THERMAL ENERGY STORAGE PLANTS:
A KEY TO UNLOCKING FLEXIBILITY AND SUSTAINABILITY IN THE ENERGY TRANSITION?

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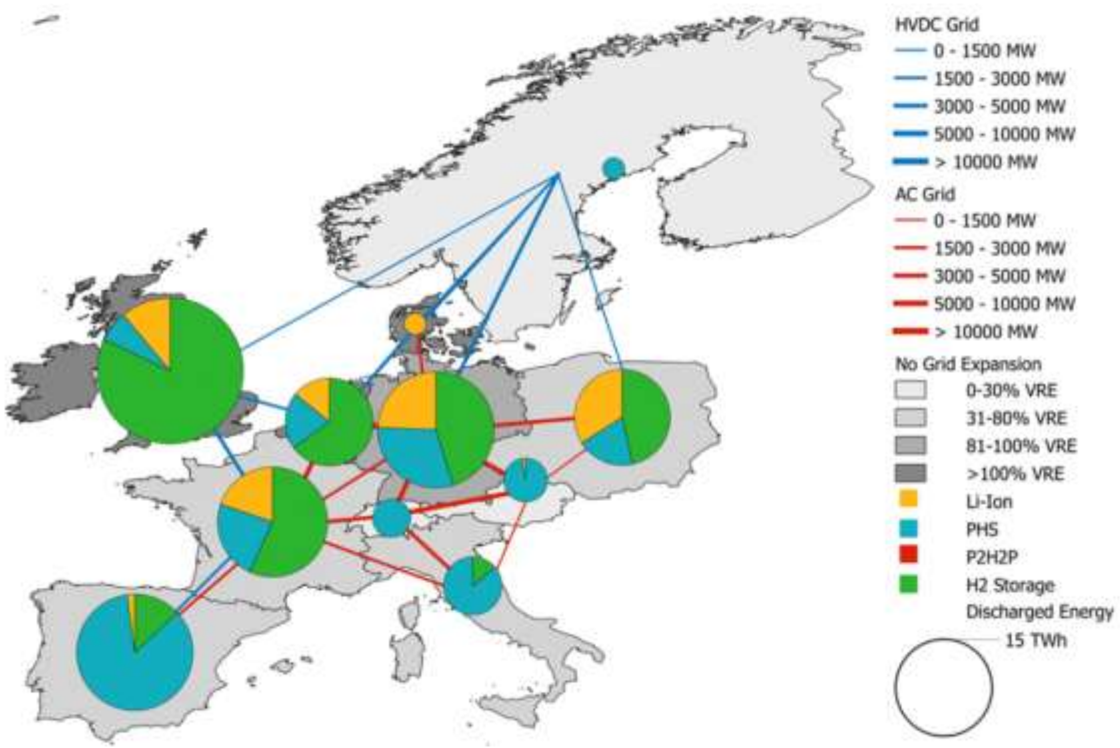
THE SYSTEM PERSPECTIVE

Energy systems analysis: examples

Storage expansion planning



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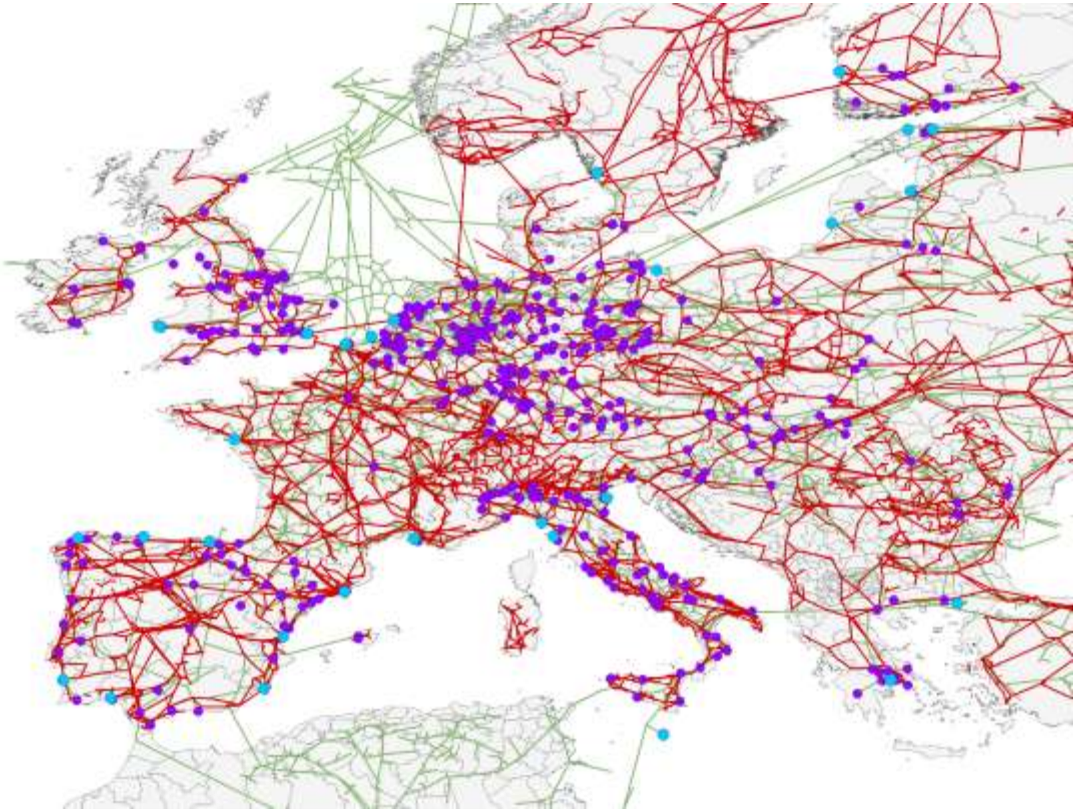
Joint European power and gas infrastructure



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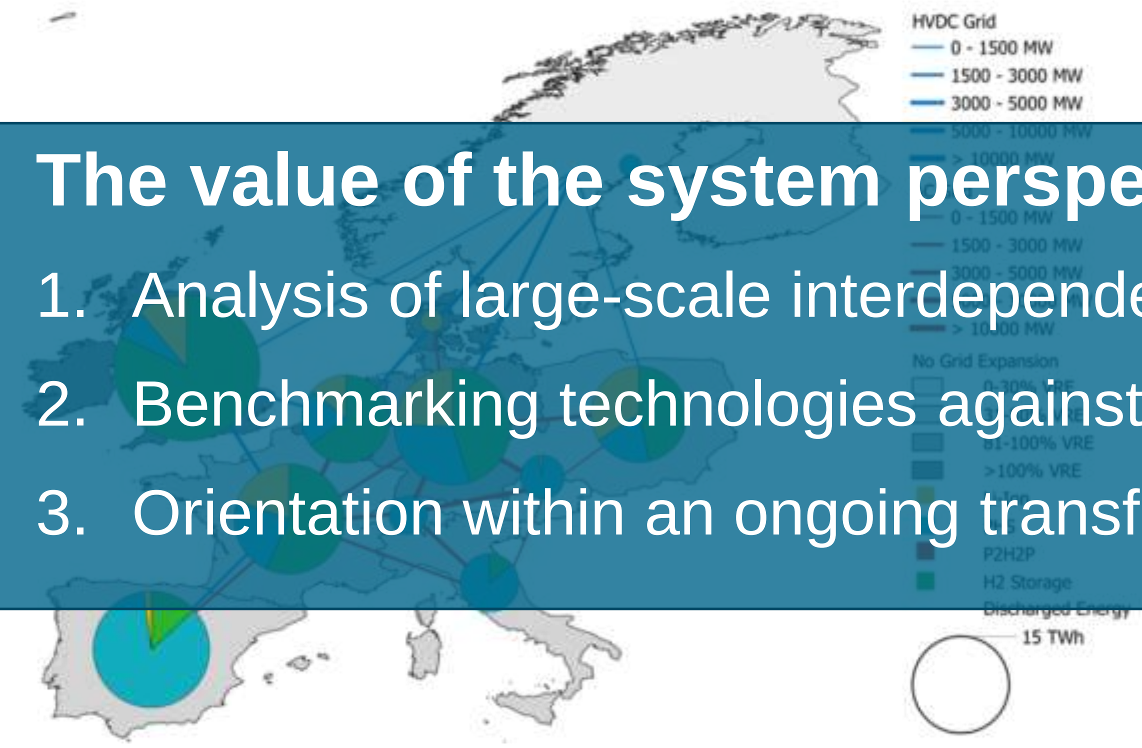

The value of the system perspective

1. Analysis of large-scale interdependencies
2. Benchmarking technologies against multiple alternatives
3. Orientation within an ongoing transformation

