Digitalisation for Sector-Coupling and the Future Weather-Driven Energy System

DaCES' - System Integration
March 2023

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(IFD projects: FED + HEAT 4.0 + DynFlex + Cool Data)
(EU projects: syn.ikia + ELEXIA + ARV + ebalanceplus + CitCom.ai + EDIH)

ebalanceplus
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DIGITAL FOUNDATION OF FUTURE ENERGY NEEDED Read contribution in **Altinget.dk** by **Jacob Østergaard**, Professor, **DTU Elektro** and **Henrik Madsen**, Professor and Head of Department, **DTU Compute**: Research holds the key to the future of green energy systems, but the national focus needs to be on the digital operating system that will connect it all.

Read here: **https://lnkd.in/eemjyNfQ**

#DTUdk #energysystems #dkgreen #dkenergi #renewableenergy

Digital foundation of future energy needed - DTU

elektro.dtu.dk • 4 min read

Laurent Schmitt • 1st
Head of Utilities & European Developments at dcbel & President at Digital4Grids
9h •

Some interesting reading. The accelerated introduction of **#DER** - PV, storage, **#V2G** - across congested grid systems in Europe requires open and transparent **#flexibility** price discovery where nodal optimisations are without any doubt the most accurate and efficient to use for grid real-time congestion and redispatch management. Looking forward next regulatory developments

Sarah Keay-Bright FEI FRSA MEng • 2nd
Energy policy expert and strategist
9h • Edited •

Just released! - the latest **Energy Systems Catapult** report – "Introducing Nodal Pricing to the GB Power Market to Drive Innovation for Consumers' Benefit: Why now and How?" - lays out the case for nodal pricing in the GB power market as the first-best approach to signalling locational value in a more deeply decarbonised, decentralised, and digitised electricity system. We are calling on **Department for Business, Energy and Industrial Strategy (BEIS)** and **Ofgem** to require **National Grid ESO** to commission a detailed study on the introduction of nodal pricing in the GB power market, encompassing an assessment of the cost benefit case and the implementation and transition practicalities.
See report here: **https://lnkd.in/gsHYuyyg**

The escalating redispatch costs for the congested GB power system are inefficient and unsustainable. Our view is that the GB market should transition directly to nodal pricing and not via zonal pricing given experience in the US, Australia and Europe. It could be introduced right away at transmission level, providing a more efficient alternative to network charges (TNUoS); over time it can be moved down to lower voltage levels.

Yes, there will be distributional impacts to manage and some incumbents and consumers may need temporary support during the transition, but the overall net benefits for consumers will likely significantly outweigh the downsides given the

Rethinking Electricity Markets

EMR 2.0: a new phase of innovation–friendly and consumer–focused electricity market design reform

Rethinking Electricity Markets is an Energy Systems Catapult initiative to develop proposals to reform electricity markets so that they best enable innovative, efficient, whole energy system decarbonisation.

Digitalization and Markets for Energy Systems Integration

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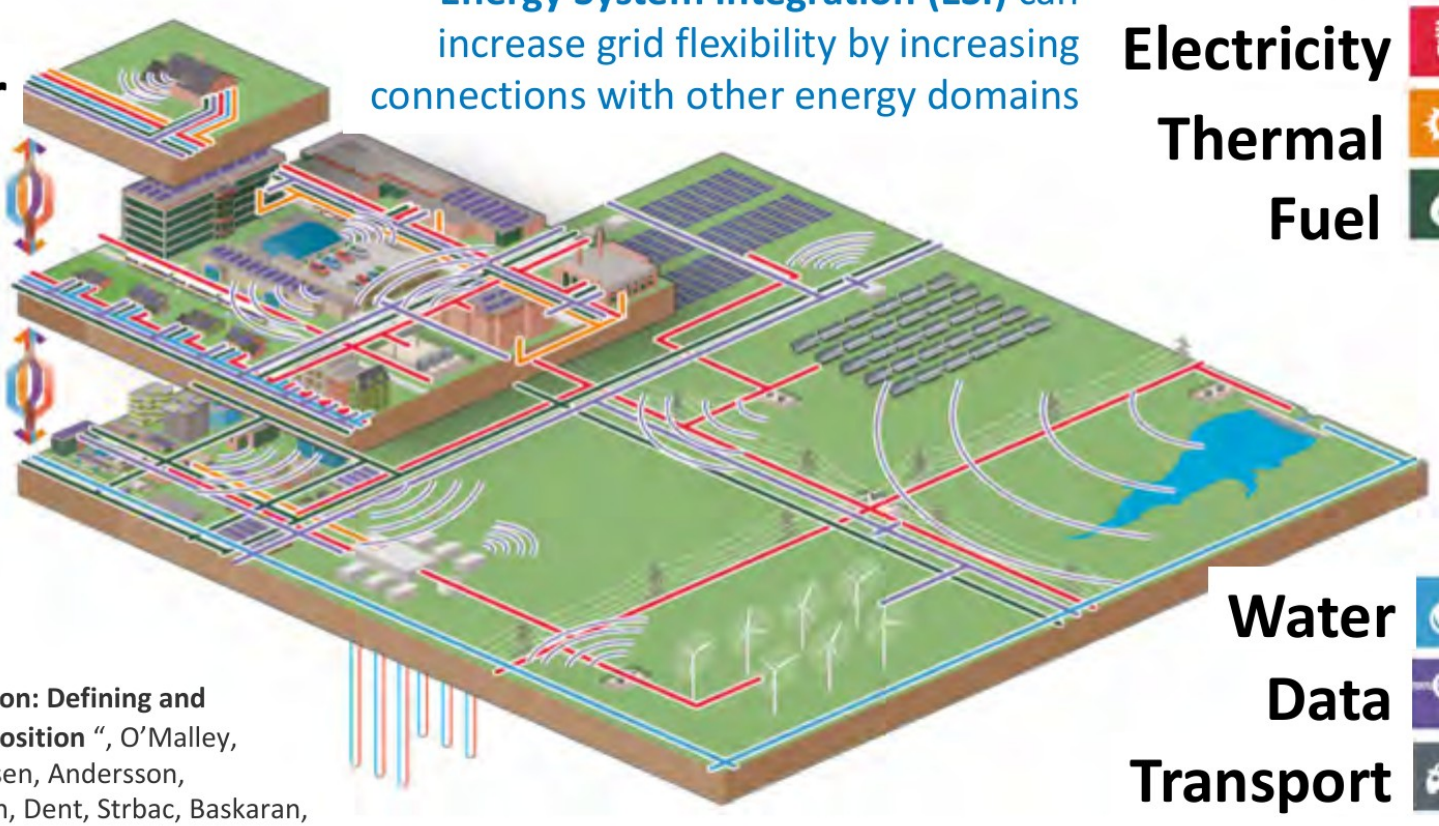
Energy Systems Integration

