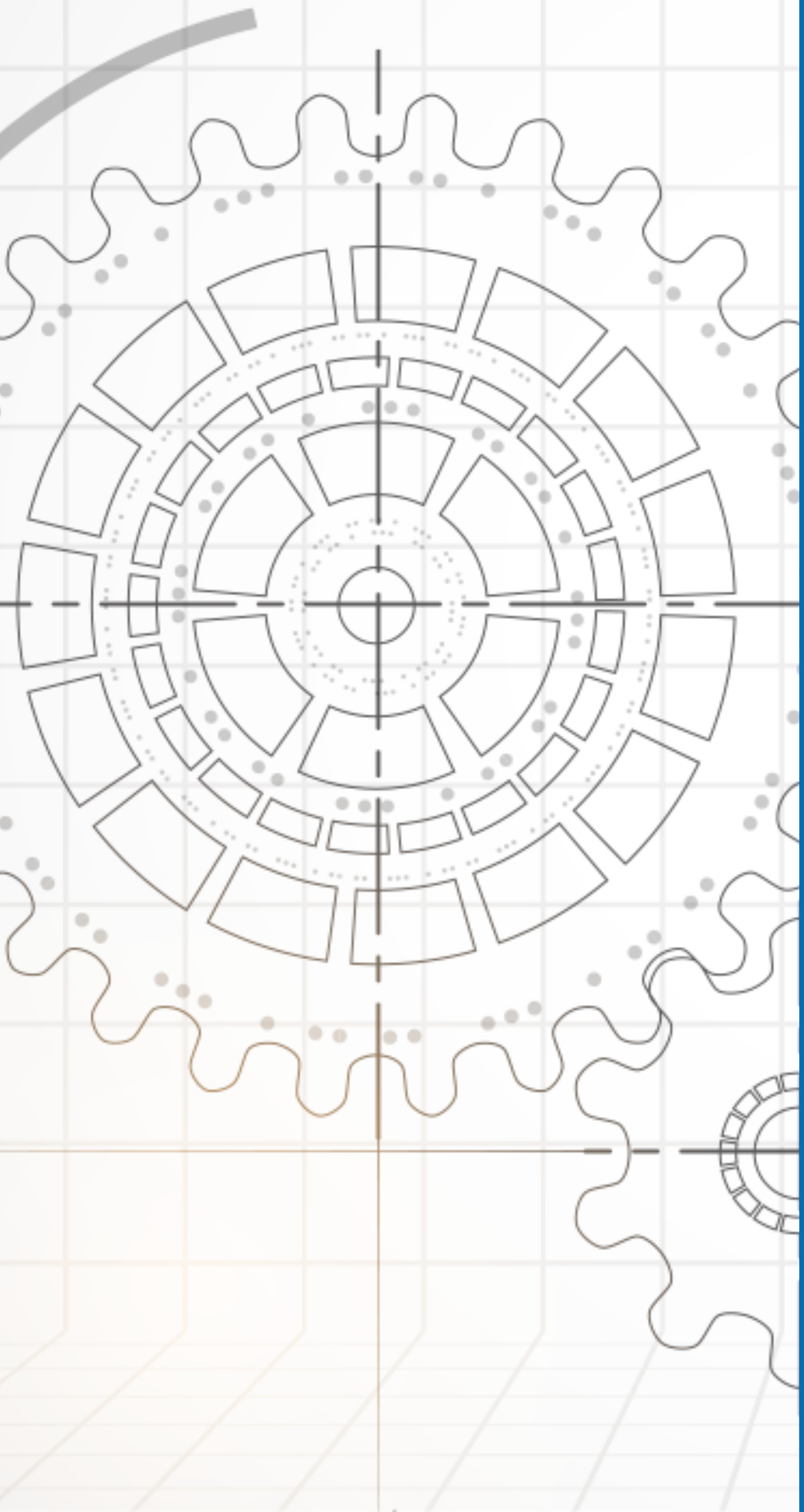
pyxidr

The Value of Flexibility

Two examples of large-scale energy storage system

September 2019

info@pyxidr.com
www.pyxidr.com



EXECUTIVE SUMMARY

- We will continue to deploy solar and wind generation at scale in Europe and North America as their cost keeps decreasing.

- However, the intermittency of solar and wind creates a high demand for flexibility because the load profile is more rigid than their variability. For instance, in Germany, the difference between the day-ahead plan associated with renewables and their actual generation can be up to 75% of the total load.

- Energy storage and demand-side management are the only forms of flexibility that ensure 100% clean-power: New energy storage is reputed to be expensive, and some are just difficult to build (e.g., pumped hydro); and, demand-side management is not as reliable as energy storage.

- For practical reasons, we have assessed the cost of mitigating energy intermittency through energy storage by installing a large Lithium-Ion battery (e.g., 100 MW) in California and Germany where solar and wind represent a vital share of the generating capacity. That is, energy storage takes advantage of capturing low prices when there is an excess of solar and wind generation and providing peaking generation when there is a lack of mid-merit order generation.

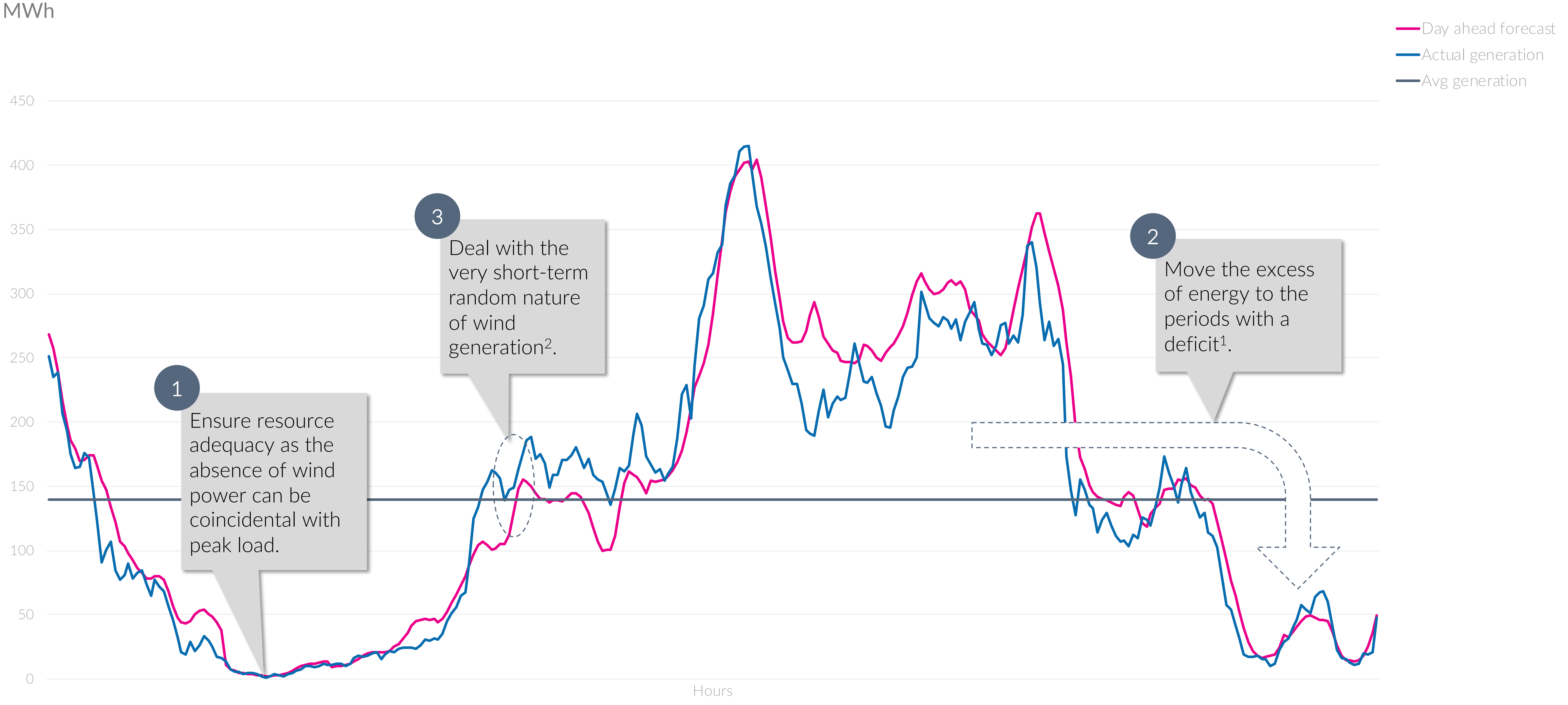
- In both markets, a new large battery is today profitable if we can capture the value associated with its capacity (i.e., its extrinsic value). In other words, a battery is today more valuable as an insurance product than a device for smoothing renewable generation profile.

- A corollary is that it should be expensive for renewable merchant generation to hedge forward their energy intermittency in these markets.

ISSUES RELATED TO INTERMITTENT ENERGY

There are three issues related to intermittent energy that we can address at the wholesale, transmission, distribution, or behind the meter levels.

Wind generation: Forecast vs. actual
MWh



1 We can emulate this with conventional thermal power plants by ramping-down when there is an excess of energy (leading to very low prices) and ramping-up when there is a lack of energy (leading to high prices).
2 The power developed by a wind turbine is proportional to the wind speed power three. This cubic relationship means small changes in wind speed translate to significant changes in power.

USE CASES RELATED TO ENERGY STORAGE

Focus of this document

There are many forms of energy storage (e.g., batteries, pumped hydro, flywheel) but we only explore Lithium-Ion batteries in this document as they are efficient, scalable and accessible. These are the primary use cases for Lithium-Ion battery technology ("energy storage") that we can observe today – it is by no means exhaustive.

WHOLESALE

We develop large scale energy storage systems to address the following opportunities or services:

- Resource adequacy
- Energy arbitrage
- Frequency regulation
- Primary/secondary reserves

UTILITY-SCALE

We complement wind or solar projects with energy storage to mitigate the risk associated with intermittent energy. E.g., it allows the project developer to get a better market price by selling baseload or peak power instead of "as produced."

TRANSMISSION & DISTRIBUTION

We use energy storage to delay transmission or distribution projects.

BEHIND-THE-METER

Commercial or residential use energy storage for peak shaving, power quality signal, complementing PV, backup power, etc.

KEY USE CASES

Europe and many states in the U.S.[1] want to achieve 100 percent clean-power in 15-25 years with the use of wind and solar power (i.e., intermittent energy). The implications for transmission and distribution networks will be significant but meeting the energy demand will be challenging too. Indeed, the markets will need an amount of reserve proportional to the installed capacity of wind and solar to provide "firm" generation (and avoid blackouts). Therefore, our focus is on the use of energy storage for **resource adequacy** and **energy arbitrage** (i.e., shaping intermittent energy into a given load profile) as we think they will represent the most significant use of flexible power generating capacity in the medium term.

1 California, Colorado, Hawaii, New Mexico, New York and Washington have enacted laws requiring them to be near 100% renewables and zero emissions by 2050.