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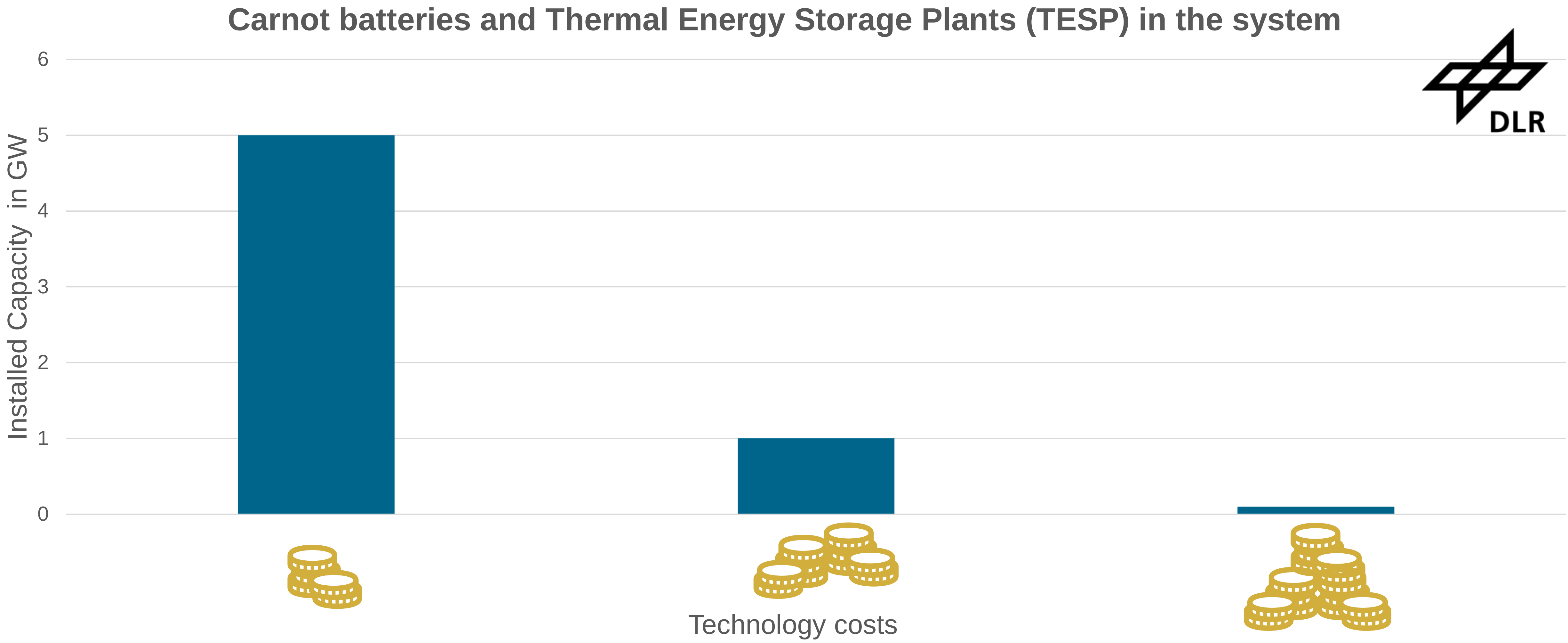
RESEARCH QUESTION

In which scenarios do **Thermal Energy Storage Plants** contribute to an affordable, secure and sustainable overall energy supply?



APPROACH 1: DESIREABLE COSTS

Model setup 1/2

Method	Optimization + Agent-based model
Sectoral scope	Electricity (incl. E-Mobility), heat, hydrogen
Technological scope	90 technologies
Spatial scope	22 regions, focus: Germany
Temporal scope	2050 (target year expansion, hourly dispatch optimization)
Scenarios (net zero)	1. Base 2. „Low electrolyzer flexibility“ (min. 6500h/a) 3. „No grid expansion“
Parameter variation for Carnot batteries	Converter cost: {100 … 400 €/kW(th)} Storage cost: {20 … 90 €/kWh(th)} Roundtrip eff.: {55%, 65%, 75%, 86%}
Carnot bat. strategies	Min. system cost | Max. profit

Blues: Research focus (ABM-Scope)
Grey: Within system boundaries (Optimizer Scope)
White: Outside system boundaries

Model setup 2/2

Scenarios

Input

- Demand scenarios
- Techno-economic data

Model coupling (iog2x)

Energy system optimization

REMix

Output

- Capacities
- RE feed-in
- Electrical demand

Electricity market simulation

AMIRIS

Output

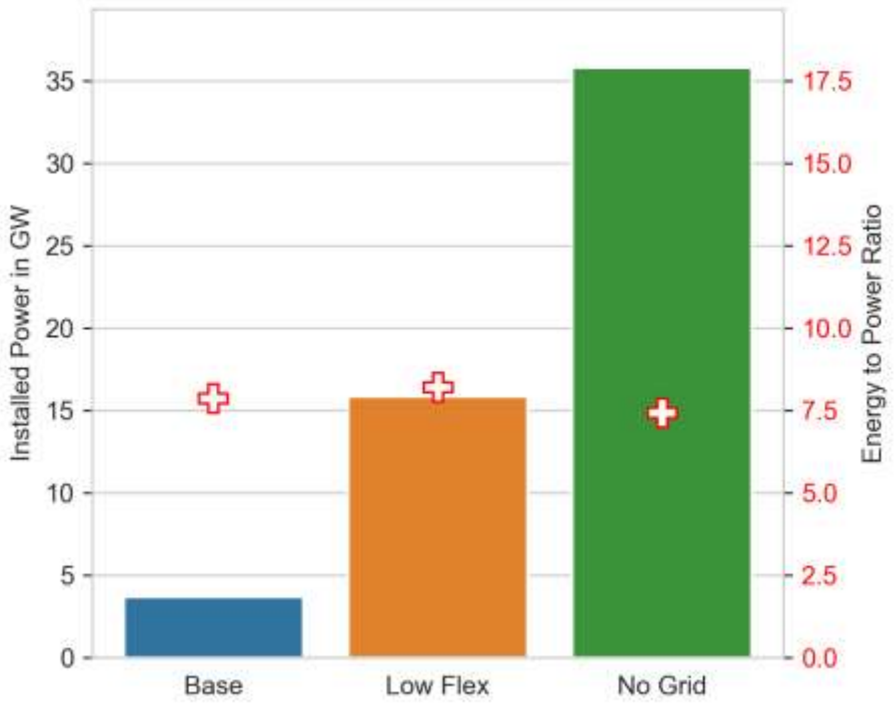
- Power plant and storage investment
- Spatial distribution
- Hourly dispatch
- Consideration of emissions limits
- Sensitivity analysis on system operation and grid investment

Output

- Electricity prices
- Market values
- Storage dispatch
- Impact of policy instruments

Results: Carnot batteries in the German electricity market

Total capacity of Carnot batteries and energy to power ratio (red framed crosses)



Carnot battery assumptions: 65% round trip efficiency, 150 €/kW, 20 €/kWh

Nitsch et al. (2024a). 10.1016/j.est.2024.110959

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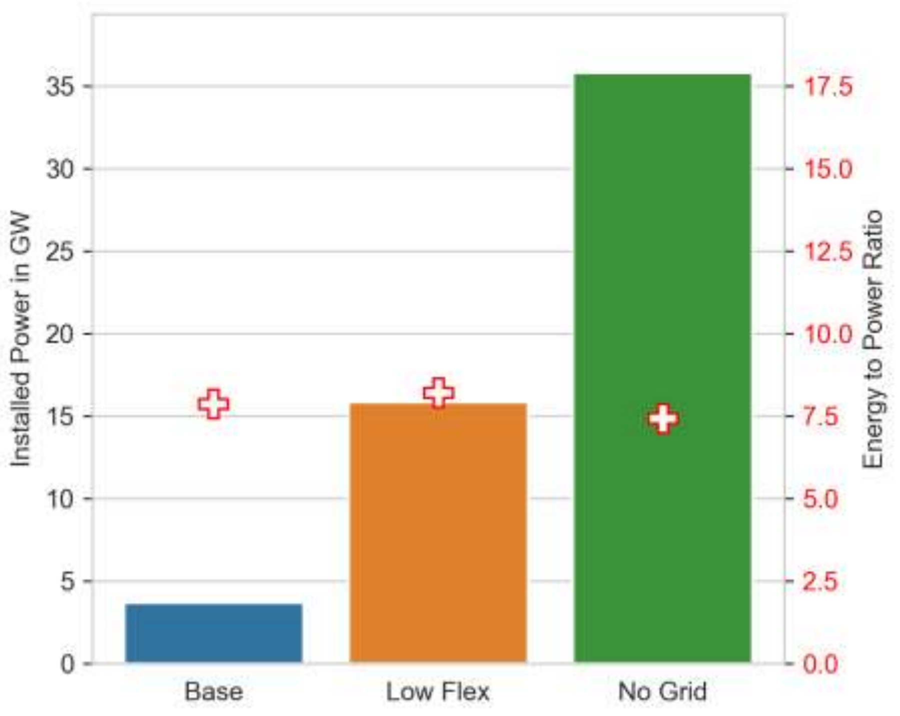
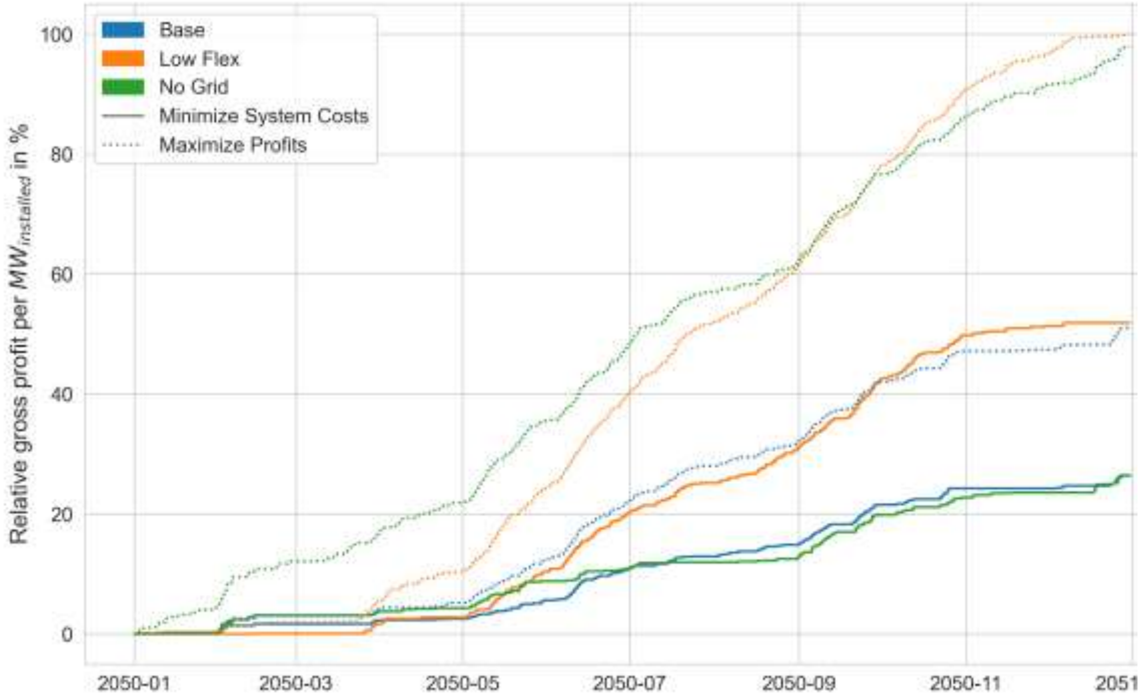


