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Local multi modal energy market for thermal-electric energy systems

with consideration of temperature flexibility in heating subnetworks

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Market driven allocation of energy for thermal-electric energy systems
Local multi modal energy markets

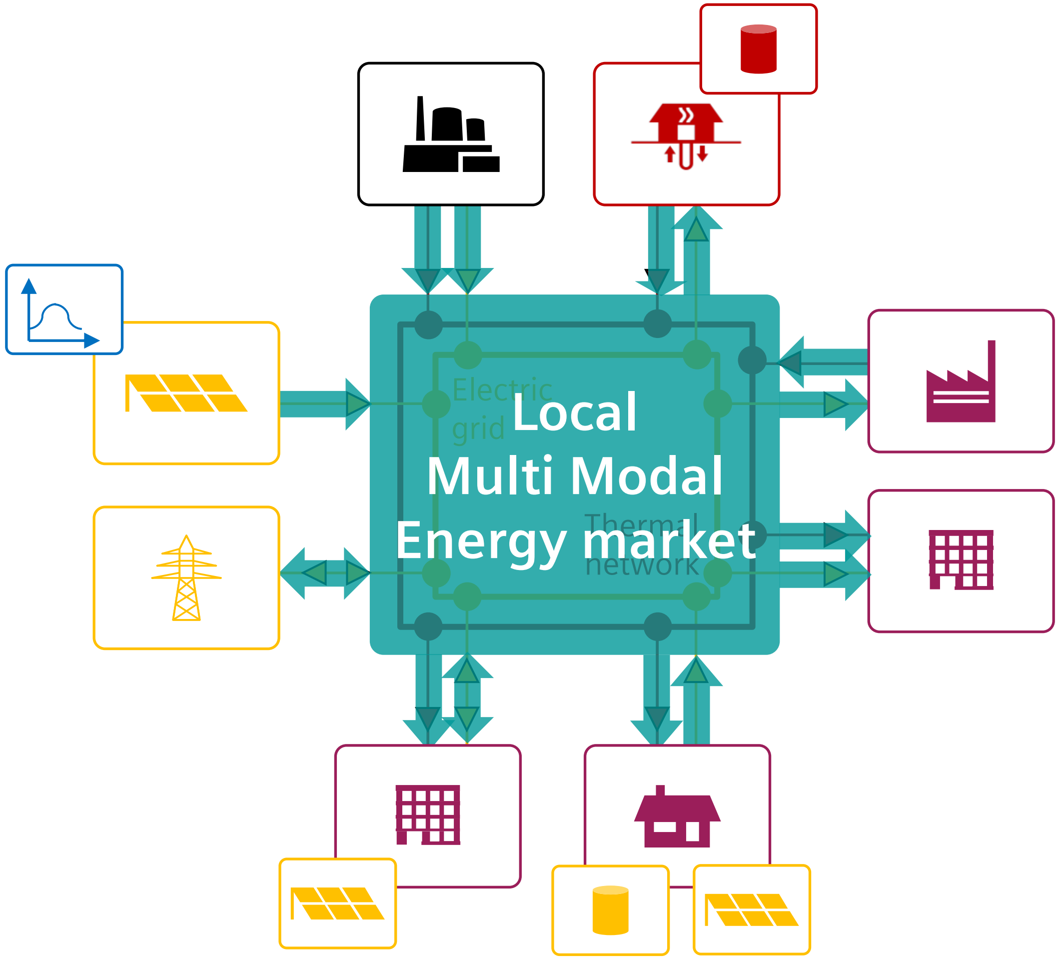
Local
- Leveraging local energy sources minimizes transmission losses [1,2]
- District heating is inherently local to minimize thermal losses during distribution[3]

Multi modal energy
- Maximize value through the integrated management of multiple energy carriers
  - e.g., using renewable energy from PV systems for heat pumps [1,4]

Markets
- General idea of markets: increased efficiency and innovation [2]
- Decomposes complex problems to reduce computational burden [5]
  - Achieves equilibrium between supply, demand and flexibility of multi modal energy

Requirements:
- Linear optimization model is required for the handling of complex multi-modal energy systems and for direct market pricing through dual variables
- Consideration of supply temperature in hydraulicly separated district heating subnetworks

Focus question of this presentation:
- How can the temperature flexibility of heating subnetworks within district heating systems be incorporated into a linear market-matching algorithm?



