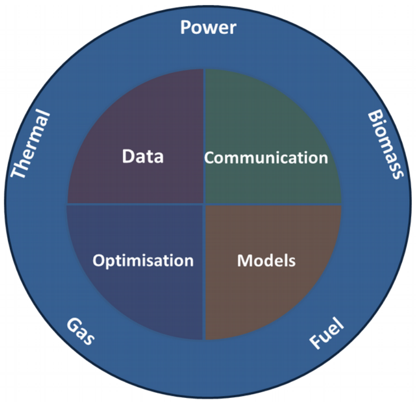
How to use flexibility for accelerating the green transition



Henrik Madsen

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

https://fmezen.no/

http://www.henrikmadsen.org

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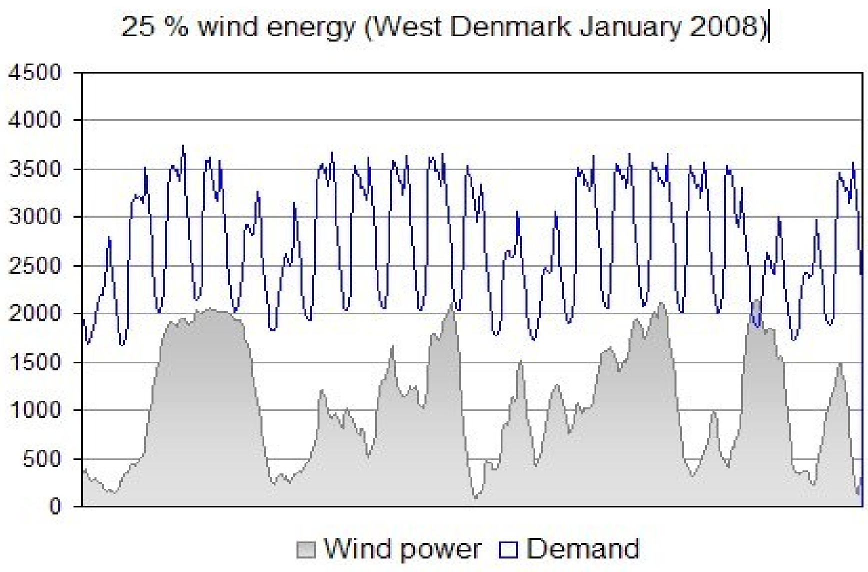
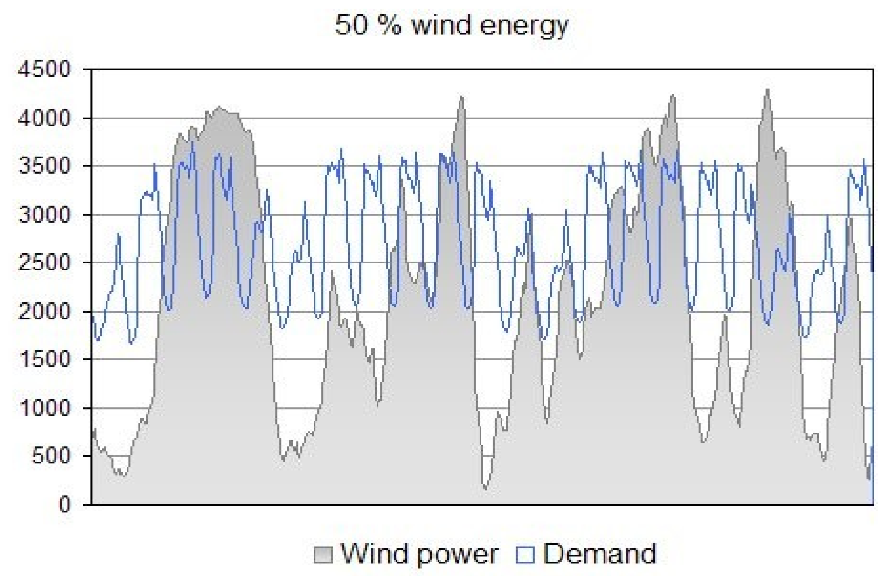
CenSES, Annual Conference, Oslo, November 2018

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 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

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Challenges

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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

The Ecodesign Preparatory Study on Smart Appliances (Lot 33) has analysed the technical, economic, market an[illegible]tal 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.

Almost no Flexibility

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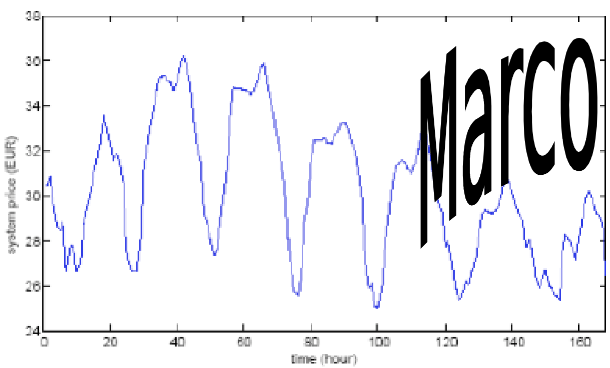
COMPETITIVE BIDDING AND STABILITY ANALYSIS IN ELECTRICITY MARKETS USING CONTROL THEORY

Main idea: **applying control theory to the study of power markets**

Advantages in handling effectively

Dynamics

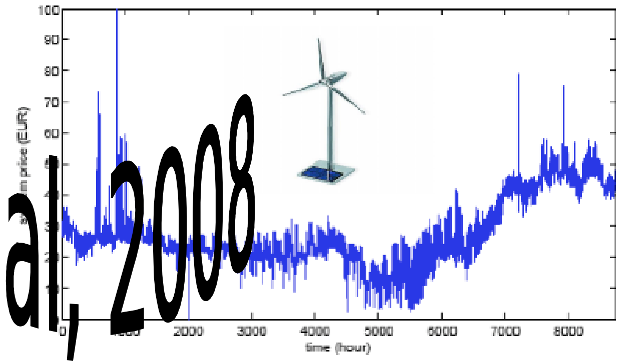


control theory provides ways of modeling the dynamics which is intrinsic in energy markets

↓

it is possible to develop advanced bidding strategies which exploit the inclusion of the dynamics in the model

Uncertainty



stochastic control theory allows for taking into account different sources of uncertainty (wind, ...)

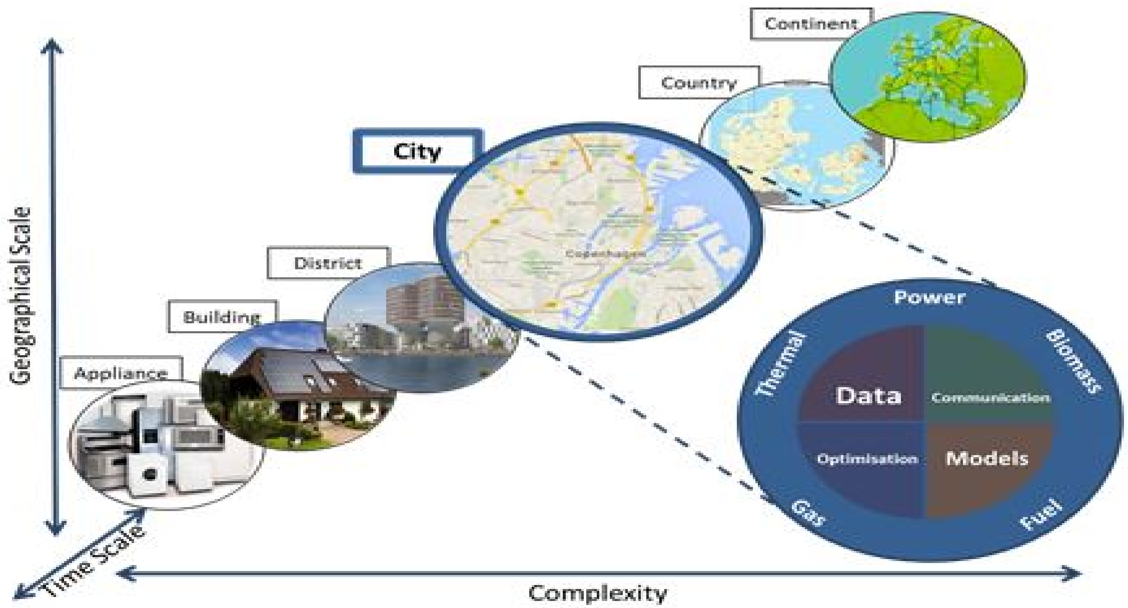
↓

it is possible to develop bidding strategies which are optimal with respect to the stochastic characteristics of the market