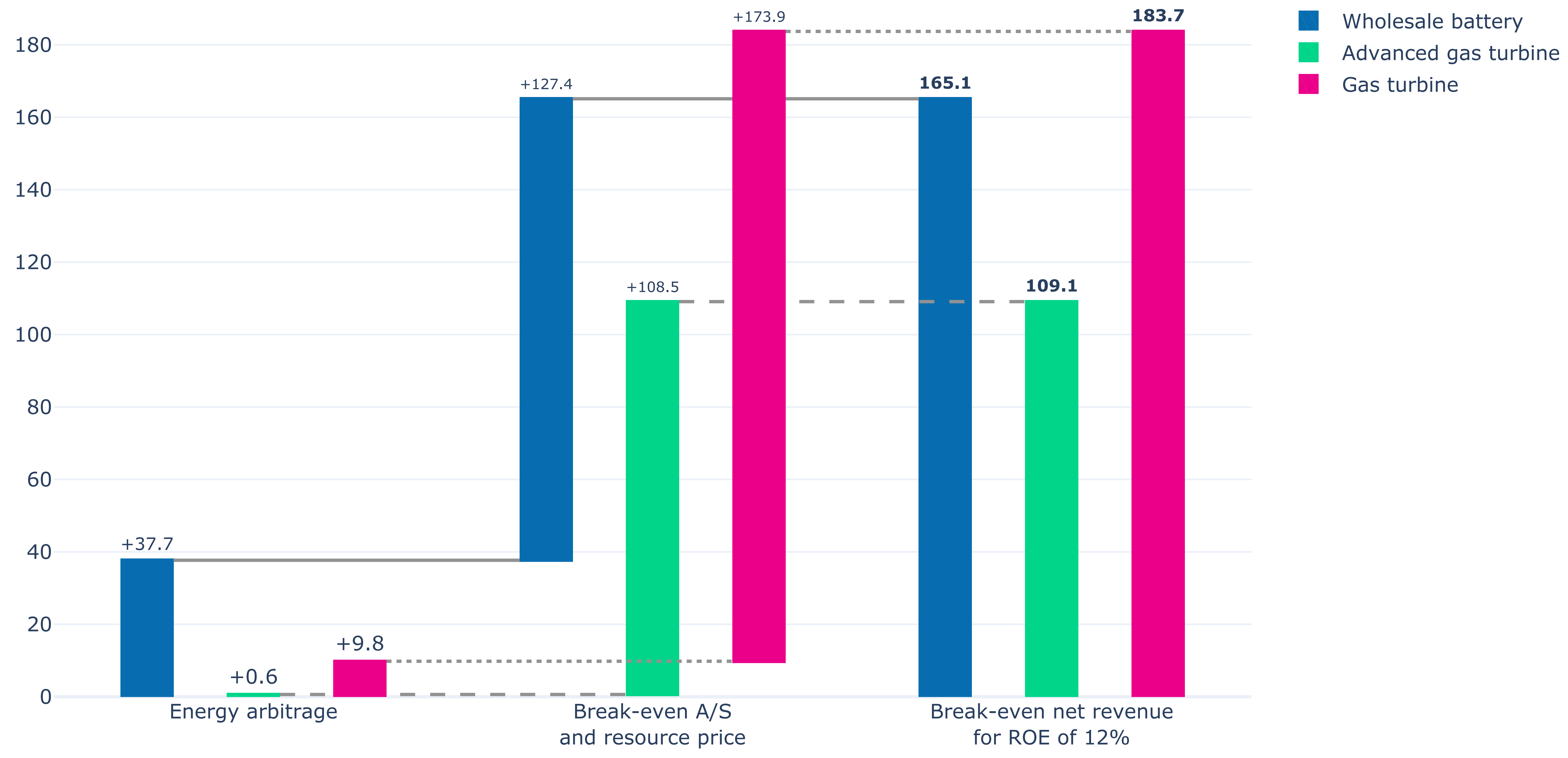
RESOURCE ADEQUACY IN CALIFORNIA

Wholesale batteries are currently competitive to meet peak generation requirements in California.

DESCRIPTION

- A wholesale battery (100 MW and 400 MWh) has the advantage of capturing time spreads that are more valuable than clean spark spreads (due in no small amount of renewable energy in CAISO and low natural gas price).
- This type of battery requires, to break even, revenues from ancillary services[1] (A/S) and resource adequacy that are 26% lower than a gas turbine but 17% higher than an advanced gas turbine.
- A battery is better positioned to offer A/S than a gas-fired plant and, thus, it will become more profitable in the future as California will be increasing its share of intermittent renewable energy.
- We show our key assumptions and modeling in the appendix.

Net revenue: Battery vs. Gas Turbine
€/kW-yr



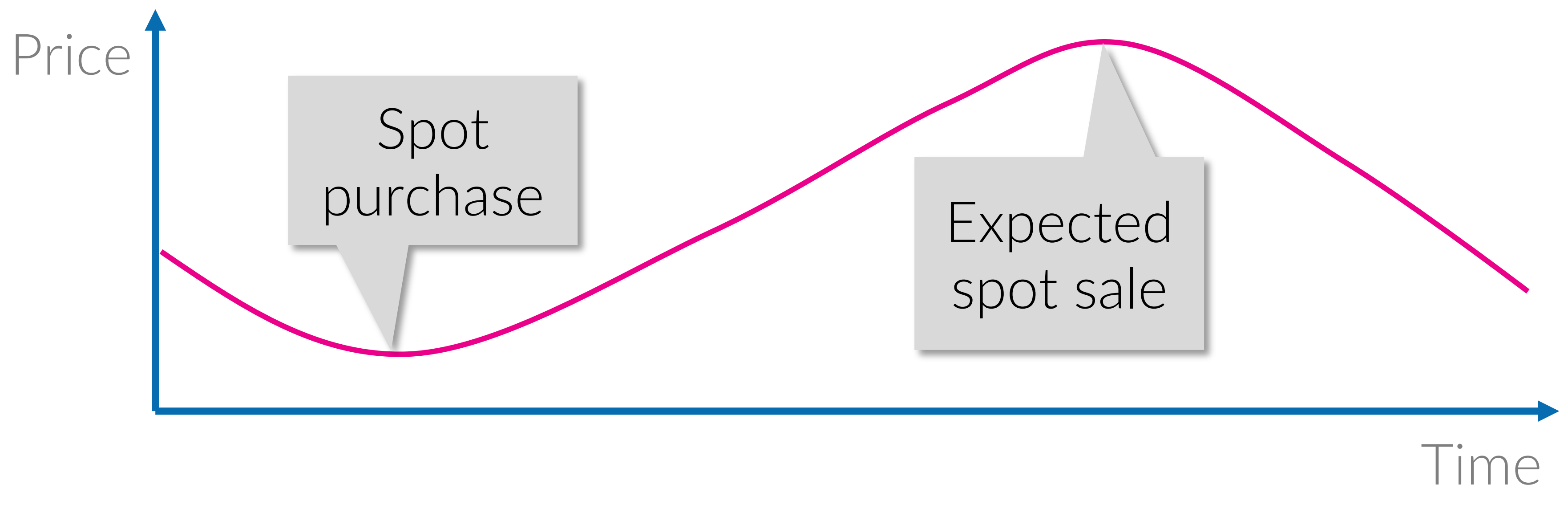
1 Revenues associated with ancillary services and energy arbitrage are not mutually exclusive (e.g., regulation up requires discharging at less than the power rating).

TYPES OF ENERGY ARBITRAGE

Energy storage can arbitrage energy prices in three ways.

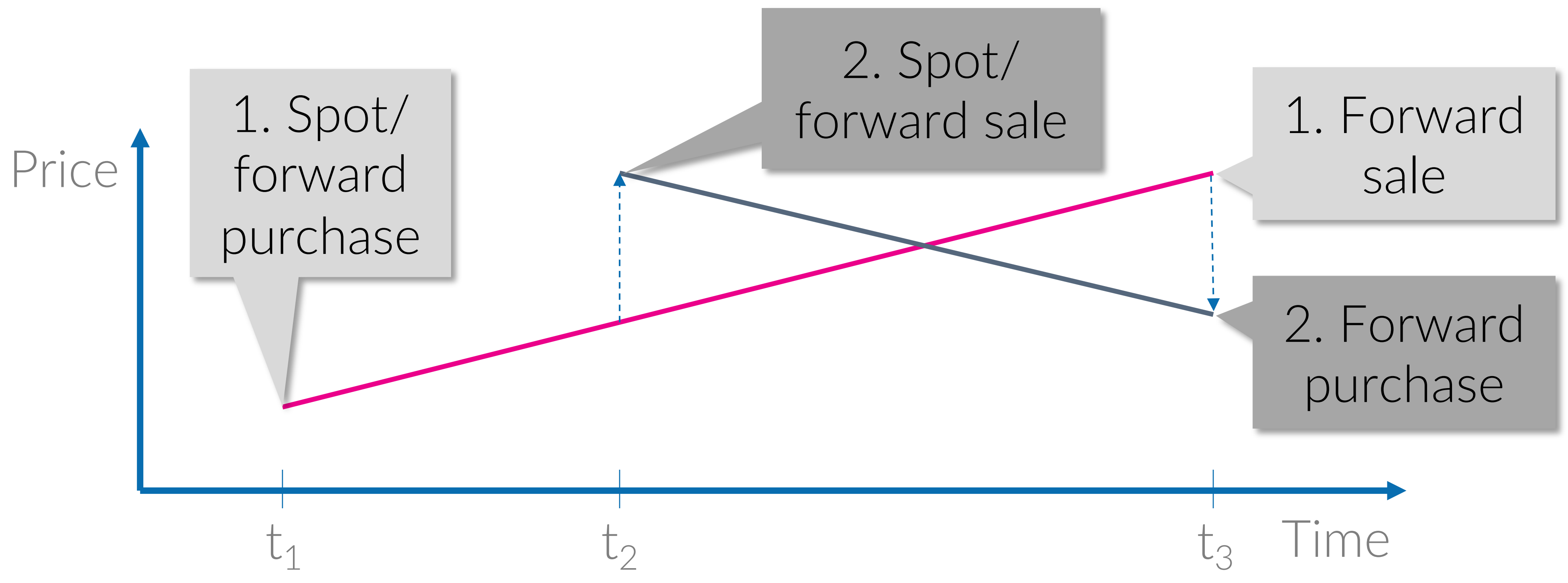
CASH TIME SPREAD

- Within a given time horizon (e.g., 24 hours), we buy energy in the spot market when the price is low with an expectation to sell it for a profit in the future – it represents a "statistical" arbitrage as there is no guarantee of a positive margin.
- This is the most popular approach for managing energy storage, but it is not necessarily the most profitable one.



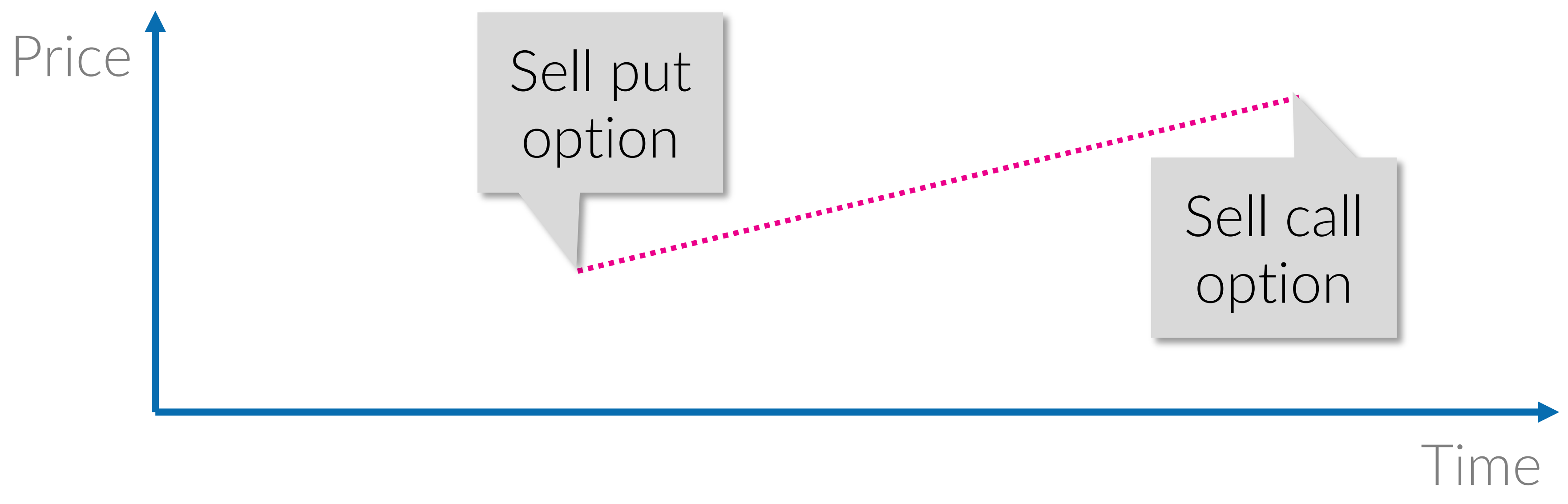
ASSET-BACKED TIME SPREAD

- We match each purchase done in the spot or forward markets (t_1) with a forward sale (t_3) – it is a pure arbitrage.
- There is a chance in the future (t_2) that the spot/forward price gets above our forward sale (t_3). If it is the case, we buy back our forward sale (t_3) and sale instead our energy at t_2 – it is again a pure arbitrage.
- This is quite profitable in volatile forward markets and there are no market risk exposures (in opposition to the previous approach).



