



Large-Scale Battery Storage Systems in Germany: Market Development and Revenue Opportunities

inspired workshop

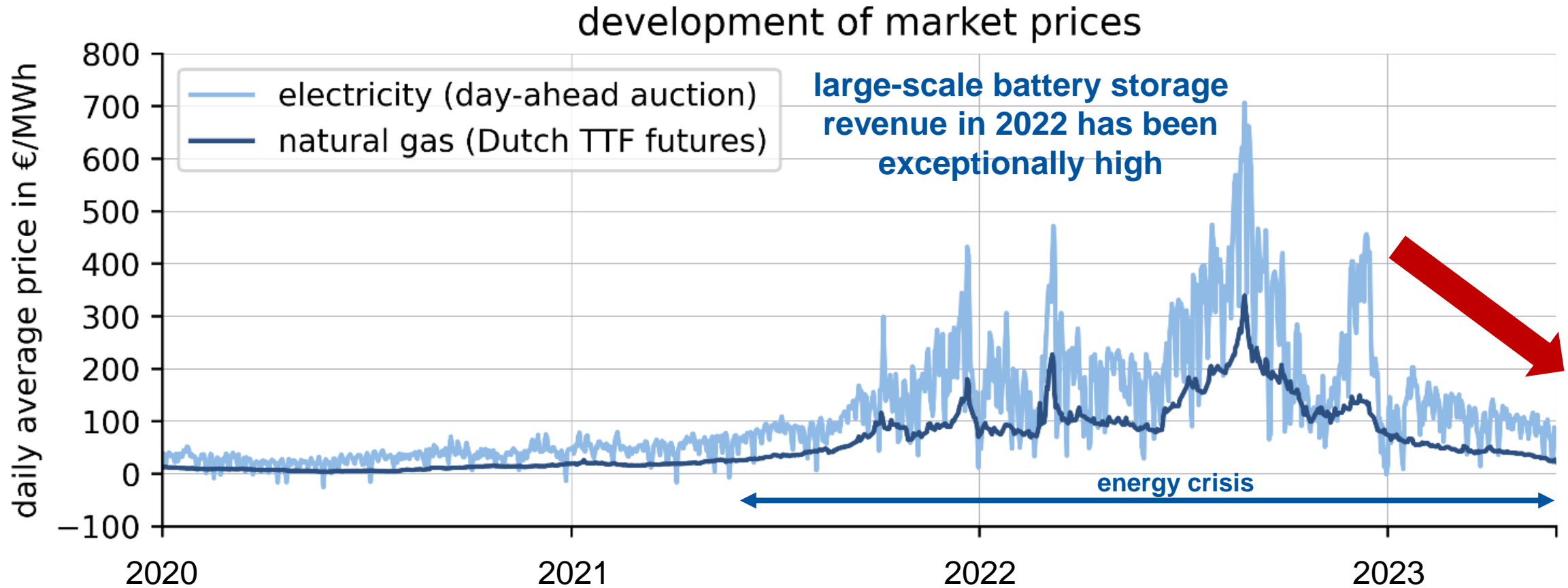
Vienna 2023

Jonas van Ouwerkerk, Jan Figgener, Lucas Koltermann, Maurico Celi Cortés, Dirk Uwe Sauer

Chair for Electrochemical Energy Conversion
and Storage Systems



Energy market development is difficult to predict

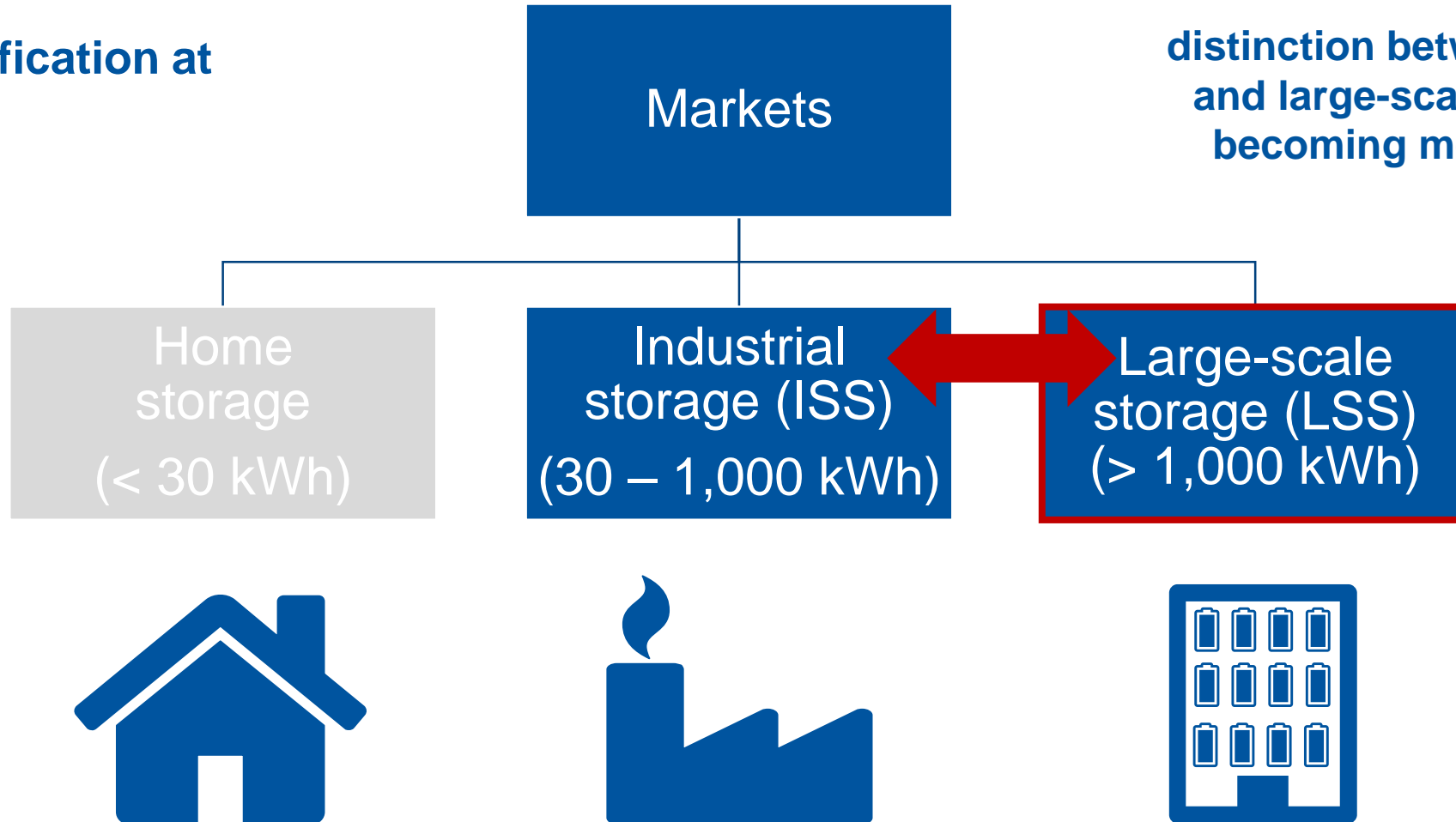


Source: van Ouwerkerk et al., 2023, <https://www.sciencedirect.com/science/article/pii/S2352152X22011392>

How to classify large-scale battery storage (LSS) ?



