CITIES
Centre for IT Intelligent Energy Systems

SmartNet

Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation

Pilot B (Denmark)

Flexibility in Summer Houses with a Swimming Pool

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DTU Compute

Florence SmartNet Workshop, October 24th - 26th, 2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691405

Overview of Pilot B

Description:

- 30 Summer houses with a swimming pool – and either boilers or heat pump.
- Indirect control using price (or other penalty signals)
- One way communication

Extension:

- **CO2-base control** since May 2017 for demonstrating how to accelerate the transition to a low fossil future.
- **DSO congestion** based on real-time measurements for better integration of PV, EV and Heat Pumps
- Optimize the end-user **flexibility** for the best **integration of wind and solar**

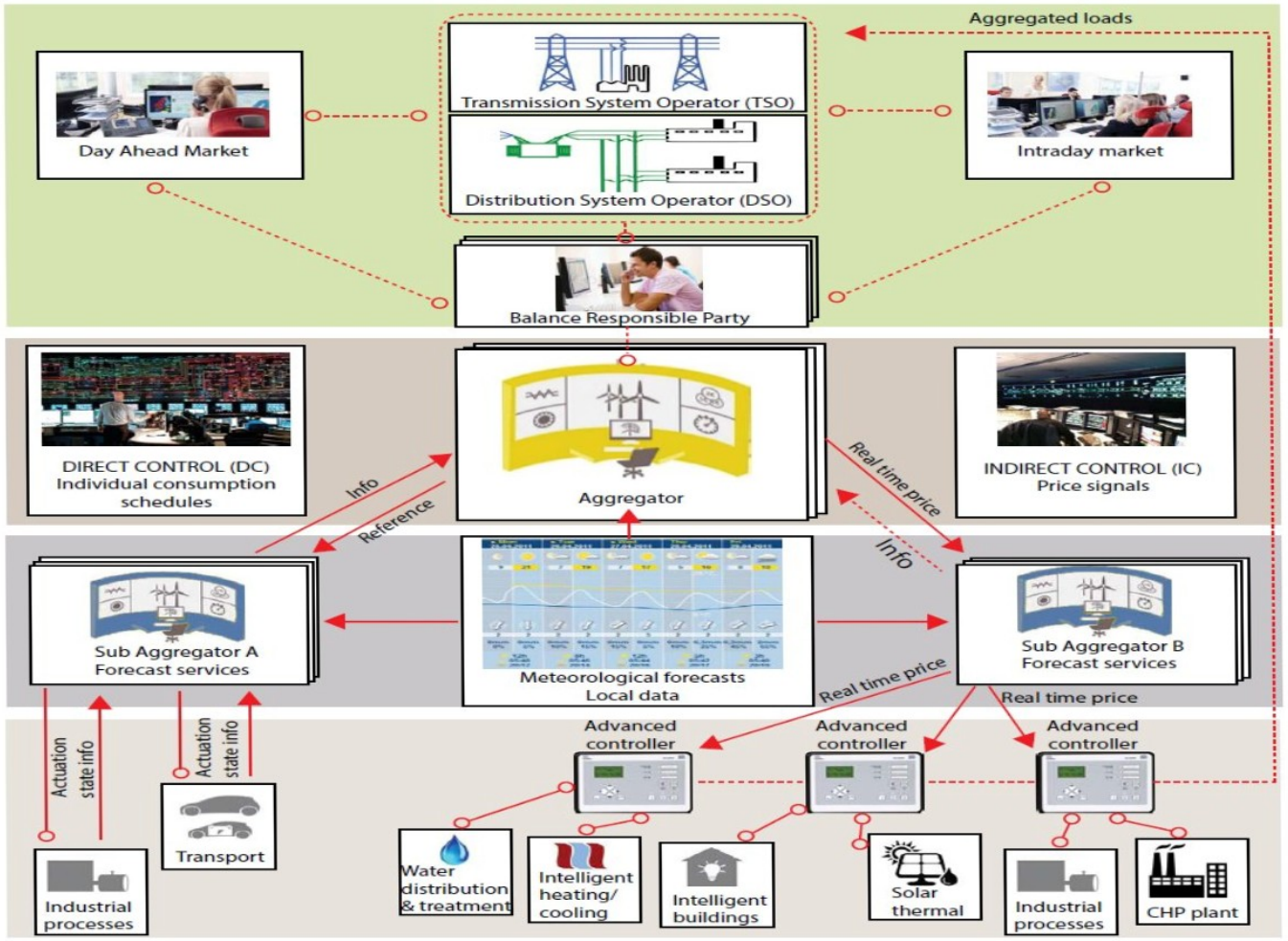
Functionalities:

- **Aggregation of information every 5 minutes** and presented via the SmartNet WEB interface.
- **CO2-based control** since May 2017.
- **Price-based control** since beginning of January 2018.
- **Estimation and forecasting of 5-min balancing prices.**
- Data exchange between 'TSO' and Economical Aggregator (ONE) established
- Data exchange between Eco. Aggregator and Tech. Aggregator (ENFOR) established
- **Flexibility concepts for smart grid applications established.**
- Common TSO-DSO market setup established

