Hvordan kan digitalisering understøtte den grønne omstilling?

Digitalisering af fjernvarmen – viden fra CITIES, HEAT4.0, IDASC, FED, mv.

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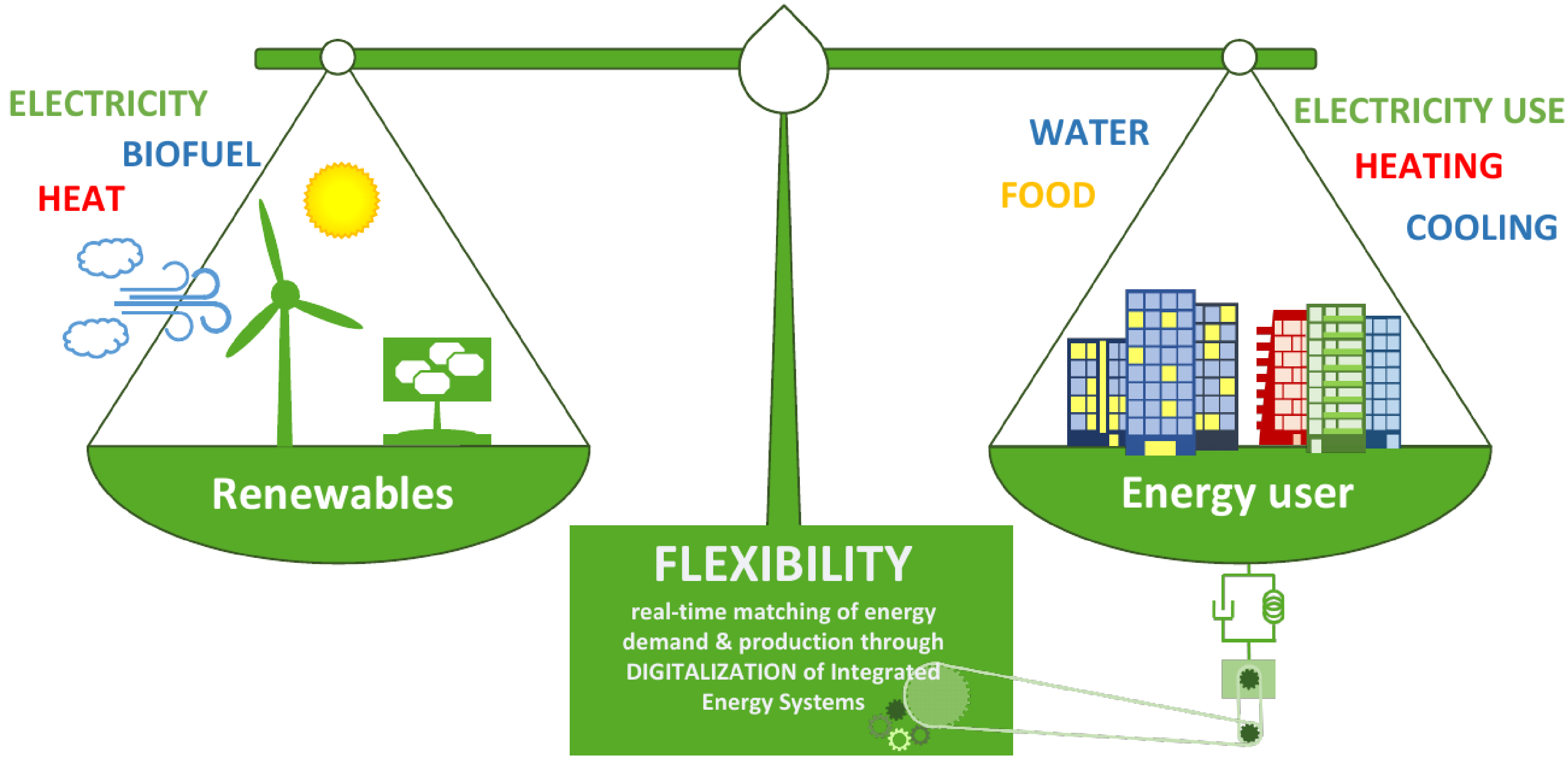
Outline

- Challenges related to the green transition
- **Load forecasting** – incl. forecasting hierarchies
- **Temperature Optimization v.2.0** (Current)
- **Temperature Optimization v.4.0** (Future – IDASC, CITIES, HEAT4.0)
- Use of **meter data**
- **Flexible load** in buildings and DH systems
- **Cloud Hub** at Center Denmark (HEAT4.0 cloud)
- **(Optimal Bidding** for District Heating Providers)

The Challenge: Denmark Fossil Free 2050



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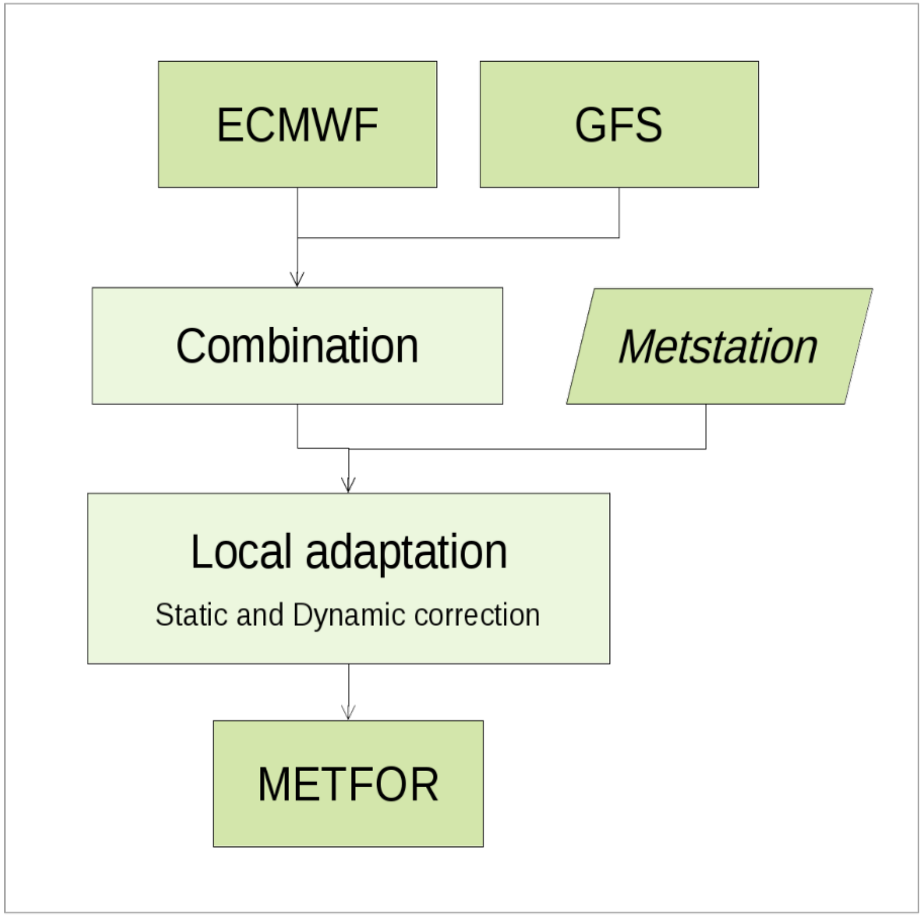
Data Intelligent Load Forecasting

