Modelling balancing service provision in 5th gen district heating systems

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Erik Fröhlich, Kerem Öncel, Dr. Annette Steingrube

Fraunhofer ISE

Introduction and research question

Research project „CLUE - Concepts, Planning, Demonstration and Replication of Local User-friendly Energy Communities“ investigates technological solutions for local energy communities in the electricity sector in different national subprojects

German subproject lead by Fraunhofer ISE in cooperation with eon and Fakt AG

Case study is Shamrockpark in Herne, a former industrial site from the coal mining company RAG which is now converted into a mixed used area with mostly commercial buildings.

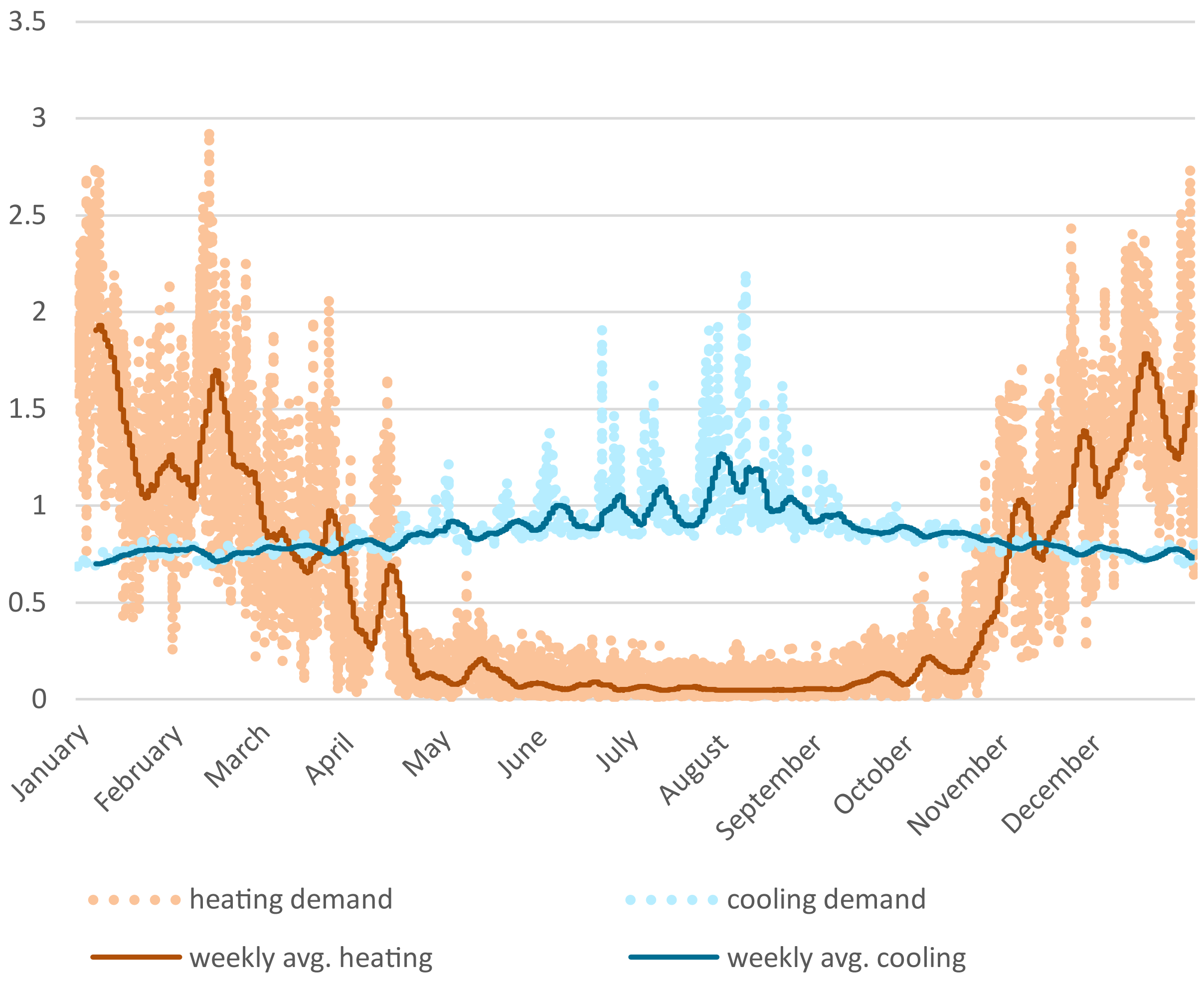
Scope of the project:

- Scientific support of the planning and implementation of the innovative energy concept with a LowEx heating network
- Evaluation of the advantages of the energy concept to gain insights for the optimization of planning and implementation of LowEx heating networks
- Active involvement of the stakeholders
- **Potential of this energy concept for the provision of flexibilities by the Shamrockpark district for the surrounding electricity system**

Source: [1]

Case study Shamrockpark – Specifications of the energy system

- 5GDHC [(1)] system: 22°C warm conductor, 12°C cold conductor
  - Heat sources: internal waste heat (LT) [(2)] , industrial waste heat (LT), gas boilers, district heating (HT) [(2)]
  - Building supply at different temperature levels through decentralized heat pumps
  - Passive cooling and compression chillers
- 72 % coverage of heat demand from low-temperature waste heat
- 45 % coverage of cooling demand through passive cooling using the cold conductor and utilization of waste heat



(1) 5th generation district heating and cooling (actually a subtype of 4th gen DH, according to IEA)

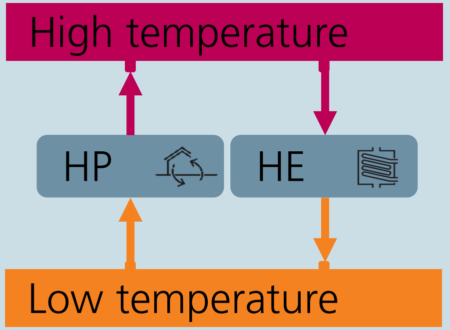
(2) LT: low temperature, HT: high temperature

