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8th Korean-German Energy Day

Rethinking capacity mechanisms

An advanced reliability reserve to incentive power sector flexibility while safeguarding the electricity market

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1. Motivation

Germany’s power sector

Status quo

- Supply: decreasing firm capacity and increasing shares of wind and solar energy
- Demand: electrification → variability and increased peak load
- Security of supply concerns
- Result: political desire for additional firm capacity → assets with low utilization

“Energy-only-market 2.0”

- Wholesale market: trading of electrical energy only
- Strategic reserves: capacity and grid reserve

Why do we need capacity mechanisms?

Barriers for investments in firm capacity

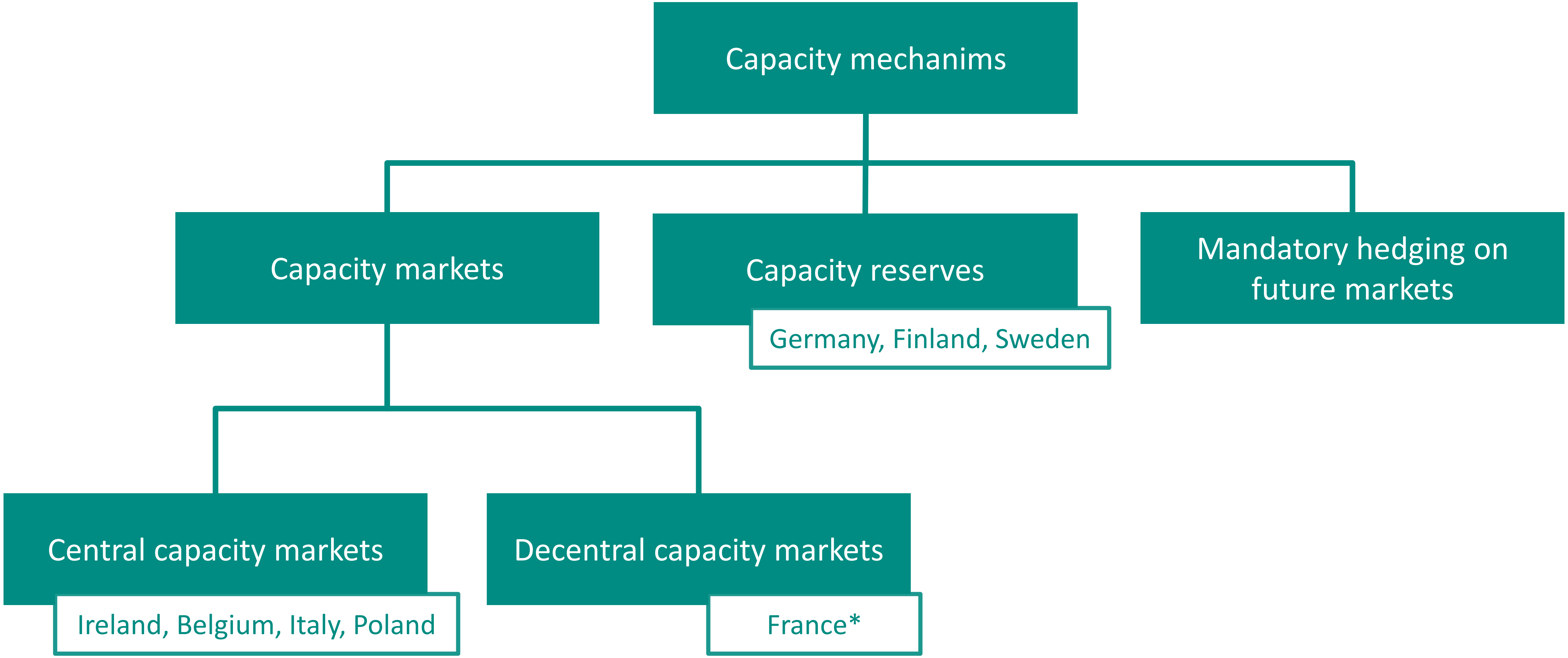
- Missing money: Capping of scarcity prices to protect consumers anticipated
- Missing market: prohibitively high financing costs from lack of long-term risk allocation
- Wholesale price uncertainty
- Anticipation of subsidy delays investment

Capacity mechanisms

- Aim: ensure sufficient dispatchable capacity when needed
- Mechanism: replace uncertain revenues with a long-term, low-risk revenue stream to incentivize investments in firm capacity

