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Local Energy Markets for Thermal-Electric Energy Systems considering energy carrier dependency and energy storage systems

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Local Multi Modal Energy Market
for Thermal-Electric Energy Systems

Motivation of Local Multi Modal Energy Markets

- Handling **volatile** renewable energy sources in electricity sector
- Decarbonization of thermal heating sector (e.g. with el. RES)

Market Driven Allocation of Energy Demand and Supply

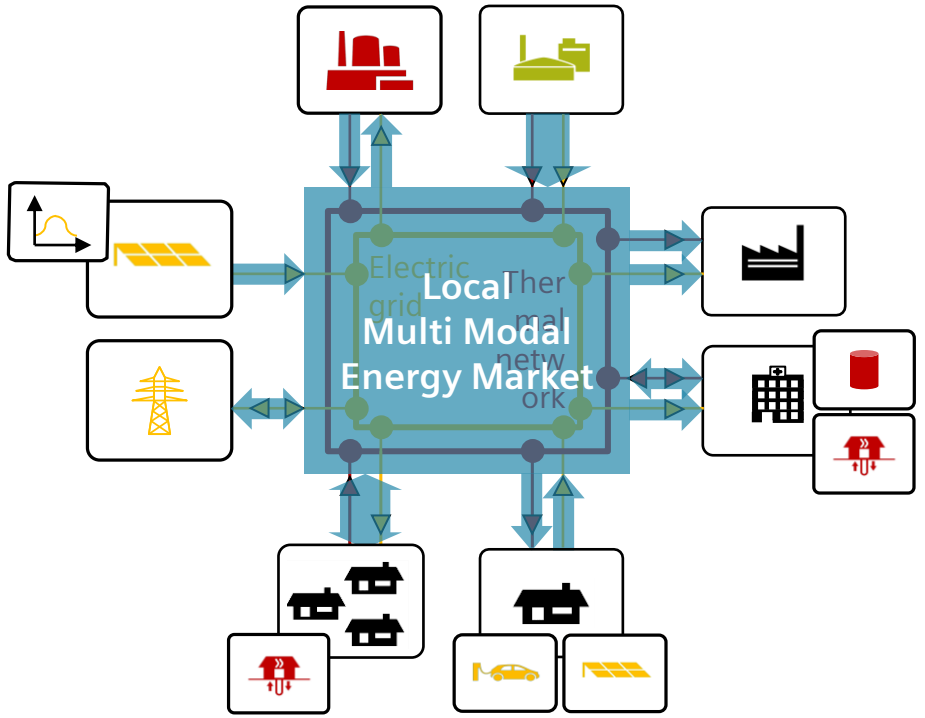
- Doubled sided day ahead auction with closed order book
- **Max. Social welfare** and/ or min. network fees, min. supply temp, …
- Consider physical capacities of heating and electric network

Market Output

- Power sources and sinks for cleared market orders
- Locational marginal prices

<u>Market Order Formulations considers</u>:

- Non-flexible and flexible energy sources and sinks
- Flexibility options e.g. storage systems, load shifting
- Multi modal energy carriers



Objective Function of Market Matching Problem (among others)

$$\max \sum_{t \in T} \left(\sum_{a \in A} \underbrace{P_{a,t} c^{max}_{a,t}}_{Demand} - \sum_{b \in B} \underbrace{P_{b,t} c^{min}_{b,t}}_{Supply} - \sum_{st \in ST} \underbrace{P_{st,t} c^{min}_{st,t}}_{Storage} \right) \Delta t$$

Sets		
	A	Ask Orders
	B	Bid Orders
	ST	Storage Orders

P: Power | c: Cost

RES: Renewable energy sources

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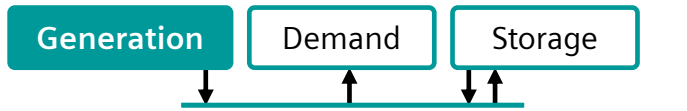
Modeling of Market Orders
Formulation of Ask-, Bid-, Coupling and Storage Orders