The Shamrock Park energy system in the model

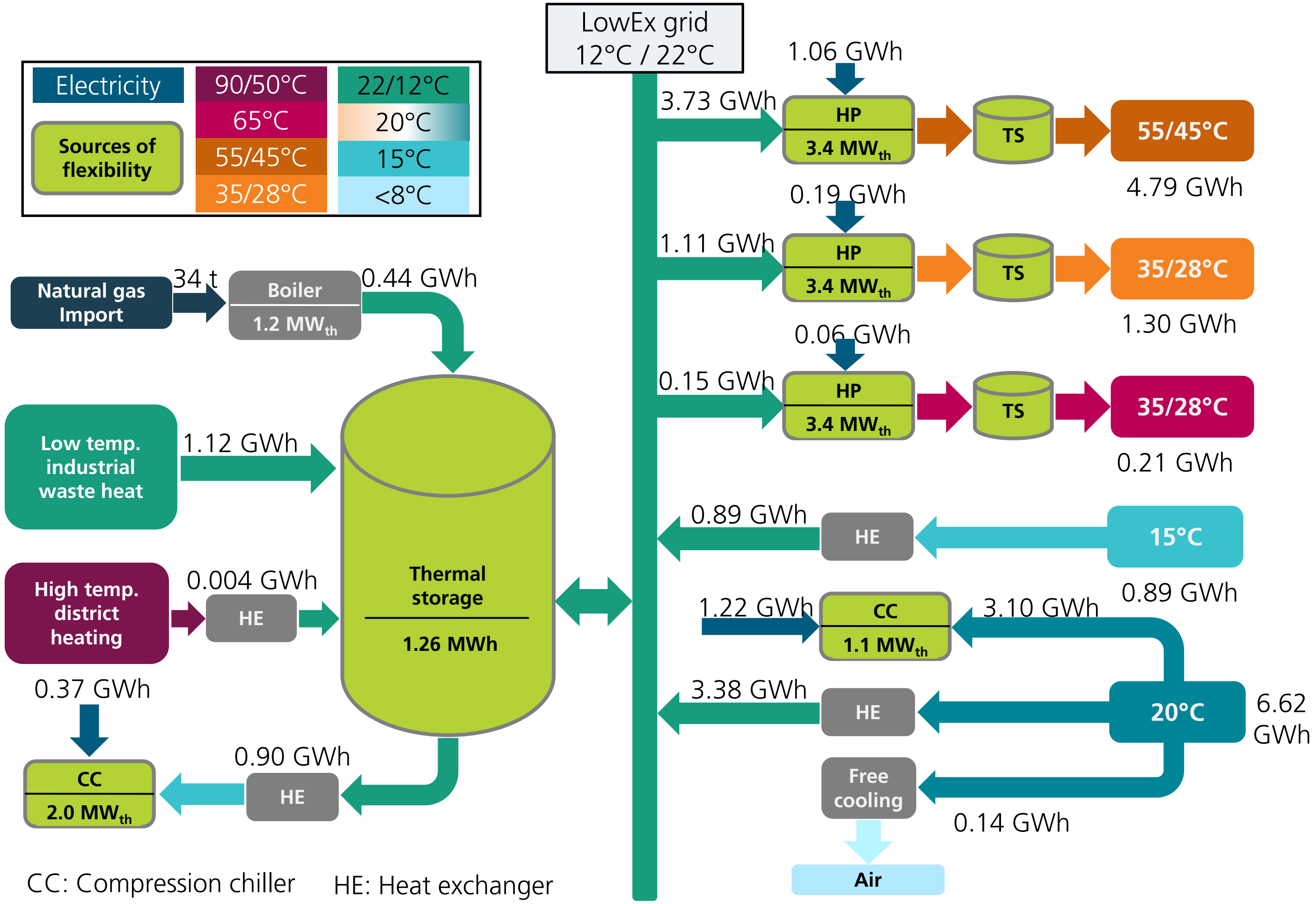
Optimization Model

- Linear Optimisation with lowest total energy system costs as target function (AMPL, Gurobi solver) [2]
- Hourly temporal resolution
- Sector-coupling (electricity, heating, cooling, transport, material flows)
- Calculations based on energy differences

Model extension



Temperature level coupling elements allow calculating energy balances for heating network



CC: Compression chiller

HP: Heat pump

HE: Heat exchanger

TS: Thermal storage

Advantages and disadvantages of the simplified model

Simplifications made in the energy system model

- Calculating only with energy differences
- Linear formulation
- The thermal demands are aggregated for each temperature level
- Electricity demands are aggregated as one node
- Hot water and cold water conductors are combined

Model advantages

- Optimization allows to find cost optimal energy system design as well as operation
- Comparably low computational effort
- Simple implementation of sector coupled energy systems
- Can be used to assess sensitivity w.r.t certain parameters

Model disadvantages

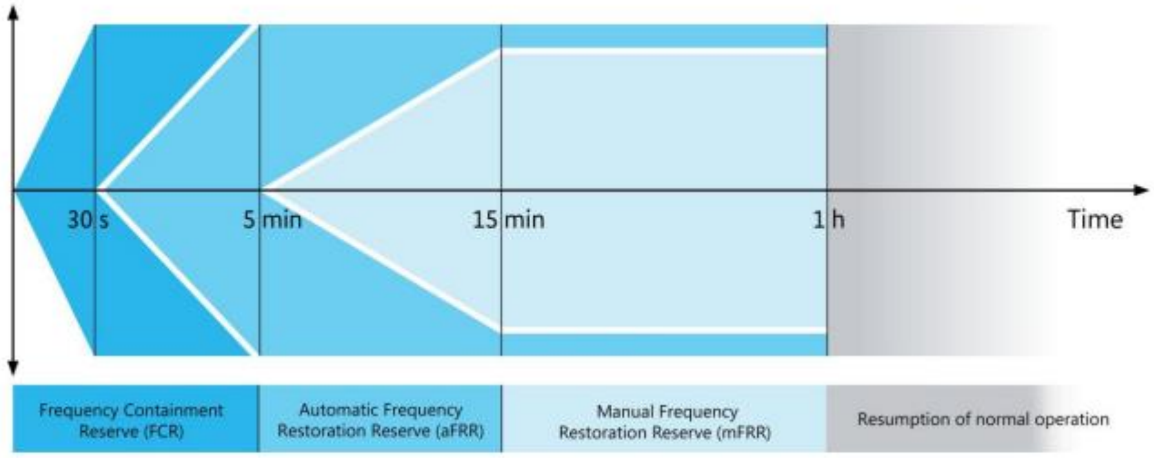
- Calculating with energy differences: No modelling of thermodynamic properties
- Linear formulation leads to simplified representation of the system
- In the optimization problem “perfect foresight“ is applied, optimal solutions might not be achievable

→ Model provides insights not a detailed energy system design

Control reserve for providing external flexibilities

Control reserve

- Serves to balance generation and consumption and maintaining a stable frequency in the power grid
- Different kinds of control reserve w.r.t time requirements are distinguished
- Positive and negative reserves are traded on separate markets for the different reserves