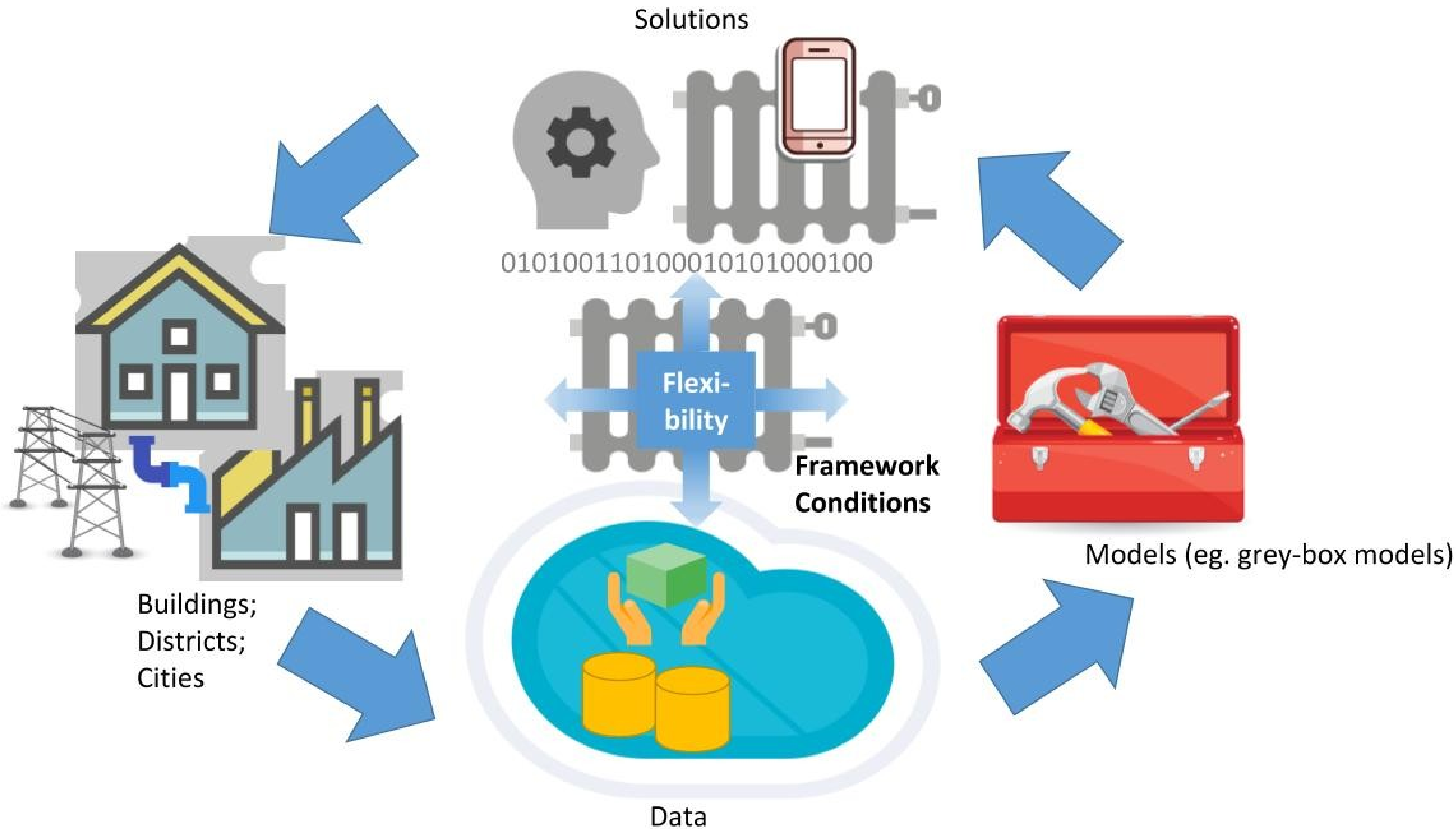
Marco Zugno et.al, 2008

Temporal and Spatial Scales

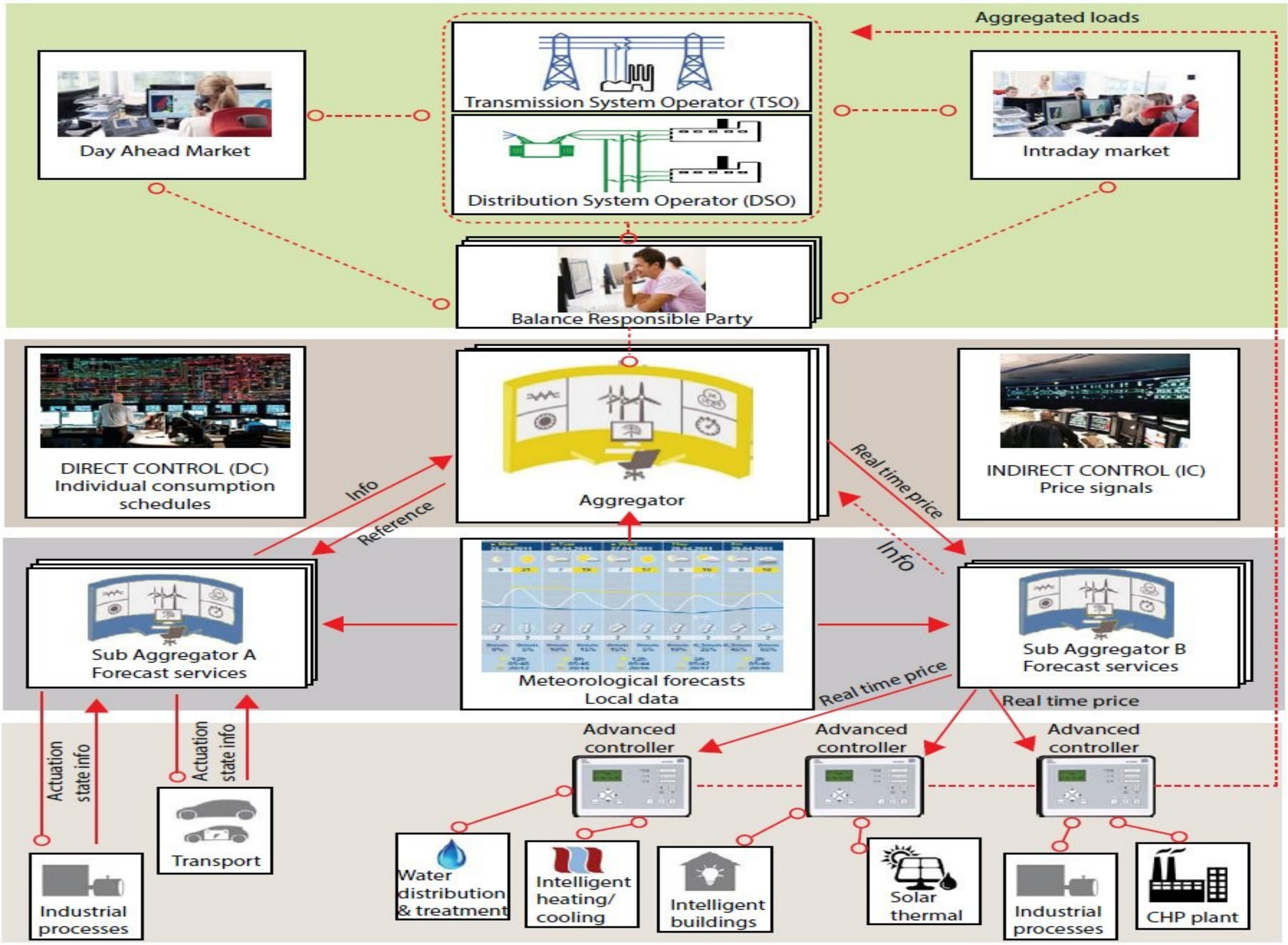
The ***Smart-Energy Operating-System (SE-OS)*** is used to develop, implement and test of solutions (layers: data, models, optimization, control, communication) for ***operating flexible electrical energy systems*** at **all scales**.



