Cross-optimization and interaction of tools

HEAT 4.0 – Monthly Meeting 06-07-2022

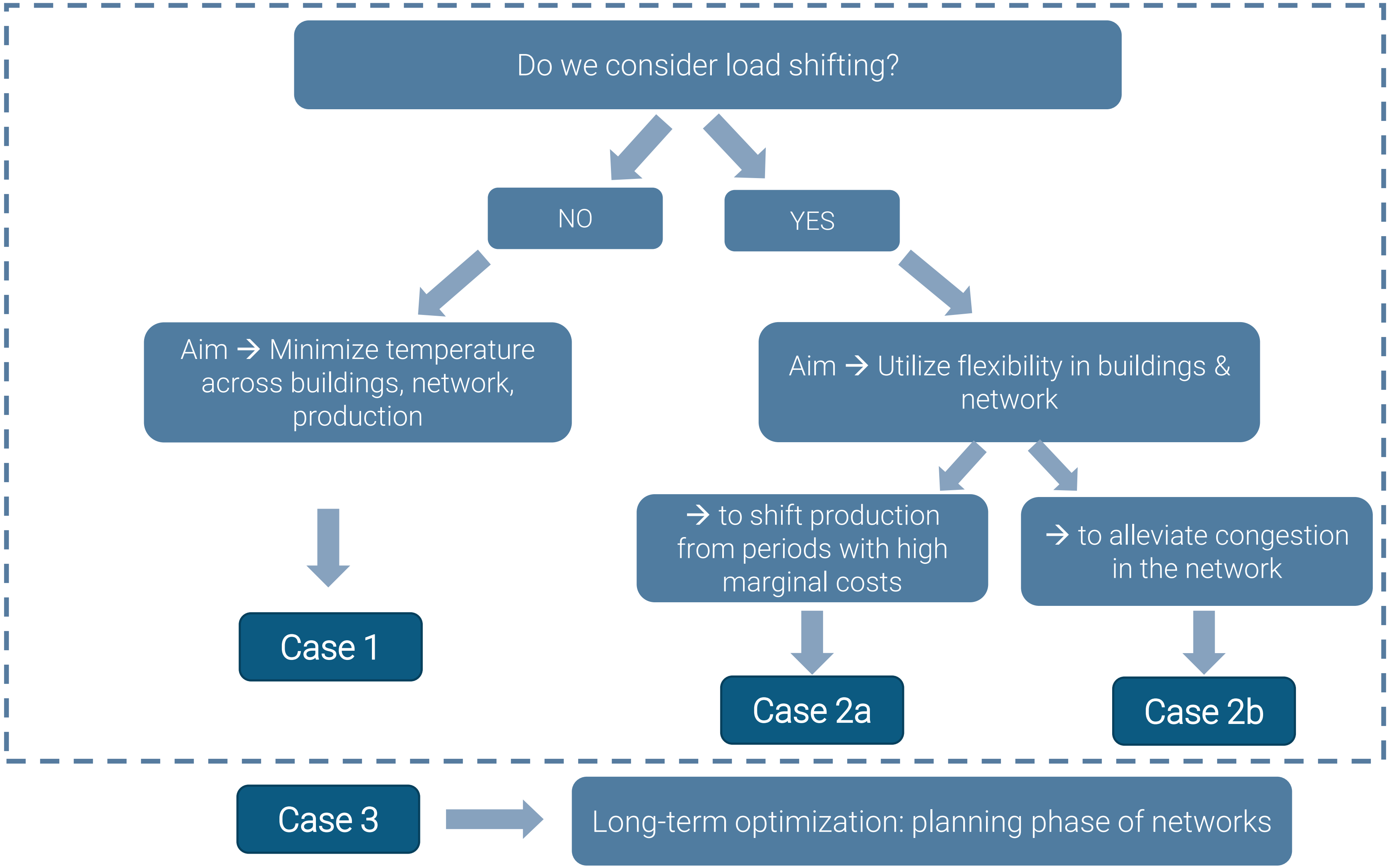
Agenda

- Cross-optimization concept recap (EMD – Marta)
- The production component (EMD – Marta)
- The network component (Enfor – Torben)
- The building component (Neogrid/Leanheat cooperation - Pierre)
- Estimation of CSO (Case 2) value based on Brønderslev example (EMD - Marta)
- Feedback & discussion

Agenda

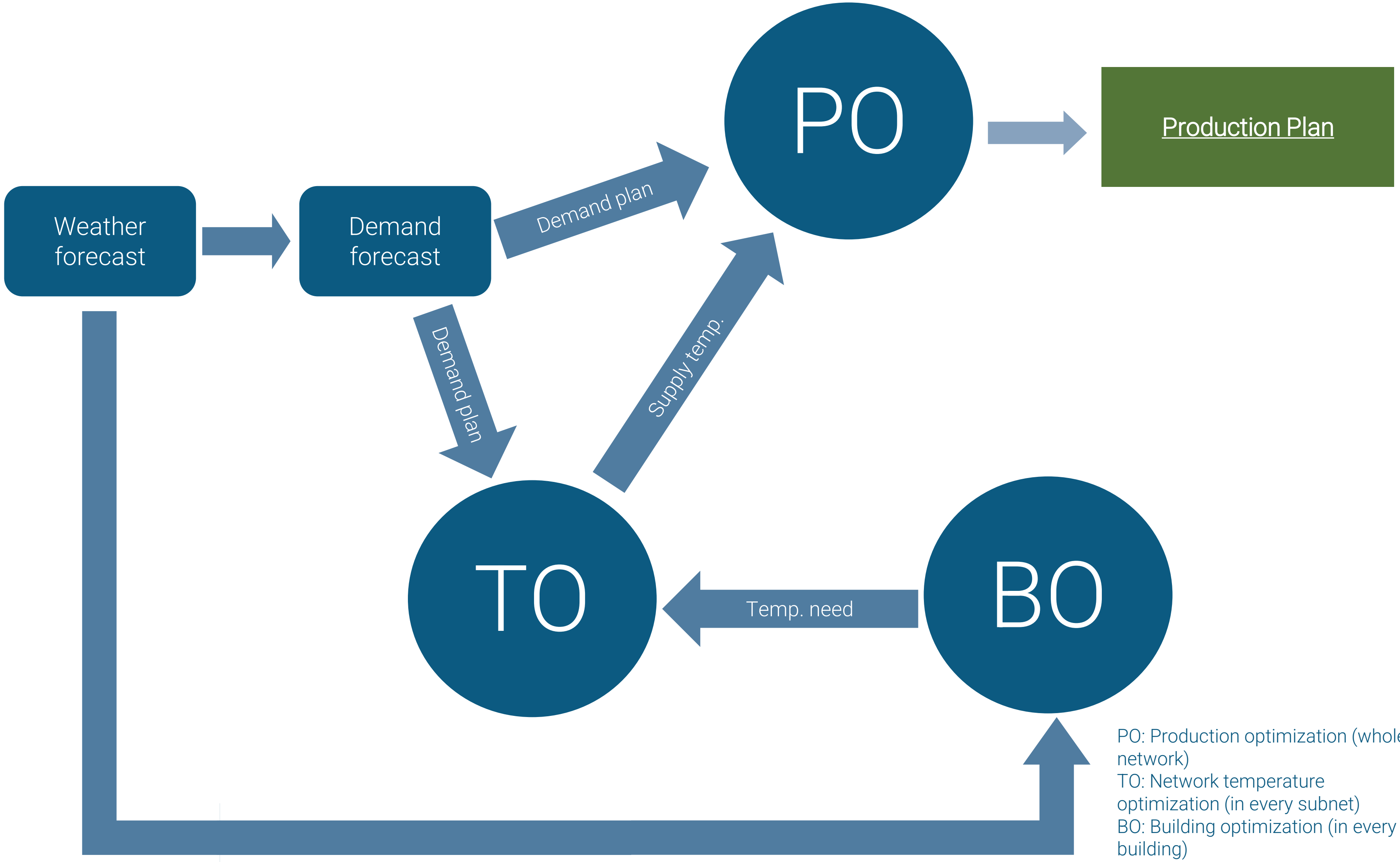
- **Cross-optimization concept recap (EMD – Marta)**
- The production component (EMD – Marta)
- The network component (Enfor – Torben)
- The building component (Neogrid/Leanheat cooperation - Pierre)
- Estimation of CSO (Case 2) value based on Brønderslev example (EMD - Marta)
- Feedback & discussion

Cross-optimization concept



Cross-optimization: Case 1

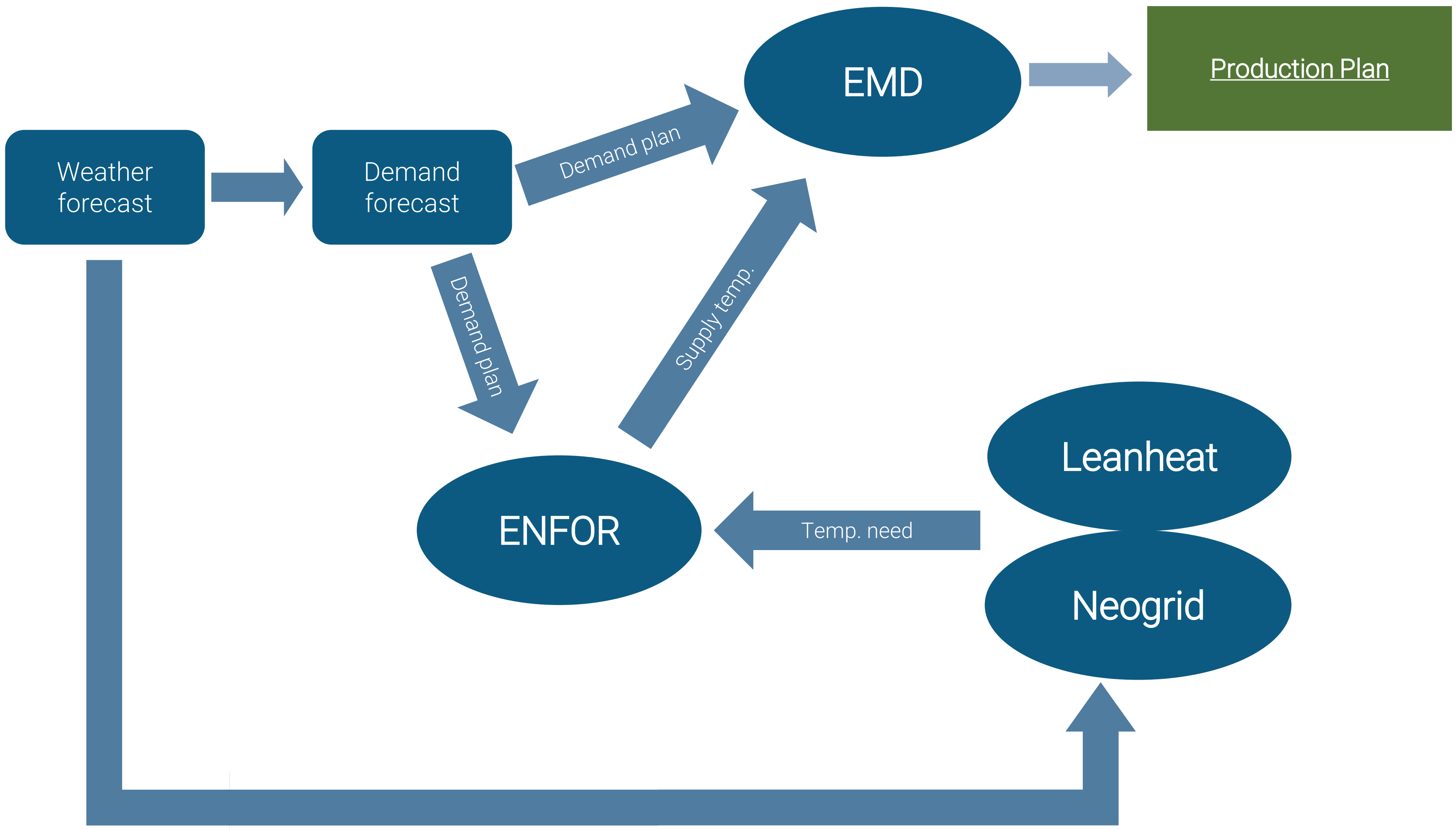
Optimized baseline: minimize supply temperature across buildings, network and production



PO: Production optimization (whole network)
TO: Network temperature optimization (in every subnet)
BO: Building optimization (in every building)

Data exchange

Status:
Interface between tools developed and tested

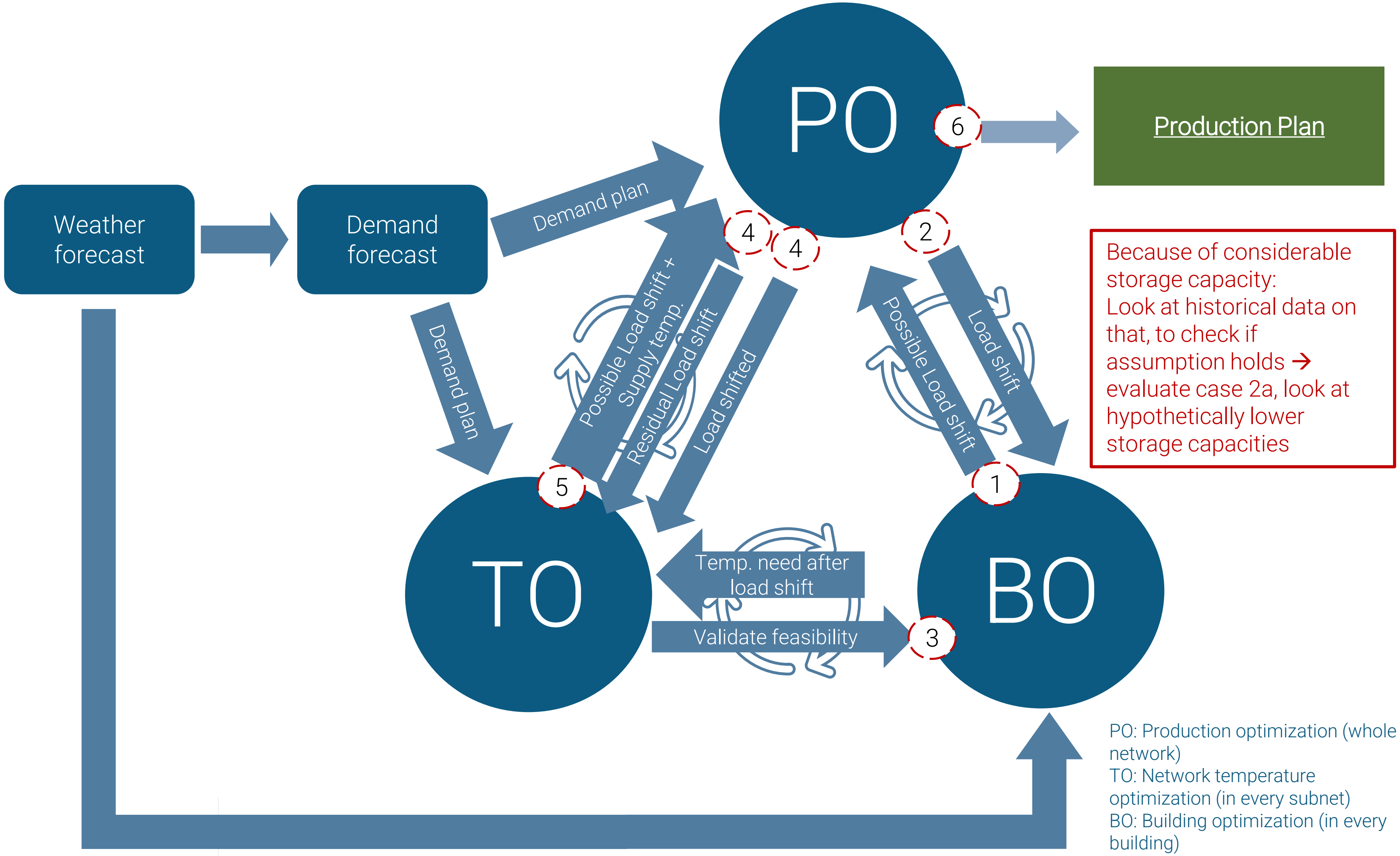


Overview of installations in demos

	EMD	ENFOR	Leanheat	Neogrid
Brønderslev	• EnergyPro • EnergyTRADE *Installed, but not used*	Heat Solutions: • MetFor • HeatFor • HeatTO *All networks*		•2 single family houses BR2020 •1 kindergarden •1 office + workshop
Hillerød	• EnergyTRADE *Installed & tested*	Heat Solutions • MetFor • HeatFor • HeatTO *All networks*	• 12 multi-family buildings (~500 apartments) *Sensor-less installation*	•1 single family house
Trefor	---	HeatSolutions • MetFor • HeatFor • HeatTO *All networks*	• 13 multi-family buildings (~400 apartments) *Full installation*	