Demand → Ask Order:

$$P_{a,t}^{cleared} \leq P_{a,t}^{max} \; \forall t \in T \qquad \sum_{t \epsilon T} P_{a,t}^{cleared} \leq E_a$$

Min. Ask Price (t) | Max. Power (t) | Max. Energy (T)
- Demand of energy e.g. non-flexible, flexible , …
- Load shift possible in case of: $\sum_{t \epsilon T} P_{a,t}^{max} > E_a$

Generation → Bid Order:



$$P_{b,t}^{cleared} \leq P_{b,t}^{max} \; \forall t \in T \qquad \sum_{t \epsilon T} P_{b,t}^{cleared} \leq E_b$$

Min. Bid Price (t) | Max. Power (t) | Max. Energy E (T)
- Generation of energy e.g. PV, solar thermal, …

r: coupling ratio

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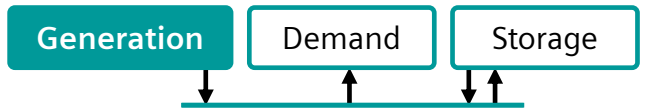

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Coupling Orders

Coupled Order IDs | Ratio | Coupling Type
- Enables **link** of demand and supply for **different** underlying **energy carriers**
- For assets with **conversion dependencies** e.g. heat pump, electric boilers, CHPs, …
- **Fix**: fixated coupling of power
- **Flex**: allows coupling with min/ max statement
- **Substitute**: coupled power is interchangeable

Fix

Example: $P_{b,t}^{cleared} = r \cdot P_{a,t}^{cleared} \quad \forall t \epsilon T$

Flex

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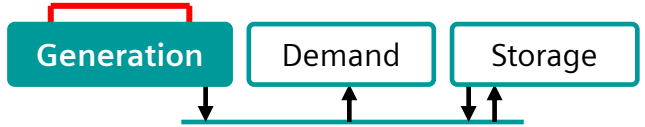
Fix



Example: $P_{b1,t}^{cleared} = r \cdot P_{b2,t}^{cleared} \quad \forall t \epsilon T$

Substitute

Example: $\sum_{t \epsilon T} \left(r \cdot P_{a1,t}^{cleared} + P_{a2,t}^{cleared} \right) \leq E_a$

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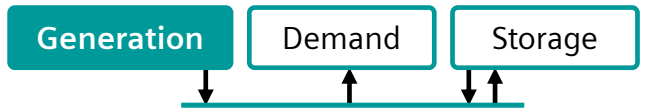

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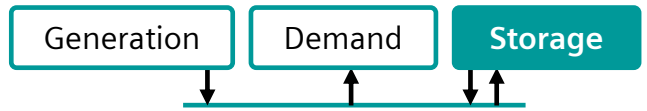
Min. Bid Price (t) | Max. Power (t) | Max. Energy E (T)
- Generation of energy e.g. PV, solar thermal, …

Storage Systems → Storage Order:



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

Min. Bid Price (t) | Max. Power (t) | Capacity (T)
- Storing systems e.g. battery storage systems
- Enables among others load shift, arbitrage
- Temporal interdependency of stored energy

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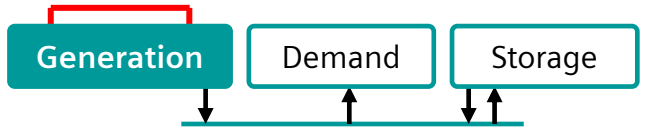

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Substitute

Example: $\sum_{t \epsilon T} \left(r \cdot P_{a1,t}^{cleared} + P_{a2,t}^{cleared}\right) \leq E_a$