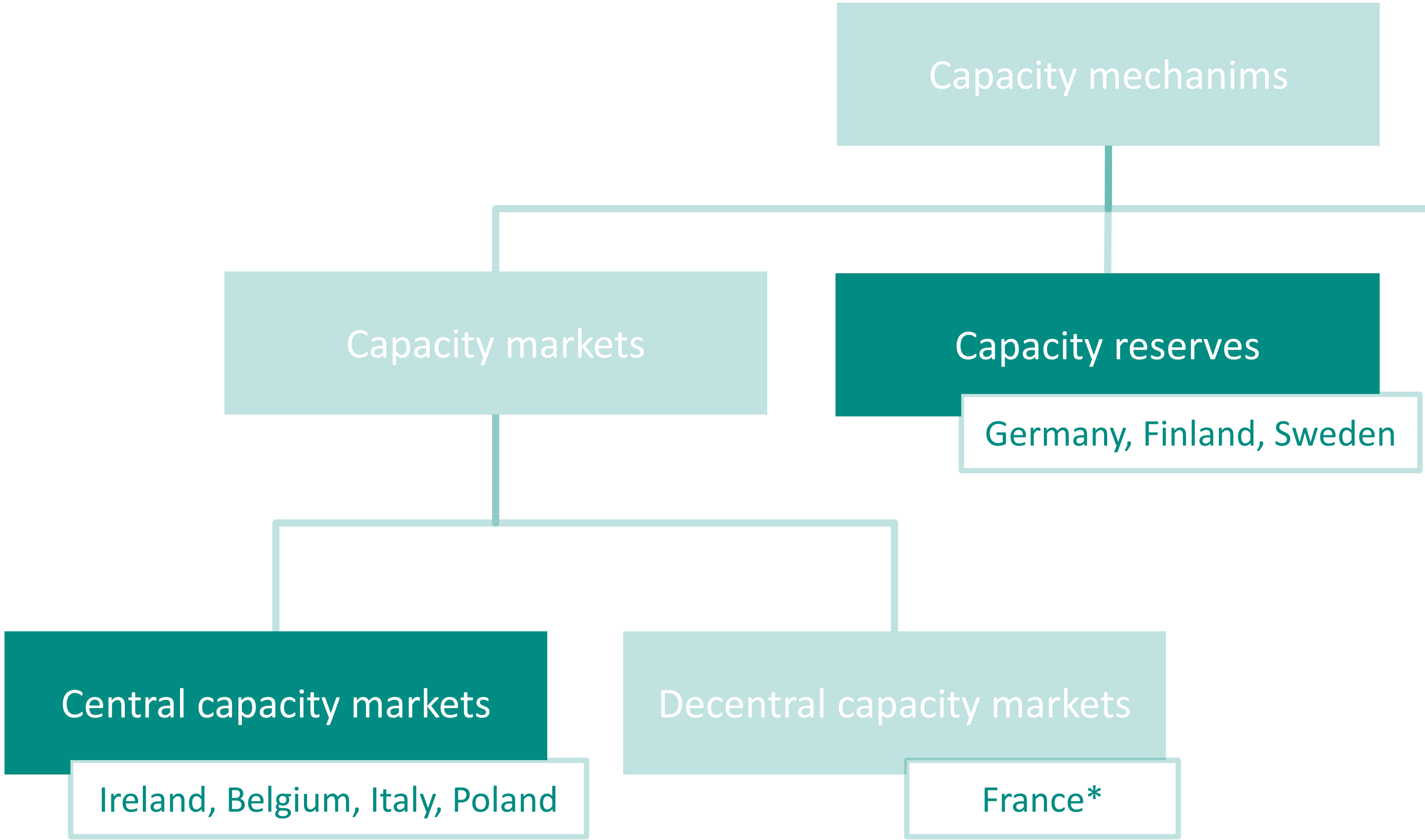
2. Design options for capacity mechanisms

Overview



*to be replaced with central capacity market in 11/2026

Overview



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Central capacity market

- Central actor defines necessary firm capacity level
- Assets in capacity and wholesale markets
- Penalty or reliability options to incentivize dispatch in scarcity situations

Strengths

- Long-term contracts incentivize investment in firm capacity
- Avoids politically prohibitively high scarcity prices

Challenges

- Tendency for overcapacity
- Effective price cap in wholesale market depresses revenues

Advanced reliability reserve

- Central actor contracts dispatchable capacity outside the market
- Assets maintained exclusively in reserve
- Activation signaled through strike price

Strengths

- Security of supply with moderately higher peak prices than price cap of capacity market
- Fast implementation and gradual adjustments possible