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

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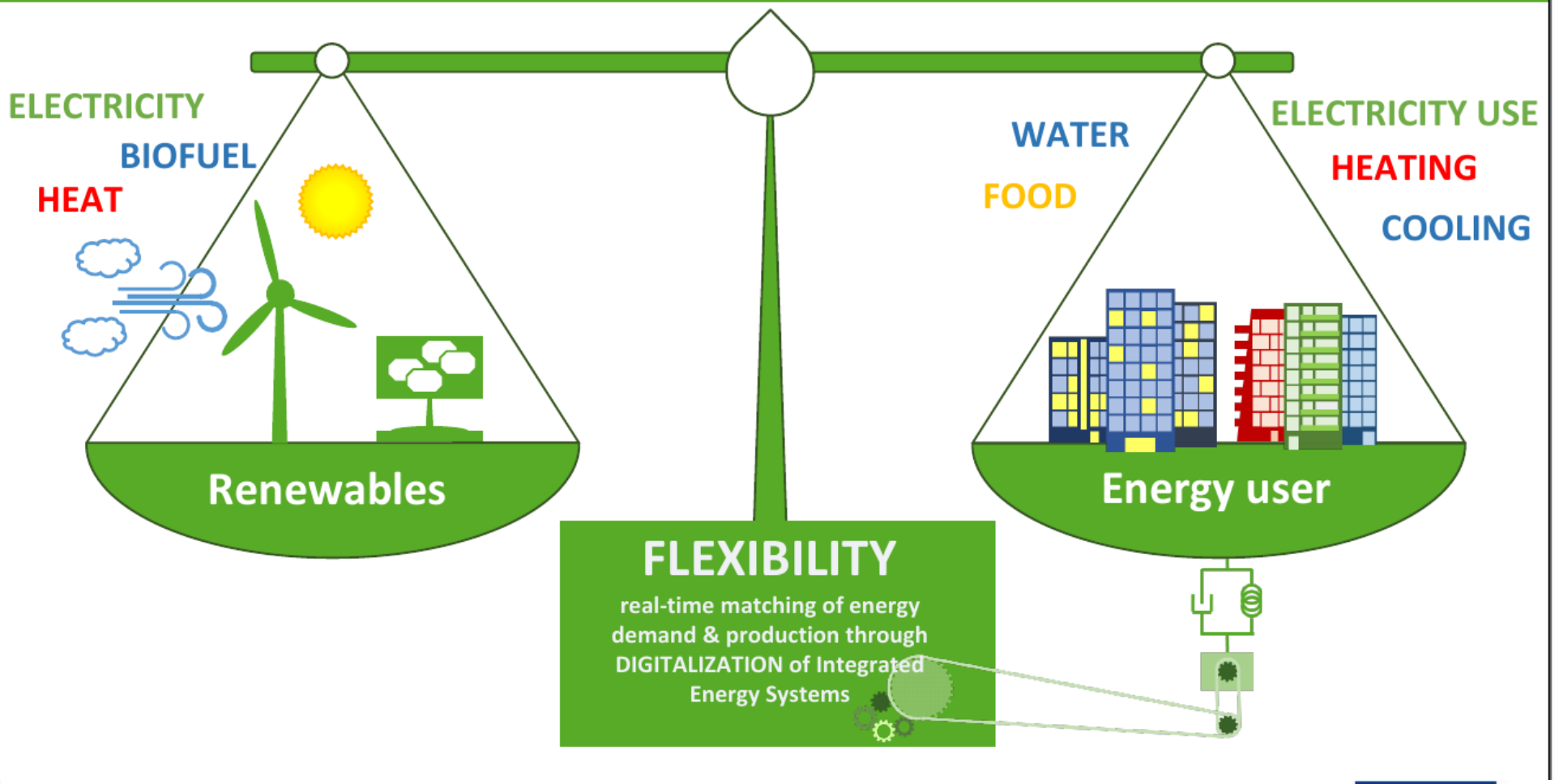
The Challenge: Denmark Fossil Free 2050



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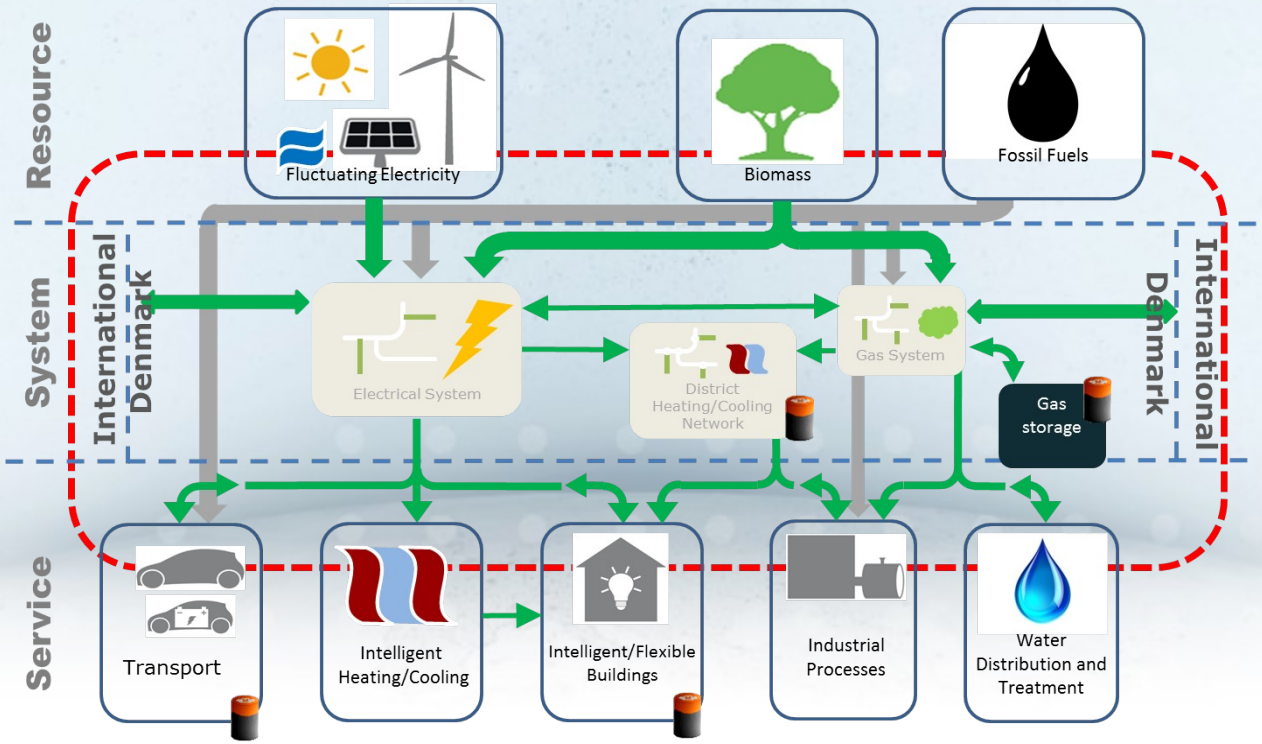
Data-driven Digital Twins for Real Time Applications

Grey-box models are simplified Digital Twin models facilitating system integration and use of sensor data in real-time