Weather data and forecasts

Optimize local weather forecast base on:

- Local climate data
- Several MET forecasts



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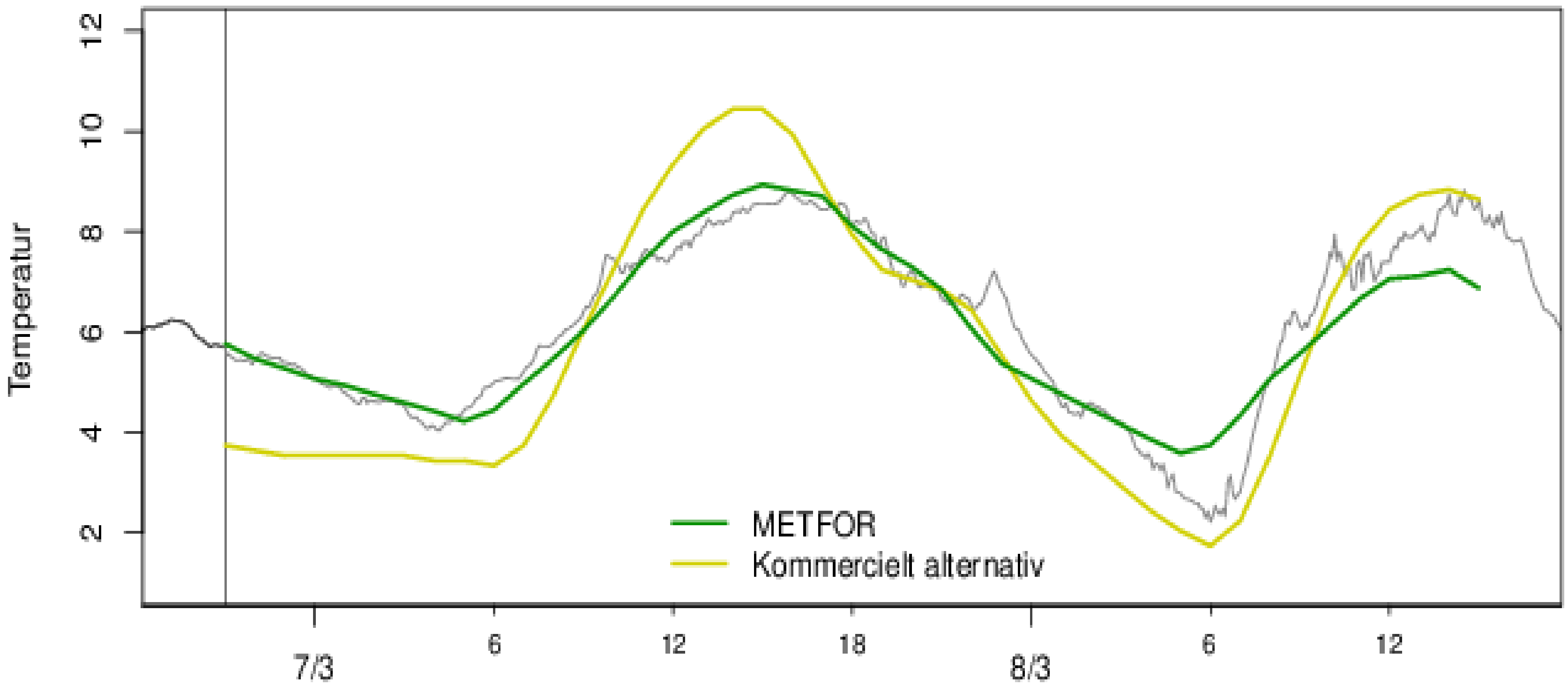
METFOR† forecast example



†ENFOR ~ https://enfor.dk/

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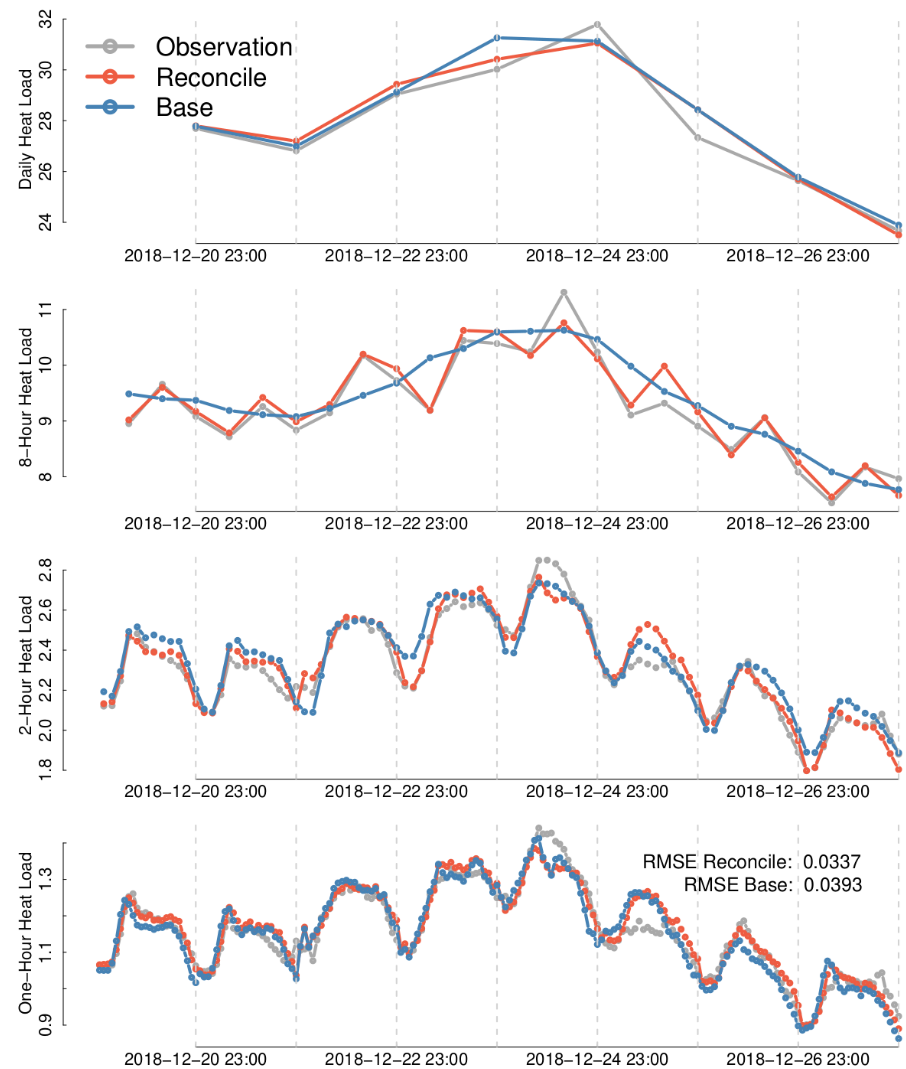
Improvements with Temporal Hierarchies