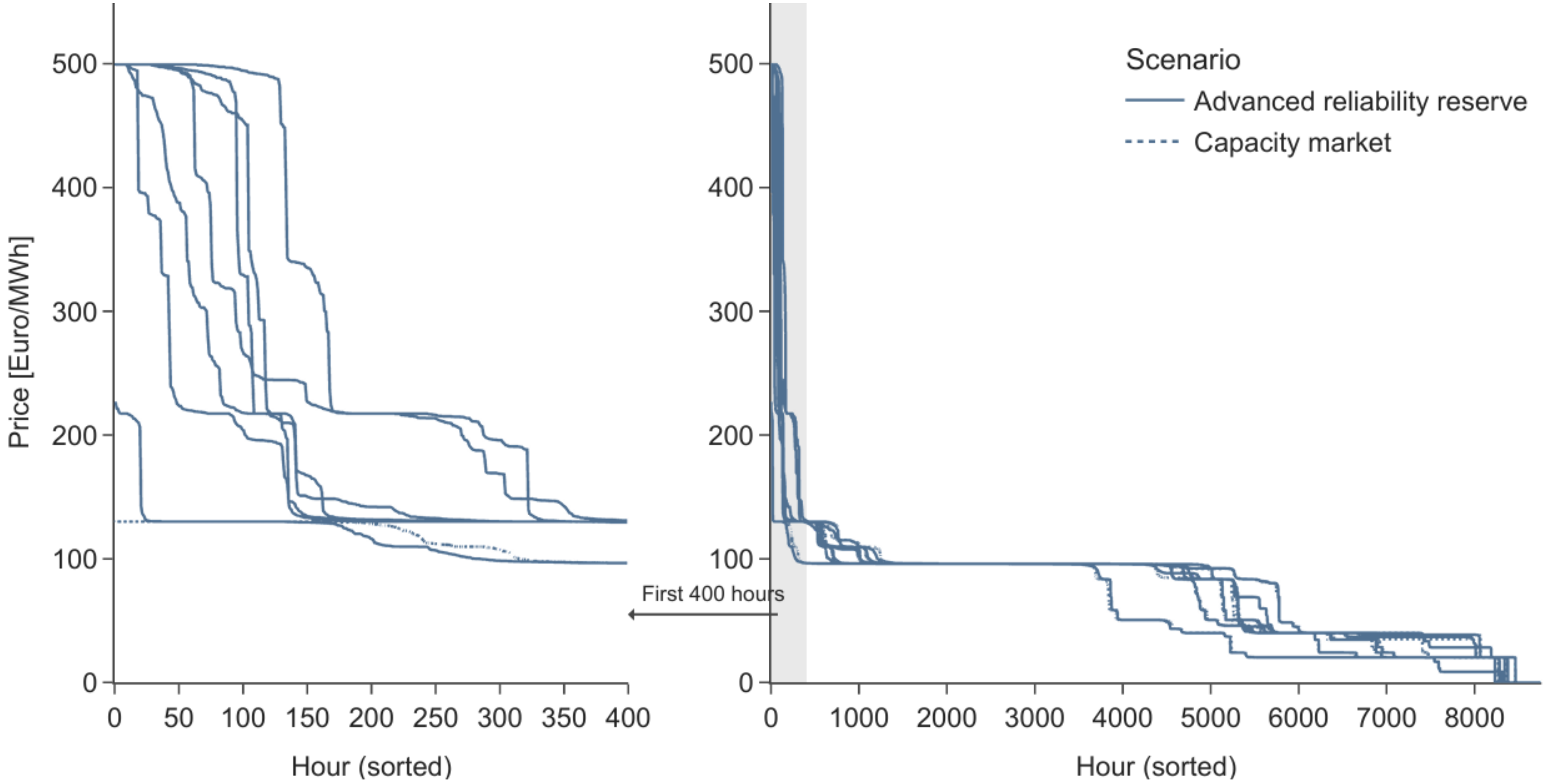
Challenge: strike price level

- Low enough to avoid excessive inefficiency from idle capacity and to retain regulatory credibility
- High enough to enable investment incentive for demand-side flexibility
- Initial suggestion: 500€/MWh