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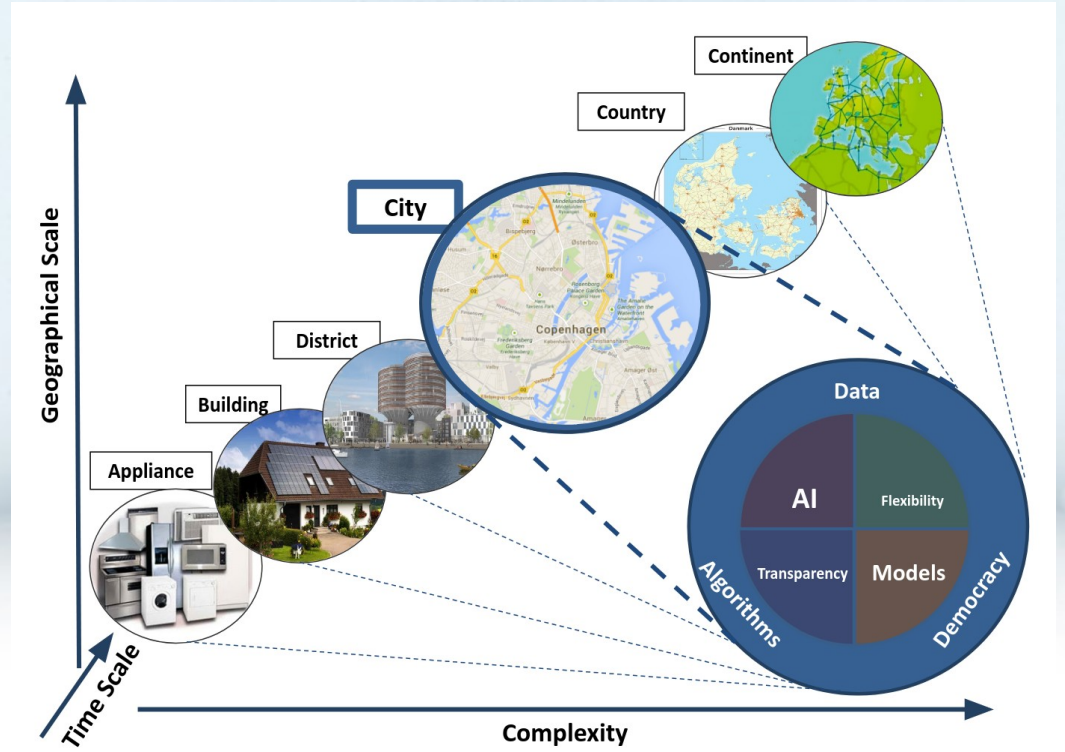
Data-driven Digital Twins
Example – Port of Sines

- +1B Euros, Port of Sines (ELEXIA project)

Temporal and Spatial Coherency

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



FED FLEXIBLE ENERGY DENMARK

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Where does the physics stop and the market begin?

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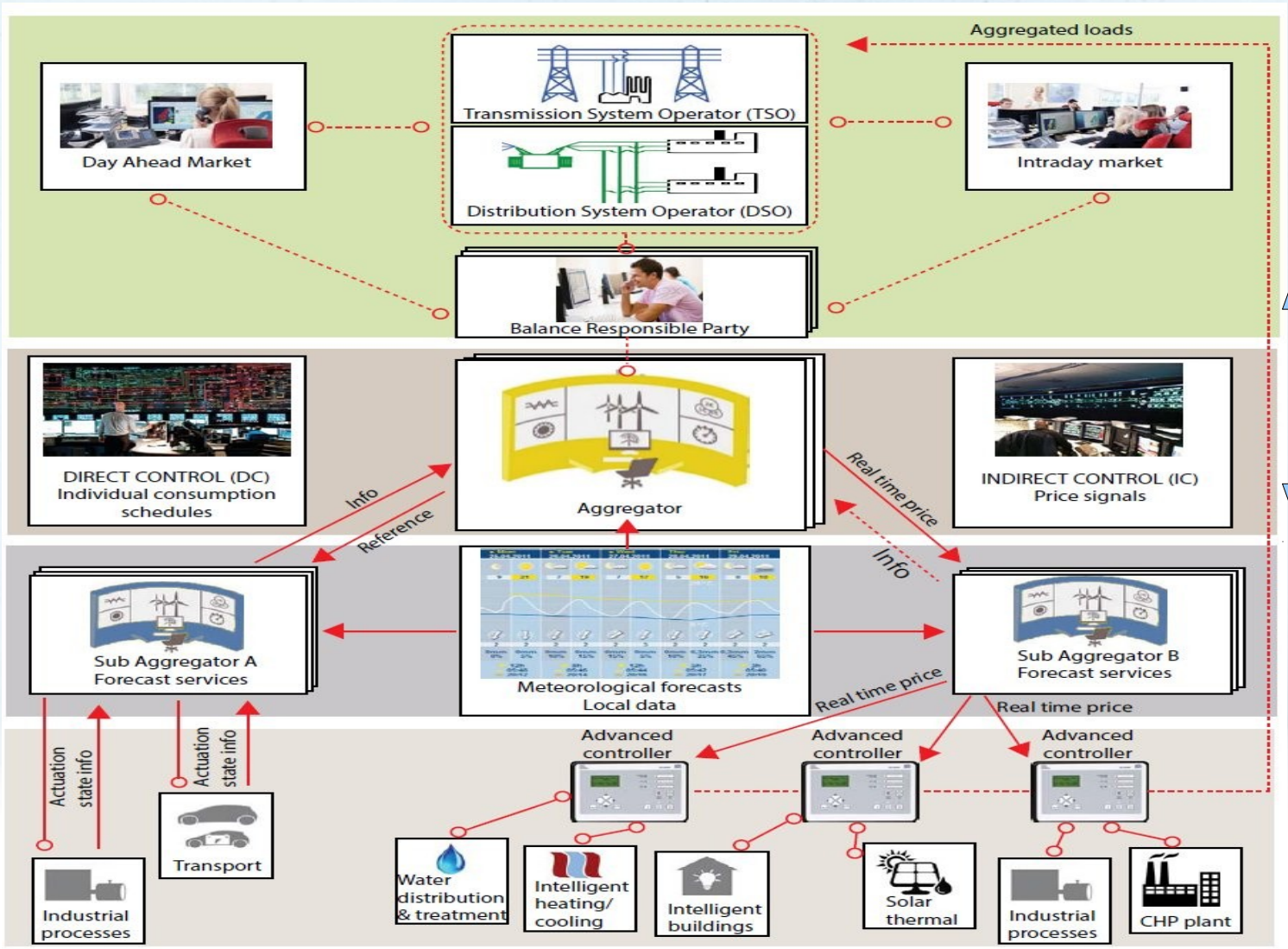
Local Flexibility (Markets) vs Classical Markets

- 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**
- Markets for Energy Systems Integration -> **Price-based solution**

EU Report: Smart-Energy OS
The Transformative Power of Digitalisation



(**Static**)

Conventional Markets

Linking Markets to Physics using MIMs

(Flexibility Functions)

(**Dynamic**)

Local Flexibility Markets

(Hierarchy of controllers)