Relative gross profit per $MW_{installed}$



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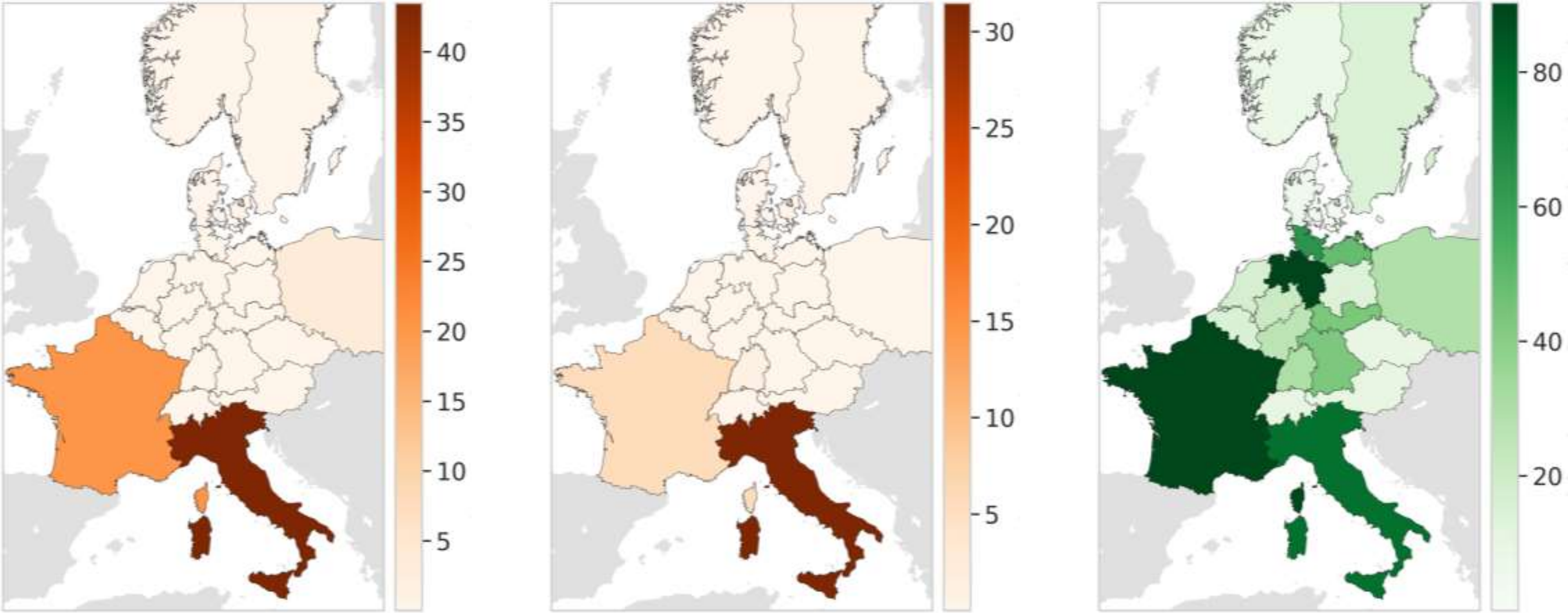
Competition of flexibilities: annual storage output in TWh



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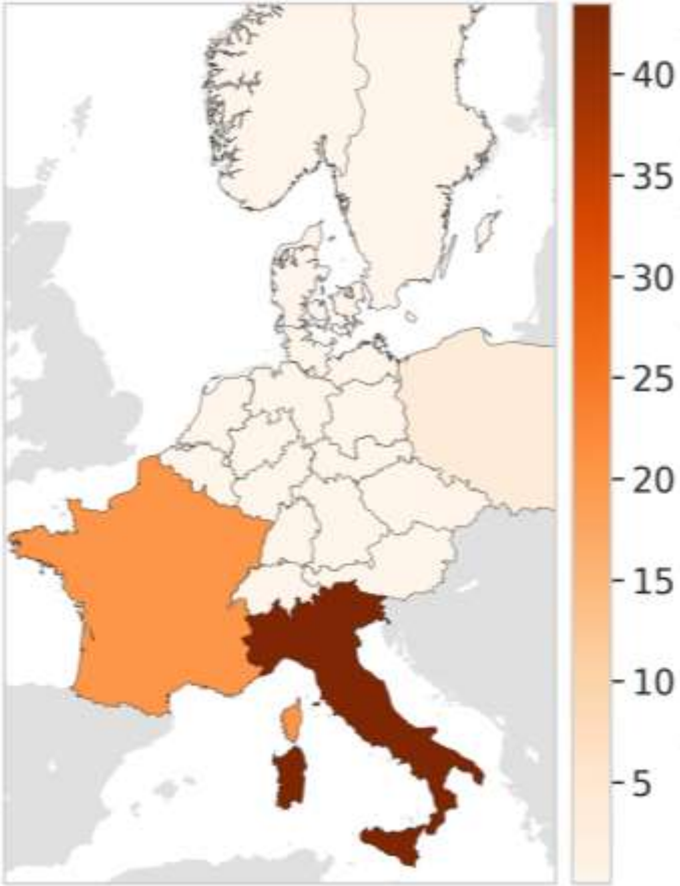
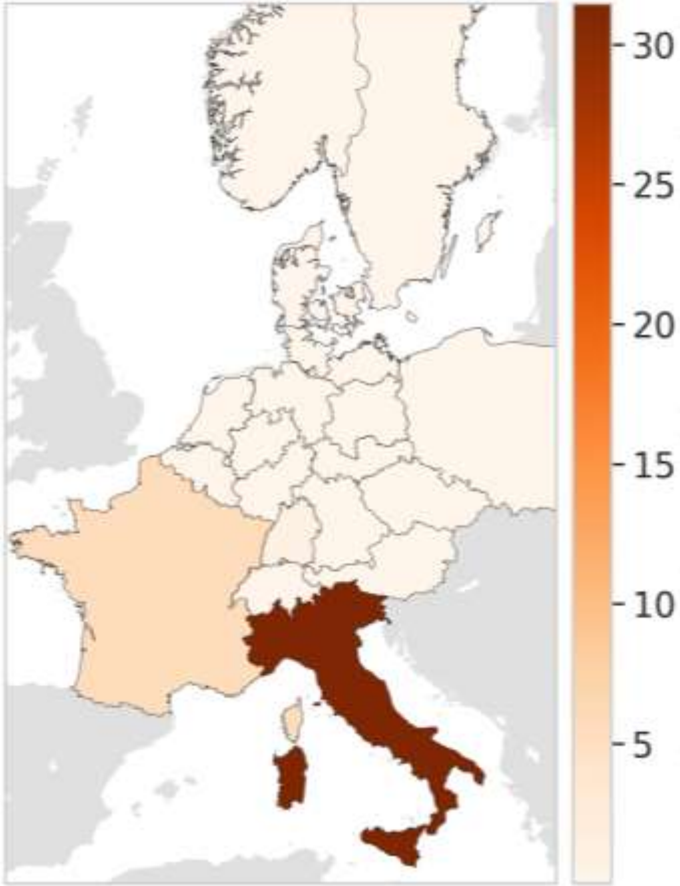
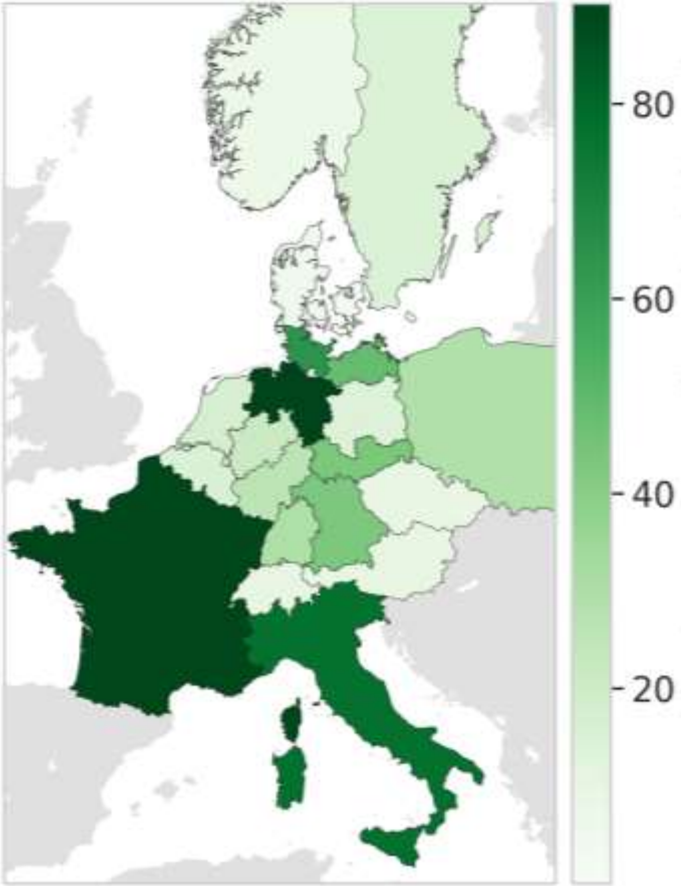


