Methodologies for Controlling the Electricity Load in Future Intelligent and Integrated Energy Systems

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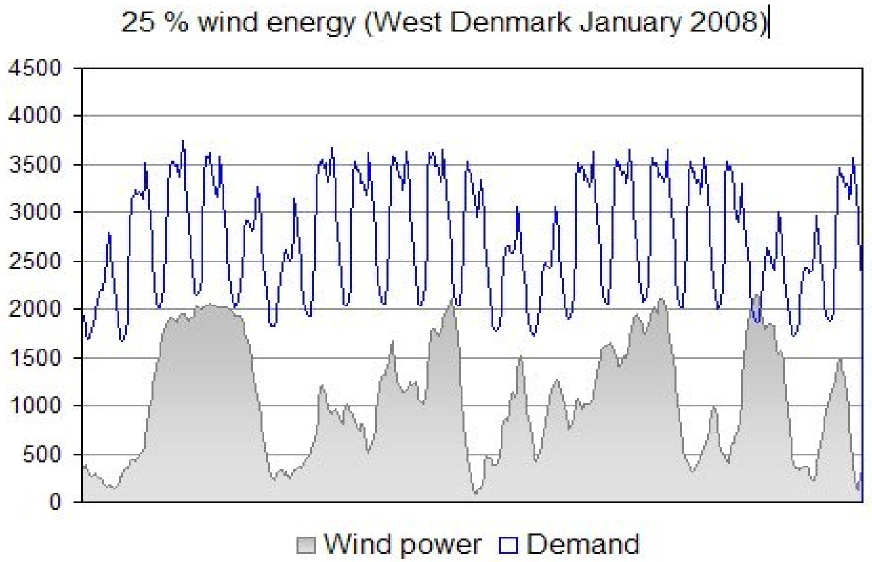
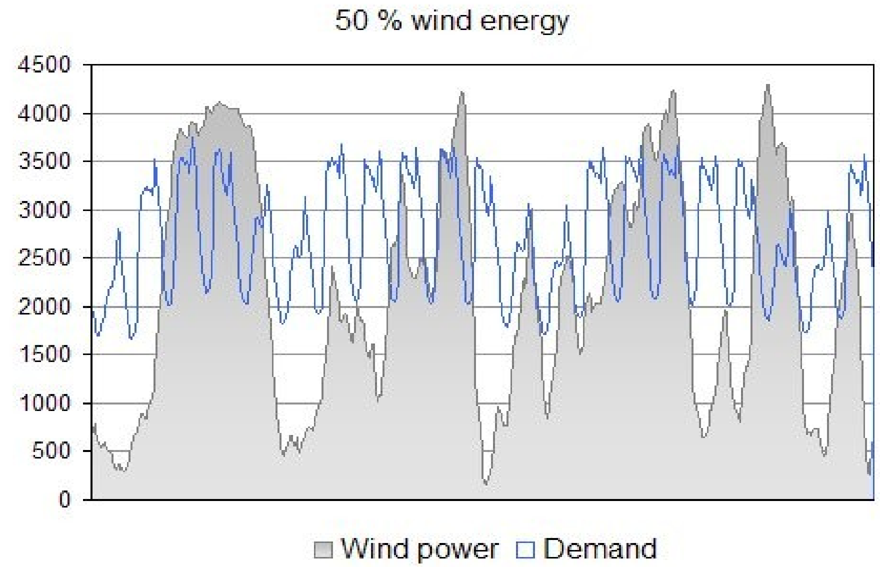
Argonne National Lab., Dec.2017

The Danish Wind Power Case

…. balancing of the power system





In the first half of 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.

Periods with more than 140 pct of the power load covered by wind power are seen

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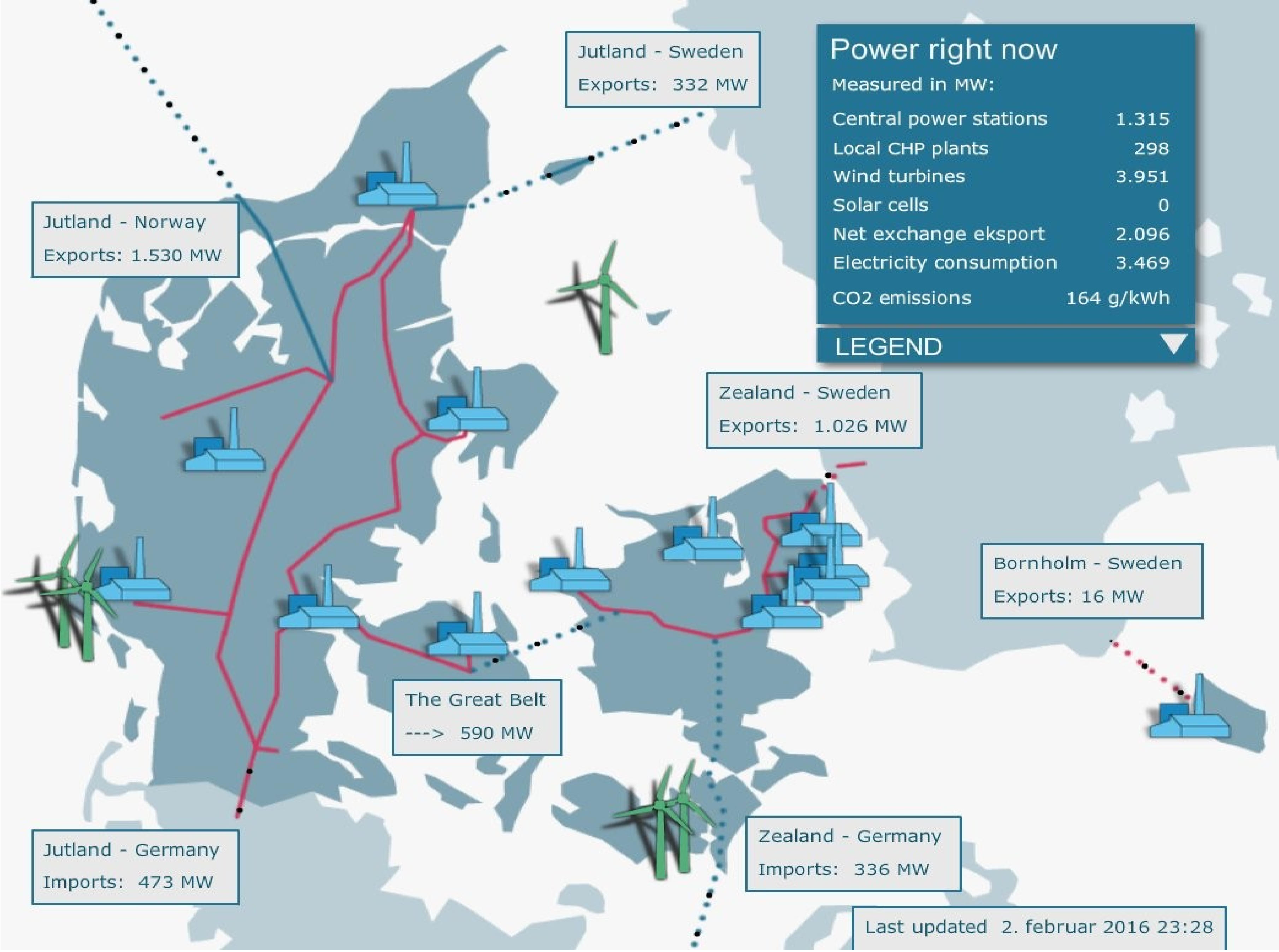


Jutland - Sweden
Exports: 332 MW
Power right now
Measured in MW:
Central power stations 1.315
Local CHP plants 298
Wind turbines 3.951
Solar cells 0
Net exchange eksport 2.096
Electricity consumption 3.469
CO2 emissions 164 g/kWh
LEGEND
Jutland - Norway
Exports: 1.530 MW
Zealand - Sweden
Exports: 1.026 MW
Bornholm - Sweden
Exports: 16 MW
The Great Belt
---> 590 MW
Jutland - Germany
Imports: 473 MW
Zealand - Germany
Imports: 336 MW
Last updated 2. februar 2016 23:28

Existing Markets - Challenges

- Dynamics
- Stochasticity
- Nonlinearities
- Many power related services (voltage, frequency, balancing, spinning reserve, congestion, ...)
- Speed / problem size
- Characterization of flexibility
- Requirements on user installations

Challenges

Conclusion: Almost no flexibility ?!


Preparatory study on
Smart Appliances

Ecodesign Preparatory Study performed for the European Commission

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 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:

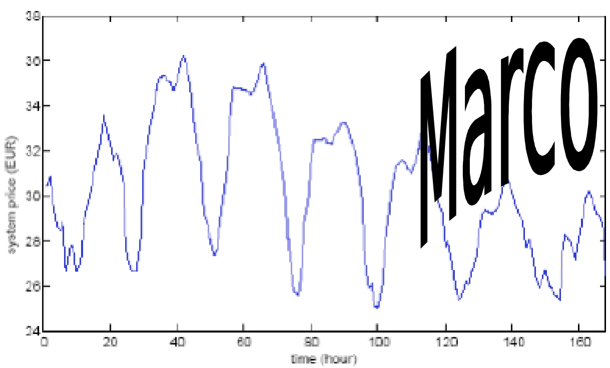
- Chargers for electric cars: technical potential and other relevant issues in the context of demand response.
- The modelling done in the framework of MEErP Task 6 and 7 will be updated with PRIMES data that recently became available, and with the EEA-countries.
- The development and assessment of policy options that were identified in the study will be further elaborated and deepened.