r: coupling ratio

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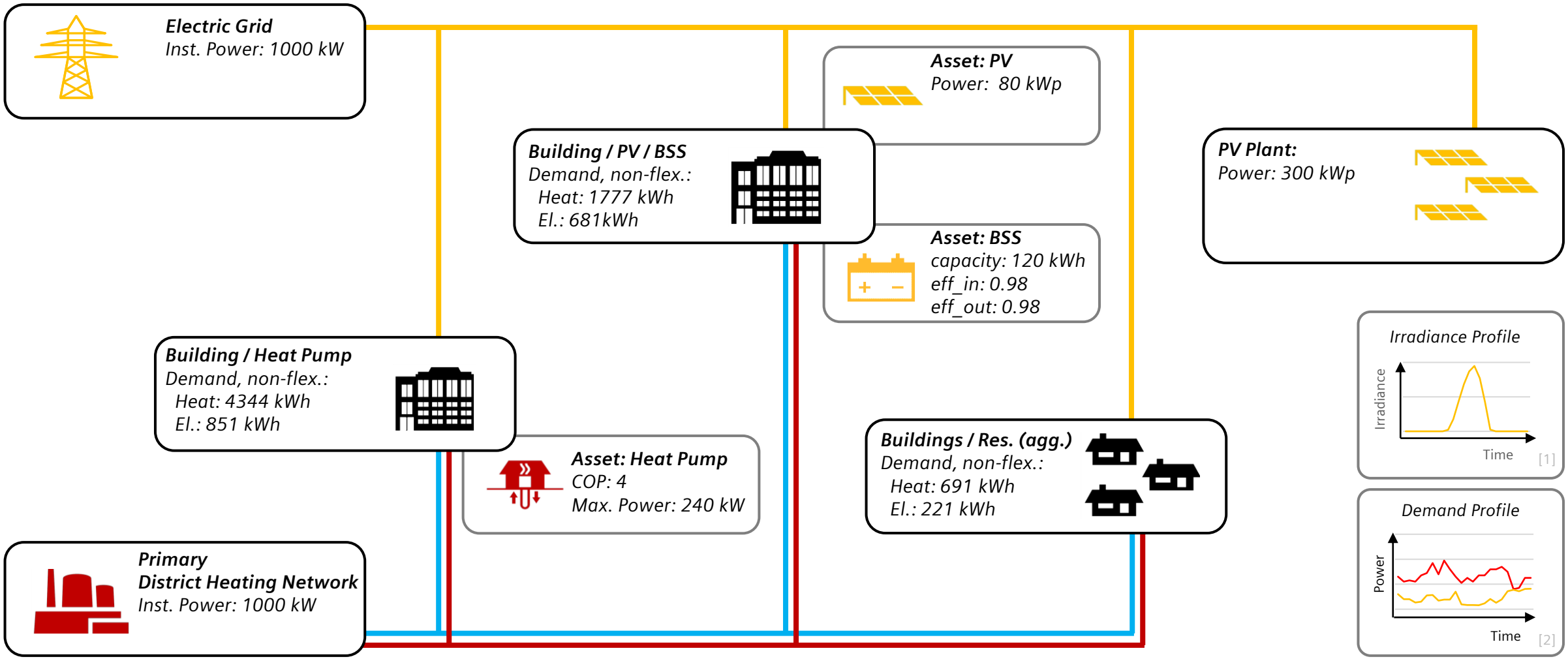
Exemplary Results: Case Study
Characteristic Model Parameters



BSS: Battery Storage System

[1] VDI 4655: Reference load profiles of single-family and multi-family houses
[2] Gelaro, R., McCarty, Et al. (2017). The modern-era retrospective analysis for research and applications, version 2 (MERRA-2)

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Exemplary Results: Case Study
Market Orders by Trading Agents

Bid Orders	Ask Orders	Storage Order

Price $\boldsymbol{c}$ *in €ct / kWh*
Power $\boldsymbol{P}$ *in kW*

Electric Grid

$c_{b,t}^{min} = [27, 27, \dots]$
$P_{b,t} = [1000, \dots]$

$c_{b,t}^{max} = [Wholesale]$
$P_{a,t} = [1000, \dots]$

Building / PV / BSS

$c_{b,t}^{min,el} = [0,0, \dots]$
$P_{b,t}^{el} = [PV - Dem - BSS]$

$c_{a,t}^{max,el} = [30, 30, \dots]$
$P_{a,t}^{el} = [Dem - PV - BSS]$

$c_{a,t}^{max,heat} = [10,10, \dots]$
$P_{a,t}^{heat} = [Dem\ Profile]$

$c_{s,t}^{min,el} = [0, 0, \dots]$
$P_{s,t}^{el} = [Dem - PV - BSS]$
$cap_{st} = 120\ kWh$
$eff_{st}^{in} = 0.98$
$eff_{st}^{out} = 0.98$