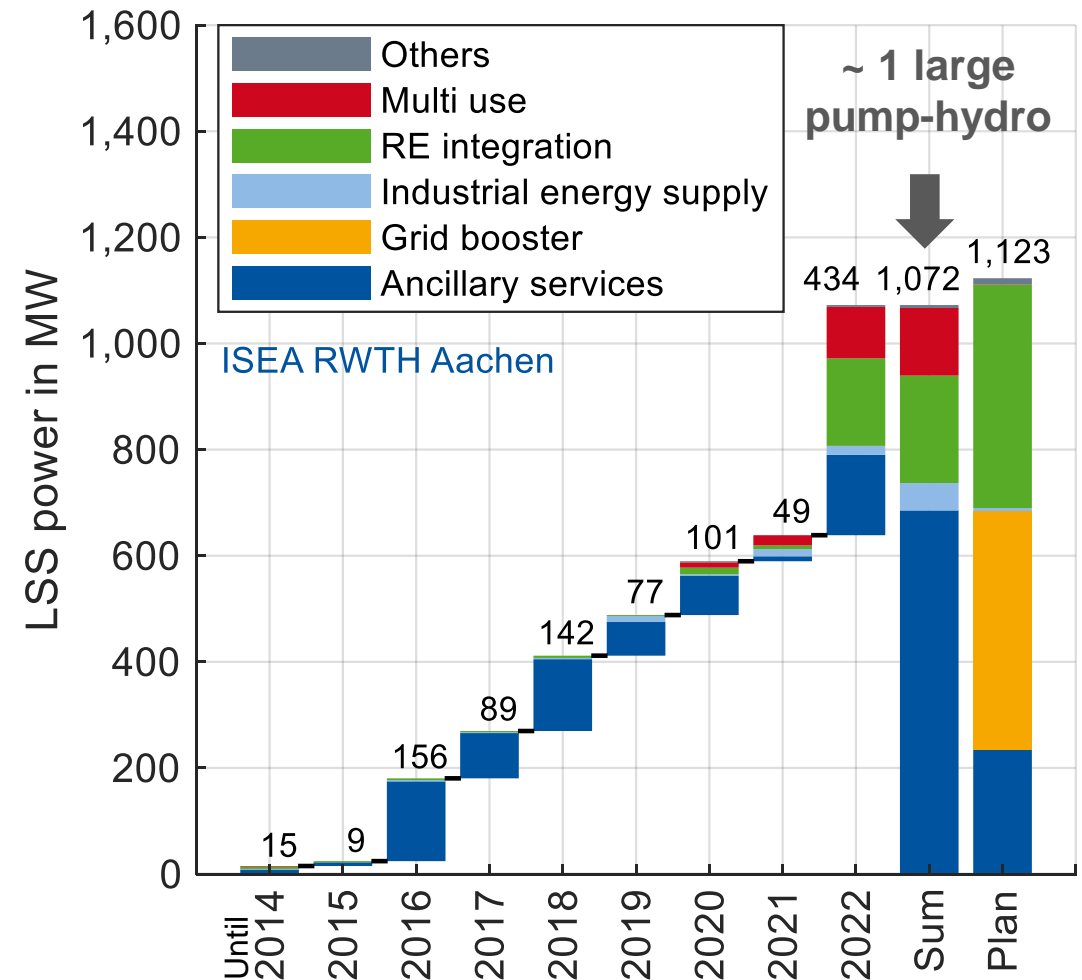
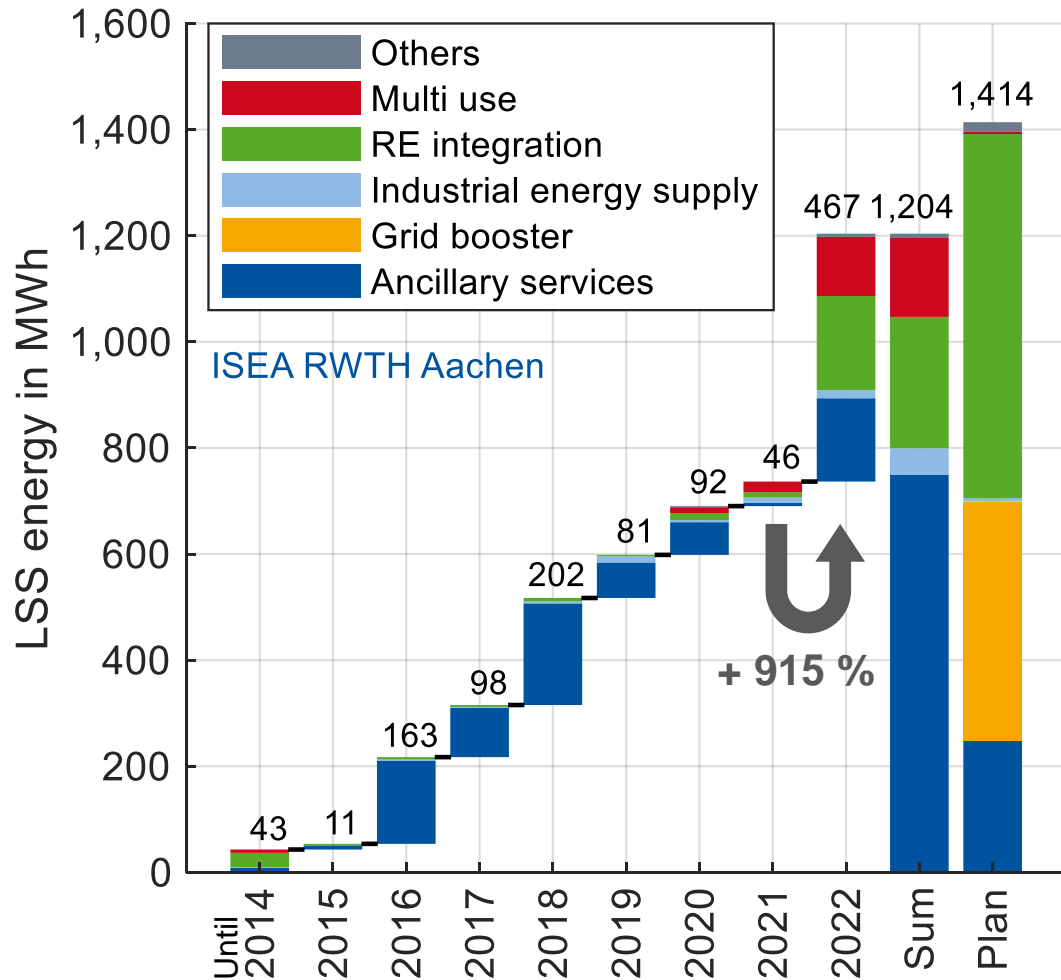
typical classification at ISEA RWTH:



Development of LSS battery energy (left) and inverter power (right) in Germany (~150 systems)