COMPETITIVE BIDDING AND STABILITY ANALYSIS IN ELECTRICITY MARKETS USING CONTROL THEORY

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

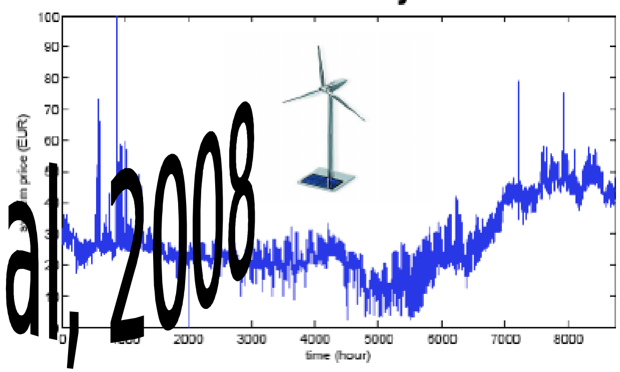
Advantages in handling effectively

Dynamics



Marco Zugno et.al, 2008

Uncertainty



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

↓

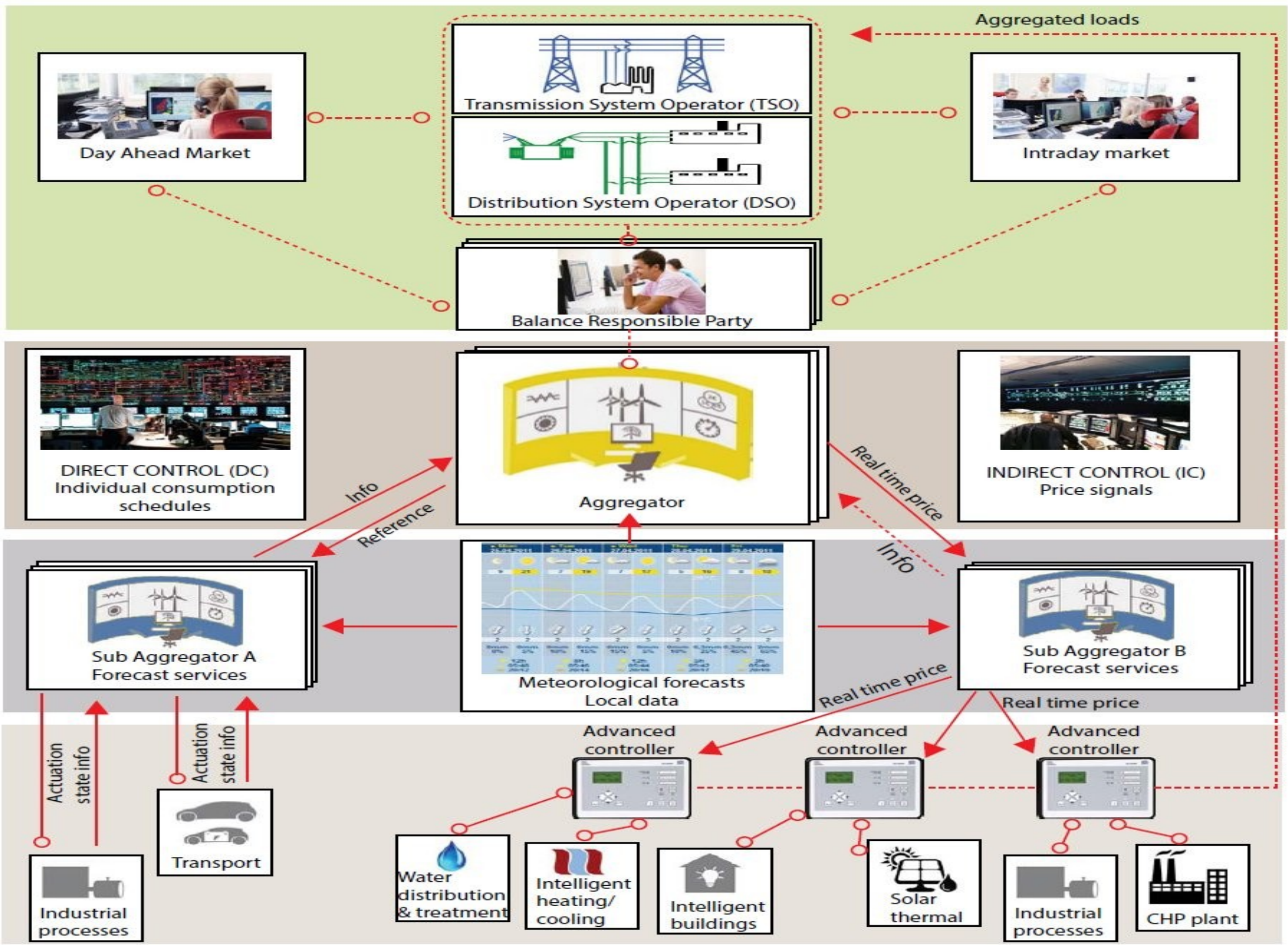
it is possible to develop advanced bidding strategies which exploit the inclusion of the dynamics in the model

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

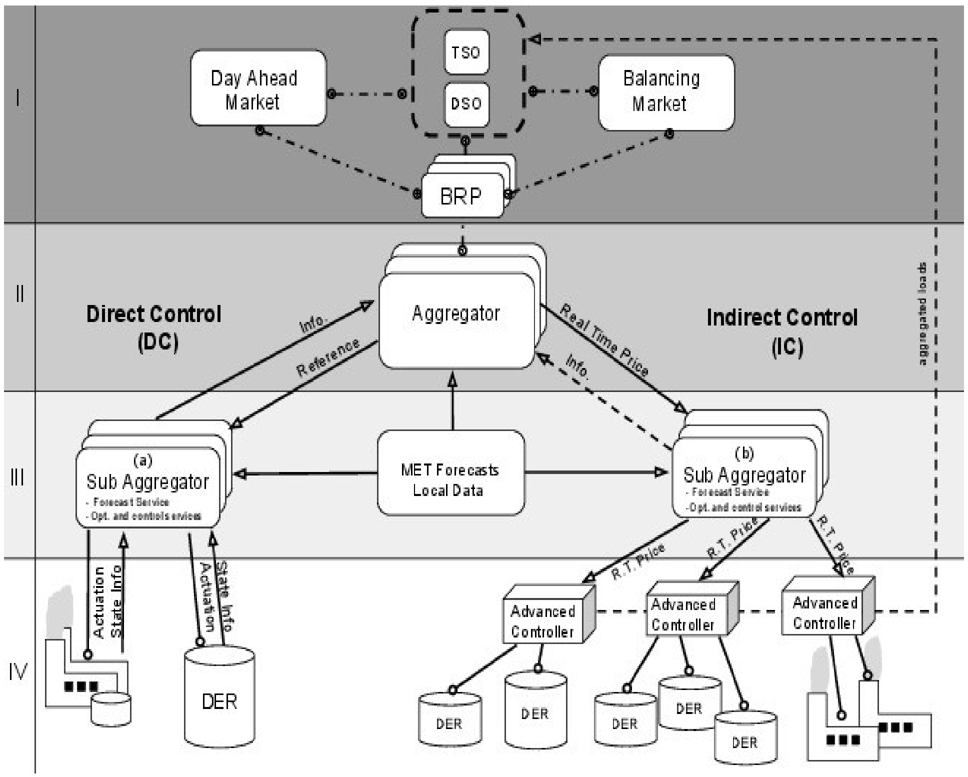
↓

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

Smart-Energy OS



Control and Optimization



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

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:

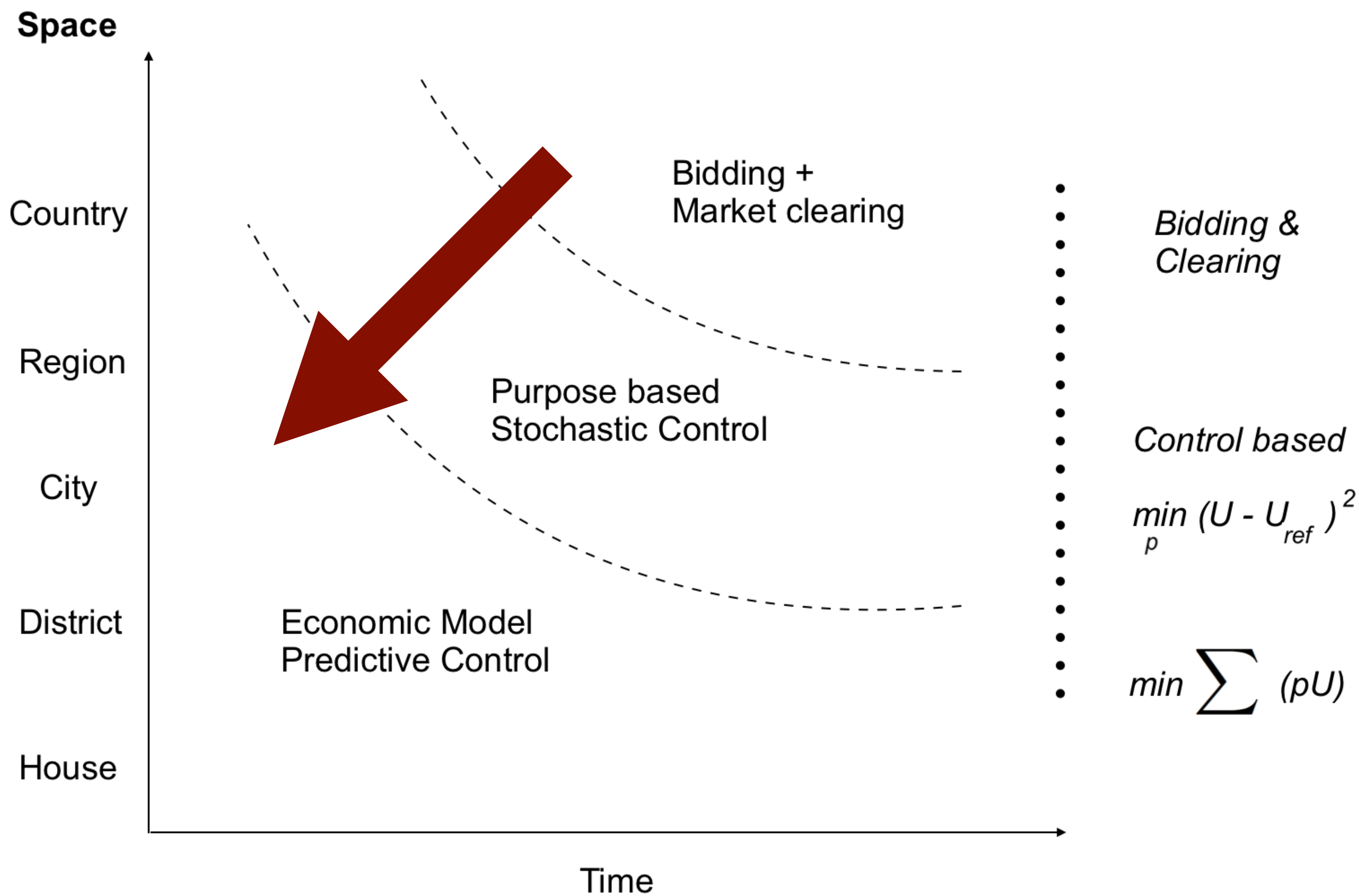
Actuator: **Price**

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

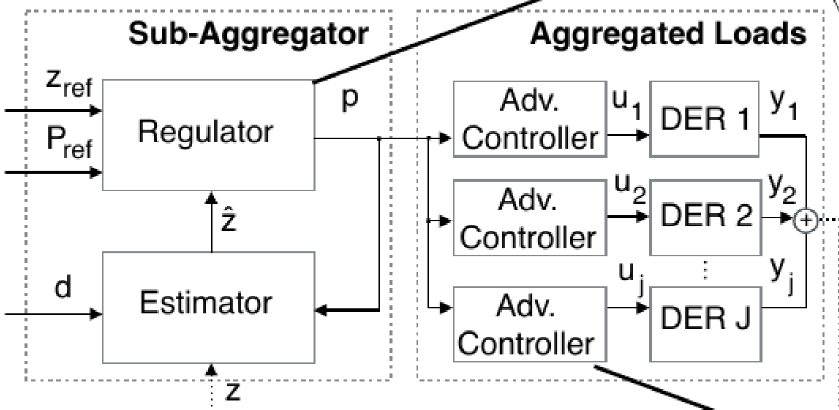
Models for DERs are not needed

Simple 'contracts'

The ‘market’ for future Smart Grids



Proposed methodology
Control-based methodology



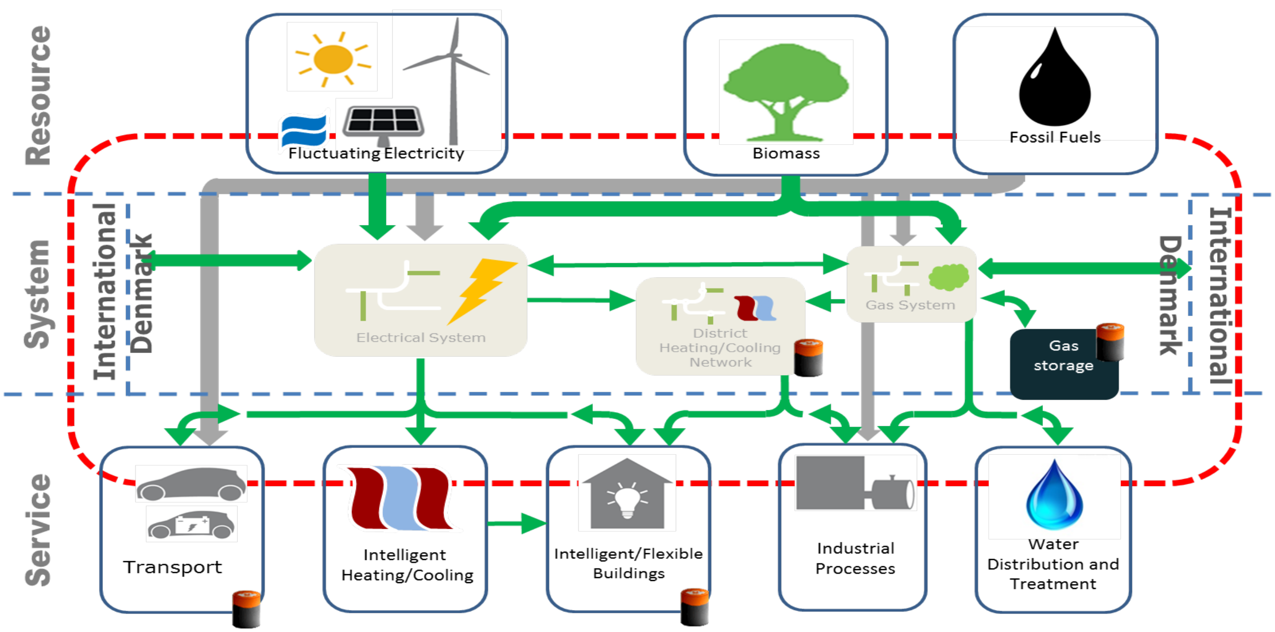
$$\begin{aligned} \min_{p} \quad & \mathrm{E}\Big[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||\Big] \\ \text{s.t.} \quad & \hat{z}_{k+1} = f(p_k) \end{aligned}$$

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

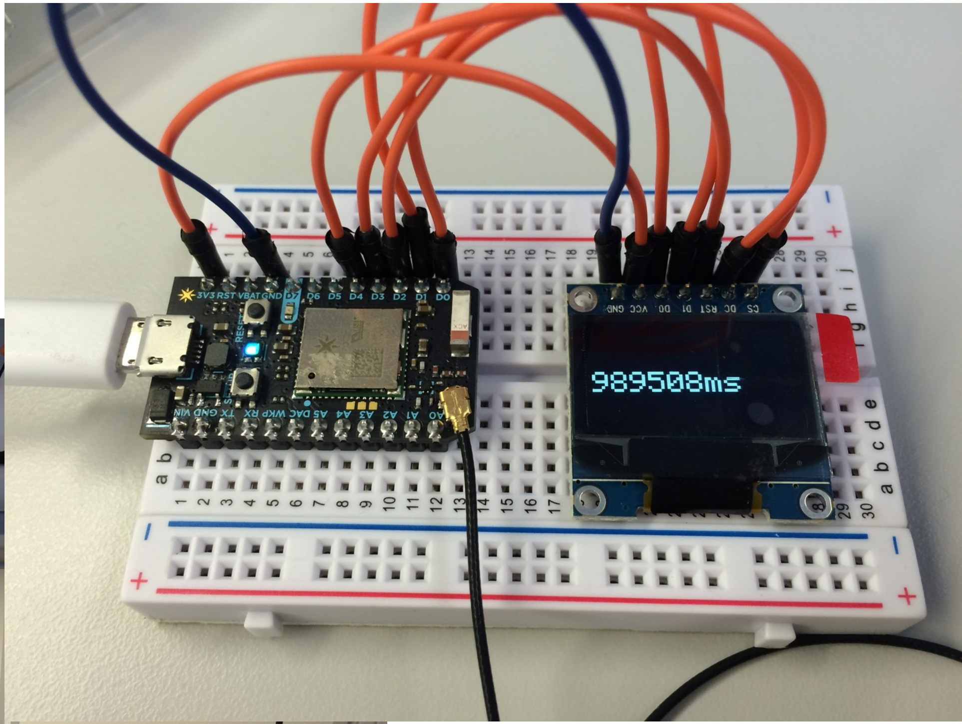
We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

