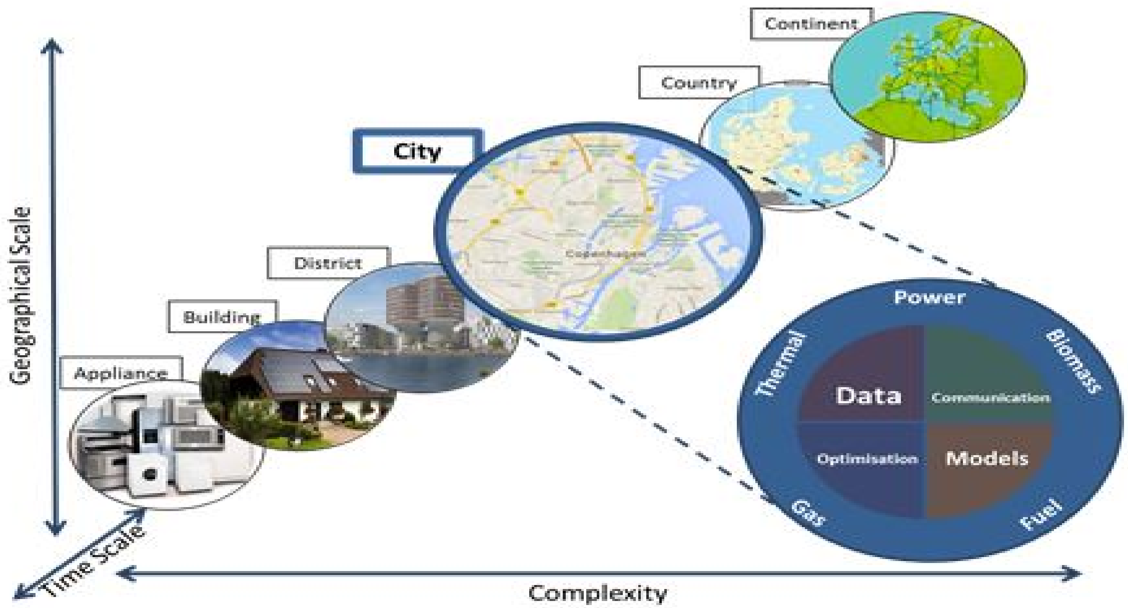
Energy System Integration (ESI) can increase grid flexibility by increasing connections with other energy domains