Flexibility enabled using data intelligence (AI)



Smart-Energy OS



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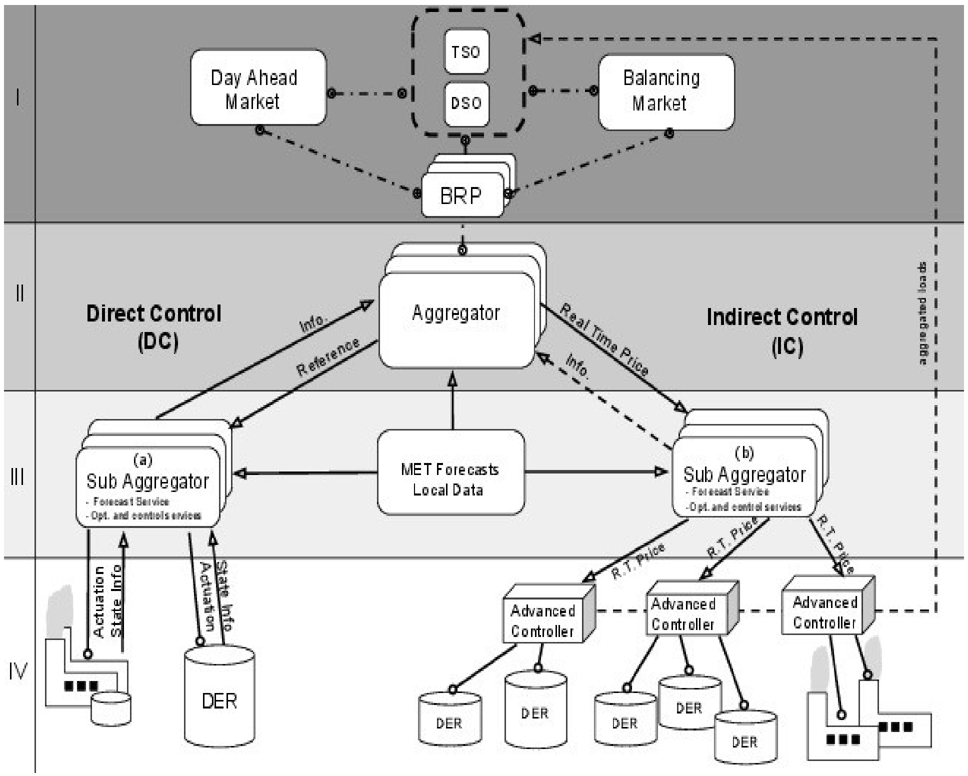
Control and Optimization



Day Ahead:

Stoch. Programming based on eg. Scenarios

Cost: Related to the market (one or two levels)

Direct Control:

Actuator: **Power**

Two-way communication

Models for DERs are needed

Constraints for the DERs (calls for state est.)

Contracts are complicated

Indirect Control:

Actuator: **Price**

Cost: E-MPC at **low (DER) level**, One-way communication

Models for DERs are not needed

Simple 'contracts'

In Wiley Book: Control of Electric Loads in Future Electric Energy Systems, 2015

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AI enabled Flexible Energy Systems

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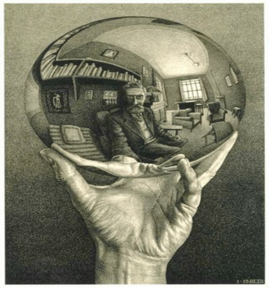
- Automatic and self-cal. methods based on Big Data and AI
- Labs – Virtual, HiL, Live
- Nested sequence of systems – systems of systems
- **Hierarchy of stoch. optimization and control problems**
- Bidding – clearing – activation at higher levels
- Multivariate probabilistic forecasting
- Cloud or Fog (IoT, IoS) based solutions – eg. for 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**



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Case study

Control of heat pumps for swimming pools (Minimization of CO_2 emission)

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Example: CO2-based control

For more information ...

See for instance

https://fmezen.no/
– http://www.smart-cities-centre.org

...or contact

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henrik.madsen@ntnu.no

Acknowledgement:

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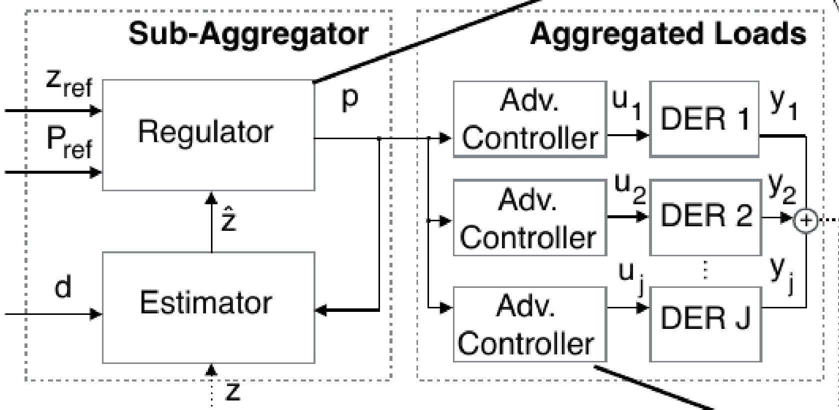
Proposed methodology
Control-based methodology



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

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

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

Some case studies ….