Use cases for LSS battery systems are becoming more diverse with increasing focus on multi-use operation

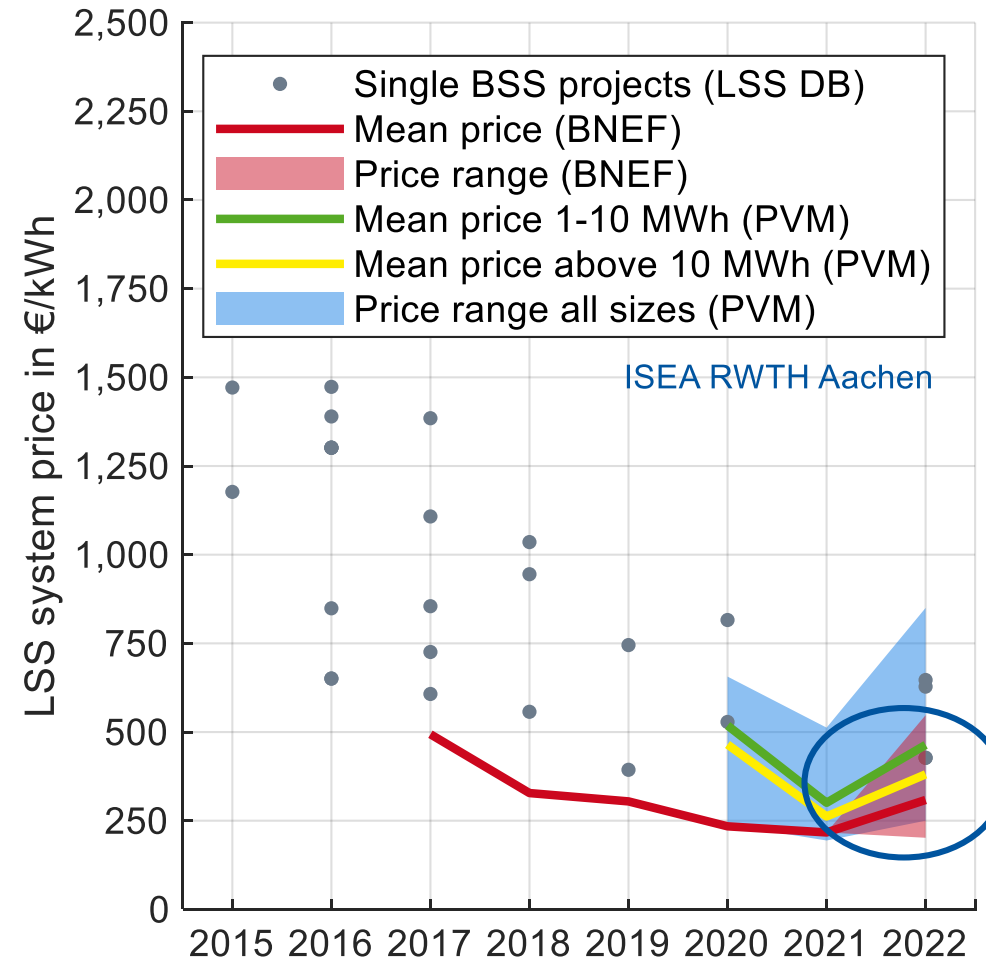
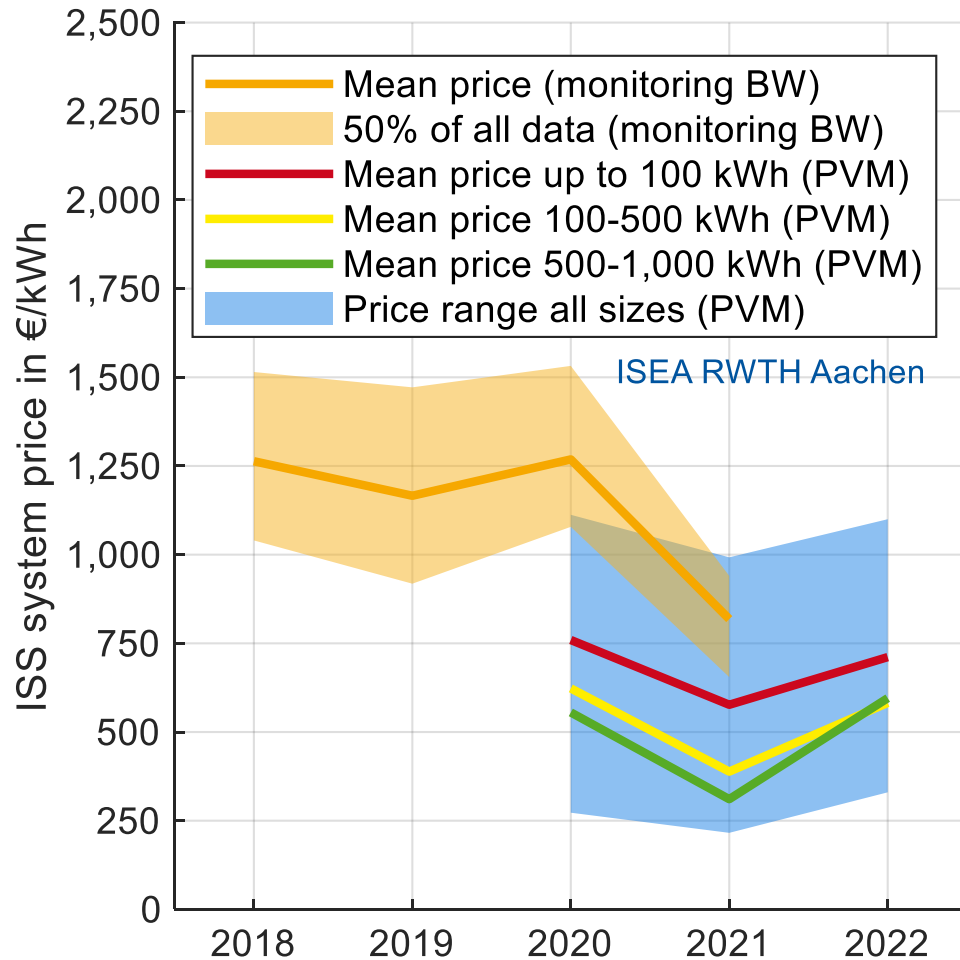


Source: based on Figgenger et al., <https://www.researchgate.net/publication/369479477> The development of battery storage systems in Germany A market review status 2023

Price development of industrial storage systems (ISS) (left) and large-scale storage systems (LSS) (right)



Average system prices for LSS battery systems were below 500 €/kWh in 2022



Source: based on Figgenger et al., <https://www.researchgate.net/publication/369479477> The development of battery storage systems in Germany A market review status 2023

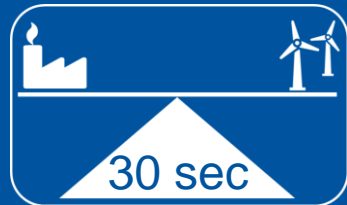
How to make revenue with large-scale battery storage?