[1] X. Jin, Q. Wu, et al., "Local flexibility markets: Literature review on concepts, models and clearing methods,", 2020. [2] G. Mendes, et. al., "LOCAL ENERGY MARKETS: OPPORTUNITIES, BENEFITS, AND BARRIERS,", 2018. [3] Thomas Nussbaumer, "Planungshandbuch Fernwärme," 2018. [4] E. Mengelkamp, et. Al., "Trading on local energy markets: A comparison of market designs and bidding strategies,", 2017. [5] S. Schreck, "Local Energy Markets Simulative Evaluation and Field Test Application of Energy Markets on Distribution Grid Level,",2022.

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Modeling of market orders
Formulation of buy-, sell-, storage and coupling orders

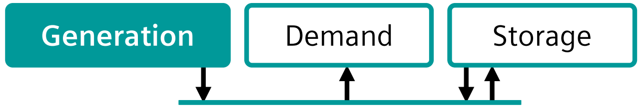
Buy order: Demand

$$P_{buy,t}^{traded} \leq P_{buy,t}^{max} \; \forall t \in T \qquad \sum_{t\epsilon T} P_{buy,t}^{traded} \leq E_{buy}$$

Max. price (t) | Max. power (t) | Min. temperature (t)

- Demand of energy e.g. non-flexible, flexible , ...
- Load shift possible in case of: $\sum_{t\epsilon T} P_{buy,t}^{max} > E_{buy}$

Sell order: Generation

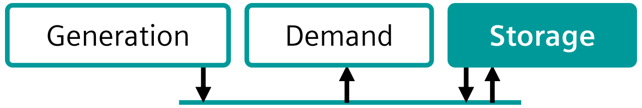


$$P_{sell,t}^{traded} \leq P_{sell,t}^{max} \; \forall t \in T \qquad \sum_{t\epsilon T} P_{sell,t}^{traded} \leq E_{sell}$$

Min. price (t) | Max. power (t) | Max. temperature (t)

- Generation of energy e.g. waste incineration, PV

Storage order: Storage systems



$$E_{sto,t+1} = E_{sto,t} + \left(\eta_{ch} P_{sto,t}^{ch} - \frac{1}{\eta_{dch}} P_{sto,t}^{dch}\right) \Delta t$$

Min. price(t) | Max. power (t) | Capacity (T)

- Storing systems e.g. battery storage systems
- Enables among others load shift, arbitrage, ...

Coupling order: Energy and temporal dependency

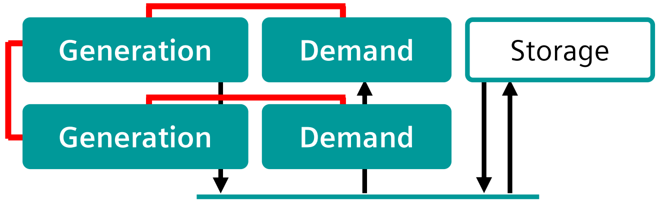
Heat pump with 1 supply temperature

$$P_{sell,t}^{traded} = r \cdot P_{buy,t}^{traded} \qquad \forall t \epsilon T$$

Coupled order IDs | Coupling Type | Ratio (t)

- Multiple types of couplings: fix, flex substitute, ...
- e.g. heat pump: buy electricity and sell heat with COP

Heat pump offering multiple supply temperatures



$$P_{sell=1,t=1}^{traded} + P_{sell=2,t=1}^{traded} \leq P_{hp,t=1}^{max} \qquad \forall t \epsilon T$$

- e.g. heat pump with variable supply temperature

Market orders for local multi modal energy market considering network temperature

- Demand → Buy order with min. temperature.
- Generation → Sell order with max. temperature.
- Heat pump → Coupling order accounts for various supply temperatures, each affecting the COP.

