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Assessing flexibility option potential by combining electricity price forecasting and agent-based electricity market modelling

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INREC, 26th August 2025

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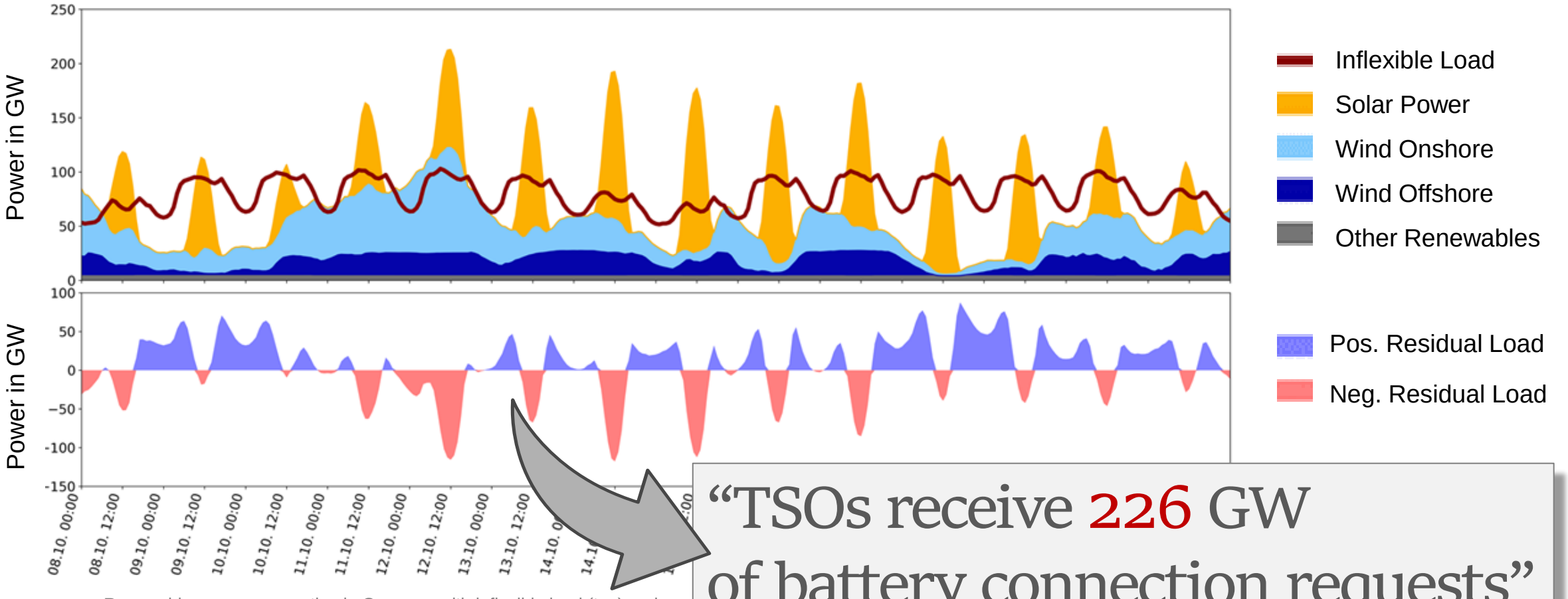
DLR

Challenges of Intermittent Energy Sources

Residual Load and Attractive Price Spreads



Renewable energy generation in Germany with inflexible load (top) and resu

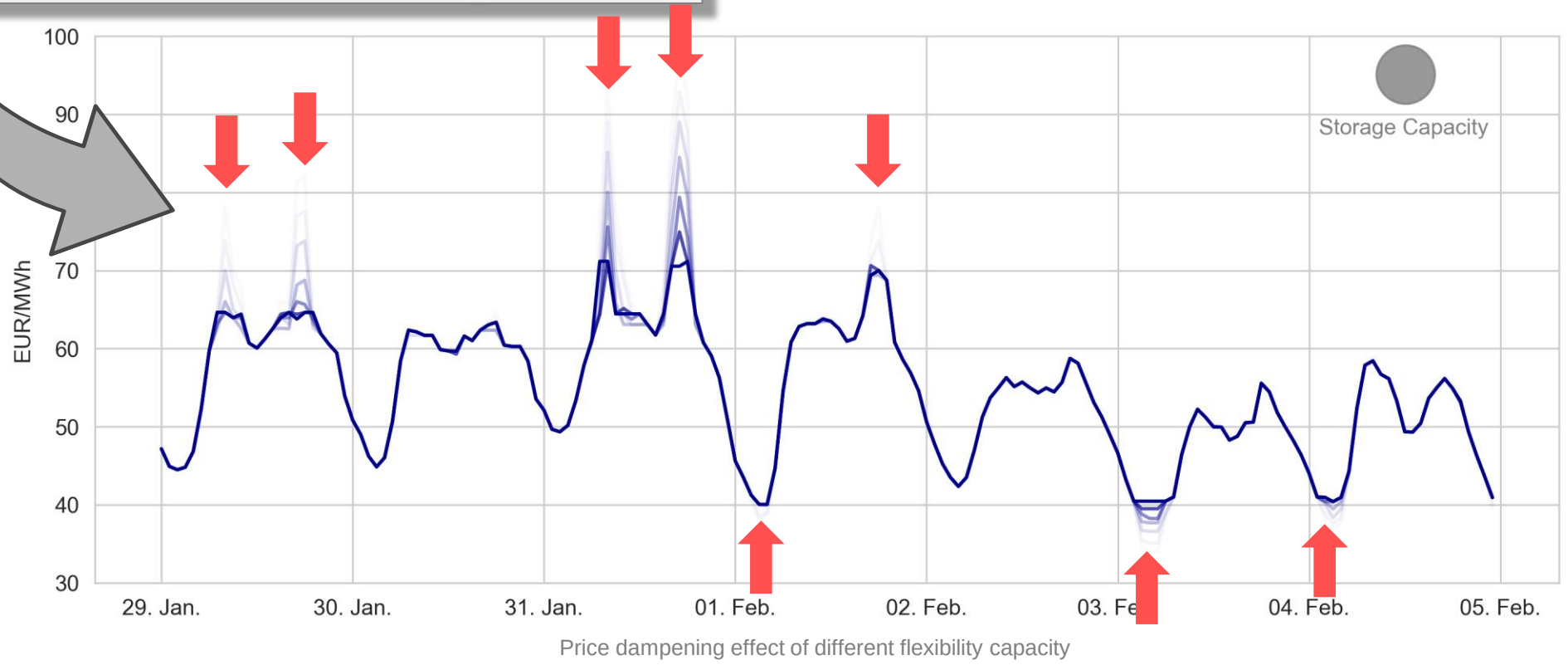
"TSOs receive 226 GW of battery connection requests"

[Kochems 2024](#)
[PV-Magazine 2025](#)