FLEXIBLE TIME SPREAD

- We can use storage's capacity for selling insurance against low (put option) or high (call option) prices.
- For instance, a wind producer may want to buy a put option during the off-peak hours in case it produces more energy than anticipated.
- This approach is quite relevant in markets with a significant share of intermittent energy.



TIME HORIZONS

Focus of this document

Time spreads occur over various time horizons (e.g., night vs. daylight, summer vs. winter), and energy storage usually addresses a specific time horizon.

Intermittent energy impacts mostly within day markets

	Within day	Within week	Beyond week
RELEVANT ENERGY STORAGE TECHNOLOGIES	• Chemical batteries • Pumped hydro • Conventional hydro • Run-of-river with some regulation capacity • Compressed air • Flywheel • Thermal energy storage	• Pumped hydro • Conventional hydro	• Seasonal pumped hydro • Large conventional hydro
MARKETS INVOLVED[1]	• Day ahead • Intraday • Real-time • Balancing	• Day ahead • Forward (e.g., balance of the week)	• Day ahead • Forward (e.g., balance of the month)

1 We provide a glossary of the various energy markets in the appendix.

ASSESSING THE ARBITRAGE OPPORTUNITIES

We have developed a backtester[1] to identify all the potential energy arbitrages that an energy storage asset or thermal power plant can do based on historical day ahead and intraday prices.

BACKTESTER

The rules allow emulating the various ways energy storage or thermal plant can arbitrage prices.

Trading rules

- Any sales must be backed by generation, fast-start/spinning generating capacity or actual purchases
- Any purchases must be backed by consumption, charging capacity or actual sales

Asset

- Energy storage
- Coal-fired plant
- CCGT

Mathematical program

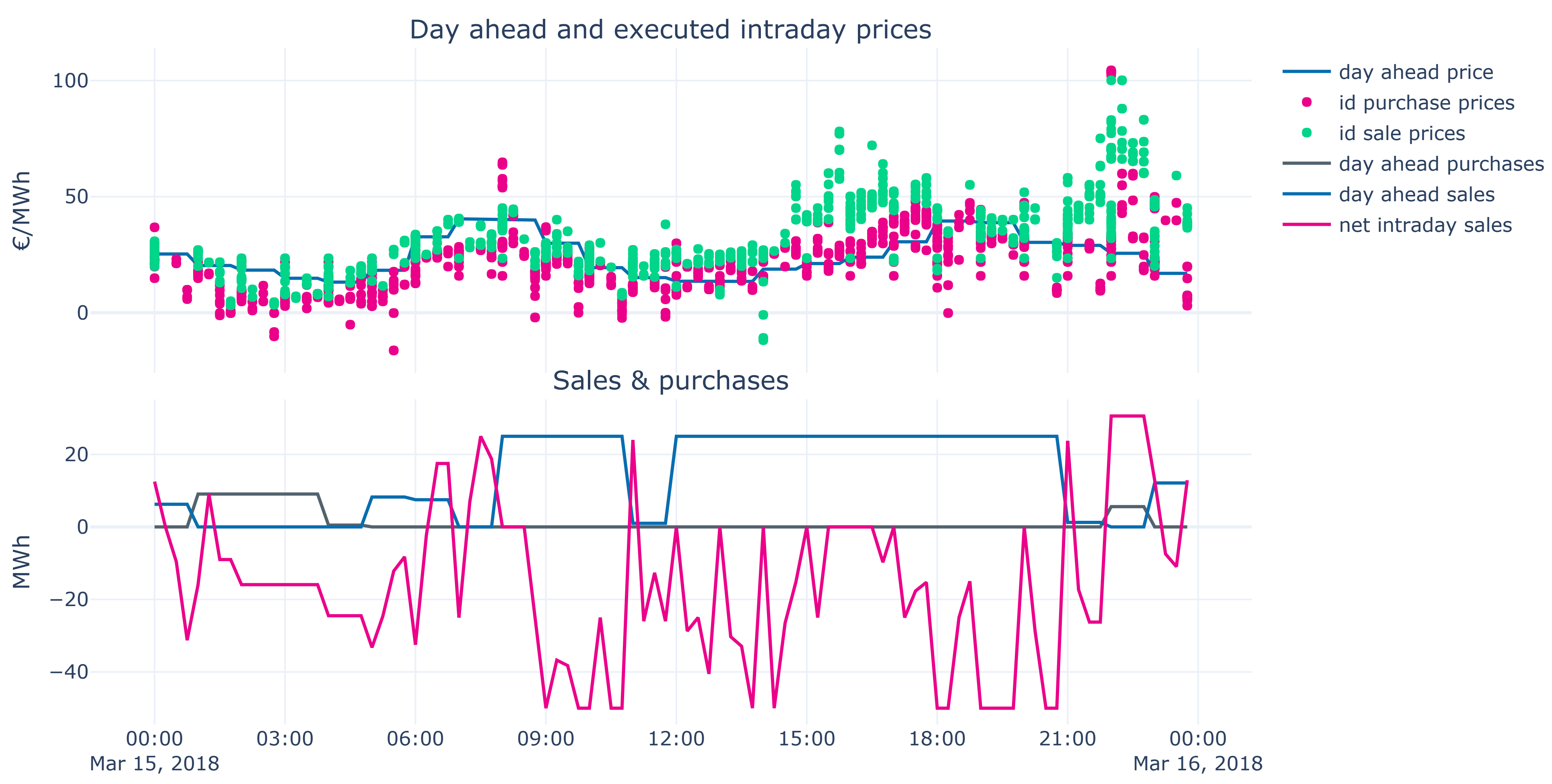
- Mixed-integer
- 15-min periods
- 1+ million variables

Historical market prices

- Day ahead
- Intraday
- Fuels and emissions

RESULTS

Energy arbitrage: Day ahead vs. intraday



1 Backtesting consists of validating a trading strategy based on historical prices. It is popular among technical traders as it is easier to identify patterns than anticipating market movements. Past performance is no guarantee of future results, but backtesting helps supporting trading strategies – it is harder to convince someone if a given strategy did not produce in the past. We use backtesting results to calibrate our optimization/trading algorithms.

ENERGY ARBITRAGE IN GERMANY (1/2)

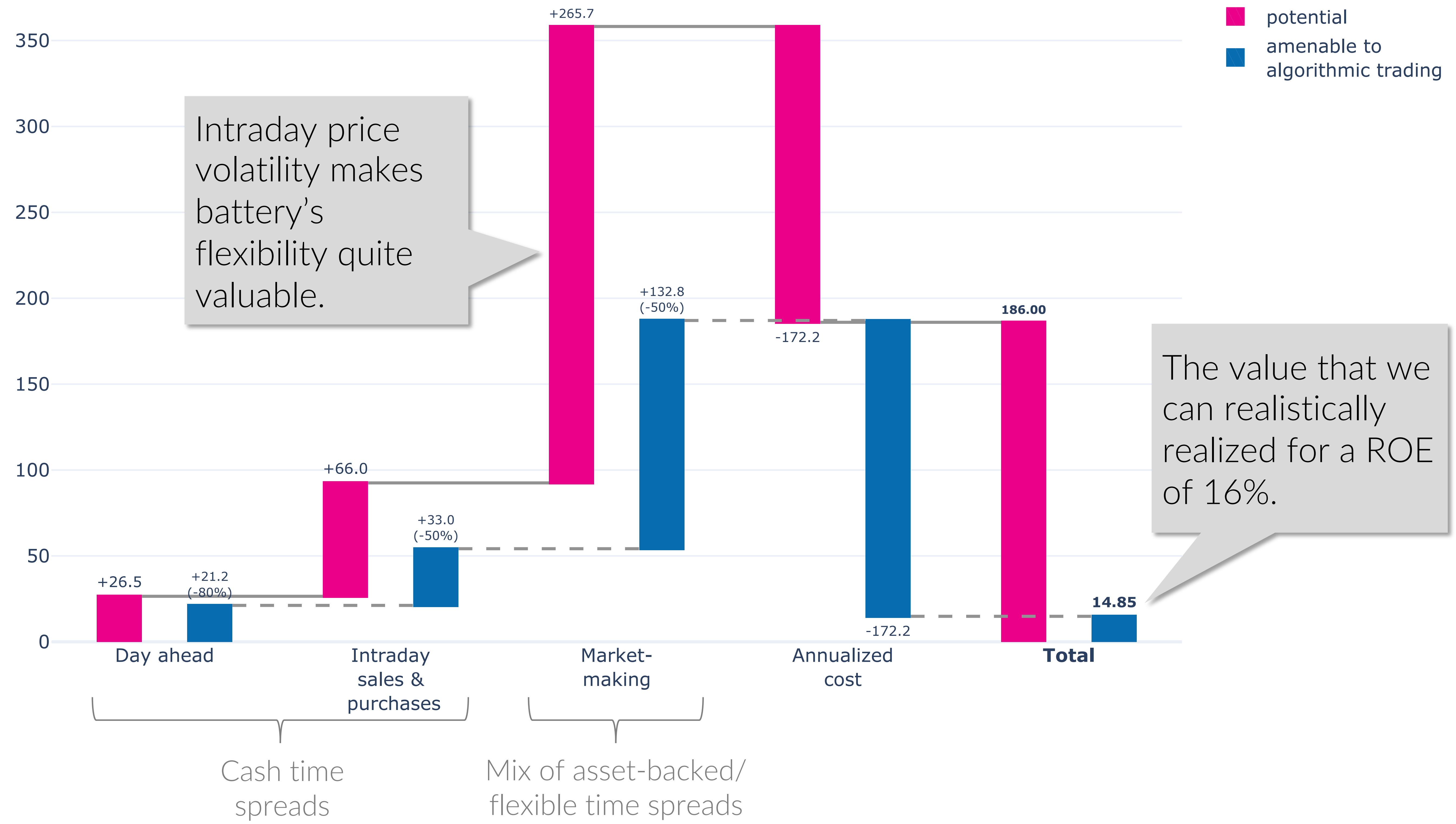
BACKTESTER RESULTS

In markets where intermittent energy constitutes 50+% of the generating capacity, energy arbitrage represents a significant potential for wholesale batteries.

DESCRIPTION

- Germany has 42 GW of solar and 56 GW of wind for 91 GW of conventional thermal generating capacity – the average peak load is ~70 GW.
- In Germany, we can rebalance our day ahead position in the intraday market[1] to mitigate our exposure to the balancing market – essential for managing intermittent energy and forced outages. This market is quite liquid with some days having more than two million orders.
- Energy storage is well-positioned to capture the time spreads offered in day ahead and intraday markets and be a market-maker[2] to arbitrage the various asks and bids.
- We have assessed the potential of these commercial opportunities where market-making is the most important one.