Models for systems of systems

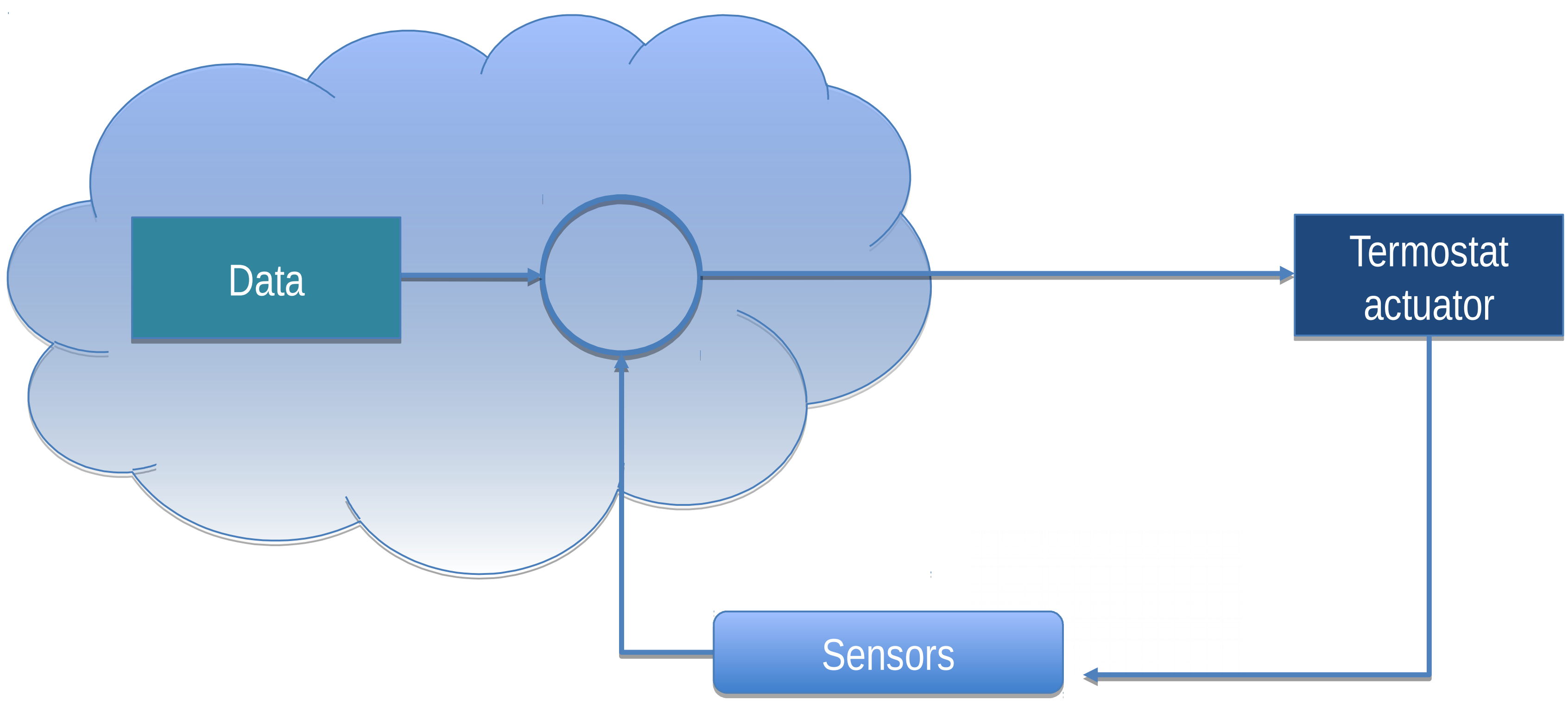
Intelligent systems integration using **data and ICT solutions** are based on **grey-box models for real-time operation of flexible energy systems**



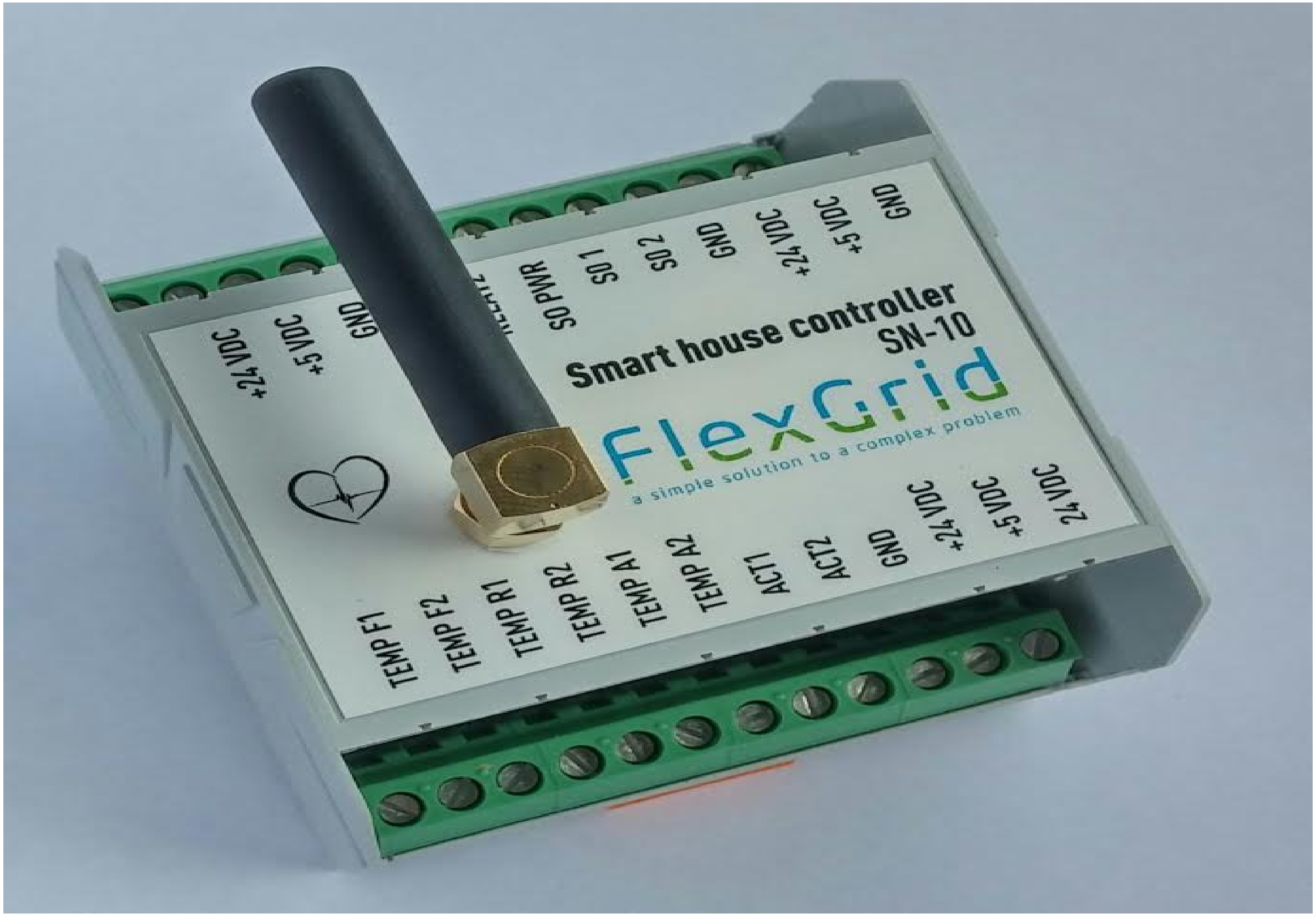
Lab testing ….



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

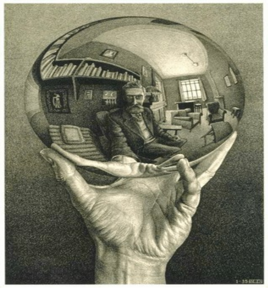


SN-10 Smart House Prototype



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 or Fog (IoT, IoS) based 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
- Harvest flexibility at all levels



Case study (Level III)

Price-based Control of Power Consumption (peak shaving)