Price Impact of Flexibility Options

Decreasing Price Spreads

"TSOs receive 226 GW of battery connection requests"



Price dampening effect of different flexibility capacity

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PV-Magazine 2025
Nitsch et al. 2024

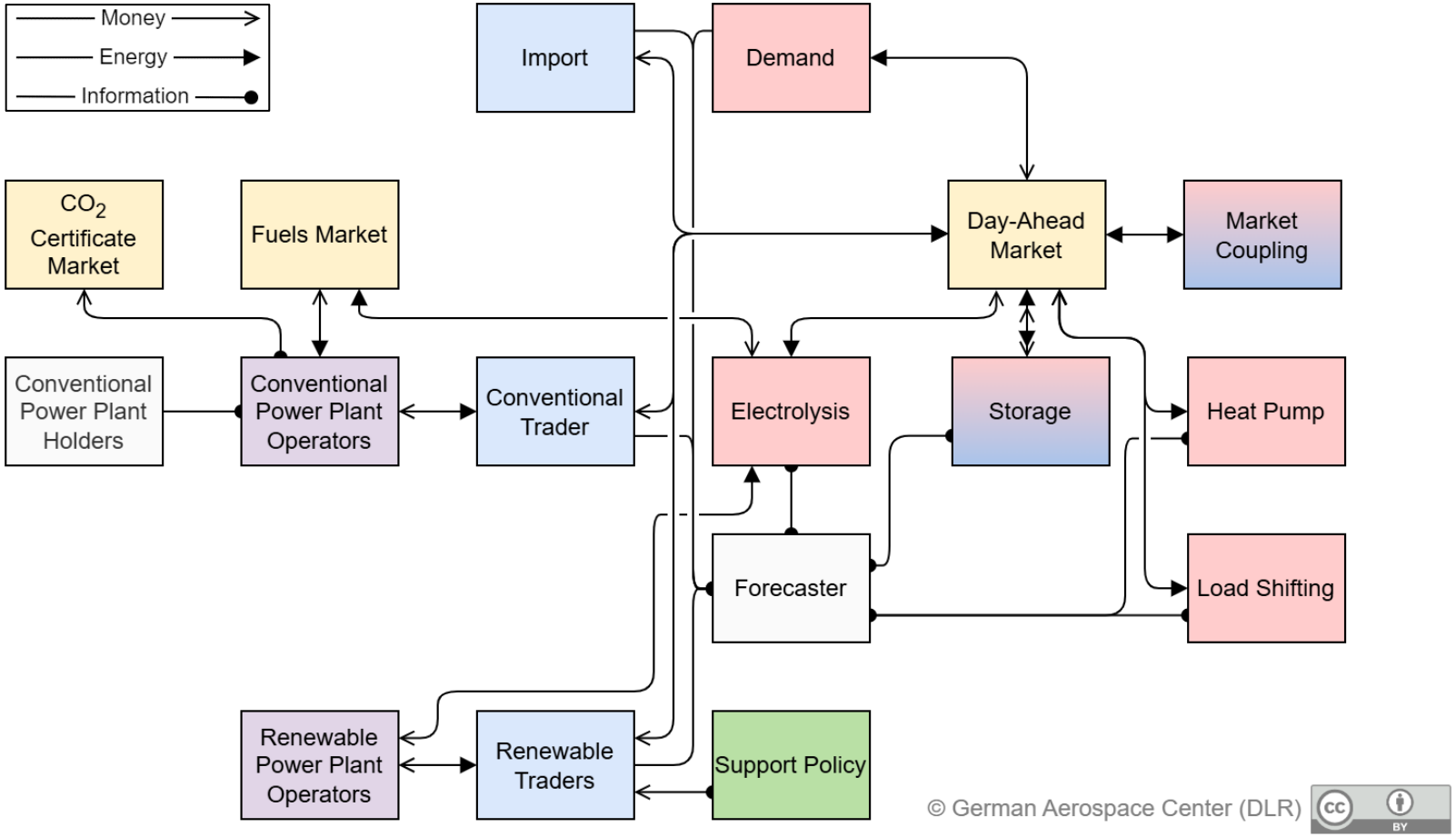
State of the Literature
Flexibility Options on Future Electricity Markets

- Renewable energy (RE) power plants essential Twidell (2021)
- Increasing electricity demand by electrification Staffell and Pfenninger (2018)
- Flexibility options (FO) becoming more important Zöphel et al. (2018)
- Thorough ex ante analysis necessary for FO investment Keles (2013), Ölmez, Ari, and Tuzkaya (2024)

- Existing studies
  - Focus on individual FO devices without considering market implications Lund et al. (2015), Elalfy et al. (2024)
  - Assume “central planner” and perfect coordination Mancò et al. (2024), Barbosa et al. (2024)

- Identified gaps
  - Need for analysis of high RE scenarios while incorporating operational uncertainty Bessa et al. (2019)
  - Lack of endogenous modelling of FO impacts on market dynamics Siala et al. (2022)
  - Limited open science to promote transparency, reproducibility, and wider application Chang et al. (2021)

