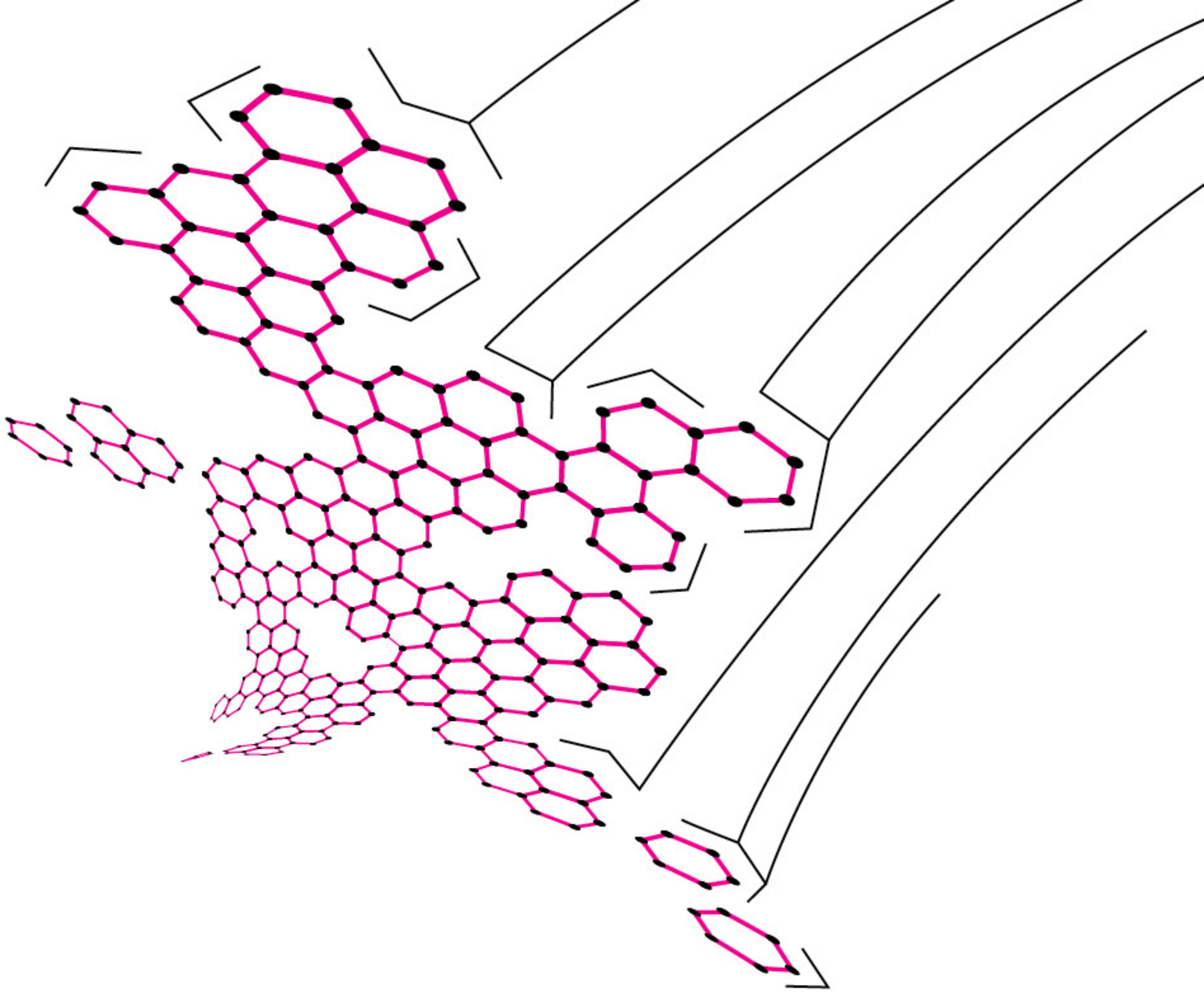
# Operational optimization and bidding for district heating systems



Twente Energy Seminar, University of Twente
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# Focus today:
# **Operational optimization and bidding for district heating systems**

Guericke, D., Schledorn, A., & Madsen, H. (2022). A generic stochastic network flow formulation for production optimization of district heating systems. arXiv preprint arXiv:2211.00934.

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# Decarbonisation of the energy sector

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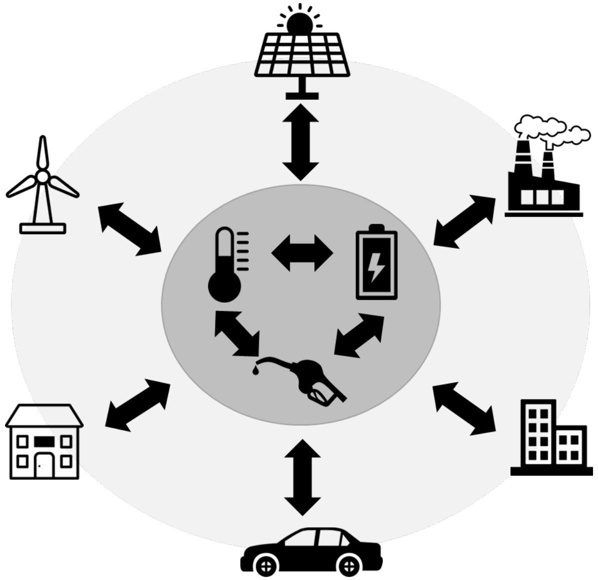
"Demand, generation and location must always be matched, but this becomes difficult when we are integrating more variable and decentral renewables into the grid. Therefore, **flexibility in time and location can be of great value.**" Source: TenneT, https://www.tennet.eu/overview-electricity-market

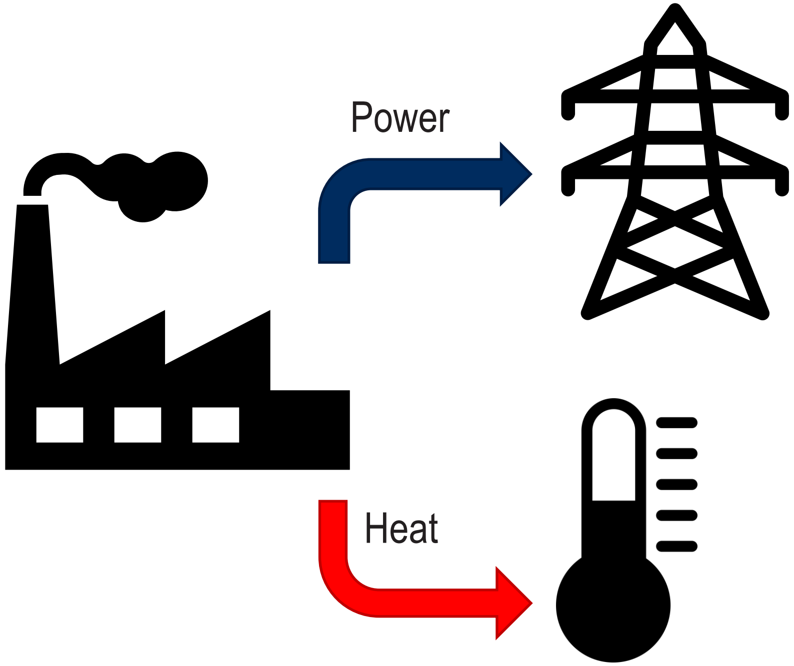
**Integrated energy systems** provide flexibility