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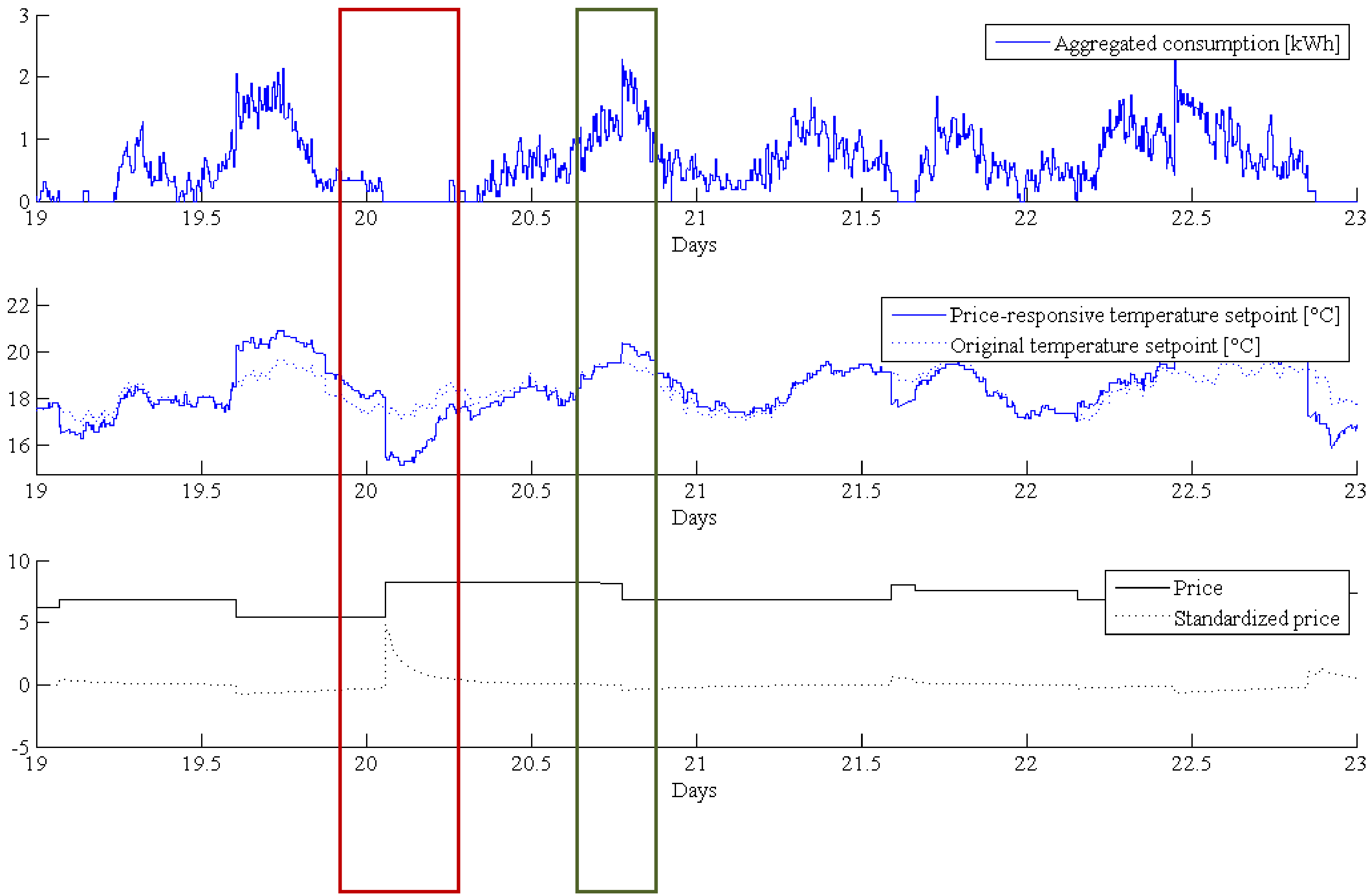
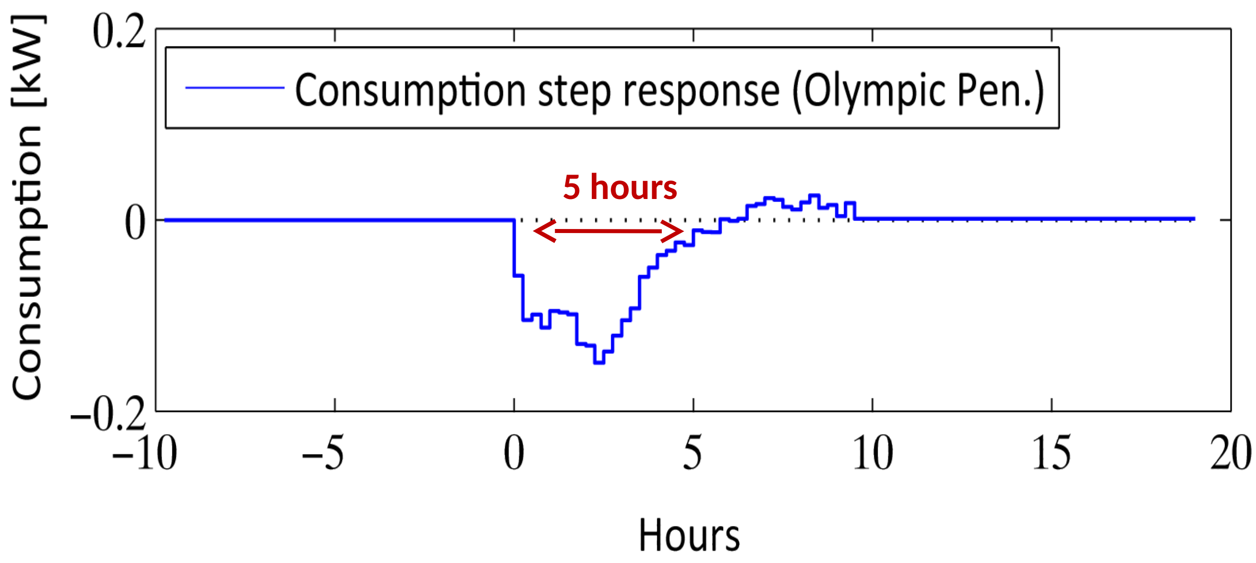
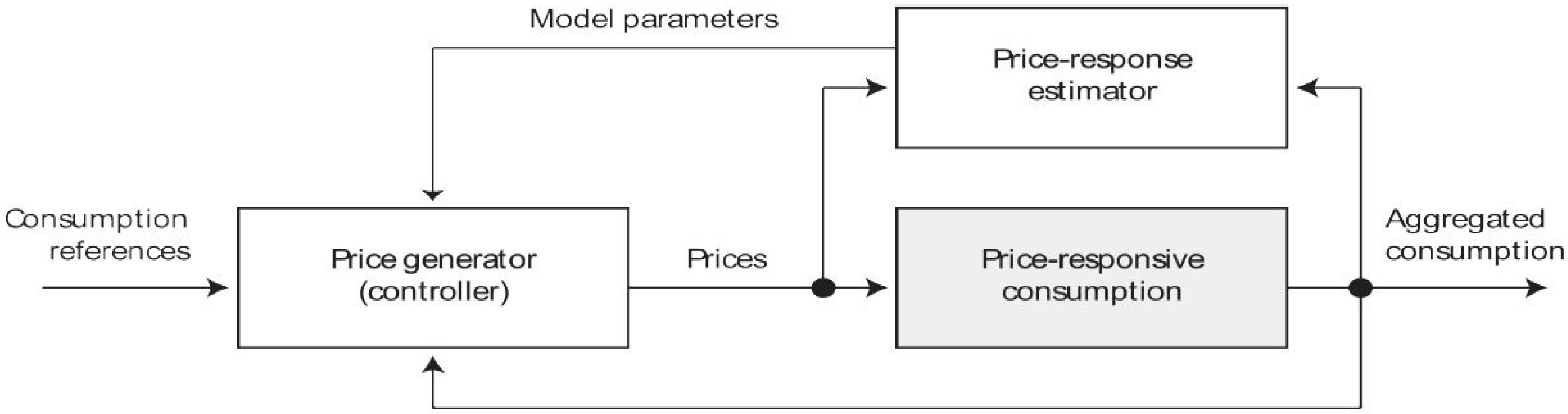
Aggregation (over 20 houses)

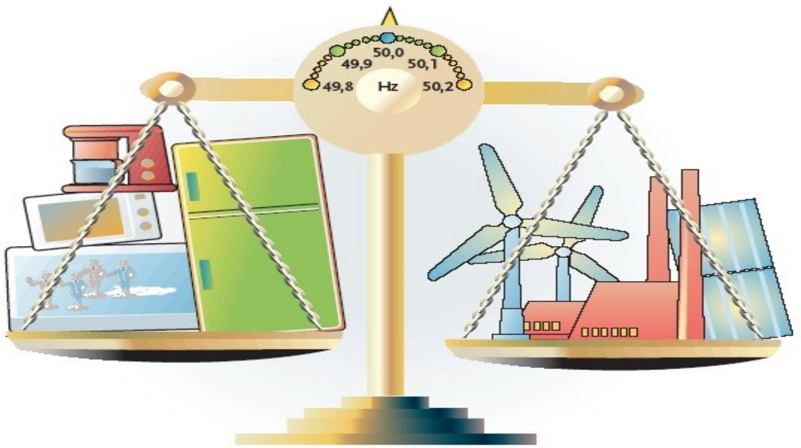


Response on Price Step Change



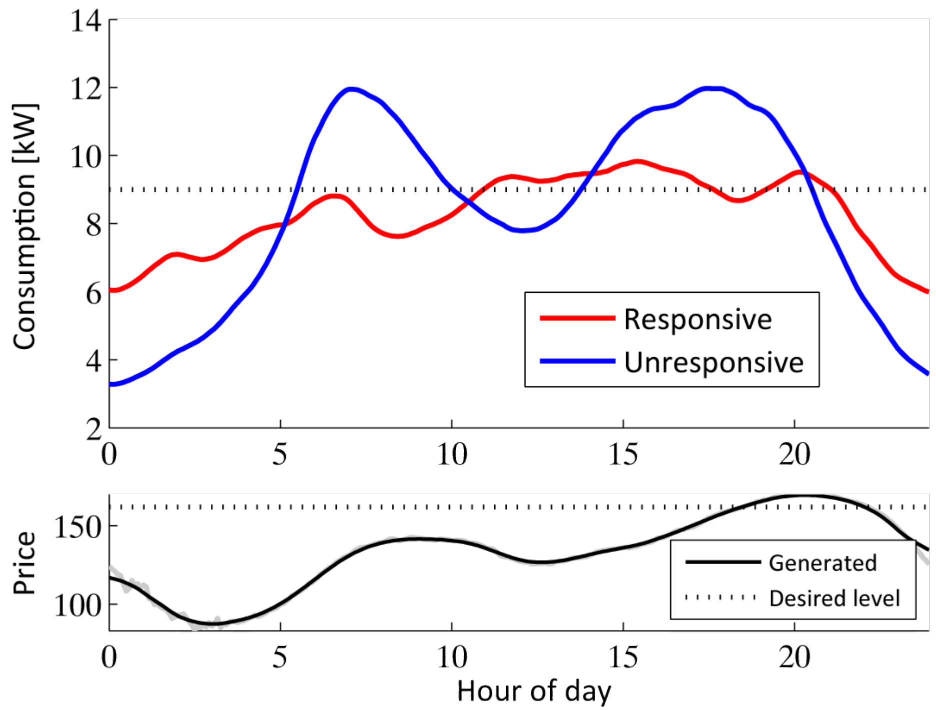
Control of Power Consumption





Control performance

Considerable **reduction in peak consumption**



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Case study

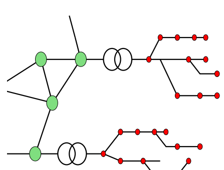
Control of Power Consumption to Summer Houses with a Pool (H2020 SmartNet Project)