3. Case study: stylized power sector in Germany in 2030

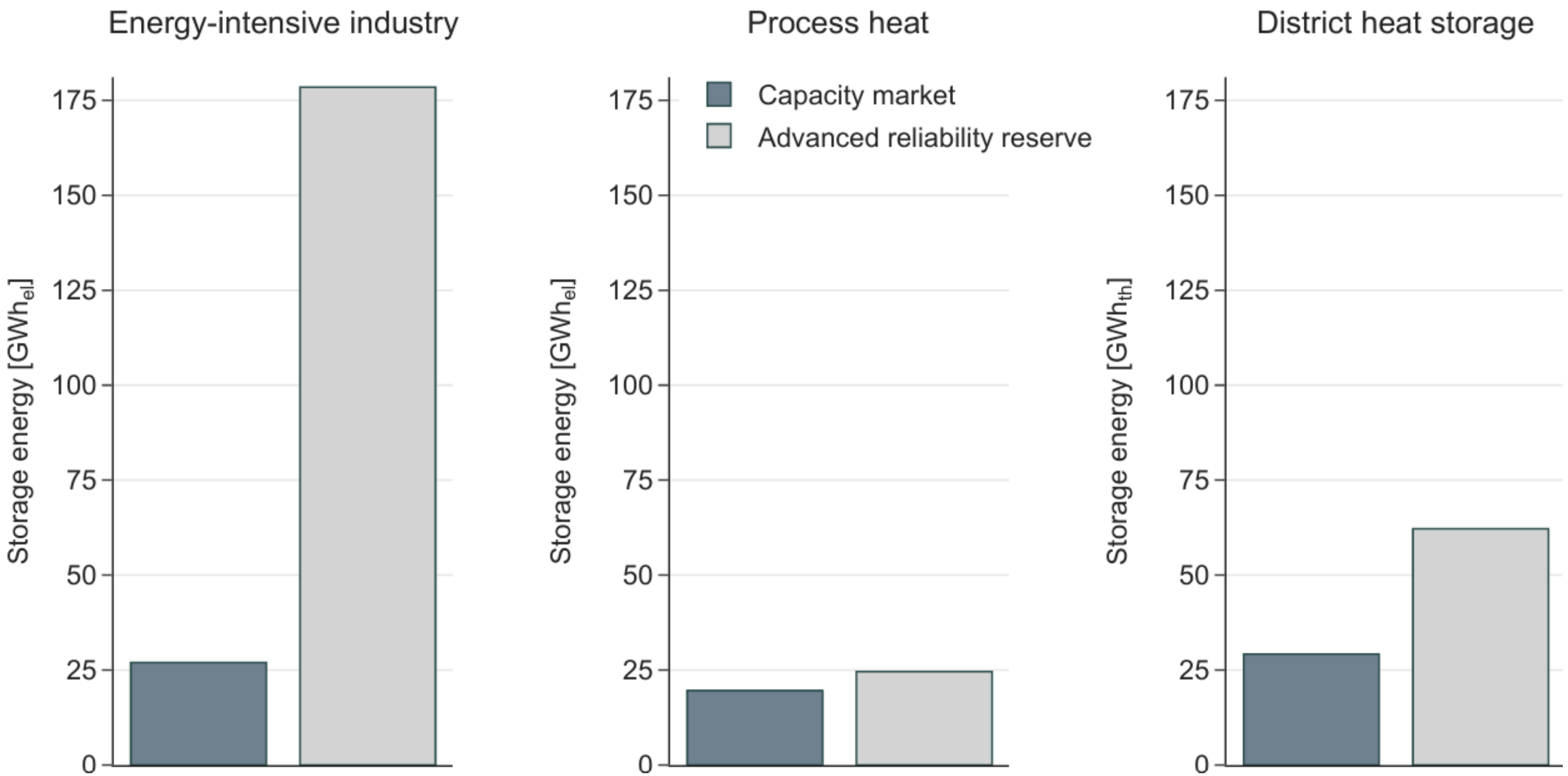
Case Study: impact on wholesale prices

- Prices largely align other than peak hours
- Market: price cap at 130€/MWh (marginal cost of gas turbine)
- Reserve: higher prices up to 500€/MWh (activation of reserve)



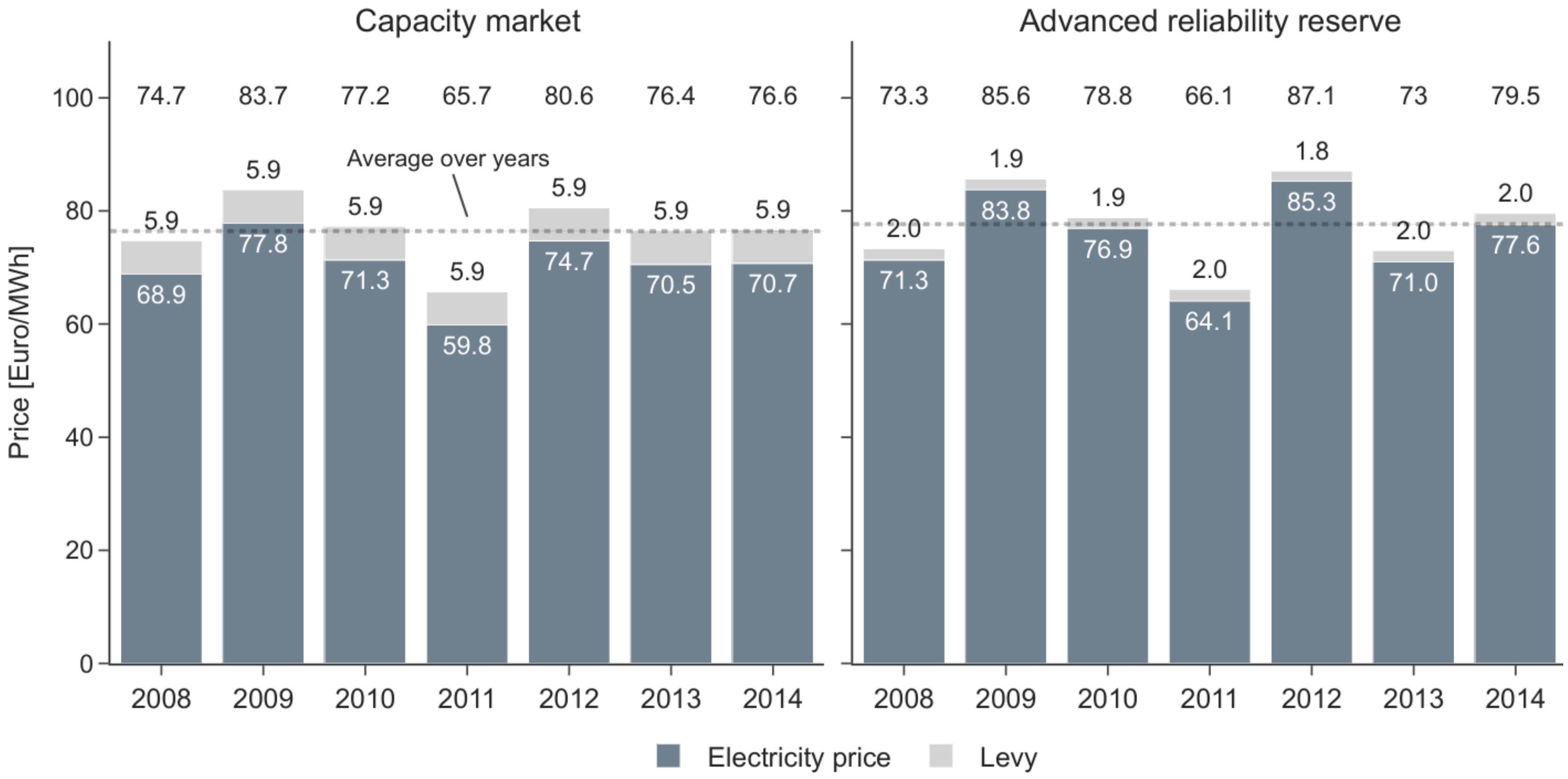
Case Study: impact on investment in demand-side flexibility