Pilot B

Introduction

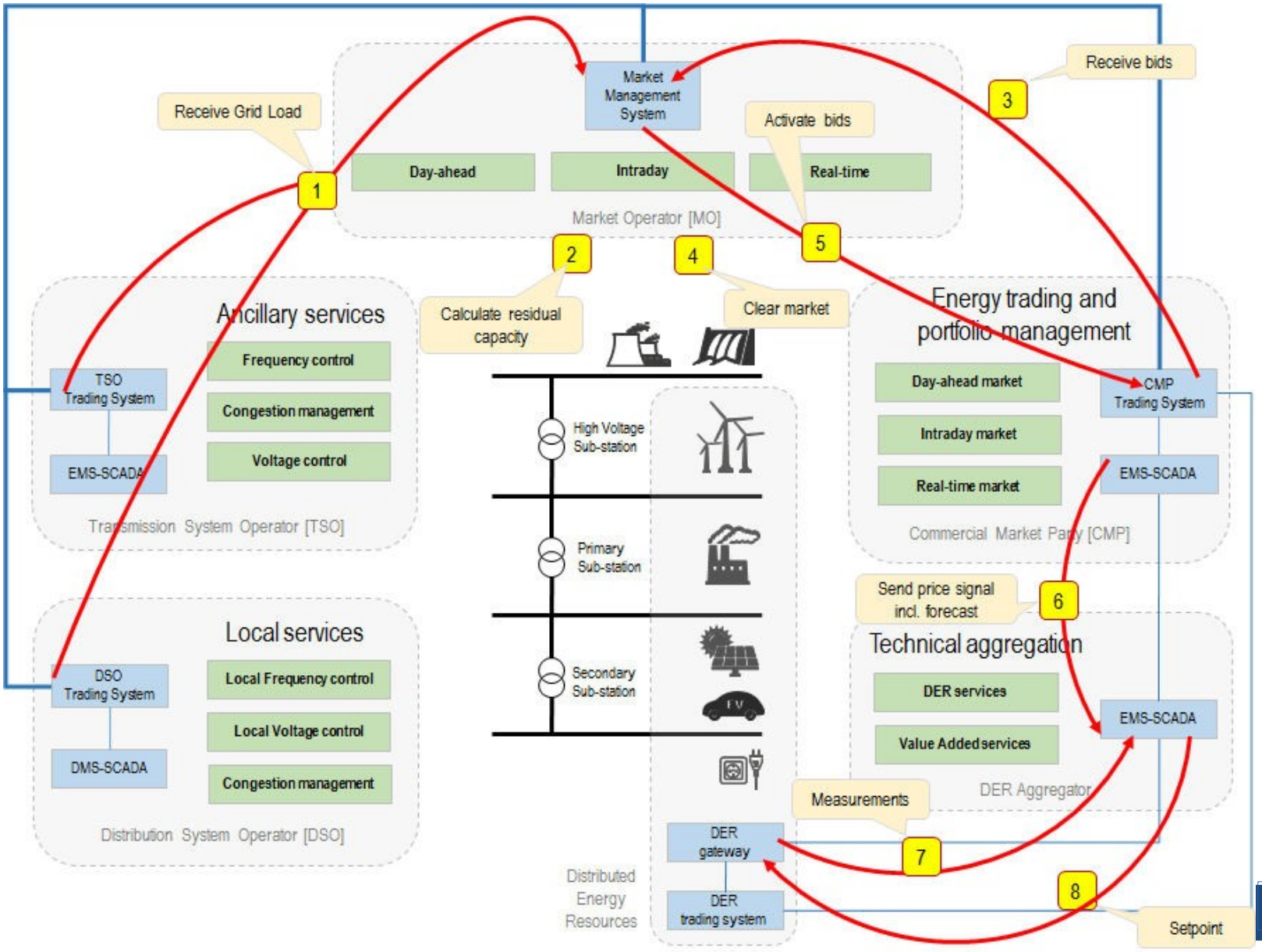
Smart-Energy OS



Maximizes the flexibility – Simple communication – No contracts

Described in Wiley Book, DTU Annual Report, and several IEEE papers

Overview Pilot B



Pilot B (short summary)

The SmartNet Technical Aggregator at ENFOR is designed such that we can shift between any external 'penalty signal'. We are able to shift to any 'penalty signal' with a very short notice.

Have been up and running with CO2-based control since May 2017.

Shifted to price-based control on January 4th, 2018 – using 5 min balancing prices from ENFOR.

Flexibility function for price-based control is estimated for the aggregated consumption, and ONE has been able to send the prices to ENFOR (Technical Aggregator)

We have learned a lot about how to establish **a cloud-based control of smart buildings** – and in such a way that they can support the future smart grid (eg. **Voltage control** and **congestion management** also in DSO areas)

Danish Pilot participated in the HiL simulation test (WP4.5) with AIT.

Flexibility Function

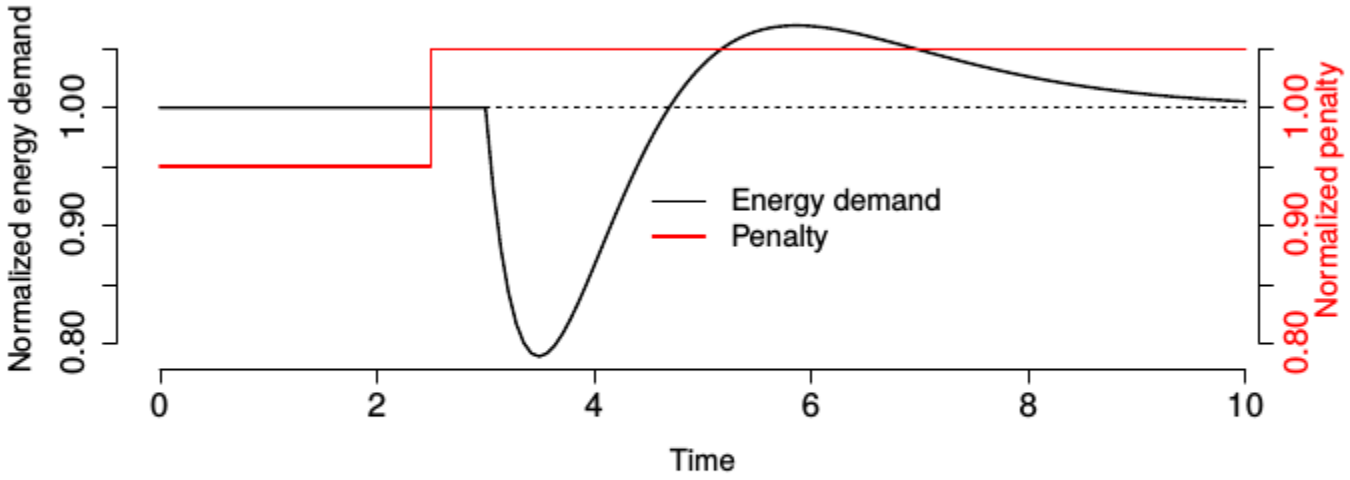


Figure 2: The energy consumption before and after an increase in penalty. The red line shows the normalized penalty while the black line shows the normalized energy consumption. The time scale could be very short with the units being seconds or longer with units of hours. At time 2.5 the penalty is increased,

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*.

Smart Grid Applications

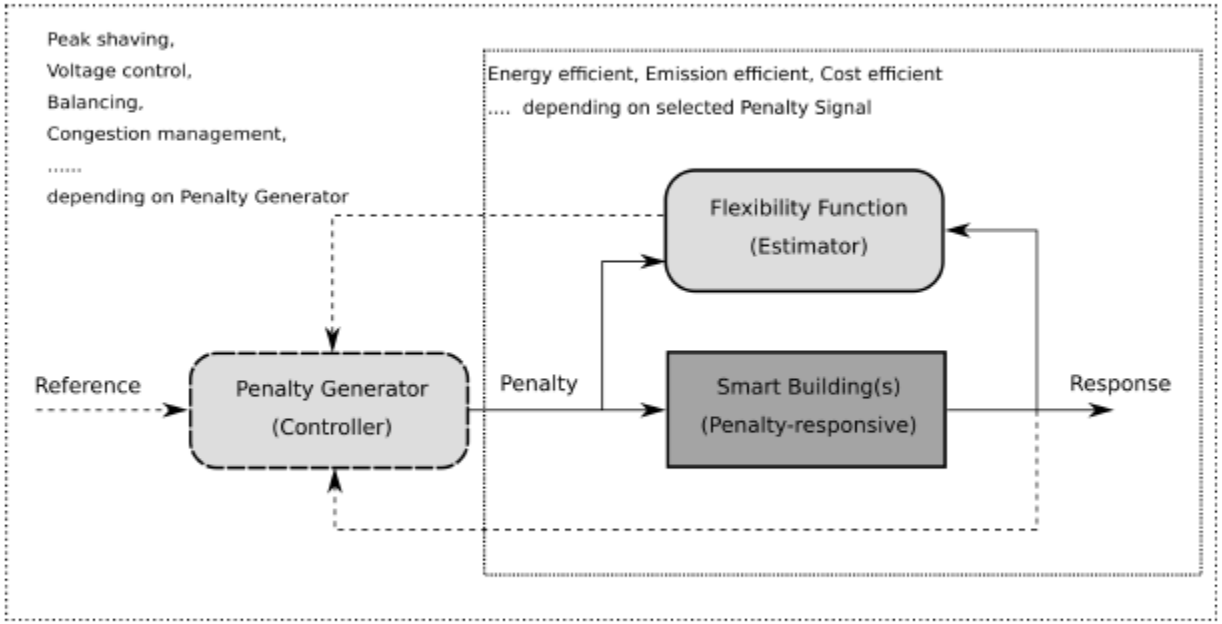


Figure 8: Smart buildings and penalty signals.