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Flexibility Functions is the Fundamental MIMs for Linking Markets to the Physics

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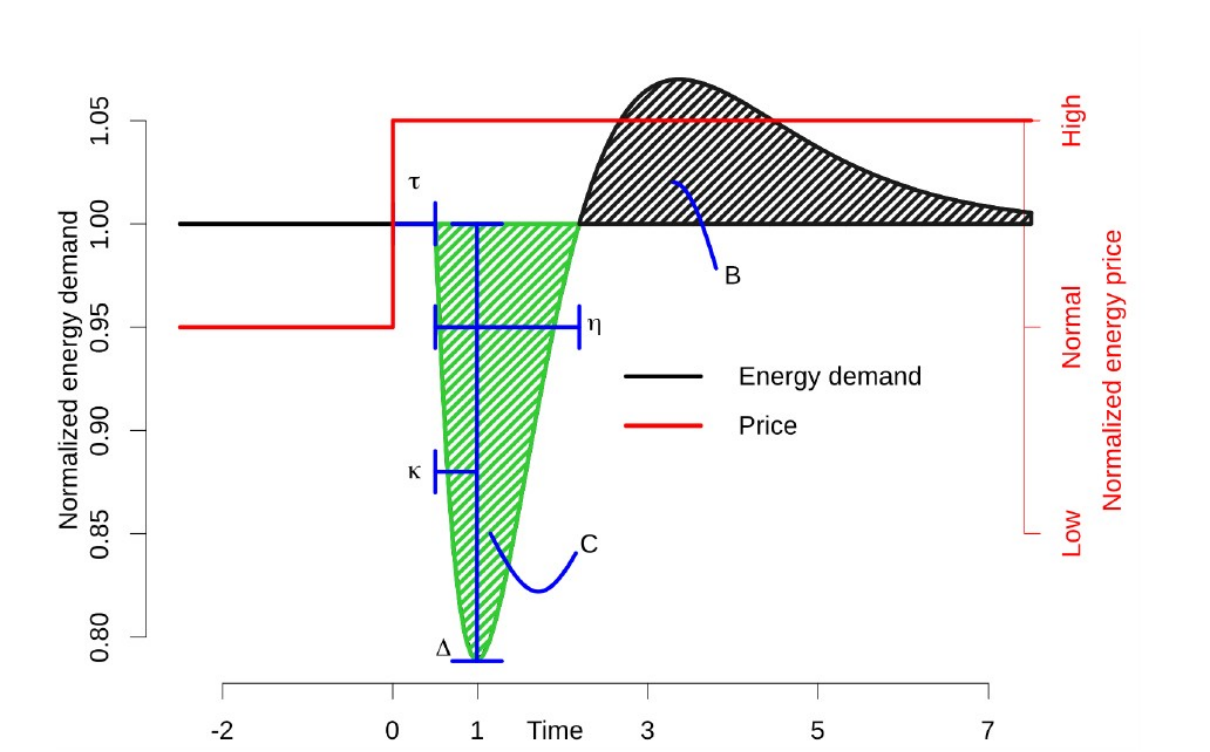
Flexibility Function

The ***Flexibility Function (FF)*** is a **MIMs for energy systems** used to characterize flexibility and providing an interface between local and high-level markets



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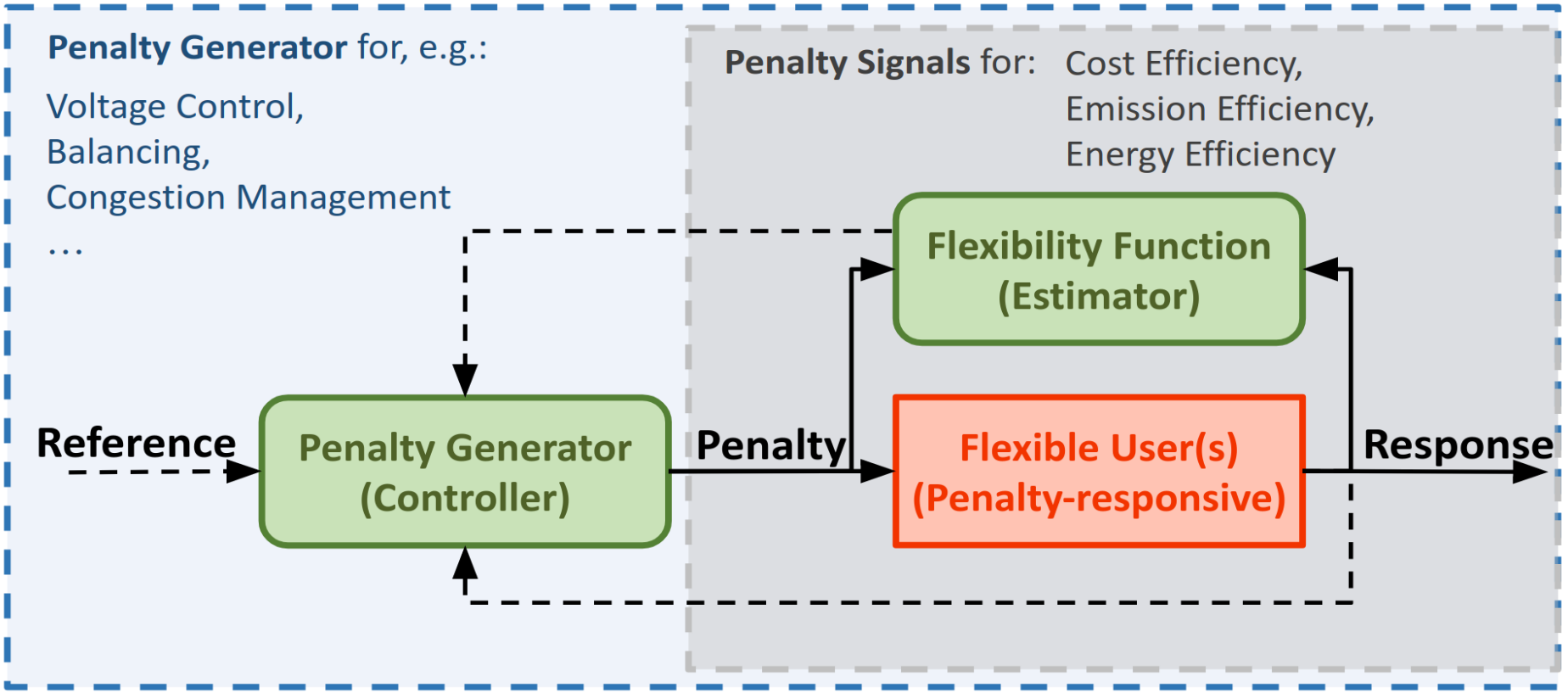
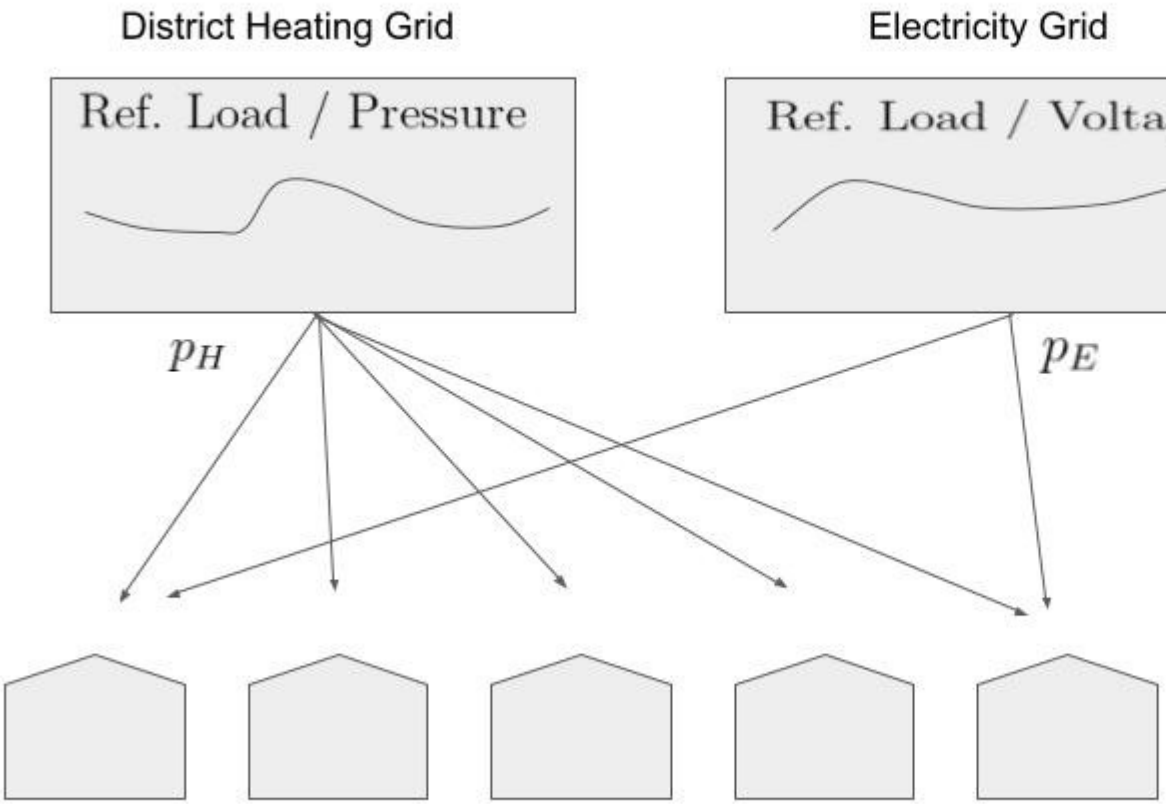
Flexible Users and Penalty Signals