"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

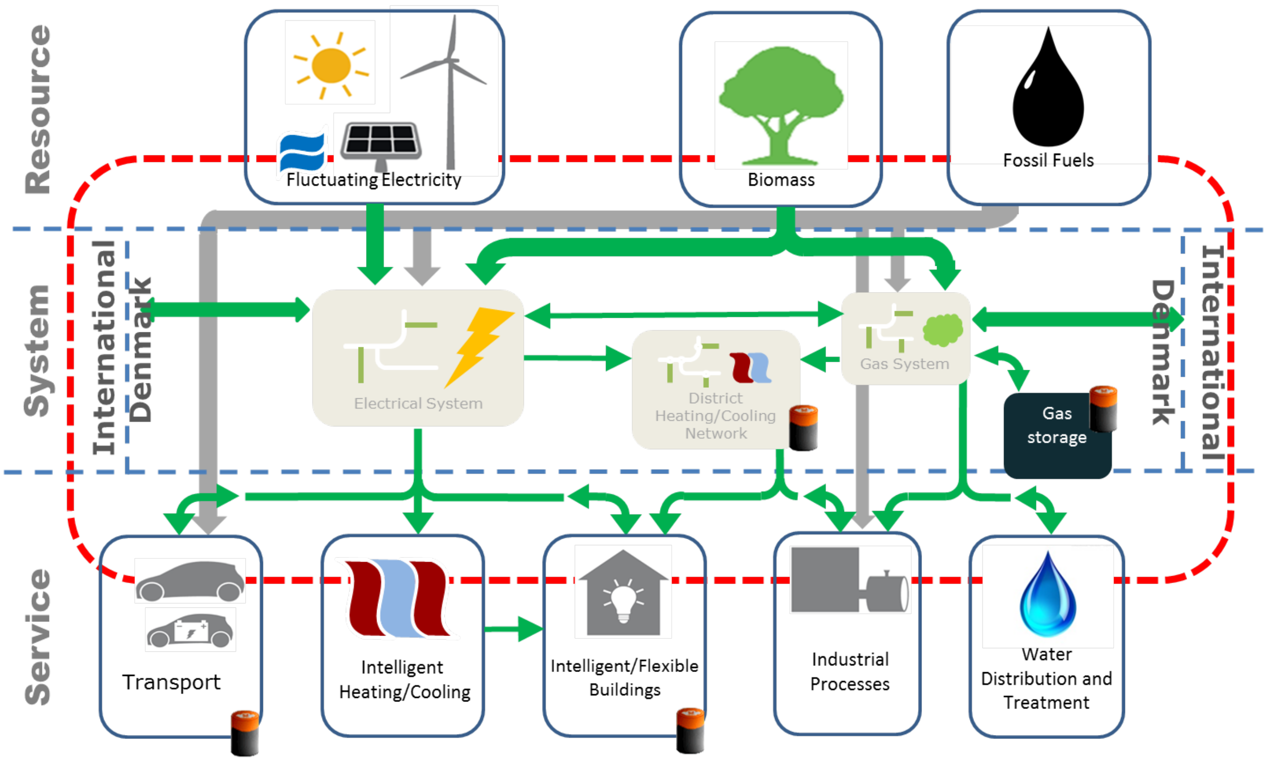
Temporal and Spatial Scales

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



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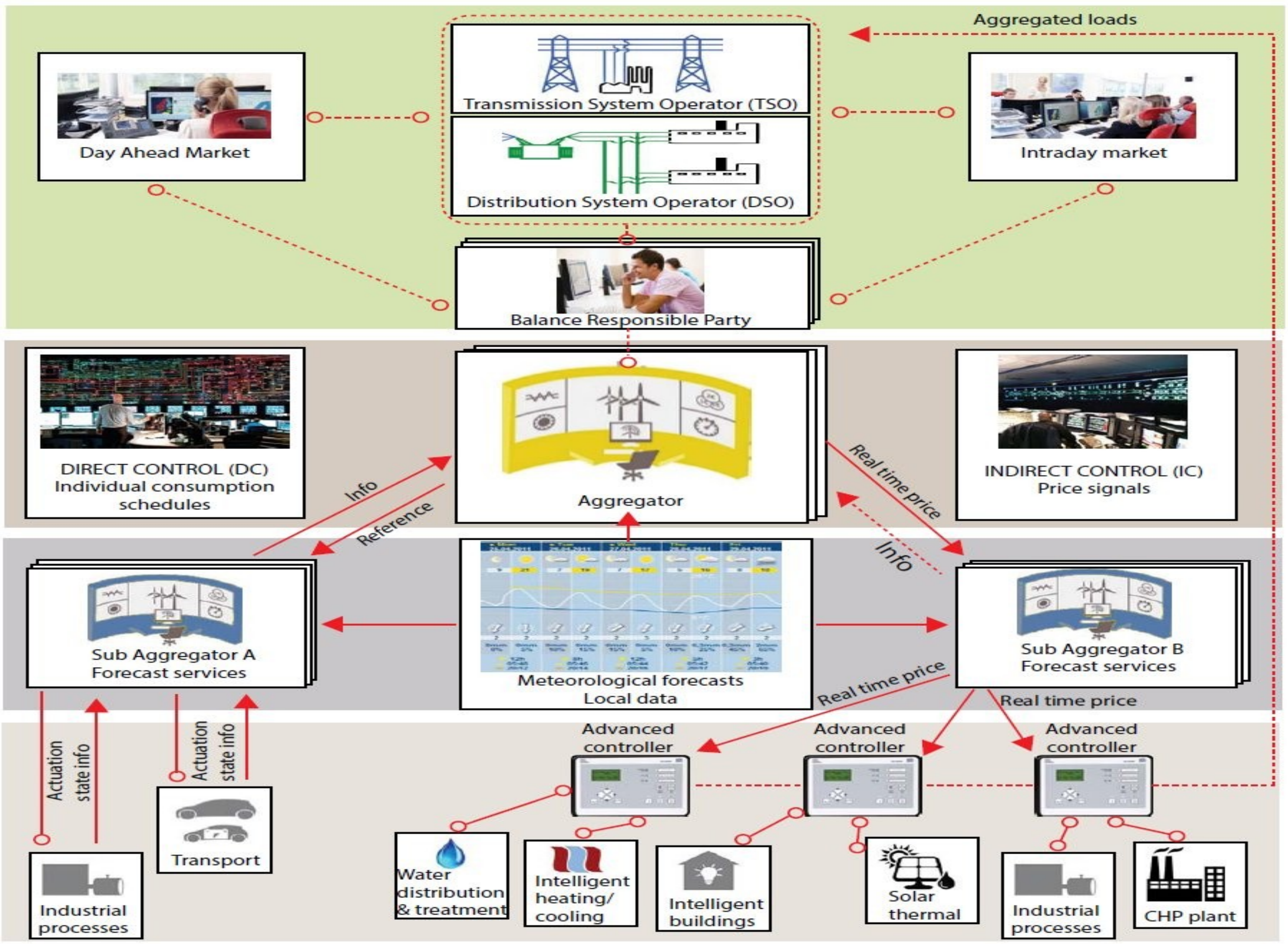
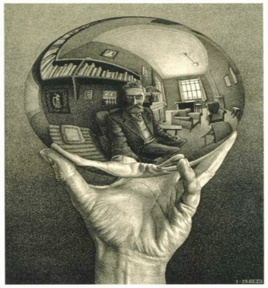
Smart-Energy OS