Cross-optimization: Case 2a

Utilize flexibility in network & buildings for shifting production from periods with high marginal costs

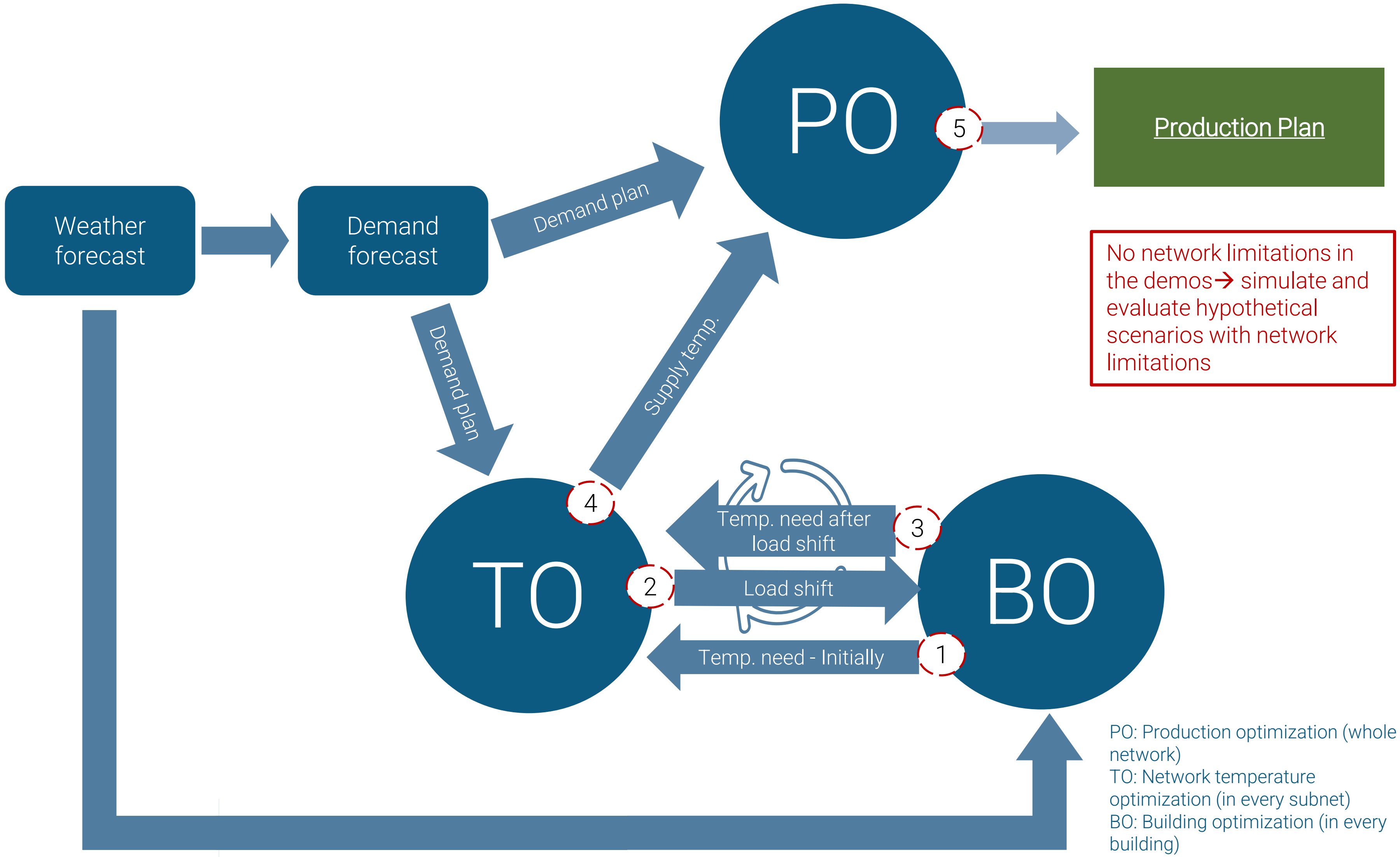


Because of considerable storage capacity:
Look at historical data on that, to check if assumption holds → evaluate case 2a, look at hypothetically lower storage capacities

PO: Production optimization (whole network)
TO: Network temperature optimization (in every subnet)
BO: Building optimization (in every building)

Cross-optimization: Case 2b

Utilize flexibility in network & buildings to alleviate congestion in the network



No network limitations in the demos→ simulate and evaluate hypothetical scenarios with network limitations

PO: Production optimization (whole network)
TO: Network temperature optimization (in every subnet)
BO: Building optimization (in every building)

Agenda

- Cross-optimization concept recap (EMD – Marta)
- **The production component (EMD – Marta)**
- The network component (Enfor – Torben)
- The building component (Neogrid/Leanheat cooperation - Pierre)
- Estimation of CSO (Case 2) value based on Brønderslev example (EMD - Marta)
- Feedback & discussion

Production Optimization Solution by EMD

energyPRO

Software suite for production optimization

energyPRO

Investment and operation analysis

energyTRADE

Daily operation planning

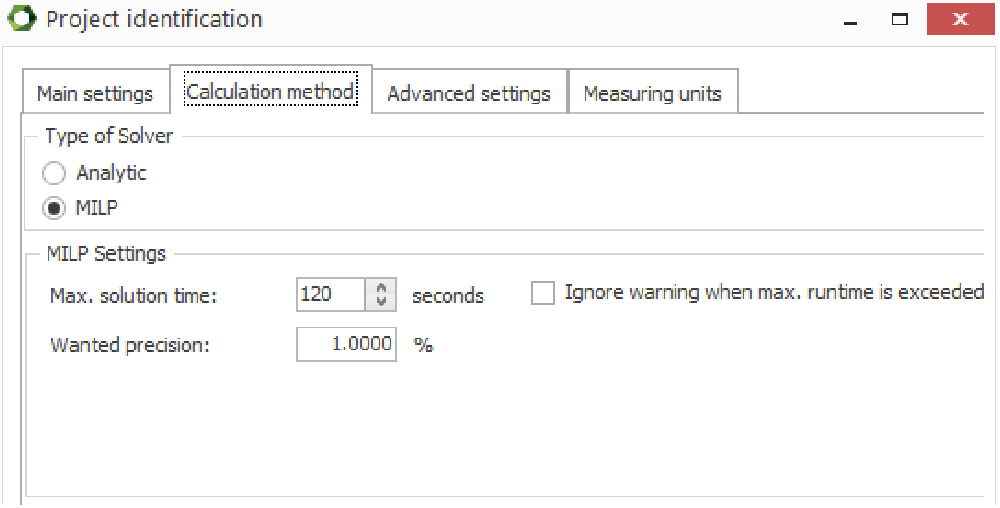
Improvements to the production optimization solution

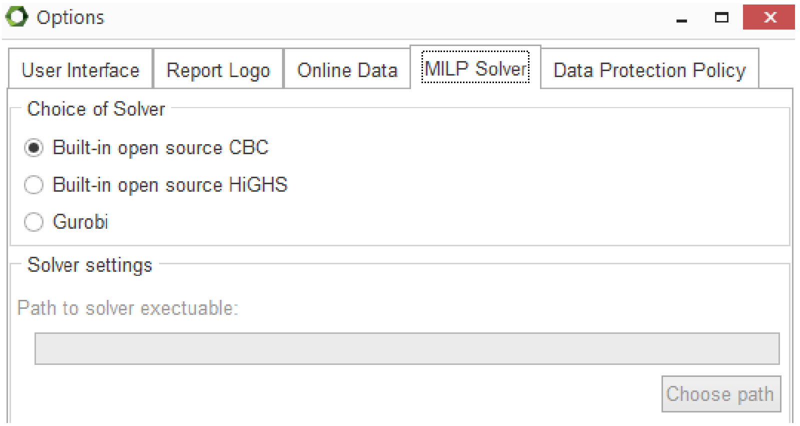
- Implementation of a MILP Solver
- Development of a CSP model
- Hydraulic calculations for heat transmissions
- Improvements to the PV model for Assens District Heating

MILP Solver

This implementation allowed to optimize the operation of highly complex systems where:

- units are producing various energy outputs (e.g., heat, electricity and cooling)
- the operation of some of the units depends on the operation of others (e.g., heat recovery, Organic Rankine Cycle running on heat produced from CSP)
- units with complex efficiency curves
- units operating with restricted fuel consumption

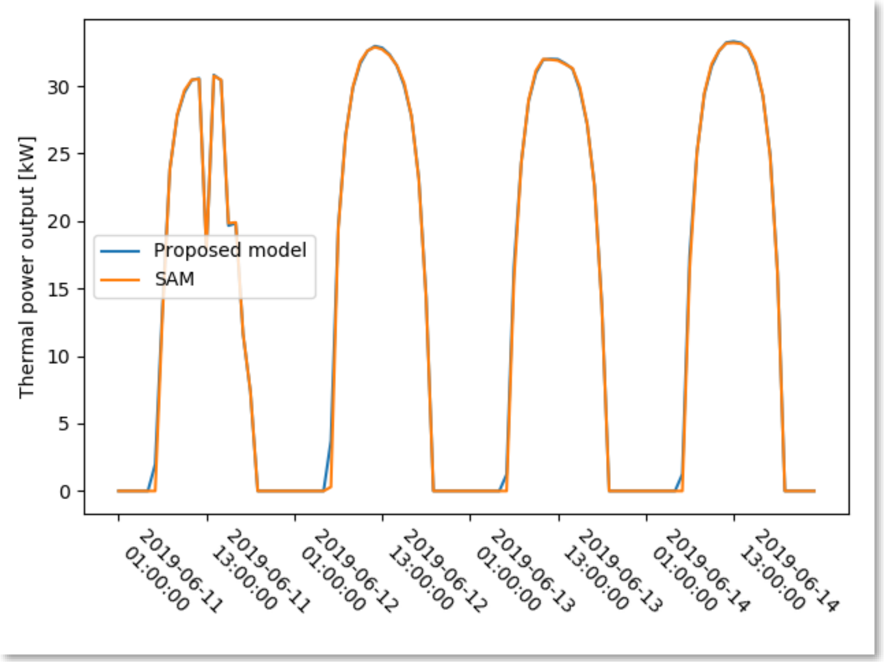




energyPRO

CSP model

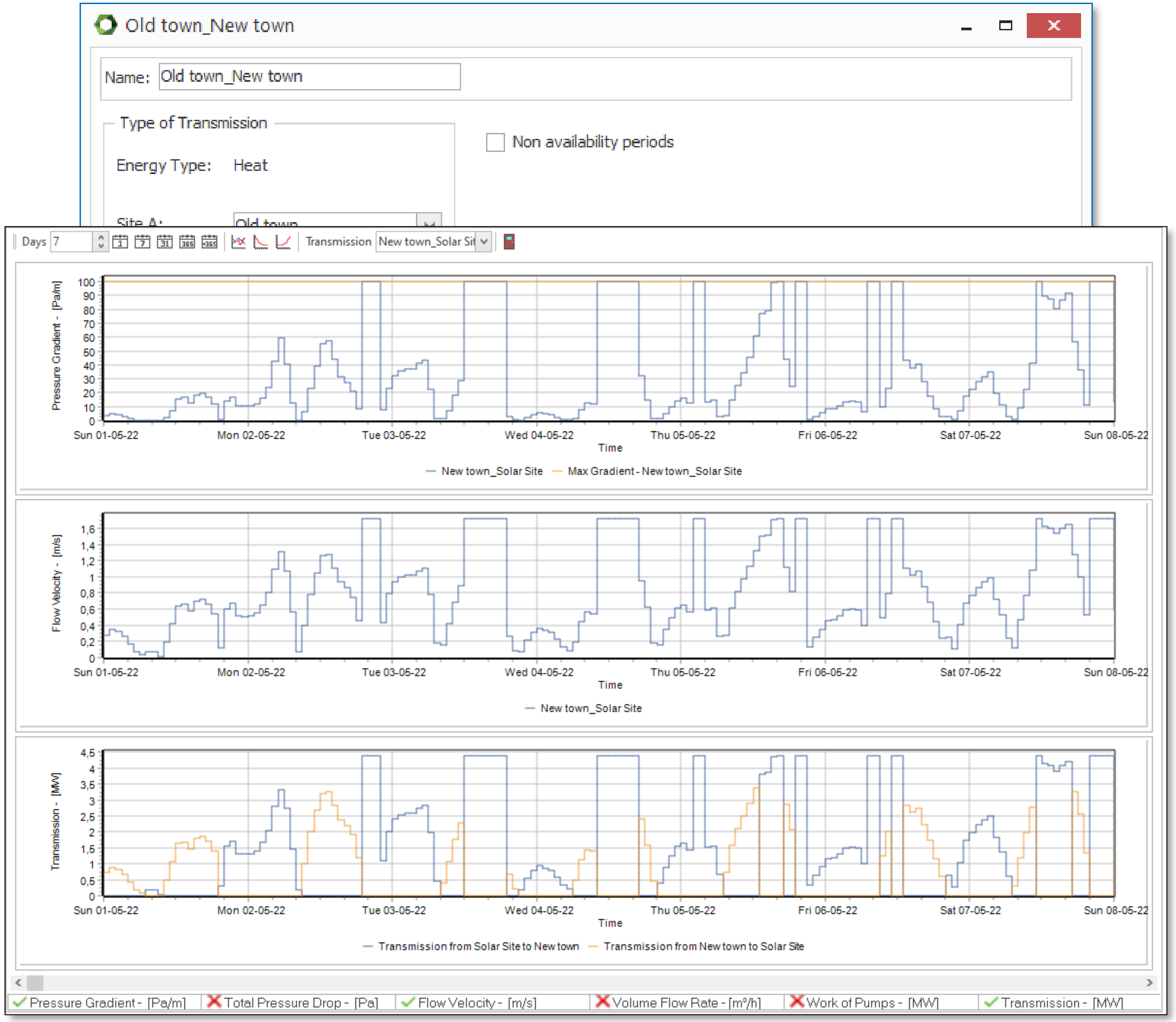
- Enables to estimate thermal power output from the Concentrated Solar Power unit in Brønderlev
- Input to the model: Irradiance prognosis
- With Enfor's irradiance prognosis, the model estimates the CSP production in Brønderslev for 7 days
- Model validated against SAM



energyPRO

Hydraulic calculations for heat transmissions

- Transmission constraints in pipes
- Economic optimal investment also in pipes
  - Considering pipe size
  - Heat losses
  - Pumping costs
- Parameters of the flow in transmission lines – hourly values
  - Pressure Gradient
  - Total Pressure Drop
  - Flow velocity
  - Volume flow rate