PV Plant

$c_{b,t}^{min,el} = [0, 0, \dots]$
$P_{b,t} = [\ Irradiance\ Profiles]$

Building / Heat Pump

$c_{a,t}^{max,el} = [30, \dots]$
$P_{a,t}^{el} = [Demand\ Profile]$

$c_{b,t}^{heat} = [0, 0, \dots]$
$P_{b,t}^{heat} = [HP - Demand]$

$c_{a,t}^{el} = [0, 0, \dots]$
$P_{a,t}^{el} = P_{b,t}^{heat} / ratio$

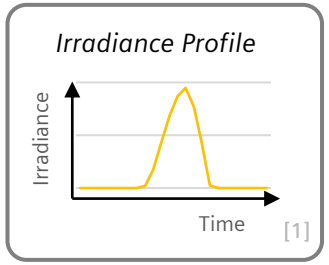
Coupling Type: Fix | Ratio: 4

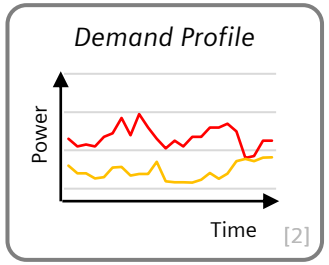
Res. Building

$c_{a,t}^{max,el} = [30, \dots], c_{a,t}^{max,heat} = [10, \dots]$
$P_{a,t}^{el,heat} = [Demand\ Profiles]$

District Heating Network

$c_{b,t}^{min} = [8, 8, \dots]$
$P_{b,t} = [1000, \dots]$





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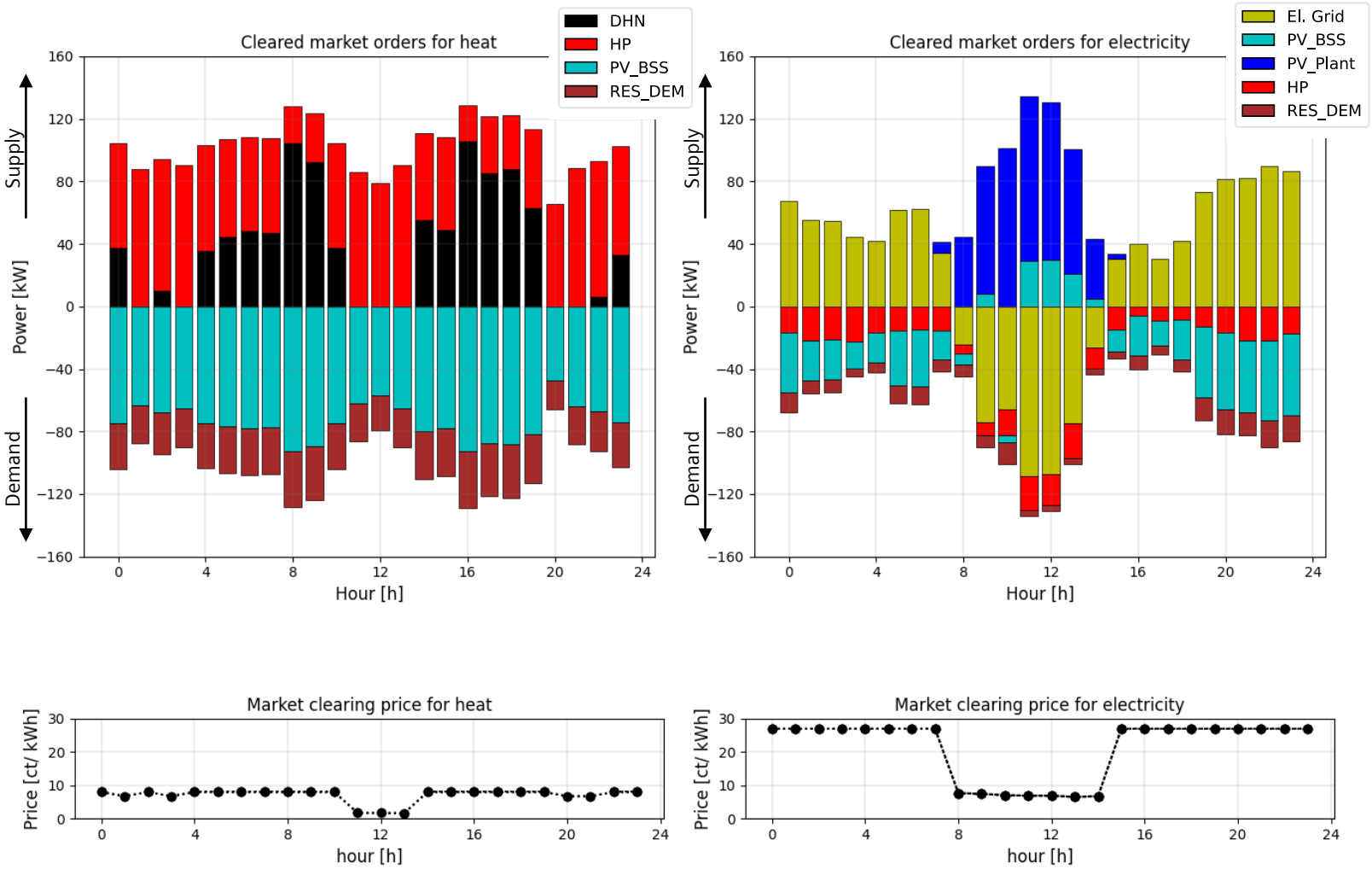
Exemplary Results
Coupling Orders for Heat Pump