Pilot B

Upper Level

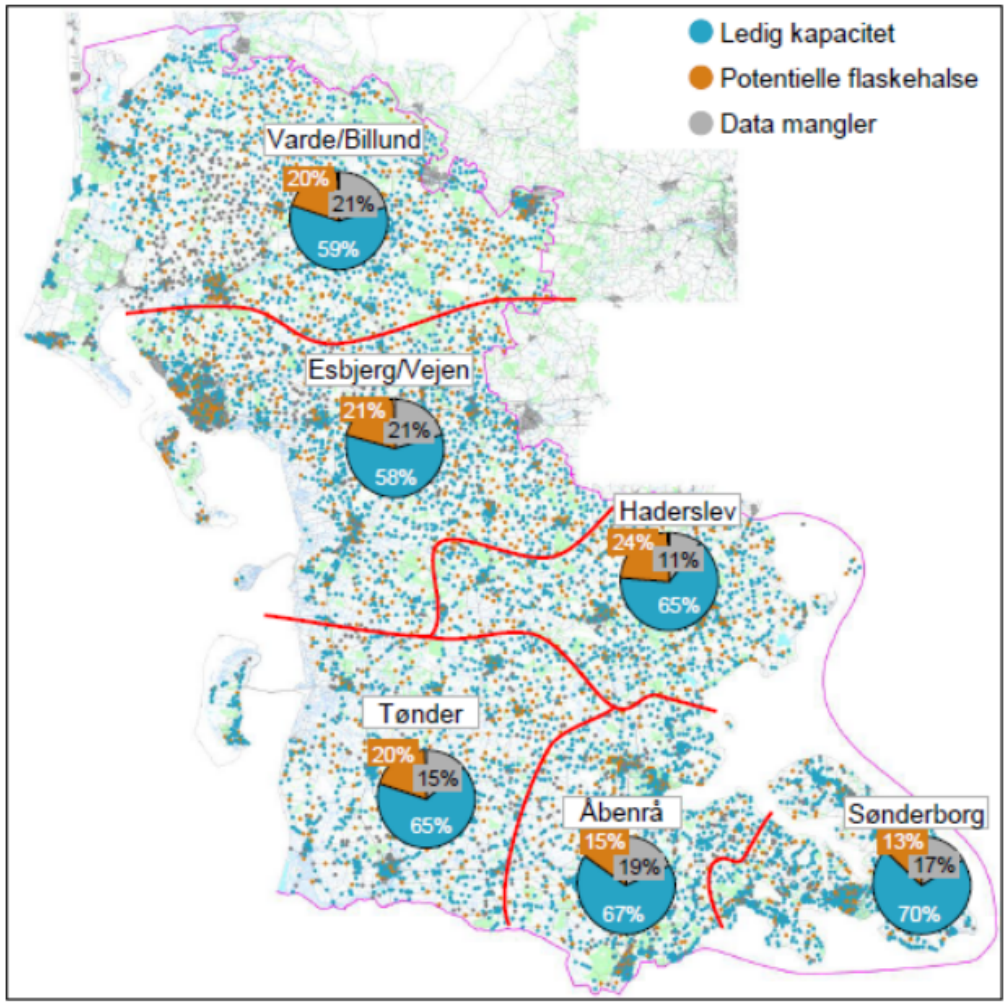
Evonet's supply area

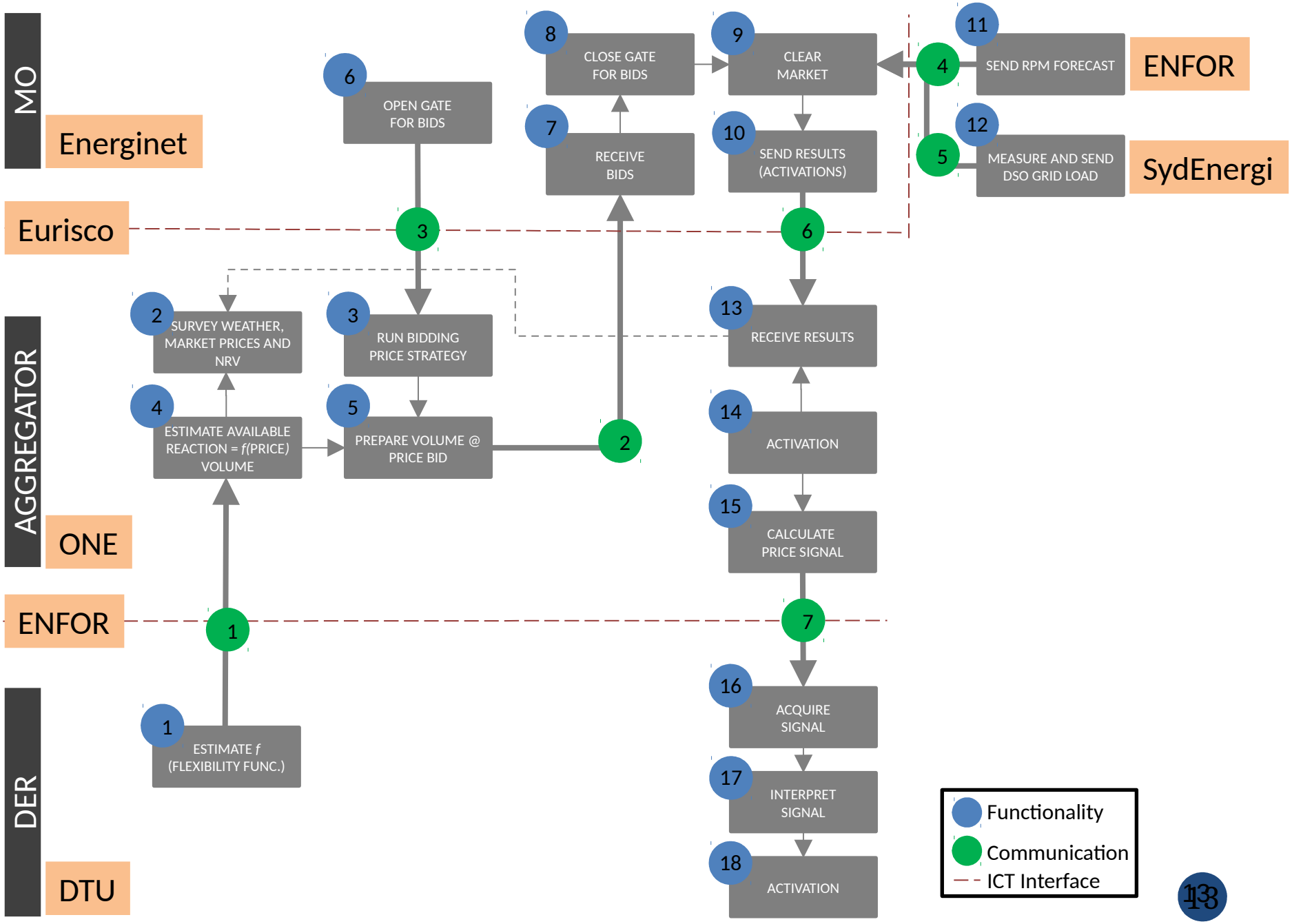
- Supply area in Syd- og Sønderjylland and a part of Nordjylland
- Created through 26 mergers
- Supply of app. 324.000 installations
- A part of SE-koncernen