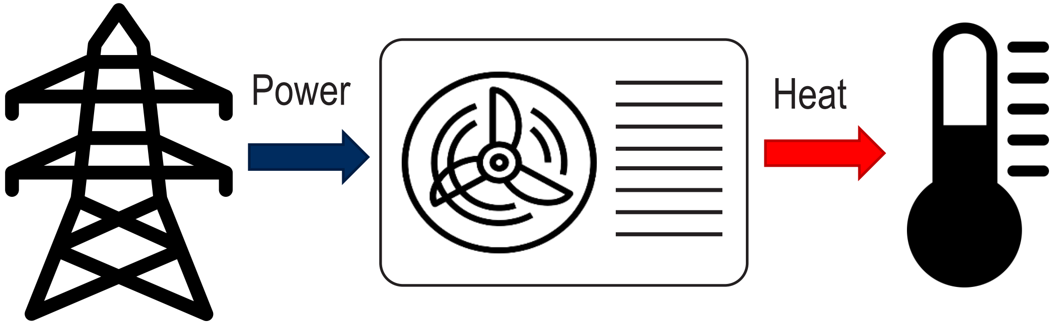
# Integration of power and heat



Combined heat-and-power (CHP) plants




Power-to-heat




Both technologies are used in large-scale in district heating systems.

# District heating

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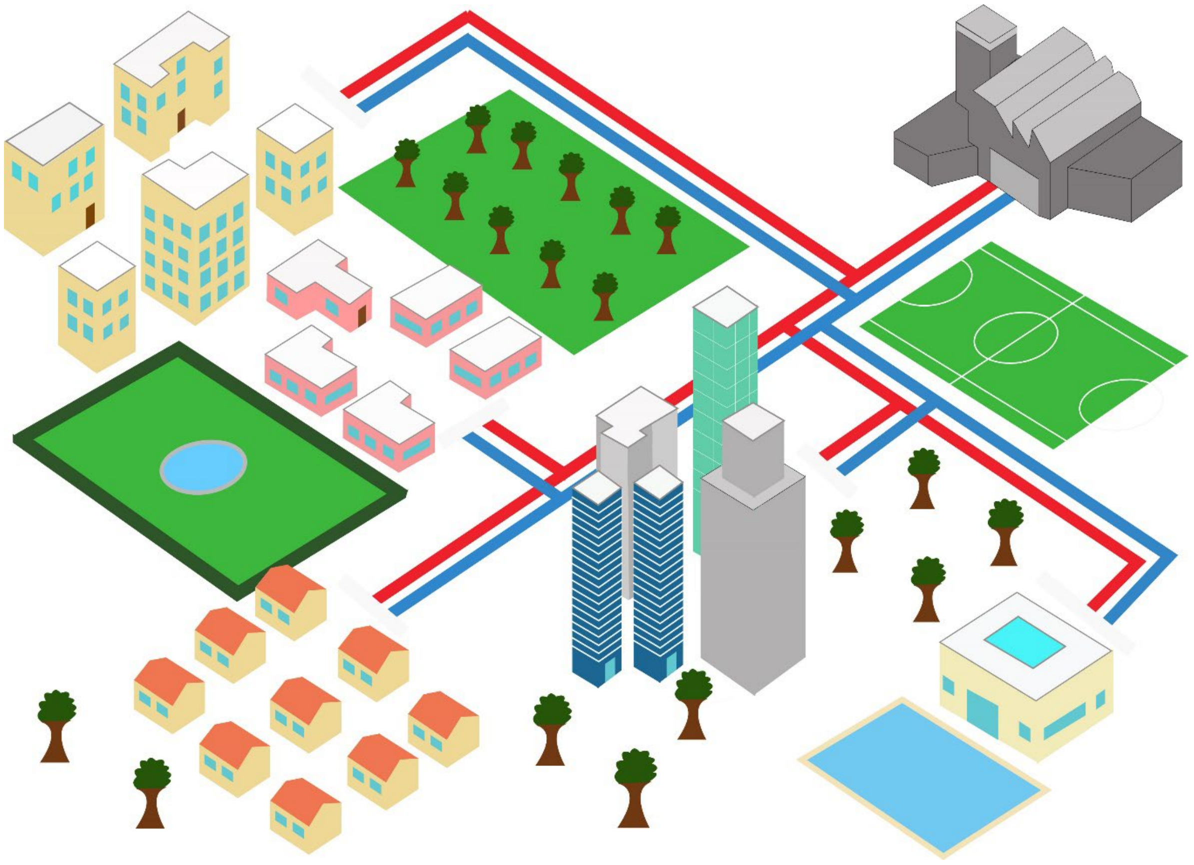


By POWER SOLUTIONS FRANCE [CC BY-SA 3.0], from Wikimedia Commons

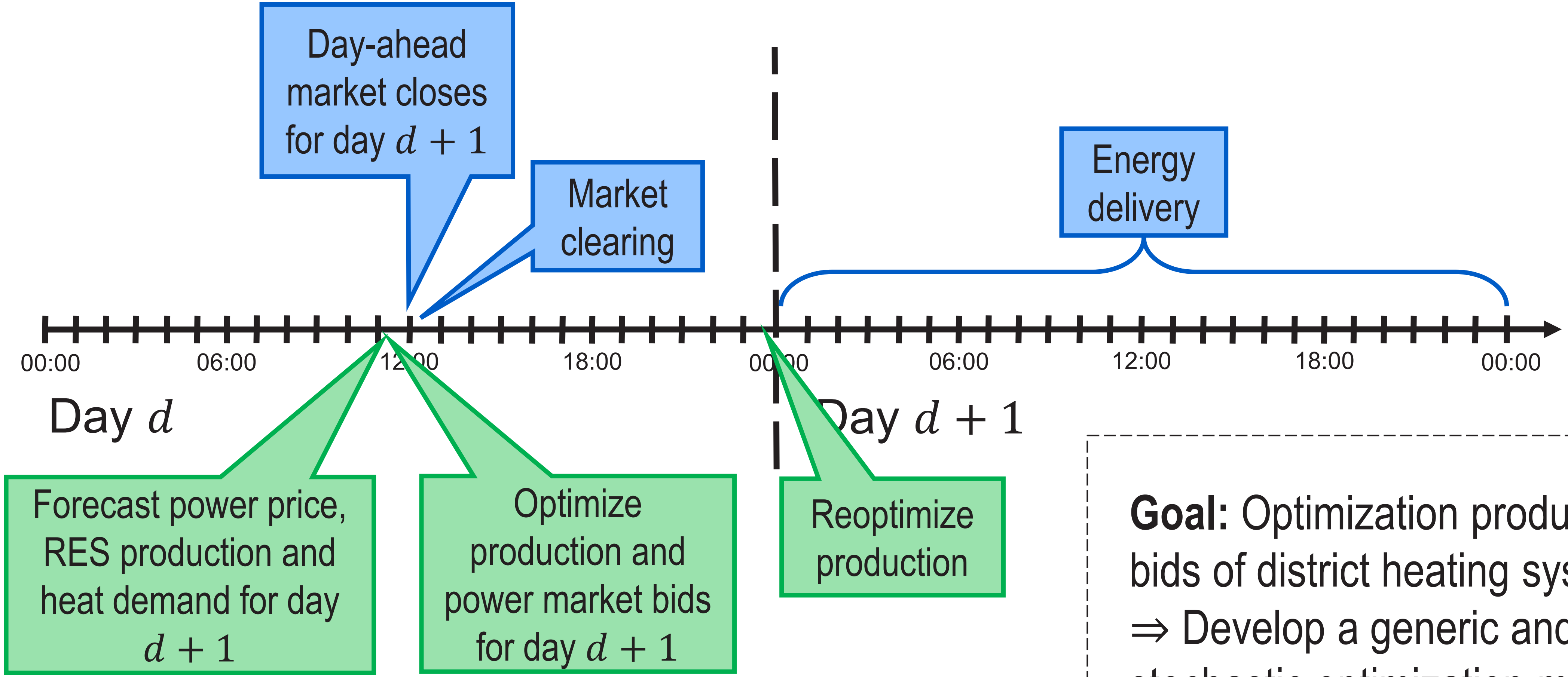
District heating networks play an important role in integrating renewable energy source through flexible production and storage possibilities. [European Commission 2021, Connolly et al. 2014]