- Forecast for different aggregation levels
- Share information between levels
- Reconciled forecast is the process of optimally combining hierarchial forecast to yield coherent forecast
- The result are guaranteed to be at least as good as the base forecast



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Improvements using Temporal Hierarchies

	2017				2018			
	Base RMSE	Expanding Window	Rolling Window	Exp. Smoothing	Base RMSE	Expanding Window	Rolling Window	Exp. Smoothing
Daily	0.5585	-17.88	-17.7	**-18.1**	0.6218	**-23.02**	-19.56	-22.94
Twelve-hourly	0.3151	-17	-16.72	**-17.19**	0.3766	-25	-22.25	**-25.01**
Eight-hourly	0.3333	-39.78	-39.61	**-39.9**	0.3508	-40.24	-38.56	**-40.48**
Six-Hourly	0.2628	-41.07	-40.77	**-41.17**	0.2876	-42.16	-40.21	**-42.23**
Four-hourly	0.1715	-35.24	-34.86	**-35.34**	0.1725	-31.81	-30.16	**-32.32**
Three-hourly	0.1273	-31.98	-31.62	**-32.09**	0.1315	-30.34	-28.62	**-30.75**
Two-hourly	0.0846	-29.07	-28.64	**-29.16**	0.088	-27.99	-26.33	**-28.51**
Hour	0.0372	-14.83	-14.26	**-14.92**	0.0389	-14.77	-12.91	**-15.44**

	2019				2017:2019			
	Base RMSE	Expanding Window	Rolling Window	Exp. Smoothing	Base RMSE	Expanding Window	Rolling Window	Exp. Smoothing
Daily	0.6022	-30.4	**-31.03**	-30.94	0.5947	-23.86	-22.7	**-24.07**
Twelve-hourly	0.3579	-29.22	-29.07	**-29.46**	0.3508	-24.16	-22.97	**-24.29**
Eight-hourly	0.3735	-49.89	-49.58	**-50.13**	0.3529	-43.5	-42.75	**-43.7**
Six-Hourly	0.3095	-49.84	-49.63	**-50.06**	0.2872	-44.68	-43.83	**-44.81**
Four-hourly	0.1839	-40.73	-40.3	**-41.06**	0.1761	-36.03	-35.19	**-36.34**
Three-hourly	0.1401	-36.35	**-35.62**	-36.55	0.1331	-33.01	-32.05	**-33.25**
Two-hourly	0.092	-33.06	-32.21	**-33.27**	0.0883	-30.12	-29.12	**-30.4**
Hour	0.0387	-14.52	-13.22	**-14.7**	0.0383	-14.71	-13.44	**-15.02**

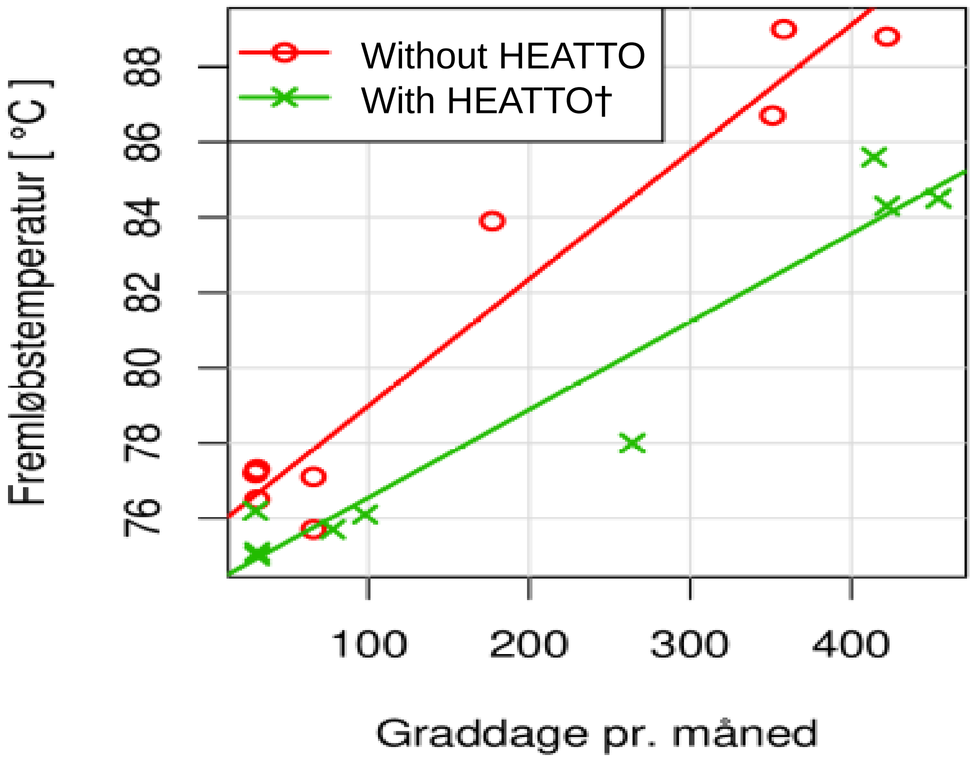
Table 2

Out-of-sample RMSE for the base forecasts and RRMSE for the reconciled forecasts for daily heat load consumption in the Greater Copenhagen area. It shows the results for three different years and the whole period from 2017 to 2019.

- Negative value describe a percentage improvement of the reconciled forecast from the base forecast

Data-driven Temperature Optimization (current version 2.0)

Supply temperature with/without data-driven temperature opt.

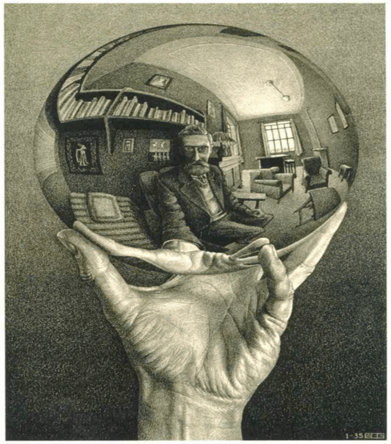


Savings:
Reduction in heat loss 18.4 pct
Annual cost saving 2.4 mill dkr

†ENFOR ~ https://enfor.dk/

Data-driven Temperature Optimization for DH Systems

- Able to take advantage of **information in data**
- **Self-calibrating** models for the DH network
- Shows where to **upgrade** the DH network
- **Fast** (real time) calculations
- Use DH net for **peak shaving** and **storage**
- Able to use **online MET forecasts** etc.
- **Savings up to 800 Mill. DKK annually** by using data-driving temperature opt. (Damvad report 2019)



Data-driven Temperature Optimization (v.4.0) (Incl. use of meter data)