Services

Balancing

Voltage regulation (DSO)

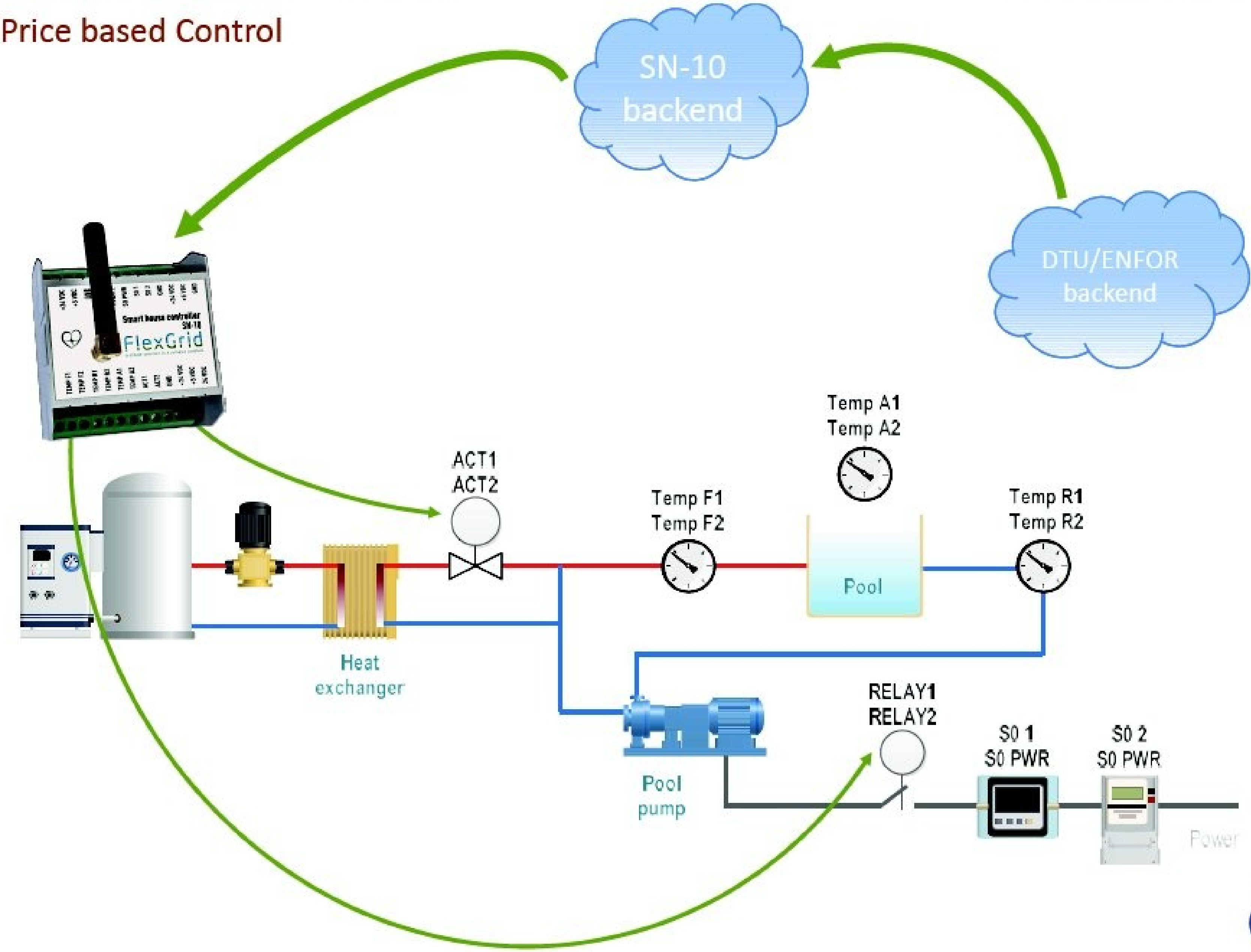
Congestion management

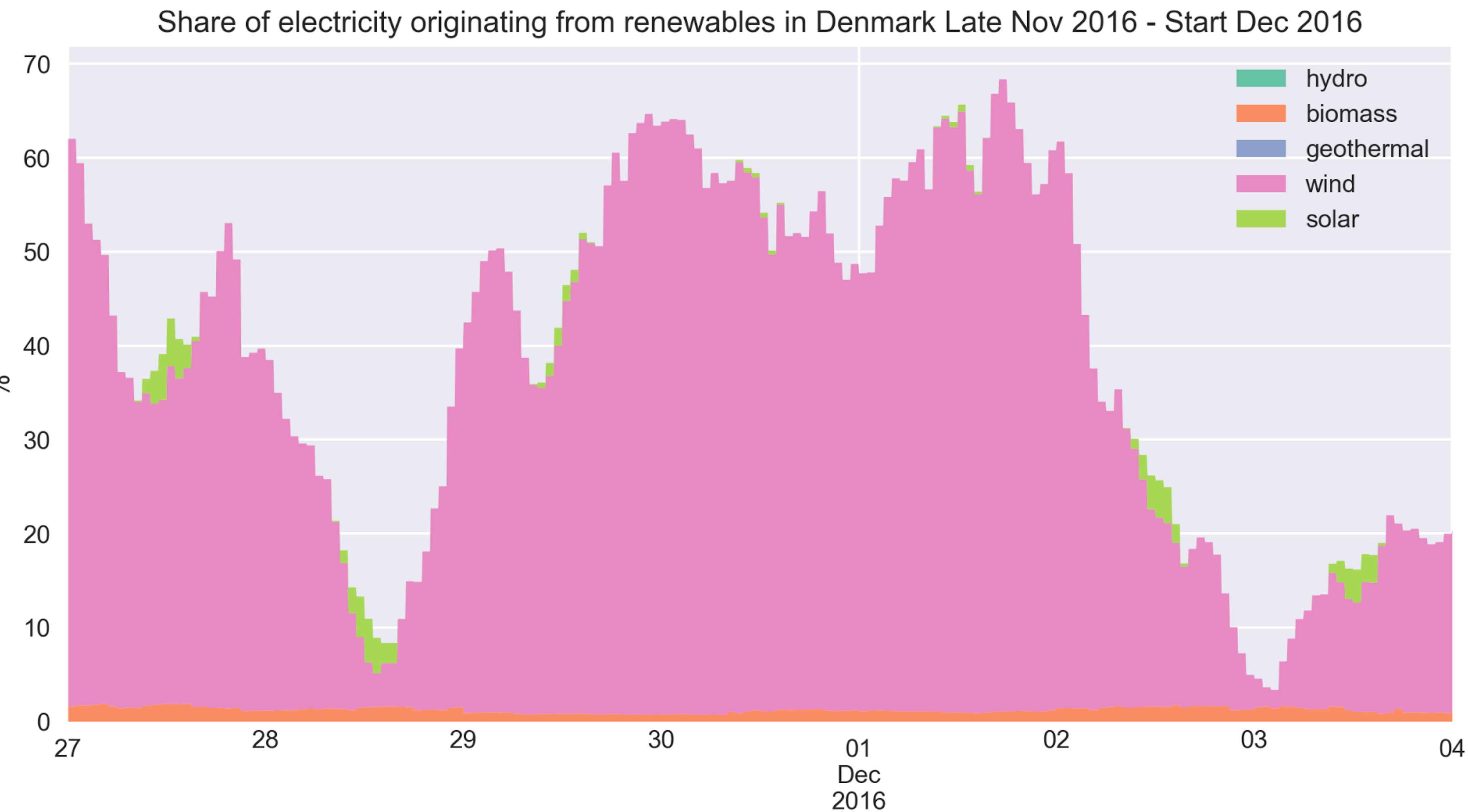


- The large inertia of pools allows for shift of electricity consumption by several hours.
- Via active coordination of the flexibility below a critical node on the DSO grid.
- Active load management to help finding an optimal routing of the power.

How does it work?