Connected households to district heating:

- Netherlands: 5.9% [Statistics Netherlands 2019]
- Germany: 13.9% [BDEW 2019]
- Denmark: 64% [Danish District Heating Association 2021]

# Power market participation






**Goal:** Optimization production and bids of district heating systems
⇒ Develop a generic and stochastic optimization model

# Generic network presentation

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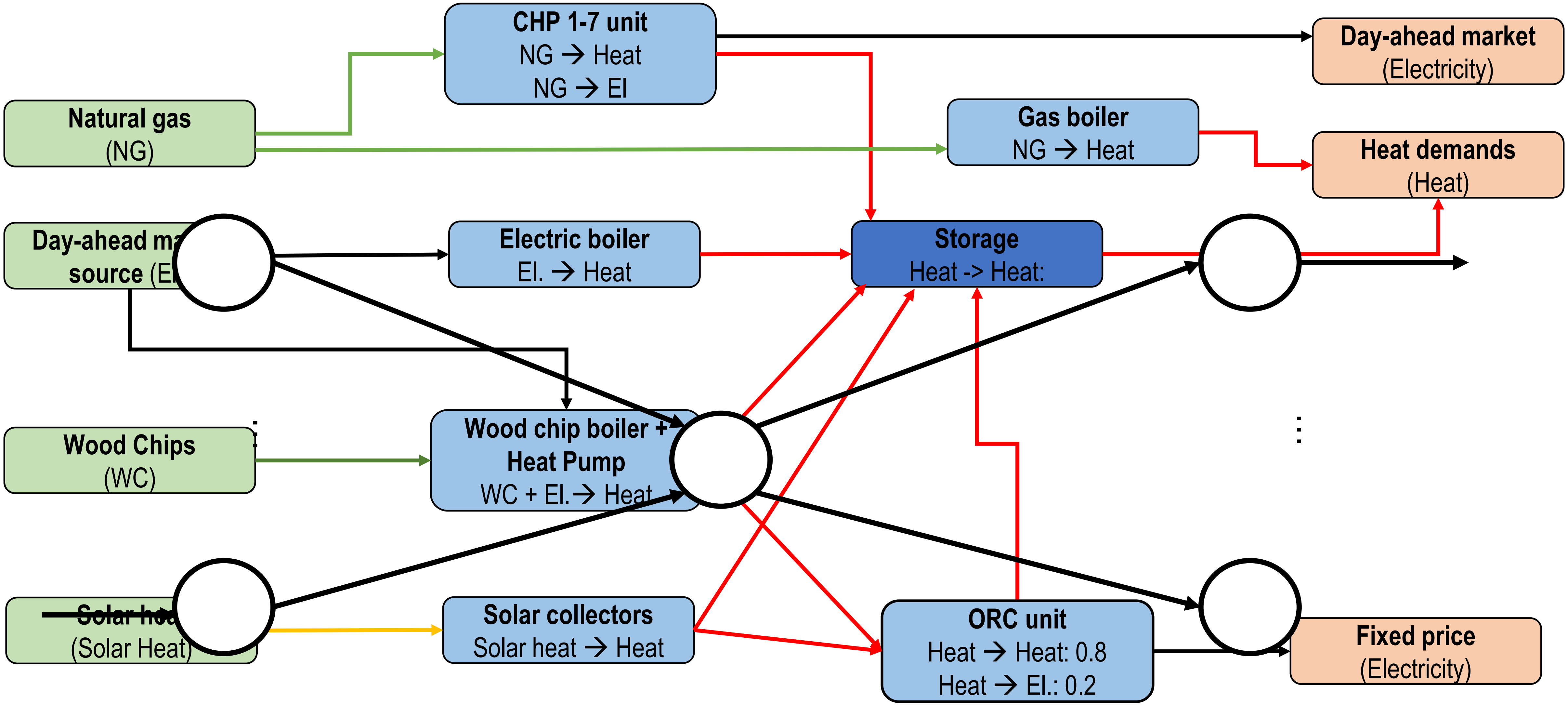
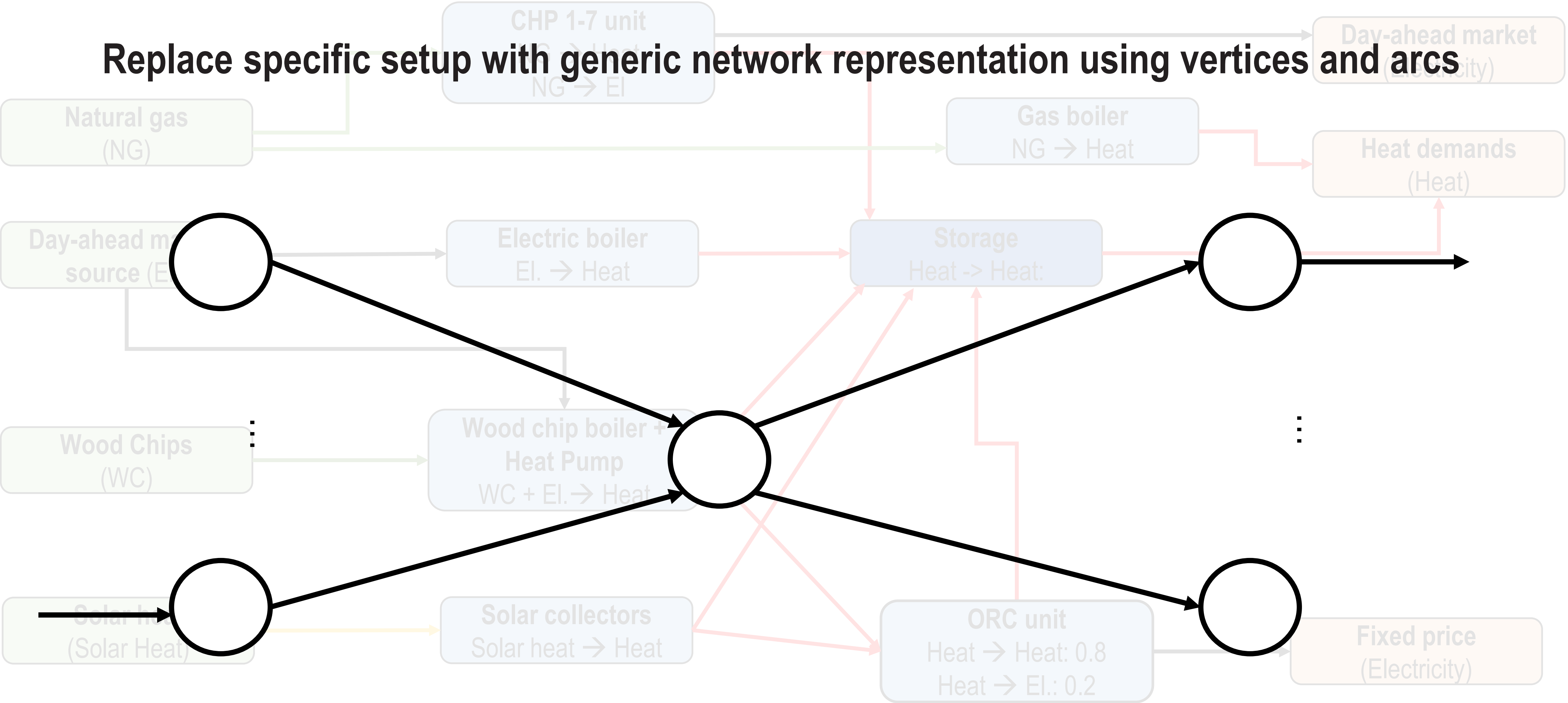


