Economic evaluation of battery storage systems participating in the day-ahead and automatic frequency restoration reserves markets

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Motivation

Background:

- Transformation of energy system
- Provision of systems services (such as reserve power) have to be ensured
- Battery storages one promising technology

Aim:

- Assess use and economic potentials of battery storages in combined use:
  - Day-ahead (DA) market
  - Automatic Frequency Restoration Reserve (aFRR) market

Method:

- Analysis of historic price time series
- Agent-based modelling of DA and aFRR market in AMIRIS
- Optimization model of battery storage application

Modelling approach: two-step soft coupling

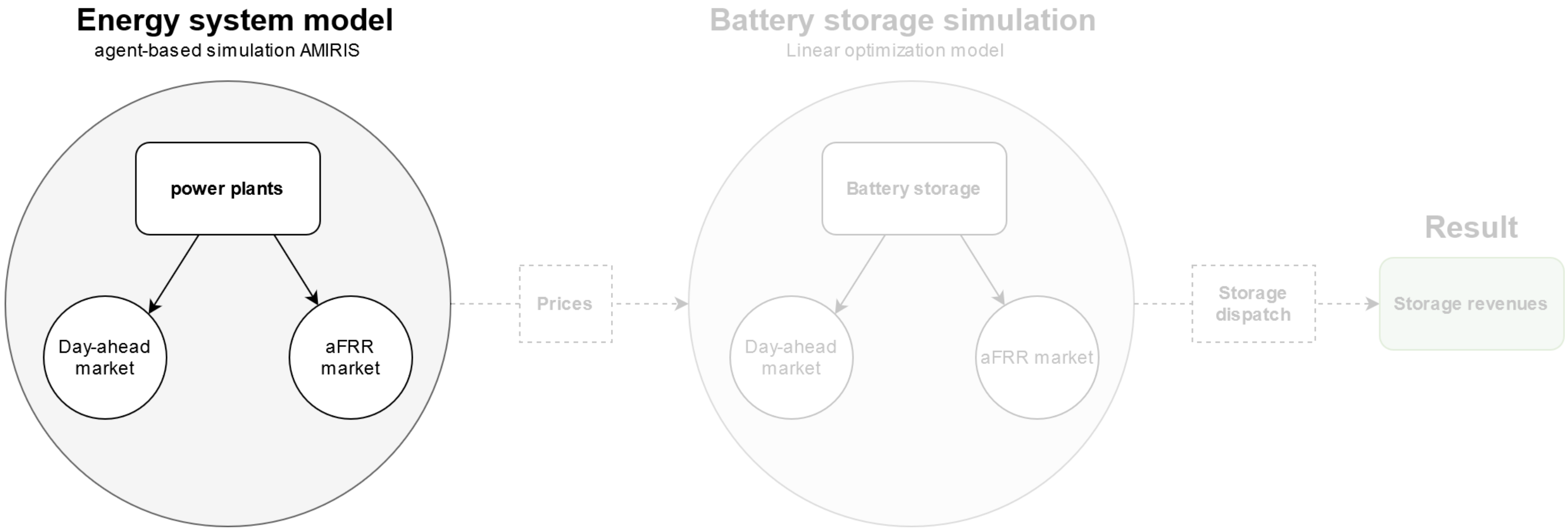

Fig. 1: Schematic overview of coupling the agent-based model AMIRIS (left) and the linear optimization model in GAMS (right)

Simulating the DA & aFRR electricity markets with AMIRIS

Input
- RE feed-in
- Load
- Power plant park
- Efficiencies
- Availabilities
- Fuel costs
- CO_2 costs

Output
- Electricity prices
- Power plant dispatch
- Storage dispatch
- Market values
- Emissions
- System costs