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Method Overview
Market matching with subnet temperature optimization

External input

DHN operator
DHN topology
Pipeline parameter

DSO
Grid topology
Power line parameter

Weather data
Ambient temp.

Backup heat plant
Back up prices

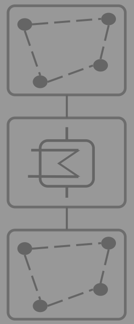
Market participant
Market orders

Wholesale market
Wholesale prices

Local Multi Modal Energy Market Plattform

Network parameter
- DHN: pipelines
- DG: power lines

Closed order book
- Buy order
- Sell order
- Coupling orders
- Storage orders



Subnet 1:
80, 90, …120 °C

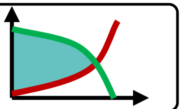
Heat Exchanger

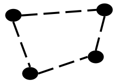
Subnet 2:
70, 80, 90 °C

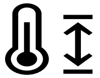
Comb.1: 120 °C / 90 °C
Comb.2: 90 °C / 80 °C

Subnet temperature Combinations

Market matching

Max. WF 

Min. fees 

Min. losses 

Market contracts
Heat and electricity schedule for each trading interval for market participants

Market matching

Closed order book

Network parameter

Fixed subnet temperatures

Objective

$$\max\left(\sum_{t\in T}\left(\underbrace{\sum_{buy\in B} \boldsymbol{P}^{\boldsymbol{traded}}_{\boldsymbol{buy,t}}\, c^{max}_{buy,t}}_{Demand} - \sum_{sell\in S} \underbrace{\boldsymbol{P}^{\boldsymbol{traded}}_{\boldsymbol{sell,t}}\, c^{min}_{sell,t}}_{Supply} - \sum_{sto\in ST} \underbrace{\boldsymbol{P}^{\boldsymbol{traded}}_{\boldsymbol{sto,t}}\, c^{min}_{sto,t}}_{Storage}\right)\Delta t\right)$$

Subject to

Transport capacity of energy networks

$$\boldsymbol{P}_{\boldsymbol{pipe,t}} \leq c_w \cdot \dot{m}_{max} \cdot (\vartheta^{sup} - \vartheta^{ret}) \qquad \boldsymbol{P}_{\boldsymbol{line,t}} \leq V_0 \cdot I_e^{max}$$

Temperature threshold for heat commodity

$$\boldsymbol{P}^{\boldsymbol{traded}}_{\boldsymbol{buy,t}} \leq P^{max}_{buy,t} = \begin{cases} P^{max}_{buy,t} & if\ \vartheta^{min}_{buy} \leq \vartheta^{sup} \\ 0 & else \end{cases}$$

$$\boldsymbol{P}^{\boldsymbol{traded}}_{\boldsymbol{sell,t}} \leq P^{max}_{sell,t} = \begin{cases} P^{max}_{sell,t} & if\ \vartheta^{max}_{sell} \leq \vartheta^{sup} \\ 0 & else \end{cases}$$

"Heat producers are unable to supply heat if the supply temperature of the DHN falls below the operational range of their own energy systems."

Sets		Variables	Parameters
B Buy orders	ST Storage orders	P Power	ϑ Temperature
S Sell Orders	T Trading Intervals	E Energy	c Price

DHN District Heating Network
DSO Distribution Grid Operator
DG Distribution Grid

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Preliminary results
Case study: Darmstadt 2030, Winter-Weekday-Cloudy day