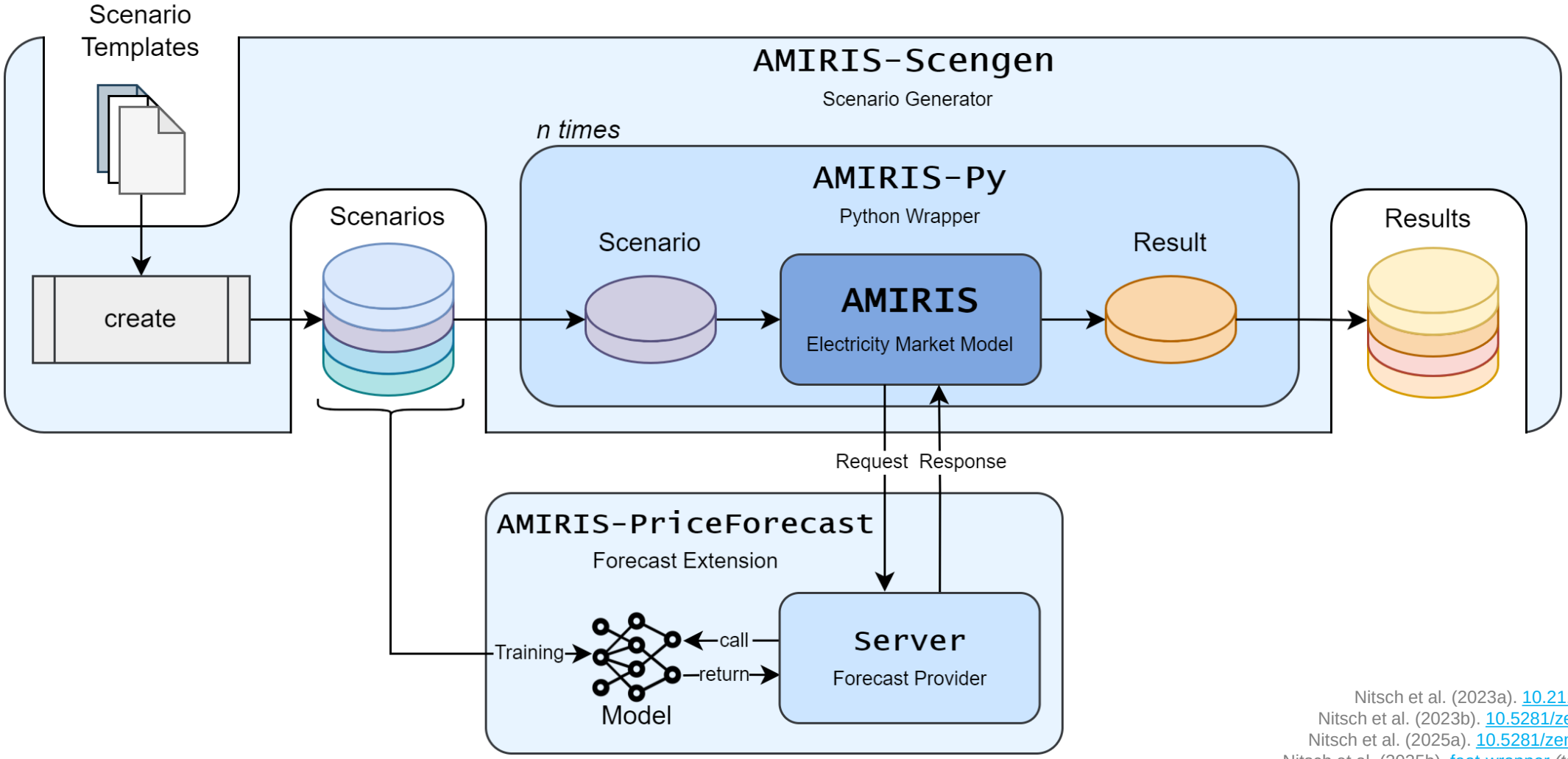
AMIRIS
Open Agent-based Electricity Market Model



Schimeczek et al. (2023a). 10.21105/joss.05041
Schimeczek et al. (2023b). 10.21105/joss.05087
Nitsch et al. (2023a). 10.21105/joss.04958

Model Development and Simulation Setup

Enabling Machine-Learning Based Electricity Price Forecasts



Nitsch et al. (2023a). 10.21105/joss.04958
Nitsch et al. (2023b). 10.5281/zenodo.8382789
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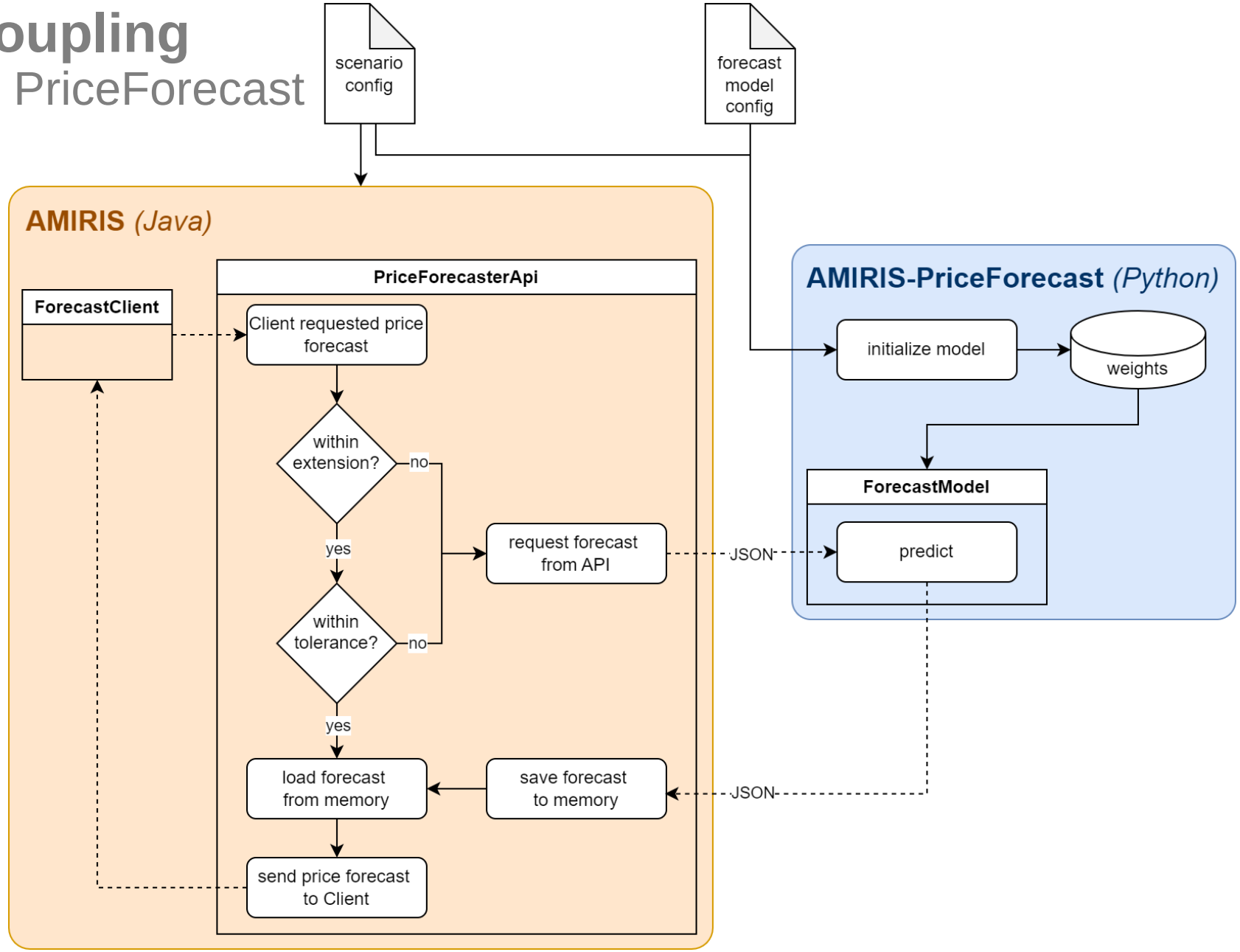
Schimeczek et al. (2023a). 10.21105/joss.05041
Schimeczek et al. (2023b). 10.21105/joss.05087
Schimeczek et al. (2023c). 10.5281/zenodo.14273248