Example: DSO challenges

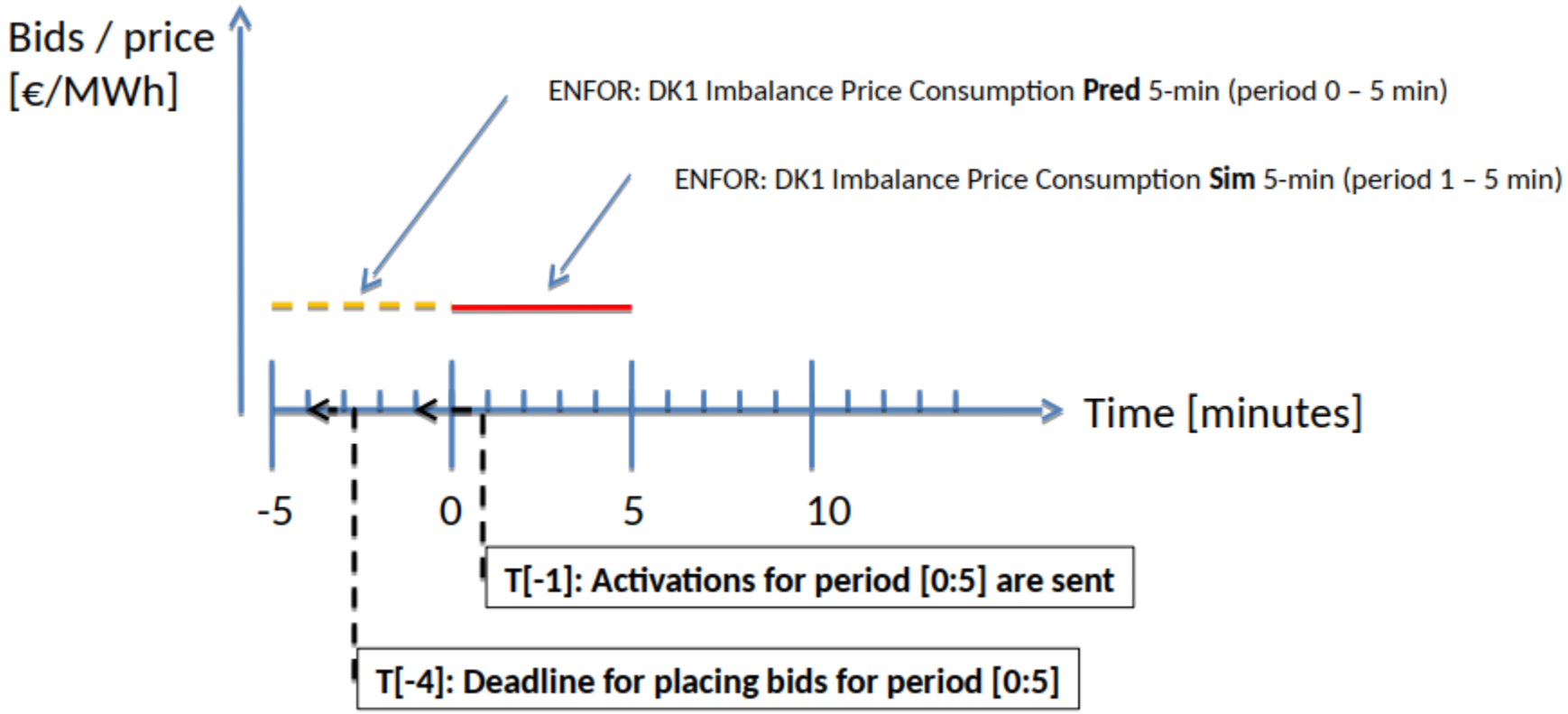
Evonet

The load rate of the grid




MO
Energinet
Eurisco
AGGREGATOR
ONE
ENFOR
DER
DTU
6
OPEN GATE FOR BIDS
8
CLOSE GATE FOR BIDS
9
CLEAR MARKET
11
SEND RPM FORECAST
ENFOR
4
7
RECEIVE BIDS
10
SEND RESULTS (ACTIVATIONS)
12
5
MEASURE AND SEND DSO GRID LOAD
SydEnergi
3
6
2
SURVEY WEATHER, MARKET PRICES AND NRV
3
RUN BIDDING PRICE STRATEGY
13
RECEIVE RESULTS
4
ESTIMATE AVAILABLE REACTION = f(PRICE) VOLUME
5
PREPARE VOLUME @ PRICE BID
2
14
ACTIVATION
15
CALCULATE PRICE SIGNAL
1
7
1
ESTIMATE f (FLEXIBILITY FUNC.)
16
ACQUIRE SIGNAL
17
INTERPRET SIGNAL
18
ACTIVATION
Functionality
Communication
ICT Interface

Pilot B Upper Level
– Time line for bids and activation



Pilot B

Lower Level

How does it work?