Breakdown of the value related to 100 MW battery installed in Germany
€/kW-yr, Jul-17 to Jun-18



1 The Intraday market offers the opportunity to continuously trade power products in hourly, 30-minute and 15-minute intervals as well as loosely defined block orders up to 5 or 30 minutes before delivery.
2 Market-making consists of buying from some ask orders that we feel confident of selling back later to some bid orders (and vice versa). It is a way to "emulate" asset-backed and flexible time spreads in short-term markets.

ENERGY ARBITRAGE IN GERMANY (2/2)

Even German conventional thermal generation plants

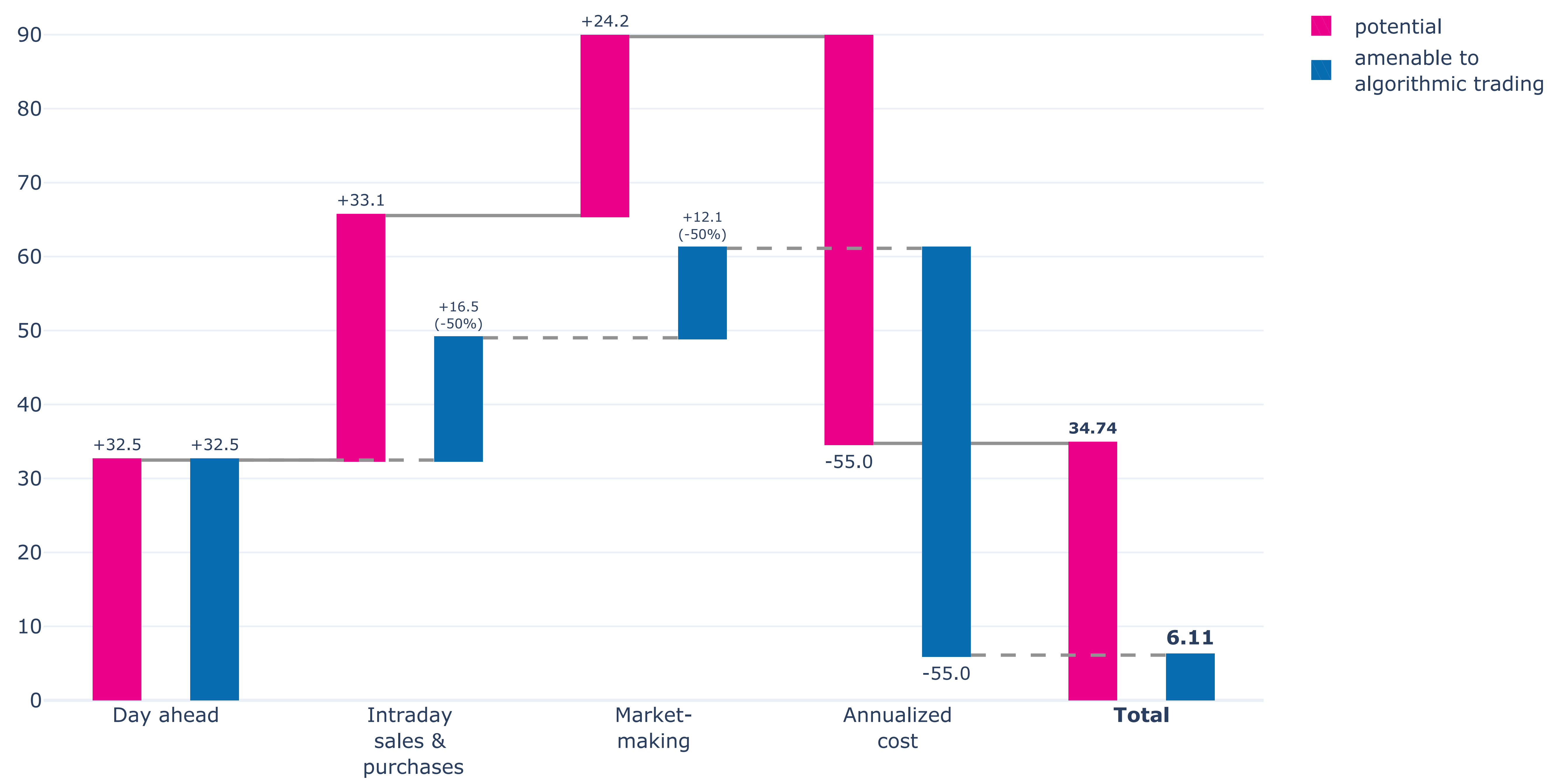
can take advantage of the short-term price volatility.

DESCRIPTION

- Coal-fired plants in Germany can allocate "spinning" ramping capacity (up & down) in day ahead market to actively participate in the intraday market. For instance, ramping-up capacity allows selling at a higher price in the intraday market than day ahead one. However, they cannot capture any time spreads.
- We can use the same ramping capacity for market-making activities in the intraday market.
- The economics for thermal power plants associated with ramping capacity are more expensive than batteries and, therefore, the commercial opportunities are not as high.
- As shown by our assessment (see graphic on the right), capturing these commercial opportunities can make the difference between a positive EBITDA or not for German coal plants.

Breakdown of the value related to a mid-size coal-fired plant in Germany

€/kW-yr, Jul-17 to Jun-18

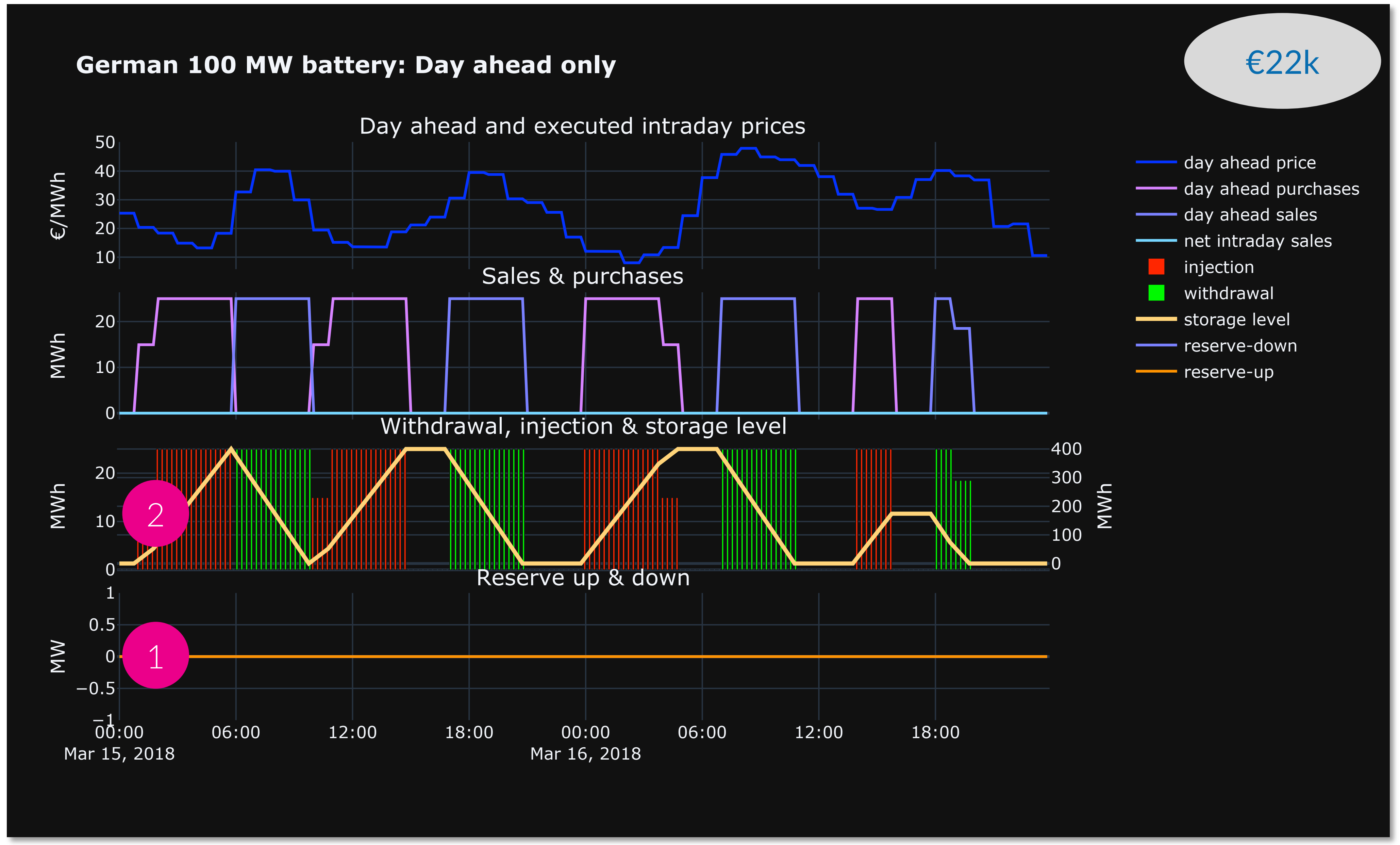


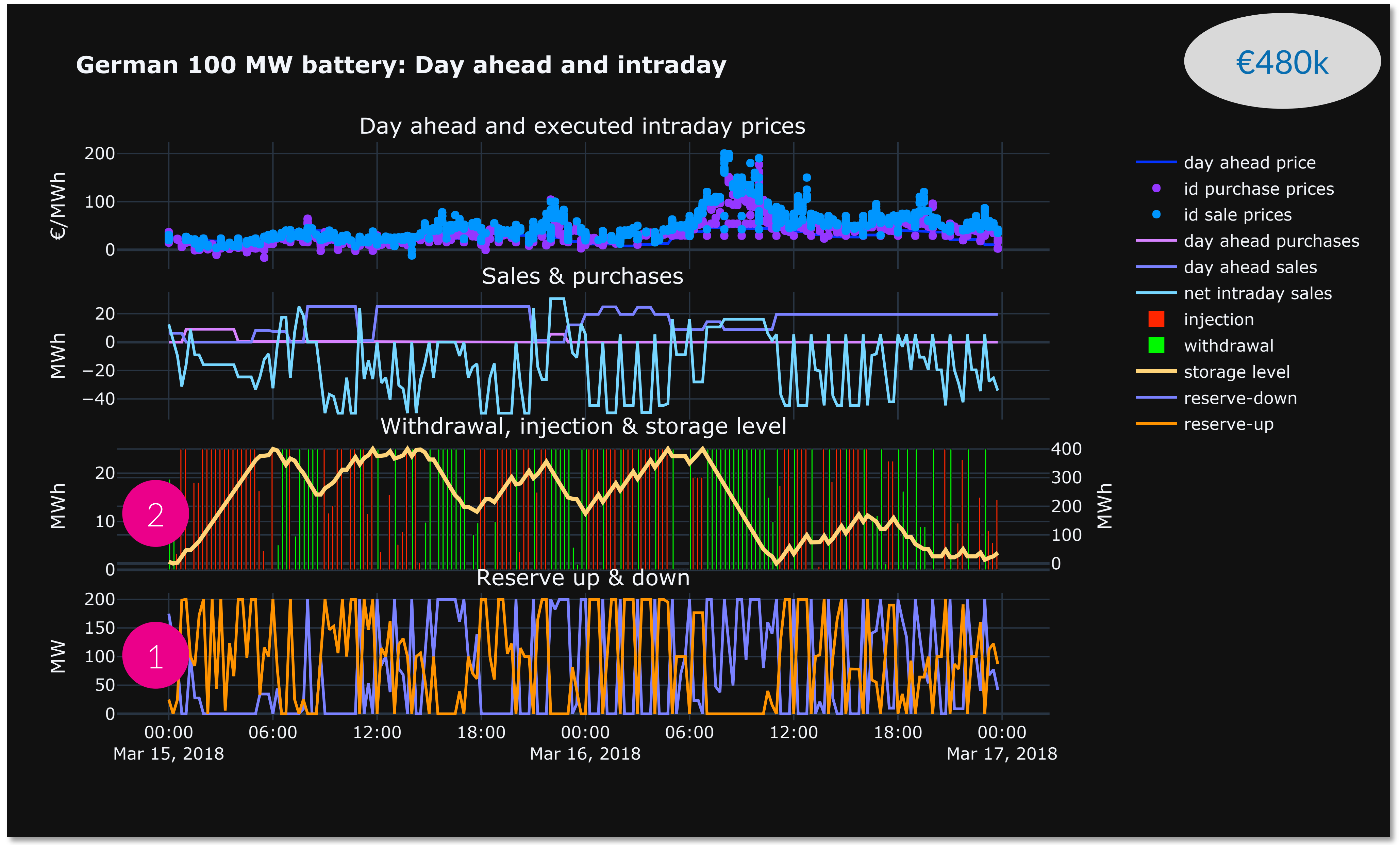
THE VALUE OF FLEXIBILITY

BACKTESTER RESULTS

€x Total margin

The ability to buy/sell multiple times the same intraday product (i.e., market-making) represents a significant commercial opportunity for wholesale batteries.