Price based Control





Source: pro.electicitymap.org

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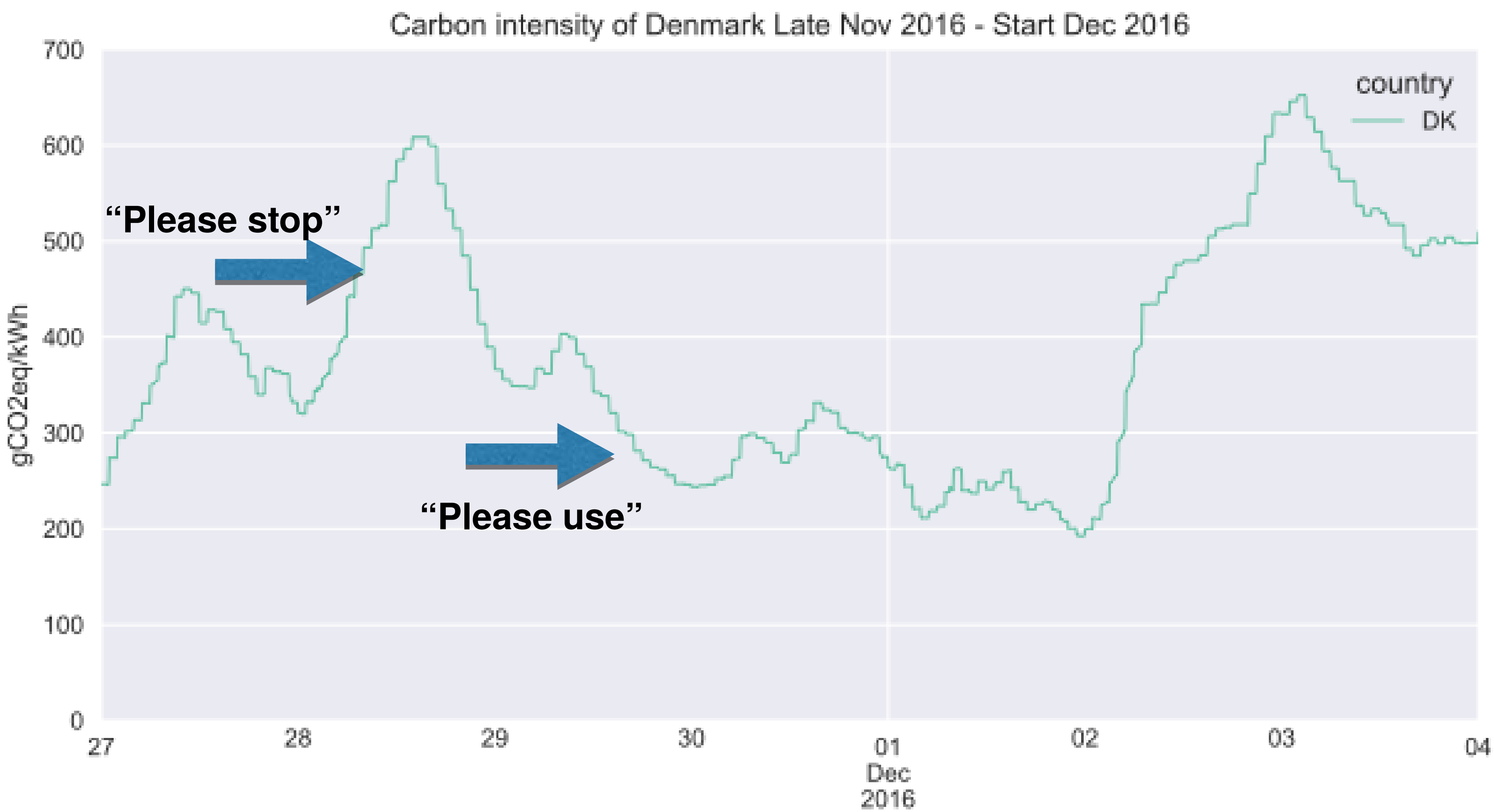
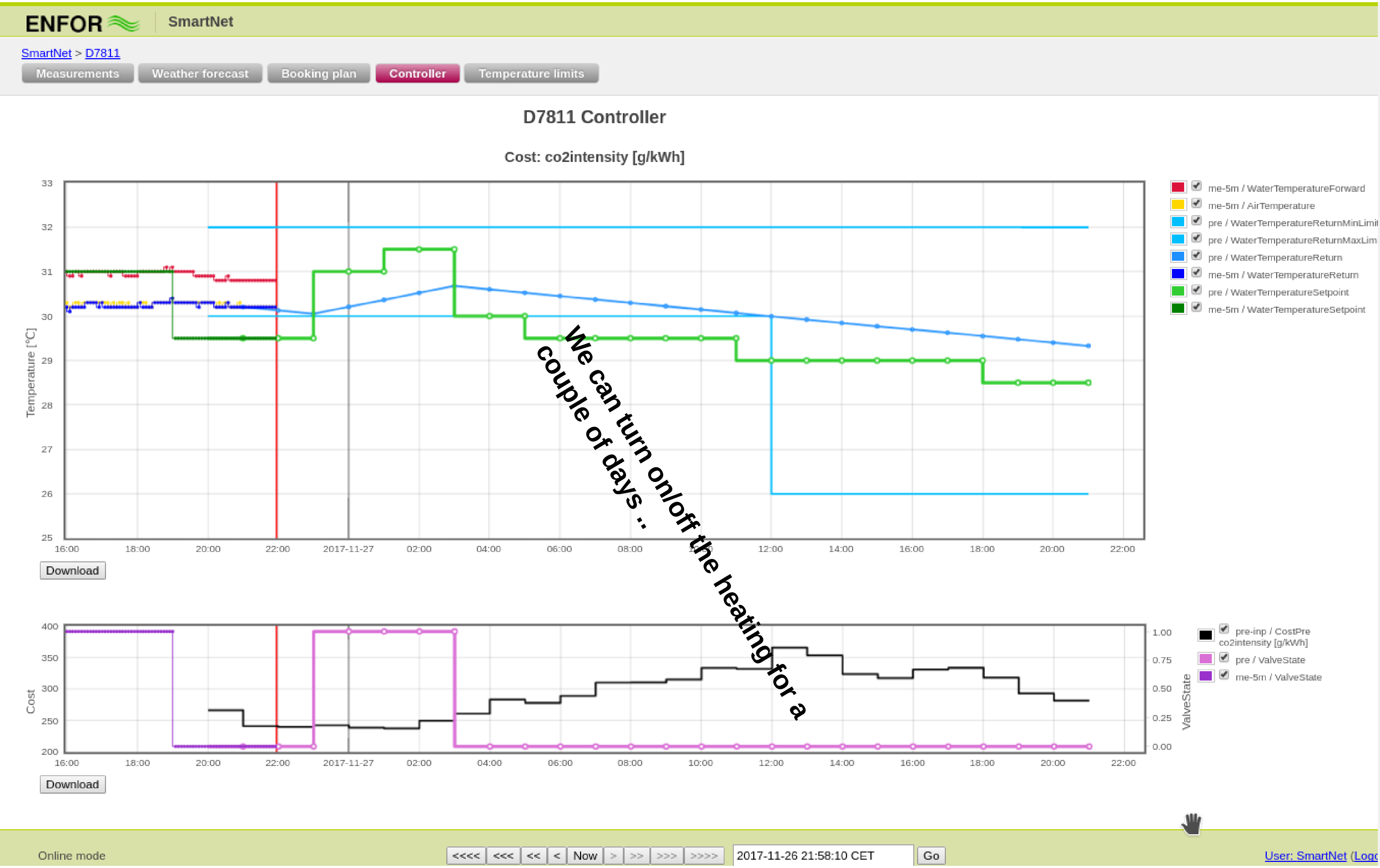
Argonne National Lab., Dec.2017



Carbon intensity of Denmark Late Nov 2016 - Start Dec 2016
country
DK
"Please stop"
"Please use"
gCO2eq/kWh
0
100
200
300
400
500
600
700
27
28
29
30
01
Dec
2016
02
03
04



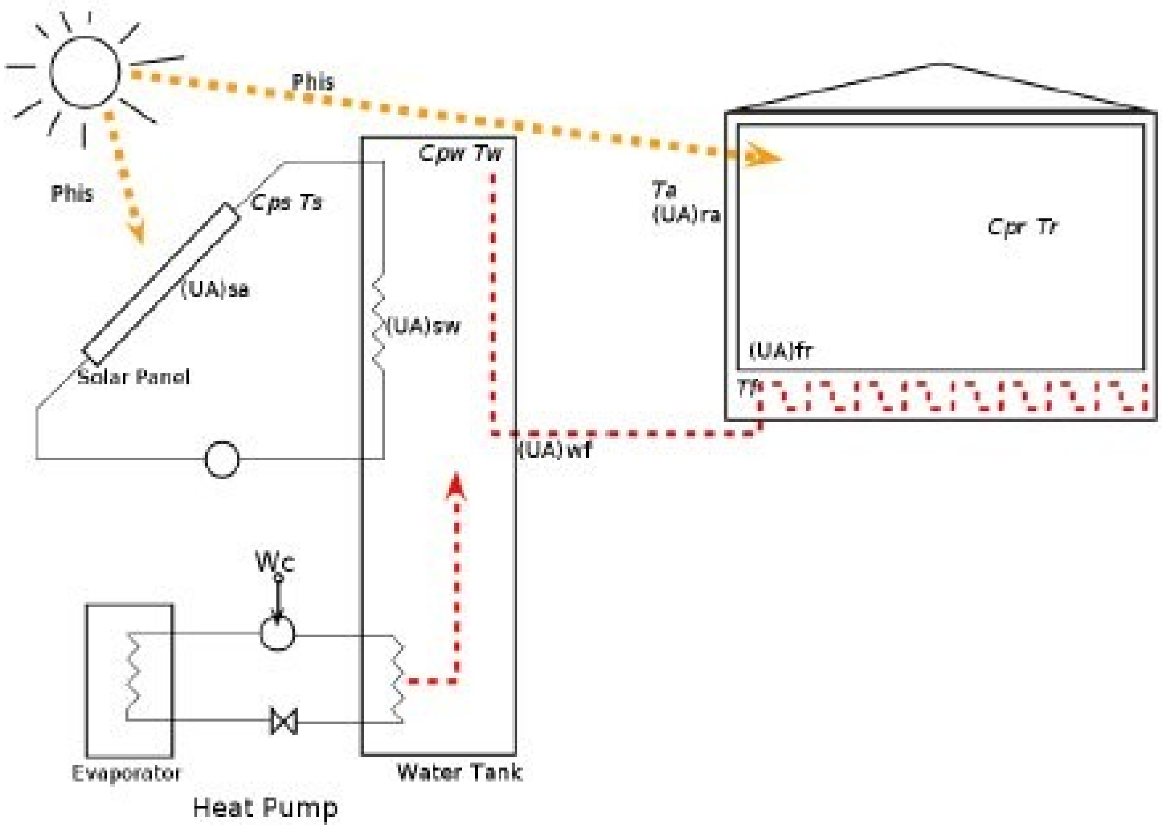
We can turn on/off the heating for a couple of days ..