Lithium-ion battery

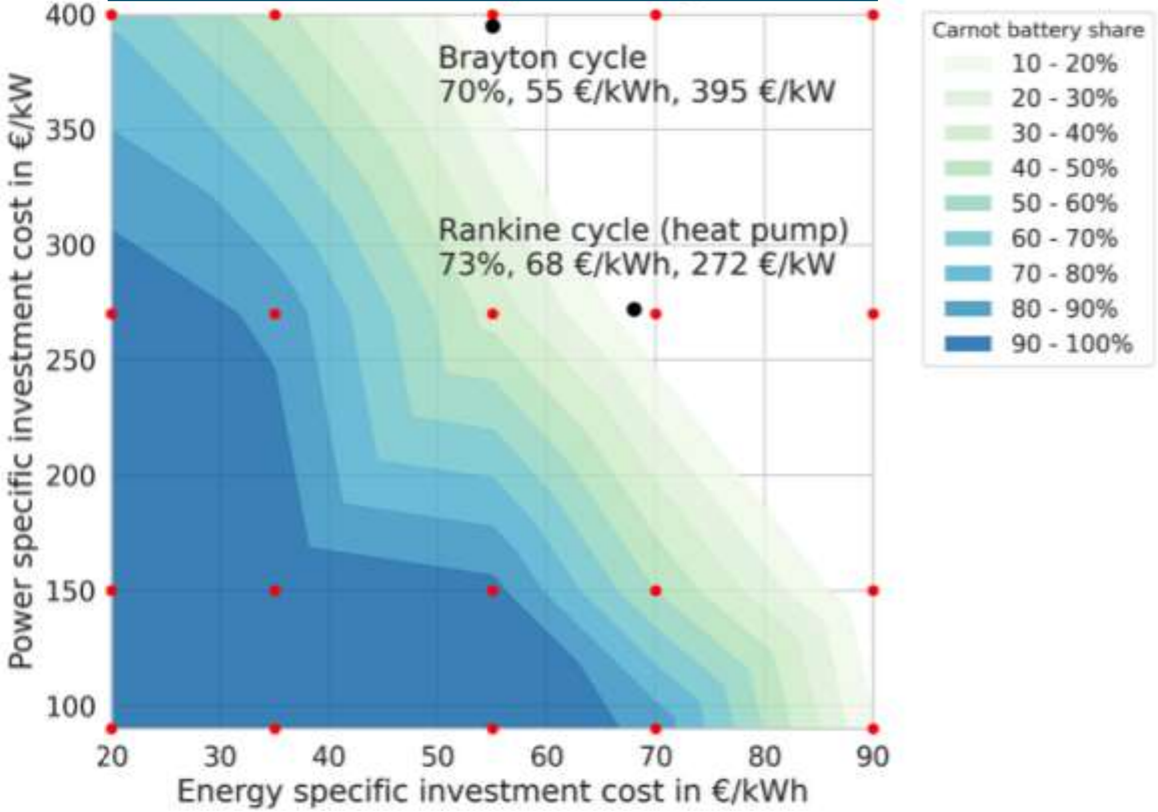


Hydrogen cavern



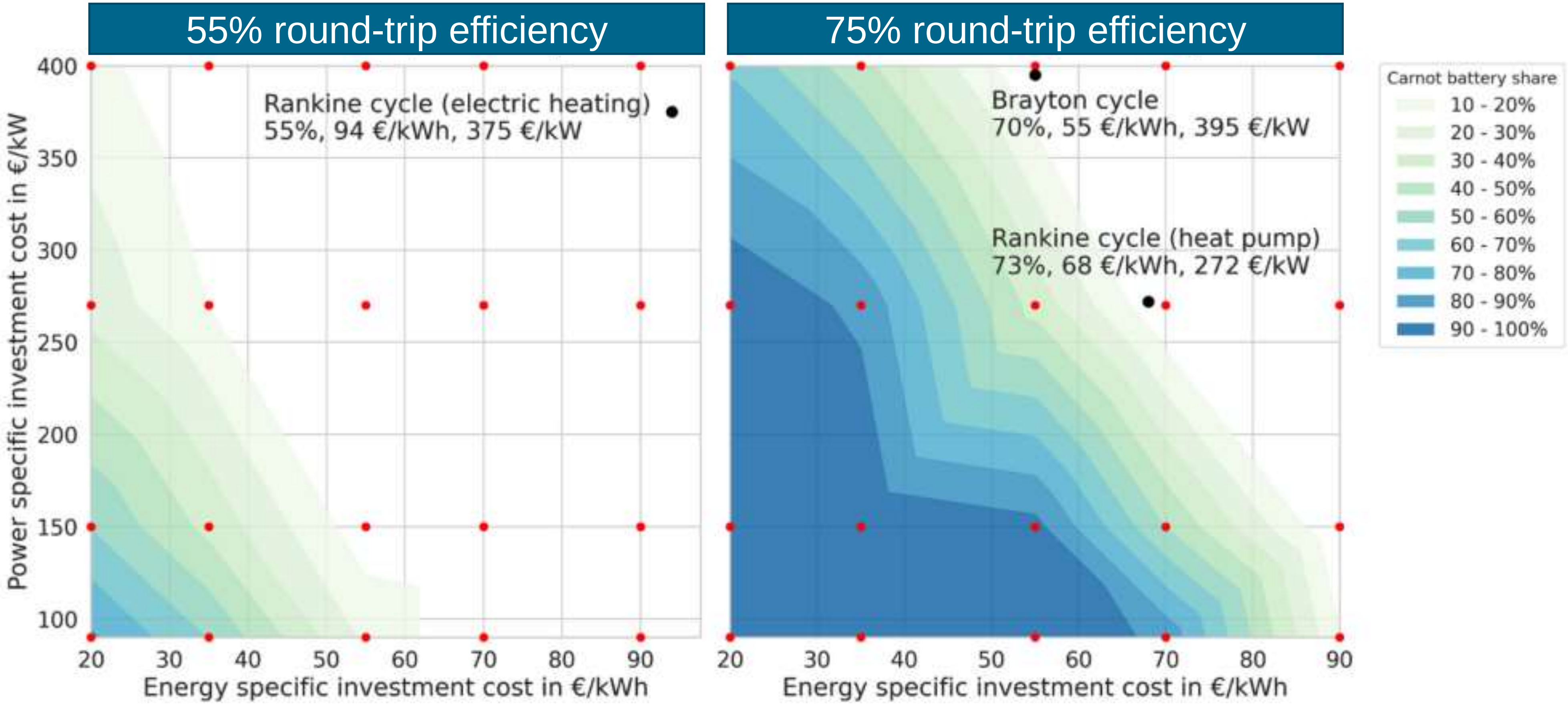
Specific costs for heat conversion and storage

75% round-trip efficiency



- **Red dots** indicate points of the parameter scan, **black dots** indicate state-of-the-art technologies

However…



- **Red dots** indicate points of the parameter scan, **black dots** indicate state-of-the-art technologies
- State-of-the-art so far not system-relevant, Brayton and Rankine (HP) promising candidates (black dots)
- Market introduction of Carnot batteries with **55% efficiency from 35 - 70 EUR / kWh** depending on power-specific costs

Approach 1: Discussion

Findings

- Decreasing cost for HT heat conversion is key (e.g., CAPEX today: ≥2000 €/kW[1])
- Other flexibility options are preferred (with “system planner’s cost minimization”)

[1]Y. Rahmat, J. Inigo Labairu, M. Roldán-Serrano, R.-U. Dietrich, S. Giuliano, Project Kohleatlas, 2024

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Limitations

- Carnot batteries treated as electricity storage only
- State-level resolution overestimates load balancing through grids
- Unlimited resources access

Potentially underestimating

- Not all potential flexibility options considered (e.g., controlled vehicle charging)
- No hydrogen imports
- Simplified plant operation (no dispatch restrictions and costs)