Front of the meter services (FTM)

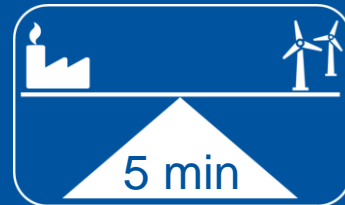
FCR

Frequency Containment Reserve

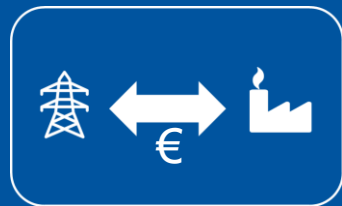


aFRR

Automatic Frequency Restoration Reserve



Spot-market trading (Arbitrage)



FFR (inertia)
mFRR
Redispatch

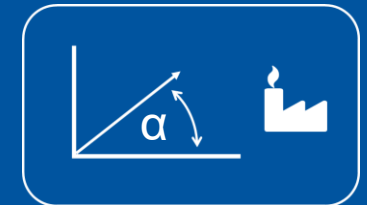


Behind the meter services (BTM)

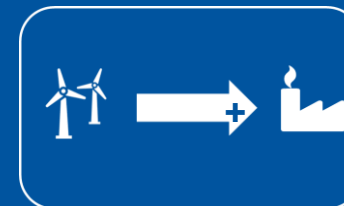
Peak shaving



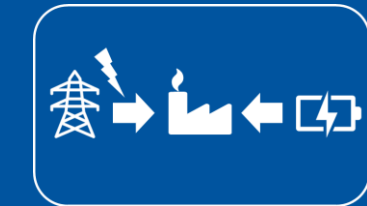
Reactive power compensation



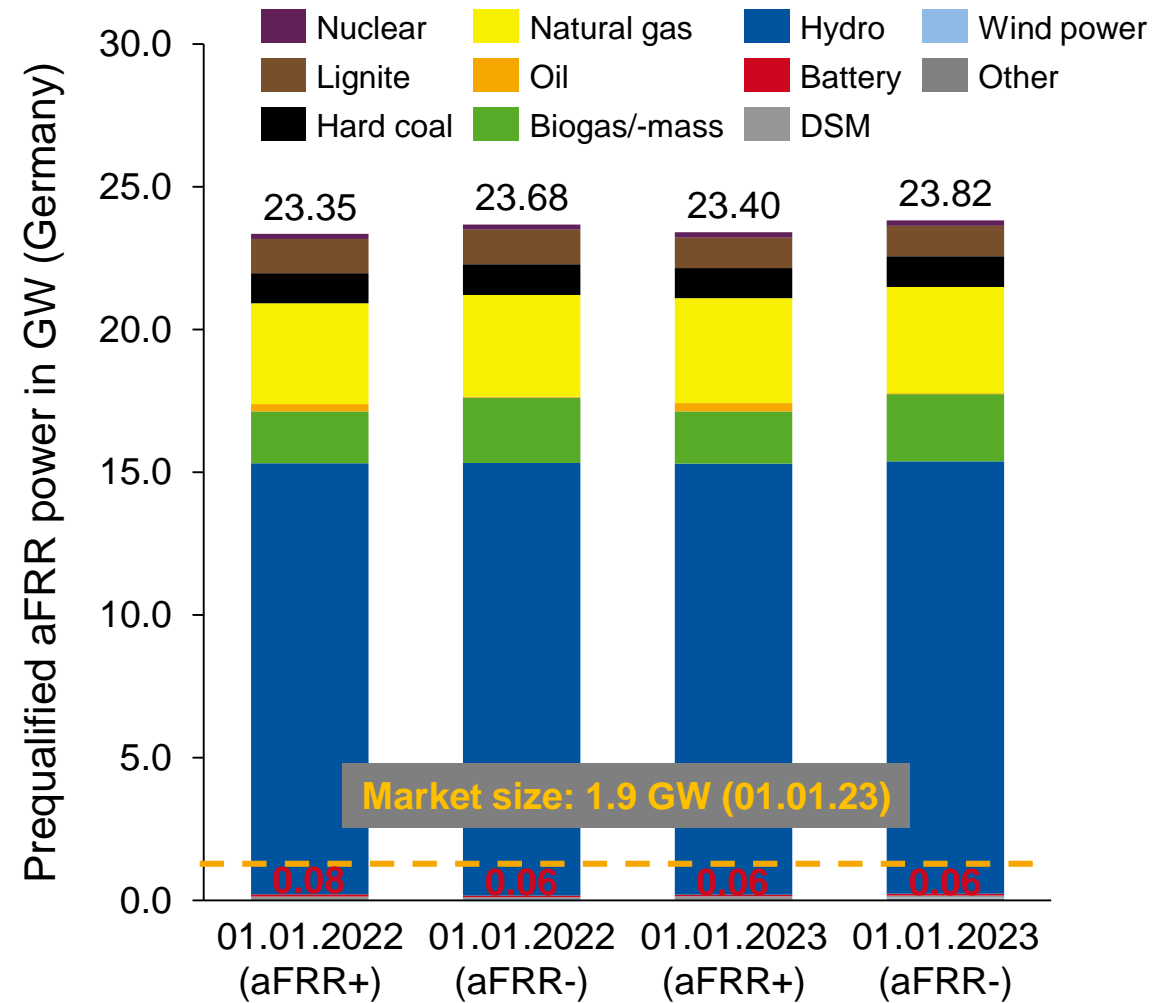
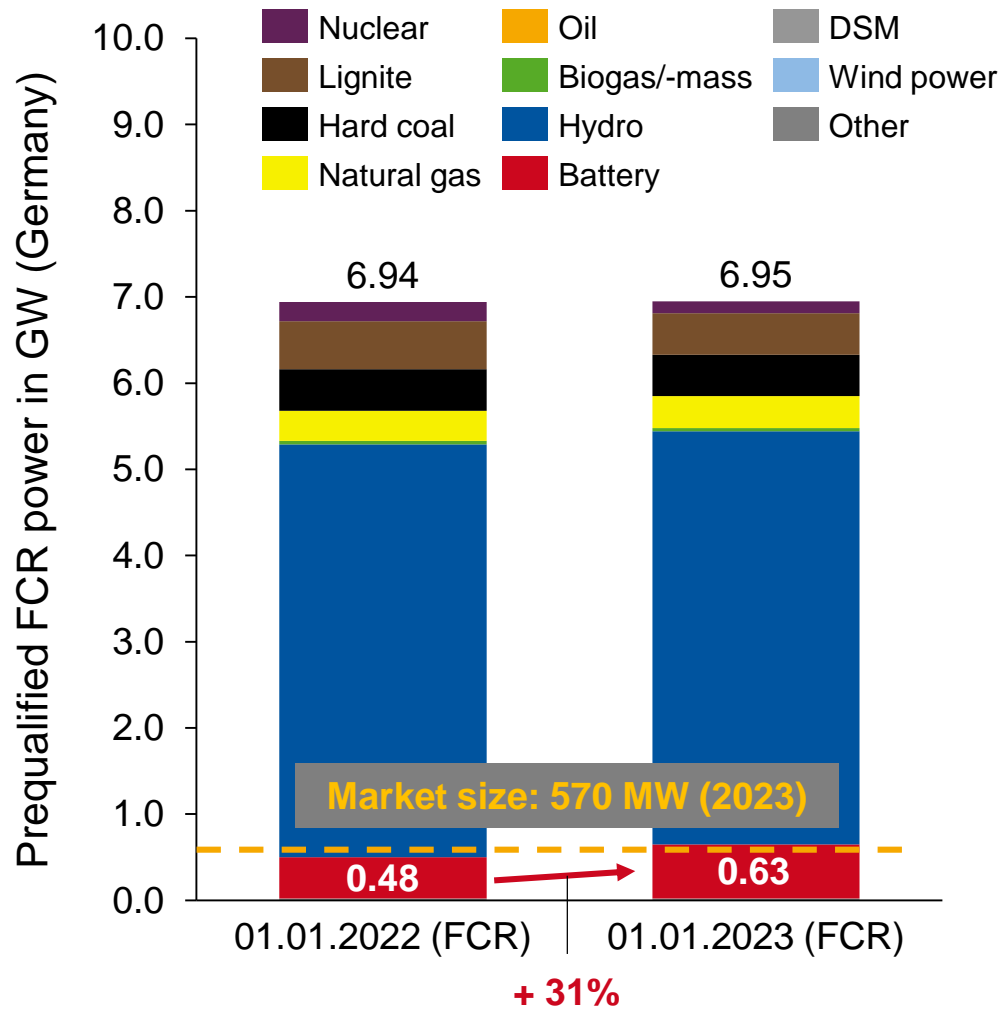
Renewable integration