Case study No. 2

Control of Heat Pumps for buildings with a thermal solar collector (minimizing cost)

Modeling Heat Pump and Solar Collector

Simplified System



Avanced Controller

Economic Model Predictive Control

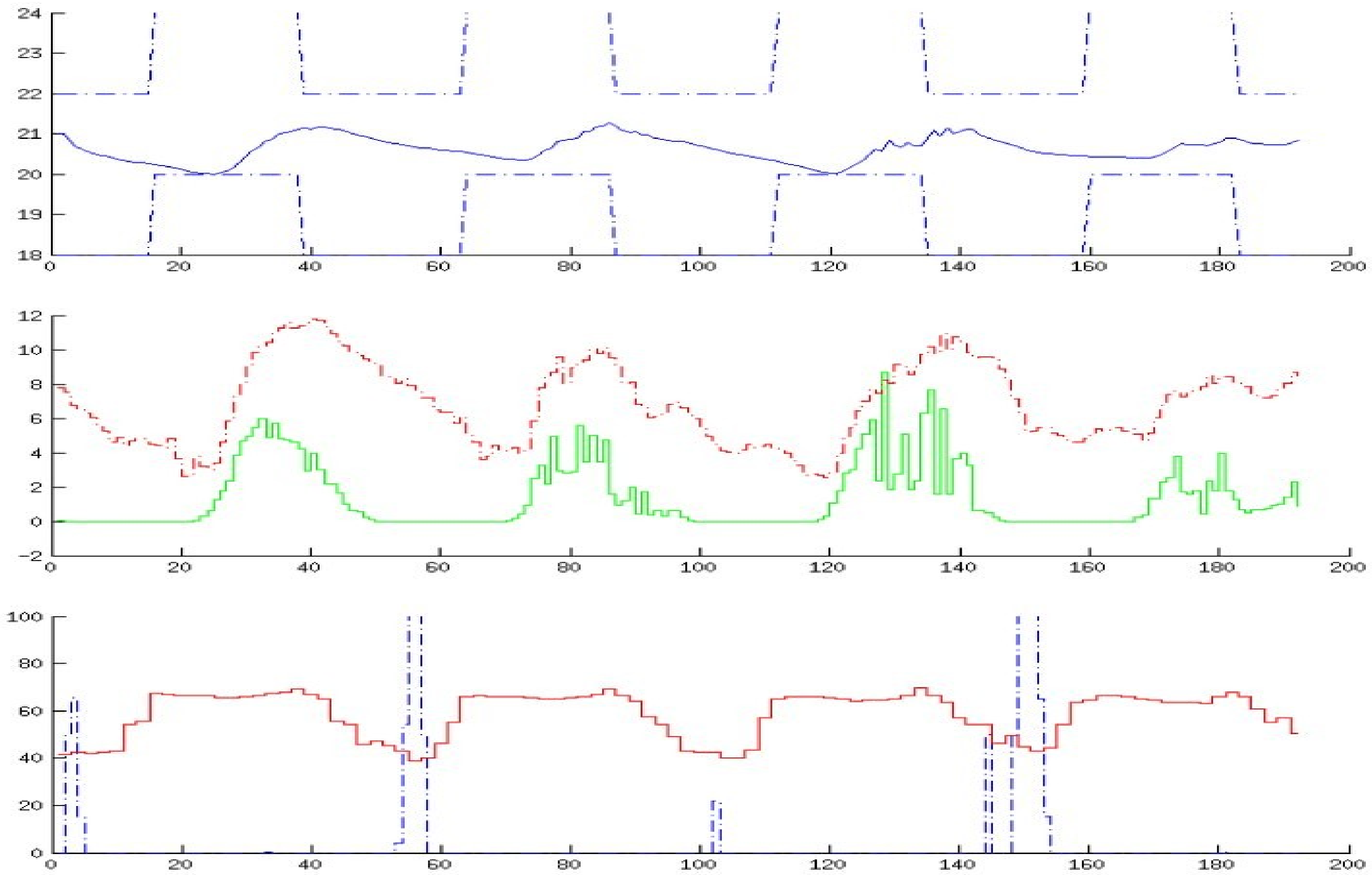
Formulation

The Economic MPC problem, with the constraints and the model, can be summarized into the following formal formulation:

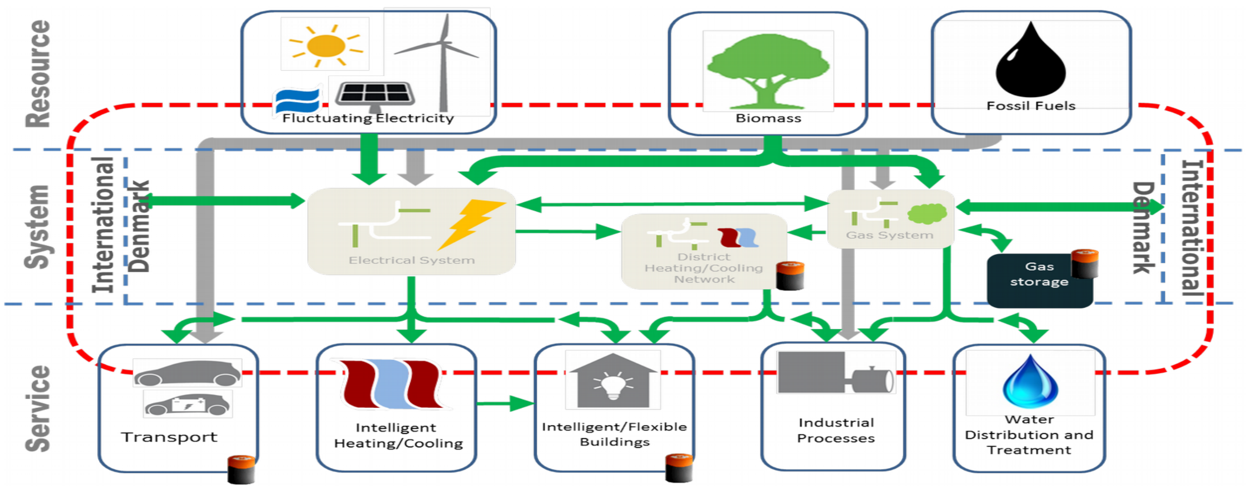
$$\min_{\{u_k\}_{k=0}^{N-1}} \phi = \sum_{k=0}^{N-1} c' u_k \tag{4a}$$

$$\begin{aligned}
\text{Subject to} \quad & x_{k+1} = Ax_k + Bu_k + Ed_k & k = 0, 1, \ldots, N-1 \quad & (4b)\\
& y_k = Cx_k & k = 1, 2, \ldots, N \quad & (4c)\\
& u_{min} \leq u_k \leq u_{max} & k = 0, 1, \ldots, N-1 \quad & (4d)\\
& \Delta u_{min} \leq \Delta u_k \leq \Delta u_{max} & k = 0, 1, \ldots, N-1 \quad & (4e)\\
& y_{min} \leq y_k \leq y_{max} & k = 0, 1, \ldots, N \quad & (4f)
\end{aligned}$$

Heat pump with thermal solar collector and storage
(cost savings up to 25 pct – increased energy consumption 8 pct)



(Virtual) Storage Solutions



- **Flexibility (or virtual storage) characteristics:**
  - Supermarket refrigeration can provide storage 0.5-2 hours ahead
  - Buildings thermal capacity can provide storage up to, say, 5-10 hours ahead
  - Buildings with local water storage can provide storage up to, say, 2-16 hours ahead
  - District heating/cooling systems can provide storage up to 1-3 days ahead
  - DH systems with thermal solar collectors can often provide seasonal storage solutions
  - Gas systems can provide seasonal/long term storage solutions

Summary

- A procedure for data intelligent control of power load, using the Smart-Energy OS (SE-OS) setup, is suggested.
- The SE-OS controllers can focus on
  - Peak Shaving
  - Smart Grid demand (like ancillary services needs, ...)
  - Energy Efficiency
  - Cost Minimization
  - Emission Efficiency
- We have demonstrated a large potential in Demand Response in Buildings. Automatic solutions and end-user focus are important
- We see large problems with the tax and tariff structures in many countries (eg. Denmark).

For more information ...

See for instance

www.smart-cities-centre.org

...or contact

– Henrik Madsen (DTU Compute)

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Acknowledgement - DSF 1305-00027B

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