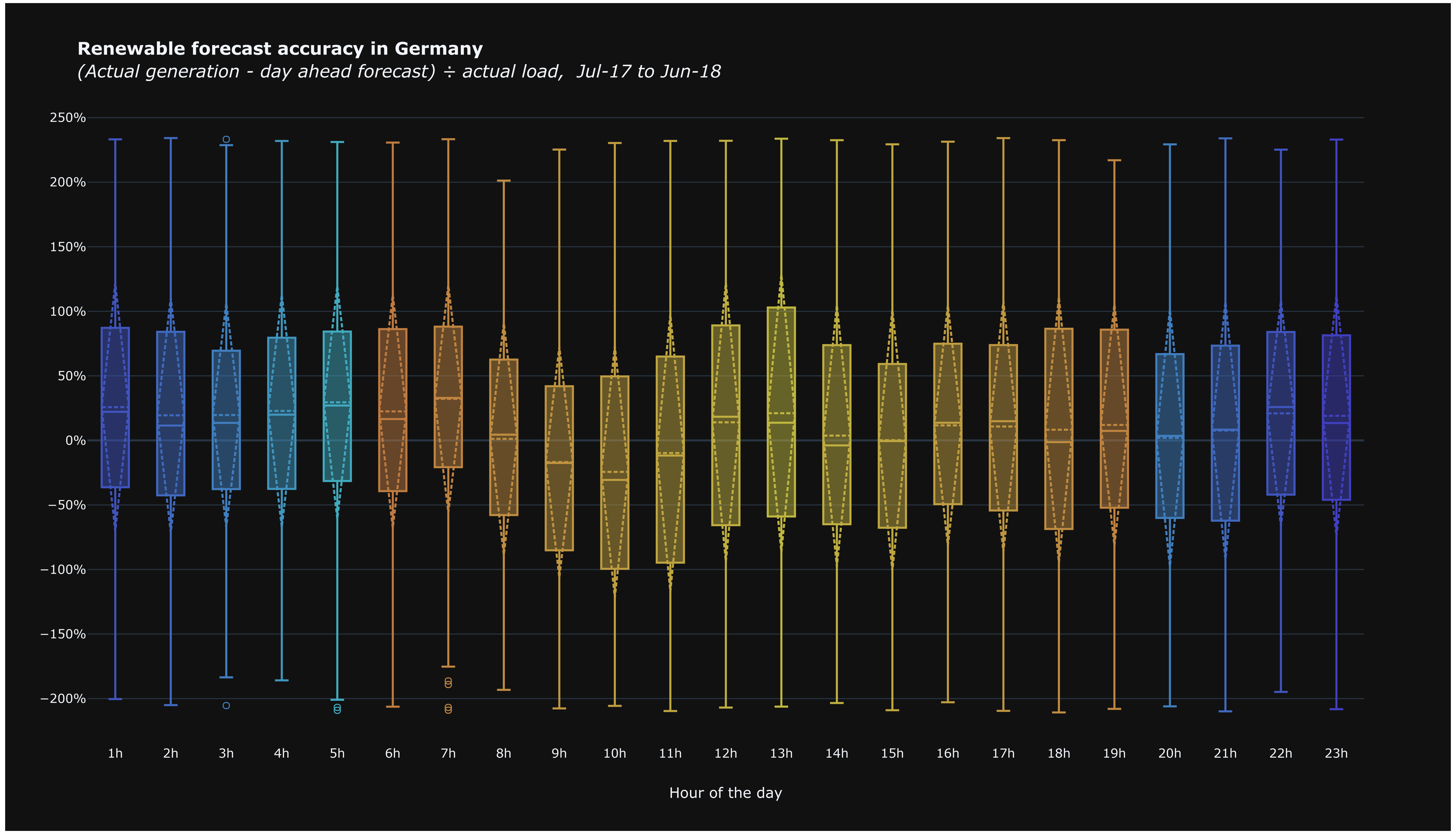
1
- In order to avoid excessive speculation, we use reserve up & down to sell/buy energy with the goal of buying/selling it back later – e.g., we can charge the battery if we cannot sell back the purchases.
- The graphic on the left shows no use of reserve as we only capture day ahead (cash) time spreads.
- However, the graphic on the right shows a significant use of reserve to support the market-making arbitrages.

2
- In day ahead only (left graphic), the battery is cycling twice a day due to solar peaking around 13h.
- Market-making arbitrages lead to less cycling due to the use of reserve.

WHY IS FLEXIBILITY SO VALUABLE?

The amount of intermittent energy (i.e., solar and wind) in Germany is such that the day ahead plan could be quite different from the actual generation leading to continuous adjustments of the supply/demand balance until delivery.

- The graphic shows for each hour of the day a bloxplot[1] of the difference between actual renewable generation and its day ahead forecast relative to the actual load.
- The variance gets pronounced during days where the load is low (e.g., weekends, holidays).
- The intraday market allows to balance the system closer to the delivery time and, thus, reduce the need for mandated reserves – it is an essential tool that lets market participants to manage unexpected changes in consumption and outages.



1 A box plot is a statistical representation of numerical data through their quartiles. The ends of the box represent the lower and upper quartiles, while the median (second quartile) is marked by a line inside the box.

APPENDIX

ENERGY MARKETS

Low liquidity

High liquidity

Glossary

DAY AHEAD

Customers can sell or buy energy for the following day in a closed auction. The objective is to maximize social welfare while taking transmission and generation constraints.

INTRADAY

The intraday market complements the day ahead market as it is a continuous market, with trading taking place every day around the clock until delivery. Prices are set based on a first-come, first-served principle, where best prices come first – highest buy price and lowest sale price. Today, this market only exists in Europe.

REAL-TIME

The real-time market is like the day ahead market, but it settles the price for 5-minute periods during the day of delivery. It is only present in the U.S.

BALANCING

The balancing market provides near real-time matching between supply and demand. The transmission system operators use this market to maintain the system frequency and comply with the amount of reserves required.

BATTERIES: U.S. LEVELIZED COST ANALYSIS

We have based our batteries' assumptions on "Lazard's levelized cost of storage analysis, version 4"

and our market operations' assumptions on actual CAISO day ahead and natural gas prices.

U.S. Levelized Cost Analysis

Lithium-Ion Batteries

September 2019

Version 1.1

($ thousands)

Key Assumptions		Wholesale	C&I
Battery characteristics			
Power rating		100.0 MW	1.0 MW
Energy-to-power ratio		4.0 kWh/kW	2.0 kWh/kW
Usable energy		400.0 MWh	2.0 MWh
Round-trip efficiency		87.0%	91.0%
Degradation rate		1.0%/yr	1.0%/yr
CAPEX			
CAPEX - DC		$232/kWh	$335/kWh
CAPEX - AC		$49/kW	$158/kW
EPC costs		$16,000	$0
	Total =	$113,700	$828
O&M			
O&M % of BESS		1.3%	2.3%
O&M % of PCS		1.7%	3.1%
	Total =	$1,272k/yr	$21k/yr
O&M escalator		2.50%	2.50%
Warranty			
Warranty % of BESS		1.5%	1.5%
Warranty % of PCS		2.0%	2.0%
	Total =	$1,490k/yr	$13k/yr
Warranty's duration		2 yr	2 yr
Capital structure			
Debt		20.0%	20.0%
Cost of debt		8.0%	8.0%
Equity		80.0%	80.0%
Cost of equity		12.0%	12.0%
Taxes			
Combined tax rate		28.0%	28.0%
Economic lifetime		20 yr	10 yr
MACRS depreciation		7-Year	5-Year
Market operations			
Cycles/day		1	1
Natural gas price		$2.60/mmBtu	$2.60/mmBtu
Gas price escalator		2.75%	2.75%
Market charging implied gas efficiency		55.0%	60.0%
Market discharging implied gas efficiency		20.0%	18.0%
Implied time spread		$28.23/MWh	$34.50/MWh
A/S and resource price		$349.06/MW-day	$408.92/MW-day
A/S and resource price		$127.41/kW-yr	$149.26/kW-yr
Resource price escalator		2.00%	2.00%

Case: Wholesale

Cash flow model

Year		0	1	2	3	4	5	6	7	8	9	10
Capacity (MW)	(A)		100	100	100	100	100	100	100	100	100	100
Capacity payments ($/MW-day)	(B)		349.06	356.04	363.16	370.43	377.84	385.39	393.10	400.96	408.98	417.16
Energy discharged (MWh)	(C)*		146,000	144,540	143,095	141,664	140,247	138,845	137,456	136,082	134,721	133,374
Average net revenue ($/MWh)	(D)		25.82	26.53	27.26	28.01	28.78	29.57	30.38	31.22	32.07	32.96
Total net revenues	**(A) x 365 x (B) + (C) x (D) = (E)***		**$16,510.0**	**$16,829.7**	**$17,155.7**	**$17,488.0**	**$17,826.7**	**$18,172.0**	**$18,524.1**	**$18,883.0**	**$19,248.9**	**$19,621.8**
O&M costs	(E)		($1,271.6)	($1,303.4)	($1,336.0)	($1,369.4)	($1,403.6)	($1,438.7)	($1,474.7)	($1,511.6)	($1,549.4)	($1,588.1)
Warranty costs	(F)				($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)
Total operating costs	**(E) + (F) = (G)**		($1,271.6)	($1,303.4)	($2,826.0)	($2,859.4)	($2,893.6)	($2,928.7)	($2,964.7)	($3,001.6)	($3,039.4)	($3,078.1)
EBITDA	**(D) + (G) = (H)**		**$15,238.3**	**$15,526.3**	**$14,329.7**	**$14,628.6**	**$14,933.1**	**$15,243.3**	**$15,559.4**	**$15,881.4**	**$16,209.5**	**$16,543.8**
Debt outstanding - beginning of period	(I)		$22,740.0	$22,243.1	$21,706.4	$21,126.8	$20,500.8	$19,824.8	$19,094.6	$18,306.1	$17,454.5	$16,534.7
Debt - interest expense	(J)		($1,819.2)	($1,779.4)	($1,736.5)	($1,690.1)	($1,640.1)	($1,586.0)	($1,527.6)	($1,464.5)	($1,396.4)	($1,322.8)
Debt - principal payment	(K)		($496.9)	($536.7)	($579.6)	($626.0)	($676.1)	($730.1)	($788.5)	($851.6)	($919.8)	($993.3)
Levelized debt service	(J) + (K) = (L)		($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)
EBITDA	**(H)**		**$15,238.3**	**$15,526.3**	**$14,329.7**	**$14,628.6**	**$14,933.1**	**$15,243.3**	**$15,559.4**	**$15,881.4**	**$16,209.5**	**$16,543.8**
Depreciation (7-Year MACRS)	(M)		($16,247.7)	($27,845.1)	($19,886.1)	($14,201.1)	($10,153.4)	($10,142.0)	($10,153.4)	($5,071.0)		
Interest expense	(J)		($1,819.2)	($1,779.4)	($1,736.5)	($1,690.1)	($1,640.1)	($1,586.0)	($1,527.6)	($1,464.5)	($1,396.4)	($1,322.8)
Taxable income	**(H) + (M) + (J) = (N)**		($2,828.6)	($14,098.3)	($7,293.0)	($1,262.7)	$3,139.6	$3,515.3	$3,878.4	$9,345.9	$14,813.1	$15,221.0
Cumulative NOL - beginning of period	(O)		$0.0	($2,828.6)	($16,926.9)	($24,219.8)	($25,482.6)	($22,343.0)	($18,827.7)	($14,949.3)	($5,603.3)	$0.0
Tax liabilities	**MAX(0, (N) + (O)) x (Tax Rate) = (P)**		**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**$0.0**	**($2,578.7)**	**($4,261.9)**
After-Tax Net Equity Cash Flow	**(H) + (L) + (P) = (Q)**	-$90,960.0	**$12,922.2**	**$13,210.2**	**$12,013.5**	**$12,312.4**	**$12,617.0**	**$12,927.2**	**$13,243.3**	**$13,565.3**	**$11,314.6**	**$9,965.8**