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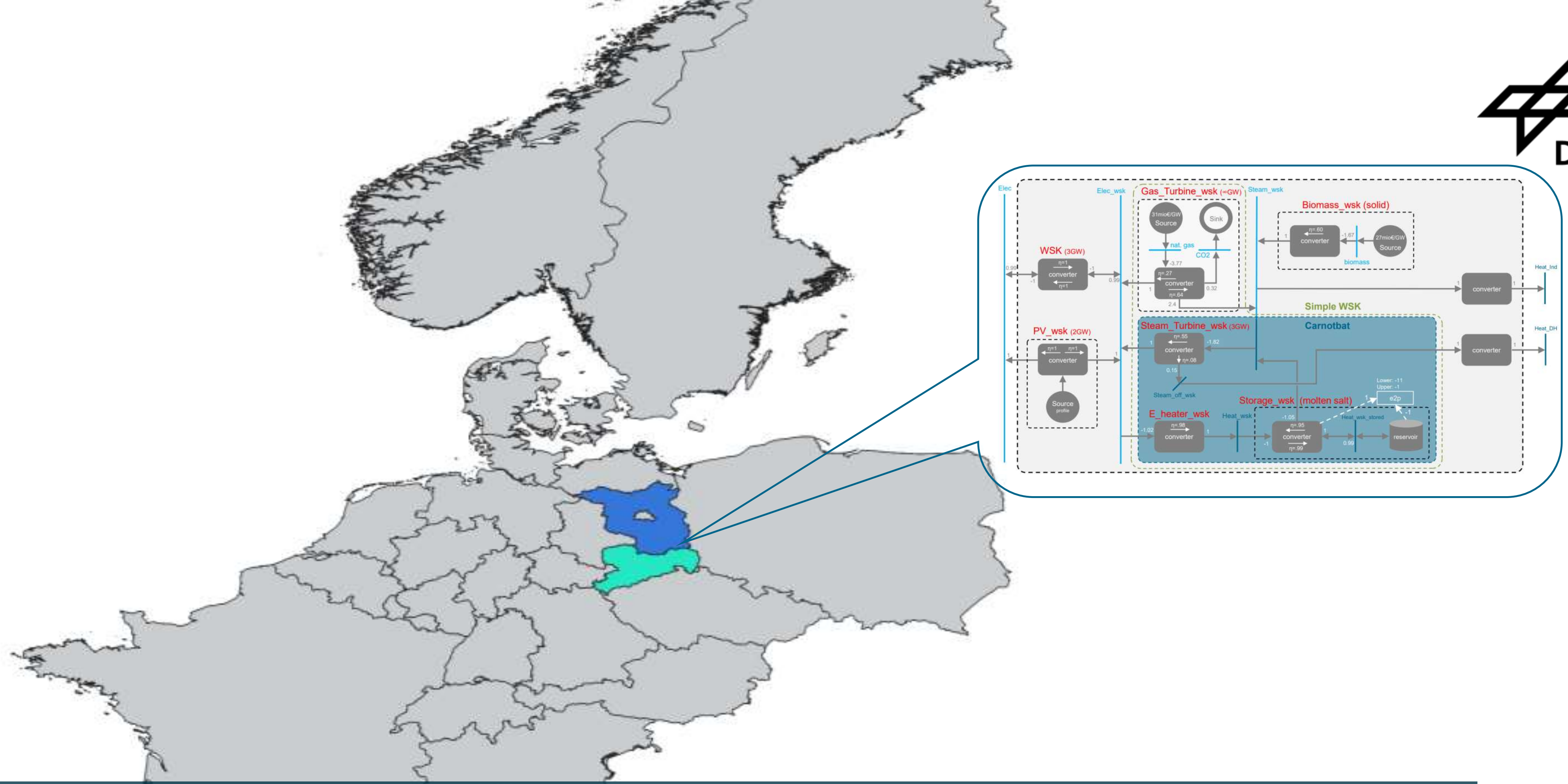
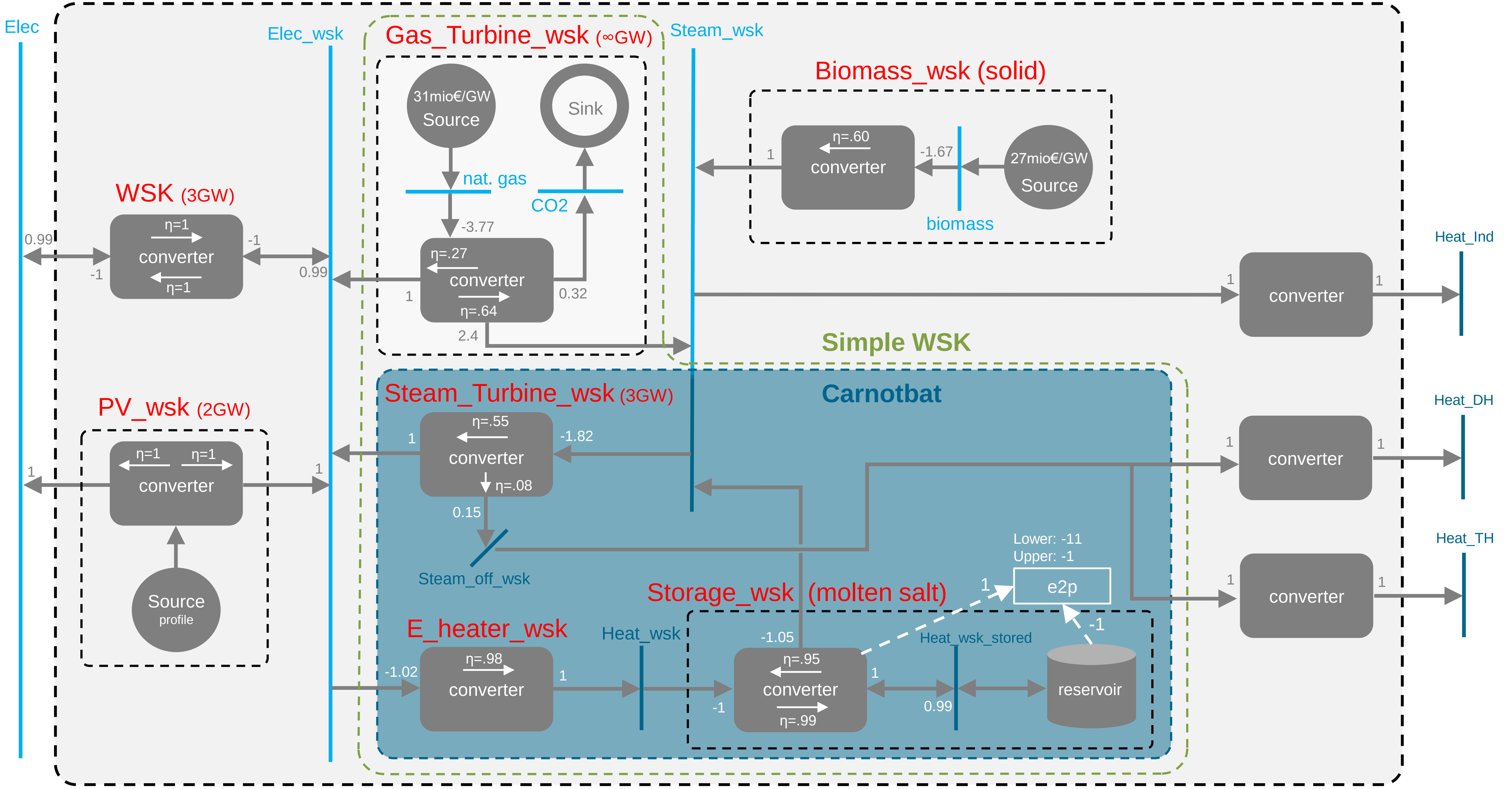


APPROACH 2: „INCREASING THE DETAIL“

Turning TESP into decarbonized CHP



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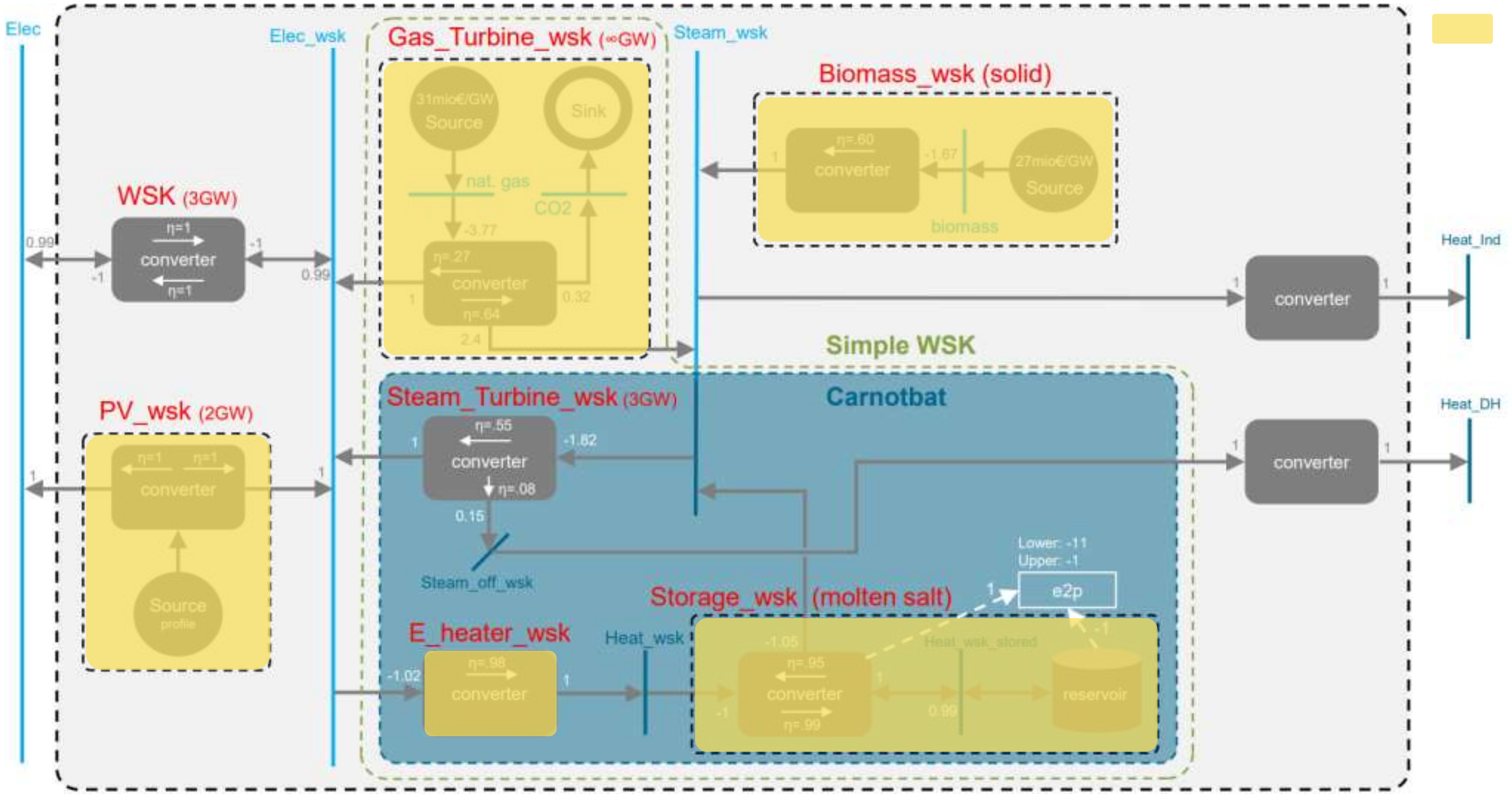