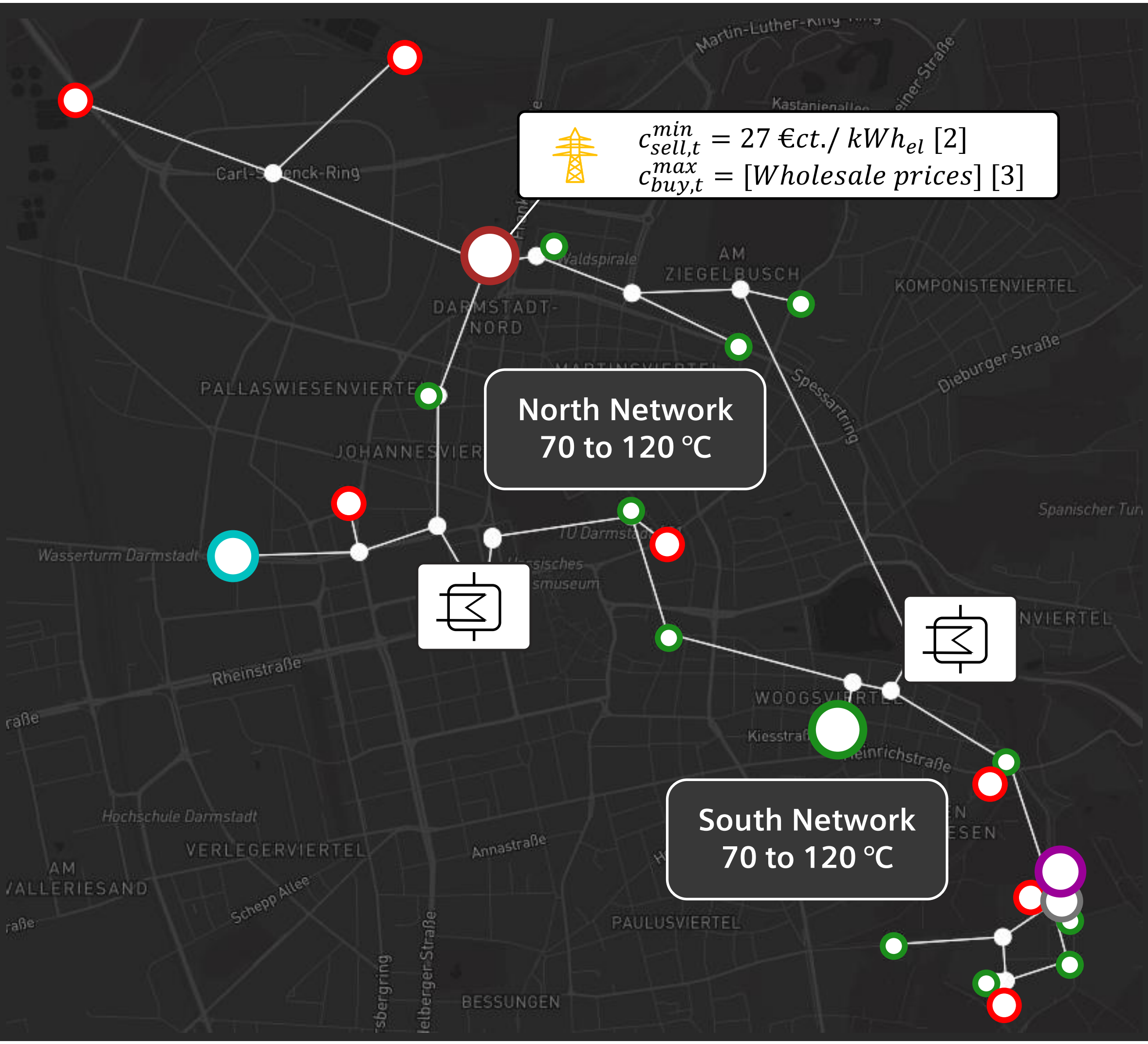
North network

Large scale heat pumps
- Heat source: Sewage water treatment plant, data center, …
- $\Delta\vartheta_{lift}$ = 30 to 50 °C
  - COP: 3.1 to 4.9 [1]
- $P_{sum}^{max} = 16.5\ MW_{th}$
- $\vartheta_{sell}^{max}: 70°C, 80°C, 90°C$
- ➢ Coupling orders for heat pumps

Incineration plant
- Waste incineration plant
- $P_{sum}^{max} = 20\ MW_{th}$
- $\vartheta_{sell}^{max} = 120°C$
- $c_{sell,t}^{min} = 5\ €ct./\ kWh_{th}$