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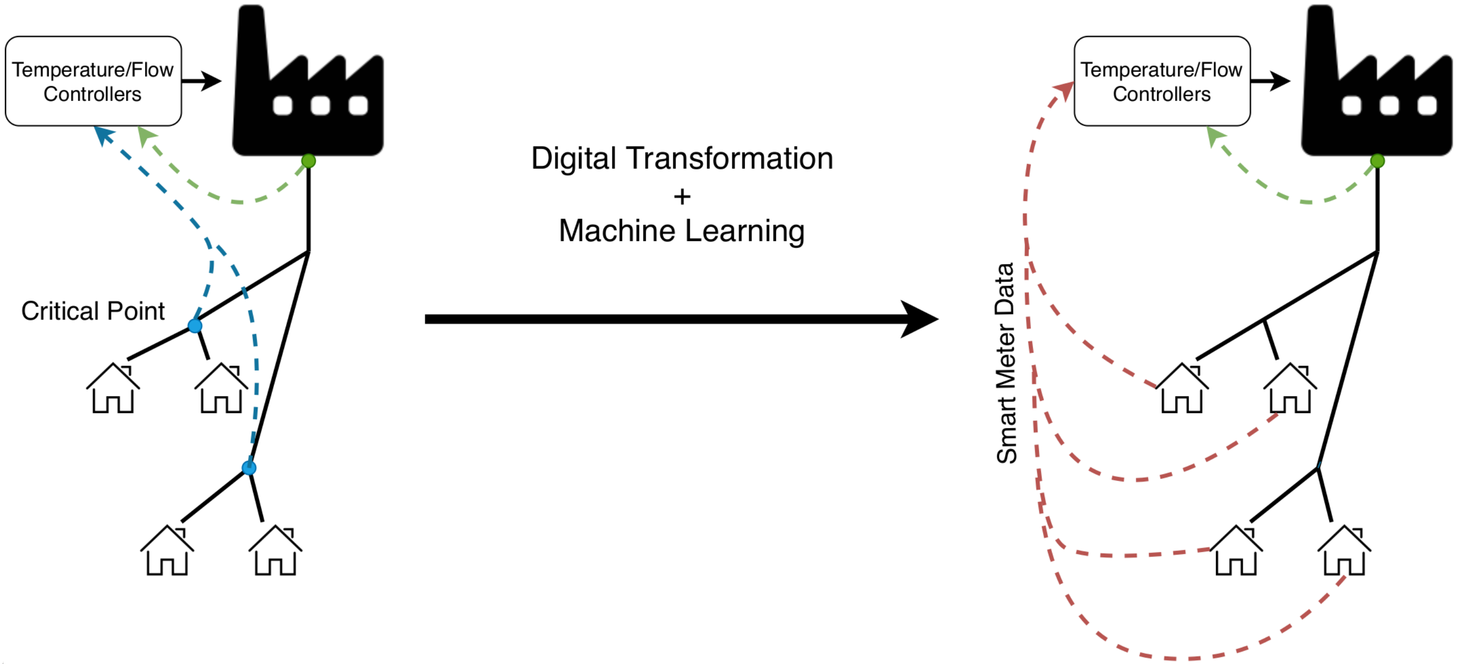
Meter Data in Data Intelligent Temperature Optimization (v.4.0)

- **Measurement feedback from end-users**:
  - Supply Temperature, Return Temperature and Flow measurements on e.g. 1 hour interval
  - Data for information, monitoring and control purposes

- End-users can be **more aware of their consumption** and can control it based on their needs (time-varying prices)
- Gives the oppurtunity take the advantage of meter reading using **big data analytics tools**: fault detection, etc.
- Having different **temperature zones** inside the network with additional pressure pumps and heat pumps
- **Enable for flexible load** in buildings

Replacing the netpoint sensors at the critical point using meter data

- Use readings from end-user to create a **artificial critical temperature** for a distribution of houses in the network
- **Replacement** of critical netpoint sensors
- **Dynamic location** of netpoints



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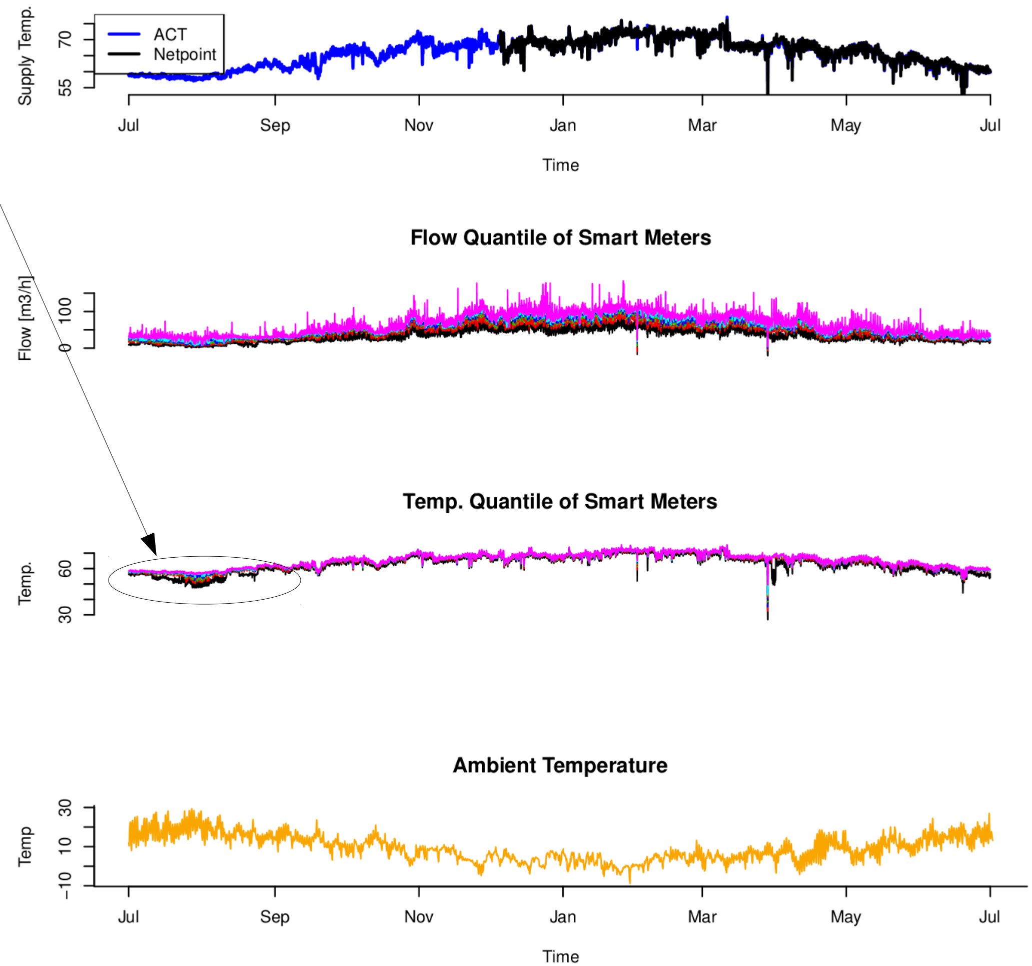
Replacing the temperature at the critical point using meter data