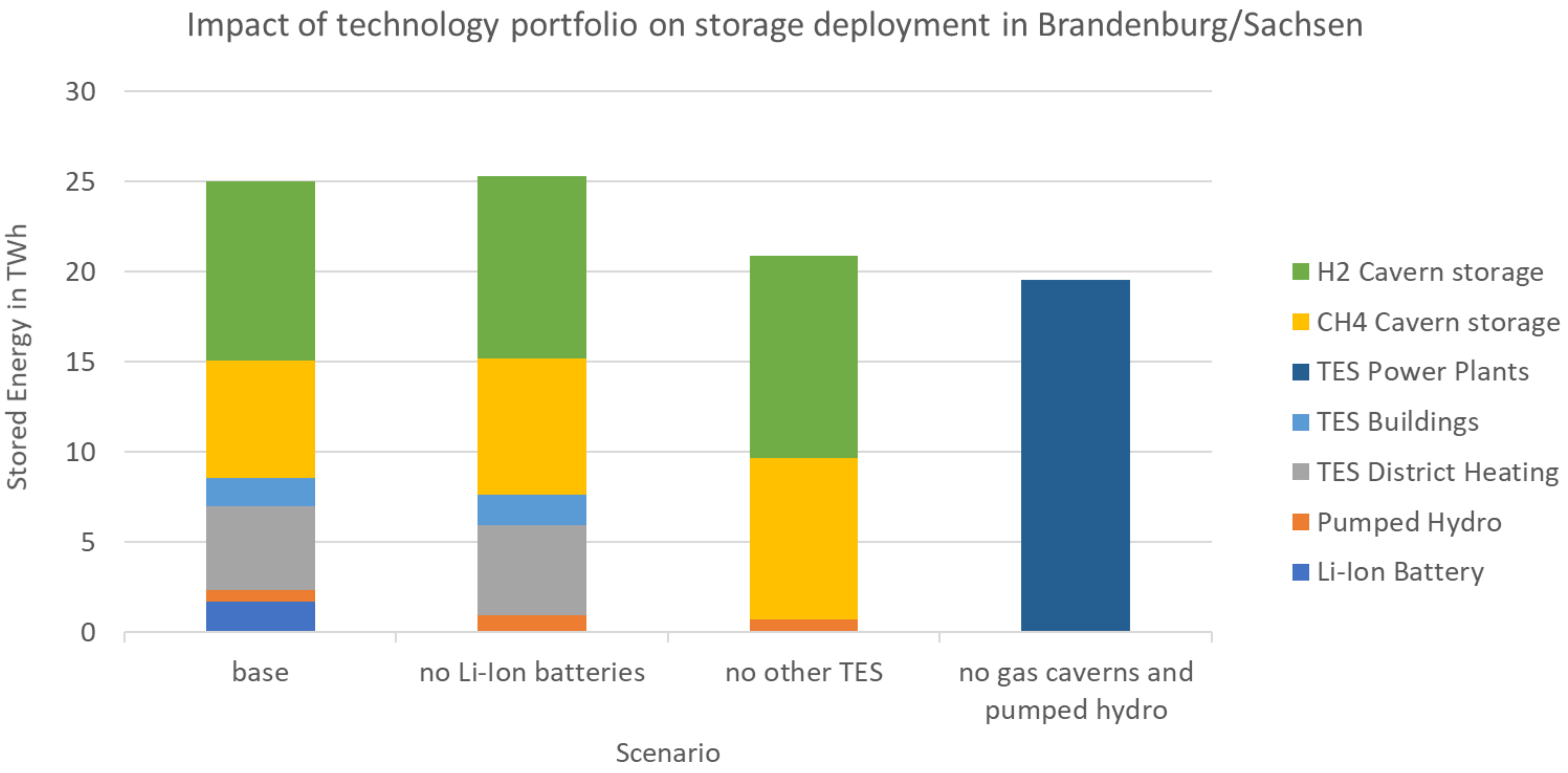
Expansion planning

Approach 2: model setup

Method	Optimization
Sectoral scope	Electricity (incl. E-Mobility), heat, hydrogen
Technological scope	90 technologies
Spatial scope	2 regions, focus: Lausitz
Temporal scope	2050 (target year expansion, hourly dispatch optimization)
Scenario (net zero)	Transforming lignite plants in the Lausitz region
Assumptions	CAPEX thermal storage unit: 56 €/kWh TESP supply local district heating demand No cost for steam turbines (3 GW existing) η: operating point independent
Variations	Stepwise removing other storage options

: Research focus, transforming existing plants
: Outside system boundaries

Result: converting Lausitz power plants into TESP?



Approach 2: Discussion

Findings

- Model prefers other technologies for both heat and electricity storage

Limitations

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- ~~Carnot Batteries treated as electricity storage only~~
- State-level resolution overestimates load balancing through grids
- Unlimited resources access
- Limited spatial scope

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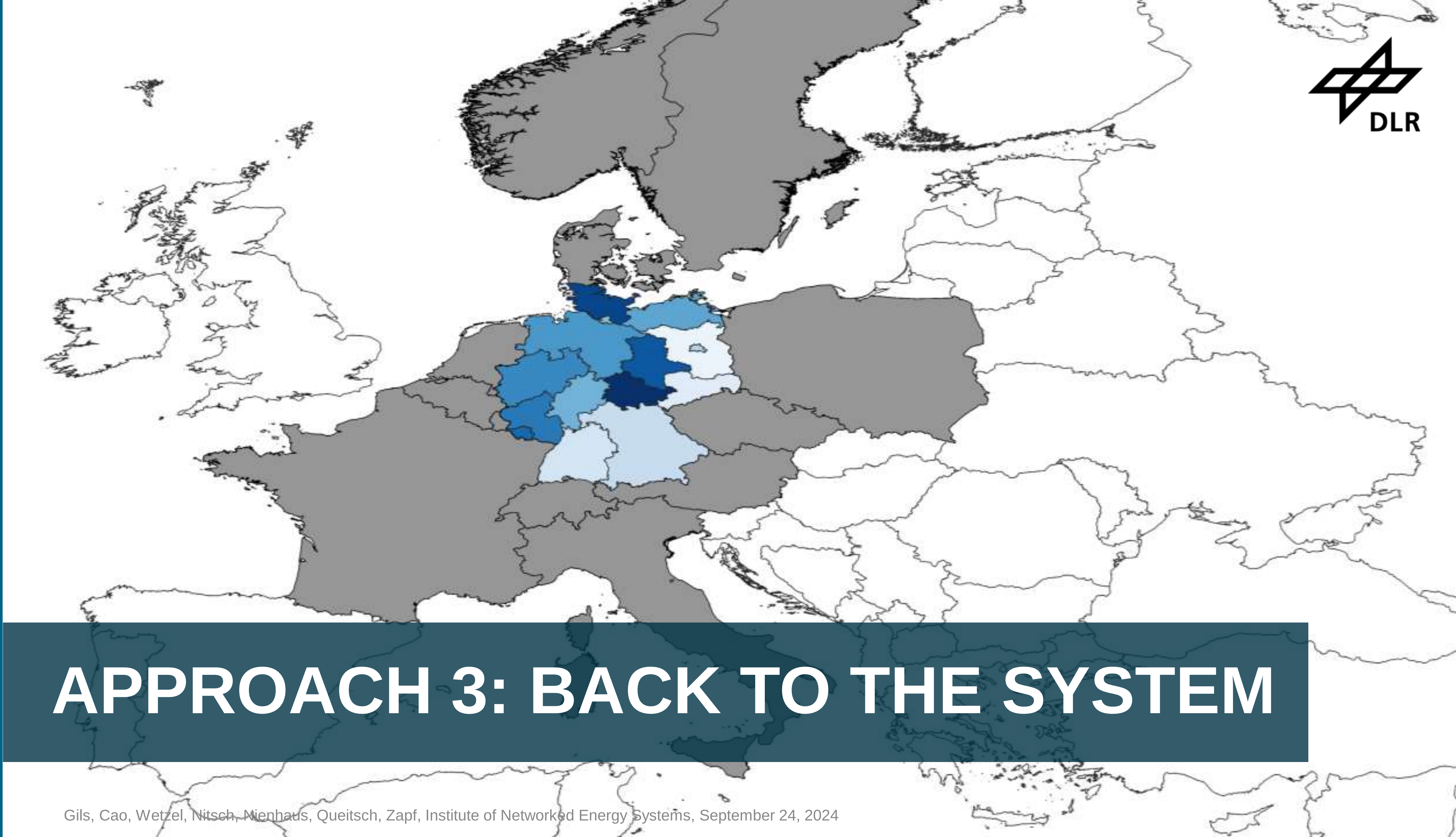
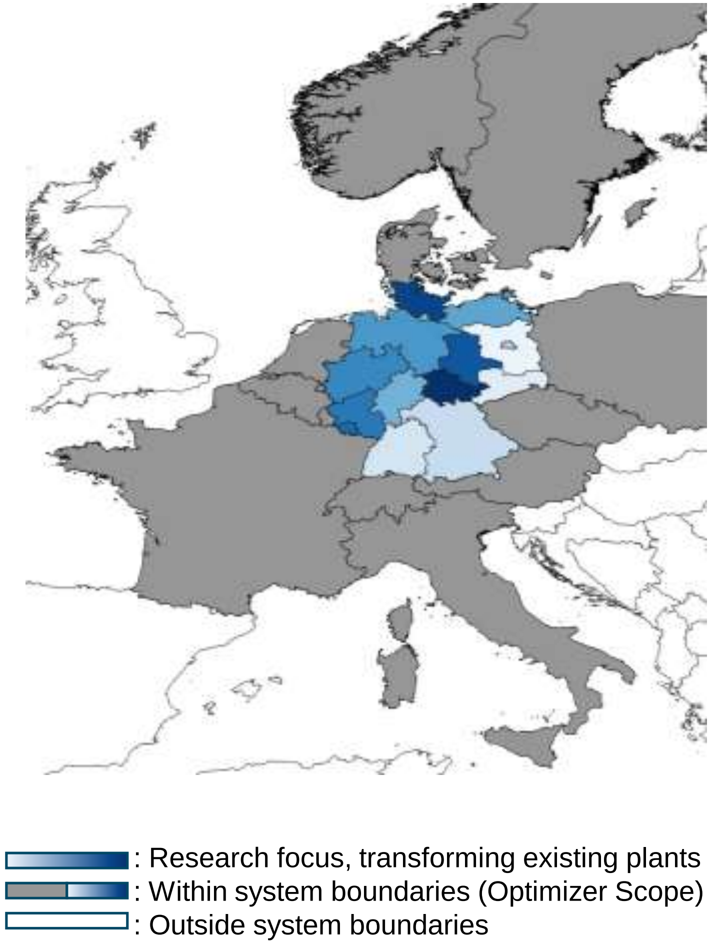