Round-based simulation - hourly resolution - one node

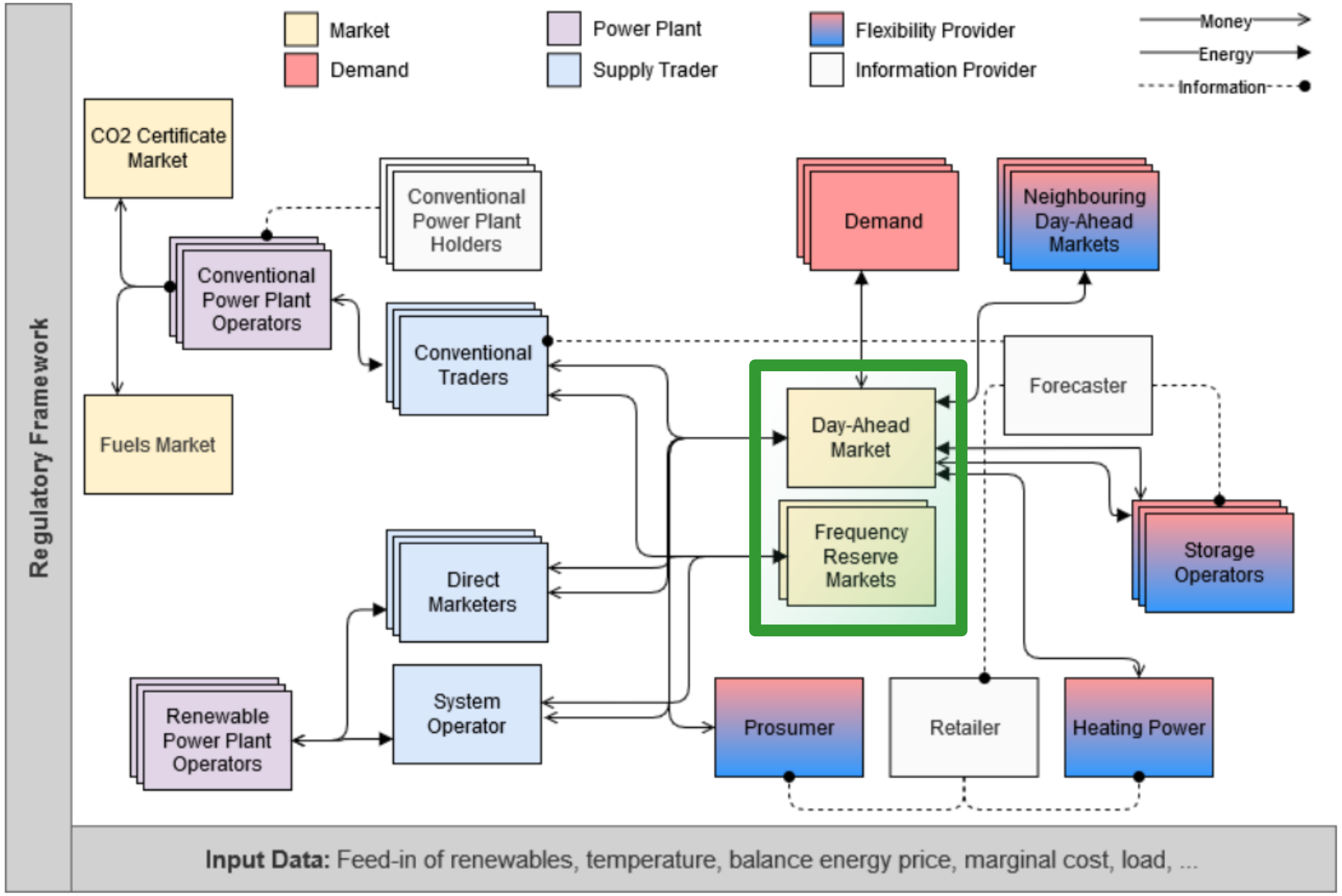

Fig. 2: Modell setup of AMIRIS

Bidding on the aFRR market

Idea:
- Comparison of opportunity costs DA & aFRR market (Müsgens et al., 2014)

Assumptions:
- Forecast of DA price is known
- aFRR demand is known
- Hourly bidding
- aFRR market clearing before DA clearing