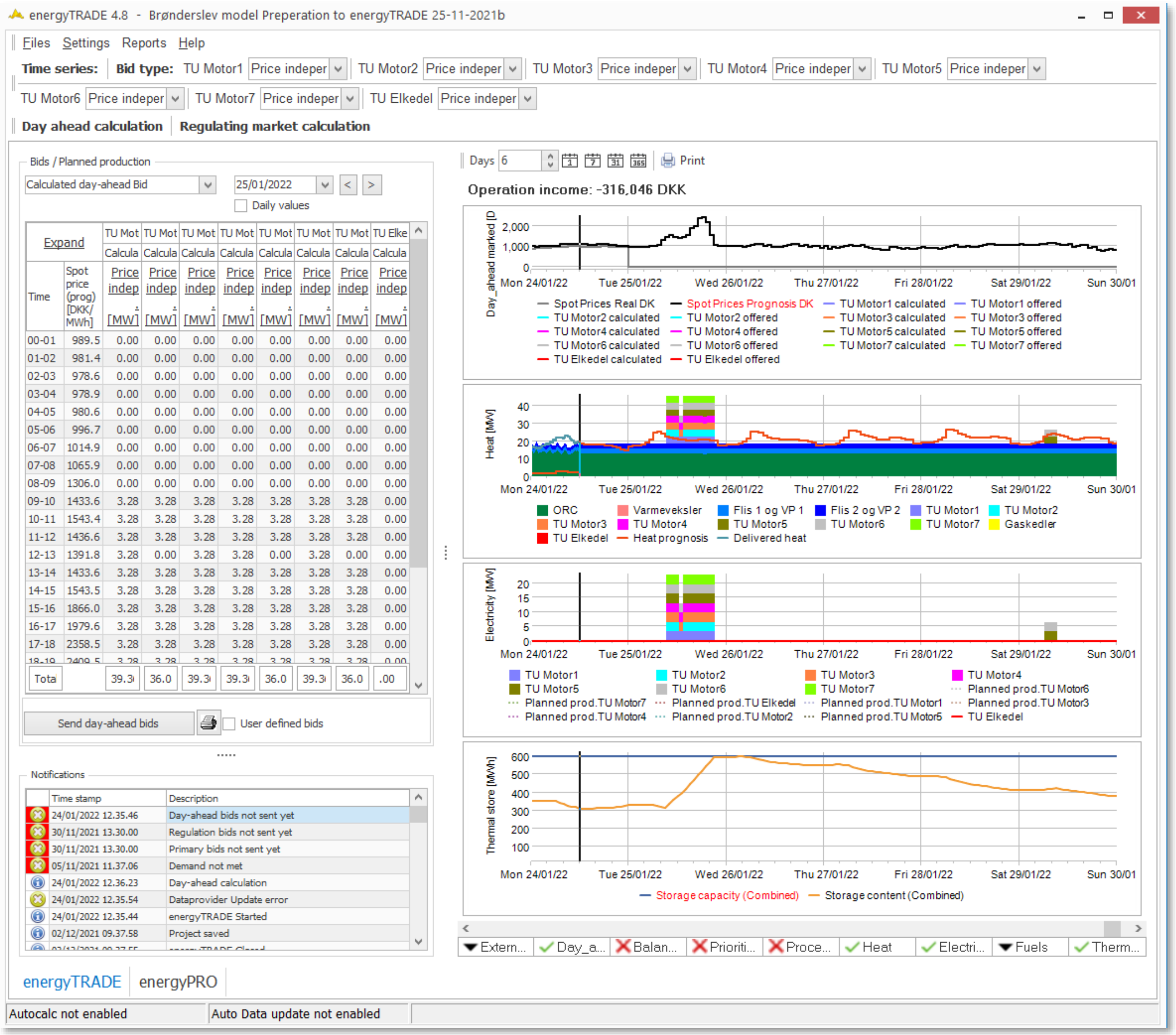


Communication with other tools

- ENFOR prognosis
  - Coming 7 days (Heat demand, Temperature, Irradiance and wind speed)
  - Delivered via FTP server
  - Dedicated data provider created in energyTRADE
- SCADA measurements
  - Production data
  - REST-API interface
  - Dedicated data provider created in energyTRADE
- Balance responsible parties
  - Energi Danmark: API
  - Danske Comodities: API

Development and installation of energyTRADE in Brønderslev

- ENFOR demand prognosis for all areas in Brønderslev
- SCADA measurements from Brønderslev system
- Connection with Energi Danmark
- Automatic update of daily gas prices – a very useful feature considering the highly variable gas prices
- CSP model included via Python script running in the background – new functionality in energyTRADE



Development and installation of energyTRADE in Hillerød

- Automatic update of daily gas prices – a very useful feature considering the highly variable gas prices
- Readings from the SCADA system for a new unit introduced to Hillerød system
- ENFOR prognosis fetched from ENFOR's FTP
- Connection with Hillerød's balance responsible party – Danske Commodities

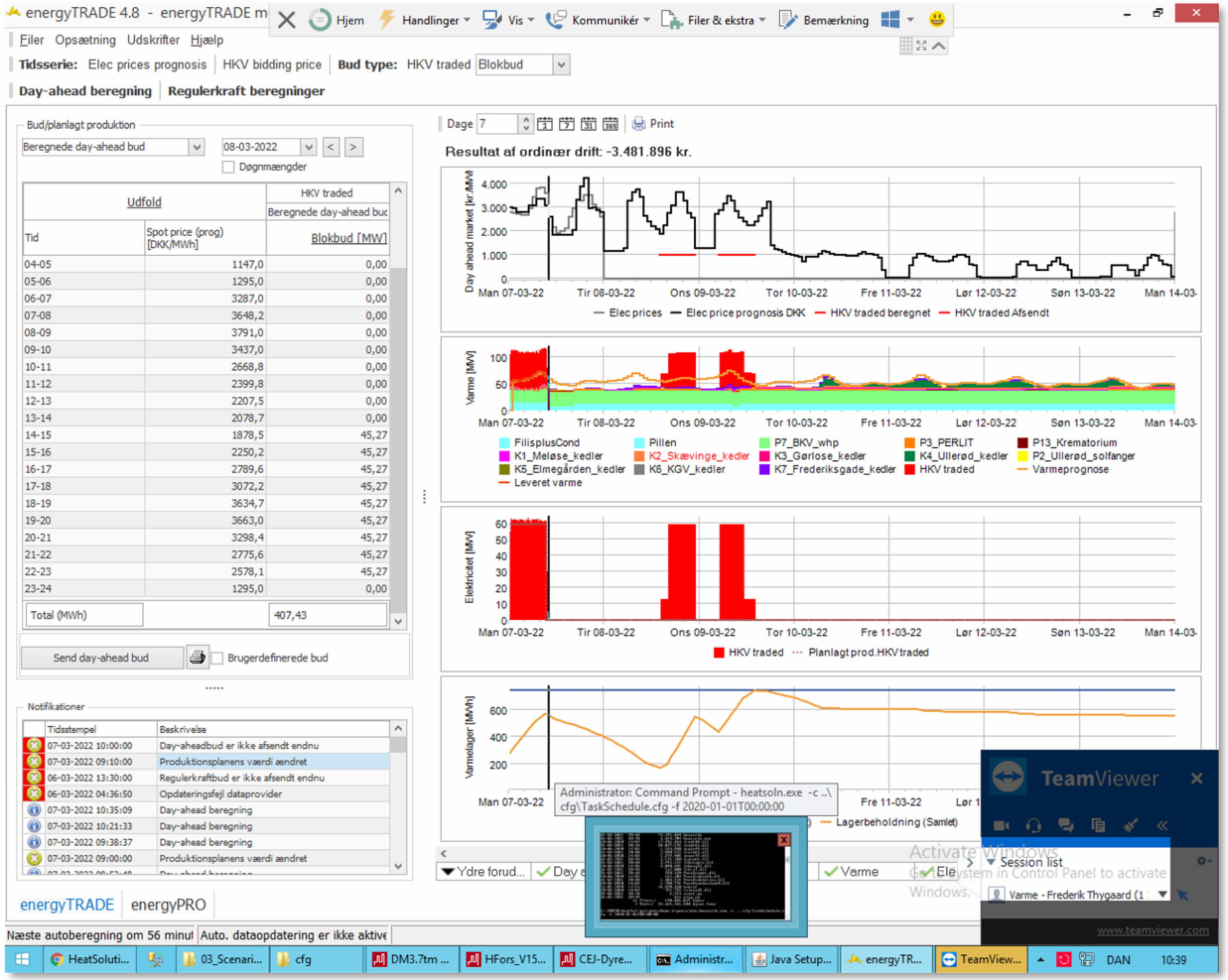
Lessons learned from Case 1 implementation in Hillerød

Testing period 7/03/2022 – 13/03/2022

- High variability in heat demand in the test week
  - During peak hours consumption was 80-90MW/h, when sun started shining, it went down to about 40MW/h.
- High variability of gas prices
  - The day ahead price was 216€/MWh, for it go down to 130€/MWh 2 days later.
- Adjustment of the model are needed to avoid short period of operation (3-4h) and changes in operation state during the night (start or stop).
- There is a high need to have the functionality of calculating regulating bids, especially with the highly variable prices in gas and electricity market. It is available in energyTRADE.
- Challenge to find an appropriate heat prognosis

Lessons learned from Case 1 implementation in Hillerød

- Improved energyTRADE, which EMD can offer to more customers
- The complex energyTRADE model enables to simulate the system in Hillerød
- Heat storage is used extensively in the system
    - This could suggest potential for implementation of Case 2a



Agenda

- Cross-optimization concept recap (EMD – Marta)
- The production component (EMD – Marta)
- **The network component (Enfor – Torben)**
- The building component (Neogrid/Leanheat cooperation - Pierre)
- Estimation of CSO (Case 2) value based on Brønderslev example (EMD - Marta)
- Feedback & discussion

Agenda

- Cross-optimization concept recap (EMD – Marta)
- The production component (EMD – Marta)
- The network component (Enfor – Torben)
- The building component (Neogrid/Leanheat cooperation - Pierre)
- **Estimation of CSO (Case 2) value based on Brønderslev example (EMD - Marta)**
- Feedback & discussion

Value in CSO – overview of the presentation

Simulation 1: Investigation of value in load shifting in a DH system

- Simulation 1a: Load shifting in a DH system
- Simulation 1b: Load shifting for peak shaving
- Simulation 1c: Load shifting without heat storage

Simulation 2: Estimation of yearly value in CSO

- Brønderslev example
- Brønderslev example without heat storage
- Brønderslev example with transmission constraint

Simulation 3: Temperature optimization value

Discussion: Value of CSO in markets other than Day-ahead market (future possibilities)

energyPRO

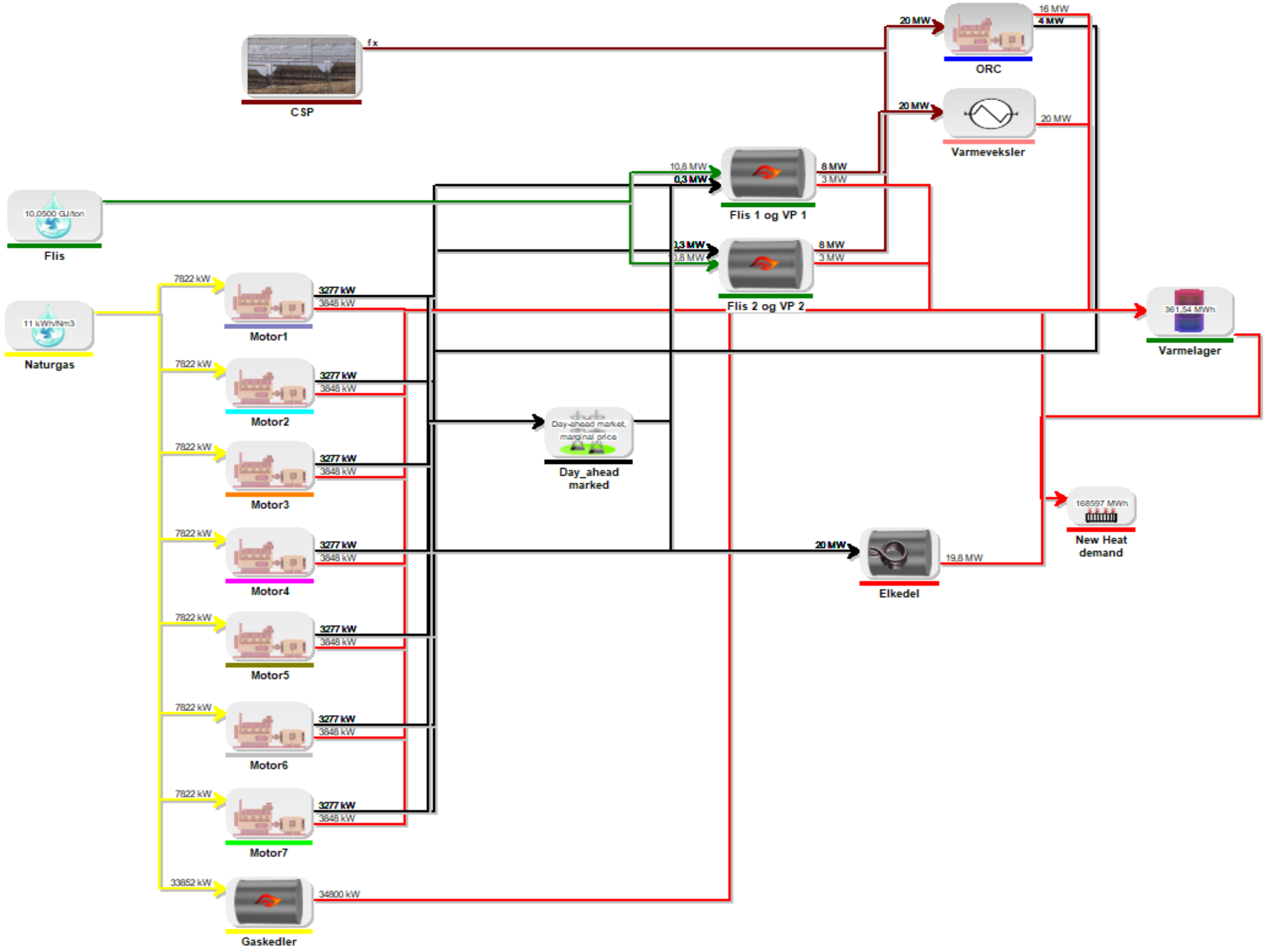
Investigation of value in load shifting in a DH system participating in the Day-ahead market