Households
- $P_{buy}^{max} = 8.2\ MW_{th}\ |\ \vartheta^{min} = 70°C$
- $c_{buy,t}^{max} = 12\ €ct./\ kWh_{th}$

Industrial (North)
- Onsite generation possible
- $P_{buy}^{max} = 5\ MW_{th}\ |\ \vartheta^{min} = 90°C$
- $c_{buy,t}^{max} = 10\ €ct./\ kWh_{th}$



South network

Large scale heat pumps
- Heat source: data center, …
- $P_{sum}^{max} = 6.16\ MW_{th}$
- $\vartheta_{sell}^{max}: 70°C, 80°C, 90°C$
- ➢ Coupling orders for heat pumps

Households
- $P_{buy}^{max} = 28.4\ MW_{th}\ |\ \vartheta^{min} = 70°C$
- $c_{buy,t}^{max} = 12\ €ct./\ kWh_{th}$

CHP (gas)
- $P_{sell}^{max} = 4\ MW_{th}\ |\ \vartheta^{max} = 120°C$
- $c_{sell,t}^{min} = 2.8\ €ct./\ kWh_{th}$
- ➢ Coupling orders for CHPs

Industrial (South)
- Onsite generation possible
- $P_{buy}^{max} = 3\ MW_{th}\ |\ \vartheta^{min} = 90°C$
- $c_{buy,t}^{max} = 10\ €ct./\ kWh_{th}$

[1] M. Jesper, et al., "Large-scale heat pumps: Uptake and performance modelling of market-available devices,", 2021. [2] BDEW, "BDEW-Strompreisanalyse 2023,", 2023. [3] BNetzA, SMARD Strommarktdaten – Marktdaten, 09.08.2023

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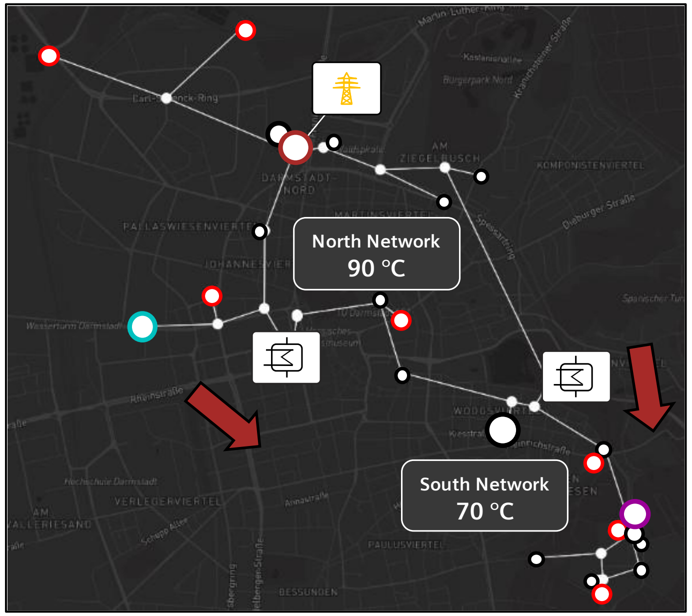
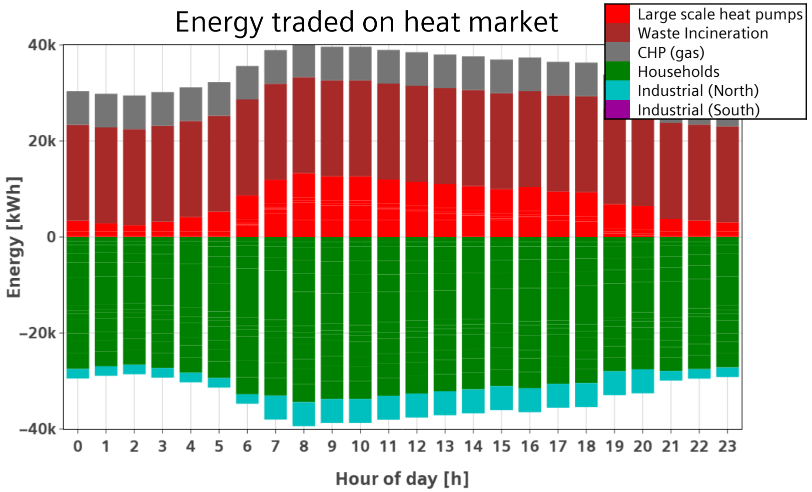
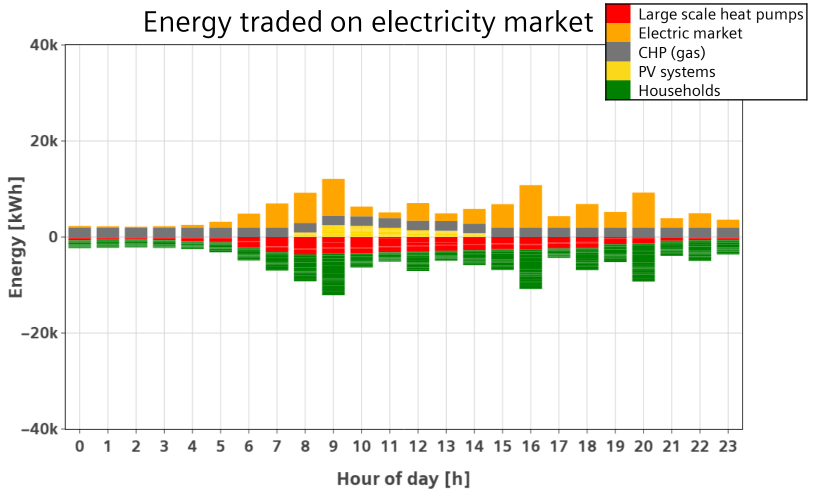
Preliminary results
Case study: Darmstadt 2030, Winter-Weekday-Cloudy