Emergency power supply

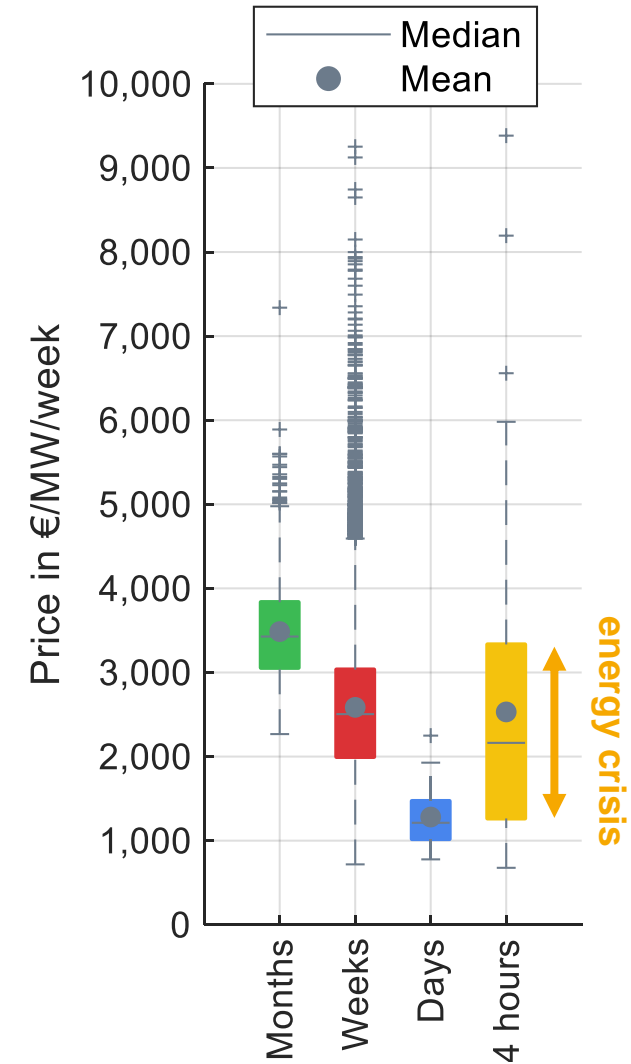
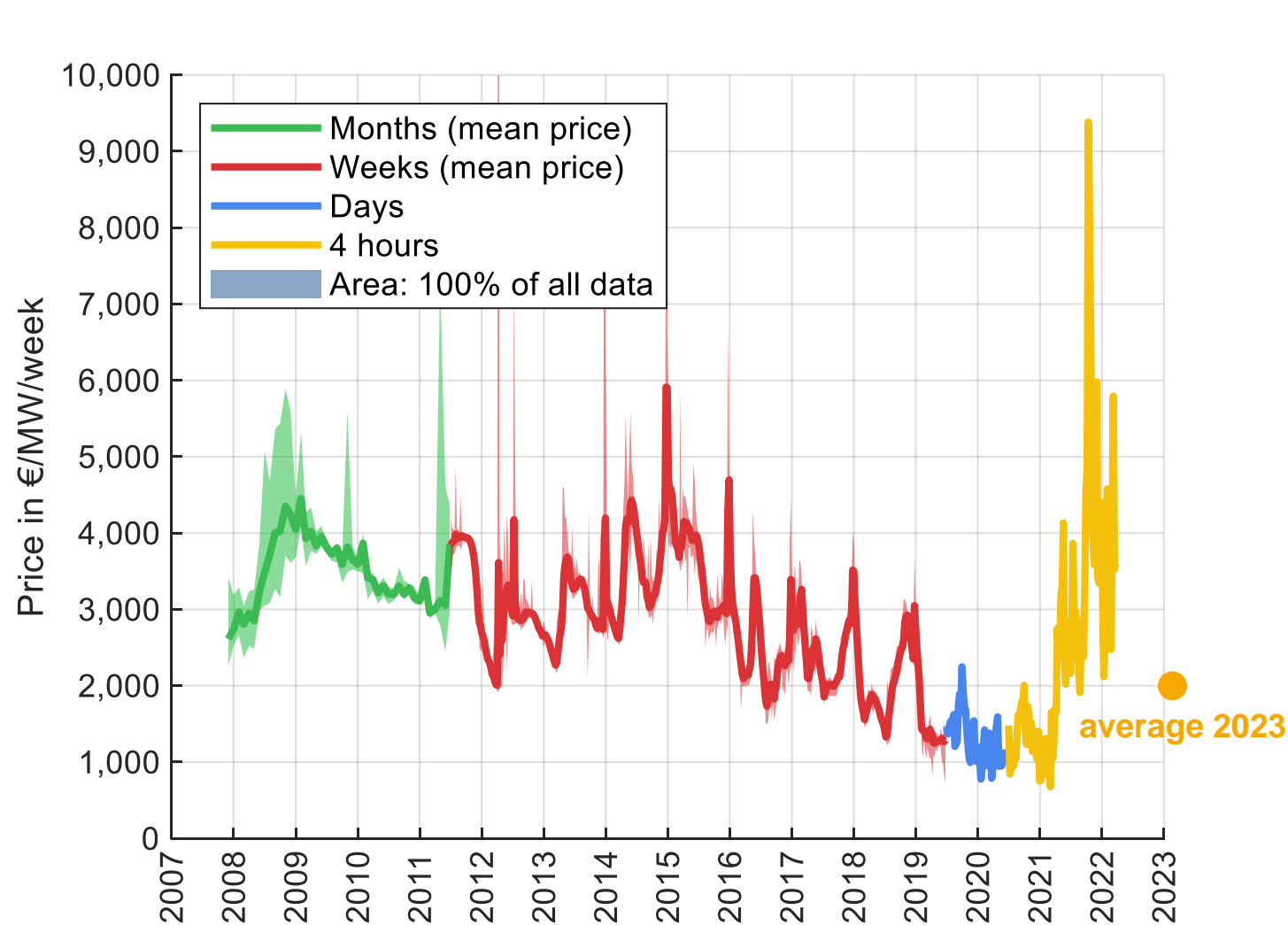