Estimation of savings in a **week of operation**

Simulation 1

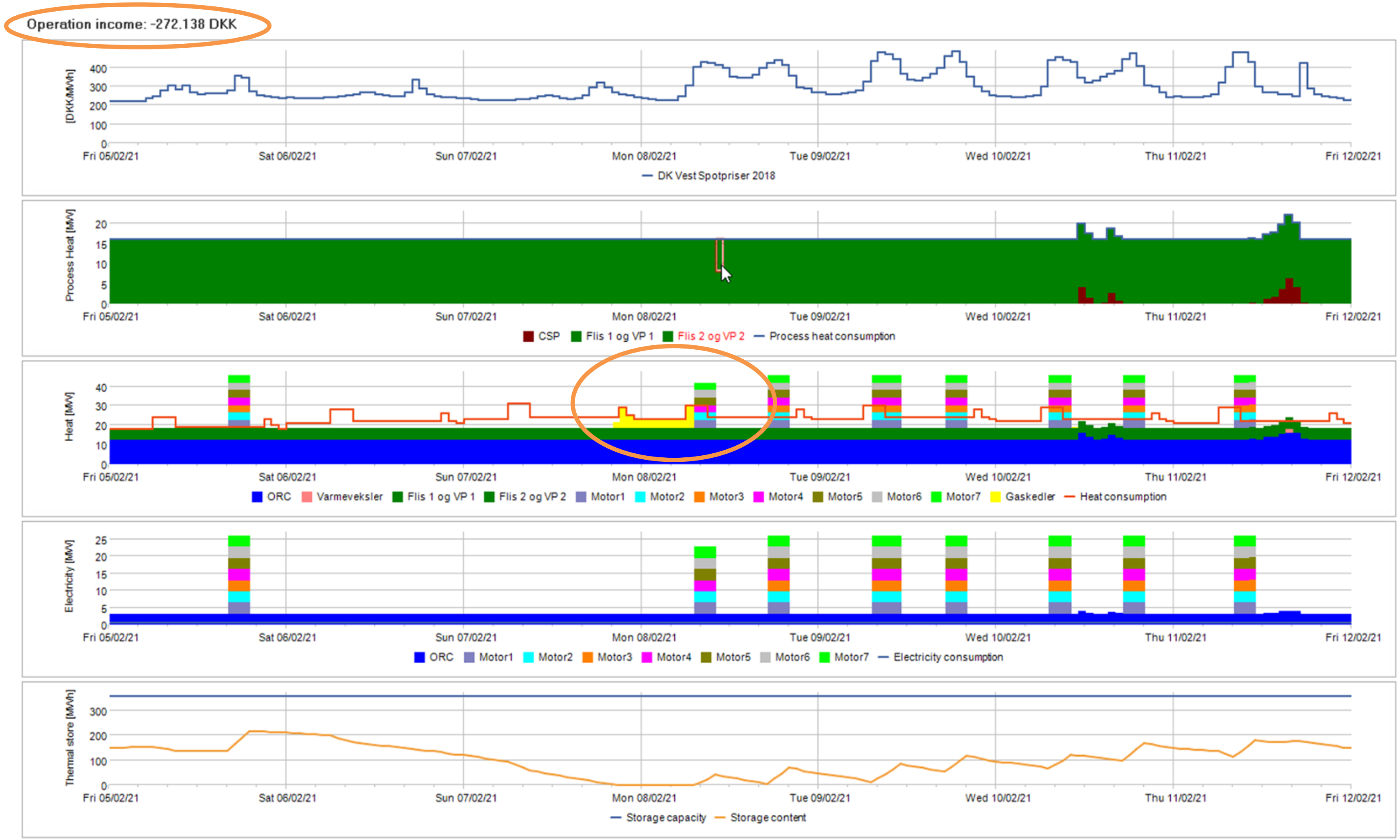
energyPRO

Initial setup of the considered plant



energyPRO

36.4 MWh load shifting forward (08/02/2021)

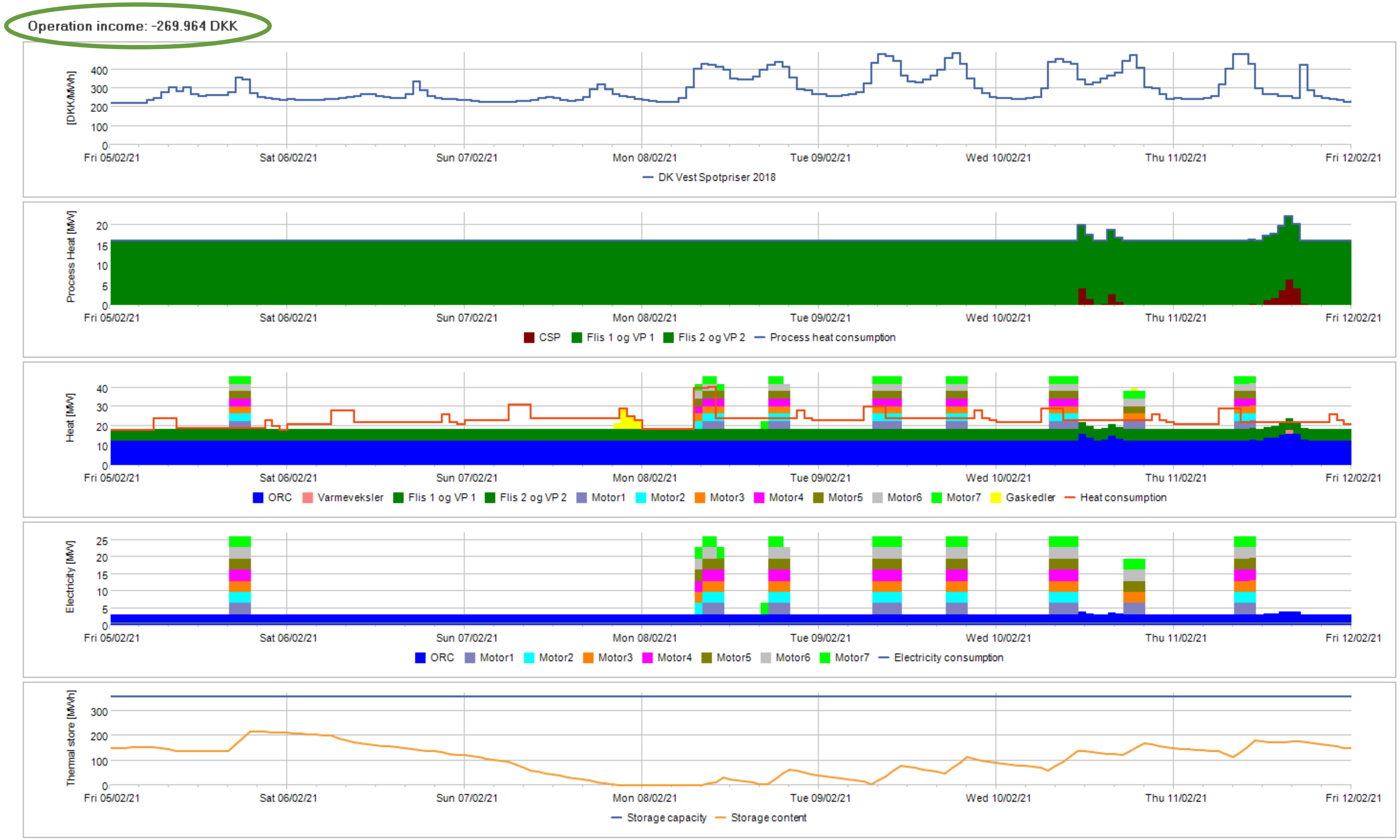


Initial operation income: -272,138 DKK

Simulation 1a

energyPRO

36.4 MWh load shifting forward (08/02/2021)



Initial operation income: -272,138 DKK

Operation income after shifting: -269,934 DKK

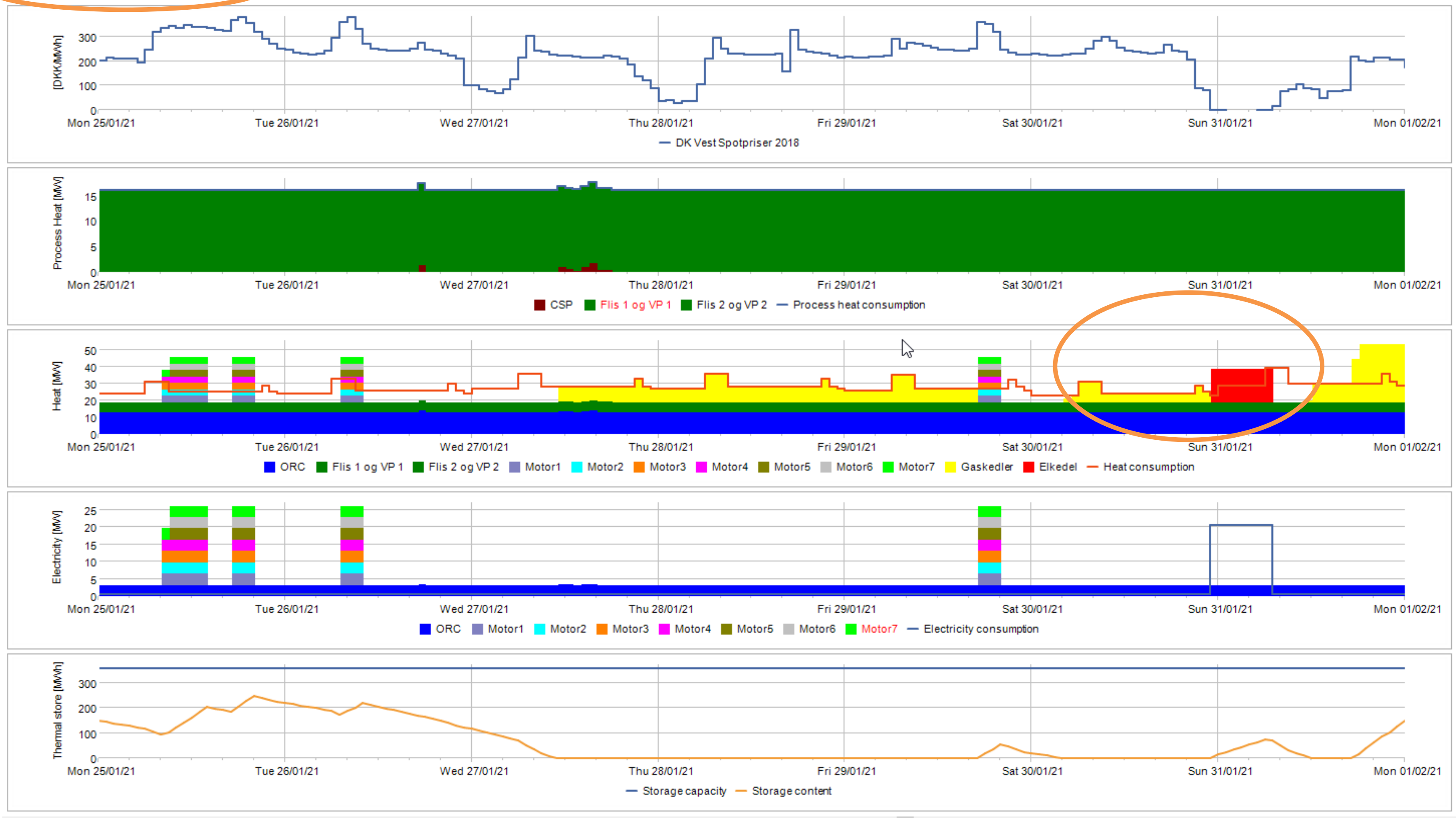
Savings: 2204 DKK
≈ 61 DKK/MWh shifted