Year	11	12	13	14	15	16	17	18	19	20
Capacity (MW)	100	100	100	100	100	100	100	100	100	100
Capacity payments ($/MW-day)	425.51	434.02	442.70	451.55	460.58	469.79	479.19	488.77	498.55	508.52
Energy discharged (MWh)	132,040	130,719	129,412	128,118	126,837	125,569	124,313	123,070	121,839	120,621
Average net revenue ($/MWh)	33.86	34.79	35.75	36.73	37.74	38.78	39.85	40.94	42.07	43.23
Total net revenues	**$20,002.1**	**$20,389.7**	**$20,784.9**	**$21,187.8**	**$21,598.5**	**$22,017.1**	**$22,444.0**	**$22,879.1**	**$23,322.7**	**$23,774.9**
O&M costs	($1,627.8)	($1,668.5)	($1,710.2)	($1,753.0)	($1,796.8)	($1,841.7)	($1,887.7)	($1,934.9)	($1,983.3)	($2,032.9)
Warranty costs	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)	($1,490.0)
Total operating costs	($3,117.8)	($3,158.5)	($3,200.2)	($3,243.0)	($3,286.8)	($3,331.7)	($3,377.7)	($3,424.9)	($3,473.3)	($3,522.9)
EBITDA	**$16,884.3**	**$17,231.2**	**$17,584.7**	**$17,944.8**	**$18,311.7**	**$18,685.4**	**$19,066.2**	**$19,454.2**	**$19,849.4**	**$20,252.0**
Debt outstanding - beginning of period	$15,541.3	$14,468.5	$13,309.9	$12,058.6	$10,707.1	$9,247.6	$7,671.3	$5,968.9	$4,130.3	$2,144.6
Debt - interest expense	($1,243.3)	($1,157.5)	($1,064.8)	($964.7)	($856.6)	($739.8)	($613.7)	($477.5)	($330.4)	($171.6)
Debt - principal payment	($1,072.8)	($1,158.6)	($1,251.3)	($1,351.4)	($1,459.5)	($1,576.3)	($1,702.4)	($1,838.6)	($1,985.7)	($2,144.6)
Levelized debt service	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)	($2,316.1)
EBITDA	**$16,884.3**	**$17,231.2**	**$17,584.7**	**$17,944.8**	**$18,311.7**	**$18,685.4**	**$19,066.2**	**$19,454.2**	**$19,849.4**	**$20,252.0**
Depreciation (7-Year MACRS)										
Interest expense	($1,243.3)	($1,157.5)	($1,064.8)	($964.7)	($856.6)	($739.8)	($613.7)	($477.5)	($330.4)	($171.6)
Taxable income	$15,641.0	$16,073.8	$16,519.9	$16,980.1	$17,455.1	$17,945.6	$18,452.5	$18,976.7	$19,519.0	$20,080.5
Cumulative NOL - beginning of period	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Tax liabilities	**($4,379.5)**	**($4,500.7)**	**($4,625.6)**	**($4,754.4)**	**($4,887.4)**	**($5,024.8)**	**($5,166.7)**	**($5,313.5)**	**($5,465.3)**	**($5,622.5)**
After-Tax Net Equity Cash Flow	**$10,188.7**	**$10,414.5**	**$10,643.0**	**$10,874.2**	**$11,108.1**	**$11,344.5**	**$11,583.4**	**$11,824.6**	**$12,068.0**	**$12,313.4**

IRR for equity investors	**12.0%**
NPV for equity investors	**$0.0**

Set NPV to 0

* Denotes unit conversion

GAS TUBINES: U.S. NEW ENTRY COST

We assume that gas turbines are built in California SP-15 and we have based our market operations' assumptions on actual CAISO day ahead and natural gas prices.

US New Entrant Cost

Gas Turbines

September 2019

Version 1.0

($ thousands)

Key Assumptions		AGT	GT
Gas turbine characteristics			
Installed capacity		237.0 MW	100.0 MW
Auxiliary Requirements		2.0%	2.0%
Efficiency		34.9%	34.1%
Heat rate		9,777 kWh/Btu	10,000 kWh/Btu
Emissions			
SO2		0.001 lbs/mmBtu	0.001 lbs/mmBtu
NOx		0.030 lbs/mmBtu	0.030 lbs/mmBtu
CO2		117.0 lbs/mmBtu	117.0 lbs/mmBtu
CAPEX			
Mechanical Equipment		$301/kW	$504/kW
Electrical / I&C		$17,896	$12,065
Other EPC costs		$71,441	$47,660
	Total =	$160,579	$110,075
O&M			
Fixed O&M		$6.8/kW-yr	$17.5/kW-yr
Variable O&M		$10.7/MWh	$3.5/MWh
O&M escalator		2.50%	2.50%
Insurance			
Insurance % of CAPEX		0.5%	0.5%
	Total =	$803k/yr	$550k/yr
Insurance escalator		2.0%	2.0%
Capital structure			
Debt		20.0%	20.0%
Cost of debt		8.0%	8.0%
Equity		80.0%	80.0%
Cost of equity		12.0%	12.0%
Taxes			
Combined tax rate		38.0%	38.0%
Economic lifetime		20 yr	20 yr
MACRS depreciation		20-Year	20-Year
Market operations			
Capacity factor		16.7%	16.7%
Natural gas price		$2.60/mmBtu	$2.60/mmBtu
Gas price escalator		2.75%	2.75%
Market implied gas efficiency		20.0%	20.0%
SO2 price		$2.00/st	$2.00/st
NOx price		$150.00/st	$150.00/st
CO2 price		$15.00/t	$15.00/t
Emission price escalator		2.00%	2.00%
A/S and resource price		$297.19/MW-day	$476.38/MW-day
A/S and resource price		$108.47/kW-yr	$173.88/kW-yr
Resource price escalator		2.00%	2.00%

Case: GT

Cash flow model

Year		0	1	2	3	4	5	6	7	8	9	10
Capacity (MW)	(A)		100	100	100	100	100	100	100	100	100	100
Capacity payments ($/MW-day)	(B)		476.38	485.90	495.62	505.54	515.65	525.96	536.48	547.21	558.15	569.31
Energy sold (MWh)	(C)		143,080	143,080	143,080	143,080	143,080	143,080	143,080	143,080	143,080	143,080
Average revenue ($/MWh)	(D)		44.36	45.58	46.83	48.12	49.44	50.80	52.20	53.63	55.11	56.62
Average fuel cost ($/MWh)	(E)		26.00	26.72	27.45	28.20	28.98	29.78	30.60	31.44	32.30	33.19
Average emissions cost ($/MWh)	(F)		7.98	8.14	8.31	8.47	8.64	8.81	8.99	9.17	9.35	9.54
Clean spark spread ($/MWh)	(D) - (E) - (F) = (G)		10.37	10.72	11.07	11.44	11.82	12.21	12.61	13.02	13.45	13.89
Total net revenues	**(A) x 365 x (B) + (C) x (G) = (H)**		**$18,871.9**	**$19,269.1**	**$19,674.7**	**$20,089.0**	**$20,512.1**	**$20,944.3**	**$21,385.8**	**$21,836.6**	**$22,297.2**	**$22,767.6**
O&M costs	(H)		($2,261.0)	($2,317.5)	($2,375.5)	($2,434.8)	($2,495.7)	($2,558.1)	($2,622.1)	($2,687.6)	($2,754.8)	($2,823.7)
Insurance costs	(I)		($550.4)	($561.4)	($572.6)	($584.1)	($595.7)	($607.7)	($619.8)	($632.2)	($644.9)	($657.7)
Total operating costs	**(H) + (I) = (J)**		($2,811.4)	($2,878.9)	($2,948.1)	($3,018.9)	($3,091.5)	($3,165.8)	($3,241.9)	($3,319.8)	($3,399.7)	($3,481.4)
EBITDA	**(H) + (J) = (K)**		**$16,060.5**	**$16,390.1**	**$16,726.6**	**$17,070.1**	**$17,420.6**	**$17,778.5**	**$18,143.9**	**$18,516.8**	**$18,897.5**	**$19,286.2**
Debt outstanding - beginning of period	(L)		$22,015.0	$21,533.9	$21,014.4	$20,453.2	$19,847.2	$19,192.7	$18,485.9	$17,722.5	$16,898.0	$16,007.5
Debt - interest expense	(M)		($1,761.2)	($1,722.7)	($1,681.1)	($1,636.3)	($1,587.8)	($1,535.4)	($1,478.9)	($1,417.8)	($1,351.8)	($1,280.6)
Debt - principal payment	(N)		($481.1)	($519.6)	($561.1)	($606.0)	($654.5)	($706.9)	($763.4)	($824.5)	($890.4)	($961.7)
Levelized debt service	(M) + (N) = (O)		($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)
EBITDA	**(K)**		**$16,060.5**	**$16,390.1**	**$16,726.6**	**$17,070.1**	**$17,420.6**	**$17,778.5**	**$18,143.9**	**$18,516.8**	**$18,897.5**	**$19,286.2**
Depreciation (20-Year MACRS)	(P)		($4,127.8)	($7,946.3)	($7,349.7)	($6,799.3)	($6,288.6)	($5,817.5)	($5,380.5)	($4,977.6)	($4,911.5)	($4,910.4)
Interest expense	(Q)		($1,761.2)	($1,722.7)	($1,681.1)	($1,636.3)	($1,587.8)	($1,535.4)	($1,478.9)	($1,417.8)	($1,351.8)	($1,280.6)
Taxable income	**(K) + (P) + (Q) = (R)**		$10,171.5	$6,721.1	$7,695.7	$8,634.5	$9,544.3	$10,425.7	$11,284.5	$12,121.4	$12,634.2	$13,095.1
Cumulative NOL - beginning of period	(S)		$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Tax liabilities	**MAX(0, (R) + (S)) x (Tax Rate) = (T)**		**($3,865.2)**	**($2,554.0)**	**($2,924.4)**	**($3,281.1)**	**($3,626.8)**	**($3,961.7)**	**($4,288.1)**	**($4,606.1)**	**($4,801.0)**	**($4,976.2)**
After-Tax Net Equity Cash Flow	**(K) + (O) + (T) = (U)**	**-$88,060.0**	**$9,953.1**	**$11,593.8**	**$11,559.9**	**$11,546.7**	**$11,551.5**	**$11,574.5**	**$11,613.5**	**$11,668.4**	**$11,854.3**	**$12,067.8**