- Need models to filter out when there is a low flow (e.g. system is shut down)
- Data from 15 houses in Brønderslev
- 15 min. values
- Fine with one day latency of measurements
- Currently running in Tingbjerg demo for 15 apartment buildings, 2 buildings are used as reference



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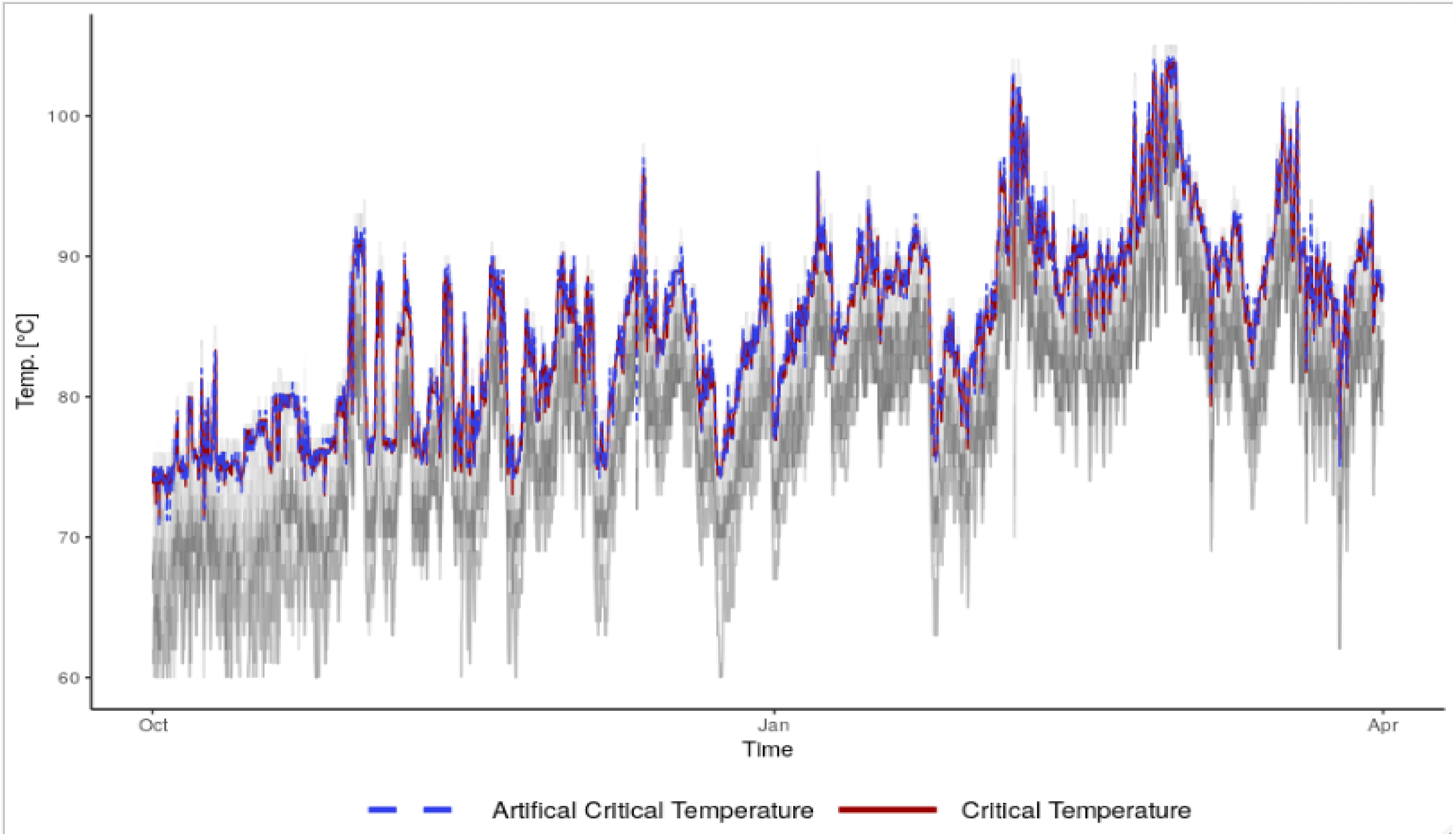
Critical Temperature estimated from Smart-Meter Data



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DIGITALISERING I FJERNVARMEN BIDRAGER TIL 2030-MÅL

Det sparer penge og CO_2, når fjernvarmesektoren styrer temperaturen med data og lokale vejrudsigter i stedet for tegninger af ledningsnettet og mavefornemmelsen.

Hanne Kokkegård
Sven Müller, DTU, Dansk Fjernvarme/Nils Rosenvold

1,7 mio. husstande i Danmark (ca. 64 pct.) bliver opvarmet med fjernvarme, der løber gennem 60.000 kilometer fjernvarmenet. Rejsen fra fjernvarmeværket til radiatorerne tager typisk flere timer, og derfor skal varmebehovet kunne forudsiges.

Man skal ikke skrue mere op for varmeproduktionen end nødvendigt, for det koster penge og er energispild, ligesom temperaturtabet i rørene er større ved højere temperaturer. Samtidig skal vandet være tilstrækkelig varmt på de såkaldt kritiske punkter i udkanten af ledningsnettet. Så det er en videnskab at styre fjernvarmeproduktionen optimalt.

På DTU Compute arbejder professor Henrik Madsen og hans kolleger med datadrevet energi- og temperaturoptimering. Flere forskningsprojekter viser, at digitalisering forbedrer prognosen for varmebehovet og tilmed letter vejen til Danmarks 2030-klimamål.

En undersøgelse, som Damvad Analytics har lavet sammen med Danmarks største smart city-projekt, CITIES, ledet af netop Henrik Madsen, samt tænketanken Grøn Energi under Dansk Fjernvarme, viser, at fjernvarmesektoren kan spare mellem 240 og 790 mio. kr. ved at indføre datadrevet temperaturregulering af fremløbstemperaturen, fordi temperaturen kan sænkes tre til ti grader. Lavere temperatur sparer også CO_2, ligesom varmetabet i nettet mindskes.

"Der er store potentialer ved at gå fra erfaring og simulationsbaseret styring ud fra tegninger af ledningsnettet til datadynamisk optimering af fjernvarmen. Vores projekter viser, at når fremløbstemperaturen er baseret på flere her og nu-datakilder, herunder vejrdata fra lokale målestationer, optimerer vi produktionen og accelererer den grønne omstilling," siger Henrik Madsen.

Lavere varmepriser

Svebølle Viskinge Fjernvarmeselskab med 535 husstande er ét af de forsyningsselskaber, der har øget digitaliseringen. Siden oktober 2019 har fjernvarmeselskabet i Nordvestsjælland benyttet bearbejdede data fra DTU-spinout-firmaet ENFOR til optimal styring af fremløbstemperaturen.