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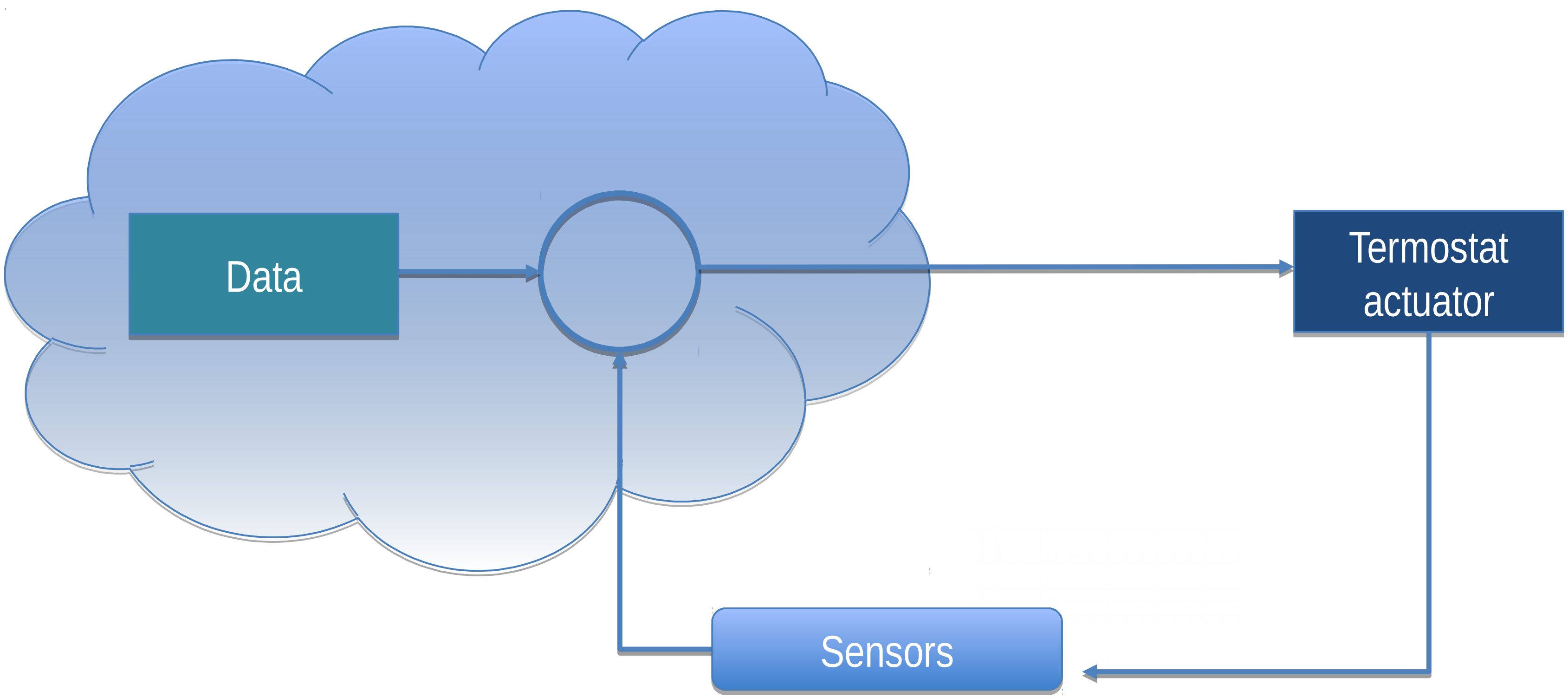
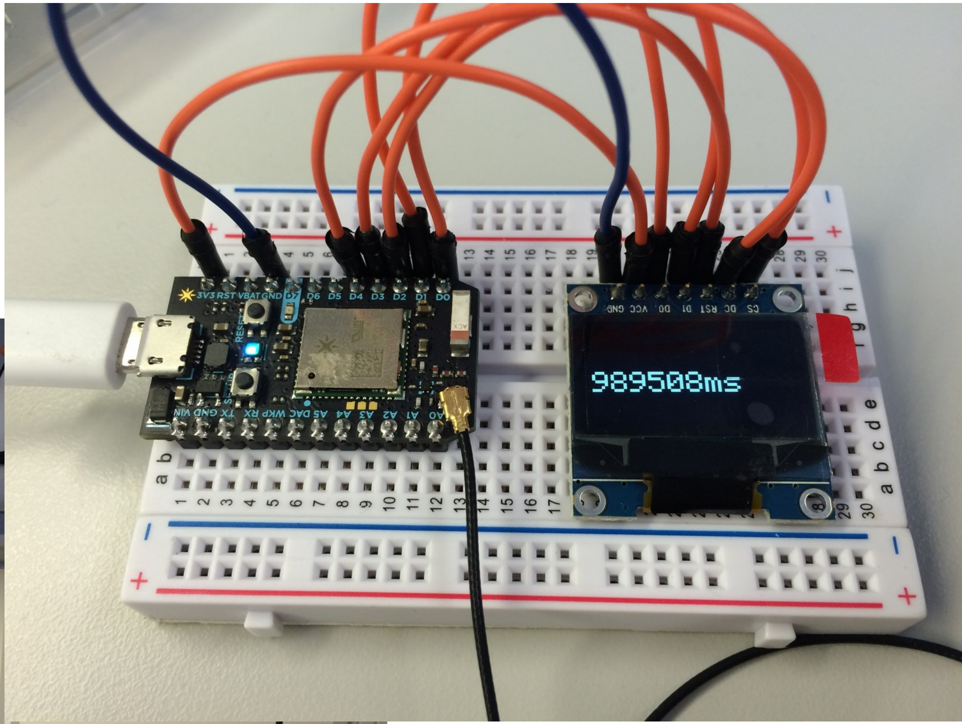
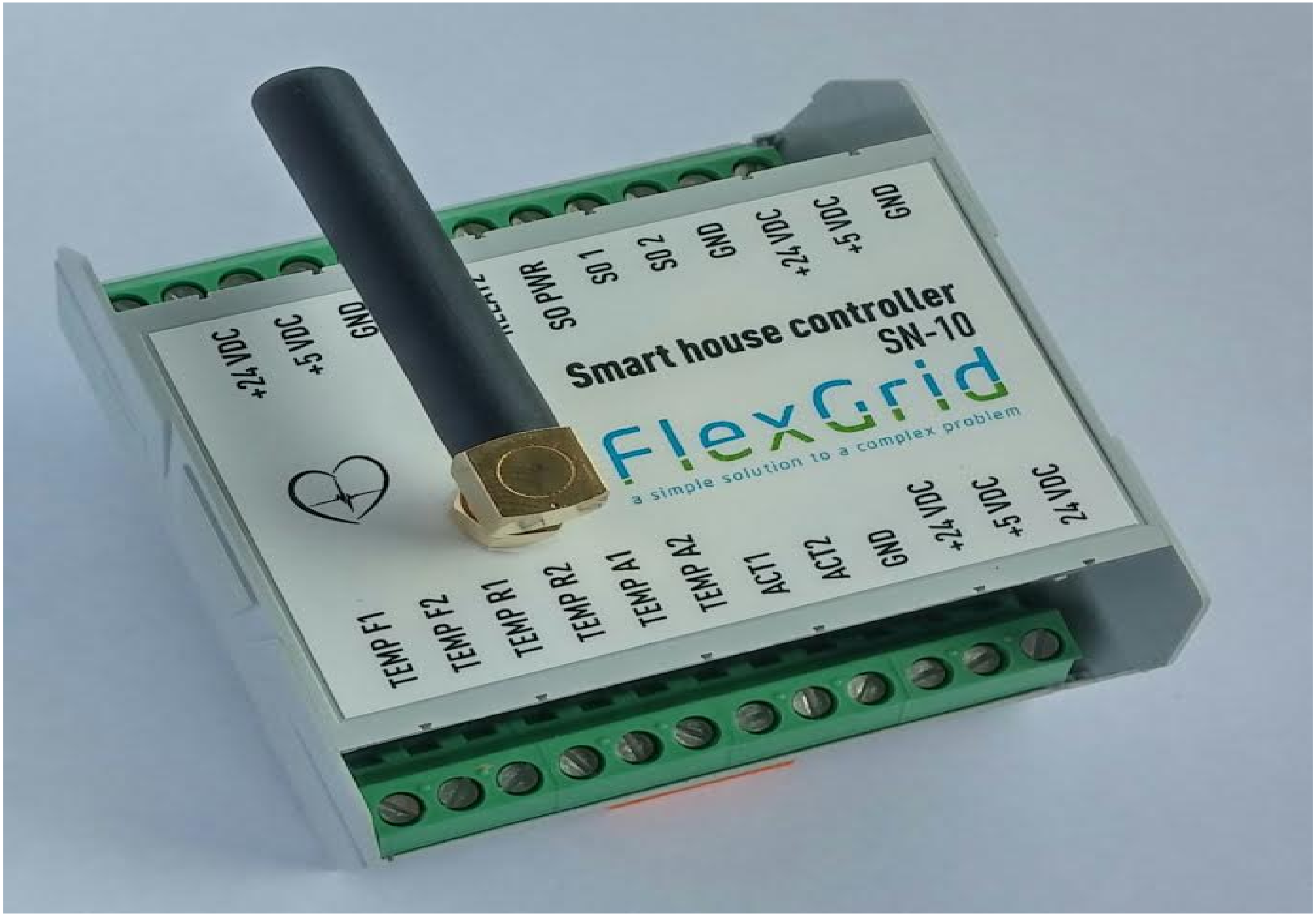
SE-OS
Control loop design – **logical drawing**



Lab testing ….