APPROACH 3: BACK TO THE SYSTEM

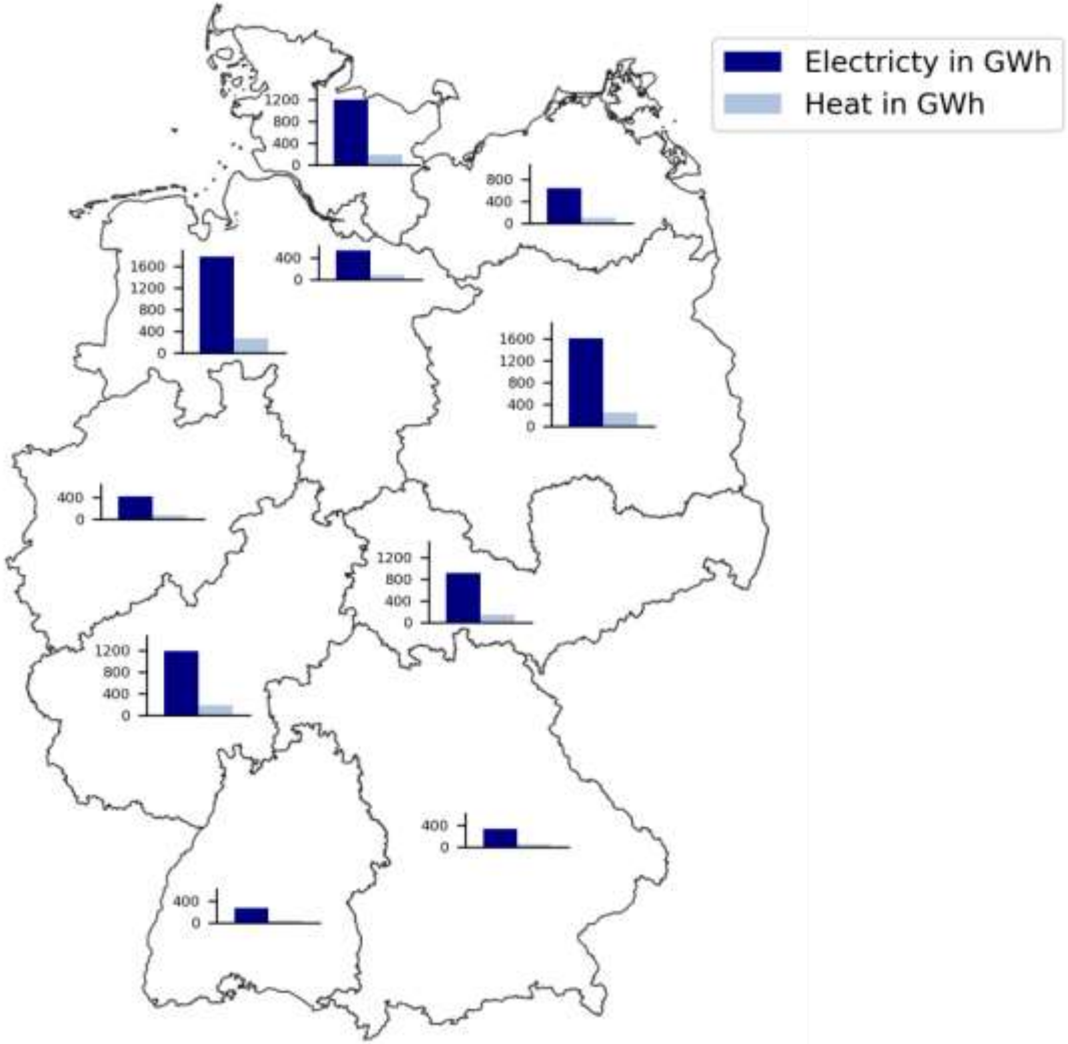
Approach 3: Model Setup

Method	Optimization
Sectoral Scope	Electricity (incl. E-Mobility), Heat, Hydrogen
Technological Scope	90 technologies
Spatial Scope	22 regions, focus: Germany
Temporal Scope	2050 (target year expansion planning, hourly dispatch optimization
Scenario (net zero)	Transforming Germany‘s heat supply
Assumptions	Global constraint: TESP cover ≥10% of Germany‘s industry/district heating demand No cost for Heat-To-Power (up to existing CHP capacity)



TESP acting as decarbonized CHP in Germany

- Provides 1,4% of the systems electricity
- System costs with TESP are ~1% more expensive, than the system costs without
- Heat is provided only as district heat, not as industrial heat



CONCLUSION AND OUTLOOK

Conclusions

Findings

- In the case studies, other storage technologies are mostly preferred
- Decreasing cost of high-temperature heat storage and conversion is key
- TESP prefers district heating against industry heat

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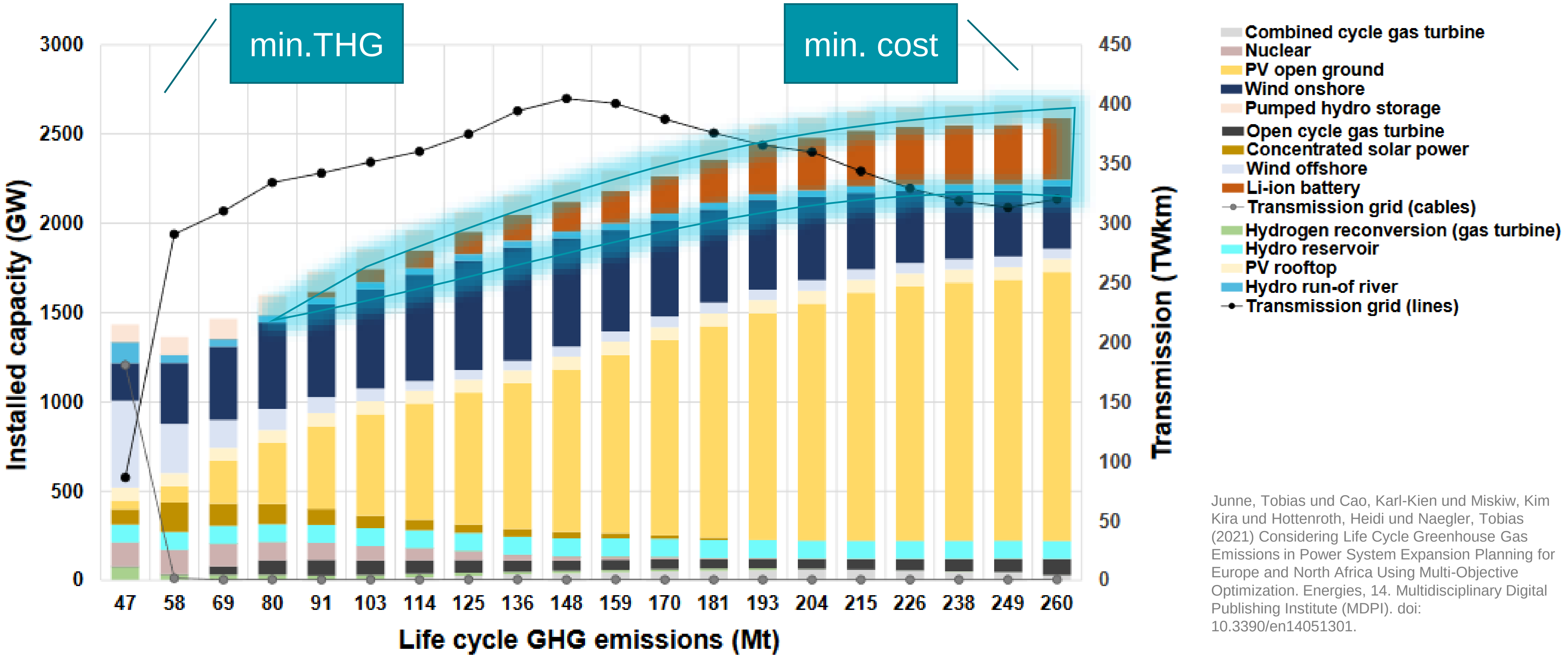
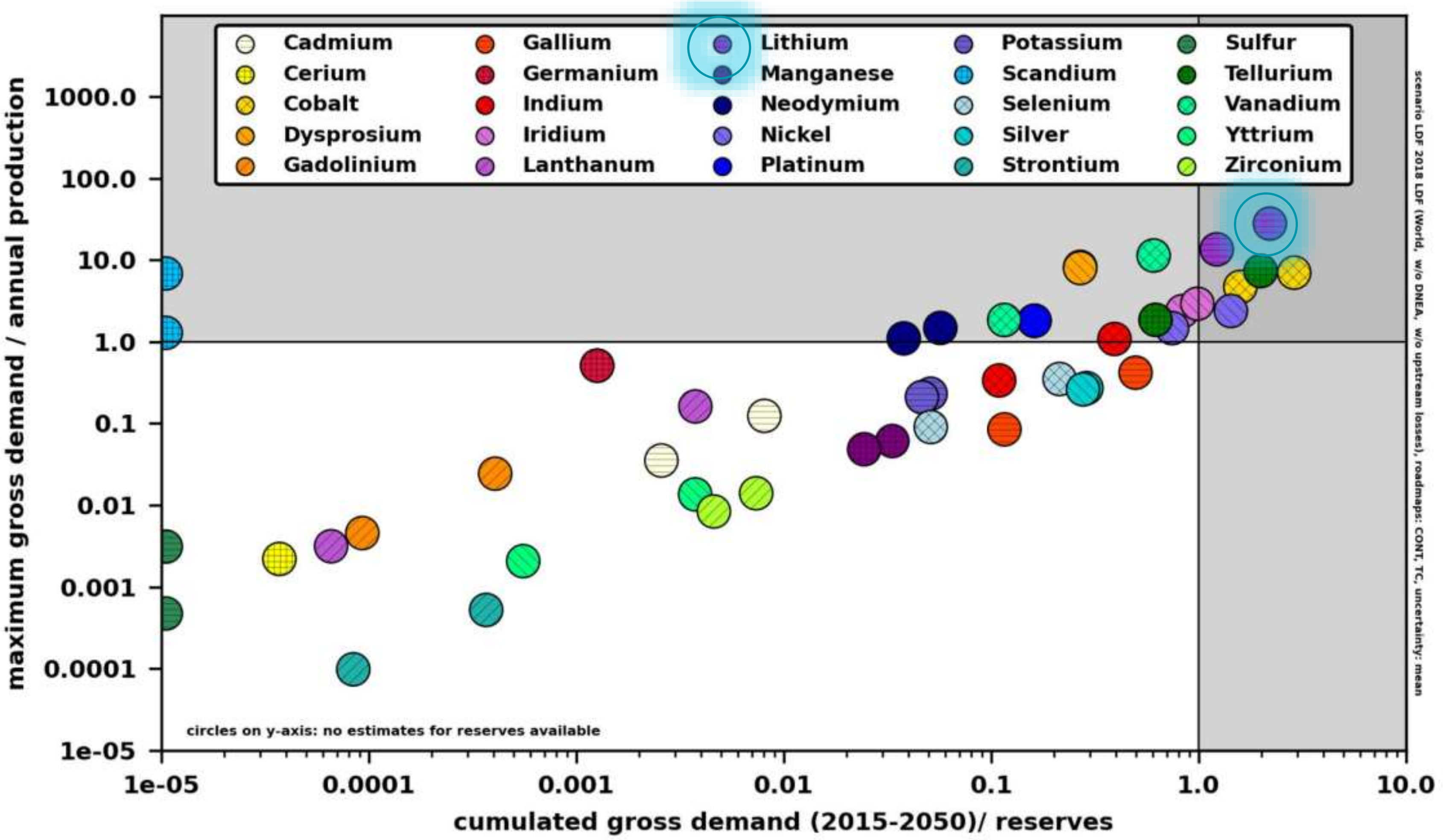
What we know about the system‘s need for Lithium-ion batteries