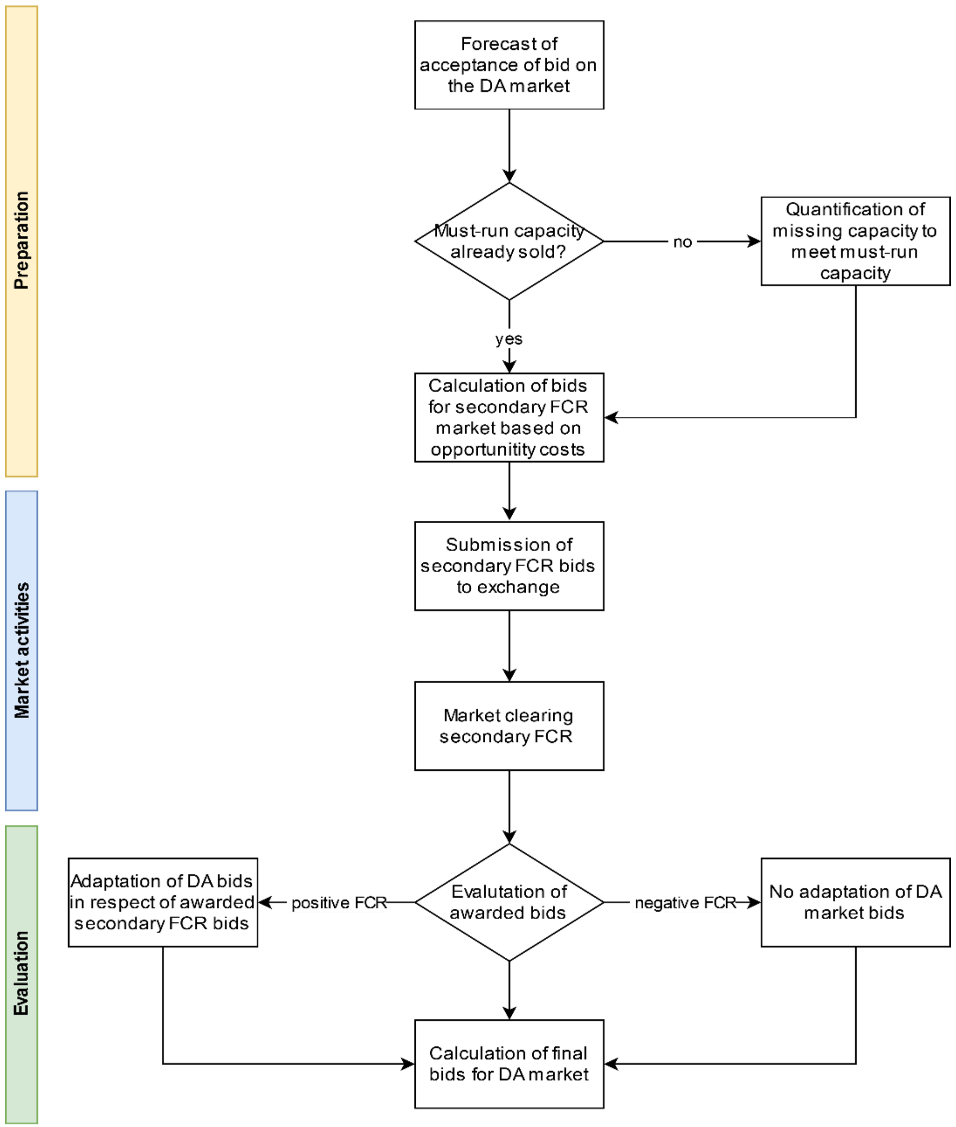

Fig. 3: Bidding procedere in AMIRIS

Modelling approach: two-step soft coupling

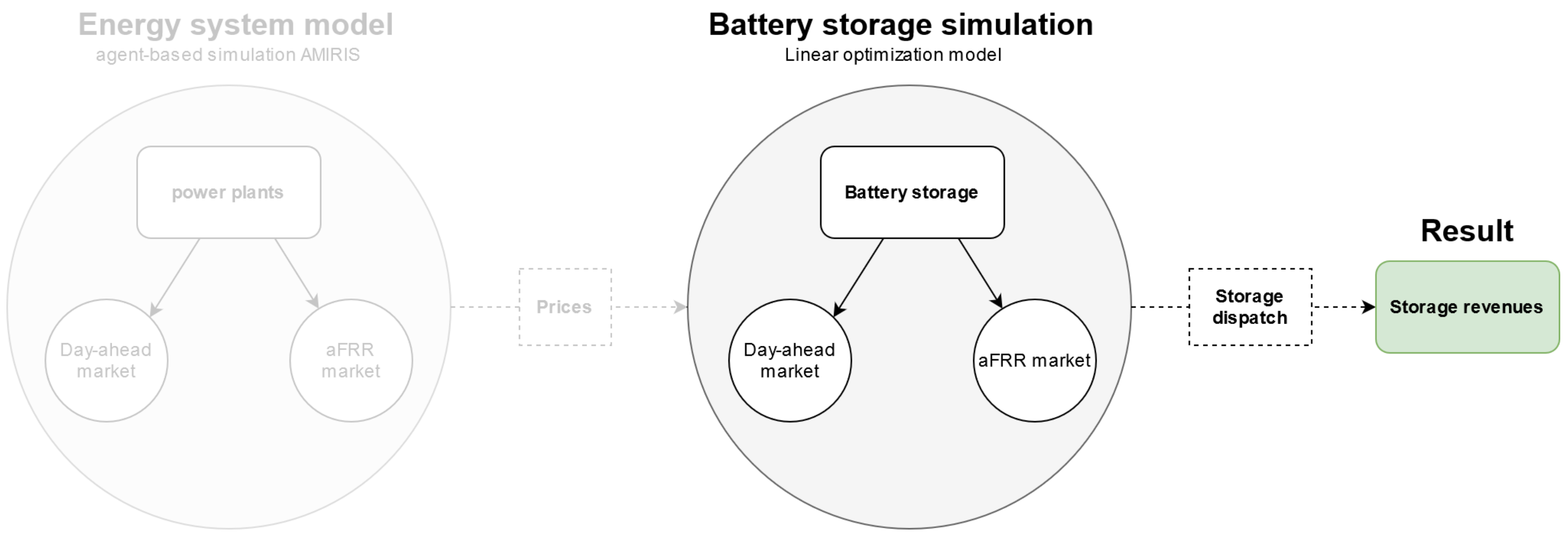

Fig. 1: Schematic overview of coupling the agent-based model AMIRIS (left) and the linear optimization model in GAMS (right)

Optimizing the battery storage revenues in GAMS

Objective function:

Maximizing total revenues from arbitrage on DA market and system services on aFRR market

Technical specifications:

Total capacity = 1 MWh
Initial state of charge = 0.5 MWh
Power as defined with $E2P$-Rate = $[1, \ldots, 10]$
Round-trip efficiency = $[85\%, 87.5\%, 90\%]$

Further assumptions:

No cycling costs, no taxes on revenues and no pre-qualification costs
Perfect foresight

Scenario

- „Gesamtwirtschaftliche Effekte der Energiewende“ (Lutz et al. 2018)
- Simulation year: 2030
- CO_2 reduction until 2050: 80-85%
- CO_2 price 35€/t
- High share of RE covering 60% of total yearly demand
- aFRR market with mainly conventional power plants