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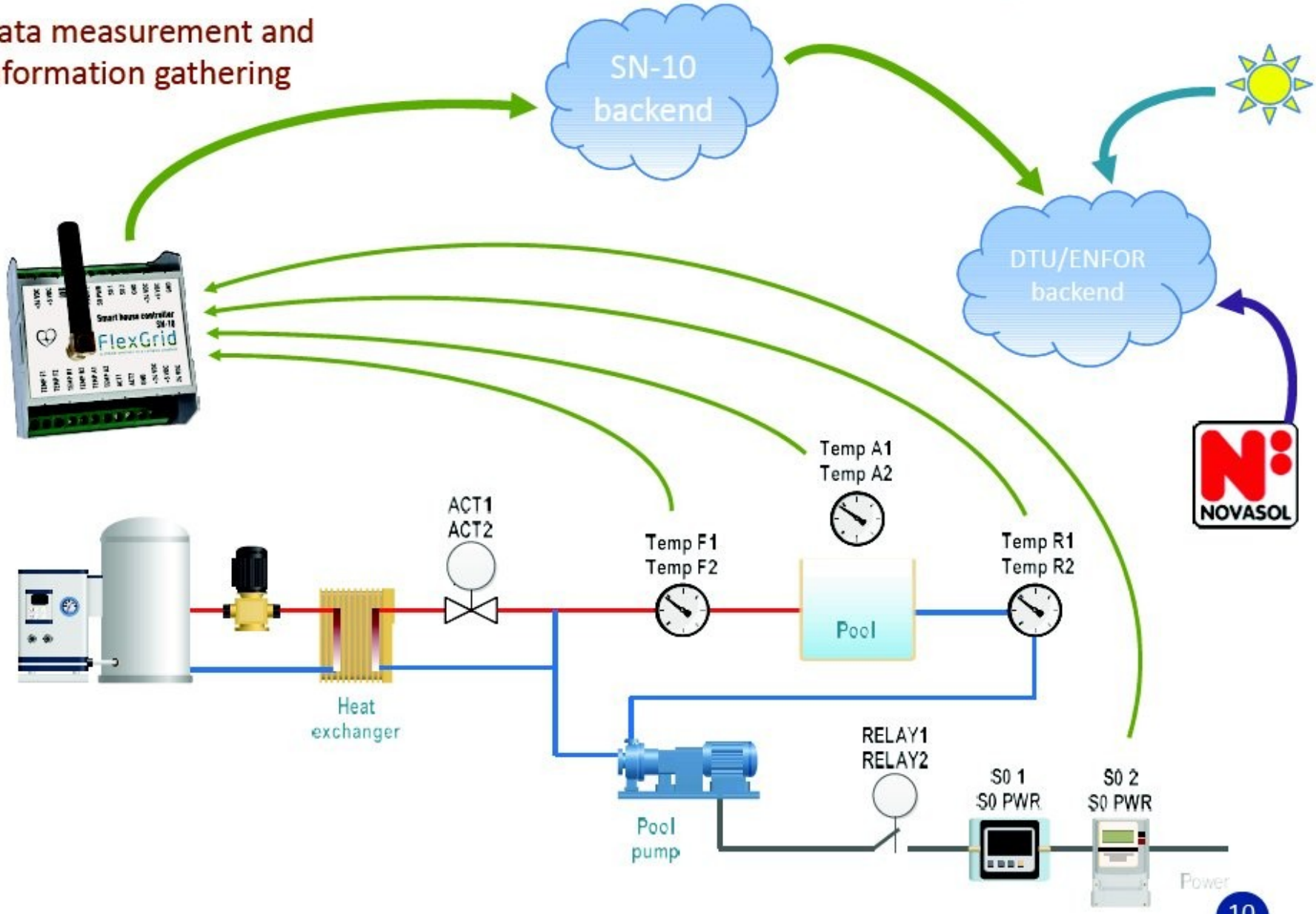
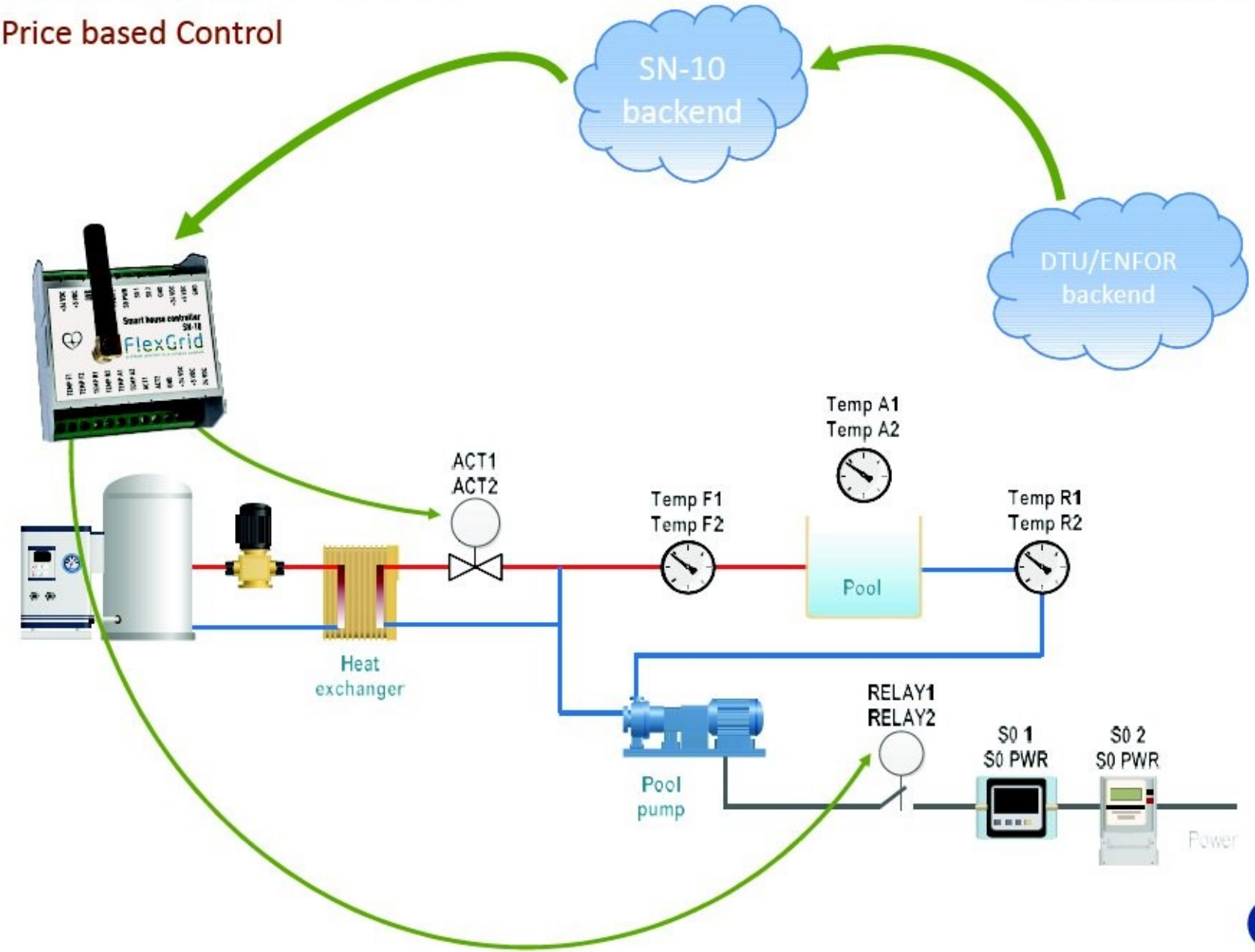
Data measurement and information gathering



How does it work?