Saturation effect on the FCR market Opportunities on the aFRR market



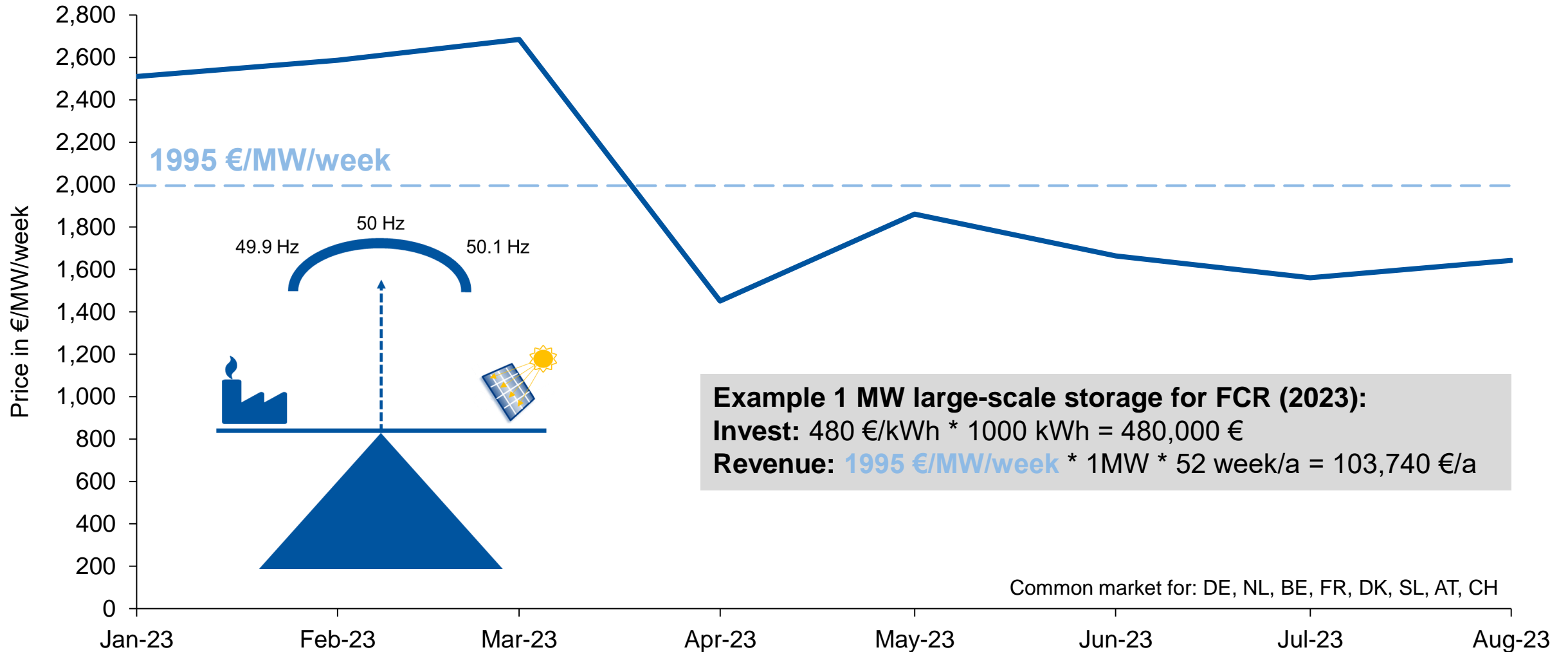
Source: based on data provided by Regelleistung.net [https://www.regelleistung.net/xspproxy/api/staticfiles/regelleistung/pg-leistungindeutschland\(stand01.01.2023\).pdf](https://www.regelleistung.net/xspproxy/api/staticfiles/regelleistung/pg-leistungindeutschland(stand01.01.2023).pdf)

FCR market – historic development



Figgenger et al., 2022, <https://www.sciencedirect.com/science/article/pii/S2352152X22011392>

Revenue potential FCR



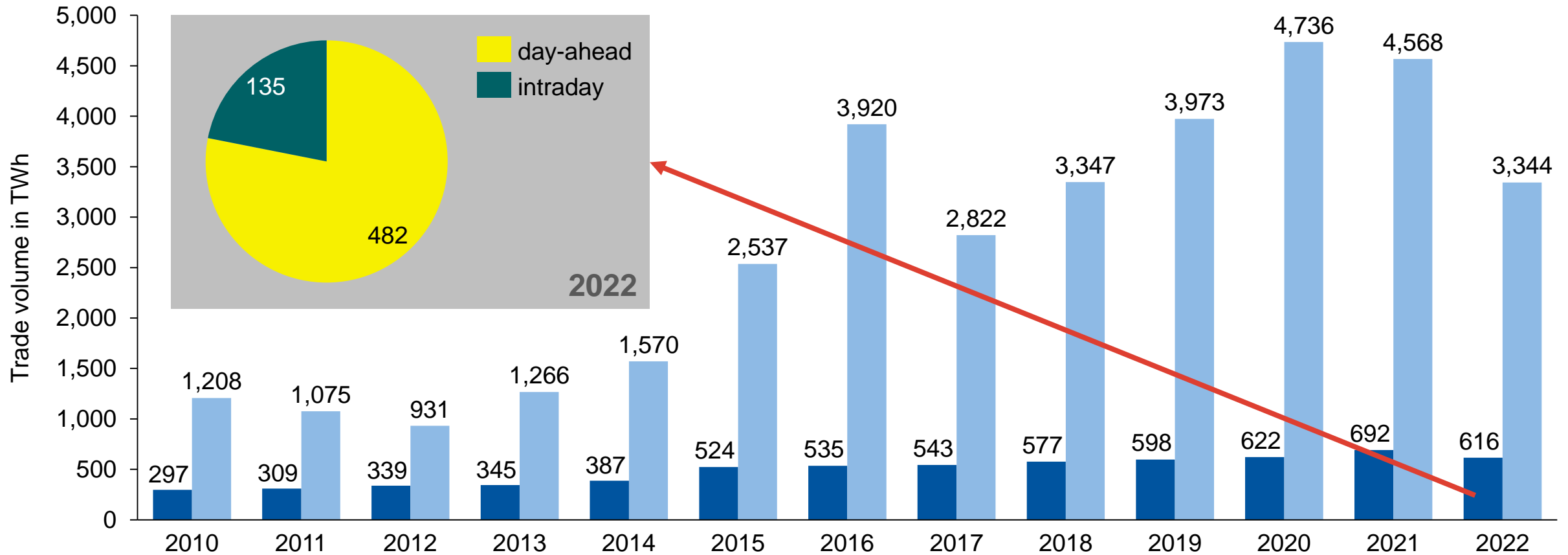
Source: based on data provided by Regelleistung.net: <https://www.regelleistung.net/de-de/>