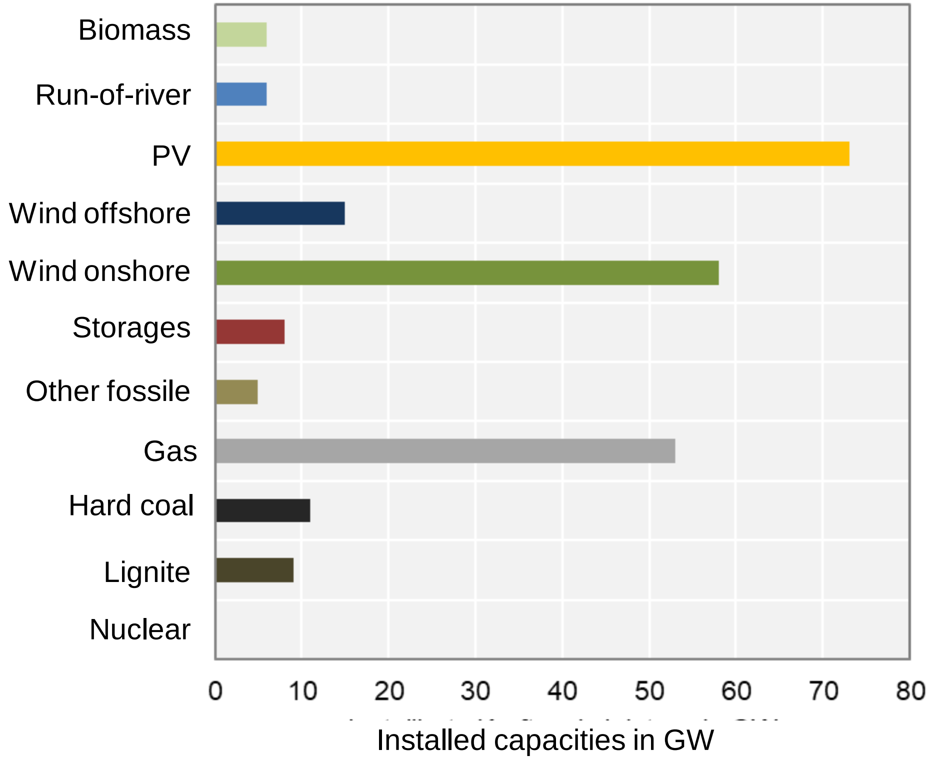

Fig. 4: Power plant park derived for the year 2030 from Lutz C et al. 2018

Lutz C et al (2018): Gesamtwirtschaftliche Effekte der Energiewende. GWS, Fraunhofer ISI, DIW, DLR, Prognos. http://www.gws-os.com/discussionpapers/gws-researchreport18-4.pdf