Source: [3]

Frequency Containment Reserve (FCR)

- Full activation in 30 seconds
- Automatic decentral activation proportional to grid frequency deviation
- Only capacity market, no distinction in positive / negative

automatic Frequency Restoration Reserve (aFRR)

- Full activation within 5 minutes
- Activation via digital control system by TSO
- Positive / negative reserves are traded separately
- Separation in Capacity and Energy market

manual Frequency Restoration Reserve (aFRR)

- Full activation within 12.5 minutes
- Activation via digital communication system (MOLS)
- Positive / negative reserves are traded separately
- Separation in Capacity and Energy market

Control reserve markets – description and conditions

	FCR	aFRR		mFRR	
	Capacity	**Capacity**	**Energy**	**Capacity**	**Energy**
Product length	4h	4h	15min	4h	15min
Gate closure	Day ahead	Day ahead	T - 25 min.	Day ahead	T - 25min
Products	Symmetric	Pos. + neg.	Pos. + neg.	Pos. + neg.	Pos. + neg.
Remuneration	Pay as cleared	Pay as bid	Pay as bid (but only if called)	Pay as bid	Pay as bid (but only if called)
Min. bid size	1 MW	1 MW	1 MW	1 MW	1 MW

Capacity market vs. Energy market

FCR and aFRR capacity:
- \+ remuneration even if not called
- – worst case: 4h of providing flexibility

aFRR energy:
- \+ **Flexible planning through later gate closure time and shorter bid slots**

mFRR:
- – Same market conditions as in aFRR but lower remuneration, only attractive for large slow systems

FCR vs. aFRR

FCR:
- – unsure if fast reaction times can be achieved in the system

aFRR capacity:
- – longer activation period means more reserve

aFRR capacity and energy:
- \+ bids can be placed on energy market independently of capacity market

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Control reserve markets – description and conditions

Only participation on aFRR energy market is modelled

	FCR	aFRR		mFRR	
			Energy	Capacity	Energy
Pr…			15min	4h	15min
G…			T - 25 min.	Day ahead	T - 25min
Products	Symmetric	Pos. + neg.	Pos. + neg.	Pos. + neg.	Pos. + neg.
Remuneration	Pay as cleared	Pay as bid	Pay as bid (but only if called)	Pay as bid	Pay as bid (but only if called)
Min. bid size	1 MW	1 MW	1 MW	1 MW	1 MW

Capacity market vs. Energy market

- \+ remuneration even if not called
- – worst case: 4h of providing flexibility

aFRR Energy:

- \+ Flexible planning through later gate closure time
- \+ Shorter length requires less reserves

mFRR:

- – Same market conditions as in aFRR but lower remuneration, only attractive for large slow systems

FCR vs. aFRR

- – unsure if fast reaction times can be achieved in the system
- – longer activation period means more reserve
- \+ bids can be placed on energy market independently of capacity market

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Modelling obstacles 1 - Remuneration only if called

Obstacle

Remuneration only if called: call probability depends on bid price and called reserves

Solution

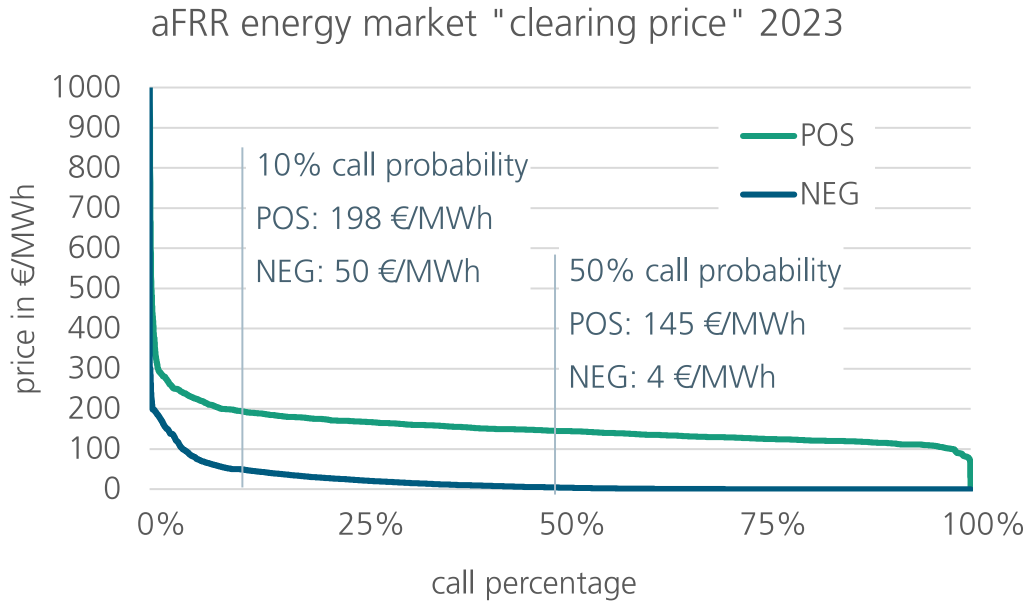
Statistic call probabilities based on historical data + different bidding scenarios

Pay as bid energy market with remuneration only if called

- Reserves are called starting with bids at lower prices
- Called amount of reserves are known in hindsight as well as the placed bids
- For each bid slot the bid with the highest price, that was called, can be calculated