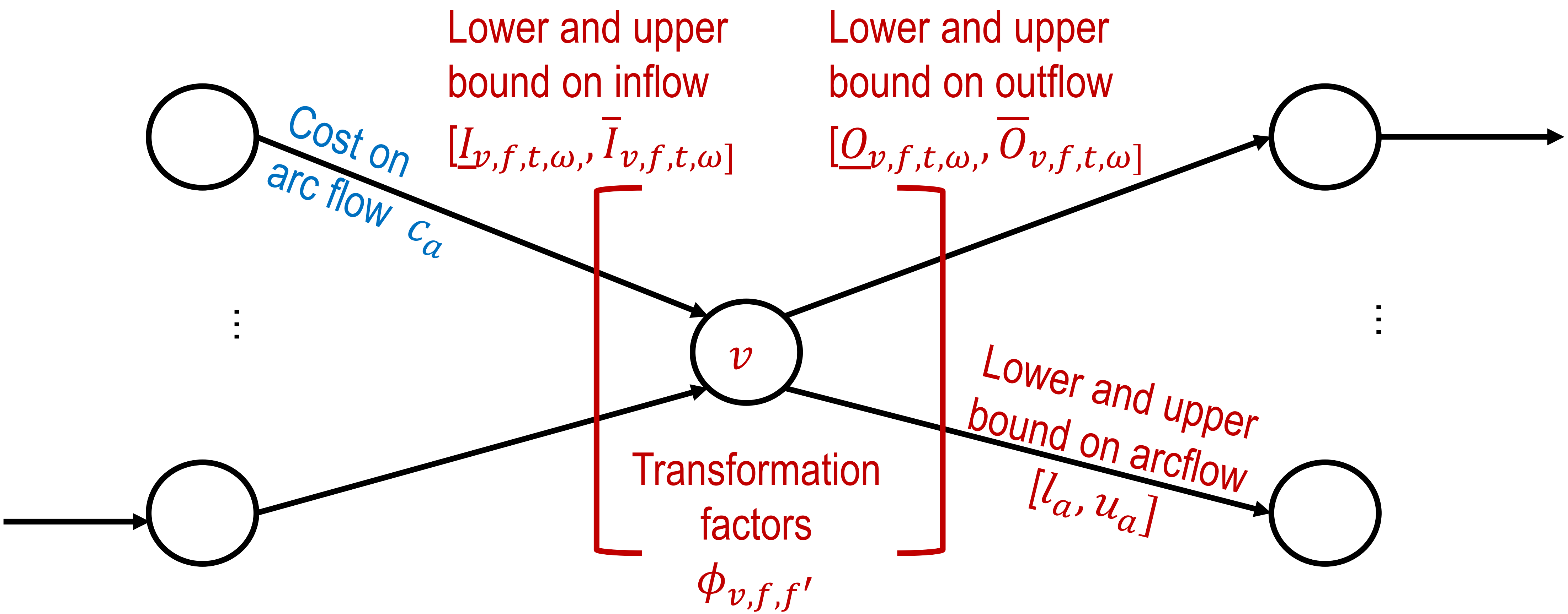
# Generic network presentation

**Replace specific setup with generic network representation using vertices and arcs**



# Generic network presentation

Components → Vertices
Connections → Arcs (with information about energy type, periods, scenarios)
Parameters → Costs + Bounds + Transformation factors



# Min-cost flow formulation

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$$\min \sum_{a \in \mathcal{A}} c_a x_a \qquad \text{(Min. cost)}$$

$$\text{s.t. } l_a \leq x_a \leq u_a \qquad \forall a \in \mathcal{A} \qquad \text{(Bounds on arc flow)}$$

$$\underline{O}_{v,f,t,\omega} \leq \sum_{a \in \mathcal{A}^{OUT}_{v,f,t,\omega}} x_a \leq \overline{O}_{v,f,t,\omega} \qquad \forall v \in \mathcal{V}, t \in \mathcal{T}, \omega \in \Omega, f \in \mathcal{F} \qquad \text{(Bounds on outflow)}$$

$$\underline{I}_{v,f,t,\omega} \leq \sum_{a \in \mathcal{A}^{IN}_{v,f,t,\omega}} x_a \leq \overline{I}_{v,f,t,\omega} \qquad \forall v \in \mathcal{V}, t \in \mathcal{T}, \omega \in \Omega, f \in \mathcal{F} \qquad \text{(Bounds on inflow)}$$

$$\sum_{a \in A^{OUT}_{v,f',t,\omega}} \phi_{v,f,f'} x_a - \sum_{a \in A^{IN}_{v,f,t,\omega}} x_a = 0 \qquad \forall v \in \mathcal{V}, t \in \mathcal{T}, \omega \in \Omega, f, f' \in \mathcal{F} \qquad \text{(Balance equation)}$$

+ binary variables for unit on/off, ramping constraints, min-up and down-time, dependencies

$$y_{u,t,\omega} = \begin{cases} 1, & \text{if unit } u \in \mathcal{V}^U \text{ is on in period } t \text{ and scenario } \omega \\ 0, & \text{otherwise} \end{cases}$$