Electricity market trading volume in Europe



Battery capacity 2022 in Germany: 72 GWh (incl. BEV)
 → 72 GWh * 365 EFC = 26 TWh (assumption: 1 cycle per day)

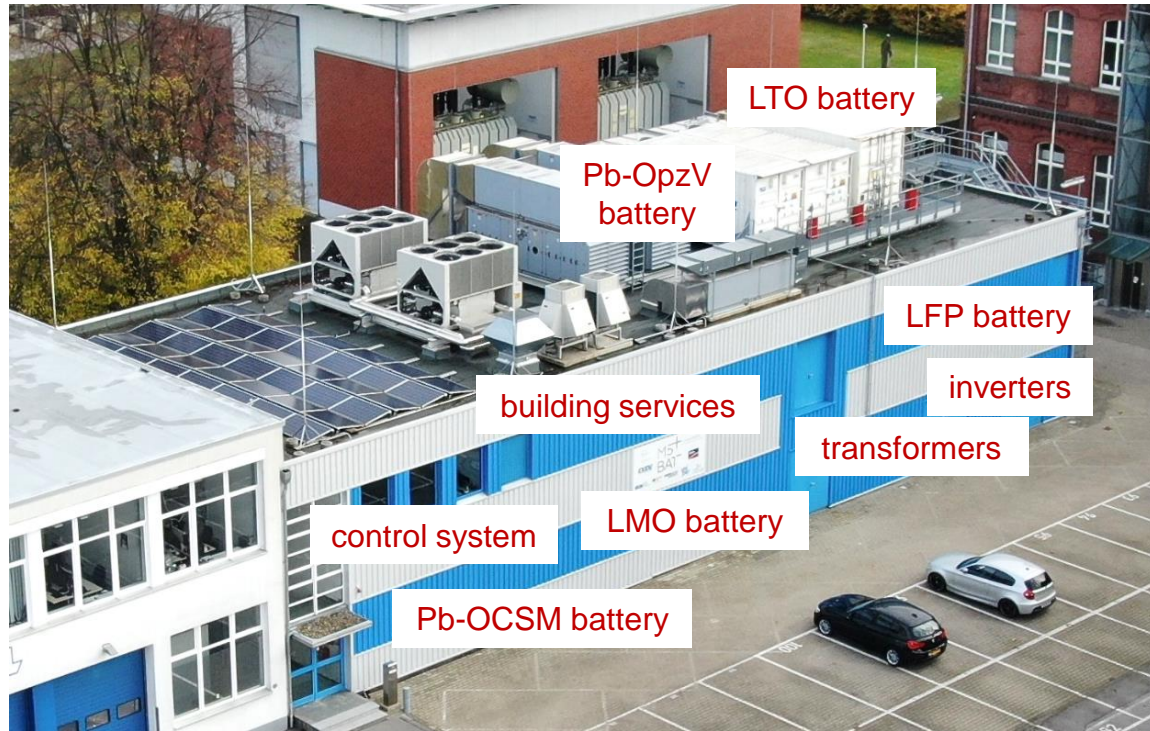
■ EPEX Power Spot Market Europe
 ■ EEX Power Derivatives Market Europe



Source: EEX Group Annual Volume Reports: https://www.eex.com/fileadmin/Global/News/Group/News/20230124_EEX_Group_Annual_Volume_Report.pdf

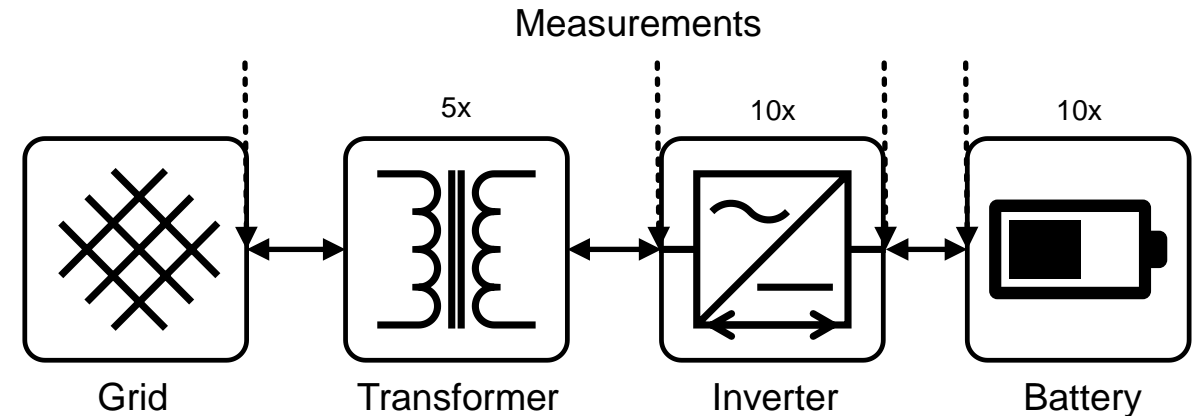
Battery storage M5BAT

Modular Multi-Megawatt Multi-Technology Medium-Voltage Battery Storage



Live Monitoring:

<https://m5bat.isea.rwth-aachen.de/>



Technical data

- Power: approx. 6 MW
- Energy: approx. 7.5 MWh
- 5 battery technologies (lithium-ion & lead-acid)
- 10 independent battery units