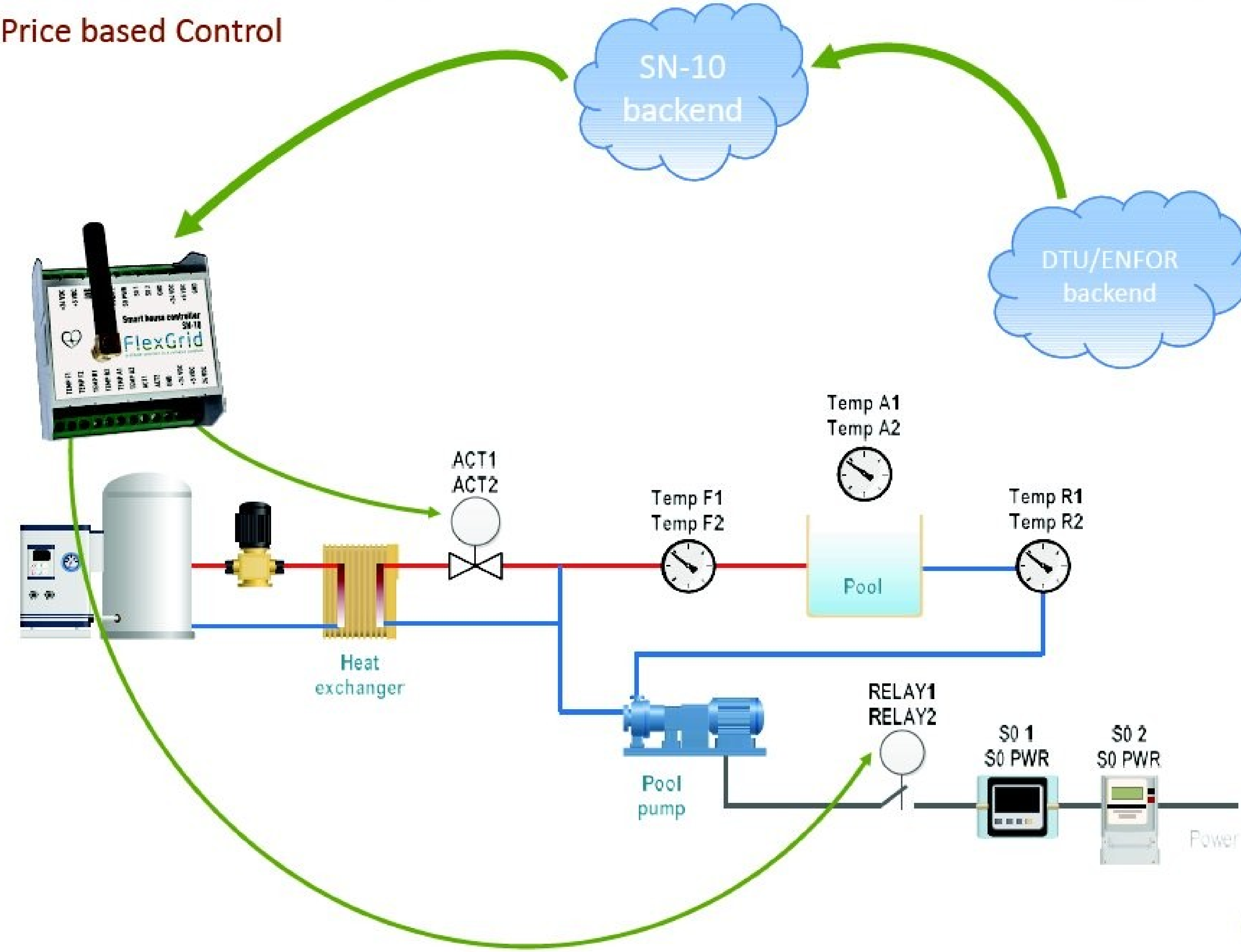


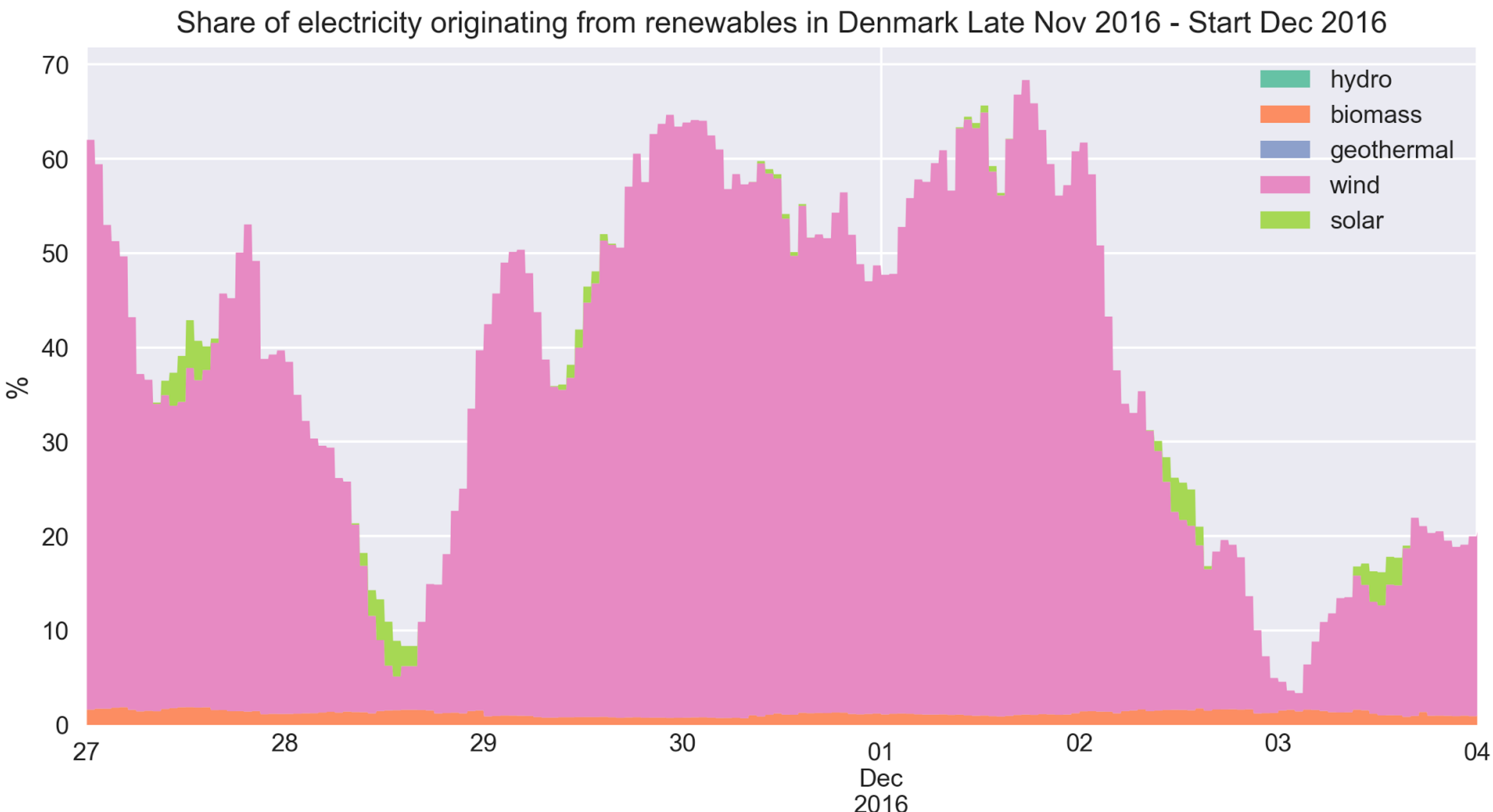
SN-10 Smart House Prototype



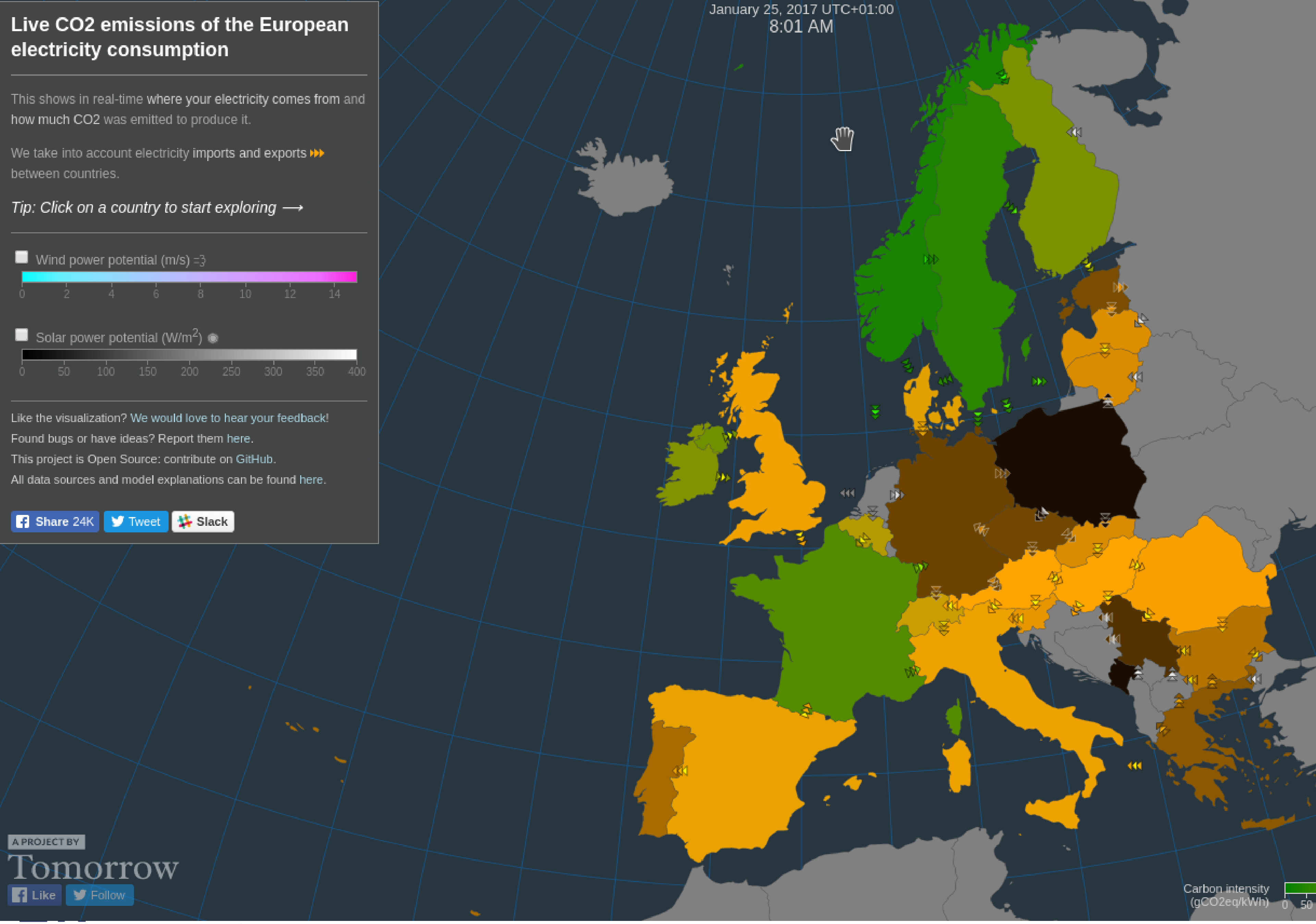
How does it work?

Price based Control

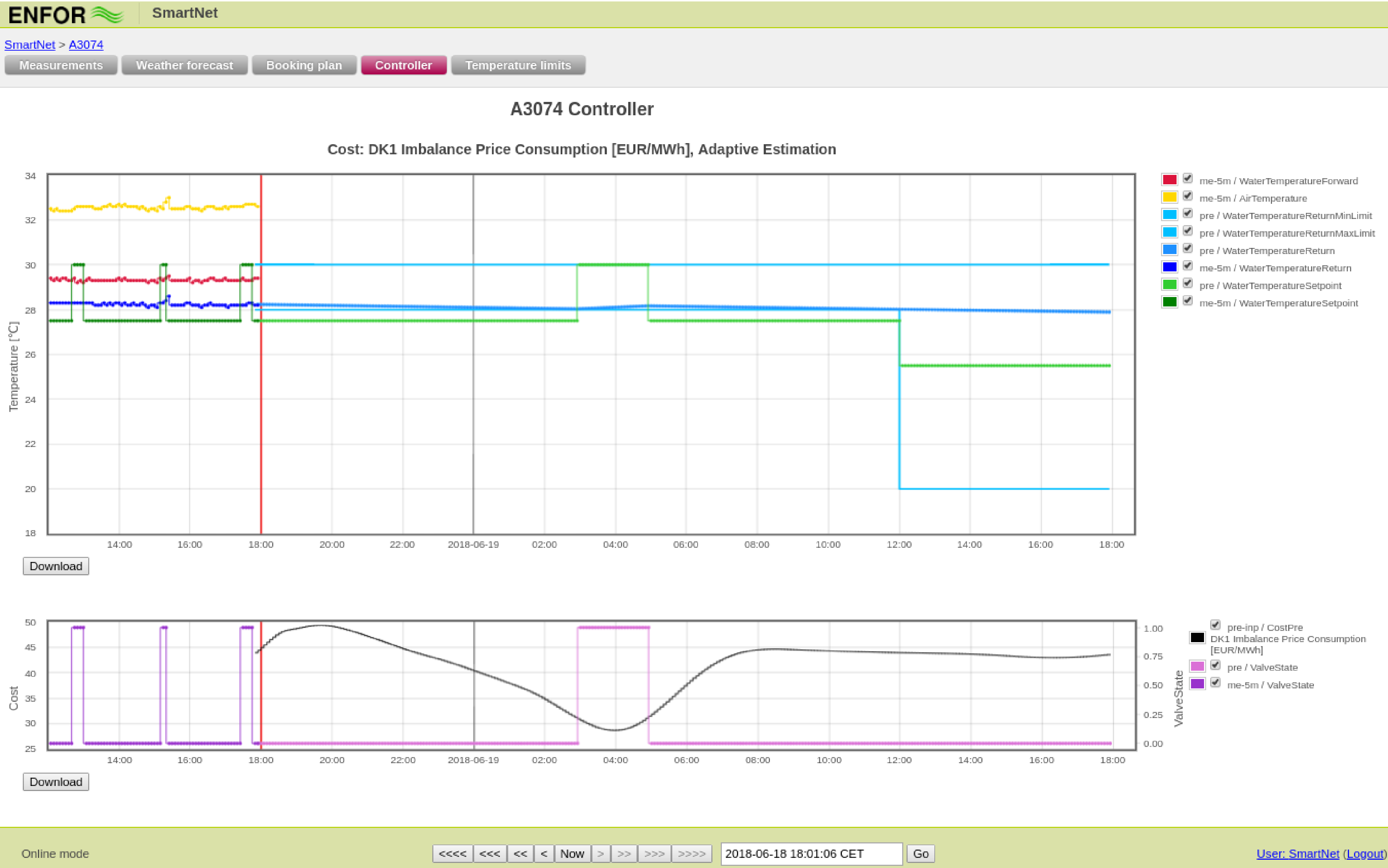




Source: pro.electicitymap.org


January 25, 2017 UTC+01:00
8:01 AM
Live CO2 emissions of the European electricity consumption
This shows in real-time where your electricity comes from and how much CO2 was emitted to produce it.
We take into account electricity imports and exports between countries.
Tip: Click on a country to start exploring ⟶
Wind power potential (m/s)
0 2 4 6 8 10 12 14
Solar power potential (W/m2)
0 50 100 150 200 250 300 350 400
Like the visualization? We would love to hear your feedback!
Found bugs or have ideas? Report them here.
This project is Open Source: contribute on GitHub.
All data sources and model explanations can be found here.
Share 24K
Tweet
Slack
A PROJECT BY
Tomorrow
Like
Follow
Carbon intensity (gCO2eq/kWh)
0 50

Example: Price-based control



Penalty Function (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*.