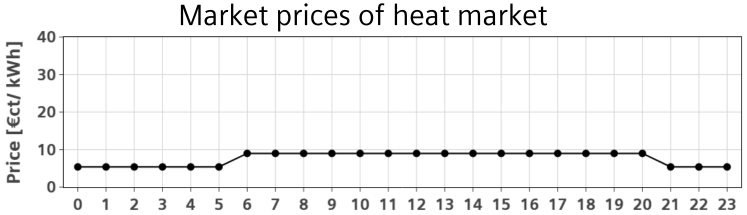


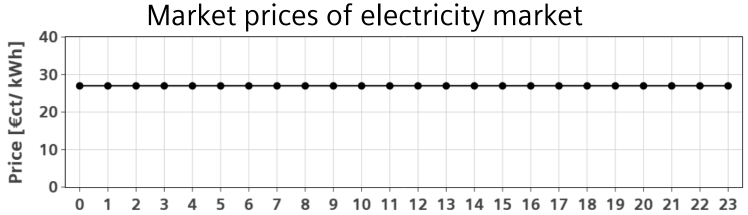
Solving market matching with consideration of:
- Market orders for multi-modal energy market
- Pricing for heat pumps depending on supply temperatures and respective COP
- Considering 16 temperature combinations

➢ **Maximum social welfare with temperature combination North: 90°C and South 70°C**









North network with supply temperature of 90°C
- **Industrial (North) is supplied by DHN**
- Waste incineration provides high-temperature heat

South network with supply temperature of 70°C
- **Industrial (South) is relying on onsite generation**
- Heat pumps are supplying heat with 70°C to DHN

- **Electricity consumption of heat pumps according to supply temperature and COP**
- Electricity for household consumers are mainly supplied by over regional electricity system
- Electricity offered by PV systems limited due to weak solar irradiation → constant local electricity price

DHN District Heating Network

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Summary - Local multi modal energy market
with consideration of temperature flexibility in heating subnetworks