→ „clearing price" can be determined using historical data

→



Modelling obstacles 2 – dealing with perfect foresight

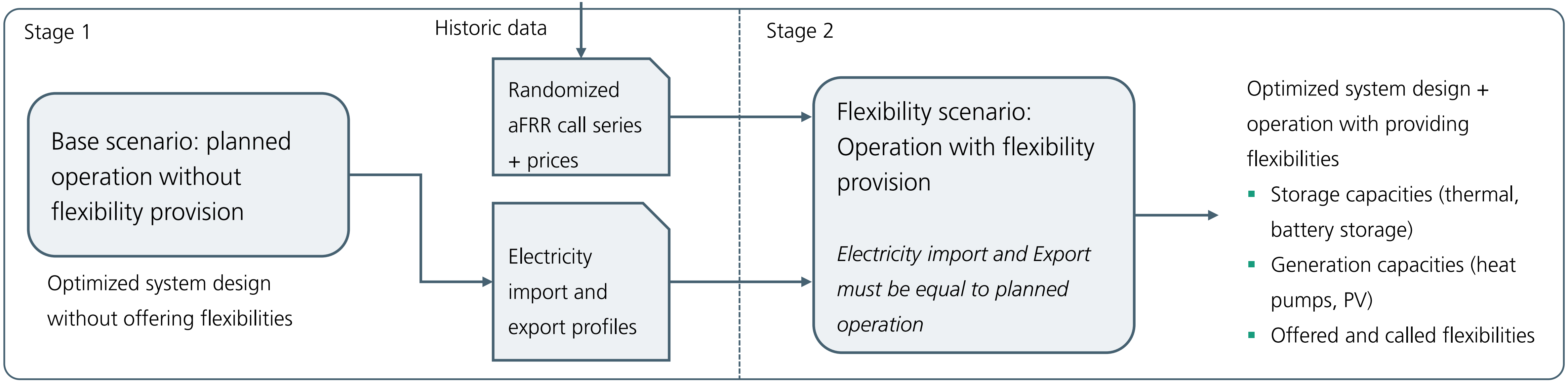
Obstacle

With „perfect foresight“ offering negative control reserve is used as cheap electricity import

Solution

Two stage modeling: first base scenario, then flexibility scenario

Modelling process



Modelling obstacles 3 – other obstacles

Obstacles		Solutions
Remuneration only if called: call probability depends on bid price and called reserves	→	Statistic call probabilities based on historical data + different bidding scenarios
With „perfect foresight“ offering negative control reserve is used as cheap electricity import	→	Two stage modeling: first base scenario, then flexibility scenario
Price for provision of flexibility is subject to changes	→	Historic prices are evaluated and a sensitivity analysis is conducted
Offered power must be above 1 MW	→	Aggregator is assumed to be in place

Results: most important findings

The **provision of balancing services** can be used to **reduce operating costs** of 5GDHC network

With **all-year heating and cooling demands** balancing services can be offered continuously throughout the year, but **only with sufficient decentral storages**

Extending thermal storages in order to increase flexibility for providing control reserves is **economically attractive**

Conclusion

Optimization problem aids to **find optimal design** for sector coupled 5GDHC energy system with **providing flexibility**

Quantifying the profits achievable through control power offerings is **difficult**

- Varying market prices, uncertainty of future developments, with small systems only indirect participation on markets possible
- Representation of bidding strategies / market environment in optimization tool difficult, also limited representation of energy system w.r.t to dynamic behaviour

By applying call probabilities and **calculating a “clearing price”** for aFRR calls the **economic potential of participating on the energy market can be assessed** and compared to other operation strategies

Next steps:

- Modelling participation on capacity market
- Modelling two other case studies

Thank you very much for your attention

Erik Fröhlich
erik.froehlich@ise.fraunhofer.de

References

[1] Gerhard Stryi-Hipp, Erik Fröhlich, Annette Steingrube, Philipp Fleischmann, Johanna Kucknat, Sebastian Gölz, Christoph Rademacher, Florian Bruskolini, Matthias Trockels, CLUE - MONITORING UND OPTIMIERUNG EINES ECTOGRID-ENERGIESYSTEMS MIT ERWEITERUNG EINES PLANUNGSTOOLS Abschlussbericht, Fraunhofer ISE, 2023.

[2] Jan-Bleicke Eggers, Das kommunale Energiesystemmodell KomMod, Dissertation, 2018.

[3] Bundesnetzagentur: This is how the electricity market works. Available from: https://www.smard.de/page/en/wiki-article/5884/5840.

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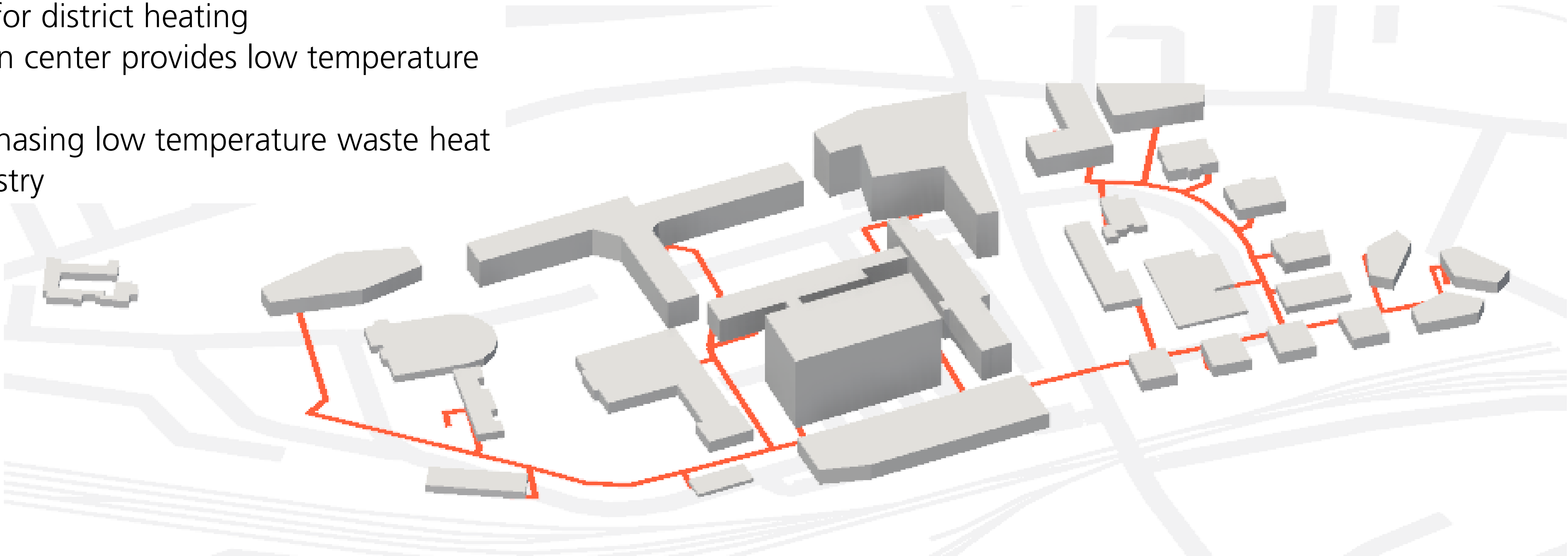
Appendix

Case Study Shamrockpark – Key facts about the neighborhood

- 200 apartment units in multistory buildings
- 500 persons
- Mostly new construction, small area of old building landmarks (Mulvany area)
- 27 supply points for district heating
- Small computation center provides low temperature waste heat
- Possibility of purchasing low temperature waste heat form nearby industry