SE-OS Characteristics

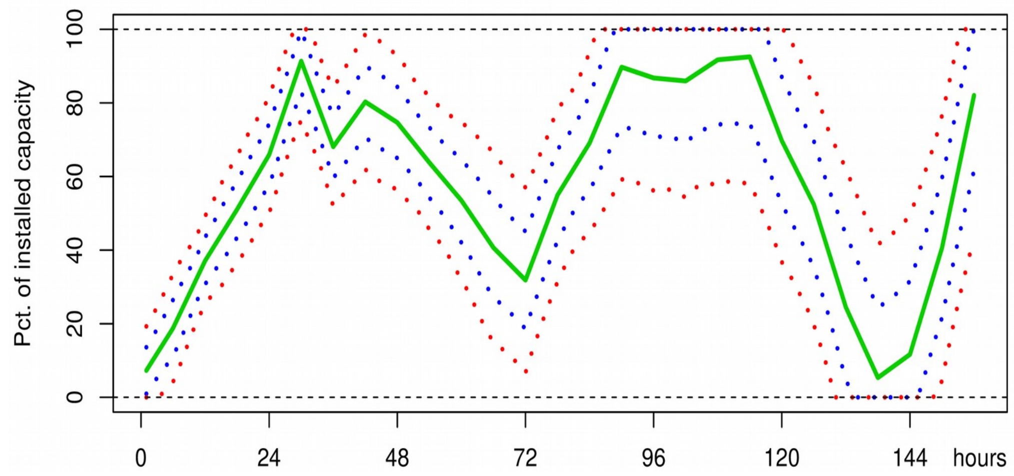
- AI and Grey-Box models for data-intelligence
- Nested sequence of systems – Systems of Systems
- Hierarchy of optimization (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud, Fog, Edge based (IoT, IoS) solutions – eg. for forecasting and control
- Facilitates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

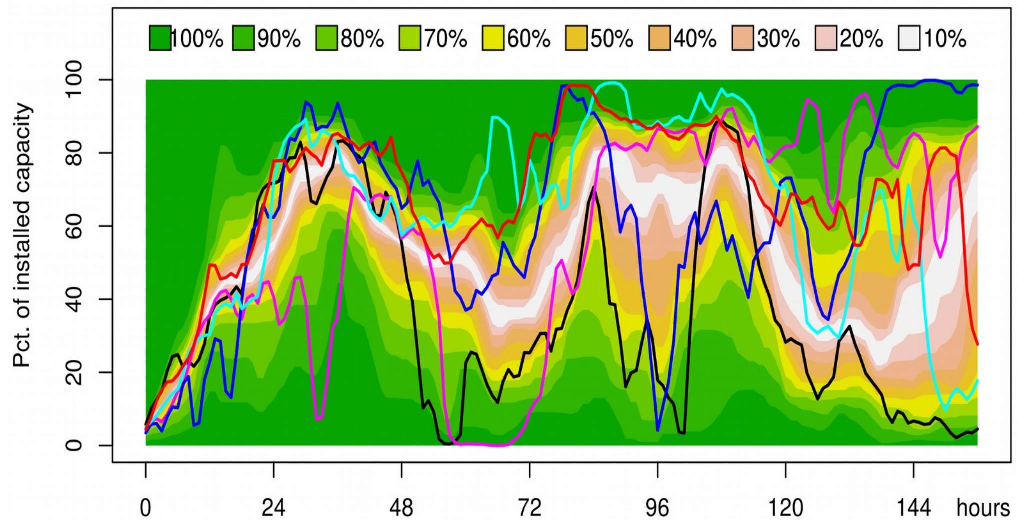


Forecasting is Essential

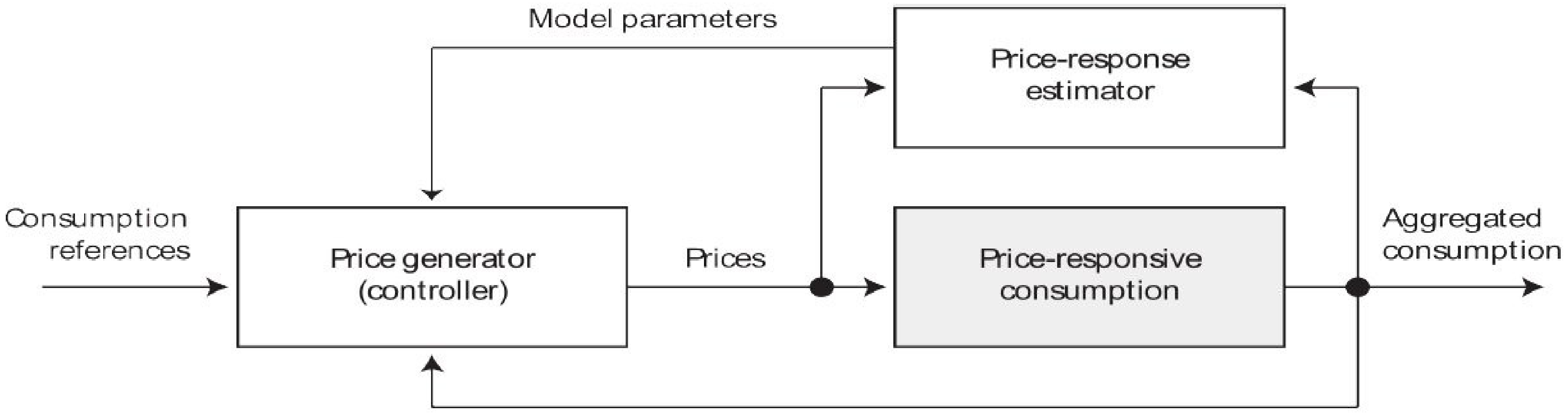
Tools for Forecasting: (Prob. forecasts)