Model Coupling

AMIRIS ↔ PriceForecast



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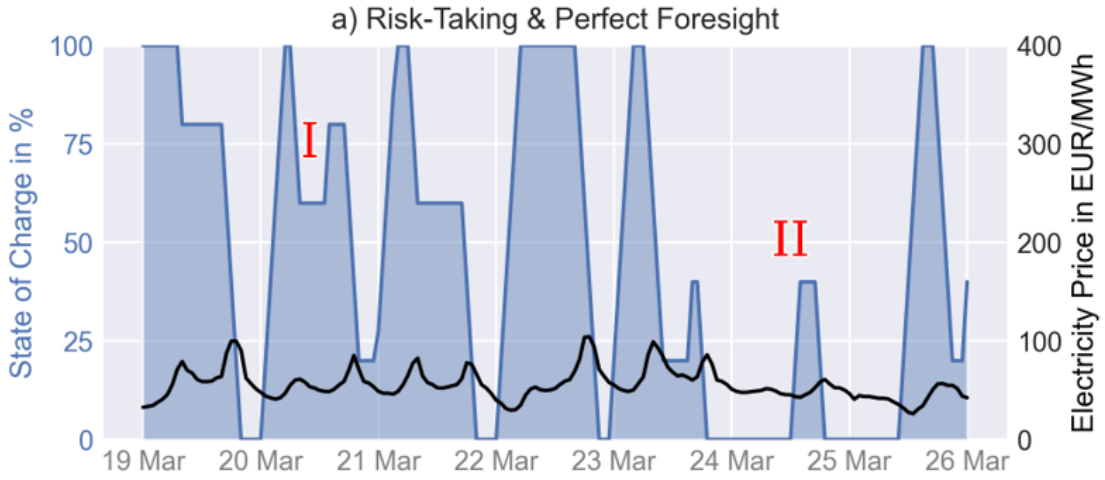
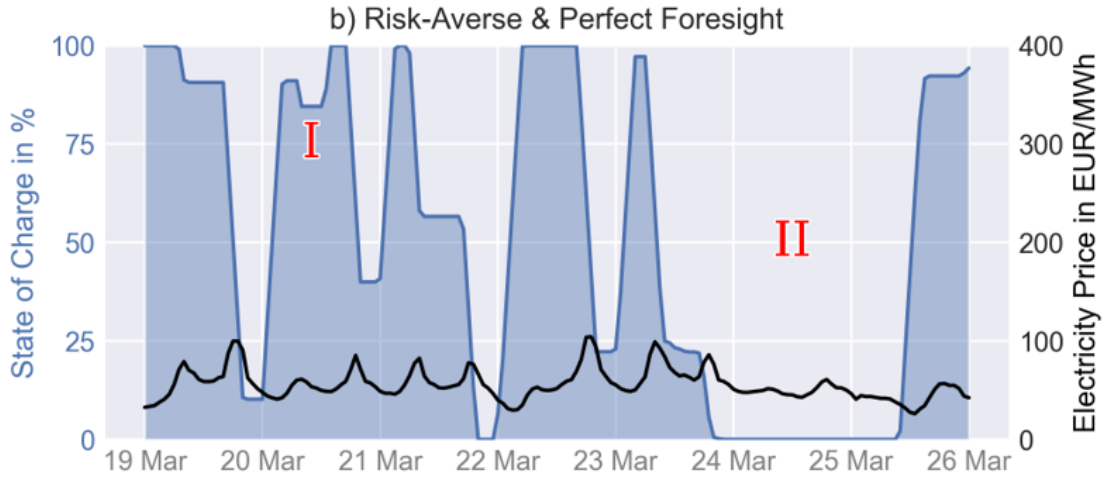
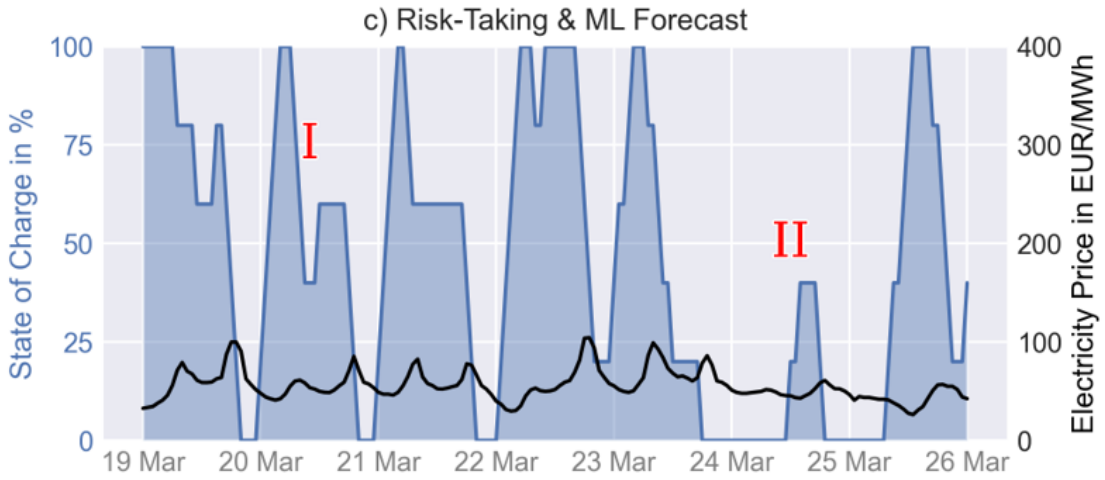
Nitsch et al. (2025). 10.2139/ssrn.5320926