Simulation 1a

energyPRO

70 MWh load shifting forward (30/01/2021)

Operation income: -691.047 DKK

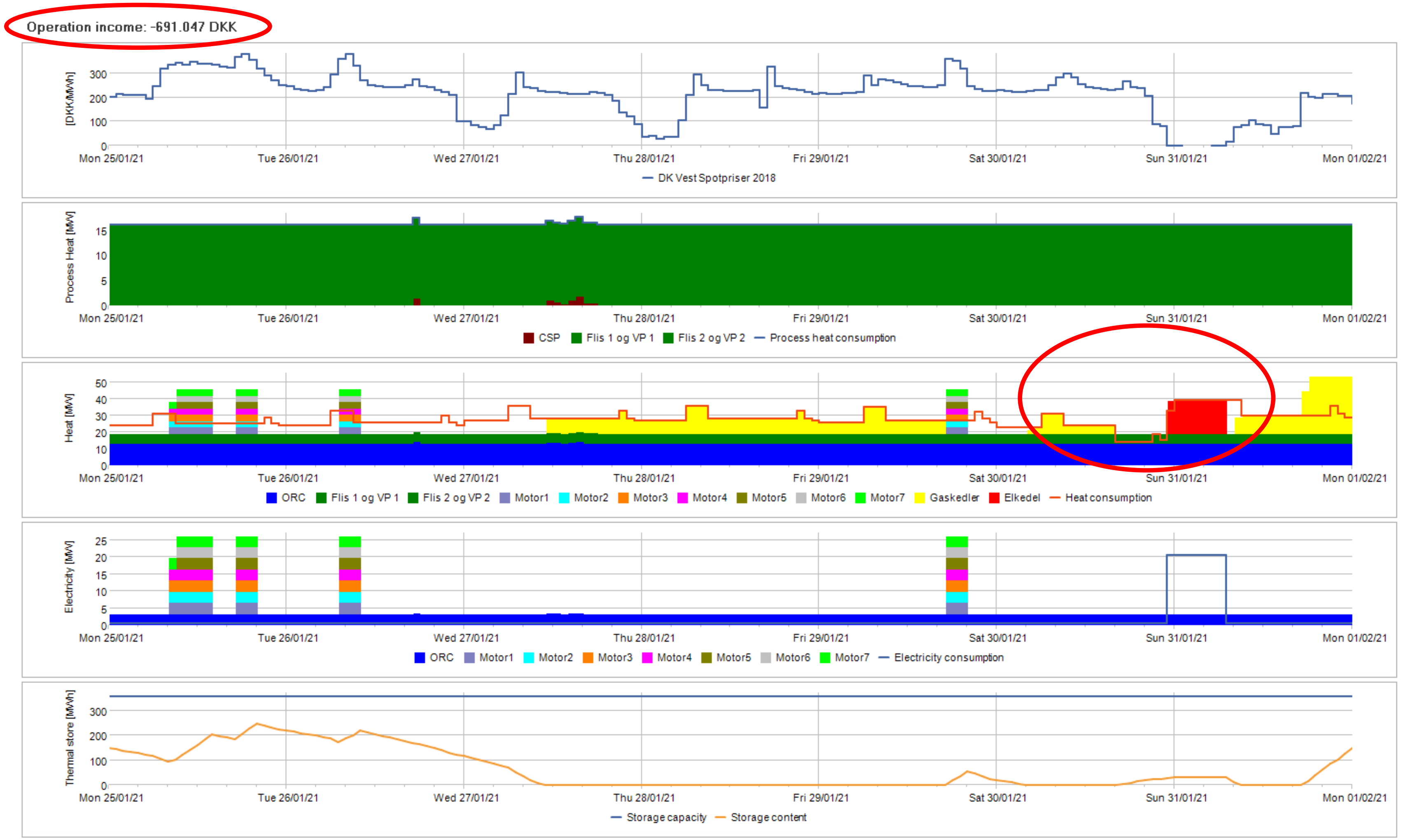


Initial operation income: -691,047 DKK

Simulation 1a

energyPRO

36.4 MWh load shifting forward (08/02/2021)



Initial operation income: -691,047 DKK

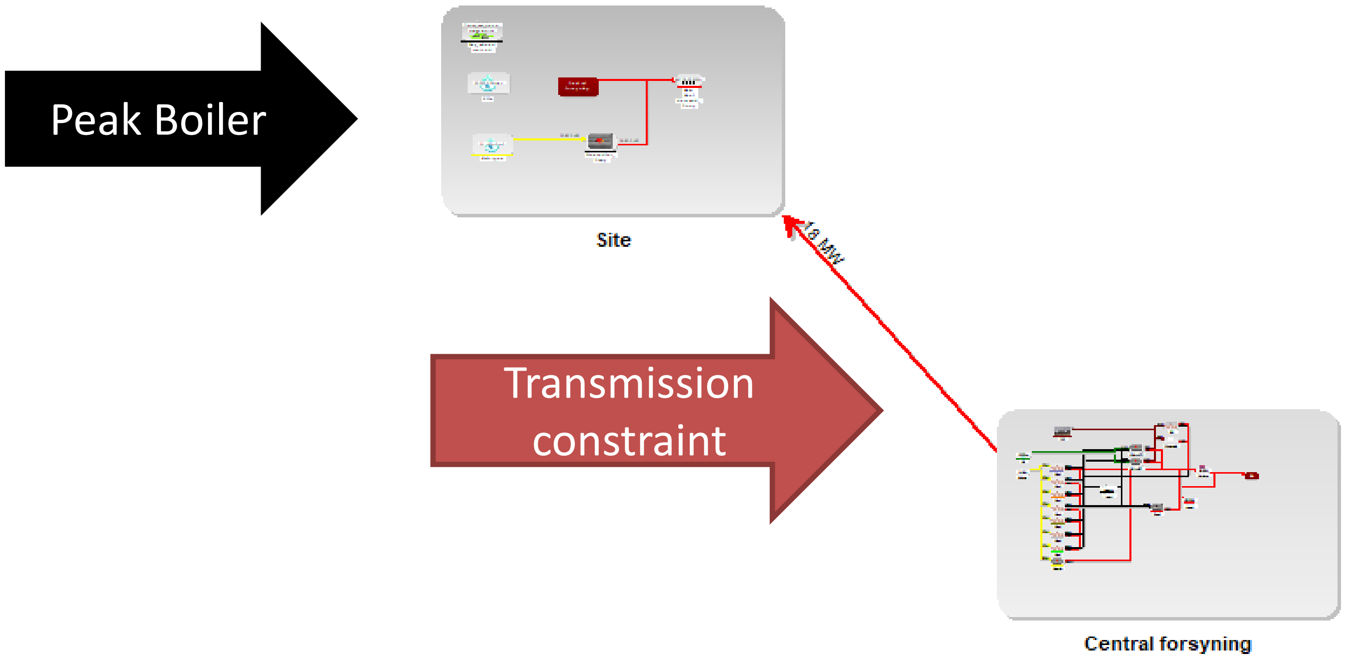
Operation income after shifting: -691,047 DKK

Savings: 0 DKK

Simulation 1a

energyPRO

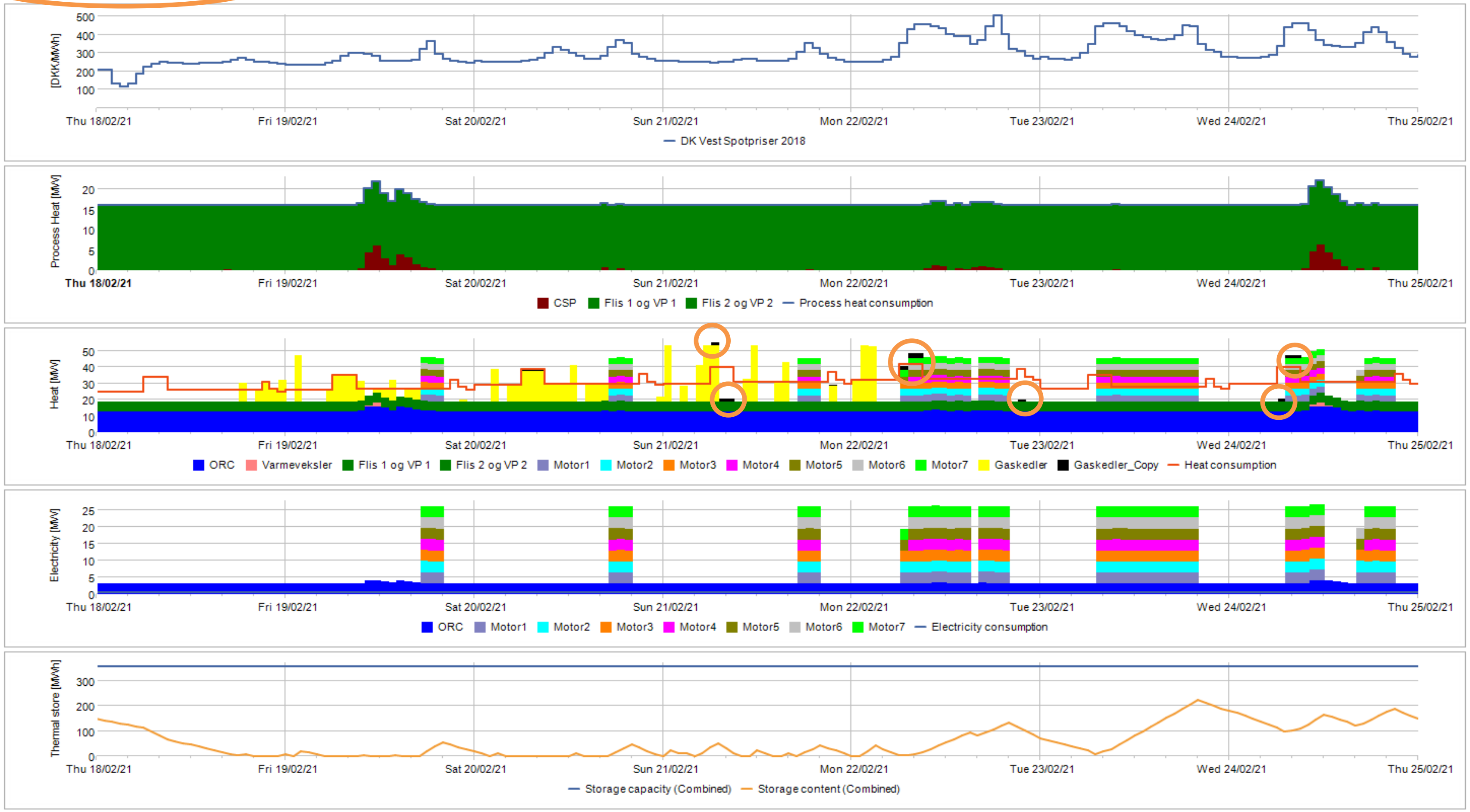
Transmission constraint introduced at the plant