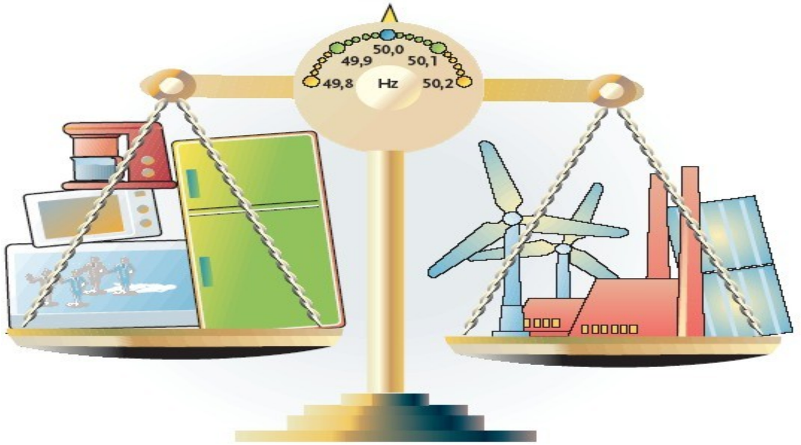
- Power load
- Heat load
- Gas load
- Prices (power, etc)
- Wind power prod.
- Solar power prod.
- State variables (DER)