Key competence: Energy system modelling

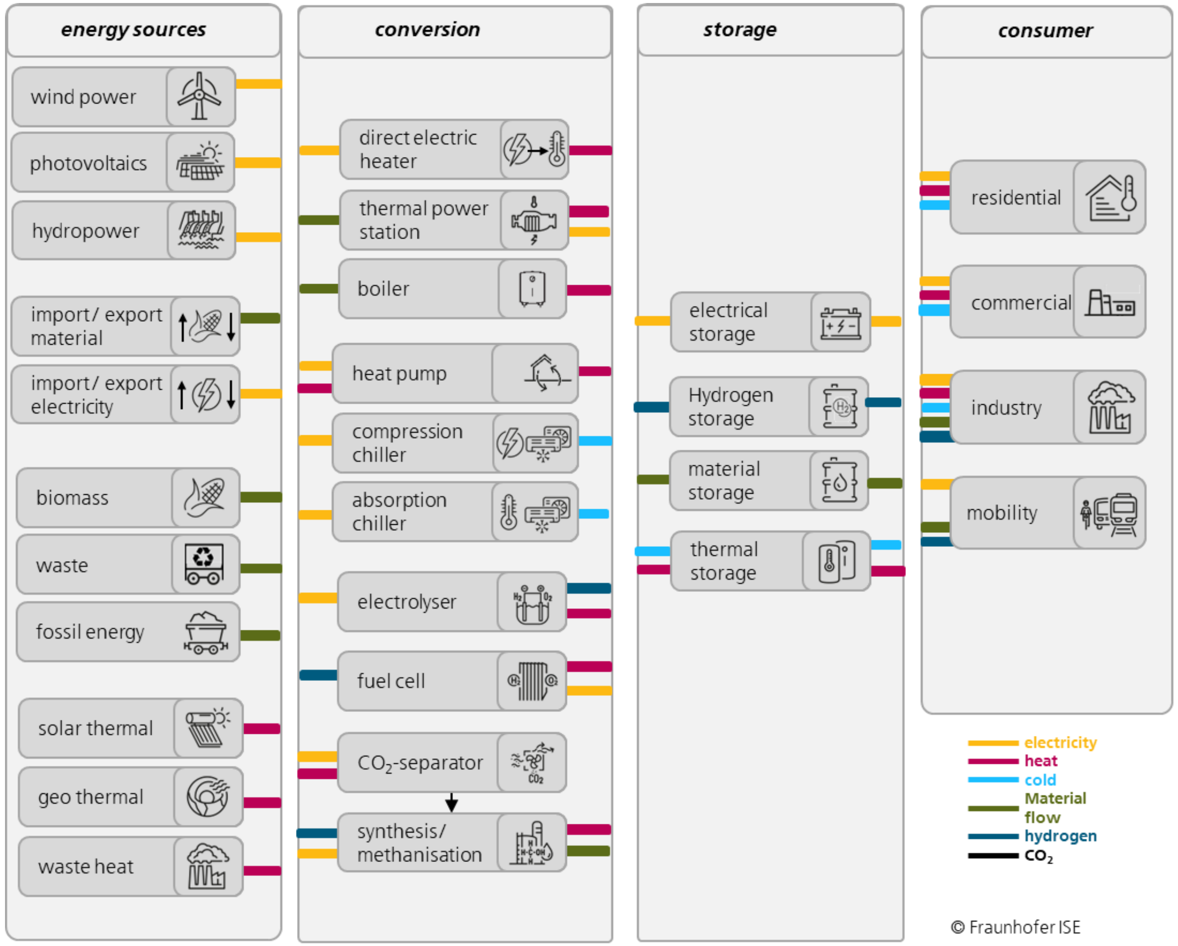
The Group developed the modelling tool »KomMod«

Key features of »KomMod*«

- Linear Optimisation with lowest total energy system costs as target function (written in Ampl)
- Hourly temporal resolution
- Sector-coupling (electricity, heating, cooling, transport, material flows)

Modelling output

- Cost-optimal **energy system design**
- Optimal **mix of different energy technologies**
- Generation and storage **capacities**
- Optimal **operation of technologies** depicted
- Remaining **energy import/export**
- Investment and operation **costs**



*KomMod = Urban Energy System Model

Die perfekte Vorhersagemöglichkeit des Optimierers führt also zu einer Überschätzung der Potenziale, die Fixierung auf den Planimport aus dem Basisszenario zu einer Unterschätzung.

Scenarios

First set of scenarios:
- Fixed price scheme
- Storage capacity optimized depending on aFFR provision
- Call rate of 100 %

Price variant	Thermal Storage variant	Description	Remuneration aFRR pos. in € / MWh	Remuneration aFRR neg. in € / MWh
0/0	Fixed	No renumeration, just savings	0	0
500/0	Fixed	Little renumeration	500	0
1000/500	Fixed	Lowest level of past three years	1,000	500
0/0	varied	No renumeration, just savings	0	0
500/0	varied	Little renumeration	500	0
1000/500	varied	Lowest level of past three years	1,000	500

Second set of scenarios:
- Price scheme of 2021
- Capacities optimized without provision of aFFR
- Call rate of 10 %

Name of scenario	Description
SC1	Base scenario
SC2	Thermal storage is optimized
SC3	3 MW PV, battery and thermal storage capacity optimized (no battery installed)