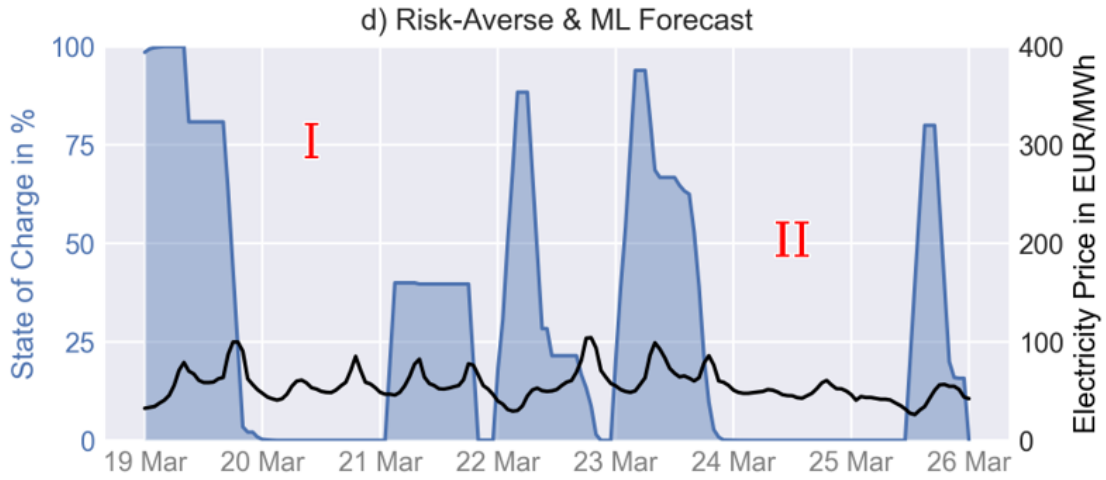
State of Charge

Impact of Forecast Type & Storage Strategy









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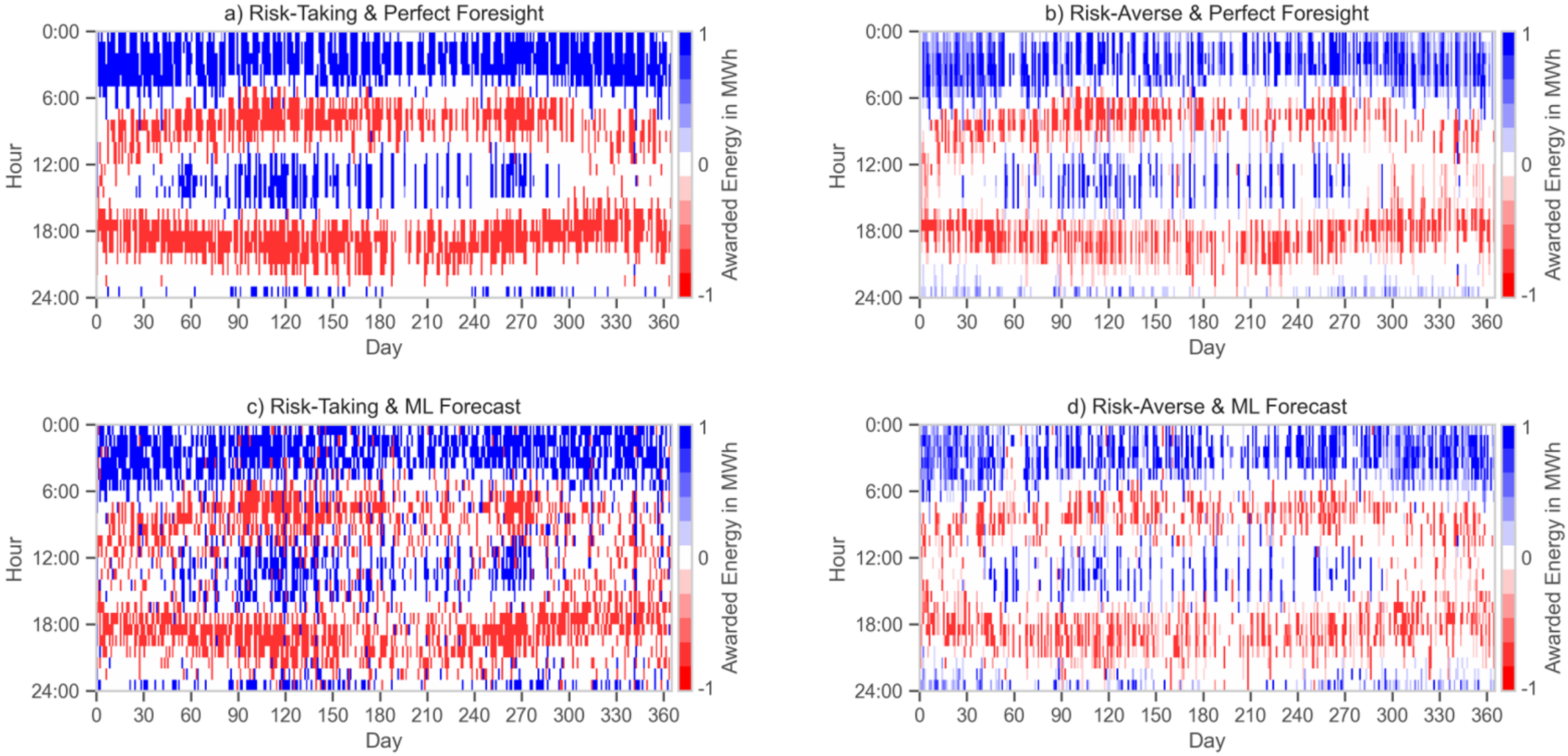
Storage Activity

Impact of Forecast Type & Storage Strategy



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Scenario ARIADNE 2030
Electricity Generation and Consumption

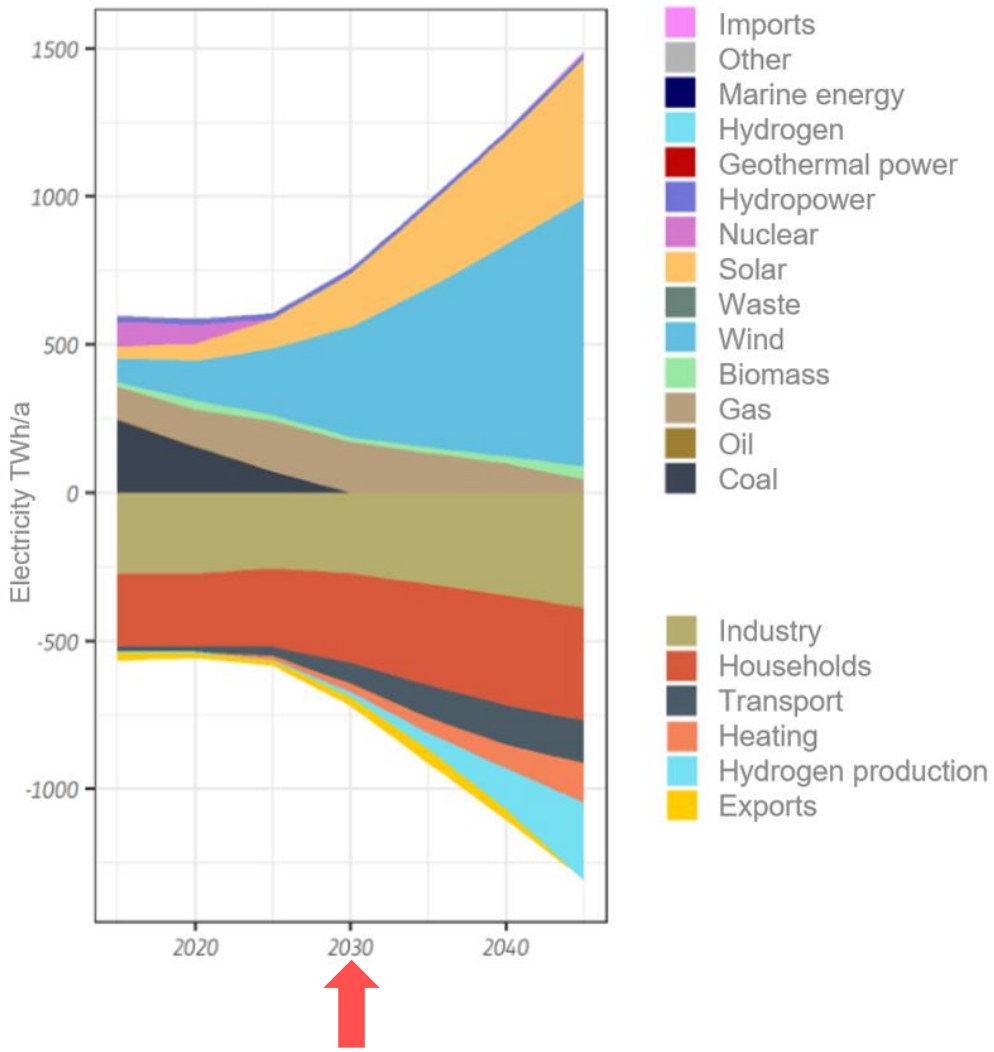

Table 1: Scenario parameters derived from Luderer et al. [39].