# Application cases

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Deterministic and stochastic optimization

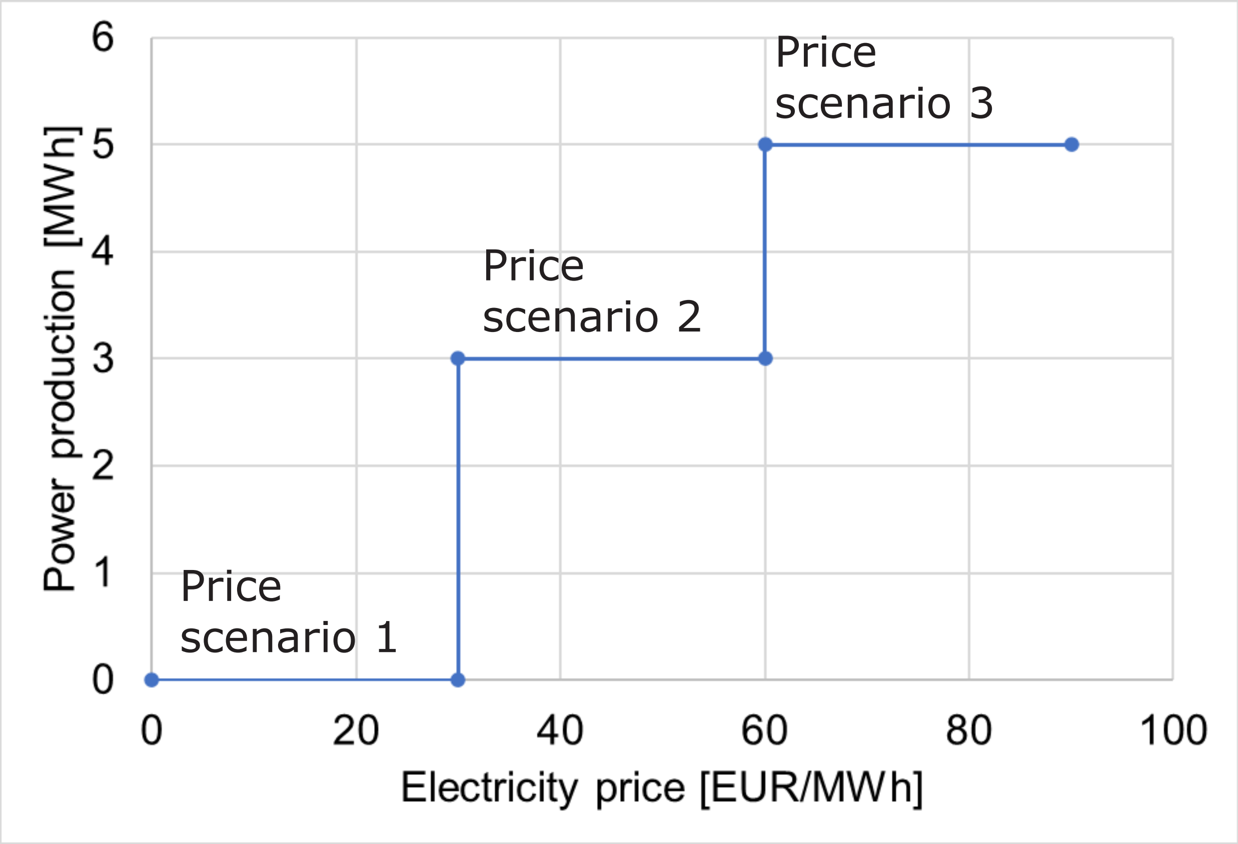
Fixed, rolling and receding horizon

Applications by adding different non-anticipativity constraints / changing data inputs:

- Planning and evaluation (deterministic)
- Operational optimization (deterministic and stochastic)
- Operational optimization + bidding to electricity markets (stochastic)

# Bidding

Implementation of bidding curves from Blanco et al. (2018) based on Virtual Power Plant bidding of Pandzic et al. (2013)



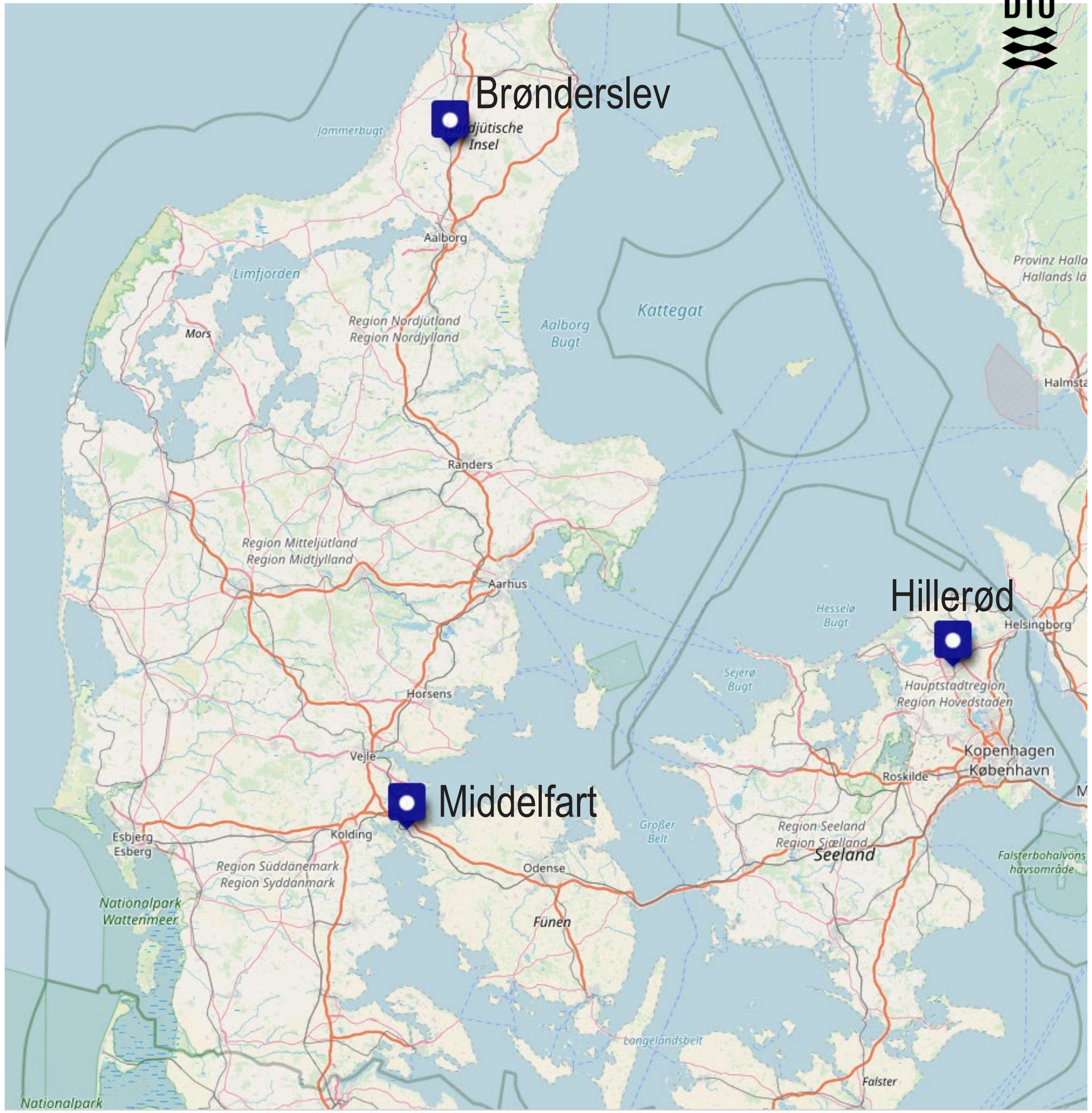
# Experiments

Real data from three district heating systems in Denmark (2019-2021):