SE-OS for Sector Coupling

Smart-Energy OS for multi-supply systems (here DH and Electricity)



$$\arg\min_{p}(L(p) - ref_{load}))^2$$

$$\arg\min_{U_H,U_E} \sum_{k=1}^{N}(p_H U_H + p_E U_E)$$

$$s.t.$$

$$Temp(U_H, U_E) \in \text{Comfort}$$

Wind Power Forecasting for DSOs and TSO using Spatial Hierarchies

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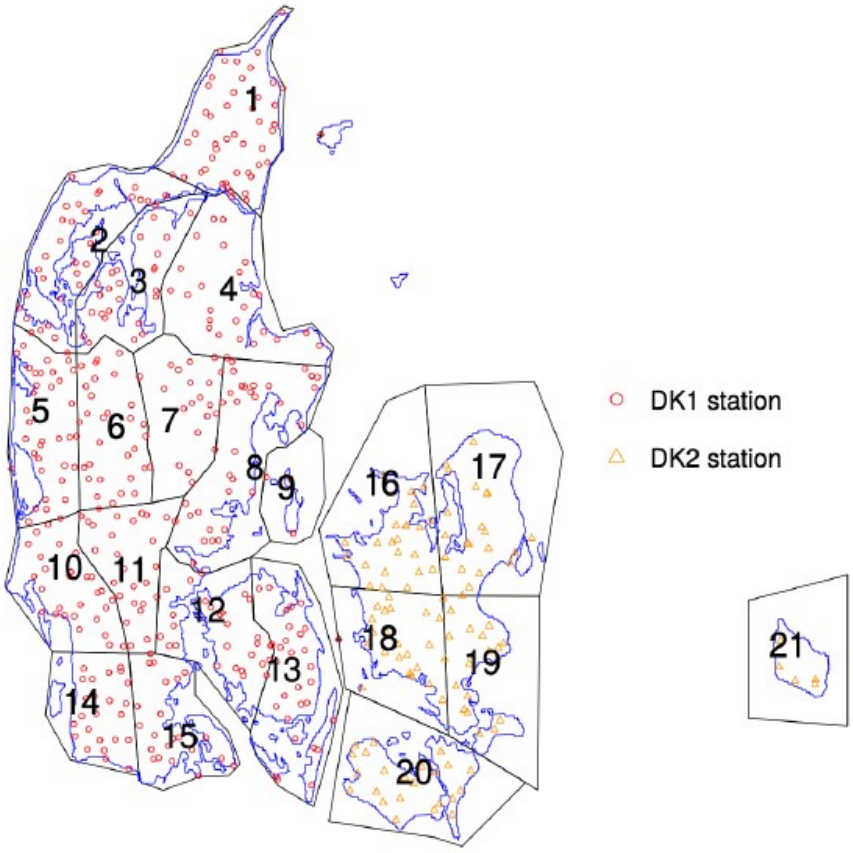
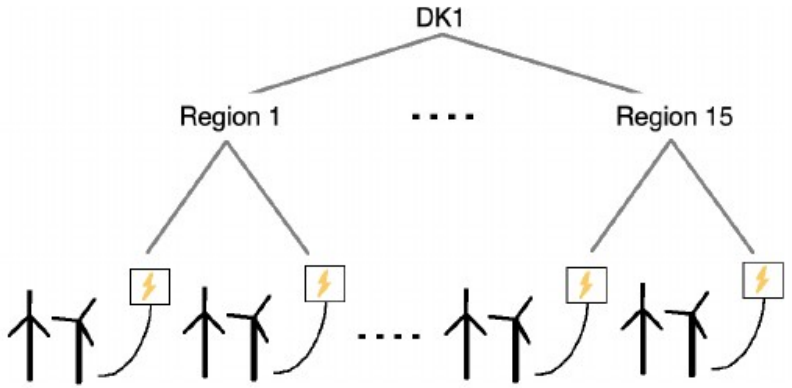
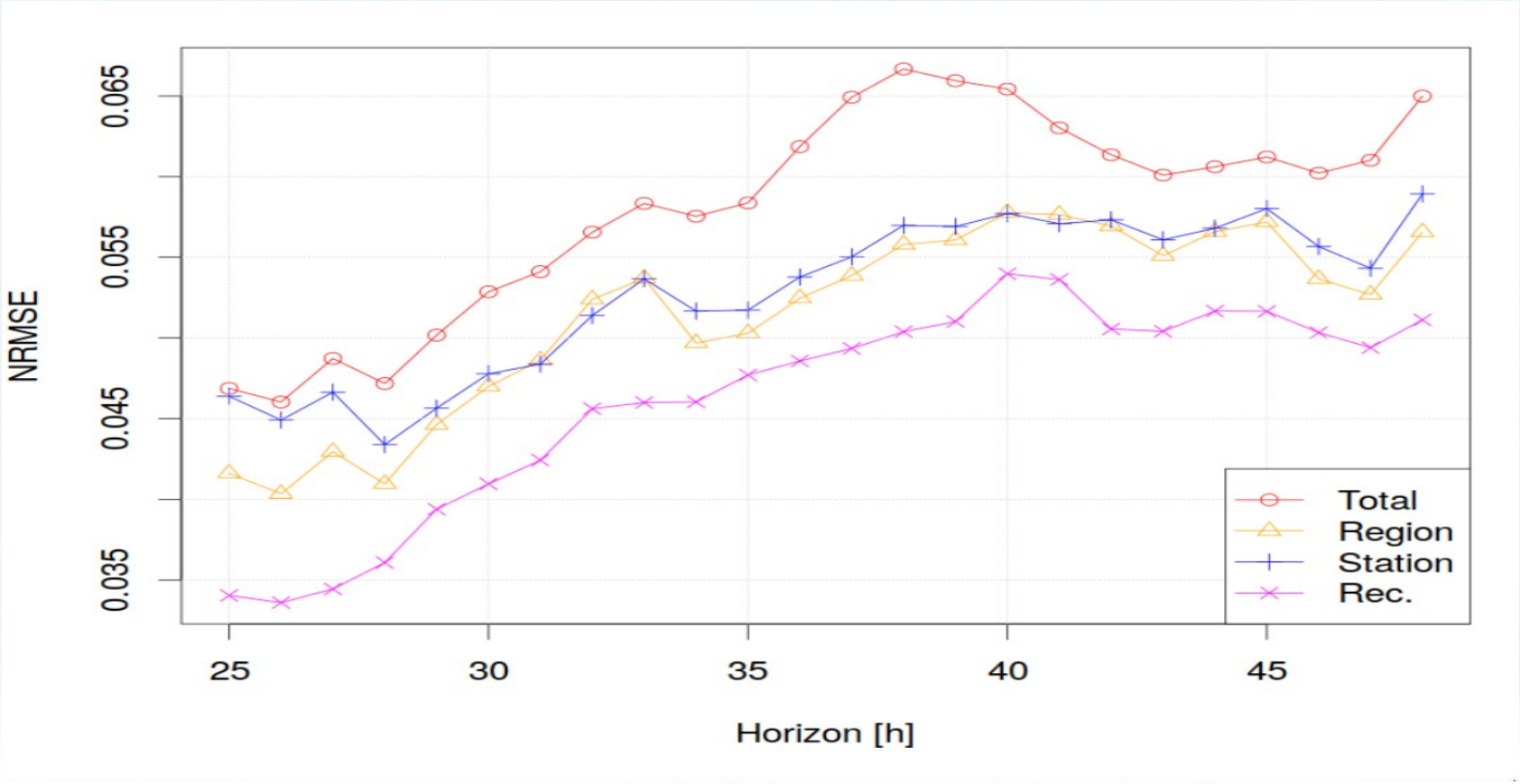
Wind Power Forecasting