Results: prices on DA market

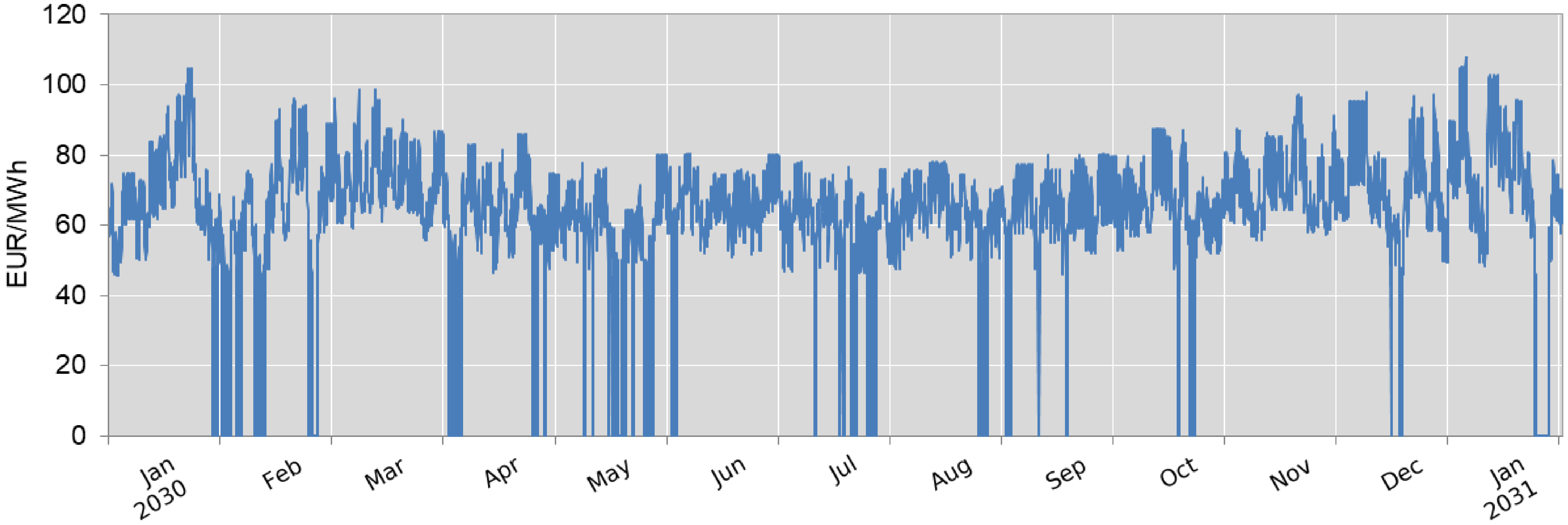

Fig. 5: Day-Ahead prices in the modelled scenario

Results: monthly prices on aFRR markets

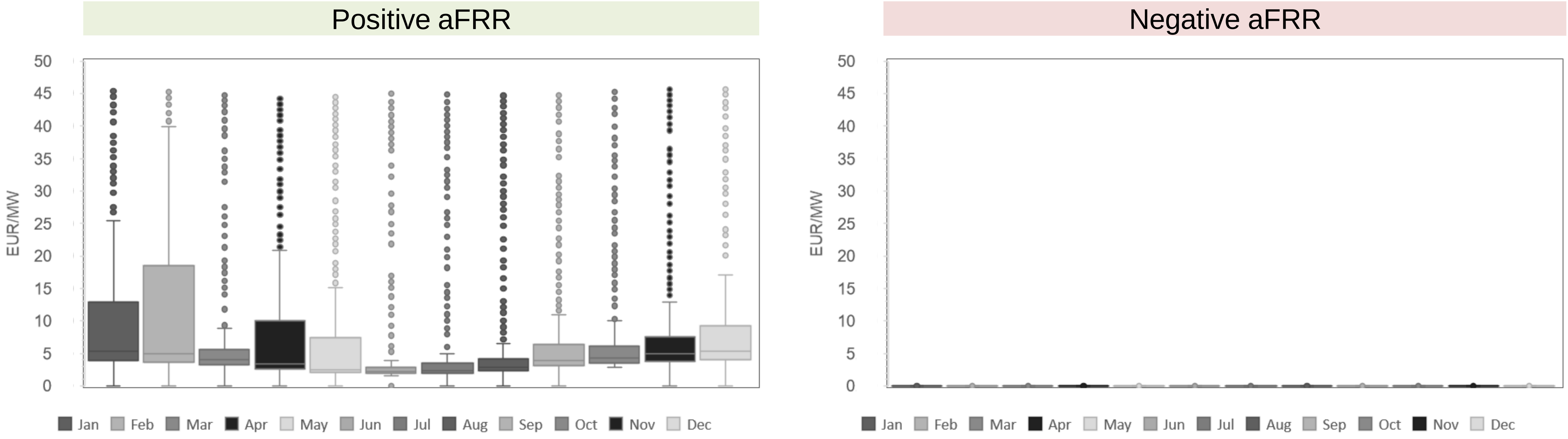

Fig. 6: Capacity prices for positive (left) and negative (right) on the modelled aFRR market

Results: Revenues for battery storage operator

Tab 1: Yearly revenues per MWh_{inst} in the scenario and a reference calculation for 2016

		Roundtrip Efficiency = 85 %	
		Scenario	Reference 2016
E2P	1	10.9 k€	26.6 k€
	2	8.0 k€	16.0 k€
	3	7.3 k€	11.9 k€
	4	6.6 k€	9.6 k€
	5	6.1 k€	8.2 k€
	7.5	5.0 k€	5.9 k€
	10	4.1 k€	4.7 k€