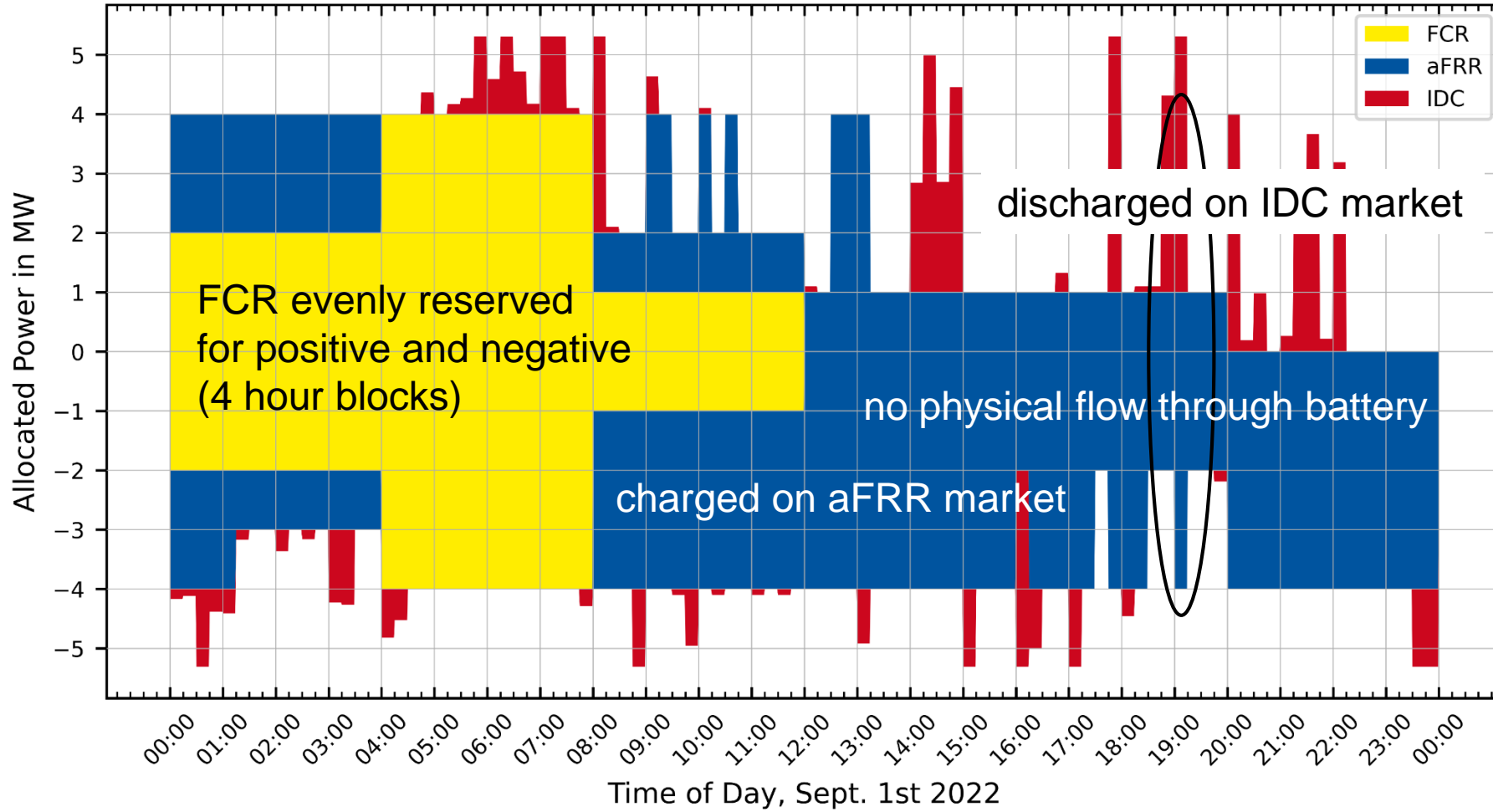
Operation

- System services
- 3MW FCR
- Intraday trading continuous trading
- In preparation: aFRR

M5Bat: Multi-Use operation



Scheduling of Multi-Use Operation



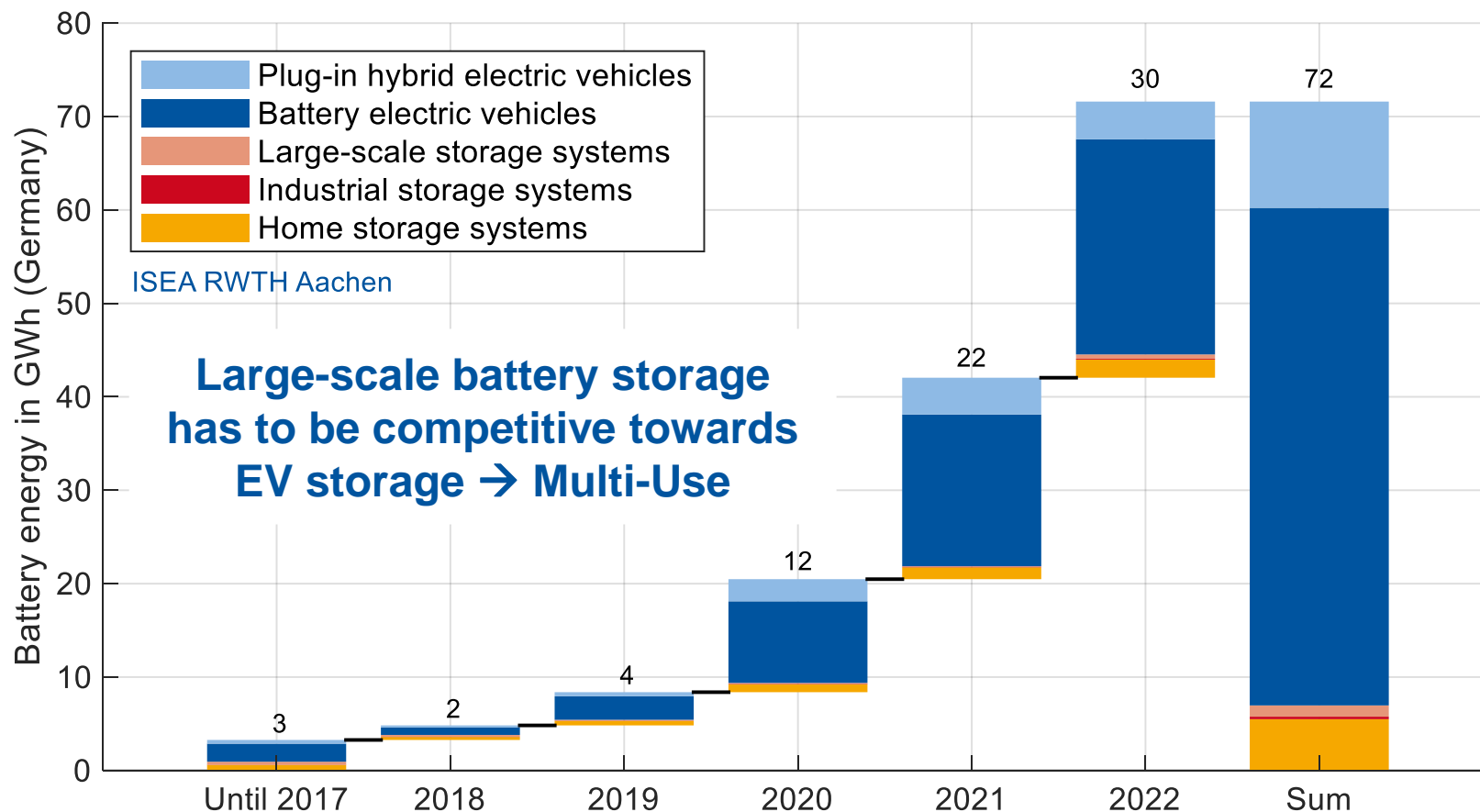
MILP optimization with perfect forecast

Source: Celi-Cortes et al.: Optimal Multi-Use Operation of Utility-Scale Battery Systems: Techno-Economic Feasibility Study of the M5BAT Hybrid Storage in Aachen

Outlook: market development of battery storage in Germany (estimate)



65 GWh battery capacity in mobility applications (end of 2022) from only 2% of the total vehicle stock equals 1.5 times the total capacity of all pumped hydro power systems in Germany: big potential for vehicle-to-grid applications



Takeaways

- FCR market almost saturated
- aFRR markets of increasing interest
- Finite trading volume on intraday continuous market
- Increasing efficiency by adequate sizing of inverters/transformers

Source: based on Figgner et al., <https://www.researchgate.net/publication/369479477> The development of battery storage systems in Germany A market review status 2023

Thank you for your attention

More market data:
www.battery-charts.de
www.mobility-charts.de

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We thank



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