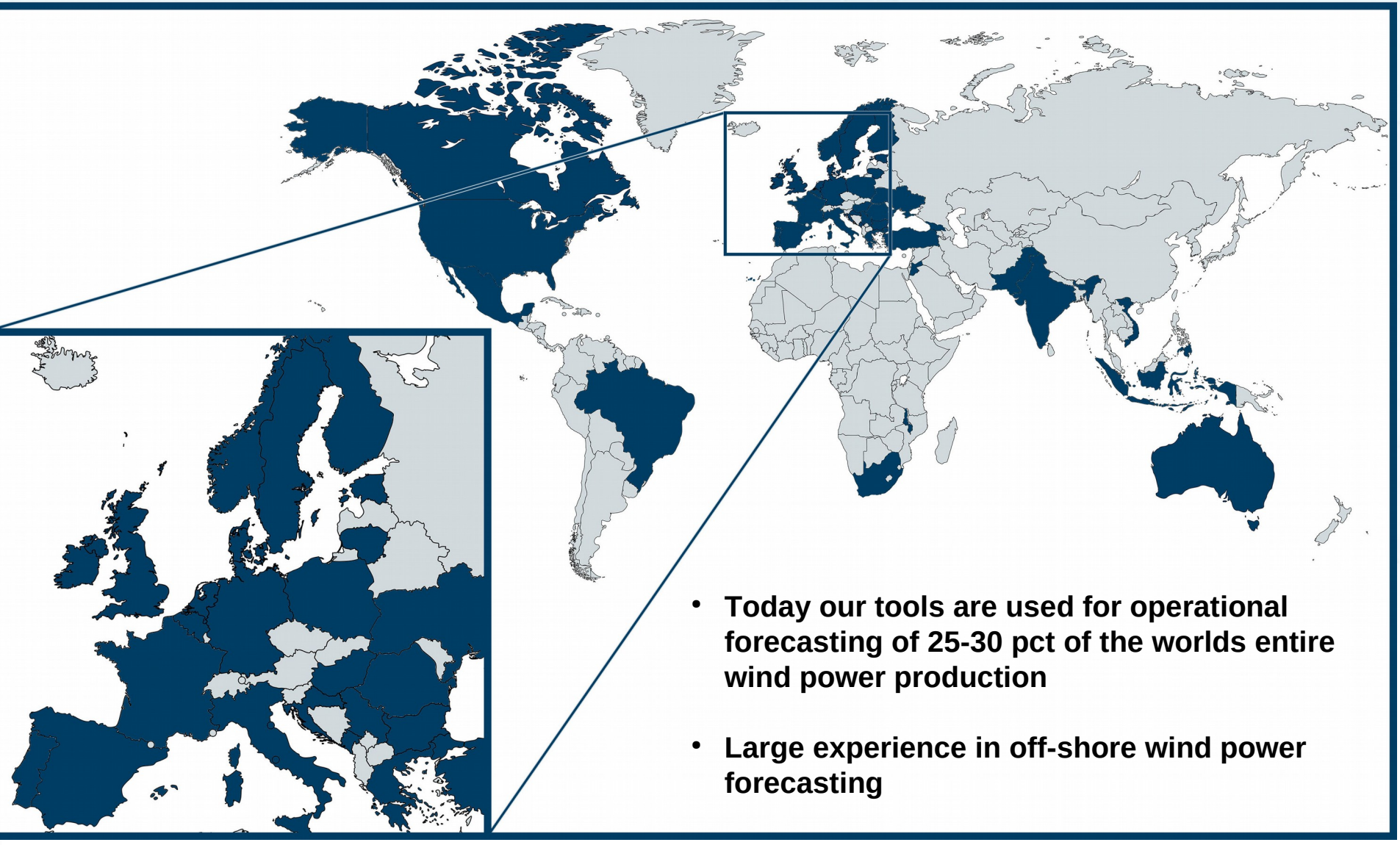


(b) Illustration of the spatial hierarchy for DK1 with 407 individual conversion stations at the bottom level, 15 regions at the middle level, and the total of Western Denmark at the top.