Simulation 1b

27.5 MWh peak shaving

Operation income: -771.373 DKK

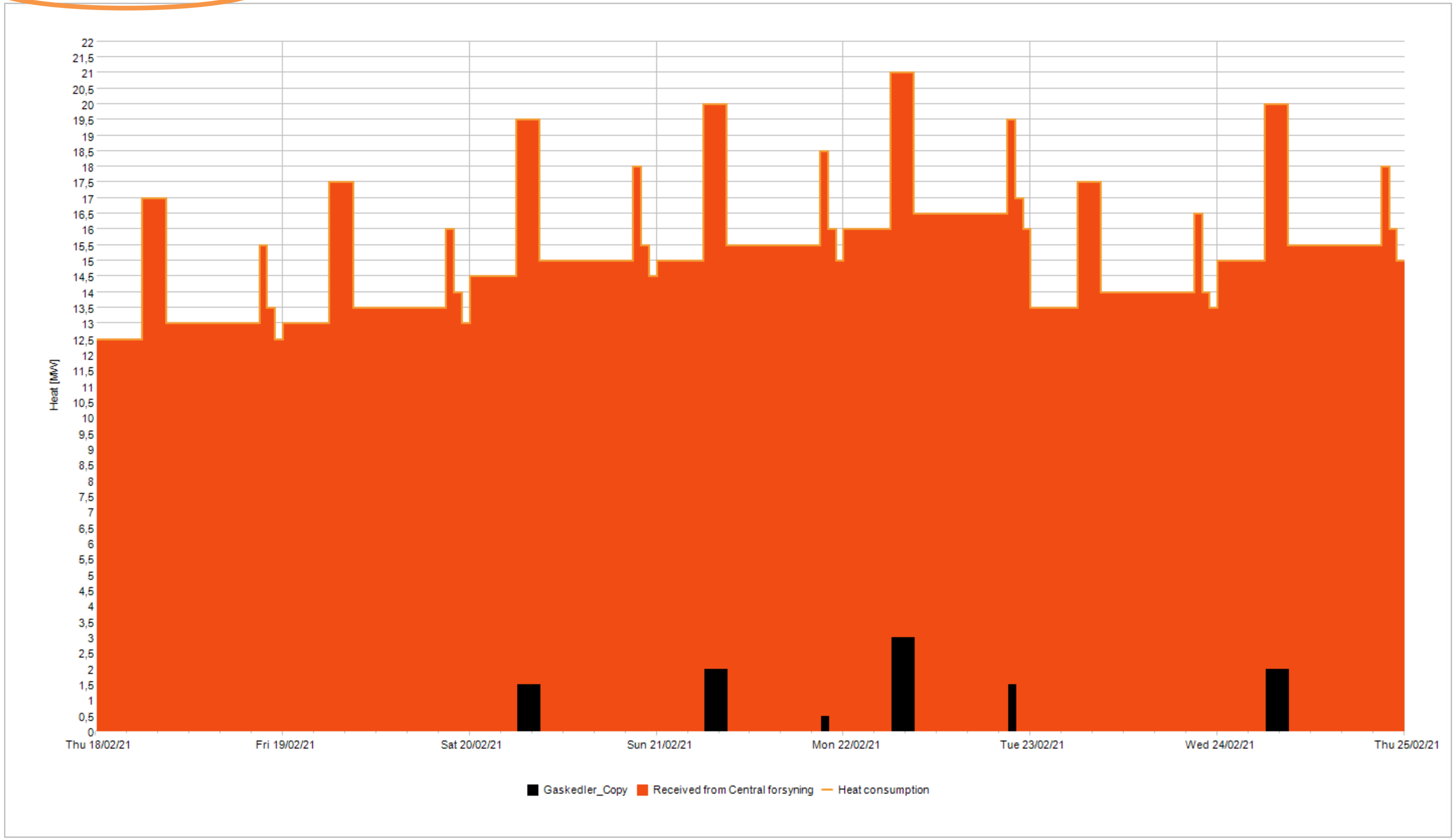


Initial operation income:
- 771,373DKK

Simulation 1b

27.5 MWh peak shaving

Operation income: -771.373 DKK

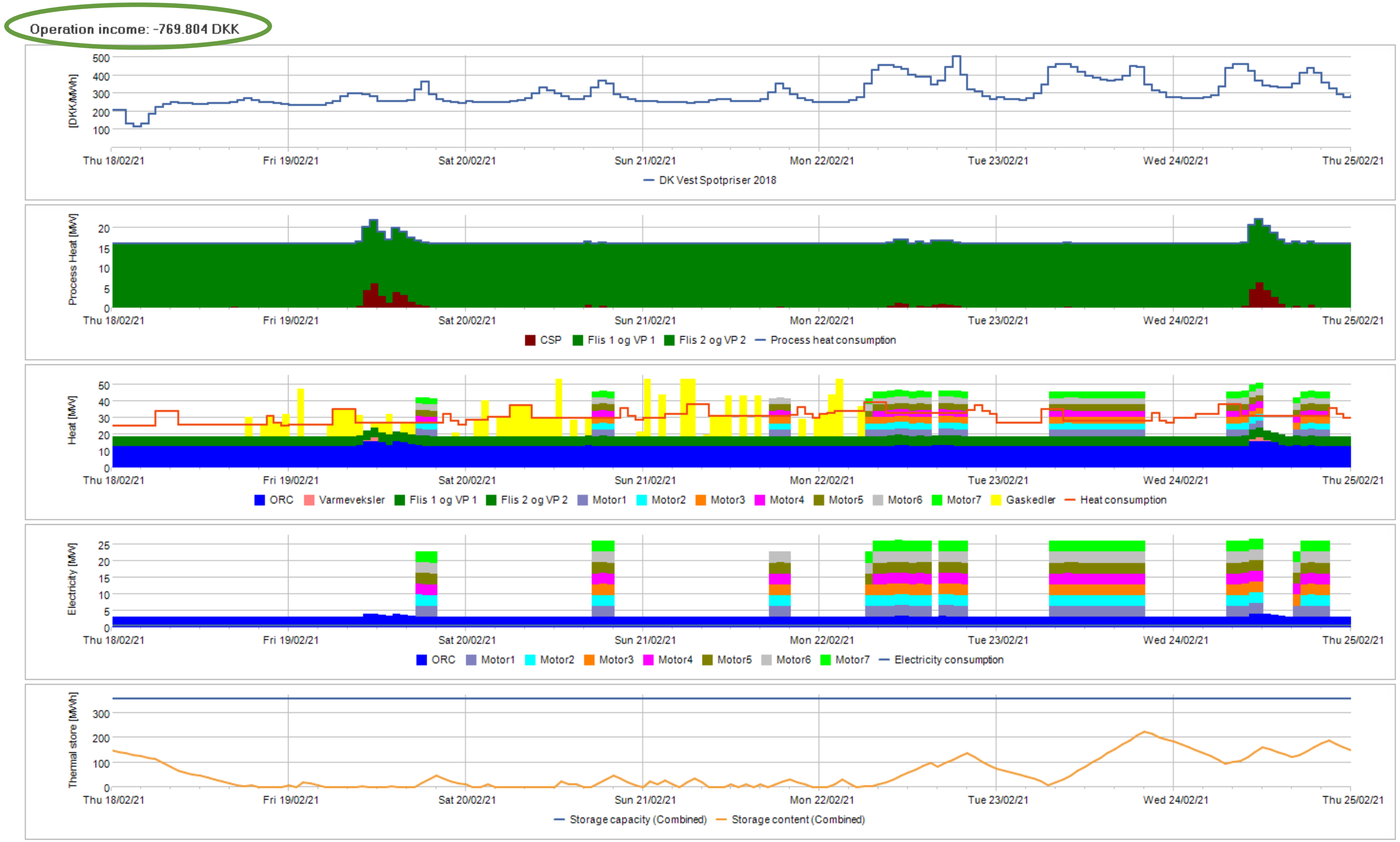


Initial operation income:
- 771,373DKK

Simulation 1b

energyPRO

27.5 MWh peak shaving



Initial operation income:
- 771,373DKK

Operation income after shifting: -769,804 DKK

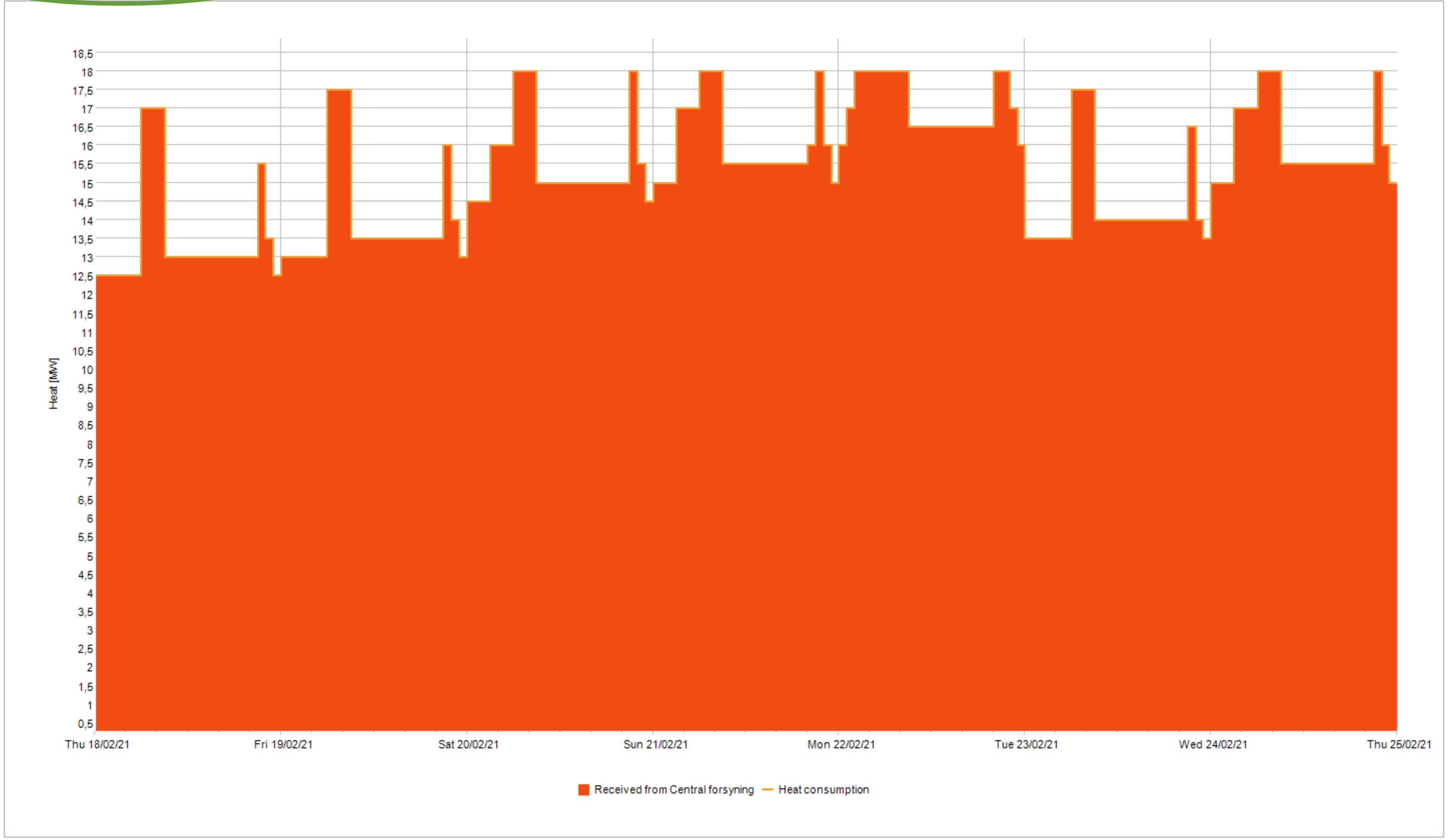
Savings: 1569 DKK
≈ 57 DKK/MWh shifted

Simulation 1b

energyPRO

27.5 MWh peak shaving

Operation income: -769.804 DKK



Initial operation income: - 771,373DKK

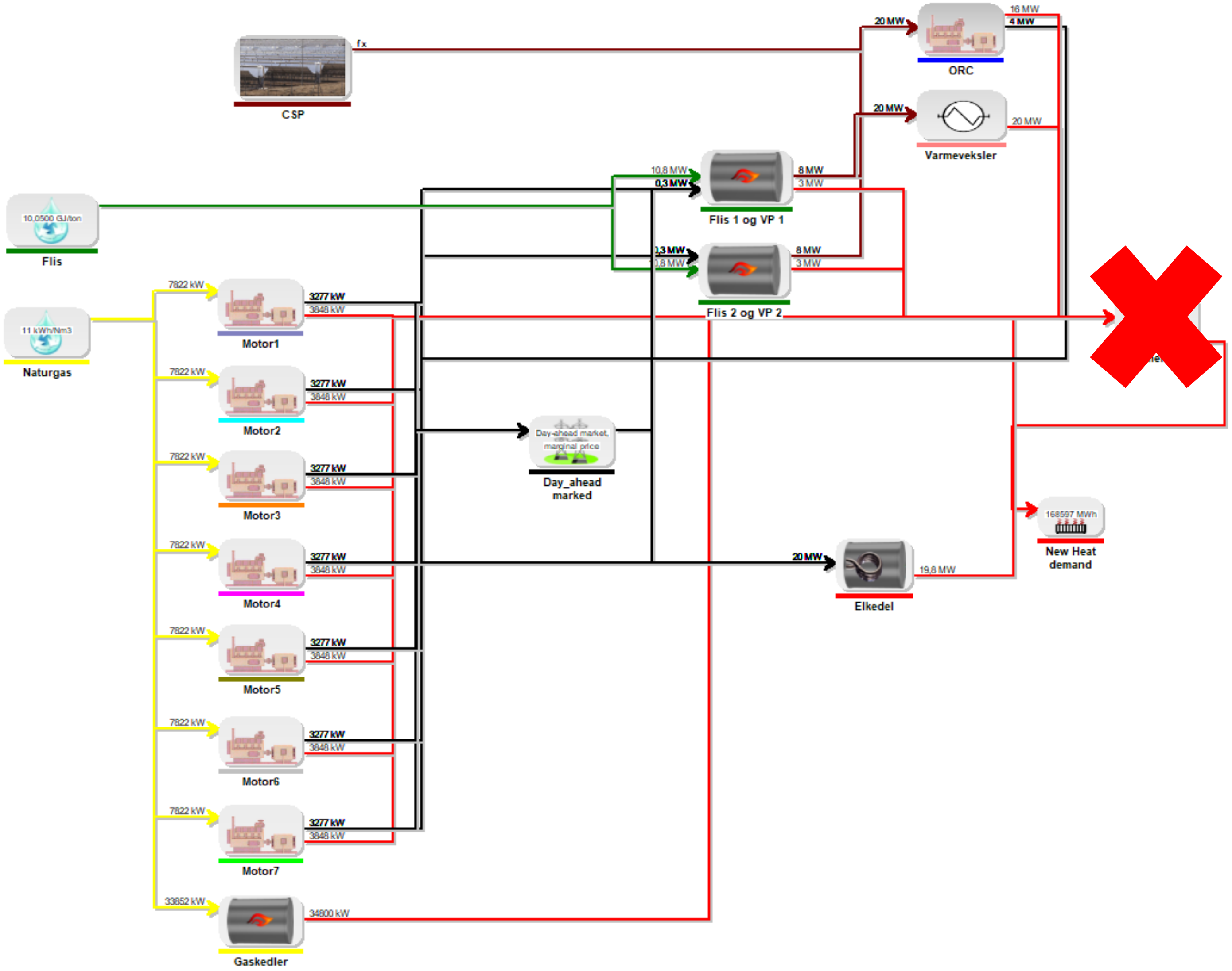
Operation income after shifting: -769,804 DKK