Parameter		Value	Unit
Capacities	Nuclear	0	GW
	Lignite	0	GW
	Hard coal	0	GW
	Natural gas	30.0	GW
	Hydrogen	15.3	GW
	Biomass	15.7	GW
	Run-of-river	12.6	GW
	PV	218.4	GW
	Wind onshore	127.2	GW
	Wind offshore	25.0	GW
	Other non-renewable	0.9	GW
CO_2 certificate costs		200.0	EUR/t
Load		615.8	TWh/a
Greenhouse gas reduction compared to 1990		65	%

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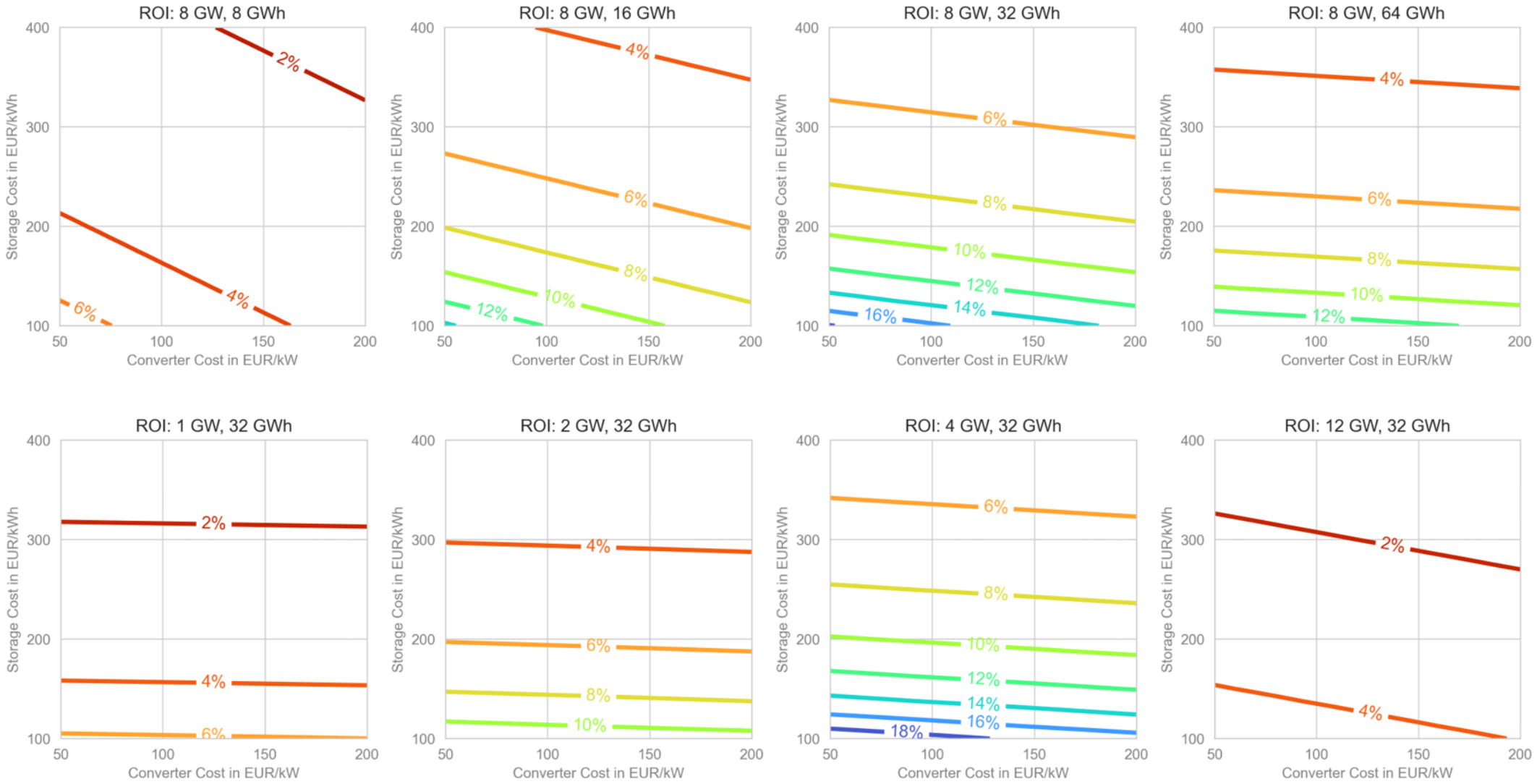
Luderer et al. (2021) 10.48485/pik.2021.006