Price based Control



SmartNet Web Portal

	Postal Code	First Measurement	Latest Measurement	Avail.	+48h	Latest Control Fcs.	TempRet	TempSetPnt	TempRetMin	TempRetMax	Adaptive	Setpoint Endpoint	Accepted at Endpoint
A3067	6857 Blåvand	2018-03-01	2018-09-19 18:40:00	1	0	2018-09-19 20:25:00	31.5 °C	30.0 °C	26.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 18:35:00
A3074	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	28.2 °C	27.5 °C	28.0 °C	30.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
A3128	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	30.7 °C	28.5 °C	28.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
A3306	6857 Blåvand	2018-09-18	NA	1	1	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
A3763	6857 Blåvand	2018-09-18	2018-09-19 22:20:00	1	1	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
P32013	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	28.9 °C	27.5 °C	28.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
P32037	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	30.0 °C	28.5 °C	28.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
P32071	6857 Blåvand	2017-11-22	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	27.5 °C	30.0 °C	28.0 °C	30.0 °C	no	server.flex-control.com	2018-09-19 22:20:00
P32121	6857 Blåvand	2017-11-10	2018-09-19 22:20:00	1	0	2018-09-19 22:20:00	27.1 °C	30.0 °C	26.3 °C	30.0 °C	no	server.flex-control.com	2018-09-19 22:20:00
P32286	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
P32359	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	28.3 °C	27.5 °C	28.0 °C	30.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
P32424	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	1	0	2018-09-19 22:20:00	29.7 °C	27.0 °C	24.3 °C	32.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
P32512	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	29.0 °C	27.5 °C	28.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
P32641	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	28.6 °C	27.5 °C	28.0 °C	30.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
P32731	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	28.7 °C	27.5 °C	28.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
P32787	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	24.9 °C	27.5 °C	28.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
P32788	6857 Blåvand	2018-03-01	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	28.3 °C	27.5 °C	28.0 °C	30.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
A07395	9480 Løkken	2018-01-26	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	29.9 °C	28.5 °C	29.0 °C	31.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
A11305	9480 Løkken	2017-11-08	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	25.1 °C	27.5 °C	28.0 °C	30.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
D7395	9480 Løkken	2018-01-25	2018-09-19 00:30:00	0	0	2018-09-19 02:15:00	30.5 °C	29.5 °C	30.0 °C	32.0 °C	no	sn10.flexgrid.dk	2018-09-19 00:25:00
A14526	9490 Pandrup	2017-03-28	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	32.0 °C	30.0 °C	30.0 °C	32.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
A13957	9492 Blokhus	2017-03-28	2018-09-19 22:20:00	1	1	2018-09-19 22:20:00	29.1 °C	27.0 °C	25.0 °C	30.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
A12216	9493 Saltum	2017-03-28	2018-09-19 22:20:00	1	1	2018-09-19 22:20:00	32.9 °C	30.0 °C	20.0 °C	32.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
A12486	9493 Saltum	2018-01-25	2018-08-22 12:45:00	0	0	*Not enabled*	-	-	-	-	no	sn10.flexgrid.dk	-
A12979	9493 Saltum	2017-11-08	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	28.4 °C	30.0 °C	30.0 °C	32.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
D7105	9493 Saltum	2017-03-28	2018-09-08 13:05:00	1	1	2018-09-08 14:50:00	-0.1 °C	23.1 °C	25.0 °C	32.0 °C	yes	sn10.flexgrid.dk	2018-09-08 13:00:00
D7227	9493 Saltum	2016-09-26	2018-09-19 22:20:00	1	0	2018-09-19 22:20:00	29.0 °C	27.0 °C	25.0 °C	32.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
D7320	9493 Saltum	2017-03-28	2018-09-19 22:20:00	0	0	2018-09-19 22:20:00	29.9 °C	31.5 °C	32.0 °C	34.0 °C	no	sn10.flexgrid.dk	2018-09-19 22:20:00
D7811	9493 Saltum	2017-03-28	2018-09-19 22:20:00	1	0	2018-09-19 22:20:00	29.2 °C	31.5 °C	24.3 °C	32.0 °C	yes	sn10.flexgrid.dk	2018-09-19 22:20:00
C7224	9690 Fjerritslev	2018-01-25	2018-08-29 01:20:00	0	0	2018-08-29 02:50:00	29.2 °C	27.0 °C	25.0 °C	32.0 °C	yes	sn10.flexgrid.dk	2018-08-29 01:15:00