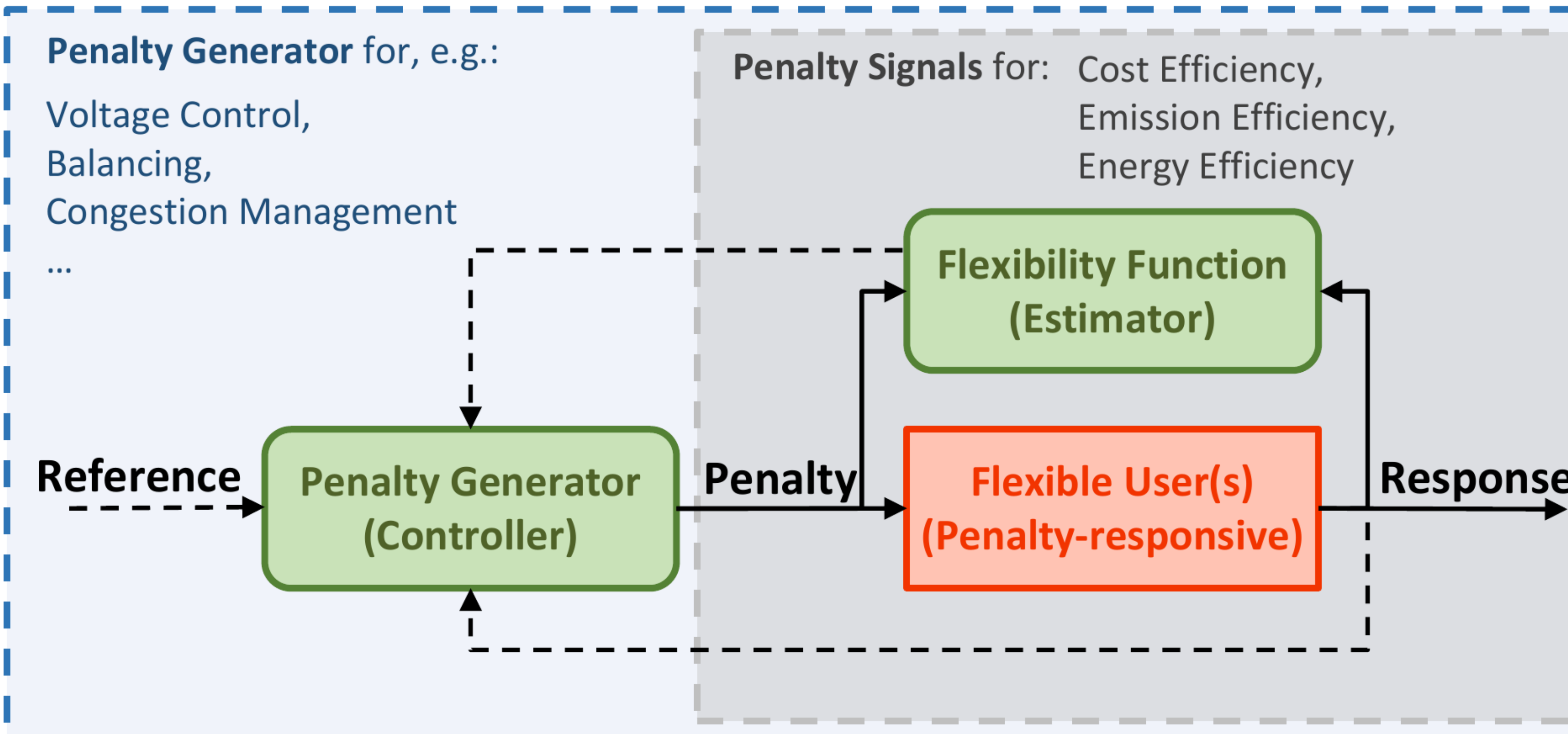


Control of Power Consumption





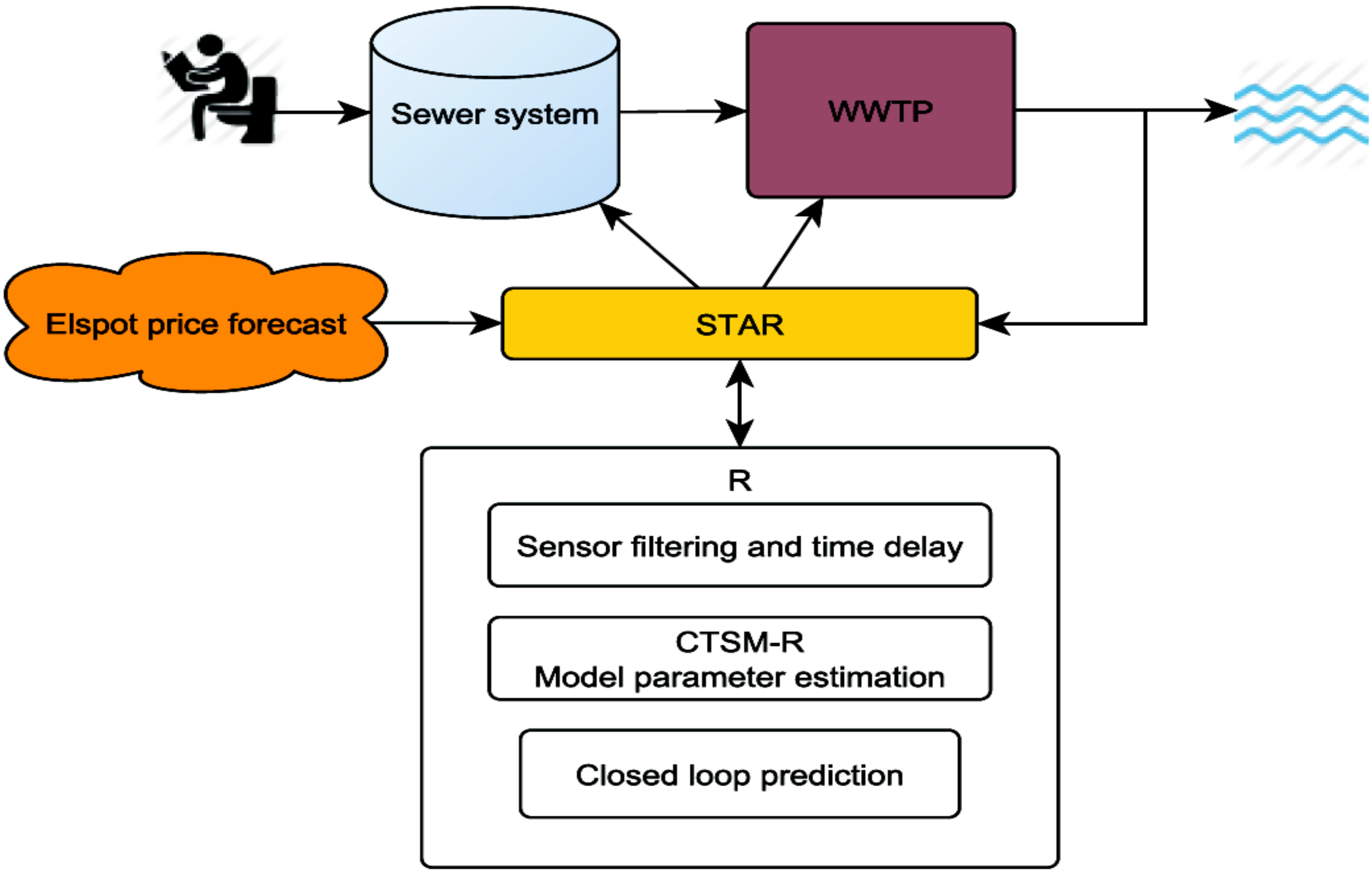
A FED example: Flexible Users and Penalty Signals