Wind Power Forecasting in DK1 (improvements 20 pct)



Wind Power Forecasting Using API's developed at DTU

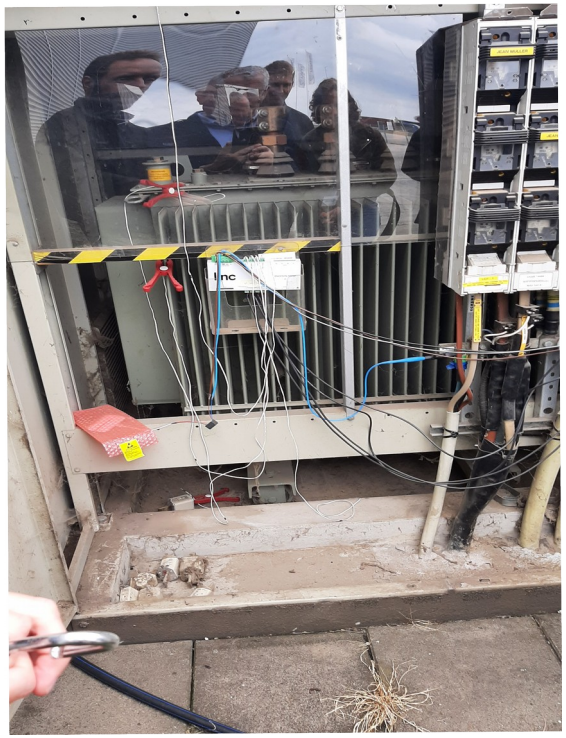


- **Today our tools are used for operational forecasting of 25-30 pct of the worlds entire wind power production**
- **Large experience in off-shore wind power forecasting**

Case Study:

Smart Grid Intelligence

Models for Dynamic Transformer Rating



Sensor setup for transformators

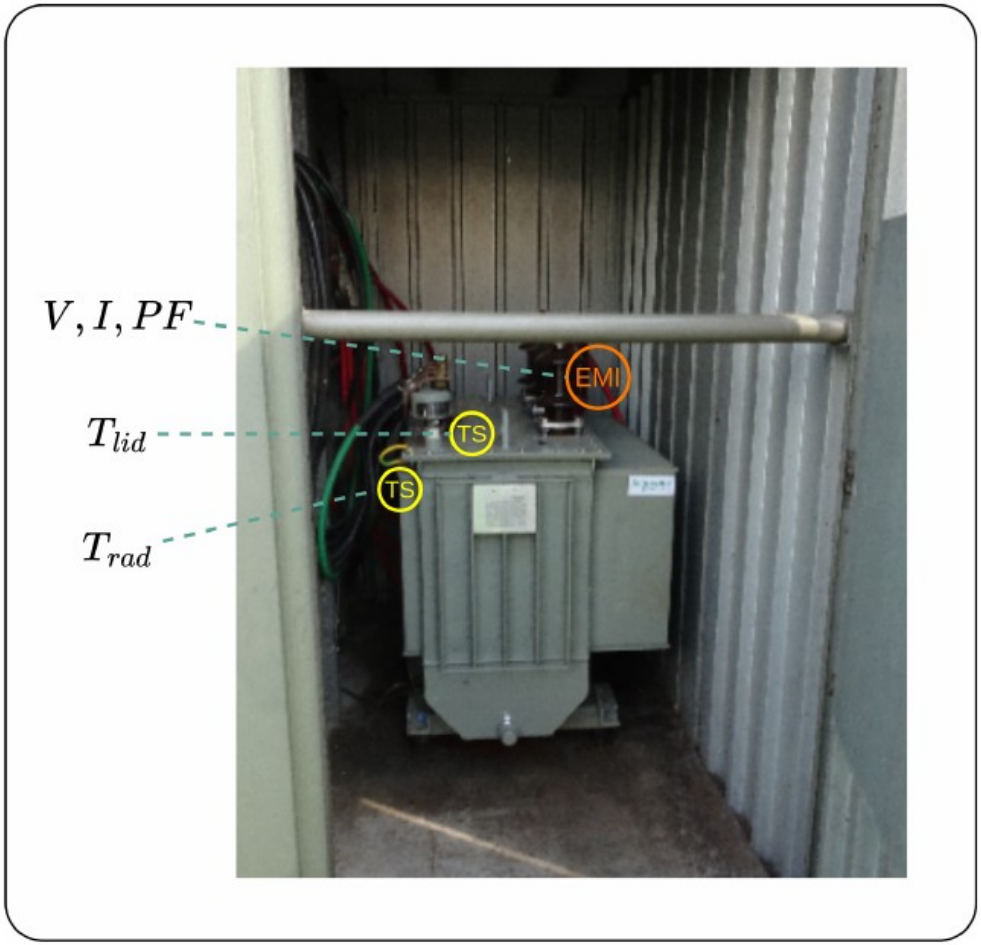


Figure 5.2: Suggested final setup for the transformers, with temperature sensor (TS) and electronic measurement instruments (EMI).

Grey-box model for transformator stations

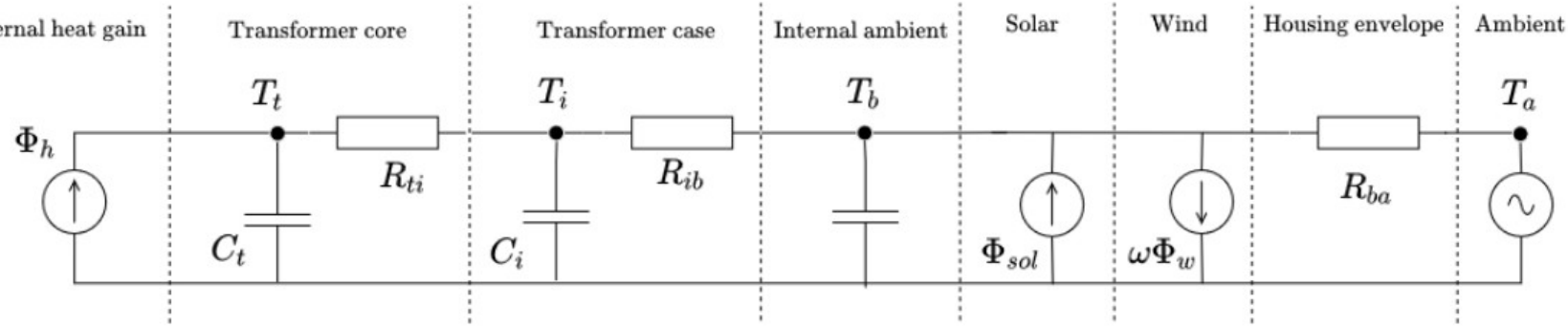


Figure 7: RC circuit of the three state model $TiTtTb$.