Storage Profitability
Return on Investment



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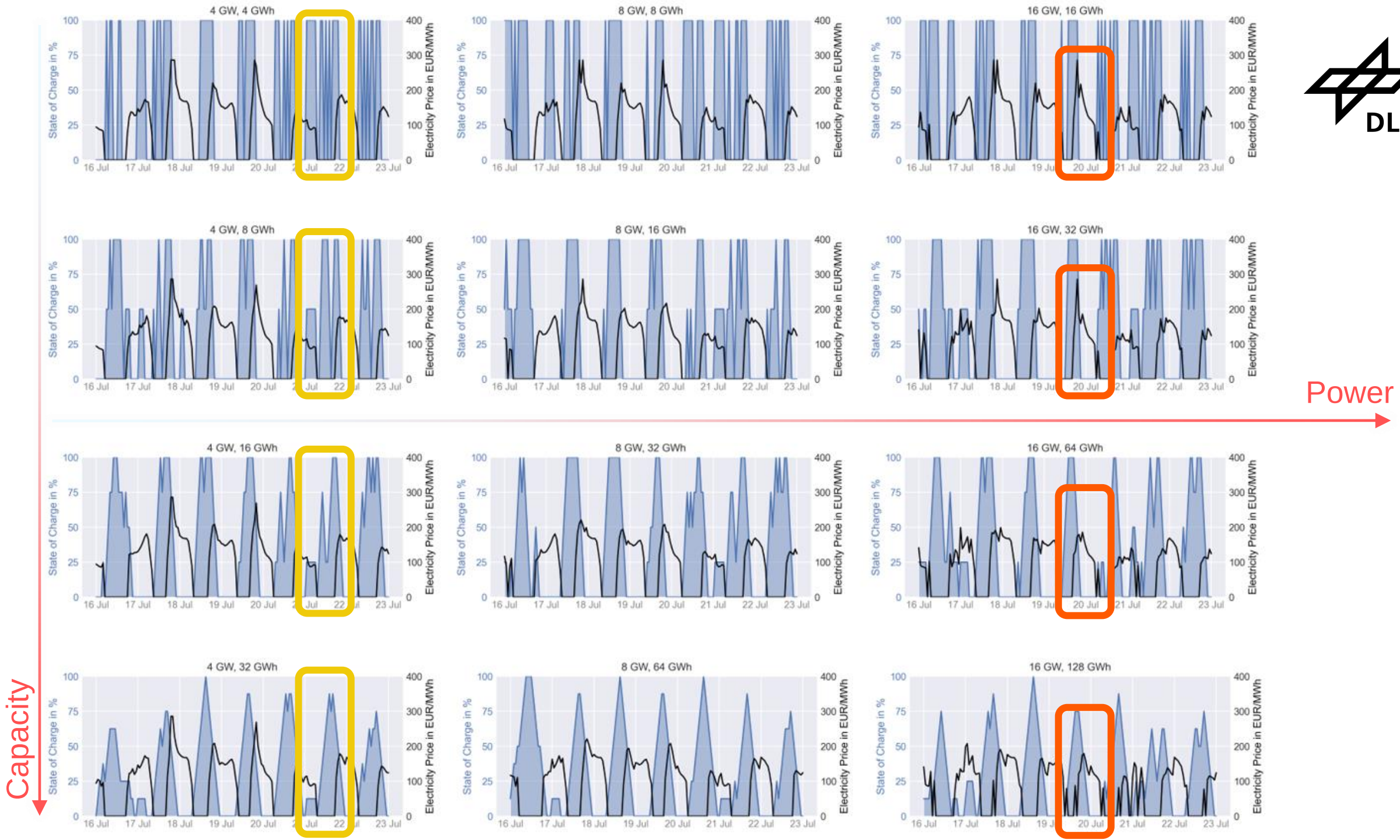

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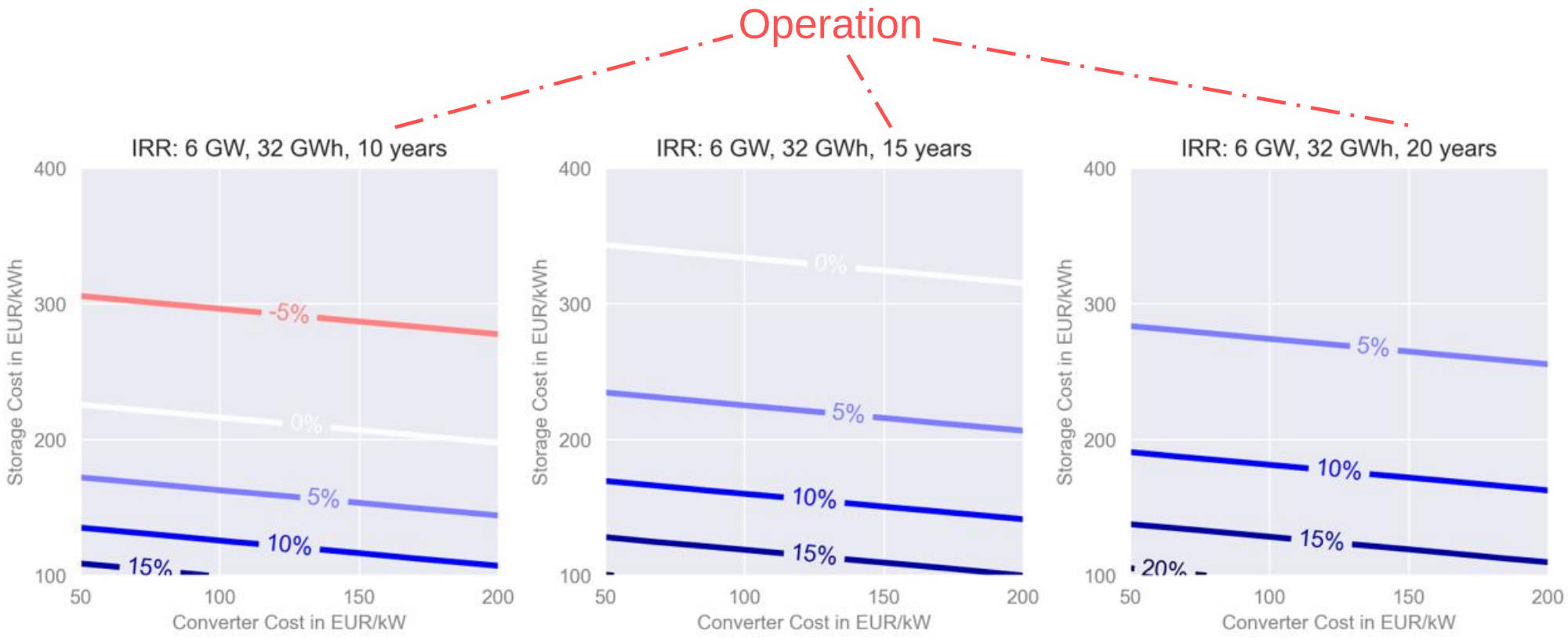
Storage Profitability
Internal Rate of Return