Savings: 1569 DKK
≈ 57 DKK/MWh shifted

Simulation 1b

energyPRO

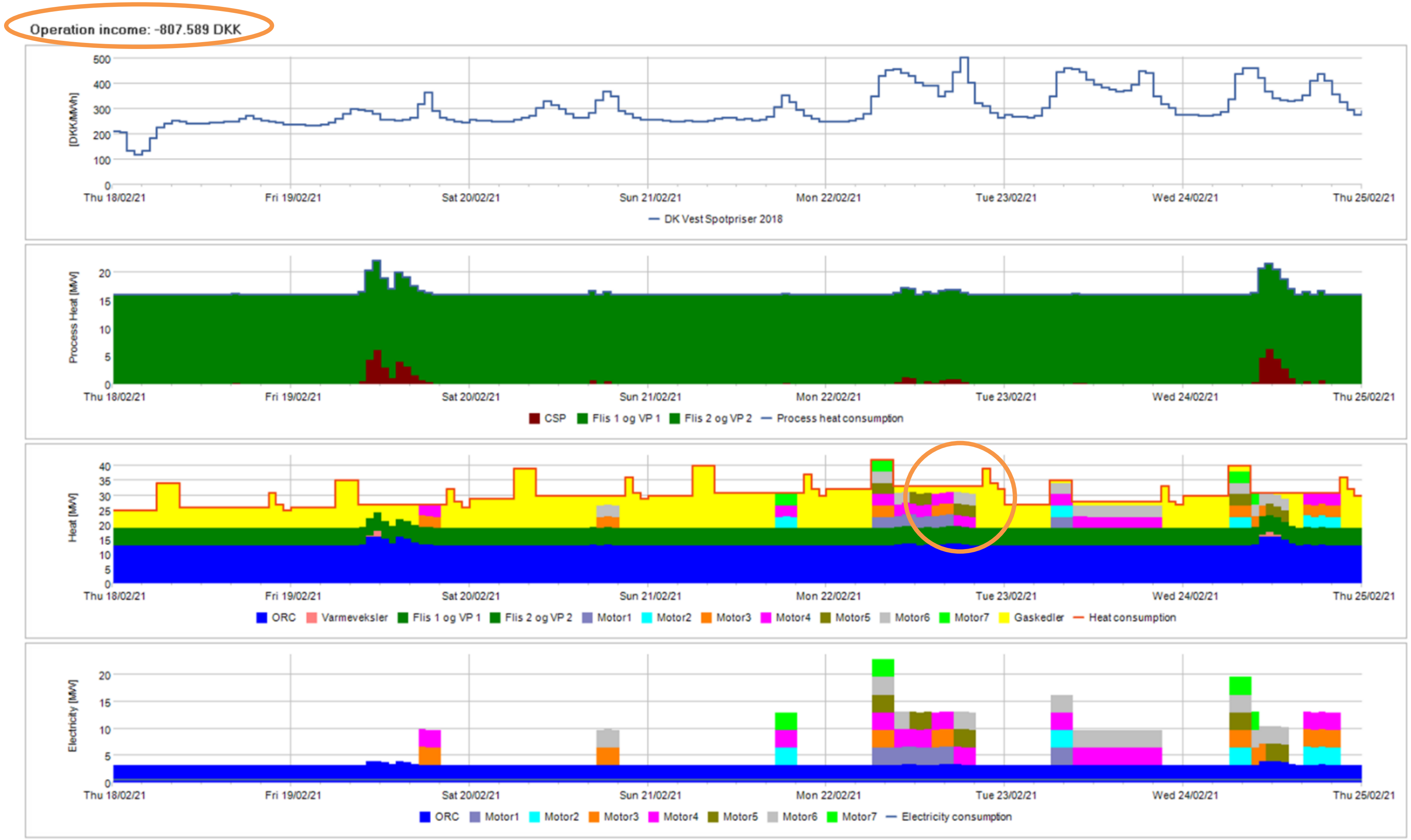
No heat storage at the plant



Simulation 1c

energyPRO

45 MWh load shifting without heat storage

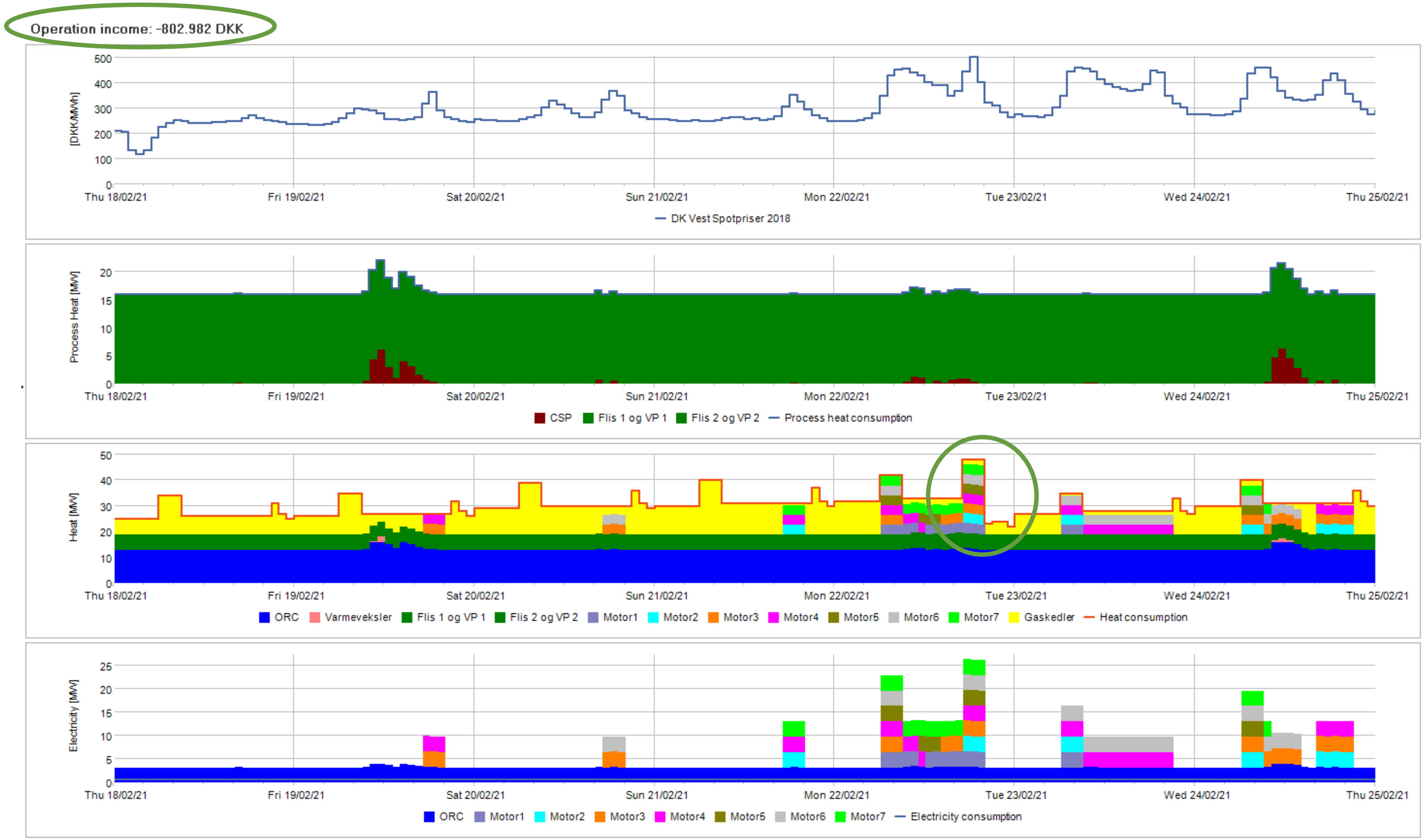


Initial operation income:
- 807,589 DKK

Simulation 1c

energyPRO

45 MWh load shifting without heat storage



Initial operation income: - 807,589 DKK

Operation income after shifting: -802,982 DKK

Savings: 4607 DKK
≈ 102 DKK/MWh shifted

Simulation 1c

energyPRO

Estimation of yearly value in CSO

Based on flexibility of buildings and network incorporated in energyPRO model

Simulation 2

energyPRO

Assumptions

Building flexibility

The flexibility depends on the ambient temperature

Buildings	Charging Power (P_flex)	Max Storage Content
Eventyrvej	0.37+0.065*max((15.8-T_amb),0)	3*P_flex
Skolegade	0.48+0.13*max((15.1-T_amb),0)	3*P_flex
Jyllandsgade	0.49+0.10*max((15.3-T_amb),0)	3*P_flex

Network Flexibility

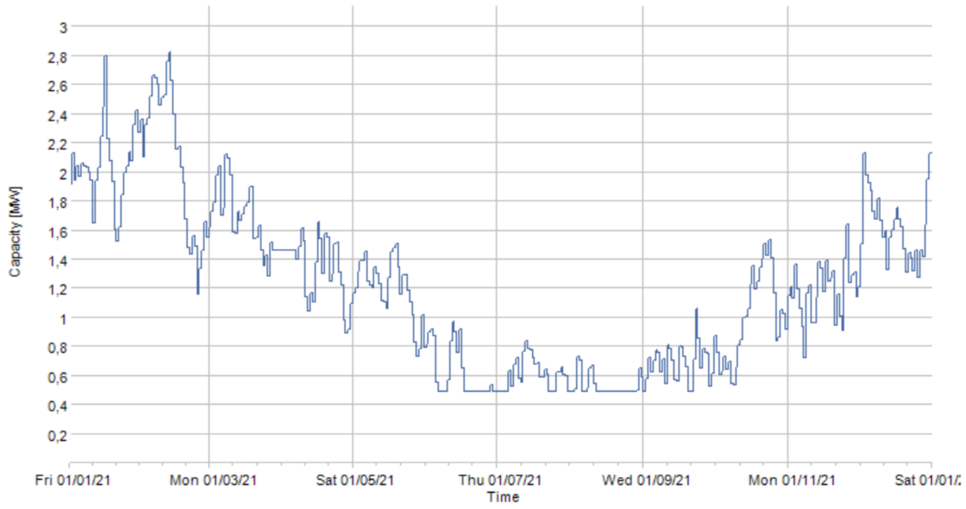
The flexibility depends on the ΔT which can be added on the water temperature. For start ΔT=2

Network	Charging Power (P_flex)	Max Storage Content
Eventyrvej	Time Series*ΔT	0.228*ΔT
Skolegade	Time Series*ΔT	0.587*ΔT
Jyllandsgade	Time Series*ΔT	0.532*ΔT

Assumptions

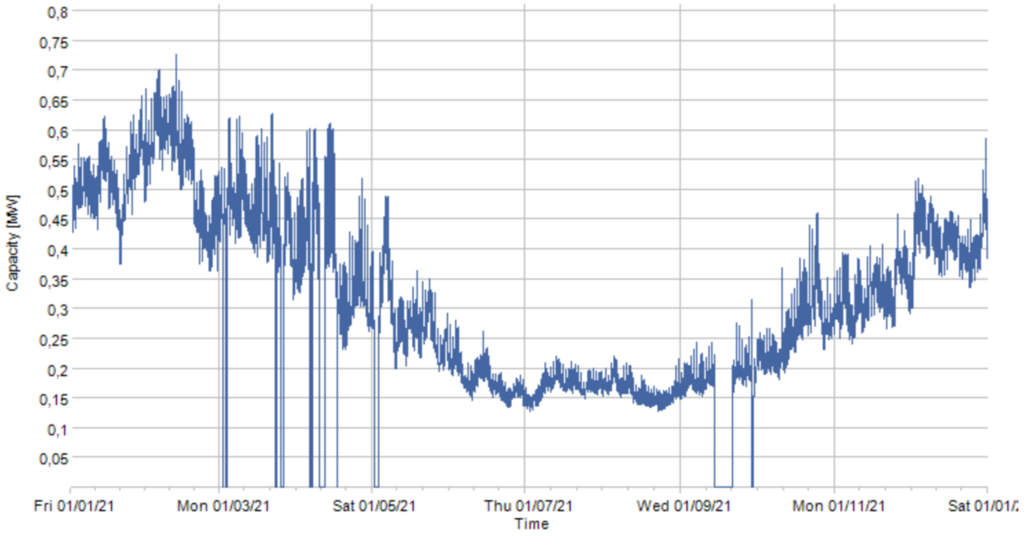
Building flexibility

The flexibility depends on the ambient temperature

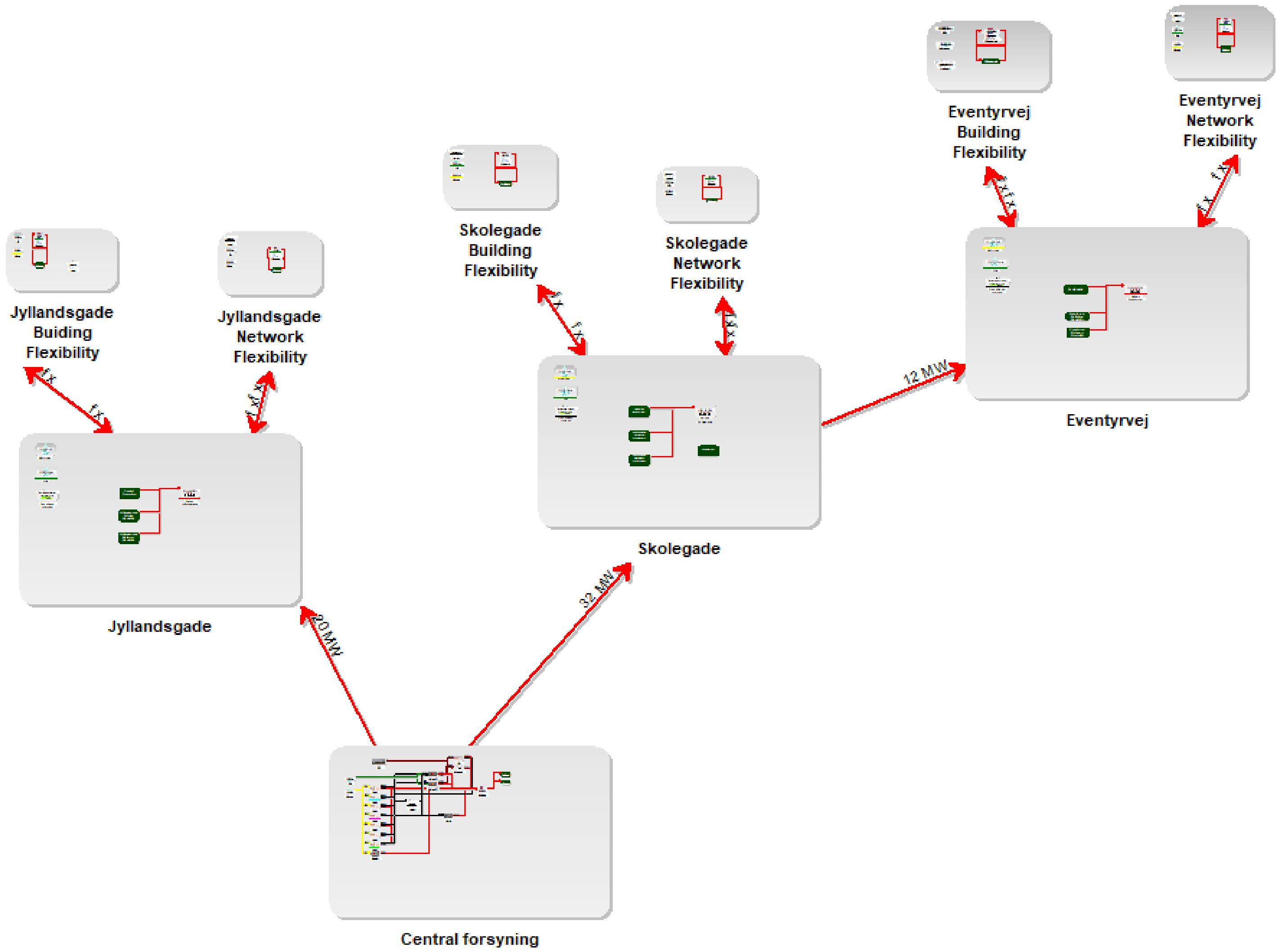


Network Flexibility

The flexibility depends on the ΔT which can be added on the water temperature. For start ΔT=2



energyPRO model



Simulation 2

Results in Brønderslev

	Without flexibility	With buildings flexibility	With network flexibility	With both flexibilities
Net heat production cost [DKK]	1.116.717	1.112.892	1.114.849	1.112.197
Savings [DKK]	0	3.825	1.868	4.520
Savings [DKK/MWh]	0	17.4	28.1	15.7

Flexibility used when Building Flexibility included [MWh]	
Buildings Eventyrvej	57.3
Buildings Jyllandsgade	78.1
Buildings Skolegade	83.9
Network Eventyrvej	0
Network Jyllandsgade	0
Network Skolegade	0
Sum	**219.3**

Flexibility used when Network Flexibility included [MWh]	
Buildings Eventyrvej	0
Buildings Jyllandsgade	0
Buildings Skolegade	0
Network Eventyrvej	11.4
Network Jyllandsgade	29.3
Network Skolegade	25.8
Sum	**66.5**

Flexibility used when Both Flexibility included [MWh]	
Buildings Eventyrvej	56.5
Buildings Jyllandsgade	74.6
Buildings Skolegade	83.4
Network Eventyrvej	13.2
Network Jyllandsgade	31.9
Network Skolegade	28.9
Sum	**288,5**