Brønderslev (14 units, 3 demand sites)
- Electricity producer and consumer
- Solar units

Hillerød (12 units, 7 demand sites)
- Electricity producer
- Solar and waste heat units

Middelfart (6 units, 2 demand sites)
- Electricity producer



# Operational planning – Value of stochastic solution

- Data from three different seasons (winter, summer, inbetween)
- Planning horizon: 168 hours
- Uncertainties: electricity prices, heat in- and outflow (heat demand, solar heat, waste heat)
- 9 scenarios: 3 historic weeks of prices and heat flows (prob. 0.5, 0.33, 0,17), all combinations

# Value of stochastic solution – In sample testing

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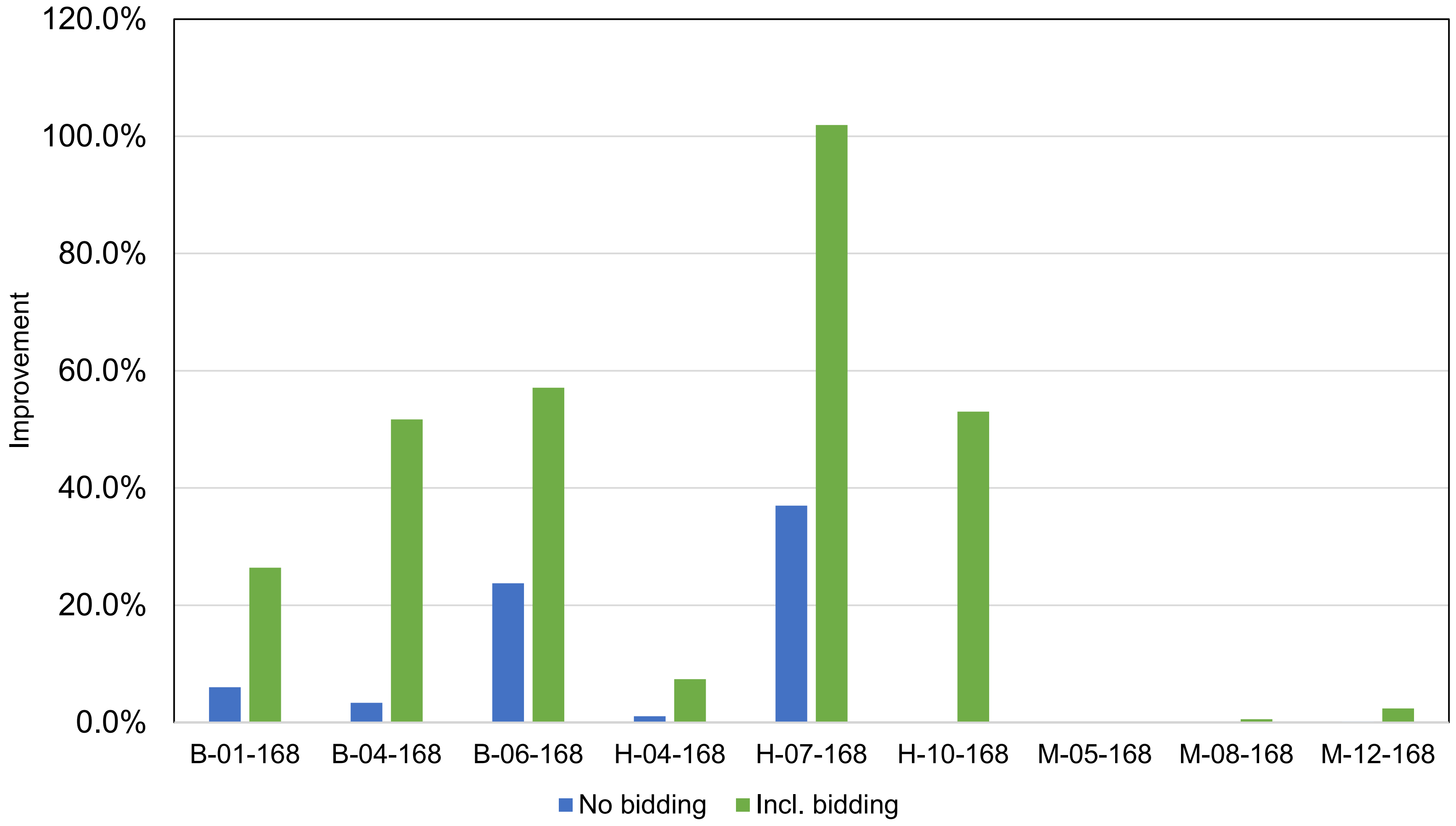
Savings of stochastic approach in %