Model performance; 6-hour predictions

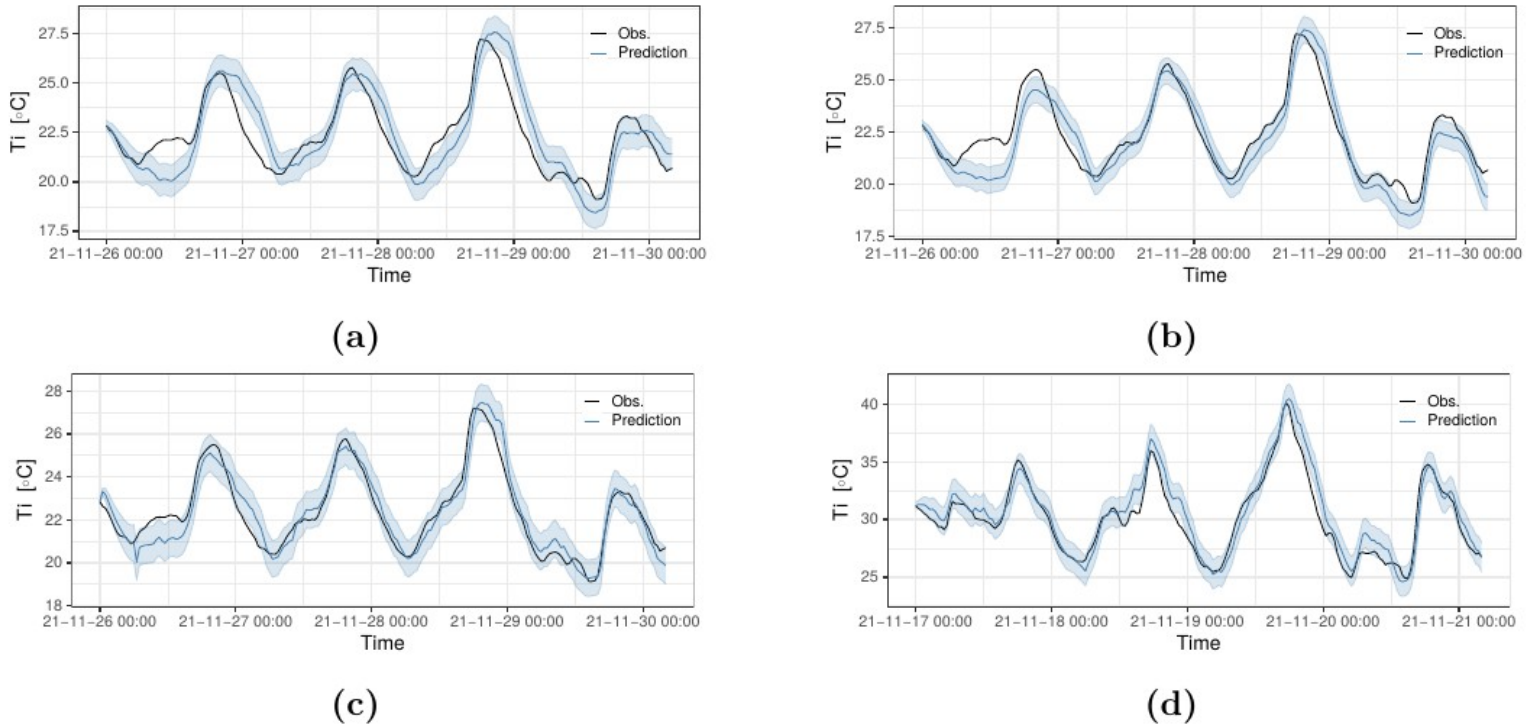
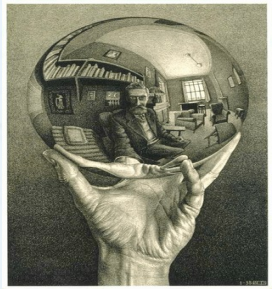


Figure 11: Prediction analysis for 12 step ahead (6 hours) predictions. Subfigures (a)-(c) show predictions for TRF 1 using the one state model (a), extended two state model (b) and the final three state model (c). Subfigure (d) shows predictions for TRF 2 using the final three state model. Black line – observations, Blue line – predictions, Light blue area – 95% PI.

Dynamic Transformer Rating

- Relies on data-driven Digital Twins of the Transformer stations
- Gives good predictions of the hidden states (e.g., oil temperatures) more than 6h ahead
- DTR can reduce the risk of overloading
- The models can be used to predict failures of transformators
- Experiences show that transformers often can be overloaded (up to 120 pct) without any problem
- **Wind farms can be expanded up to 60 pct** without problems (since wind speed and wind power generation are highly correlated)



Implementation:
Data Space for
Spatial and Temporal Data

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Center Denmark, Vision

centerdenmark
intelligent energy

Vision: Center Denmark will **accelerate the green transition towards 100 % renewable energy** in DK through **digitalization** and **sector coupling** and thereby unlocking flexibilities and utilize digital opportunities at all levels across energy systems

Mission

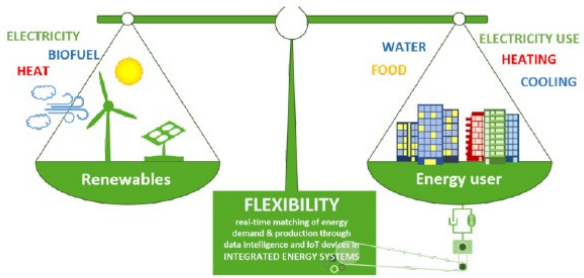
A. Utilize RE production capacity in full by demand response and avoid down-regulation of production

B. Save investments in infrastructure / avoid bottlenecks in the grids by peak shaving

C. Bring continuity into research and provide access for commercial use and market implementation

D. Strengthen digital competences within energy industry supporting new digital business models

Sector Coupling
+
Digitalization



Energy effectiveness vs. System efficiency

Services

1. Trusted Data Sharing platform with 24/7 access to energy related data and digital tools – Bi-directional.

2. Test and demonstration in representative and scalable settings

3. Digital Innovation Hub (DIH) for knowledge transfer services *(Access point for commercial services)*

4. Inkubator for digital business models aimed at new data driven services for the energy sector

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Center Denmark, some employees and board members

Center Denmark
Integrated Energy Systems
Control Room and Data Space

Center Denmark aims at facilitating a trusted data space which put priorities in cyber security and in empowering the partners such that they are able to provide Digitalized and Efficient Solutions for People and Industry without being subject to disproportionate technical requirements, administrative requirements, procedures and charges

Summary

- We have described digitalisation for **sector coupling and linking physics to the markets**
- We need **dynamic (temporal and spatial) tariffs** (and **taxes**)
- We need **data hubs** for energy related **streaming data**
- **It must be easy**. Industry and house owners should be able to participate in **flexibility markets** without being subject to disproportionate technical requirements, procedures and charges
- We have indicated how to use **control-based methods for all type of grid services**
- Implemented at the **European Digital Innovation Hub (EDIH), Center Denmark**