På få måneder har man kunnet sænke fremløbstemperaturen med over 20 grader. Hvor temperaturen før lå på 80,9 grader, blev den først sænket til 68,1 grader, hvorefter den kunne sænkes yderligere til 60 grader.

Billedet viser udstyret til temperaturmåling i ventilbrøndene: en PT100-temperaturføler og en radiosender samt et motorcykelbatteri, der holder i seks år og forsyner udstyret med strøm, så det kan sende data videre.

"Dengang kørte vi lidt med bind for øjnene, fordi vi ikke vidste, hvordan det reelt stod til med temperaturen i fjernvarmenettet. Vi havde slet ikke forestillet os, at digitalisering kunne blive så stor en gevinst."

SVEND MÜLLER, BESTYRELSESFORMAND FOR SVEBØLLE VISKINGE FJERNVARMESELSKAB

Dynamisk datadrevet fjernvarmedrift

- Teknologien anvender AI til at bearbejde data til at forudsige varmebehov, pumpebehov og temperatur på 'kritiske' steder i fjernvarmenettet, hvor temperaturen er lavest.
- Ud fra vejrudsigter og lokale målestationer foreslår systemet en starttemperatur. Systemet sender realtidsdata for temperaturen i nettet, kritiske steder, varmeforbruget hos slutbrugeren og vej tilbage. Temperaturen og trykket reguleres i rørene. Systemet agerer efter de lokale forhold og lærer nettet at kende på en til tre måneder.
- Data kan identificere potentielle fejl og brud.
- Forskerne i CITIES og andre DTU-ledede projekter arbejder også med styring af varmepumper efter CO_2-baserede elpriser, så produktionen øges, når strømmen er grøn.

KILDE: RAPPORTEN 'POTENTIALET VED DYNAMISK DATADREVET TEMPERATURREGULERING I FJERNVARMESEKTOREN; FRA DAMVAD ANALYTICS, GRØN ENERGI OG CITIES.

Transformationen

Figuren skitserer, hvordan den digitale transformation i fjernvarmen kommer til at foregå med data fra fjernaflæste målere (smartmeters).

KILDE: INTEGRERING AF LAVTEMPERATURFJERNVARME TIL EKSISTERENDE BYOMRÅDER, JANUAR 2020, DTU M.FL.

Det giver en anslået besparelse på mindst 550 MWh og en reduktion på 110.000 kr. i årlige produktionsomkostninger. Man regner med på sigt at sænke varmetabet i nettet til under 30 pct., og at varmeprisen falder med 47 pct. i perioden 2015-2025.

Inden Svebølle Viskinge Fjernvarmeselskab gik over til datadrevet drift, benyttede man såkaldt simulationsbaseret drift baseret på viden om fjernvarmenettet, erfaring og kun lidt forecast.

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Flexible load in buildings and DH systems using Cloud Computing

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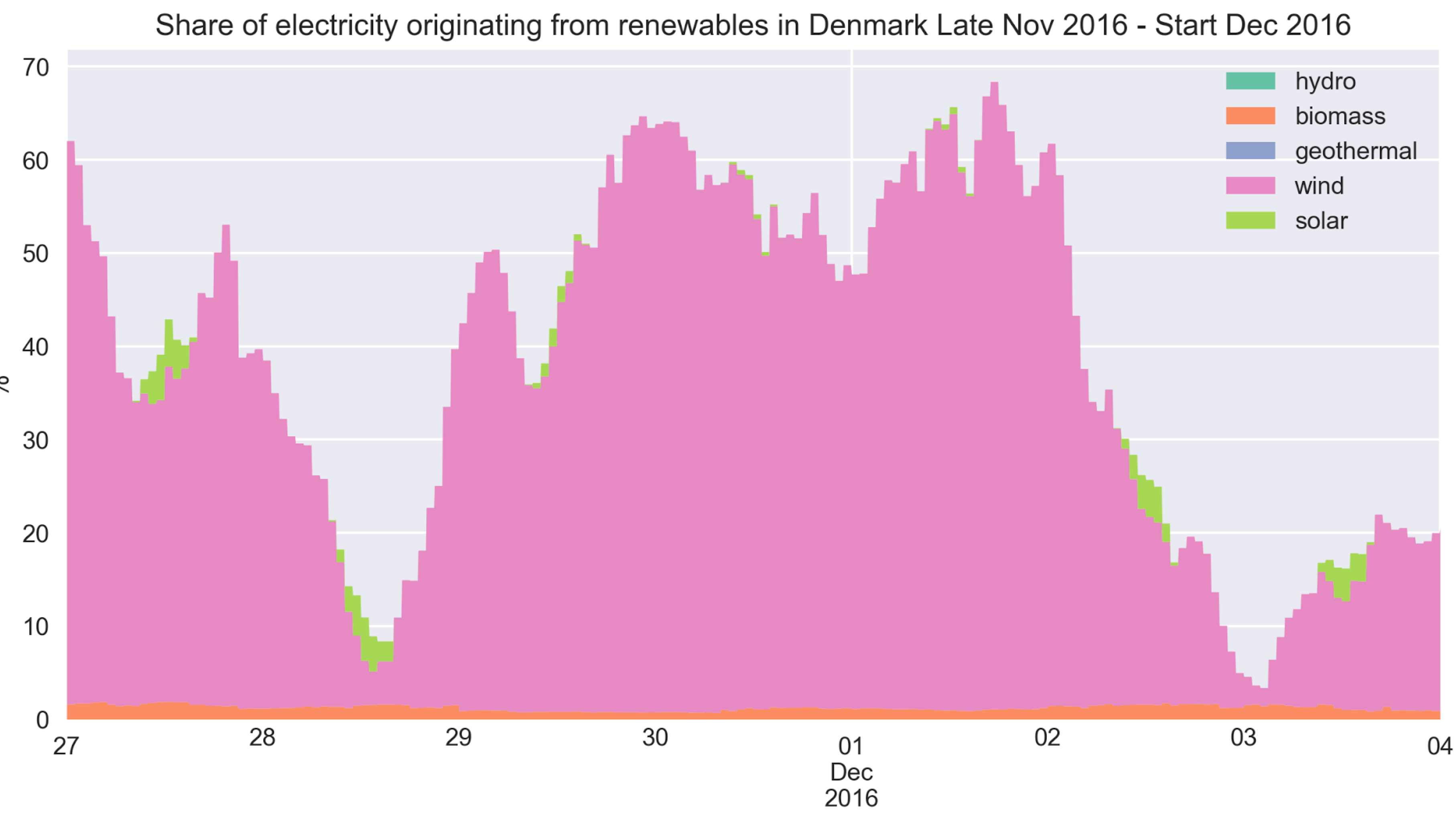

Source: pro.electicitymap.