- Capacity mechanisms interact with power sector flexibility
- Market: price cap impedes investment
- Reserve: higher prices enable investment → needed in the long-run



Case study: impact on system costs

- Both options with similar total system costs
- Market: higher mechanism costs but lower electricity prices
- Reserve: lower mechanism costs but higher electricity prices



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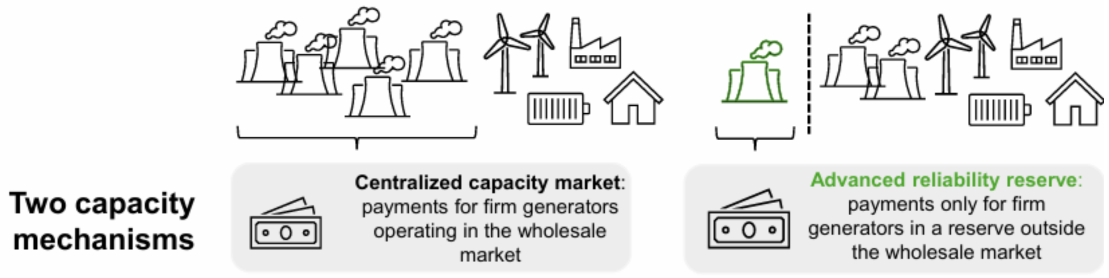
4. Conclusion

Conclusion



- Centralized capacity market caps wholesale prices, while advanced reliability reserve maintains moderate peak prices
- Centralized capacity markets crowd out demand-side flexibility investments, while reliability reserves unlocks them

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Literature

- Klaucke, F., Neuhoff, K., Roth, A., Schill, W. P., & Stolle, L. (2026). An advanced reliability reserve incentivizes flexibility investments while safeguarding the electricity market. *iScience*, *29*(6).

- Neuhoff, K., Kittel, M., Klaucke, F. K., Kröger, M., Roth, A., Schill, W. P., & Stolle, L. (2024). *Security of supply in the electricity sector: Analysing different capacity mechanisms and their interactions with demand-side flexibility potentials* (No. 203). DIW Berlin: Politikberatung kompakt.

Thank you for your attention!