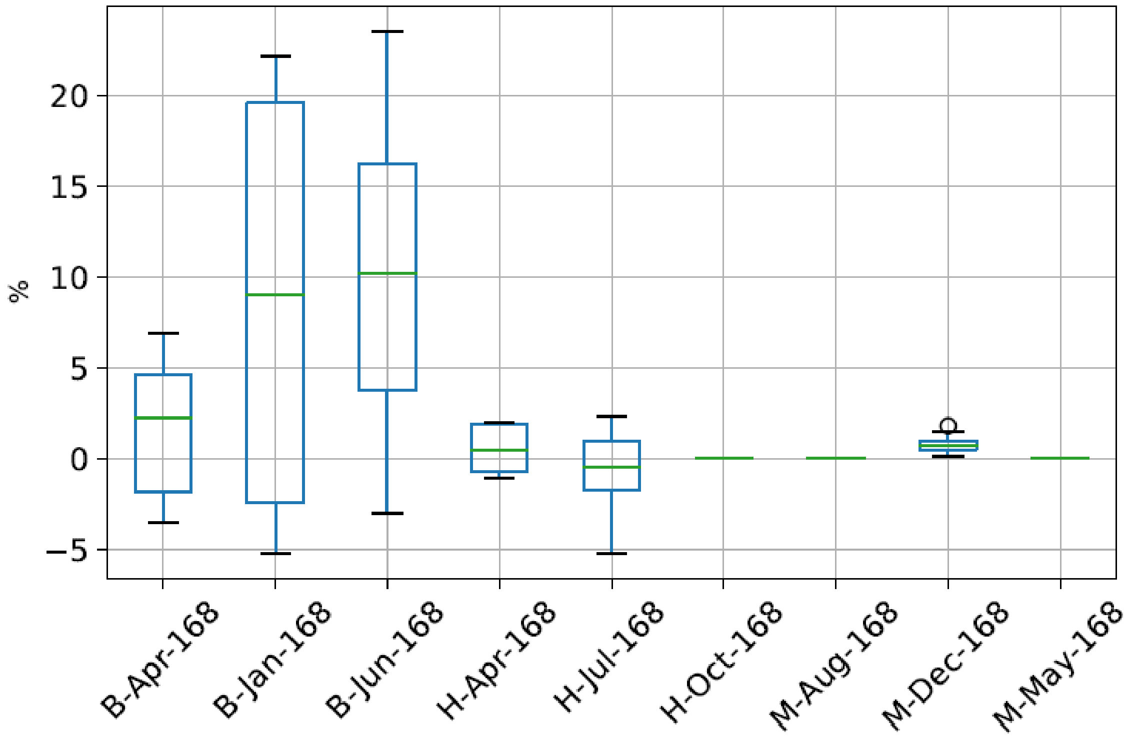



Savings of stochastic approach in EUR

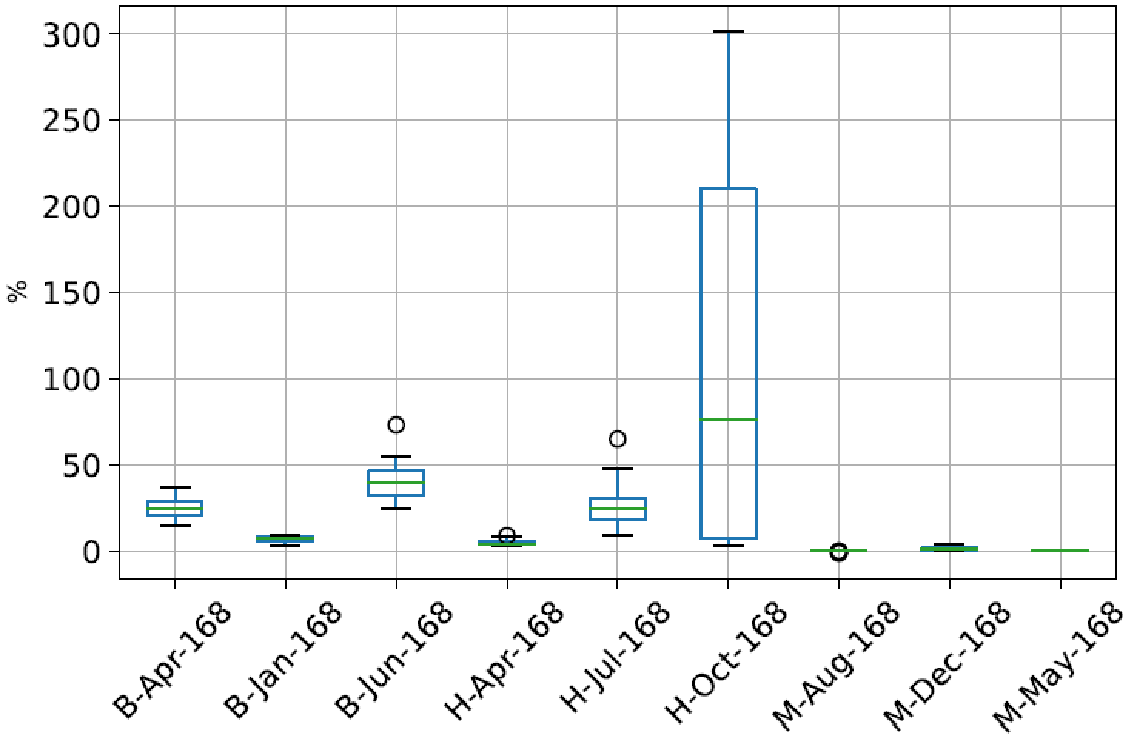
| Case | No bidding | Bidding |
|---|---|---|
| B-01-168 | 7127.2 | 38126.9 |
| B-04-168 | 1275.3 | 34252.3 |
| B-06-168 | 4716.3 | 19096.7 |
| H-04-168 | 3045.8 | 21370.3 |
| H-07-168 | 1168.7 | 29656.4 |
| H-10-168 | 0.0 | 180266.0 |
| M-05-168 | 0.0 | -0.1 |
| M-08-168 | 0.1 | 37.4 |
| M-12-168 | 41.5 | 803.2 |