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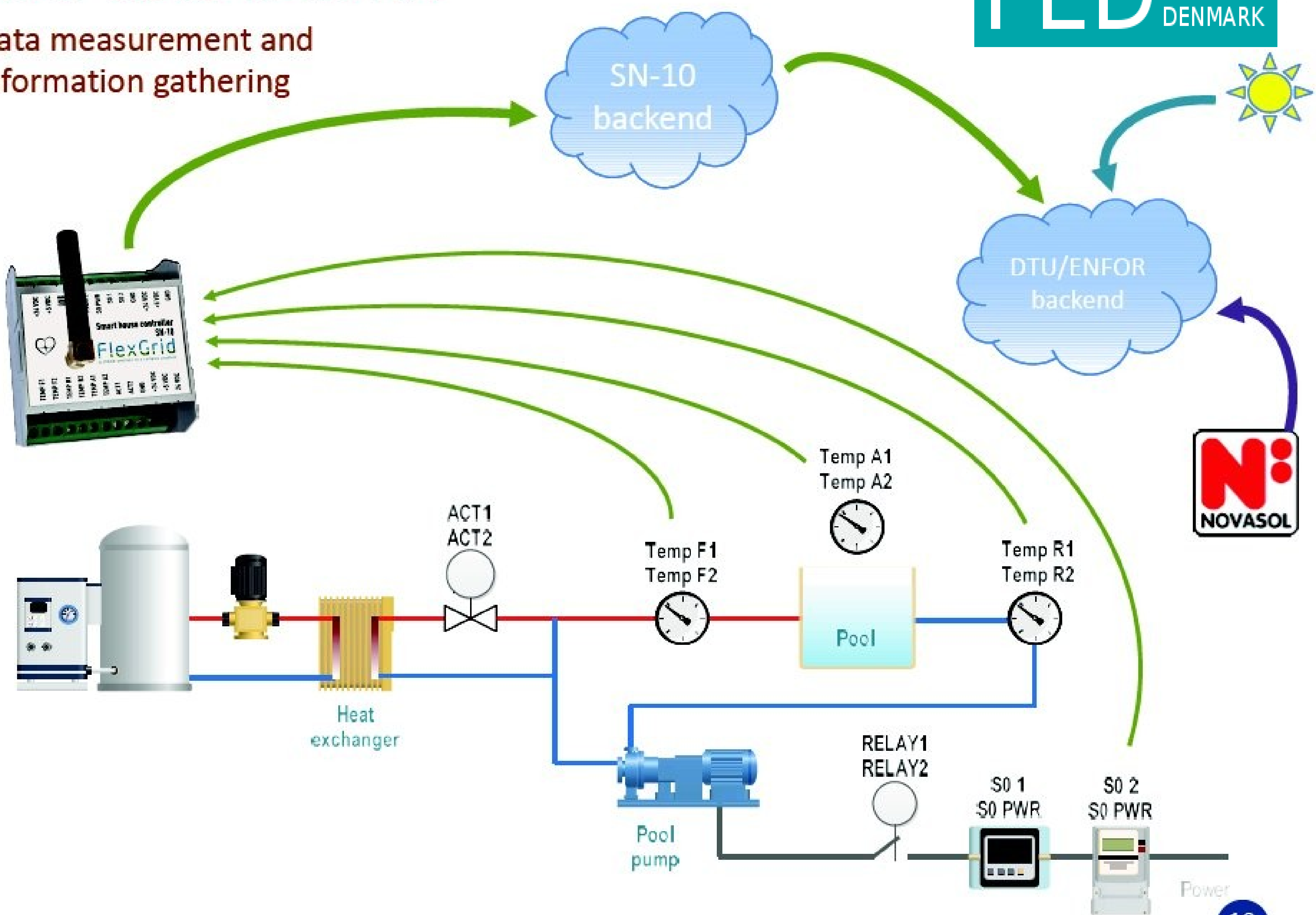
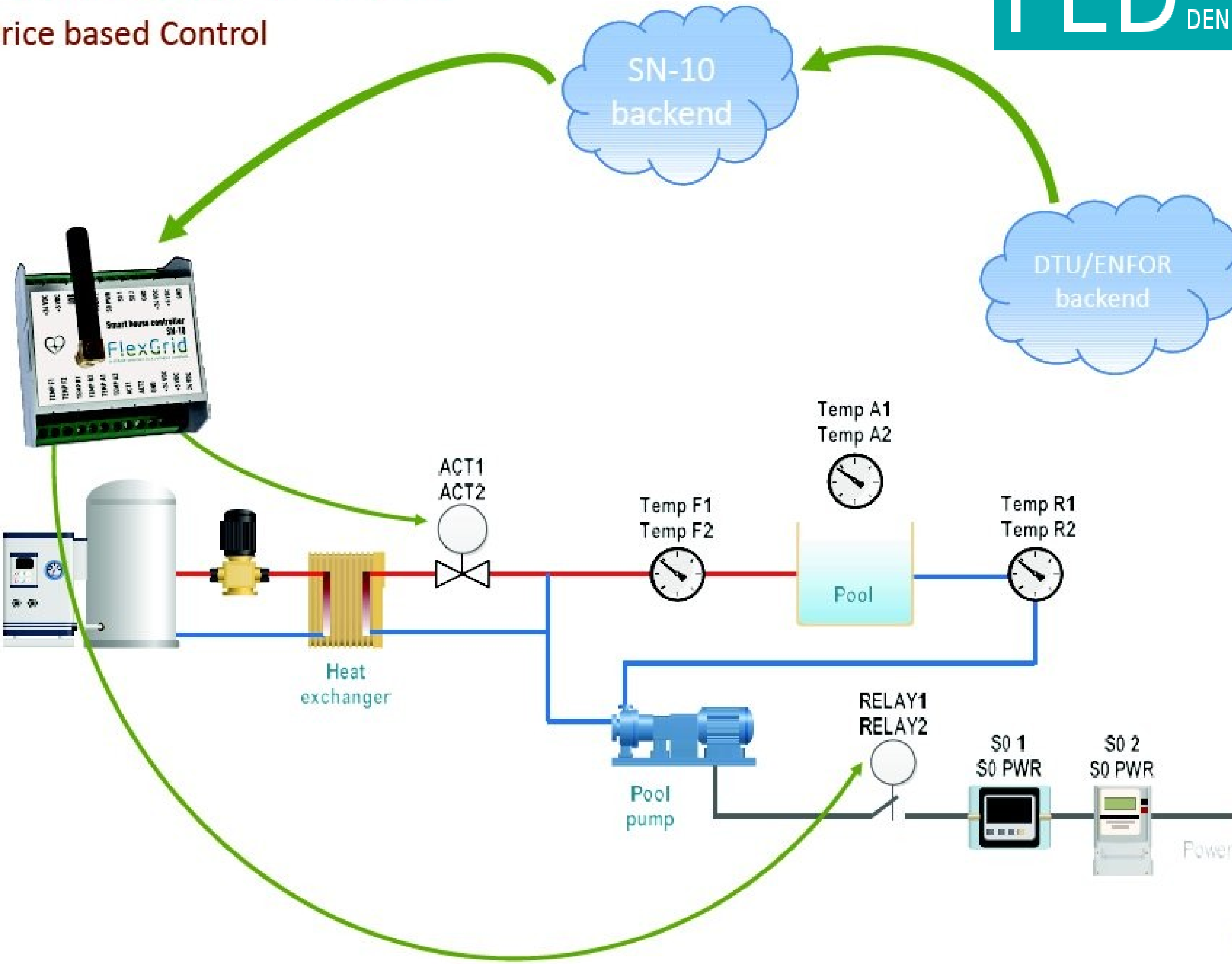
How does it work?