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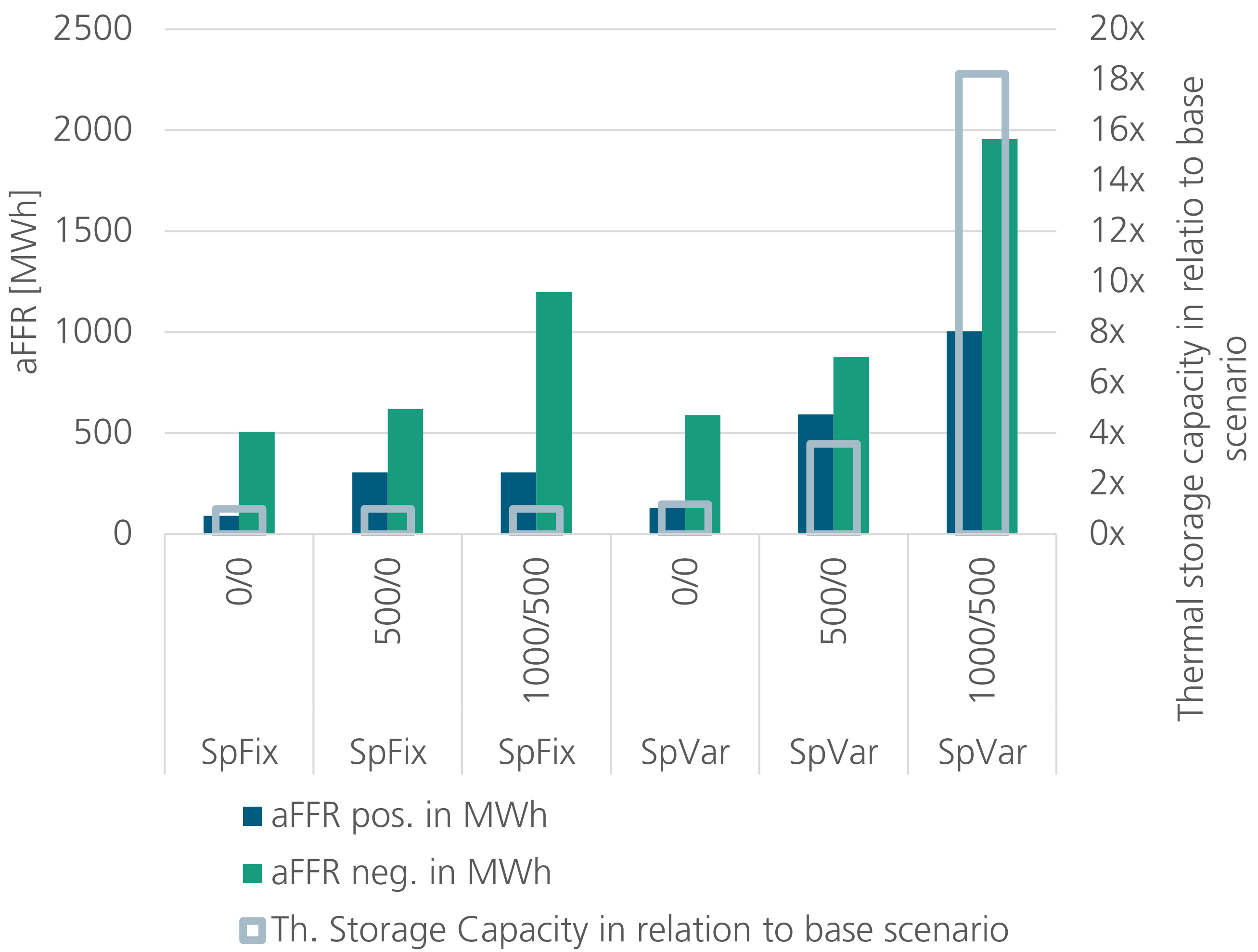
Results I

Offering balancing services at fixed price schemes without call rates

- Even with no or low renumeration levels balancing service is offered
- Seasonality: due to all-year cooling demands flexibilities can be offered continuously throughout the year
- Increasing storage capacities seems attractive but depends on call rate of flexibility and available space to build storages

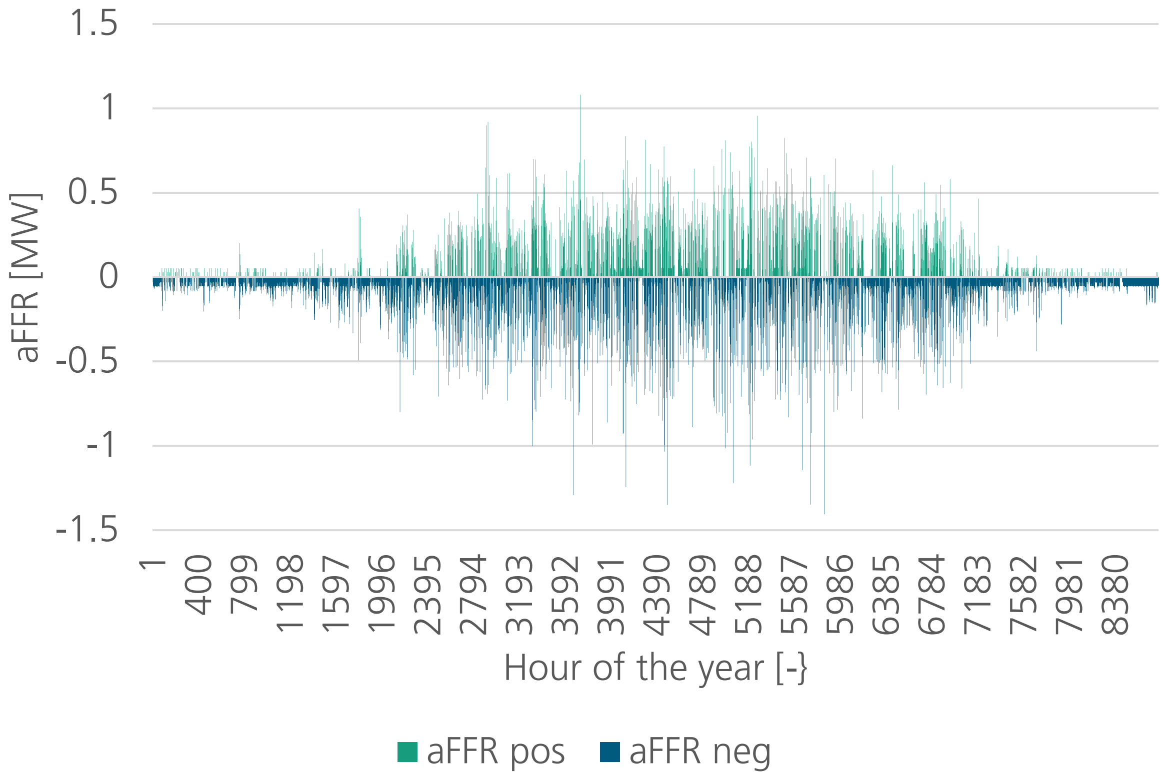
Price variant	Description	Remuneration aFRR pos. in € / MWh	Remuneration aFRR neg. in € / MWh
0/0	No renumeration, just savings	0	0
500/0	Little renumeration	500	0
1000/500	Lowest level of past three years	1,000	500



When is flexibility offered?