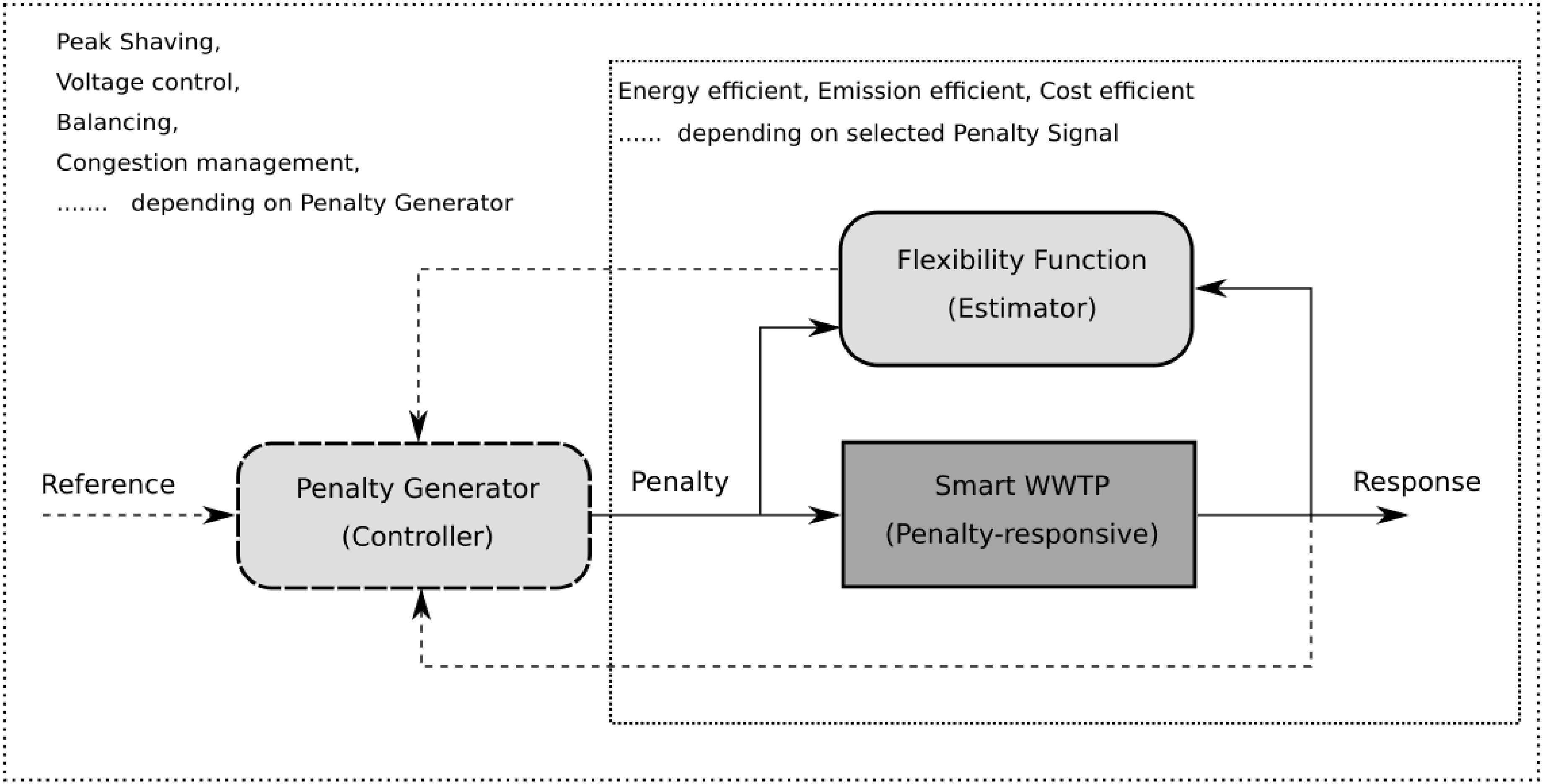
Case study

Wastewater Systems

Energy Flexibility in Wastewater Treatment



Smart Grids and Wastewater Treatment



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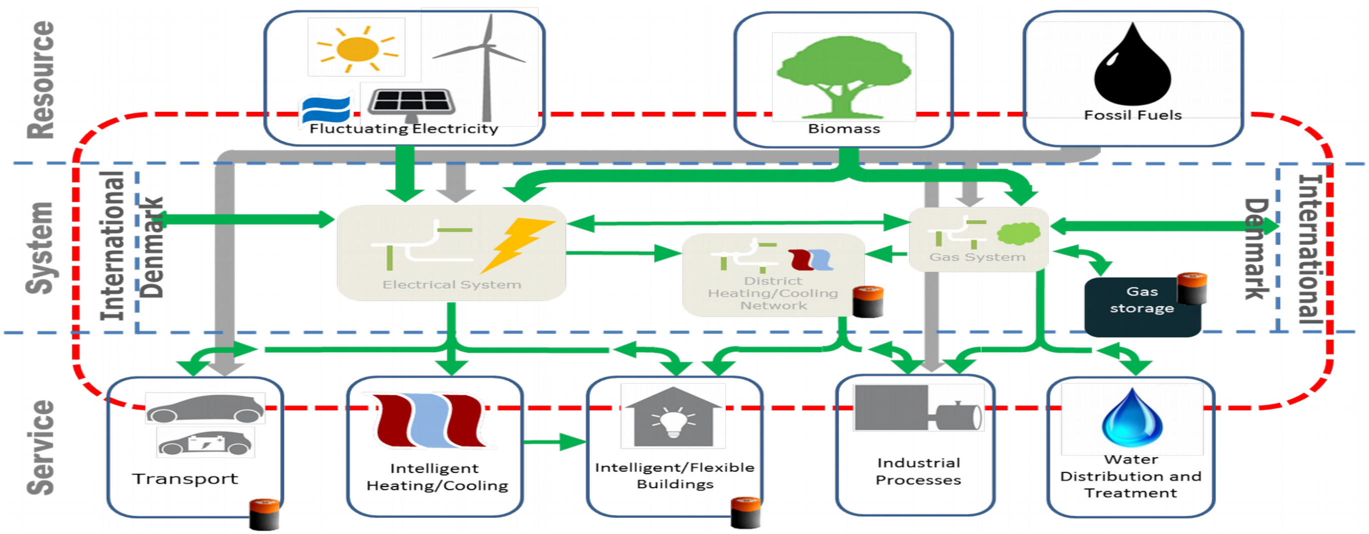
(Virtual) Storage Solutions