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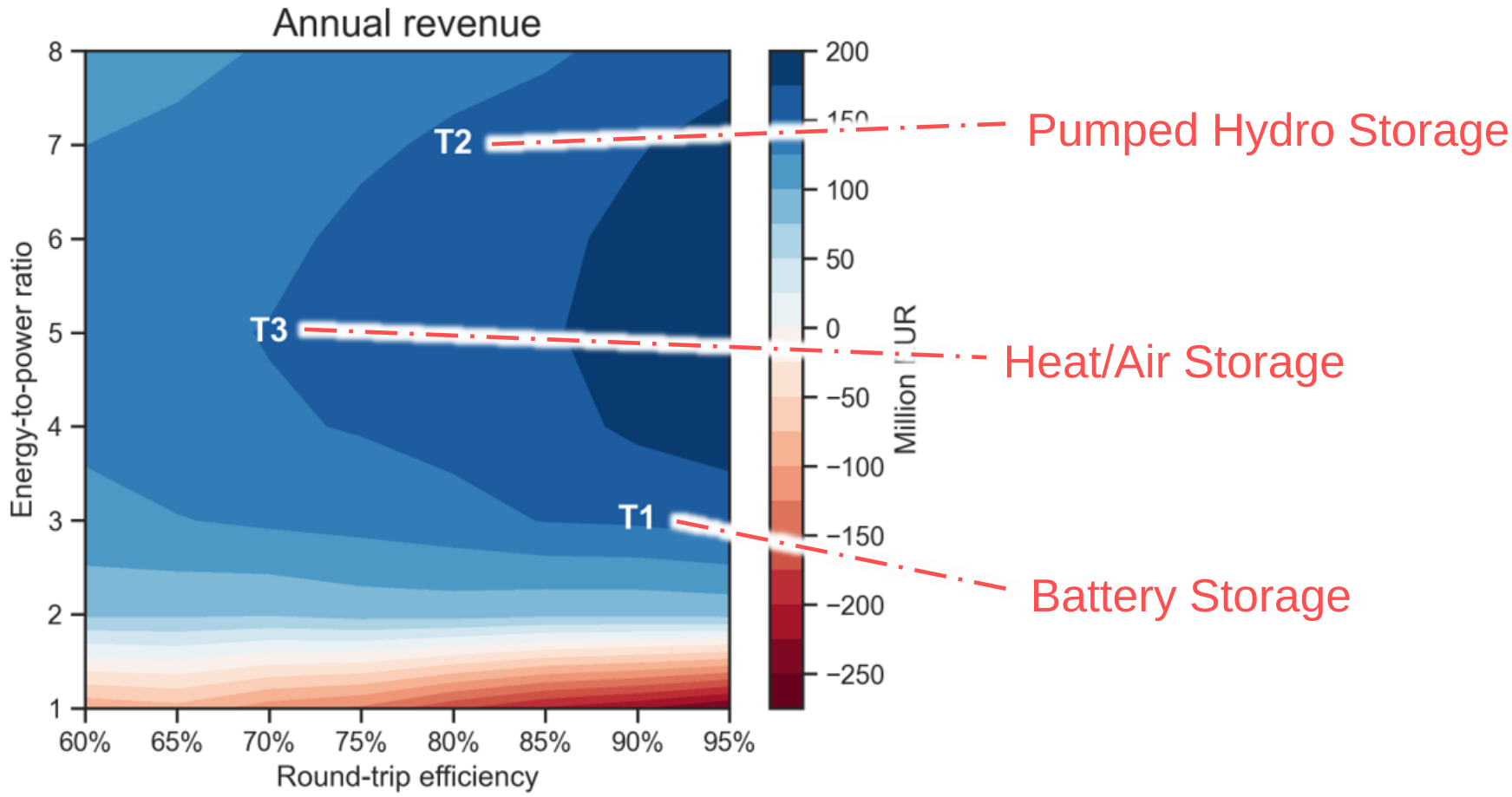
Storage Revenue
Impact of Energy-to-Power Ratio and Efficiency



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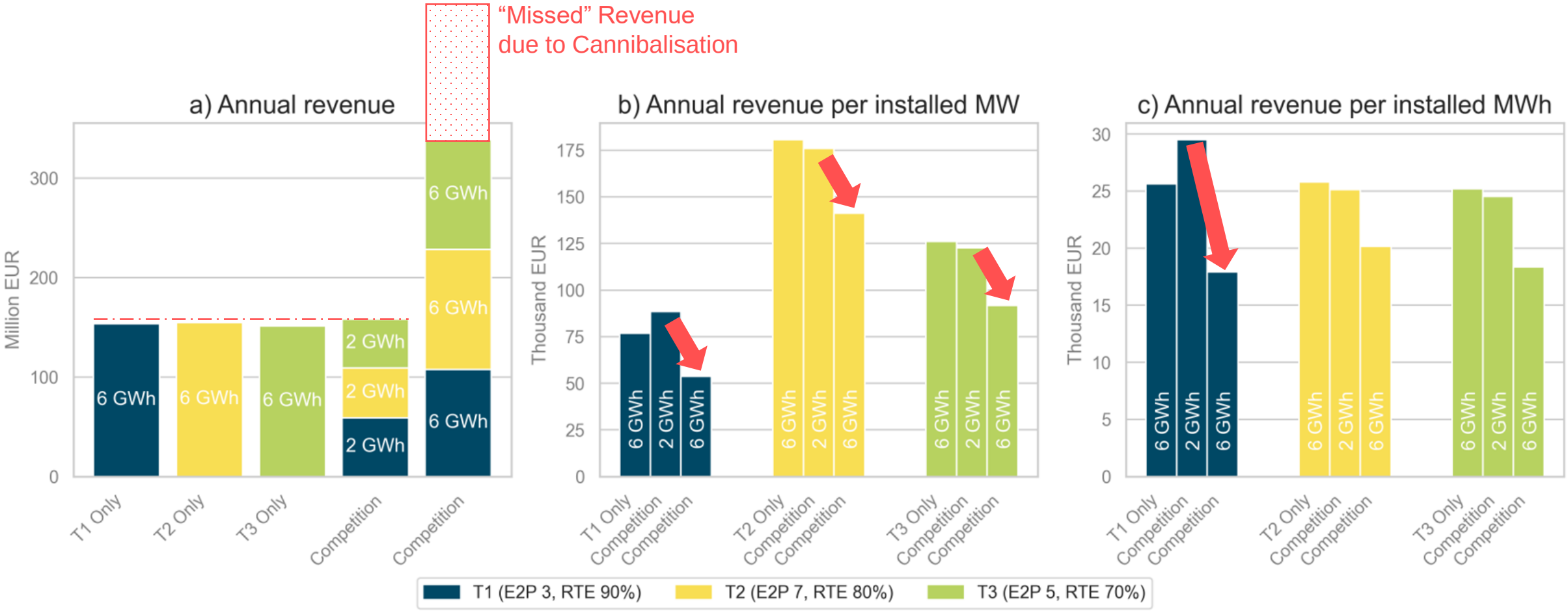
Revenue Cannibalisation
Competing Storage



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Discussion
Limitations and Contextualisation

- Pace of RE deployment, especially PV, exceeded projections Creutzig et al. (2017)
- Dynamics of a net-zero system may differ Azevedo et al. (2021)
- Contribution of sector coupling to flexibility provision not fully considered Gaafar et al. (2024)
- Only day-ahead market considered, which misses important additional revenue Agrela et al. (2022)
- However, competition also likely on intraday markets and for system services Deman et al. (2025)
- Shocks, such as the 2022 energy crisis, not considered Ruhnau, Stiewe, et al. (2023)

Conclusions

- High interest in grid-scale storage systems, yet market dynamics unclear
- Modular integration of ML forecasts in agent-based electricity market simulations
- Profitability analysis of storage systems on the spot market
- ARIADNE scenario reveals self-cannibalization of storage
- Medium-term storage most profitable
- However, cost reductions or additional revenue streams necessary

Outlook

- Comparison with enhanced storage strategies working paper Schimeczek et al. (2025)
- Detailed assessment of sector coupling impact

Model

Preprint

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Imprint

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