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Backup

Research design

Stylized scenario Germany 2030

- Completed coal phase-out
- Endogenous investment: gas turbines, battery and hydrogen storage, and demand-side flexibility
- Demand-side flexibility portfolio: intermediate product storage, electricity storage, district heating storage (excl. from capacity mechanisms)
- Weather years: 2009 as design year, 2008 – 2014 dispatch years with summer2summer horizon

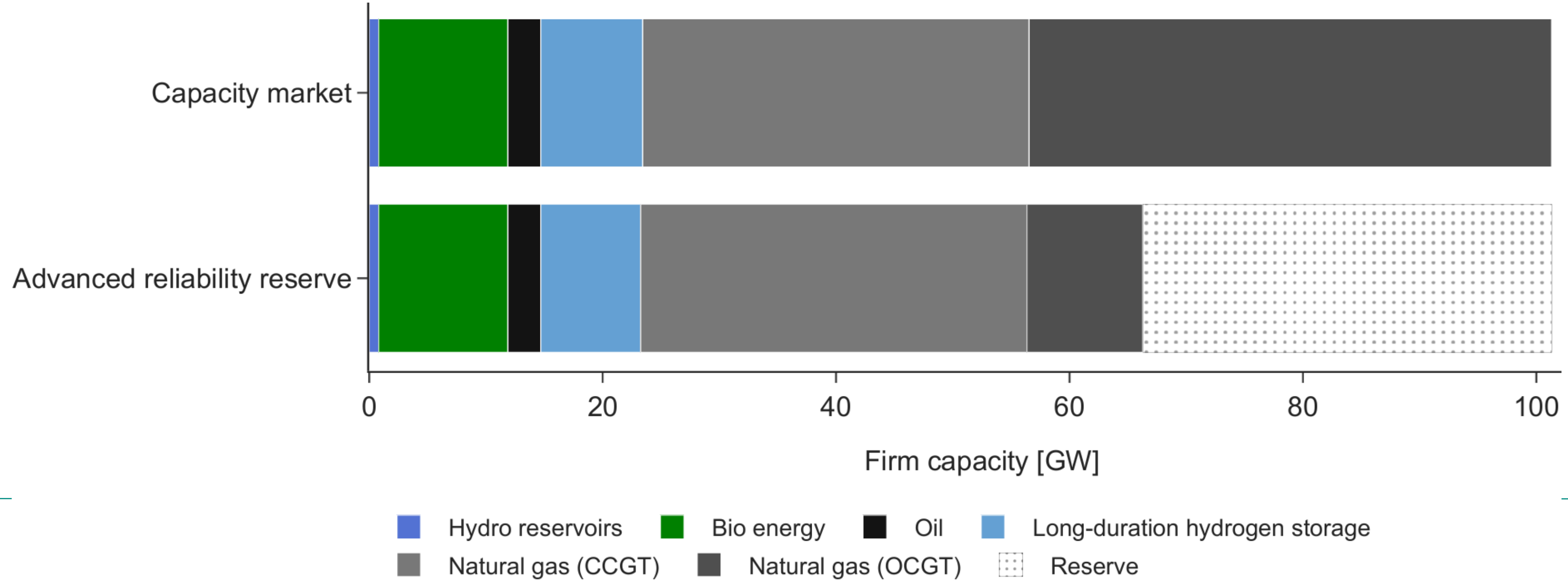
Case study: power plant portfolio

Central capacity market

- 101 GW → max. residual load + 5 GW safety margin
- Technologies: gas, hydrogen, oil, bio energy, hydro reservoir

Advanced reliability reserve

- 35 GW new capacity → sized to achieve 101 GW of firm capacity in wholesale market and reserve
- Activation at strike price = 500€/MWh_{el}