Data measurement and information gathering



How does it work?

Price based Control



Example: CO2-based control (10-20 pct savings)

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Optimal Bidding for District Heating Providers

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Hvide Sande Fjernvarme
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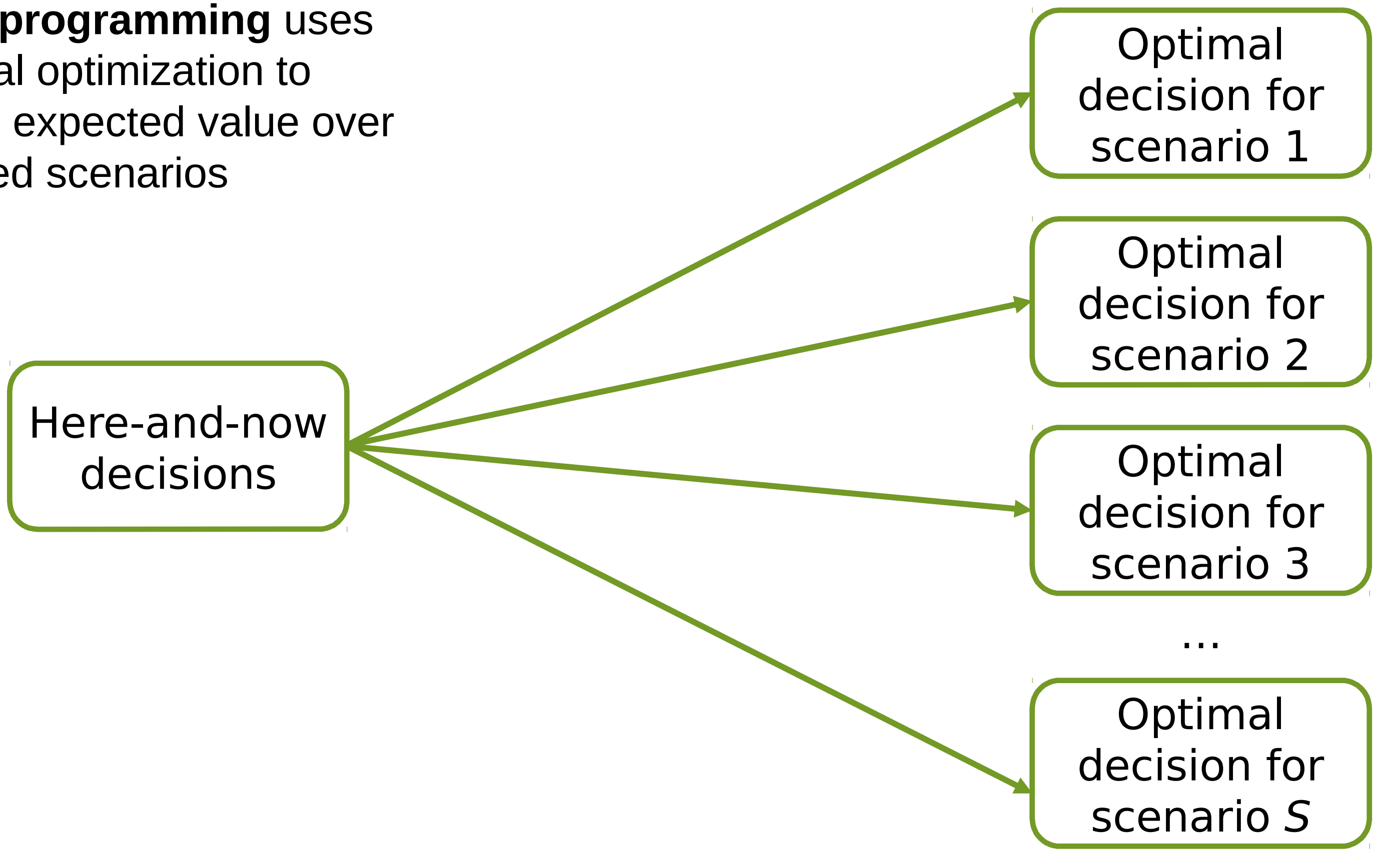
Decision-making under uncertainty

Stochastic programming uses mathematical optimization to optimize the expected value over all considered scenarios



Novel bidding method

Related bidding methods for CHP units in literature:

[Conejo et al., 2002, Rodriguez and Anders, 2004, Schulz et al., 2016, Dimoulkas and Amelin, 2014, Ravn et al., 2004]

→ Take a power producer perspective

→ all methods plan bids for the CHP units, if the electricity price forecast indicates its beneficial

Our approach:

Heat **U**nit **R**eplacement **B**idding (HURB) method

- Make use of the fact that **we have to produce the heat** for the district heating network anyway
- Bidding based on **replacing heat unit production by CHP production**

Blanco, I., Andersen, A. N., Guericke, D., & Madsen, H. (2019). A novel bidding method for combined heat and power units in district heating systems. Energy Systems. https://doi.org/10.1007/s12667-019-00352-0

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Results - Bids

Percentage of hours with bids and won bids in one month averaged over several samples

Method	Receding Horizon	CHP 1		CHP 2	
		Bids	Won	Bids	Won
HURB Worst	1	**98.91**	**41.95**	98.70	41.91
HURB Avg.	-	**99.79**	**42.19**	99.75	42.15
HURB Best	10	**99.89**	**42.28**	99.87	42.26
Conejo et al.	10	44.92	39.34	44.92	39.31
Rodriguez & Anders	5	82.52	35.85	82.40	35.82
Schulz et al.	12	45.02	18.54	45.01	18.53
Dimoulkas & Amelin	12	75.55	26.56	75.55	26.55
Ravn et al.	5	44.84	32.58	44.83	32.57

We can take advantage of the portfolio of heat production units and base the bidding amounts and prices on the heat production.

Possible savings by digital operation of DH Systems (CO_2 + Costs)

- (TO v. 2.0): 800 mill dkr annually in Denmark by data-driven temperature optimization = (tons of CO2 savings)
- (TO v. 4.0): Maybe 400 mill dkr extra (we don't know yet)
- 10 – 30 pct savings by predictive control of heat pumps
- 5 – 20 pct savings by integrating forecasts in smart house controllers
- 10 – 40 pct improvements of electricity and heat load forecasts
- Up to 10 pct savings by optimal operations of CHP and DH plants
- Up to 90 pct savings on cooling for data centers
- Many digital solutions for DH systems already exists – and more will come with HEAT4.0, IDASC, FED, TOP-UP, ...