Year		11	12	13	14	15	16	17	18	19	20
Capacity (MW)	(A)	100	100	100	100	100	100	100	100	100	100
Capacity payments ($/MW-day)	(B)	580.70	592.31	604.16	616.24	628.57	641.14	653.96	667.04	680.38	693.99
Energy sold (MWh)	(C)	143,080	143,080	143,080	143,080	143,080	143,080	143,080	143,080	143,080	143,080
Average revenue ($/MWh)	(D)	58.18	59.78	61.42	63.11	64.85	66.63	68.46	70.35	72.28	74.27
Average fuel cost ($/MWh)	(E)	34.10	35.04	36.00	36.99	38.01	39.06	40.13	41.23	42.37	43.53
Average emissions cost ($/MWh)	(F)	9.73	9.93	10.12	10.33	10.53	10.74	10.96	11.18	11.40	11.63
Clean spark spread ($/MWh)	(D) - (E) - (F) = (G)	14.35	14.81	15.29	15.79	16.30	16.83	17.37	17.93	18.51	19.11
Total net revenues	**(A) x 365 x (B) + (C) x (G) = (H)**	**$23,248.1**	**$23,738.9**	**$24,240.2**	**$24,752.3**	**$25,275.4**	**$25,809.7**	**$26,355.5**	**$26,913.0**	**$27,482.5**	**$28,064.2**
O&M costs	(H)	($2,894.3)	($2,966.6)	($3,040.8)	($3,116.8)	($3,194.7)	($3,274.6)	($3,356.5)	($3,440.4)	($3,526.4)	($3,614.5)
Insurance costs	(I)	($670.9)	($684.3)	($698.0)	($712.0)	($726.2)	($740.7)	($755.5)	($770.7)	($786.1)	($801.8)
Total operating costs	**(H) + (I) = (J)**	($3,565.2)	($3,651.0)	($3,738.8)	($3,828.8)	($3,920.9)	($4,015.3)	($4,112.0)	($4,211.0)	($4,312.5)	($4,416.3)
EBITDA	**(H) + (J) = (K)**	**$19,682.9**	**$20,088.0**	**$20,501.4**	**$20,923.5**	**$21,354.5**	**$21,794.4**	**$22,243.5**	**$22,702.0**	**$23,170.0**	**$23,647.9**
Debt outstanding - beginning of period	(L)	$15,045.9	$14,007.2	$12,885.6	$11,674.1	$10,365.8	$8,952.8	$7,426.7	$5,778.6	$3,998.6	$2,076.2
Debt - interest expense	(M)	($1,203.7)	($1,120.6)	($1,030.8)	($933.9)	($829.3)	($716.2)	($594.1)	($462.3)	($319.9)	($166.1)
Debt - principal payment	(N)	($1,038.6)	($1,121.7)	($1,211.4)	($1,308.3)	($1,413.0)	($1,526.1)	($1,648.1)	($1,780.0)	($1,922.4)	($2,076.2)
Levelized debt service	(M) + (N) = (O)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)	($2,242.3)
EBITDA	**(K)**	**$19,682.9**	**$20,088.0**	**$20,501.4**	**$20,923.5**	**$21,354.5**	**$21,794.4**	**$22,243.5**	**$22,702.0**	**$23,170.0**	**$23,647.9**
Depreciation (20-Year MACRS)	(P)	($4,911.5)	($4,910.4)	($4,911.5)	($4,910.4)	($4,911.5)	($4,910.4)	($4,911.5)	($4,910.4)	($4,911.5)	($4,910.4)
Interest expense	(Q)	($1,203.7)	($1,120.6)	($1,030.8)	($933.9)	($829.3)	($716.2)	($594.1)	($462.3)	($319.9)	($166.1)
Taxable income	**(K) + (P) + (Q) = (R)**	$13,567.7	$14,056.9	$14,559.0	$15,079.2	$15,613.6	$16,167.7	$16,737.8	$17,329.2	$17,938.6	$18,571.4
Cumulative NOL - beginning of period	(S)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0
Tax liabilities	**MAX(0, (R) + (S)) x (Tax Rate) = (T)**	**($5,155.7)**	**($5,341.6)**	**($5,532.4)**	**($5,730.1)**	**($5,933.2)**	**($6,143.7)**	**($6,360.4)**	**($6,585.1)**	**($6,816.7)**	**($7,057.1)**
After-Tax Net Equity Cash Flow	**(K) + (O) + (T) = (U)**	**$12,284.9**	**$12,504.0**	**$12,726.7**	**$12,951.2**	**$13,179.0**	**$13,408.4**	**$13,640.8**	**$13,874.6**	**$14,111.1**	**$14,348.5**

IRR for equity investors	**12.0%**
NPV for equity investors	**($0.0)**

Set NPV to 0

* Denotes unit conversion

Source:

Natural Gas Plants

Capital Cost Estimates for Utility Scale Electricity Generating Plants

Capital Cost Review of Power Generation Technologies

BATTERIES: EUROPEAN LEVELIZED COST ANALYSIS

We have based our batteries' assumptions on "Lazard's levelized cost of storage analysis, version 4" and our market operations' assumptions on backtester results.

European Levelized Cost Analysis

Lithium-Ion Batteries

September 2019

Version 1.0

(€ thousands)

Key Assumptions	France	Germany	
Battery characteristics			
Power rating	100.0 MW	100.0 MW	
Energy-to-power ratio	4.0 kWh/kW	4.0 kWh/kW	
Usable energy	400.0 MWh	400.0 MWh	
Round-trip efficiency	87.0%	87.0%	
Degradation rate	1.0%/yr	1.0%/yr	
CAPEX			
CAPEX - DC	€211/kWh	€211/kWh	
CAPEX - AC	€45/kW	€45/kW	
EPC costs	€14,545	€14,545	
Total =	€103,364	€103,364	
O&M			
O&M % of BESS	1.3%	1.3%	
O&M % of PCS	1.7%	1.7%	
Total =	€1,156k/yr	€1,156k/yr	
O&M escalator	2.50%	2.50%	
Warranty			
Warranty % of BESS	1.5%	1.5%	
Warranty % of PCS	2.0%	2.0%	
Total =	€1,355k/yr	€1,355k/yr	
Warranty's duration	2 yr	2 yr	
Capital structure			
Debt	20.0%	20.0%	
Cost of debt	8.0%	8.0%	
Equity	80.0%	80.0%	
Cost of equity	12.0%	12.0%	
Taxes			
Combined tax rate	35.0%	35.0%	
Economic lifetime	20 yr	20 yr	
MACRS depreciation	7-Year	7-Year	
Market operations			
Day ahead time spread	€2,080/yr	€2,120/yr	*80%*
Additional intraday time spread	€780/yr	€3,300/yr	*50%*
Additional market-making	€2,140/yr	€13,285/yr	*50%*
Resource price	€0.00/MW-day	€0.00/MW-day	
Resource price	€0.00/kW-yr	€0.00/kW-yr	
Resource price escalator	2.00%	2.00%	

Case: Germany

Cash flow model

Year		0	1	2	3	4	5	6	7	8	9	10
Capacity payments	(A)		€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0
Day ahead time spread	(B)		€2,120.0	€2,162.4	€2,205.6	€2,249.8	€2,294.8	€2,340.7	€2,387.5	€2,435.2	€2,483.9	€2,533.6
Additional intraday time spread	(C)		€3,300.0	€3,366.0	€3,433.3	€3,502.0	€3,572.0	€3,643.5	€3,716.3	€3,790.7	€3,866.5	€3,943.8
Additional market-making	(D)		€13,285.0	€13,550.7	€13,821.7	€14,098.1	€14,380.1	€14,667.7	€14,961.1	€15,260.3	€15,565.5	€15,876.8
Total net revenues	**(B) + (C) + (D) = (E)**		**€18,705.0**	**€19,079.1**	**€19,460.7**	**€19,849.9**	**€20,246.9**	**€20,651.8**	**€21,064.9**	**€21,486.2**	**€21,915.9**	**€22,354.2**
O&M costs	(E)		(€1,156.0)	(€1,184.9)	(€1,214.6)	(€1,244.9)	(€1,276.0)	(€1,307.9)	(€1,340.6)	(€1,374.2)	(€1,408.5)	(€1,443.7)
Warranty costs	(F)				(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)
Total operating costs	**(E) + (F) = (G)**		(€1,156.0)	(€1,184.9)	(€2,569.1)	(€2,599.5)	(€2,630.6)	(€2,662.5)	(€2,695.2)	(€2,728.7)	(€2,763.1)	(€2,798.3)
EBITDA	**(D) + (G) = (H)**		**€17,549.0**	**€17,894.2**	**€16,891.6**	**€17,250.4**	**€17,616.3**	**€17,989.3**	**€18,369.7**	**€18,757.5**	**€19,152.8**	**€19,555.9**
Debt outstanding - beginning of period	(I)		€20,672.7	€20,221.0	€19,733.1	€19,206.2	€18,637.1	€18,022.5	€17,358.8	€16,641.9	€15,867.7	€15,031.5
Debt - interest expense	(J)		(€1,653.8)	(€1,617.7)	(€1,578.6)	(€1,536.5)	(€1,491.0)	(€1,441.8)	(€1,388.7)	(€1,331.4)	(€1,269.4)	(€1,202.5)
Debt - principal payment	(K)		(€451.7)	(€487.9)	(€526.9)	(€569.1)	(€614.6)	(€663.8)	(€716.9)	(€774.2)	(€836.1)	(€903.0)
Levelized debt service	(J) + (K) = (L)		(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)
EBITDA	**(H)**		**€17,549.0**	**€17,894.2**	**€16,891.6**	**€17,250.4**	**€17,616.3**	**€17,989.3**	**€18,369.7**	**€18,757.5**	**€19,152.8**	**€19,555.9**
Depreciation (7-Year MACRS)	(M)		(€14,770.7)	(€25,313.8)	(€18,078.3)	(€12,910.1)	(€9,230.4)	(€9,220.0)	(€9,230.4)	(€4,610.0)		
Interest expense	(J)		(€1,653.8)	(€1,617.7)	(€1,578.6)	(€1,536.5)	(€1,491.0)	(€1,441.8)	(€1,388.7)	(€1,331.4)	(€1,269.4)	(€1,202.5)
Taxable income	**(H) + (M) + (J) = (N)**		€1,124.5	(€9,037.3)	(€2,765.4)	€2,803.8	€6,895.0	€7,327.5	€7,750.6	€12,816.1	€17,883.4	€18,353.4
Cumulative NOL - beginning of period	(O)		€0.0	€0.0	(€9,037.3)	(€11,802.6)	(€8,998.8)	(€2,103.8)	€0.0	€0.0	€0.0	€0.0
Tax liabilities	**MAX(0, (N) + (O)) x (Tax Rate) = (P)**		(€393.6)	€0.0	€0.0	€0.0	€0.0	(€1,828.3)	(€2,712.7)	(€4,485.6)	(€6,259.2)	(€6,423.7)
After-Tax Net Equity Cash Flow	**(H) + (L) + (P) = (Q)**	**(€82,690.9)**	**€15,049.8**	**€15,788.6**	**€14,786.0**	**€15,144.9**	**€15,510.7**	**€14,055.5**	**€13,551.4**	**€12,166.3**	**€10,788.1**	**€11,026.7**