- el. BSS is not offered on market
- **Electric System**: Generation of electric energy with PVs in timestep 8-14 leads to drop of market clearing price for electricity
- **Heat System**: Heat Pump (HP) has coupled ask order for electricity and bid order for heat with a ratio
  - $P_{HP}^{haet,gen} > P_{RES_{DM},PV\_BSS}^{heat,dem} \rightarrow c_{clear}^{heat} = \frac{c_{clear}^{el}}{ratio}$
  - $P_{HP}^{heat,gen} < P_{RES_{DM},PV\_BSS}^{heat,dem} \rightarrow c_{clear}^{heat} = c_{bid,DHN}^{heat}$

- Coupling orders enables holistic allocation of energy **considering availability and price of energy in electric and heat market**
- **Price risk** is omitted: HP only bids heat energy if market clearing price for el. energy is appropriate
- **Volume risk** is omitted: HP generates heat energy according to availability of electricity



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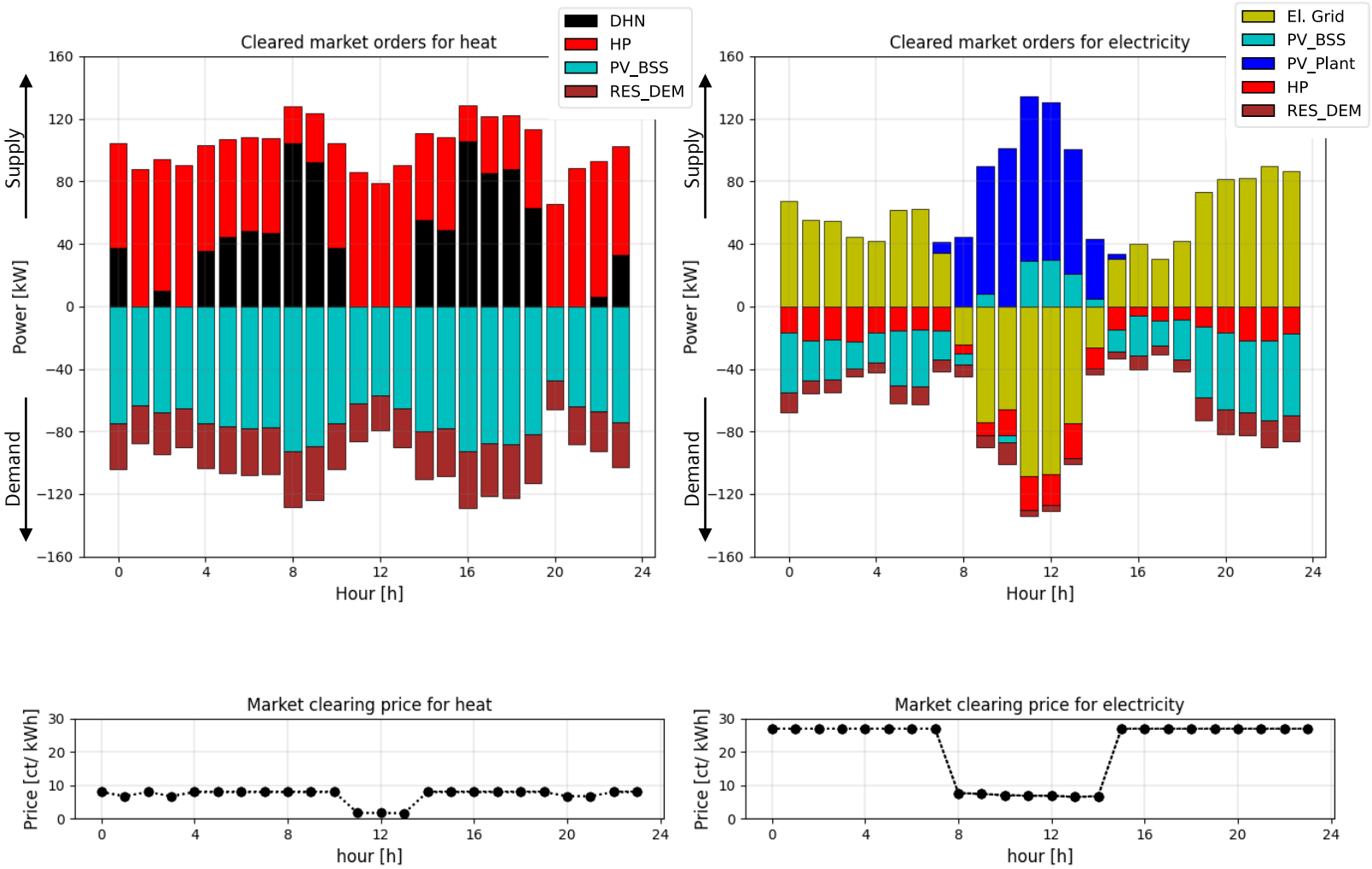