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Case study No. 2

Wastewater Treatment Plants

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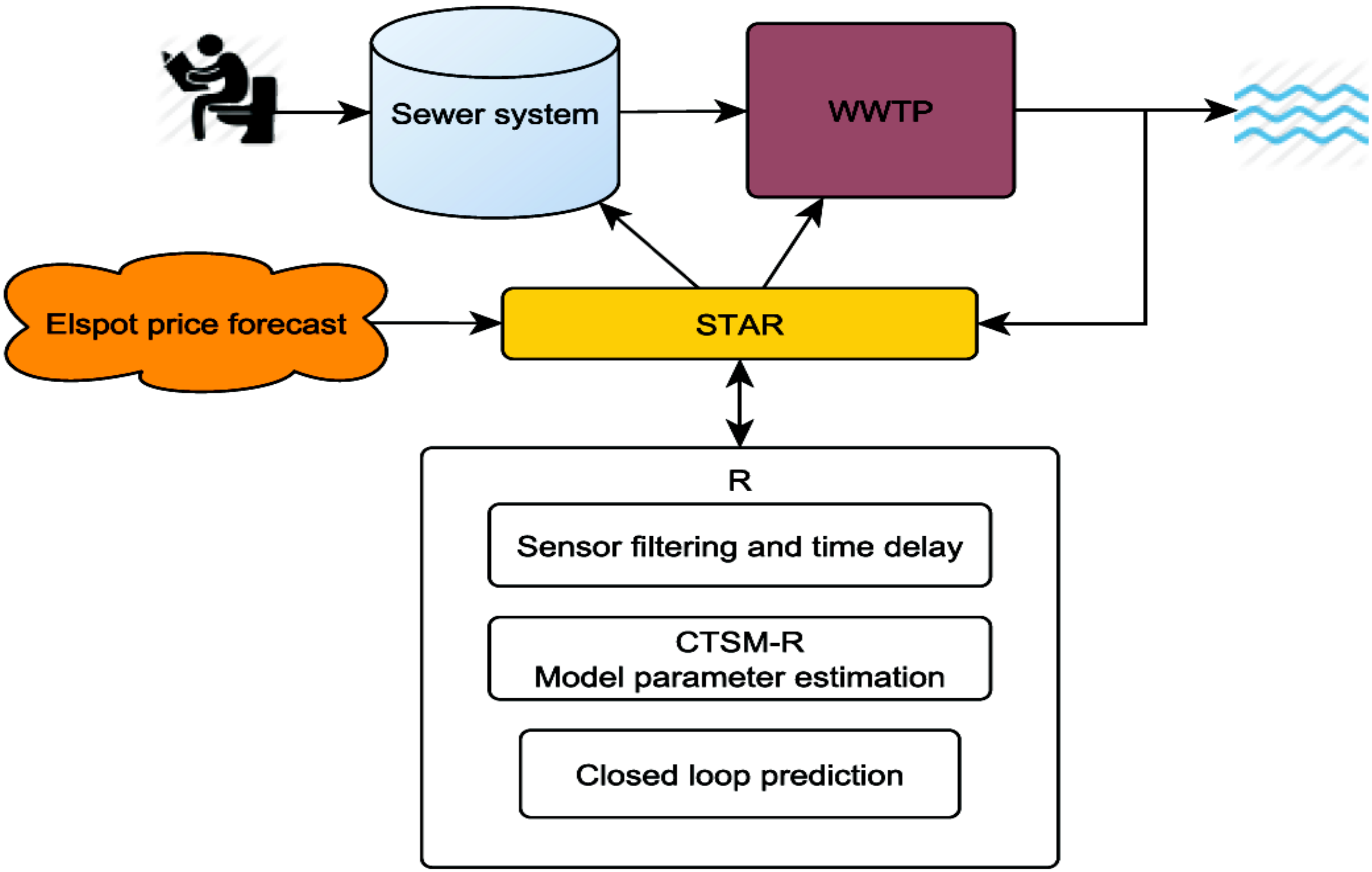
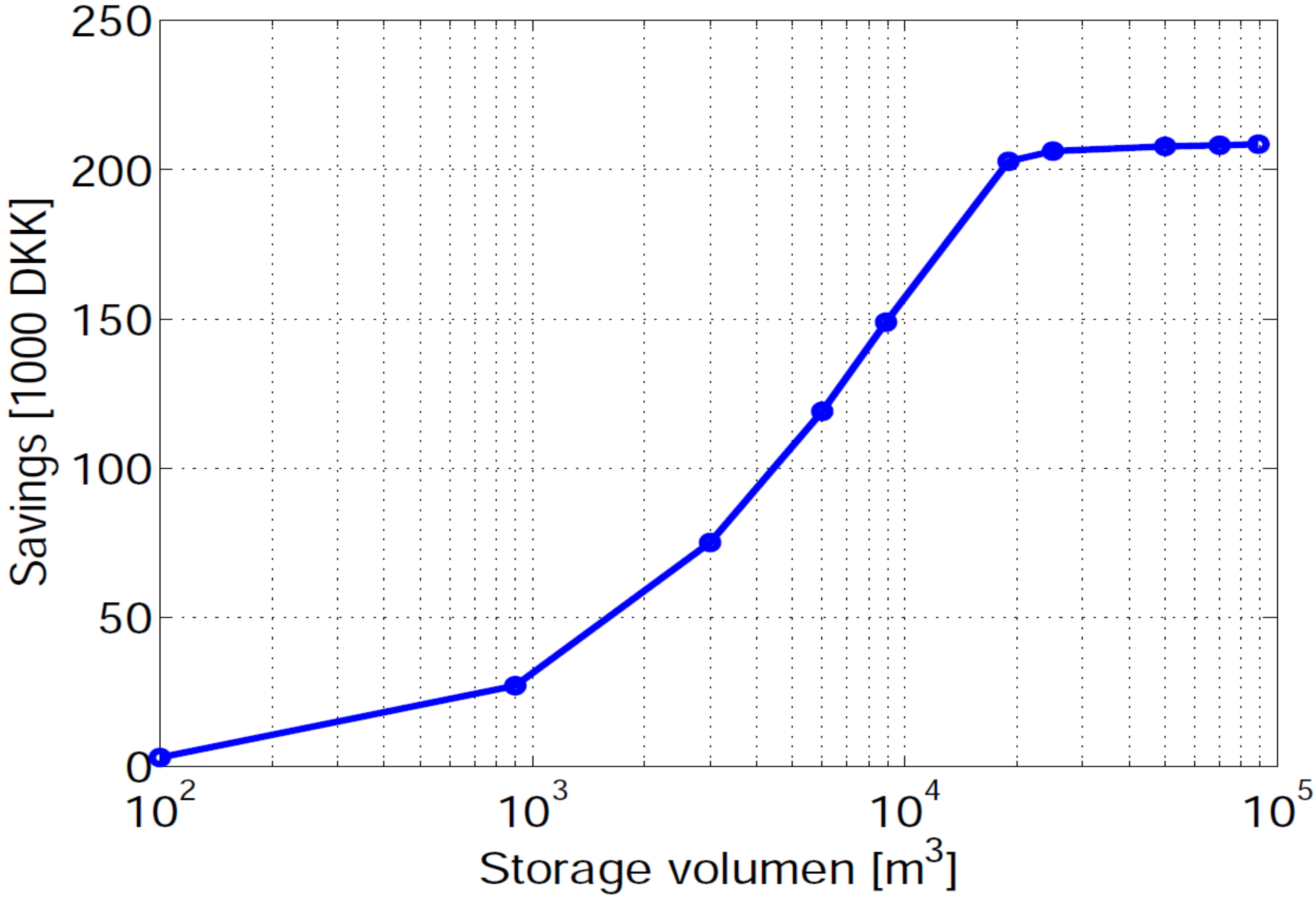
Kolding WWTP