Scenario 500/0 Thermal storage fixed

- Overall more negative than positive flexibility is provided
- Provision of flexibilities is higher in summer months than in winter
- The available flexibilities are mainly the result of shifting electrical loads, adapting the operation of the CHP unit and changing the use of free cooling
- When installing more thermal capacity a more even provision of aFFR is possible (not shown)
- The minimum value of 1 MW which is needed to participate directly at the aFFR market is only reached a few times that year

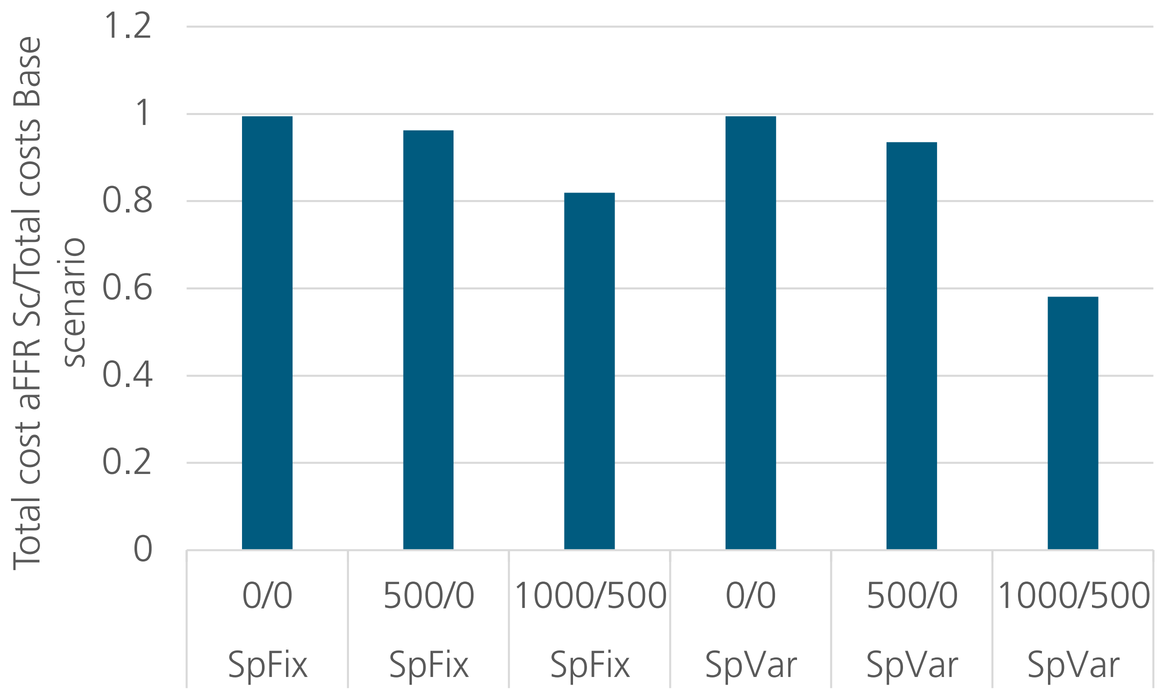


Results II

Offering balancing services at fixed price schemes

- Extending storage cpacity is especially attractive with higher prices
- Offering balancing services is profitable even on low remuneration levels,
  - But the assumption here is that all offered flexibility is provided
  - But: spacewise constraints can make storage expansion impossible

→ Call rates can help to have a more realistic picture on the probability that flexibility can be provided



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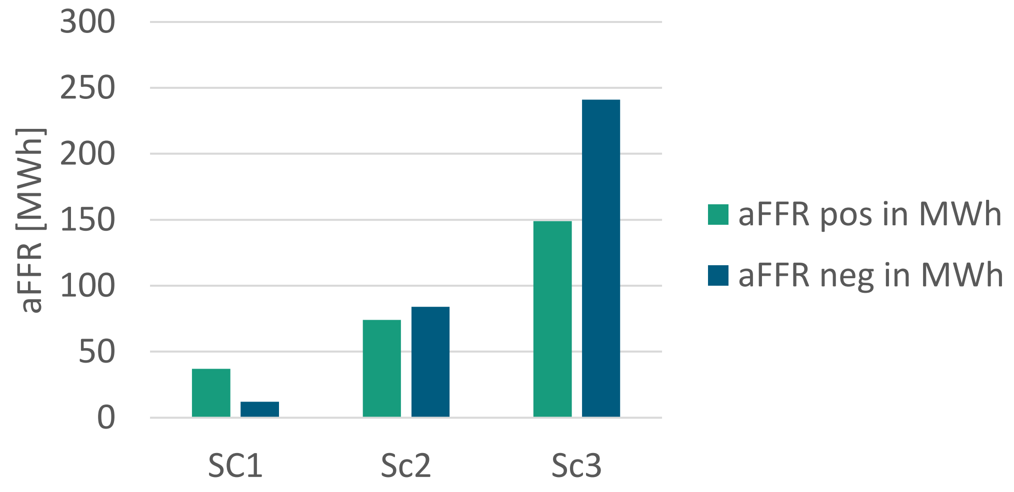
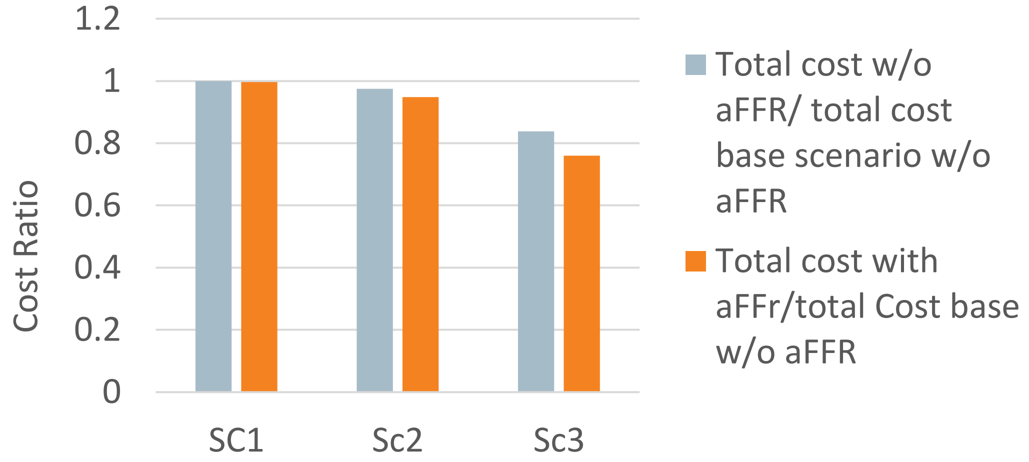
Results III