Year	11	12	13	14	15	16	17	18	19	20
Capacity payments	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0
Day ahead time spread	€2,584.3	€2,636.0	€2,688.7	€2,742.4	€2,797.3	€2,853.2	€2,910.3	€2,968.5	€3,027.9	€3,088.4
Additional intraday time spread	€4,022.7	€4,103.1	€4,185.2	€4,268.9	€4,354.3	€4,441.4	€4,530.2	€4,620.8	€4,713.2	€4,807.5
Additional market-making	€16,194.3	€16,518.2	€16,848.6	€17,185.6	€17,529.3	€17,879.9	€18,237.5	€18,602.2	€18,974.3	€19,353.7
Total net revenues	**€22,801.3**	**€23,257.3**	**€23,722.5**	**€24,196.9**	**€24,680.9**	**€25,174.5**	**€25,678.0**	**€26,191.5**	**€26,715.3**	**€27,249.7**
O&M costs	(€1,479.8)	(€1,516.8)	(€1,554.7)	(€1,593.6)	(€1,633.4)	(€1,674.3)	(€1,716.1)	(€1,759.0)	(€1,803.0)	(€1,848.1)
Warranty costs	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)	(€1,354.5)
Total operating costs	(€2,834.4)	(€2,871.4)	(€2,909.3)	(€2,948.1)	(€2,988.0)	(€3,028.8)	(€3,070.7)	(€3,113.6)	(€3,157.6)	(€3,202.6)
EBITDA	**€19,966.9**	**€20,386.0**	**€20,813.2**	**€21,248.8**	**€21,692.9**	**€22,145.6**	**€22,607.3**	**€23,077.9**	**€23,557.8**	**€24,047.0**
Debt outstanding - beginning of period	€14,128.5	€13,153.2	€12,099.9	€10,962.3	€9,733.8	€8,406.9	€6,973.9	€5,426.2	€3,754.8	€1,949.6
Debt - interest expense	(€1,130.3)	(€1,052.3)	(€968.0)	(€877.0)	(€778.7)	(€672.6)	(€557.9)	(€434.1)	(€300.4)	(€156.0)
Debt - principal payment	(€975.3)	(€1,053.3)	(€1,137.6)	(€1,228.6)	(€1,326.9)	(€1,433.0)	(€1,547.7)	(€1,671.5)	(€1,805.2)	(€1,949.6)
Levelized debt service	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)	(€2,105.6)
EBITDA	**€19,966.9**	**€20,386.0**	**€20,813.2**	**€21,248.8**	**€21,692.9**	**€22,145.6**	**€22,607.3**	**€23,077.9**	**€23,557.8**	**€24,047.0**
Depreciation (7-Year MACRS)										
Interest expense	(€1,130.3)	(€1,052.3)	(€968.0)	(€877.0)	(€778.7)	(€672.6)	(€557.9)	(€434.1)	(€300.4)	(€156.0)
Taxable income	€18,836.7	€19,333.7	€19,845.2	€20,371.8	€20,914.2	€21,473.1	€22,049.4	€22,643.8	€23,257.4	€23,891.1
Cumulative NOL - beginning of period	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0	€0.0
Tax liabilities	(€6,592.8)	(€6,766.8)	(€6,945.8)	(€7,130.1)	(€7,320.0)	(€7,515.6)	(€7,717.3)	(€7,925.3)	(€8,140.1)	(€8,361.9)
After-Tax Net Equity Cash Flow	**€11,268.5**	**€11,513.6**	**€11,761.8**	**€12,013.1**	**€12,267.3**	**€12,524.5**	**€12,784.4**	**€13,047.0**	**€13,312.1**	**€13,579.6**

IRR for equity investors	**16.0%**
NPV for equity investors	**€17,886.8**

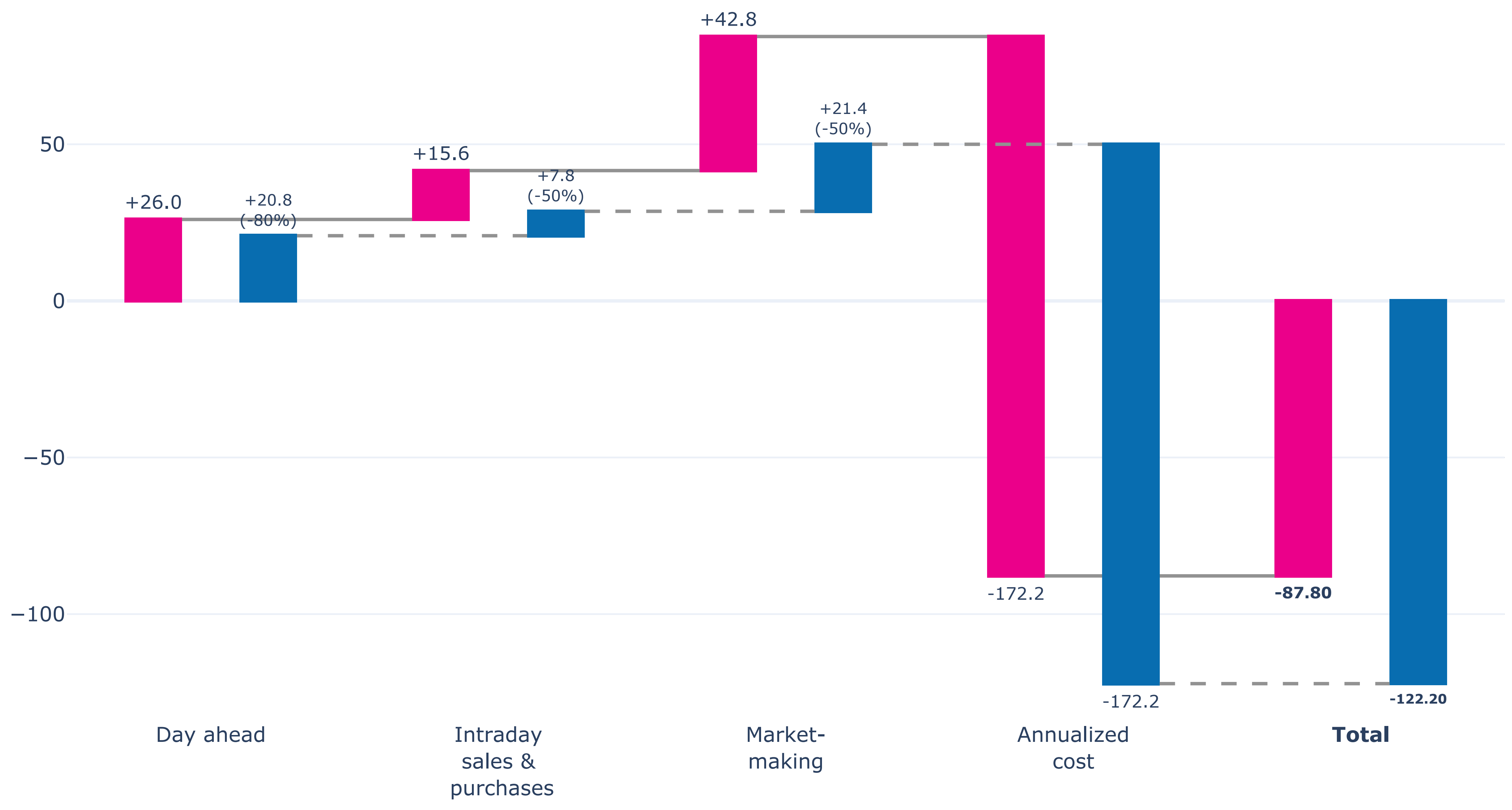
Set NPV to 0

* Denotes unit conversion

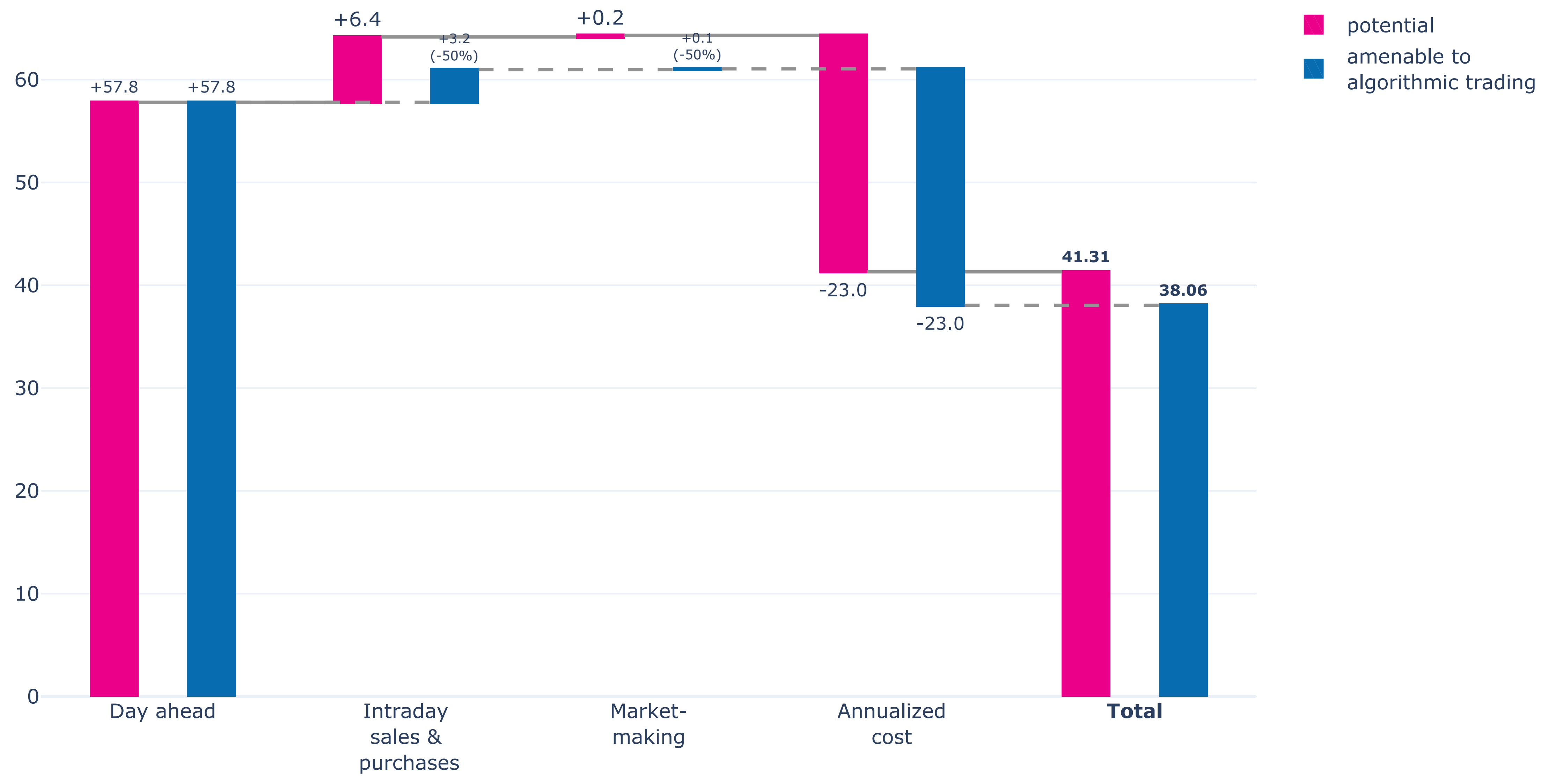
ENERGY ARBITRAGE IN FRANCE

The French short-term markets do not yet offer sizeable commercial opportunities because intermittent energy represents only 15% of the generating capacity – 10% of this capacity is from hydro water reservoir and pumped hydro.

Breakdown of the value related to 100 MW battery installed in France
€/kW-yr, Jul-17 to Jun-18



Breakdown of the value related to a CCGT in France
€/kW-yr, Jul-17 to Jun-18



MARKET-MAKING ARBITRAGES IN GERMANY

BACKTESTER RESULTS

The last five hours prior delivery experience a lot of price volatility

leading to numerous market-making arbitrage opportunities