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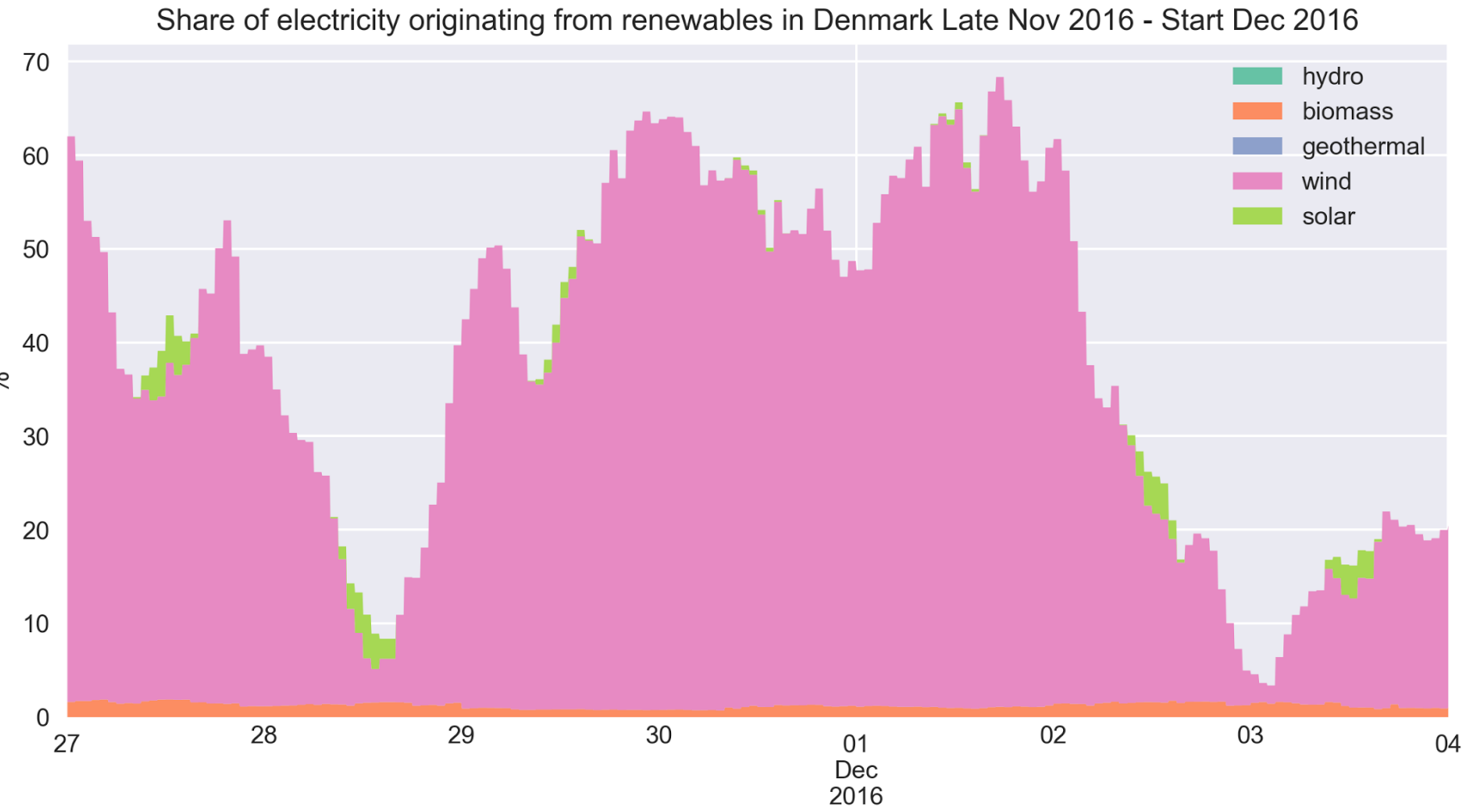
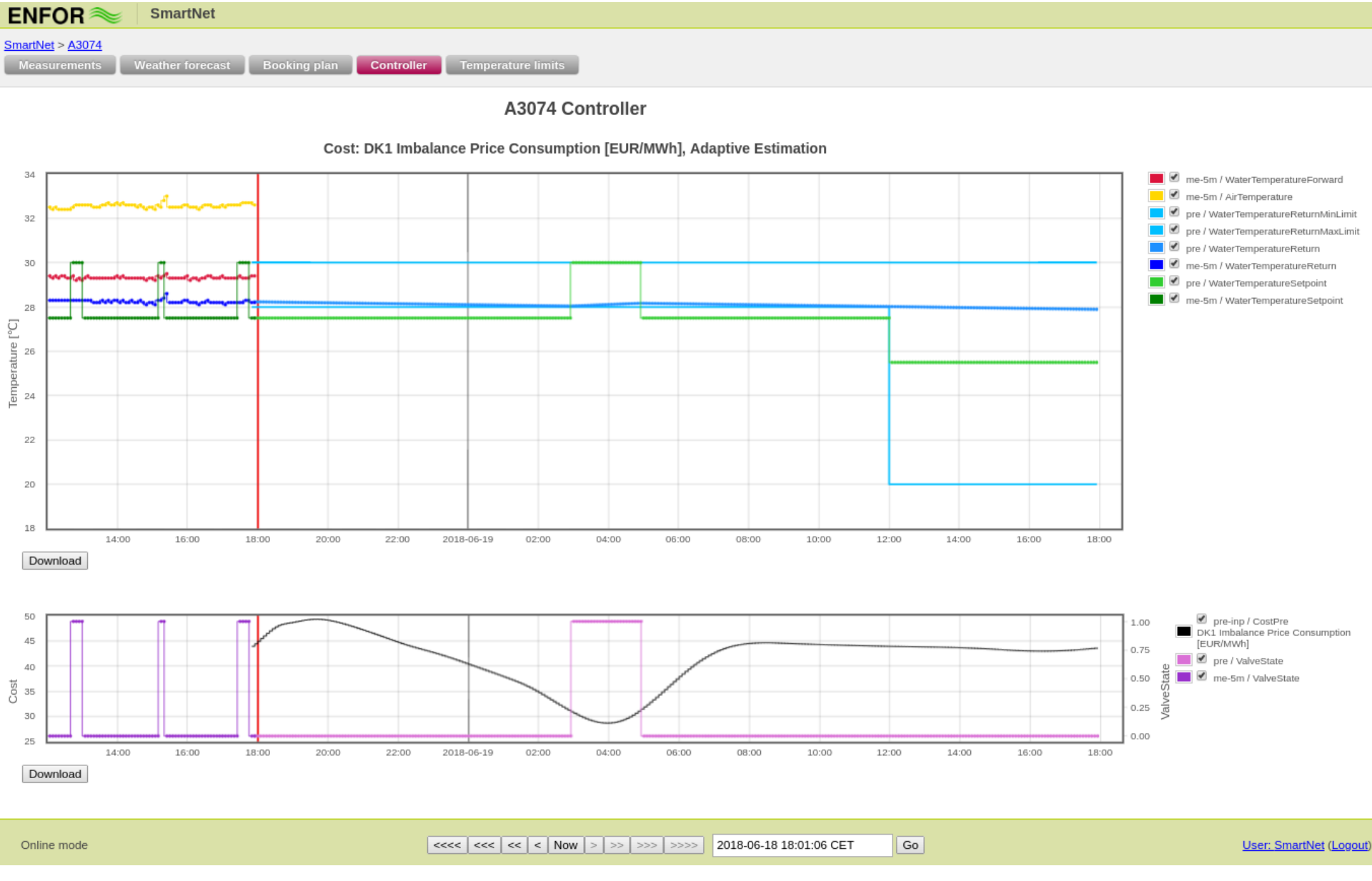


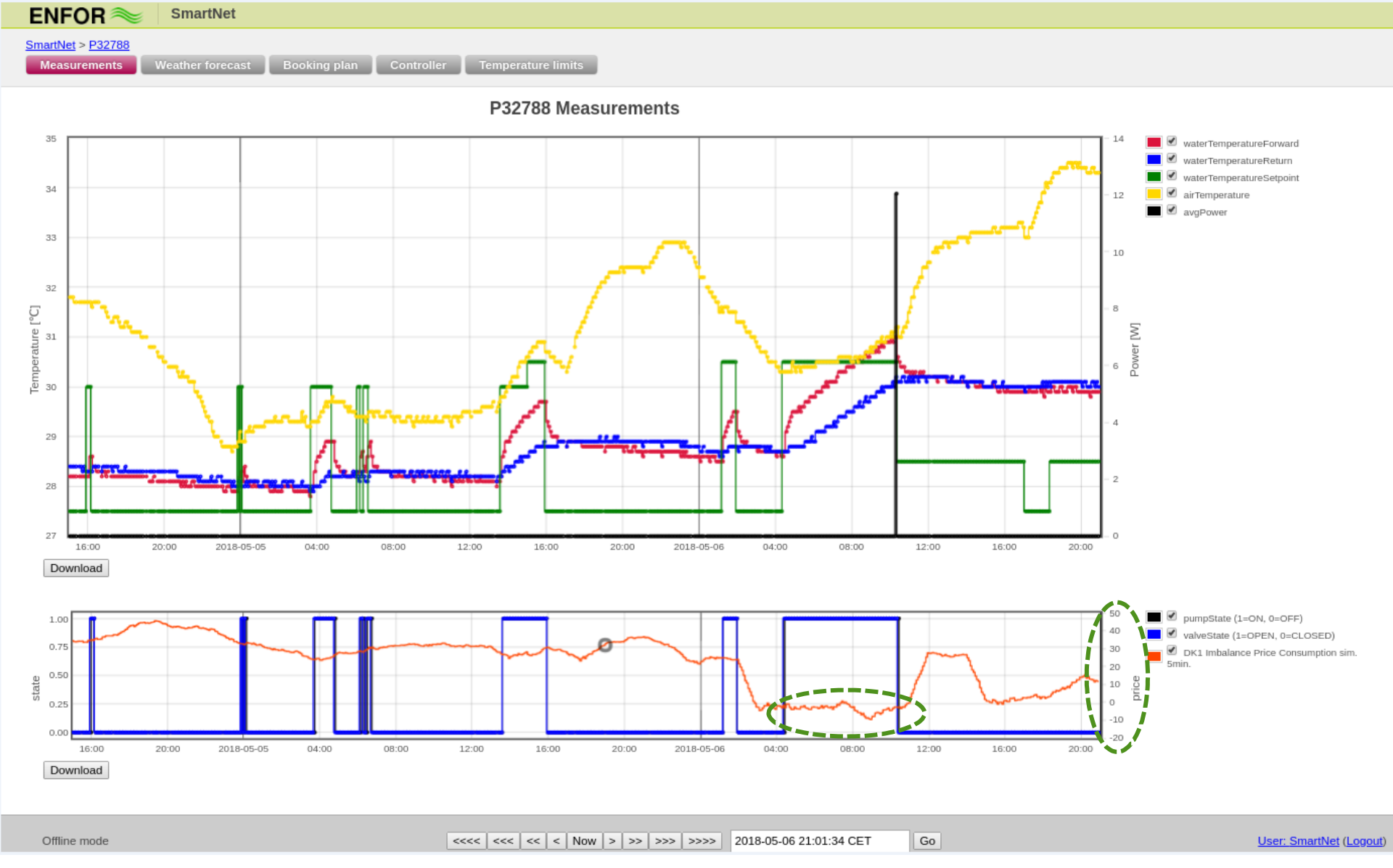
Source: pro.electicitymap.