- **Flexibility (or virtual storage) characteristics:**
  - Wastewater systems can provide storage 0.2-6 hours ahead
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 2-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-18 hours ahead
  - District heating/cooling systems can provide storage up to 1-4 days ahead
  - DH systems can provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions

Center Denmark

Centre for IT Intelligent Energy Systems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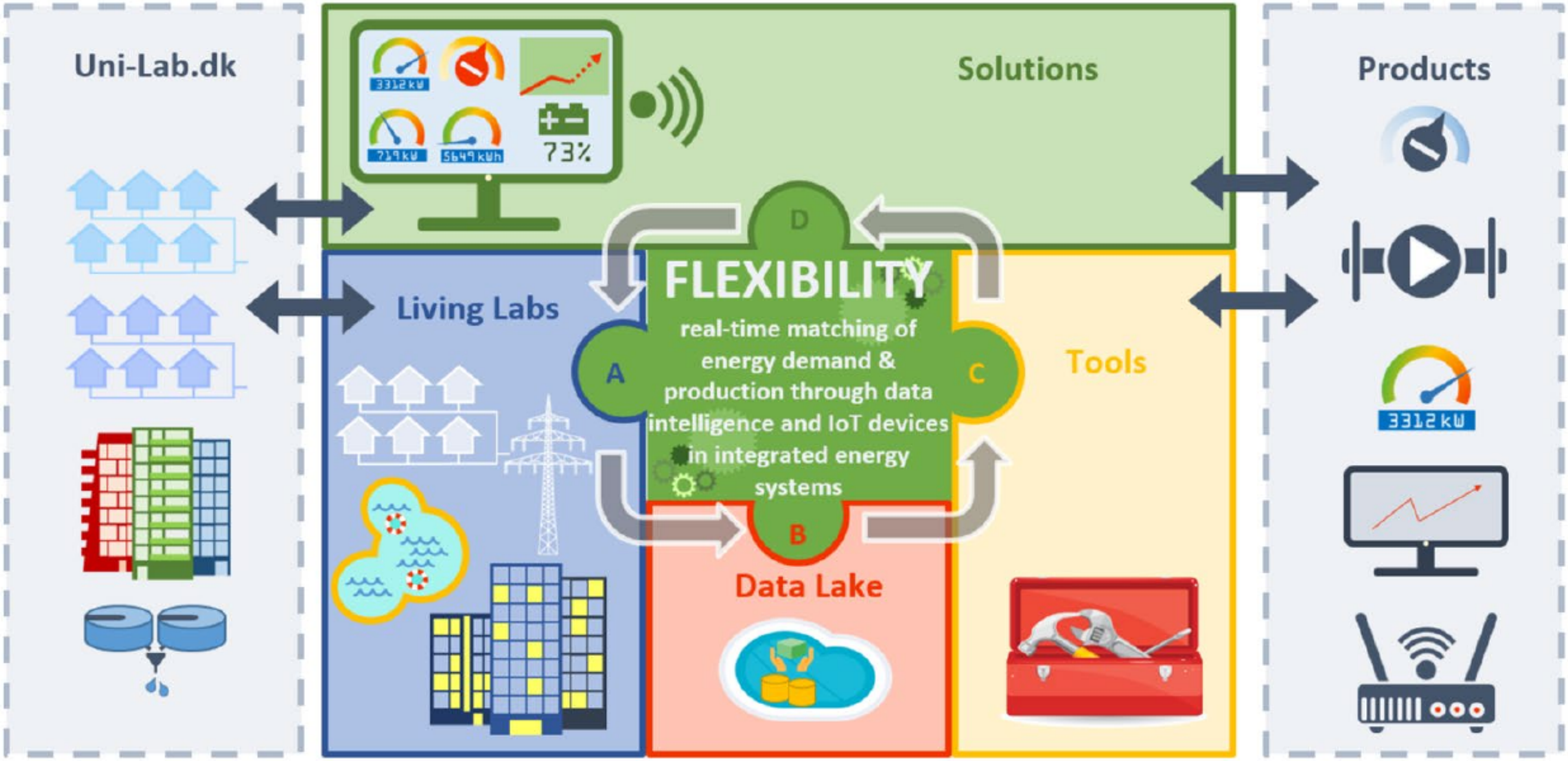
DENMARK
Connect networks and data
for a green world
Danmarks
nationale Center
Fremme den grønne omstilling.
Samle og bygge bro, mellem
forskning, teknologi, natur og formidling,
på tværs af interesseorganisationer,
virksomheder, skoler og
universiteter.