Simulation 2a

energyPRO

Results if no heat storage in Brønderslev

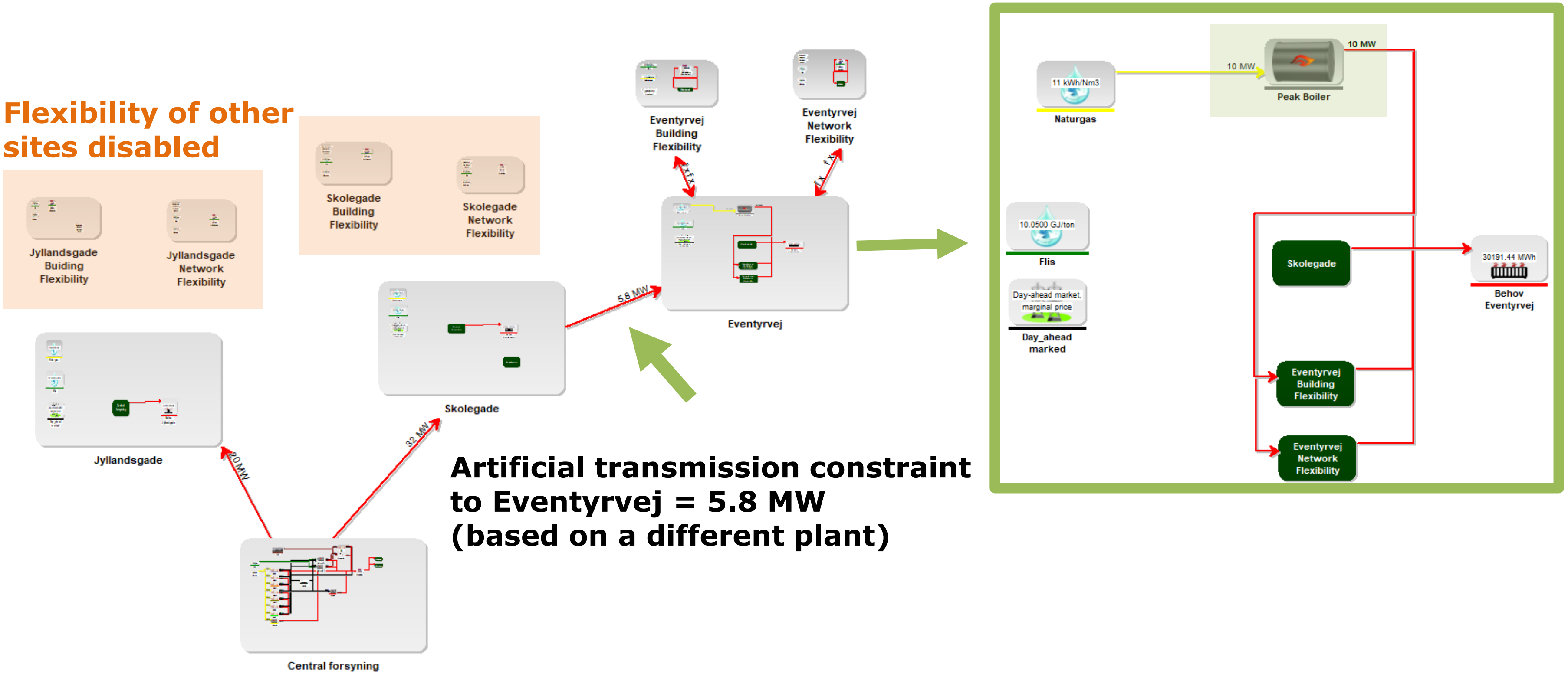
	Without flexibility	With network flexibility
Net heat production cost [DKK]	8.486.461	7.711.394
Savings [DKK]	0	775.067
Savings [DKK/MWh]	0	444.3

Flexibility used when Network Flexibility included [MWh]	
Buildings Eventyrvej	0
Buildings Jyllandsgade	0
Buildings Skolegade	0
Network Eventyrvej	364,8
Network Jyllandsgade	703,3
Network Skolegade	676,5
Sum	**1744,6**

Simulation 2b

energyPRO

energyPRO model – with transmission constraint



energyPRO

Results in Brønderslev

Comparison of operation incomes in the period: 01/04/2020 - 01/04/2021		
Net heat production cost without flexibility	1,240,789	DKK
Net heat production cost with flexibility of buildings and network	1,231,150	DKK
Savings - both flexibilities	9,639	DKK
Savings - both flexibilities	55.5	DKK/ MWh

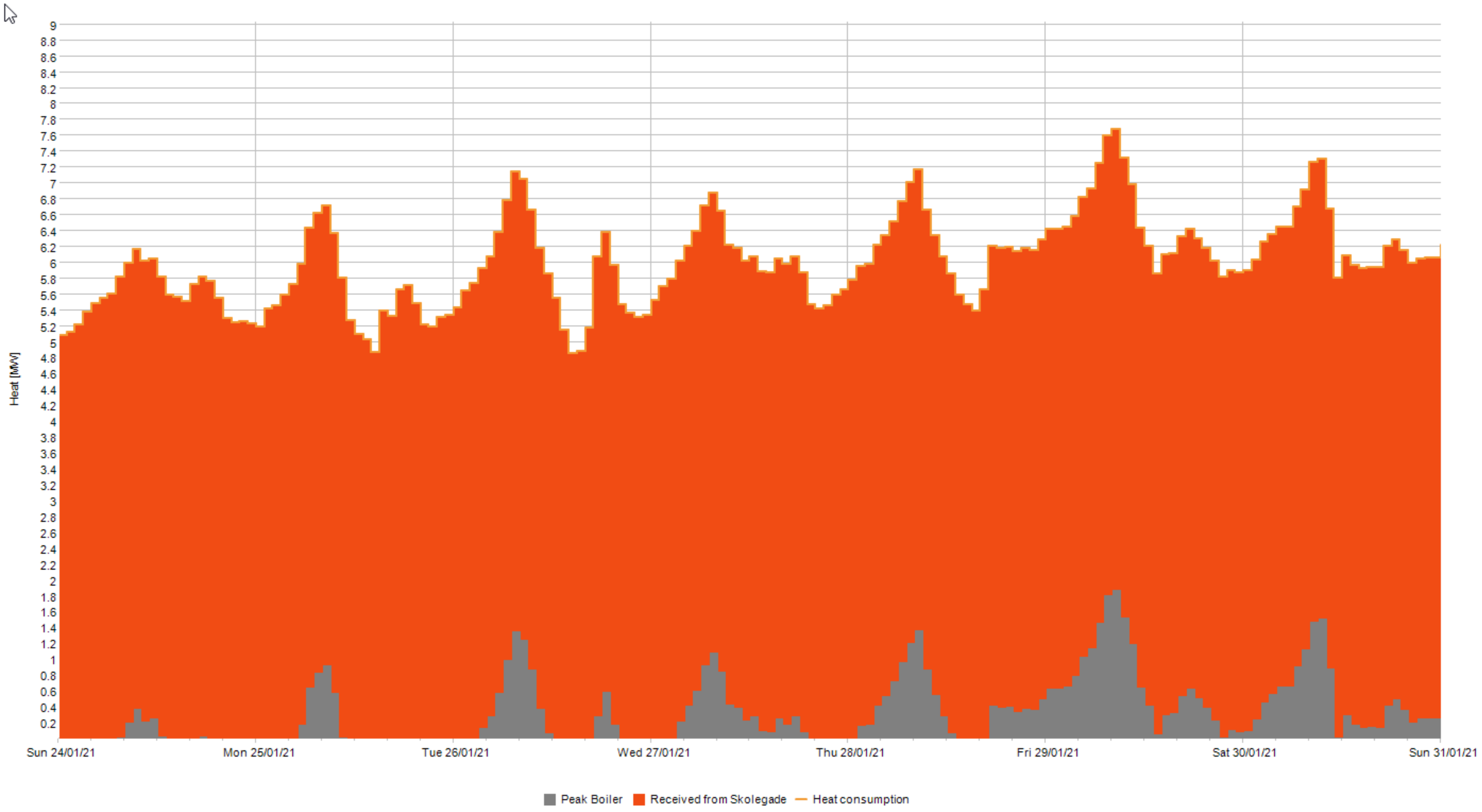
CO2 emissions in the period: 01/04/2020 - 01/04/2021		
Without flexibility	70,175	tonne
With flexibility	70,296	tonne
Decrease	-121	tonne
Decrease [%]	-0.17%	-

Flexibility used when Both Flexibility included [MWh]	
Buildings Eventyrvej	142.2
Buildings Jyllandsgade	0
Buildings Skolegade	0
Network Eventyrvej	31.4
Network Jyllandsgade	0
Network Skolegade	0
Sum	**173.6**

Simulation 2c

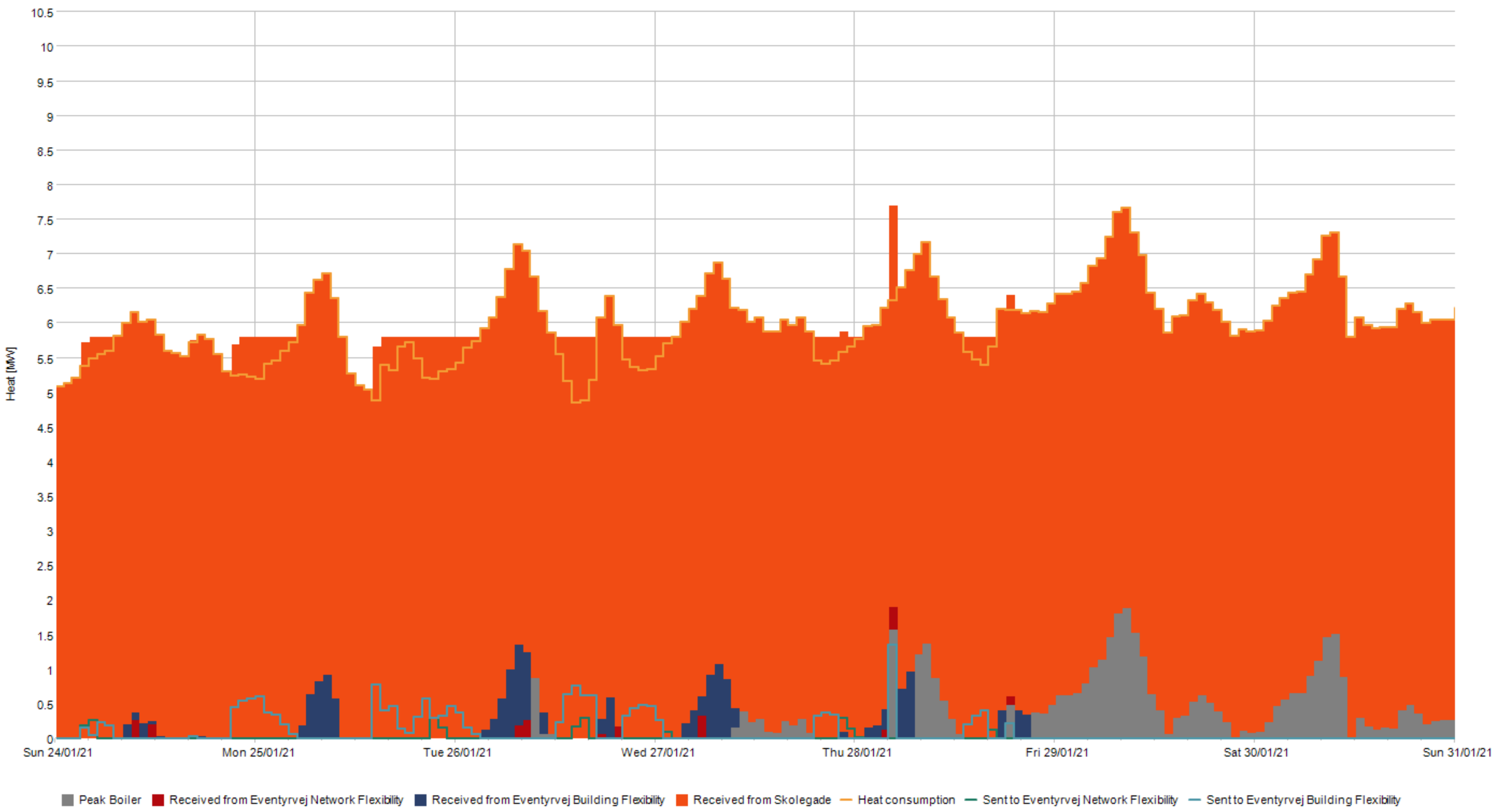
energyPRO

Eventyrvej heat demand supply – no flexibility



Simulation 2c

Eventyrvej heat demand supply – with flexibility



Simulation 2c

Value of Temperature optimization in Brønderslev

Initial estimations for a **year of operation**

Simulation 3

energyPRO

Assumptions

- Representative supply temperatures for a year of operation
- Representative return temperatures for a year of operation

- Reduction in supply and return temperature: max. 5°C
  (limits: 60°C supply and 30°C return)

Efficiency gain

Efficiency gain of the Wood Chip Boilers due to lower condensation temperature.

First estimation based on previous project: **1%/5°C**

Heat loss reduction

Reduction of heat loss in the network.

Assumptions – Heat Loss Reduction

Heat loss represents 20% of total demand

Heat loss calculation:

- Original heat loss

$$HL_1 = U \cdot (T_S - T_G) + U \cdot (T_R - T_G)$$

- Reduced heat loss

$$HL_2 = U \cdot (T_S - 5 - T_G) + U \cdot (T_R - 5 - T_G)$$

- Heat loss reduction (considering temperature assumptions)

$$\frac{HL_1}{HL_2} = \frac{T_S + T_R - 2T_G}{T_S + T_R - 2T_G - 10}$$

Savings from temperature reduction in the network

	Reference	With HL reduction	With efficiency increase	With HL reduction and efficiency increase
Net heat production cost [DKK]	1,139,628	886,548	840,451	591,592
Savings [DKK]	0	**253,080**	**299,177**	**548,036**

Value of CSO in markets other than Day-ahead market

Danish electricity markets
(which are to be implemented in the rest of EU)

Marked	Gate closure	Organisering	Prisafregning
Frekvensregulering Frequency containment reserves (FCR)	8.00 the day before	Minimum 1 MW symmetric up/down Divided into four-hour blocks Bloc 1: Kl. 00.00 - 04.00 Bloc 2: Kl. 04.00 - 08.00 Bloc 3: Kl. 08.00 - 12.00 Bloc 4: Kl. 12.00 - 16.00 Bloc 5: Kl. 16.00 - 20.00 Bloc 6: Kl. 20.00 - 24.00	Marginal price
Rådighed i regulerkraftmarkedet manual Frequency Restoration Reserves (mFRR)	9.00 the day before	Bids for each of the 24 hours tomorrow. Asymmetric bids.	Marginal price
Spotmarkedet Day ahead wholesale market	12.00 the day before	Bids for each of the 24 hours tomorrow. Asymmetric bids. Price independent, price dependent or bloc bids.	Marginal price
Aktivering i regulerkraftmarkedet Replacement Reserves (RR)	45 minutes before the operating hour	Bid for the next hour. Asymmetric bids.	Marginal price
Aktivering i specialregulering	45 minutes before the operating hour	Bid for the next hour. Asymmetric bids.	PayAsBid
Elbas Intraday wholesale market (ID)	45 minutes before the operating hour	Bid for the next hour. Asymmetric bids.	PayAsBid

energyPRO

Steps in the scenario building for CSO in Brønderslev

Starting point:

- The won sale in the Day Ahead market will fill the thermal storage in Brønderslev in this hour and Intra Day sale is thus not possible in this hour.
- Downward regulation will be offered in the Regulating Power market (RR) in the hours before to make room in the storage, making Intra Day sale possible in this hour.

However, Cross System Optimization offers another opportunity for Intra Day sale in this hour:

- A request is sent from the plant tool to the building tool asking for advancing the heat demands to be made in hours before.
- If this is possible, the building tool will send a new prognosis to the grid tool, which will create demand prognosis (amounts and temperatures) to be send to the plant tool.
- The plant tool will calculate how much sale is thus possible in this hour and calculate the marginal price for this sale, and the information will be send to the Balancing Responsible Party, that can start trading this hour in Intra Day market.

energyPRO

Overall summary

- Improvements introduced in all tools
- Potential of the tools increased
- Case 1 tested in Hillerød
- Case 2a and 2b simulated with inputs from all the partners
  - Potential gains quantified
  - High potential gain in systems where thermal storage is not present

Feedback and discussion

Marta Murkowska
R&D Engineer
E-mail: mim@emd.dk
Direct Phone: +45 6916 4870