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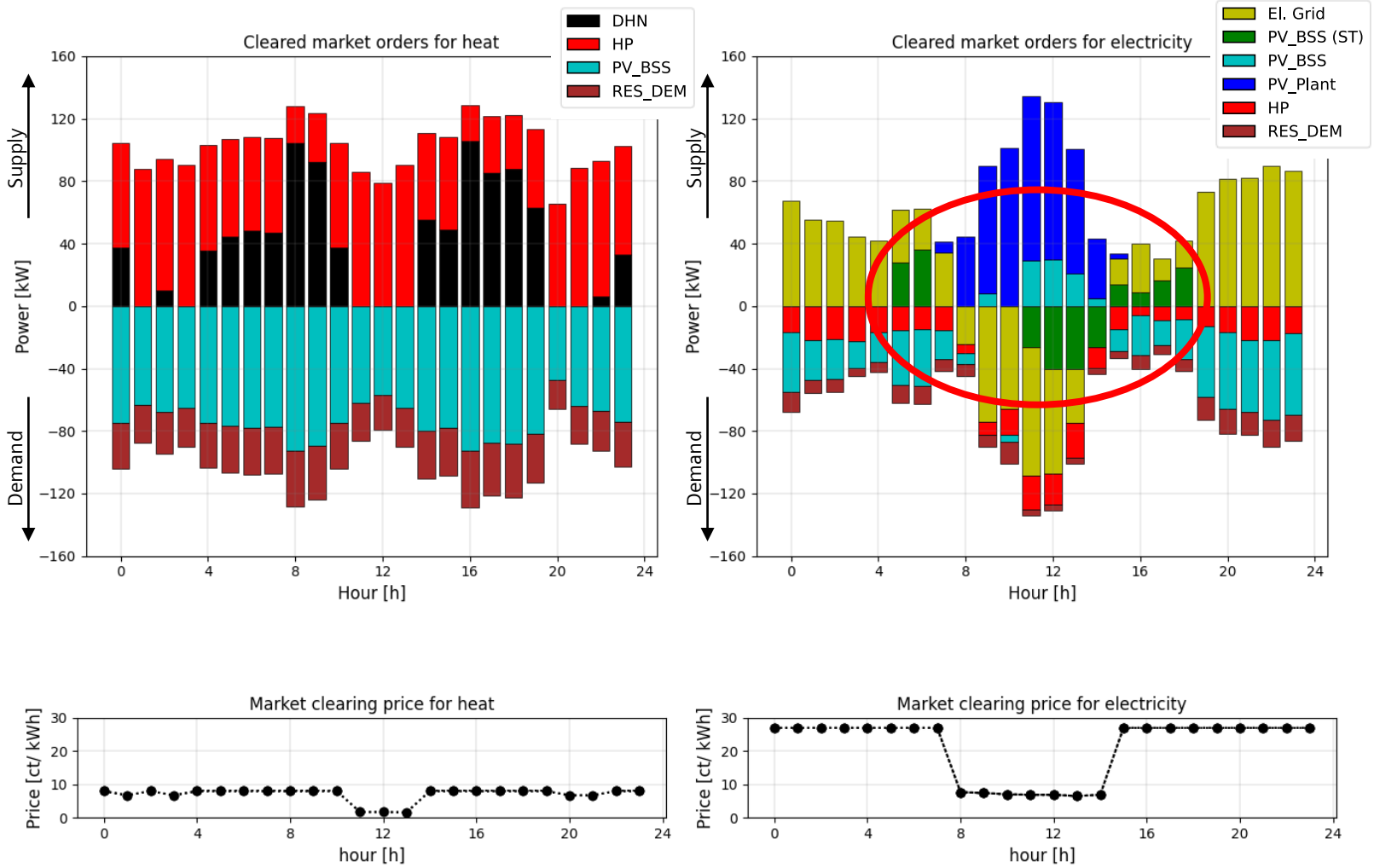
Exemplary Results
Storage Order for Battery Storage Systems

- PV_BSS offers el. BSS (120 kWh) on LEM
- **Heat System:** Storage order has no impact on market clearing heat price or cleared heat orders
- **Electric System:** market clearing price for electricity is unchanged
- **Impact on overlaying el. grid:**
  - ↘ Peak load drops by 18.1 %
  - ↘ Total exchanged energy drops by 16.5 %

- **Flexibility** of energy storage systems can be represented in market platform adequately with storage orders
- Enables **peak shaving** in multi modal energy system
- Increases **self sufficiency** of local energy system by use of local generation



BSS: Battery Storage System

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Conclusion
Local Multi Modal Energy Market | Coupling Orders | Storage Orders

Local Multi Modal Energy Market

- Market driven allocation of various energy sources and sinks considering underlying energy carrier
- Market order formulation enables integration of **versatile energy sources and sinks** with flexible, non-flexible, volatile or constant characteristics
- Depending on objective of the market (multiple) strategies can be pursued such as **max. welfare**, min. total carbon emissions, max. network fees, min. network losses

Coupling Orders

- Impacts **market clearing** for traded energy **taking into account availability and price** of involved energy carriers
- **Omits price and volume risks** for market participants with sector coupling assets such as heat pumps:
  - Prevents overbuying or overselling of energy for conversion
  - Prevents conversion of energy with economical deficiency (costs of bought energy > earnings of sold energy)

Storage Orders

- Enables market to consider **storage systems** such as electric battery storage systems
- Increase **self sufficiency of local energy system** of overlaying electric grid by decreasing consumed electric energy
  - Results in **peak shaving** at coupling point to overlaying electric grid

Local Multi Modal Energy Markets

Questions?

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