Center Danmark – Digitaliserings Hub

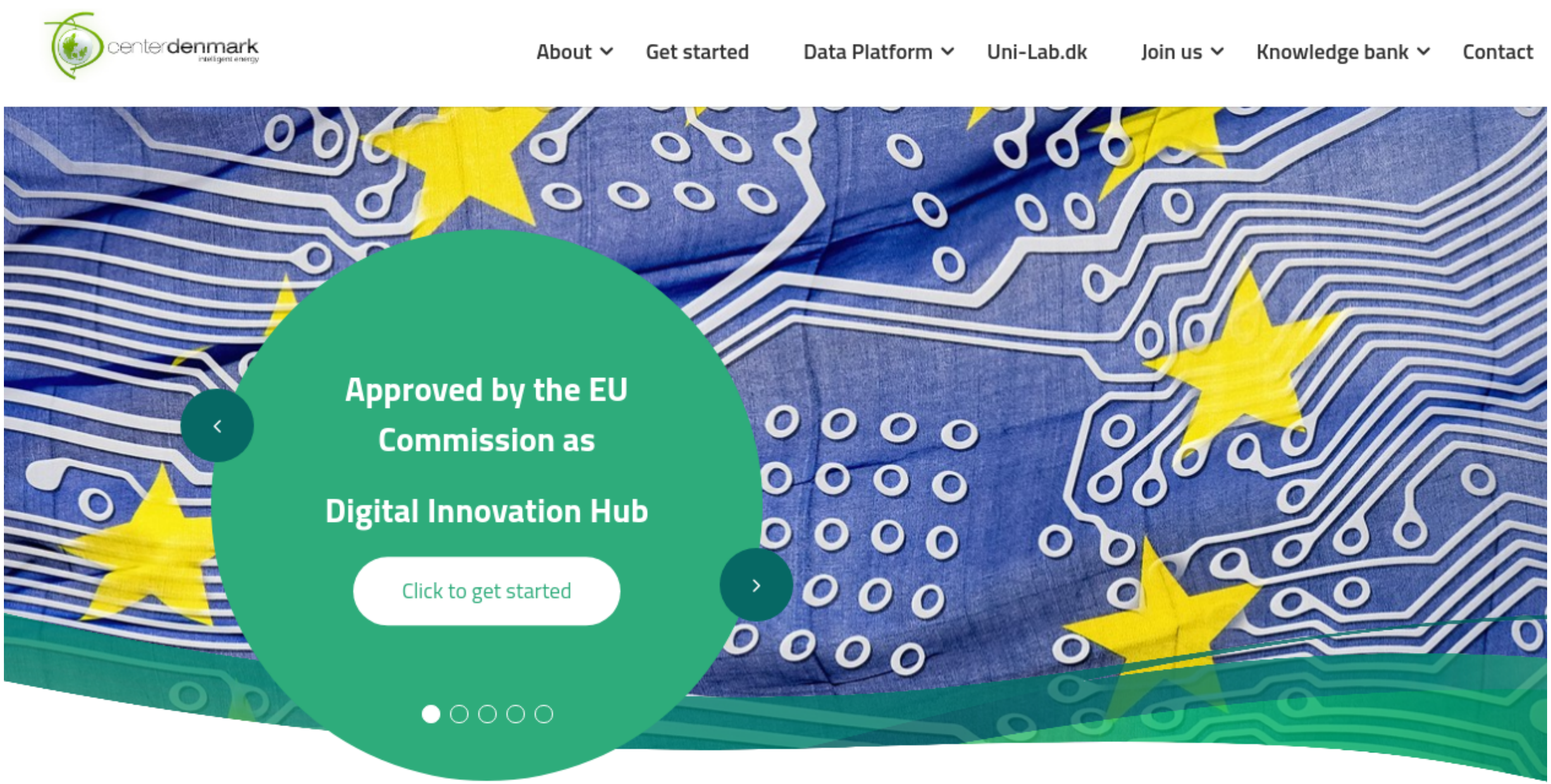
Circularity in the development of digital energy systems



Center Denmark

Become a partner – see www.centerdenmark.com

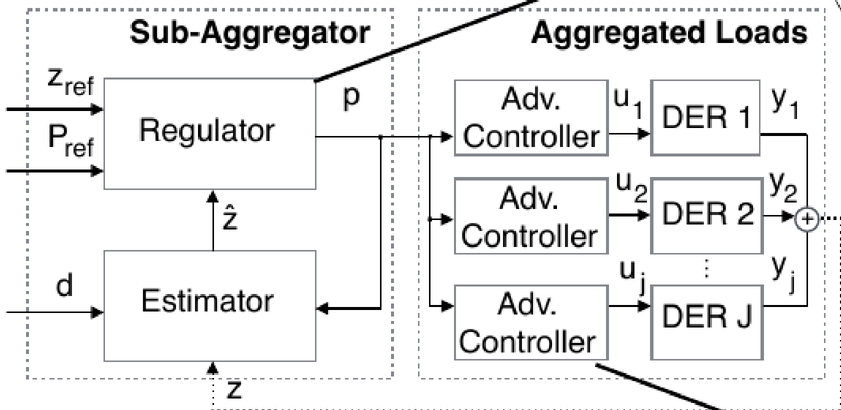
It will increase possibilities for eg. EU projects and support – also since Center Denmark is approved by the Commission



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

Proposed methodology
Control-based methodology

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



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

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