Energy Flexibility in Wastewater Treatment



Sewer System Annual Elspot Savings



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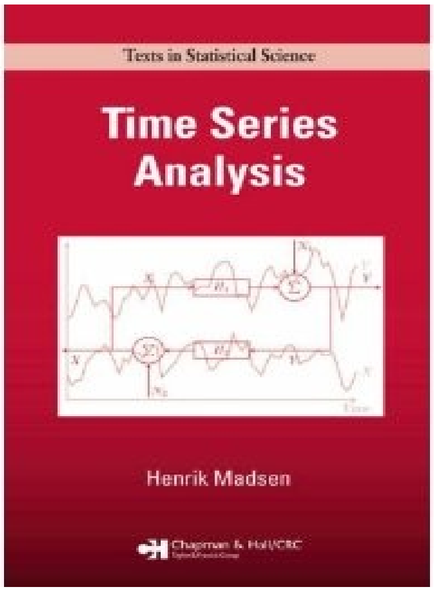
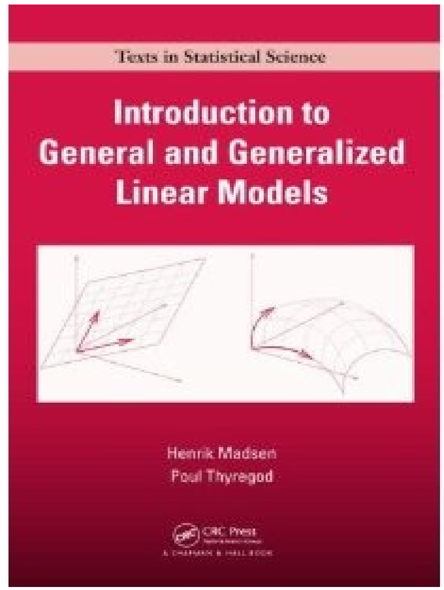
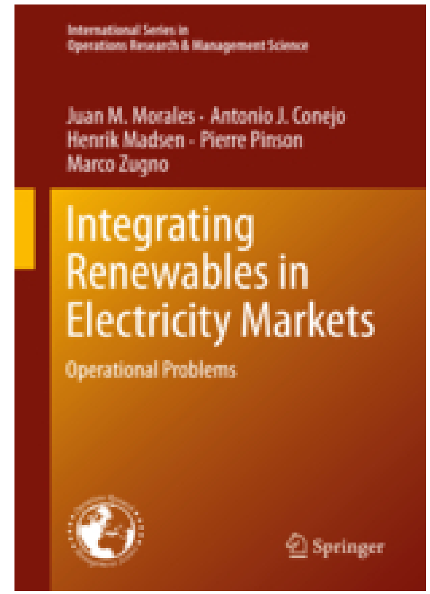
Some 'randomly picked' books on modeling ....







Some references

Madsen, Henrik; Holst, Jan. Estimation of Continuous-Time Models for the Heat Dynamics of a Building. In: Energy and Buildings, Vol. 22, 1995

Andersen, Klaus Kaae; Madsen, Henrik; Hansen, Lars Henrik. Modelling the heat dynamics of a building using stochastic differential equations. In: Energy and Buildings, Vol. 31, No. 1, 2000, p. 13-24.

Kristensen, Niels Rode; Madsen, Henrik; Jørgensen, Sten Bay. Using continuous time stochstic modelling and nonparametric statistics to improve the quality of first principles models. In: Computer – Aided Chemical Engineering, Vol. 10, 2002, p. 901-906

Kristensen, N.R.; Madsen, Henrik; Jørgensen, Sten Bay. A unified framefork for systematic model improvement. In: Process Systems Engineering, Vol. 15, 2003, p. 1292-1297.

Kristensen, Niels Rode; Madsen, Henrik; Jørgensen, Sten Bay. Parameter Estimation in Stochastic Grey-Box Models. In: Automatica, Vol. 40, No. 2, 2004, p. 225-237.

Nielsen, Henrik Aalborg; Madsen, Henrik. Modelling the Heat Consumption in District Heating Systems using a Grey-box approach. In: Energy and Buildings, Vol. 38, No. 1, 2006, p. 63-71.

Friling, N.; Jimenez, M.J.; Bloem, H.; Madsen, Henrik. Modelling the heat dynamics of building integrated and ventilated photovoltaic modules. In: Energy and Buildings, Vol. 41, No. 10, 2009, p. 1051-1057.

Bacher, Peder; Madsen, Henrik. Identifying suitable models for the heat dynamics of buildings. In: Energy and Buildings, Vol. 43, No. 7, 2011, p. 1511-1522.

Lodi, C.; Bacher, Peder; Cipriano, J.; Madsen, Henrik. Modelling the heat dynamics of a monitored Test Reference Environment for Building Integrated Photovoltaic systems using stochastic differential equations. In: Energy and Buildings, Vol. 50, 2012, p. 273-281.

Morales González, Juan Miguel; Pinson, Pierre; Madsen, Henrik. A Transmission-Cost-Based Model to Estimate the Amount of Market-Integrable Wind Resources. In: IEEE Transactions on Power Systems, Vol. 27, No. 2, 2012, p. 1060-1069 .

Halvgaard, Rasmus; Bacher, Peder; Perers, Bengt; Andersen, Elsa; Furbo, Simon; Jørgensen, John Bagterp; Poulsen, Niels Kjølstad; Madsen, Henrik. Model predictive control for a smart solar tank based on weather and consumption forecasts. In: Energy Procedia, Vol. 30, 2012, p. 270-278.

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Some references (cont.)

Morales González, Juan Miguel; Pinson, Pierre; Madsen, Henrik. A Transmission-Cost-Based Model to Estimate the Amount of Market-Integrable Wind Resources. In: IEEE Transactions on Power Systems, Vol. 27, No. 2, 2012, p. 1060-1069

Dorini, Gianluca Fabio ; Pinson, Pierre; Madsen, Henrik. Chance-constrained optimization of demand response to price signals. In: IEEE Transactions on Smart Grid, Vol. 4, No. 4, 2013, p. 2072-2080.

Bacher, Peder; Madsen, Henrik; Nielsen, Henrik Aalborg; Perers, Bengt. Short-term heat load forecasting for single family houses. In: Energy and Buildings, Vol. 65, 2013, p. 101-112.

Corradi, Olivier; Ochsenfeld, Henning Peter; Madsen, Henrik; Pinson, Pierre. Controlling Electricity Consumption by Forecasting its Response to Varying Prices. In: IEEE Transactions on Power Systems, Vol. 28, No. 1, 2013, p. 421-430.

Zugno, Marco; Morales González, Juan Miguel; Pinson, Pierre; Madsen, Henrik. A bilevel model for electricity retailers' participation in a demand response market environment. In: Energy Economics, Vol. 36, 2013, p. 182-197.

Meibom, Peter; Hilger, Klaus Baggesen; Madsen, Henrik; Vinther, Dorthe. Energy Comes Together in Denmark: The Key to a Future Fossil-Free Danish Power System. In: IEEE Power & Energy Magazine, Vol. 11, No. 5, 2013, p. 46-55.

Andersen, Philip Hvidthøft Delff ; Jiménez, María José ; Madsen, Henrik ; Rode, Carsten. Characterization of heat dynamics of an arctic low-energy house with floor heating. In: Building Simulation, Vol. 7, No. 6, 2014, p. 595-614.

Andersen, Philip Hvidthøft Delff; Iversen, Anne; Madsen, Henrik; Rode, Carsten. Dynamic modeling of presence of occupants using inhomogeneous Markov chains. In: Energy and Buildings, Vol. 69, 2014, p. 213-223.

Madsen, H, Parvizi, J, Halvgaard, RF, Sokoler, LE, Jørgensen, JB, Hansen, LH & Hilger, KB 2015, 'Control of Electricity Loads in Future Electric Energy Systems'. in AJ Conejo, E Dahlquist & J Yan (eds), Handbook of Clean Energy Systems: Intelligent Energy Systems. vol. 4, Wiley.

Halvgaard, RF, Vandenberghe, L, Poulsen, NK, Madsen, H & Jørgensen, JB 2016, Distributed Model Predictive Control for Smart Energy Systems IEEE Transactions on Smart Grid, vol 7, no. 3, pp. 1675-1682.

Bacher, P, de Saint-Aubain, PA, Christiansen, LE & Madsen, H 2016, Non-parametric method for separating domestic hot water heating spikes and space heating Energy and Buildings, vol 130, pp. 107-112.

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