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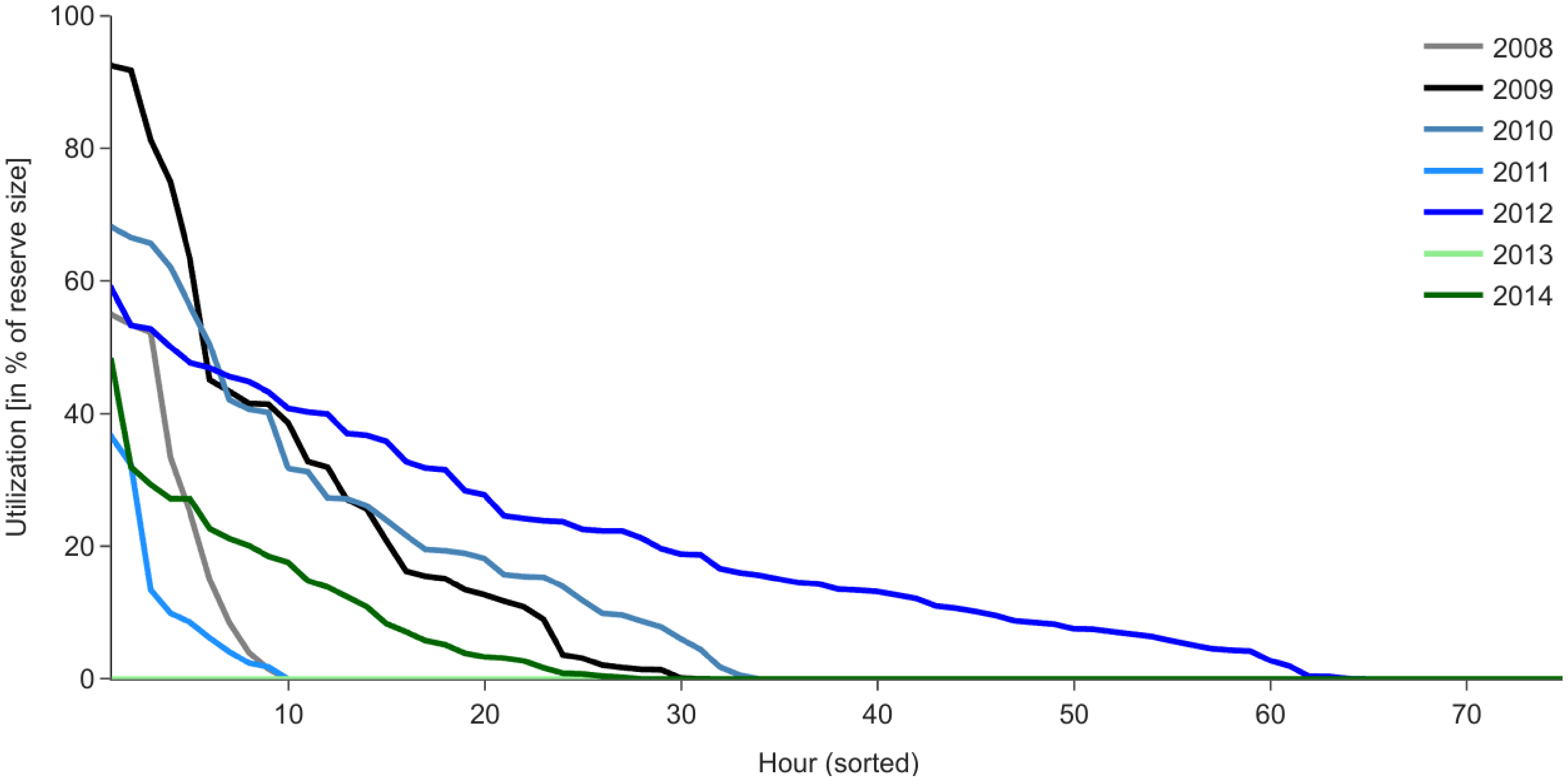
Case study: utilization of reserve capacity

- Used in only very low amount of hours



Model assumptions: generation and demand

- Annual electricity demand 700 TWh (670 TWh + 19 to 25 TWh for district heating) → additional load distributed equally across all hours of the year

- Exogenous: wind and solar power, bio energy, and hydropower

- Demand time series from ERAA 2023
- Heating demand from when2heat

Table S1: Capacity and cost assumptions, related to STAR methods

	Capacity	Lifetime	Overnight costs	Fixed costs	Efficiency	Carbon content	Fuel costs	Var. costs storing in/out
	GW	years	euro/kW	euro/kW	%	t/MWh_{th}	euro/MWh	euro/MWh
Run-of-river hydro	3.93	50	3000	30	0.9	0	0	-
Natural gas (CCGT)	0.00–∞	25	800	20	0.54	0.201	26.03	-
Natural gas (OCGT)	0.00–∞	25	400	15	0.4	0.201	26.03	-
Oil	2.82	25	400	7	0.35	0.266	41.65	-
Bio energy	11.06	30	1951	100	0.49	0	10	-
Onshore wind	115.00	25	1182	35	1	0	0	-
Offshore wind	30.00	25	3935	100	1	0	0	-
Solar PV	215.00	25	600	25	1	0	0	-
Lithium-ion batteries		20						
... power in/out	0–∞/0–∞		50/0	0.1/0	0.97/0.97	-	-	0.3/0.3
... energy [GWh]	0–∞		300	0.7	0.999989	-	-	-
Power-to-gas-to-power		22.5						
... power in/out	0–∞/0–∞		305/850	0/0	0.73/0.6	-	-	1.2/1.2
... energy [GWh]	0–∞		2	0	1	-	-	-
Open pumped hydro storage		80						
... power in/out	1.86/2.14		550/550	0/0	0.97/0.91	-	-	0.56/0.56
... energy [GWh]	471.23		10	0	0.999995	-	-	-
Closed pumped hydro storage		80						
... power in/out	6.56/6.41		550/550	0/0	0.97/0.91	-	-	0.56/0.56
... energy [GWh]	391.58		10	0	0.999995	-	-	-
Reservoirs		50						
... power out	0.82		200	30	0.95	-	-	0.1
... energy [GWh]	237.22		10	0	1	-	-	-

Notes: In the column capacity, if two numbers are connected with a hyphen, the model can choose endogenously in that range; otherwise, the value is fixed. The assumed carbon price is 130 euro/ton.