Example: Price-based control



Example: CO2-based control

Example with negative power prices



Pilot B – Some highlights

The SmartNet Technical Aggregator at ENFOR is designed such that we can shift between any external 'penalty signal'. We are able to shift to any 'penalty signal' with a very short notice. It can be **energy efficient, price efficient** or **emission efficient**. Have been up and running with CO2-based control since May 2017 and price-based control since January this year.

A real clearing platform is established with connection from our 'TSO', DSO, Aggregator and the Technical Cloud-based Aggregator/controller

We have learned a lot about how to establish a cloud-based control of smart buildings – and in such a way that they can support the future smart grid (eg. Voltage control and congestion management)

Danish Pilot participated in the HiL simulation test with simulations at AIT .

Huge national interest in the Pilot B setup due to similarities with District Heating systems wrt. flexibility

New project with NREL: Here we are simulating a grid with 2000 buildings and using our concepts of price-based control. We have two people at NREL for the moment. Report and papers will be published jointly with NREL.

We presented some of the results of Pilot B at the European Parliament on June 27th, 2018.

DSO Perspectives

Possibilities in the future

- Good price signals important in the balancing of the distribution grid.
- New tariff to support price signals.
- Maybe local tariff is necessary.
- New tariff that can take care of local energy system, which is “off grid”.
- New ways to integrate battery systems into the power grid.
- Use the inverters as voltage stabilizing devices in the grid.

TSO Perspectives

- Automatic solutions targeting small units
- External control of units
- DSO-TSO combined optimizition
- Improved flexibility and energy systems integrations

National Perspectives

- SmartNet has created a lot of attention – we are for the moment in close contact with several ministries.
- In general we begin to see issues in DSO grids, and here solutions from SmartNet will be seriously considered
- Our TSO will talk about SmartNet at an upcoming national meeting. Specifically this talk will focus on how the methodologies can provide the needed flexibility for an integration of more wind power (today we have 44 pct in our power system)
- Pilot B of SmartNet is water in swimming pools heated by heat pumps. One idea is not to use the SmartNet principles for heating the water using heat pumps in our District Heating systems (approx. 70 of buildings are heated by DH).
- Control based methods from SmartNet Pilot B (lower level) as alternative to flexibility markets will be considerede by our TSO

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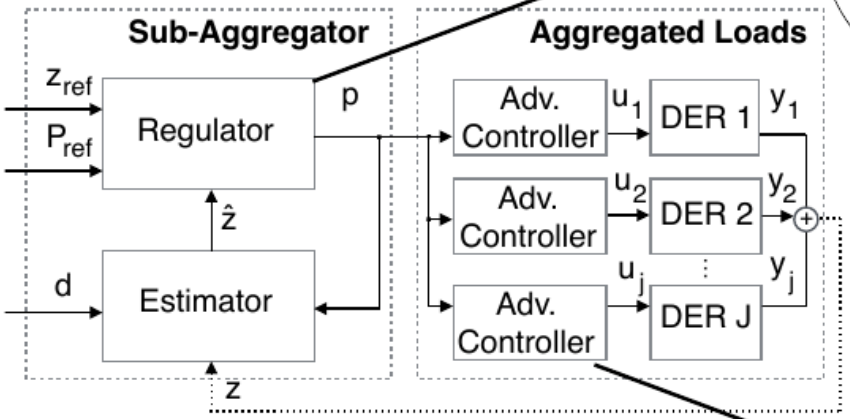
Pilot B

Misc.

Proposed methodology
Control-based methodology

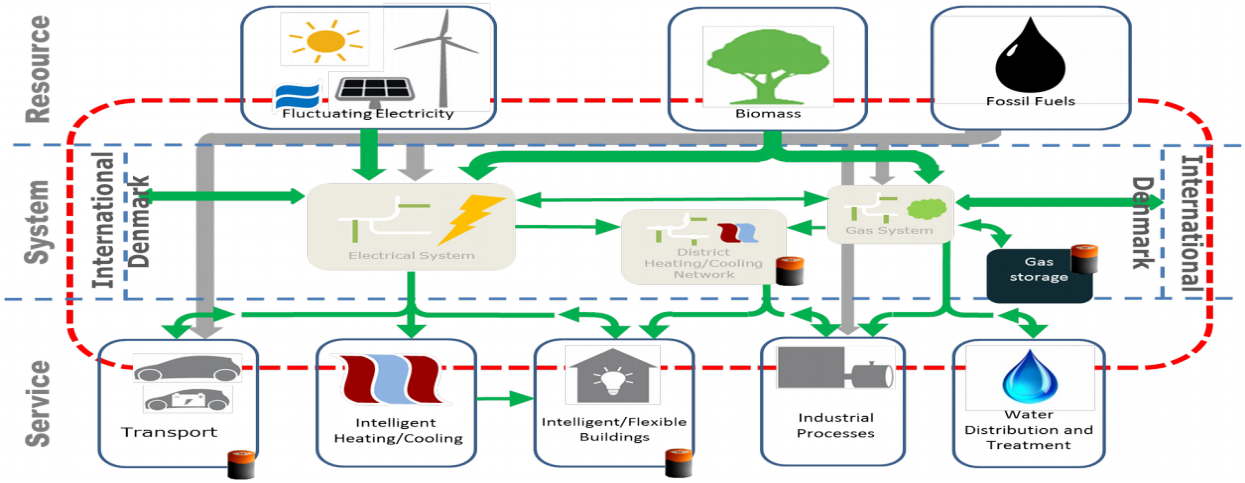
$$\min_{p} \quad \mathrm{E}[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||]$$
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$



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

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

(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, 2-12 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

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