Offering balancing services at 2021 price scheme and a call rate of 10 %

- The energy system is optimized in the case without providing aFFR, then the aFFR scenario is calculated with fixed capacities
- Especially more electrical supply by PV in combination with higher storage capacities leads to provision of more flexibility and decreased costs, batteries are not installed
- Even without the provision of flexibility these measurements lead to lower overall system costs; providing aFFR could be an additional benefit

Name of scenario	Description
SC1	Base scenario
SC2	Thermal storage is optimized
SC3	3 MW PV, battery and thermal storage capacity optimized (no battery installed)

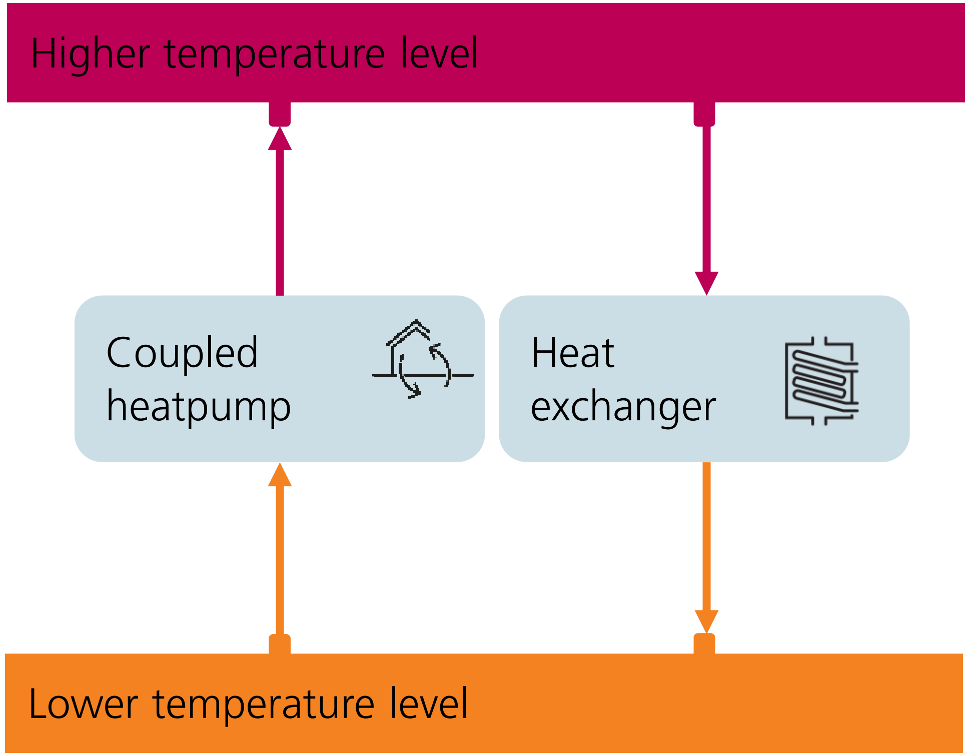




KomMod - extension

Adjustment of the model for representation of 5GDHC networks grids

- The KomMod model is a **single-node model**, but it is possible to form energy balances at different temperature levels.
- **Problem**: The temperature levels could not be coupled so far.
- **Extension**:
  - Calculations still based on energy differences (good performance)
  - Implementing a grid-coupling heat pump (including source balances)
  - Implementing a heat exchanger / temperature level coupler (simplified representation of heat exchanger + sign adjustment for coupling heat and cold nodes).




aFRR+/aFRR- Prices between 2021 and 2023
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
€/kWh
Jan 21
Mrz 21
Mai 21
Jul 21
Sep 21
Nov 21
Jan 22
Mrz 22
Mai 22
Jul 22
Sep 22
Nov 22
Jan 23
Mrz 23
Mai 23
Jul 23
Sep 23
Nov 23
Time
Positive
Negative

What amount of control reserve can be delivered for how many hours of the year?

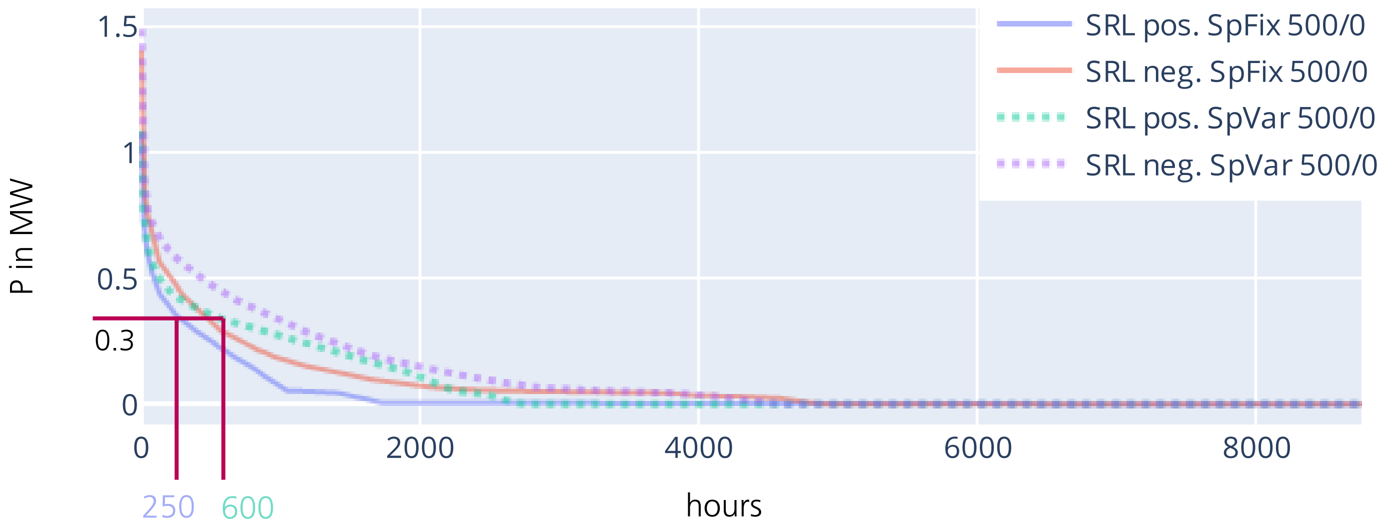


Figure 2: Results showing two different calculation variants for the provision of control reserve. At comparably low revenue levels of control reserve of 500€/MWh pos. and 0€/MWh neg. it is economically attractive to increase thermal storage capacities (+300%) to double the offered flexibility (SpFix: fixed thermal storages, SpVar: optimized storage capacities)