# Value of stochastic solution – Out-of-sample testing

Savings of stochastic approach in %



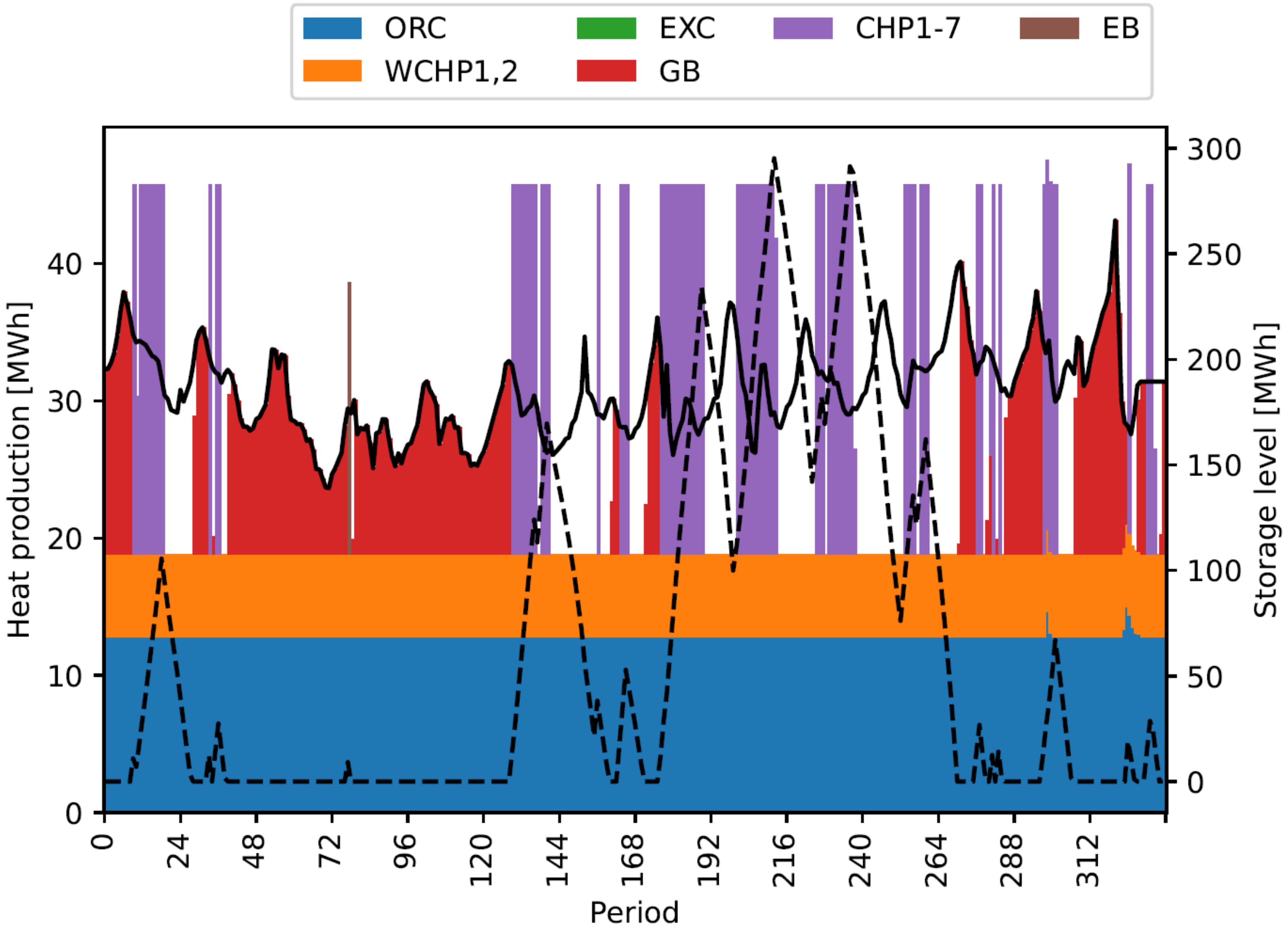

(a) Without bidding




(b) With bidding

# Rolling horizon

B-04-168
24 hours rolling horizon
for 2 weeks



# Runtimes

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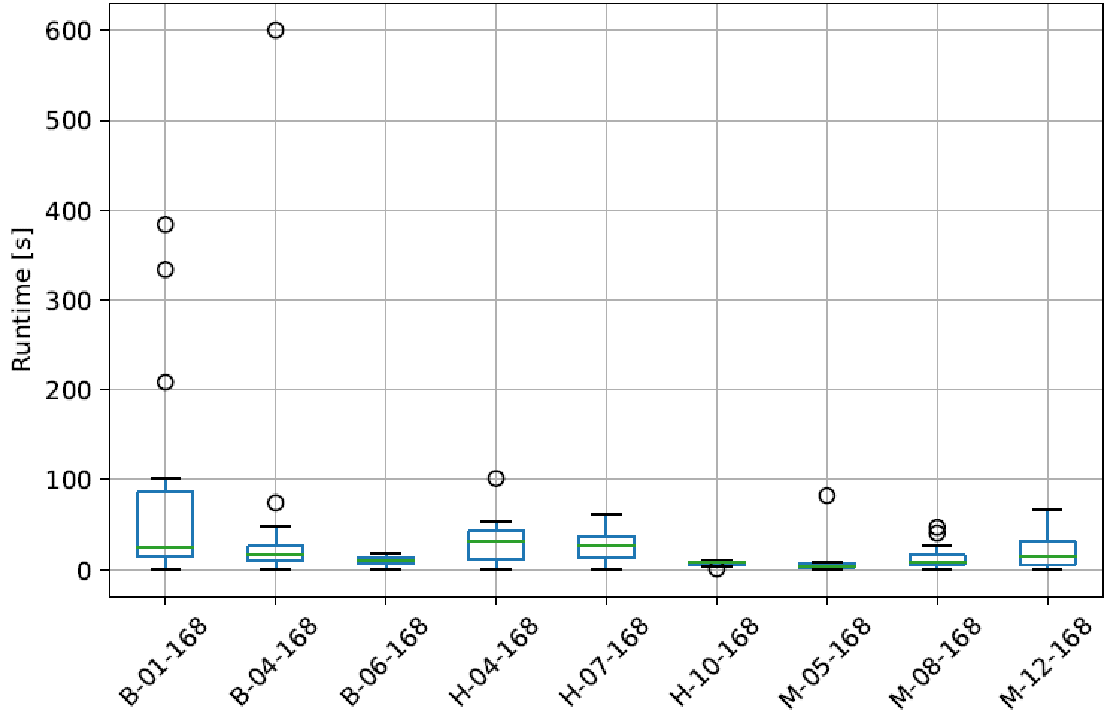
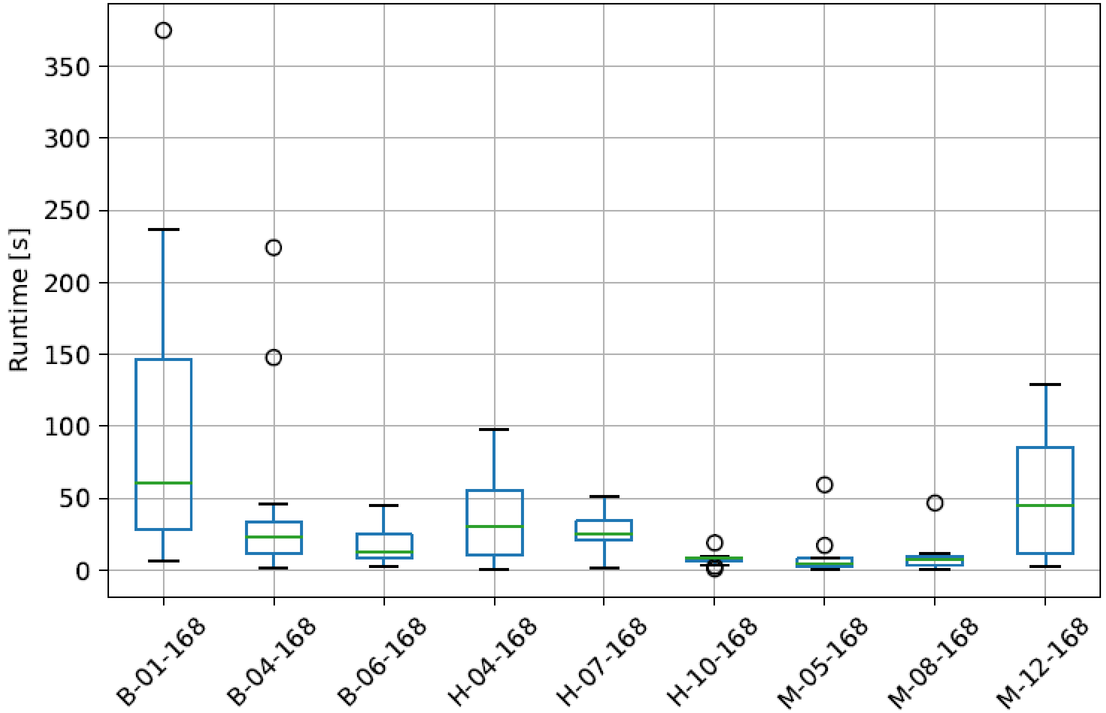
Per run of the rolling horizon approach (i.e. 14 data points)




(a) No bidding




(b) Bidding

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# Summary

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- Generic formulation for production optimization in district heating systems
- It is crucial to model the uncertainty and available flexibility appropriately in the presented application
- Stochastic programming improves the solutions significantly

**Outlook:**

- Combine with further bidding products and markets
- Focus also on $CO_2$ emissions

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