Local multi modal energy market

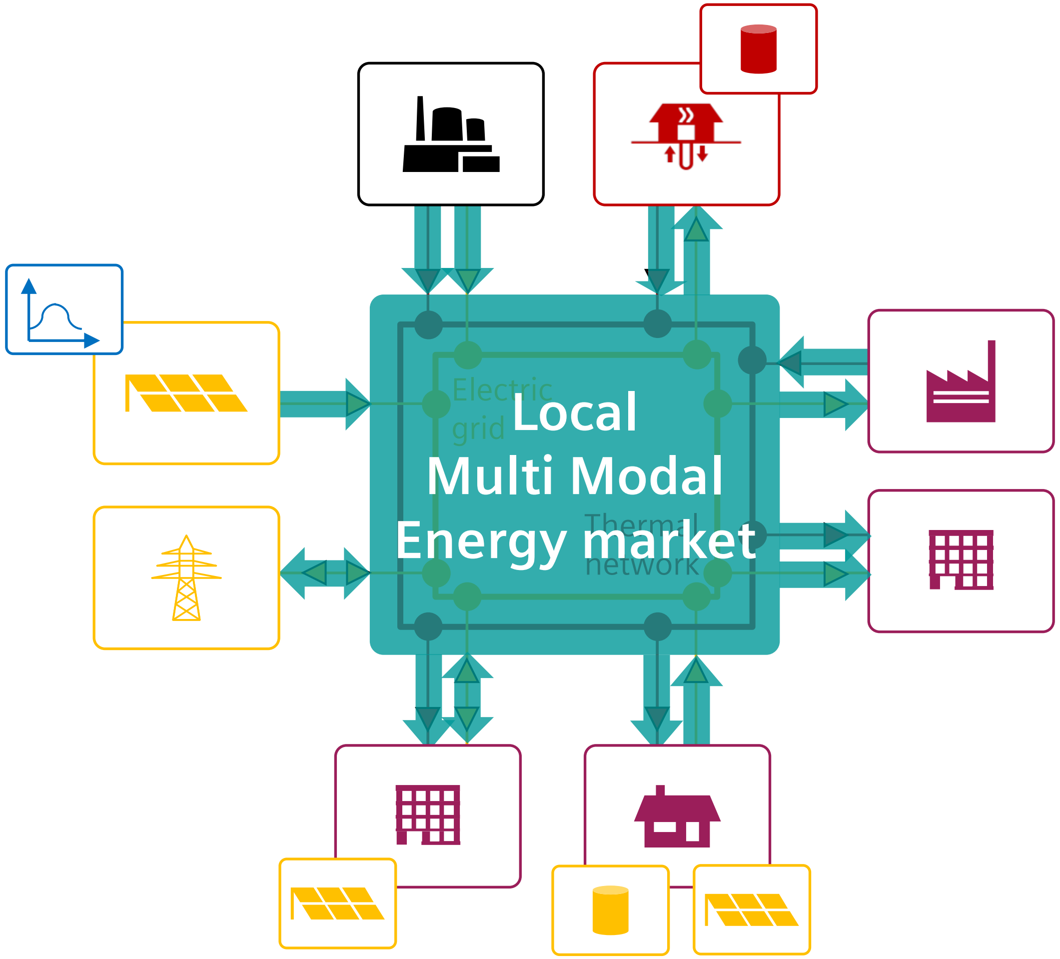
- **Market driven** allocation of **multi modal energy** in **local energy systems**, e.g., district heating systems with close coupling of underlying electric energy system
- Considering of **temperature flexibility in heating subnetworks**

Market order formulation

- Versatile market order formulation of buy-, sell-, storage- and coupling orders enable integration of **diverse energy sources and sinks**
- Buy orders: **minimum temperature** that the consumer can accept
- Sell orders: **maximum temperature** at which the producer can supply energy
- **Coupling orders** accounts for **energy and temporal dependencies**, e.g., for **heat pumps** with electricity consumption and heat supply
  - Market matching takes into account **volume of heat, price** and **COP depending on supply temperature**

Method

- **Linear optimization model** to provide direct access to **market prices via dual variables** and for the handling of **complex** local multi modal energy systems
- Optimization of temperatures of heating subnetworks by enumerating **combinations of subnetwork supply temperatures**



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Local Multi Modal Energy Markets

Thank you!

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