European Energy Scenarios



Junne, Tobias und Cao, Karl-Kien und Miskiw, Kim Kira und Hottenroth, Heidi und Naegler, Tobias (2021) Considering Life Cycle Greenhouse Gas Emissions in Power System Expansion Planning for Europe and North Africa Using Multi-Objective Optimization. Energies, 14. Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/en14051301.

What we know about resources



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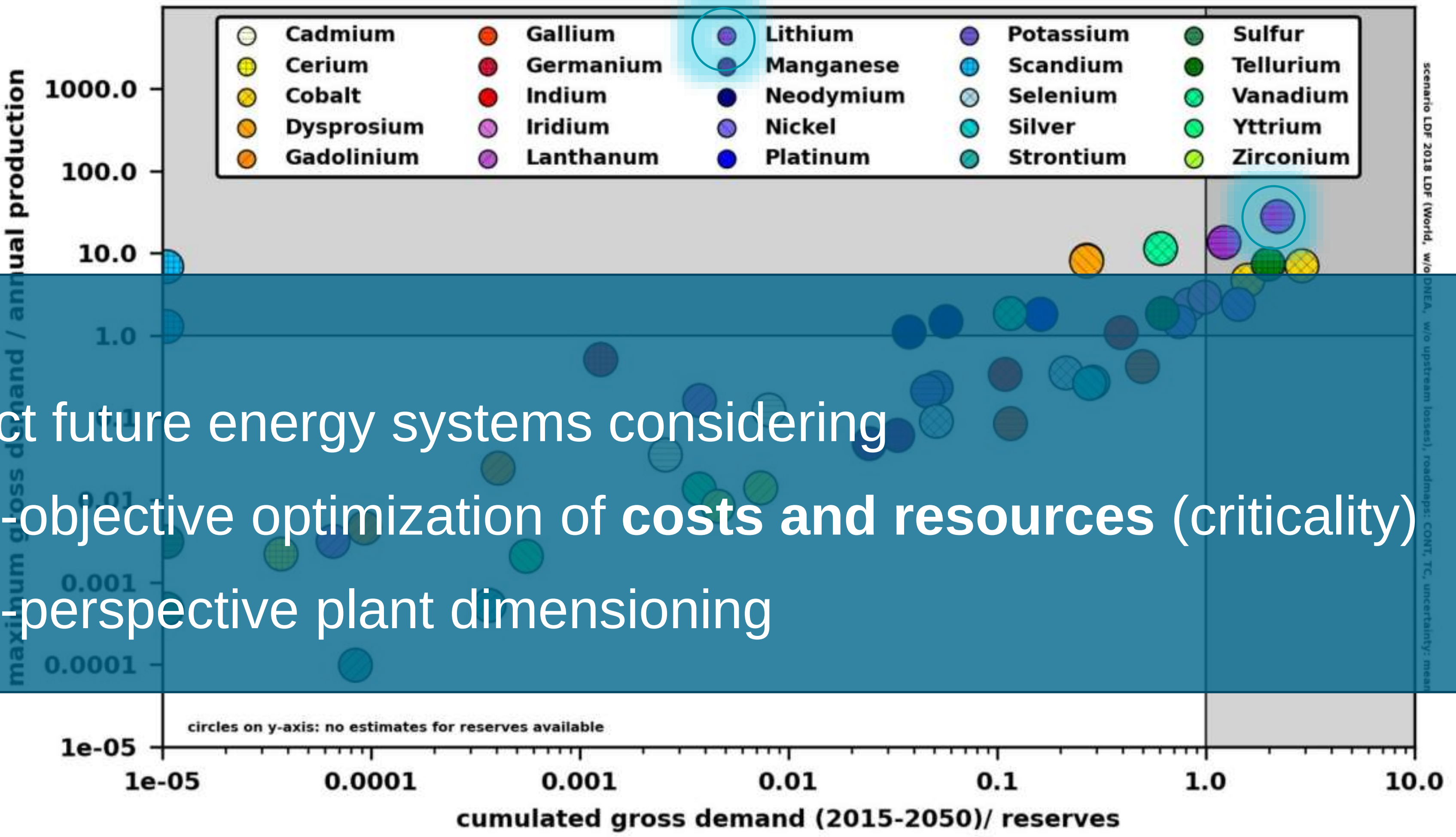

Next

Construct future energy systems considering

1. Multi-objective optimization of **costs and resources** (criticality)
2. Multi-perspective plant dimensioning

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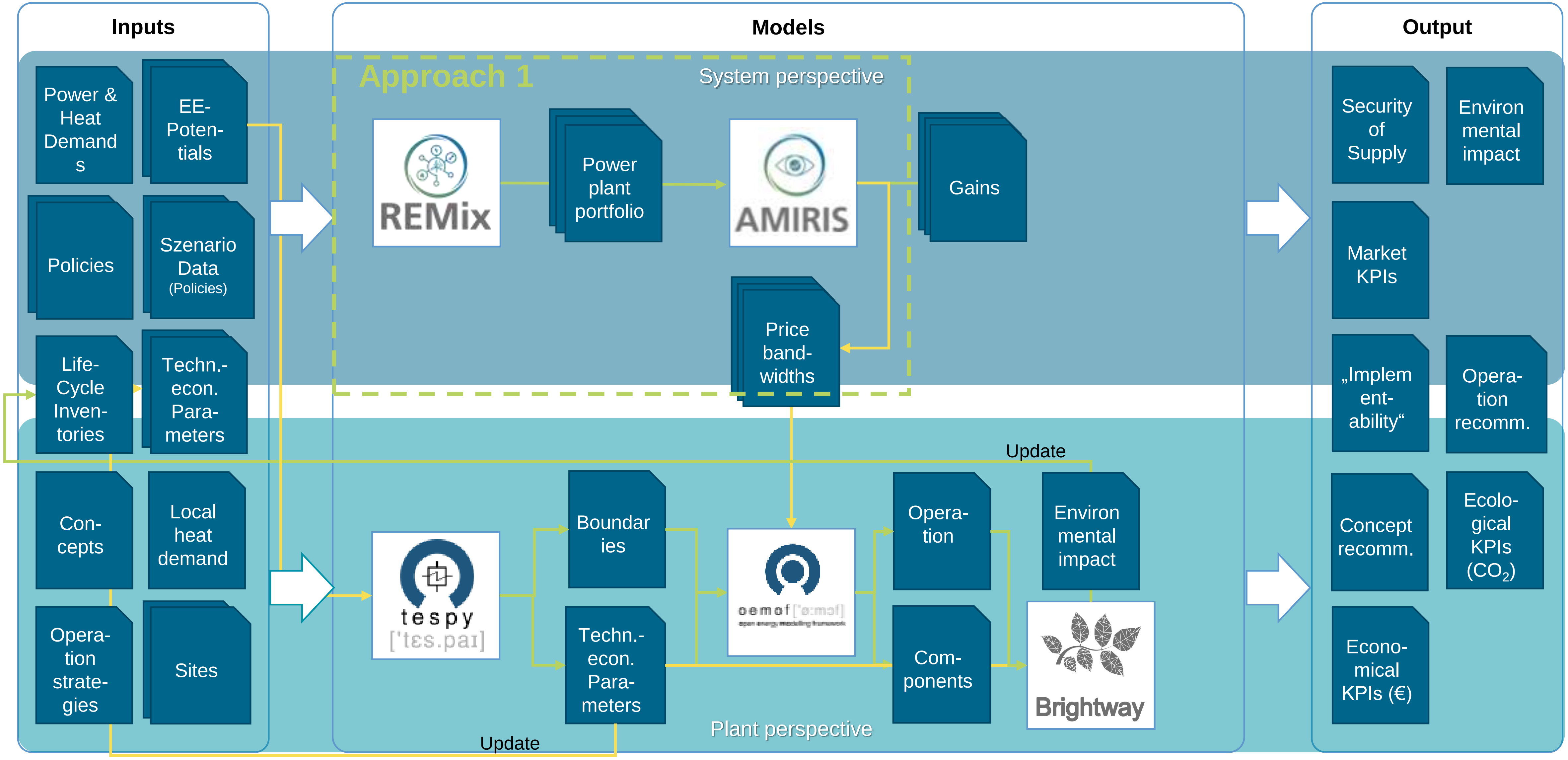
Linking perspectives



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LET‘S DISCUSS!

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