Model assumptions: energy intensive industry

- Demand flexibility from energy storage or intermediate product storage
- Load change potentials, maximum duration of load change, and costs from literature
- Implemented as storage, investment costs accrue for energy capacity

Table S2: Data and references on the demand response potentials of energy-intensive industrial processes, related to STAR methods

Energy-intensive industrial process	Demand response potential % of the installed load	Installed capacity Germany MW_{el}	Max. duration of load change[a] h	Min. load change costs[b] $euro/MW_{el}$	Load change costs $euro/MW_{el}$
Electric arc furnace	99[c]	1097[d]	336		283[e]
Aluminum	95[f]	543[d]	336		27[e]
Paper	95[g]	312[d]	12	10[d]	69[h]
Cement	90[i]	360[d]	336	80[j]	320[e]
Chlor-alkali process	54[k]	1484[l]	72	0[d]	100[l]
Air separation	70[m]	570[l]	72	0[n]	243[m]
Other	10[o]	1050[p]	336	10[n]	300[n]

[a]see assumption 6, [b]see assumption 8, [c][3], [d][4], [e]See variable load changing cost estimation calculations (equation 1), [f][5], [g][6], [h][7], [i][8], [j] assumption 25 % of the load change costs, [k][9], [l][10], [m][11], [n]own assumption, [o]see assumption 3, [p]see assumption 4 and 5.

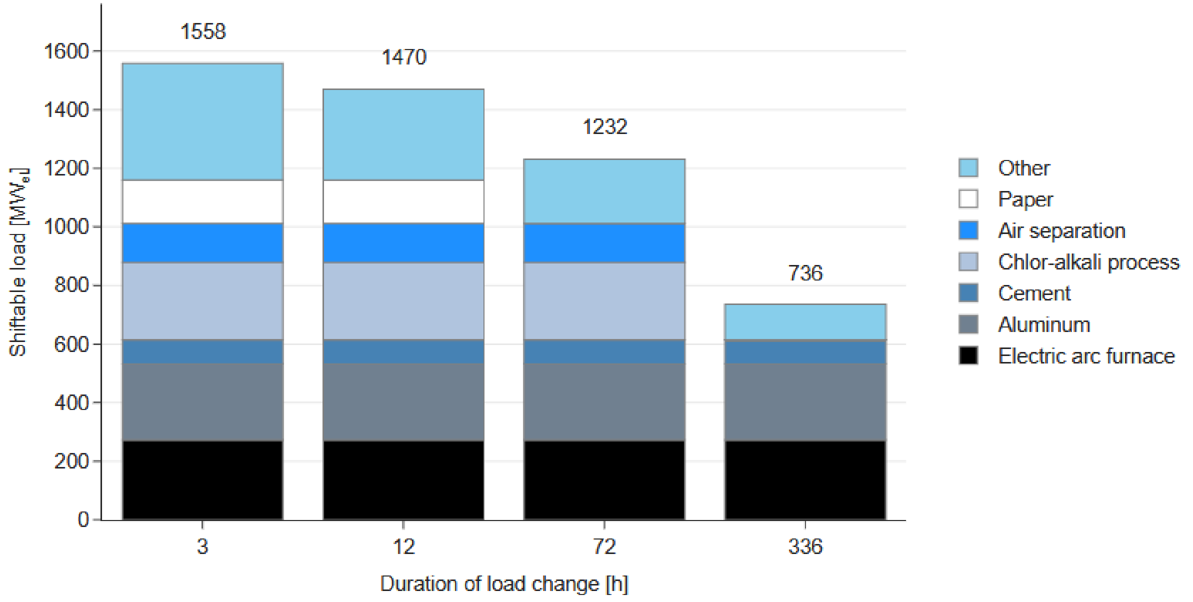


Figure S1: Projected potentials of flexible load of industrial energy-intensive processes for the year 2030 per available duration of load change

Model assumptions: process heat

- No seasonality → flat demand profile
- High-temperature heat pumps for levels up to 160° C, resistance boilers up to 500° C
- Storage efficiency = 90%, capacity 30% of electrical input, losses = 3% p.d., max. duration = 72h

Projections of future energy demand for the provision of industrial process heat

Temperature range process heat [°C]	Thermal energy demand for process heat[75] [TWh_{th}/a]	Electrical energy demand for high temperature heat pumps[a] [TWh_{el}]	Electrical energy demand for resistance heaters[b] [TWh_{el}/a]
<100	67	18.1	–
100–160	70.2	19	–
160–500	33.1	–	33.4
Sum	170.2	70.5	

[a]Assumed coefficient of performance (COP) high temperature heat-pump: 3.7.[74]
[b]Assumed efficiency factor resistance heater 99%.[74]

Model assumptions: district heating

- Strong seasonality
- Annual demand = 95TWh$_{th}$ = 30% of annual demand in residential and commercial buildings
- Larg-scale ground sources heat pumps
- Water tanks as storage medium, efficiency 90%, standing losses 2% p.d.
- Heat pumps exogenous, while storage energy capacity is endogenous with 50€/KWh$_{th}$
- No decentralized heat pumps or storage