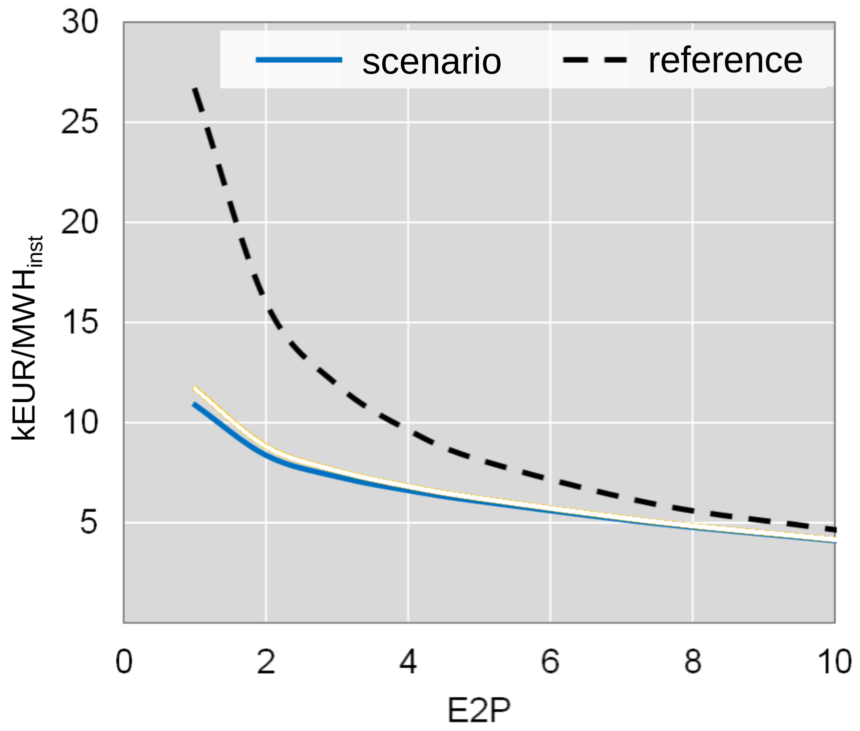

Fig 7: Yearly revenues per MWh_{inst} in the scenario and a reference calculation for 2016

Results: changing E2P and Round-trip efficiency

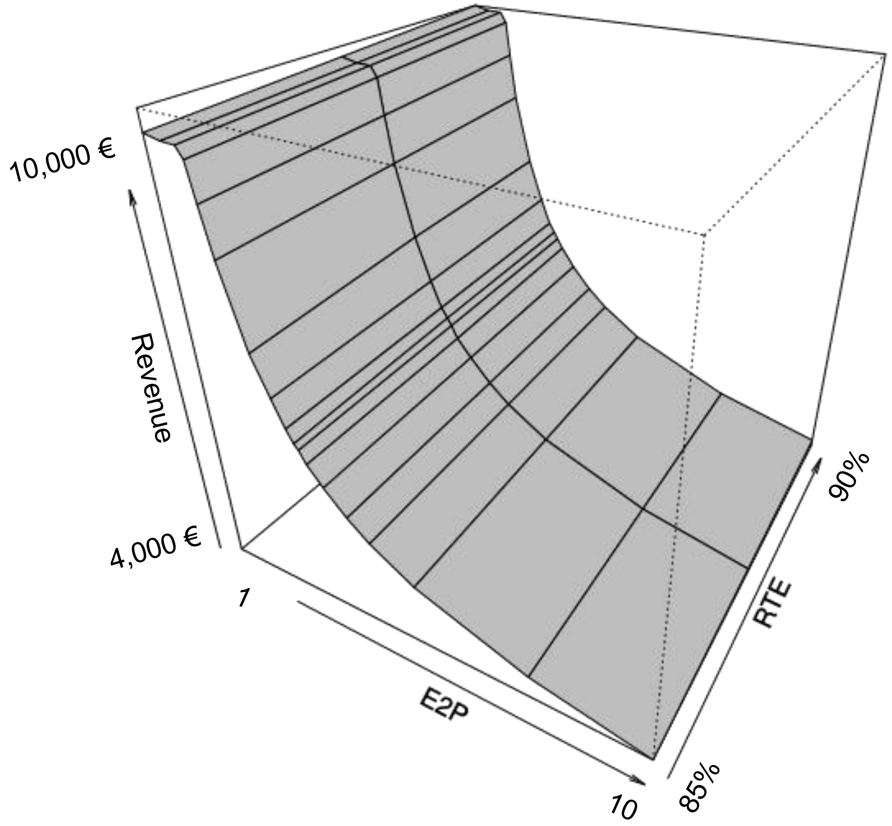

Fig 8: Yearly revenues per MWh_{inst} when E2P and Round-trip efficiency are altered

Discussion

- Additional revenue possibilities such as intraday and FCR markets
- Costs to participate in markets are not included
- aFRR demand challenging to model

- Missing modelling of competition and uncertainty among flexibility option providers:
  - Additional technologies besides battery storages
  - Impact on prices due to operational strategies of flexibility options

Conclusion

- Battery storages may contribute to energy system transformation:
  - Arbitrage on DA market
  - System services on aFRR market
- Fundamental modelling of these two markets in agent-based model AMIRIS
- Optimization of revenue potentials in GAMS

- Scenario results show challenging economic potential of battery storages compared to historic situation
- Revenue potentials are dependent on $E2P$ rather than $Round\ Trip\ Efficiency$
- Still uncertainties due to modelling of additional markets and competition

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