

# Kløftbrua kraftverk

Run-of-river · price zone **N03** — full-year optimised dispatch, 1 Jan – 31 Dec 2025.

INSTALLED **5,5 MW**    MAX FLOW **11,5 m³/s**    RESERVOIR **0 h · 0,0 Mm³**

WATERCOURSE & COMPONENTS · RENNEBU



THE HEADLINE · 2025

Co-optimising Kløftbrua kraftverk across all balancing markets lifted modelled revenue **+66 %** over day-ahead-only dispatch — almost entirely from reserve capacity, not extra energy.

**+66 %**  
REVENUE UPLIFT

**€ 127 794**  
ADDITIONAL / YEAR

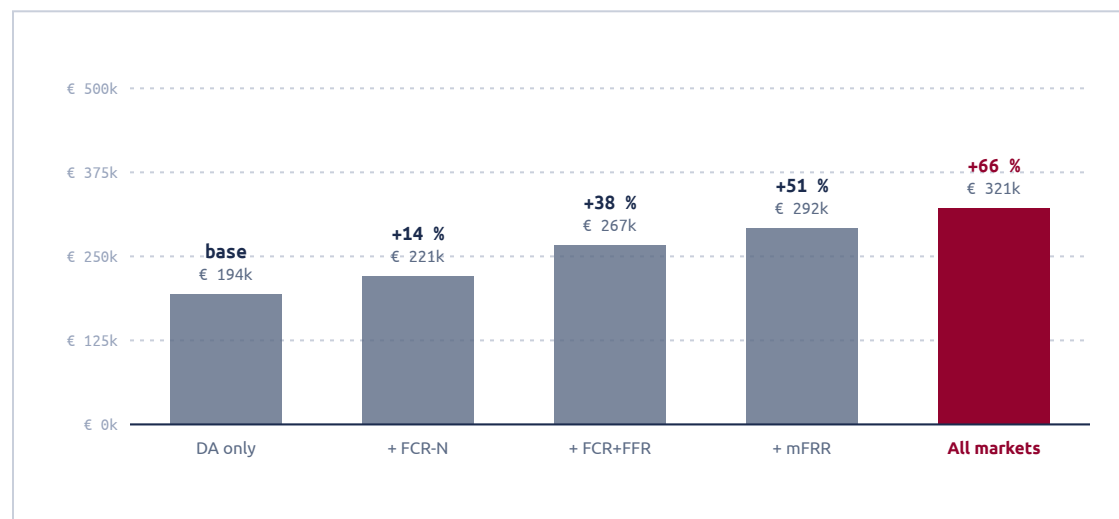
PERFORMANCE — ALL MARKETS (HYBRID)

SELECT MARKET STRATEGY ↓

Day-ahead only	DA + FCR-N (standalone)	DA + FCR + FFR (hybrid)	DA + FCR-N + mFRR (standalone)	All markets (hybrid)	
<b>TOTAL REVENUE</b> <b>€ 321 459</b> +66,0 % vs. DA only	<b>ENERGY</b> <b>10 348</b> MWh to grid	<b>CAPACITY FACTOR</b> <b>21,5 %</b> of 5,5 MW	<b>CAPTURE RATE</b> <b>96 %</b> 31,1 €/MWh realised (all markets ÷ energy)	<b>RESERVOIR CYCLES</b> <b>n/a</b> full equiv. / yr	<b>SPILL</b> <b>42,4</b> Mm³ · 35,1 %

REVENUE BY STRATEGY

EUR · Δ vs day-ahead only



REVENUE BY MARKET

All markets (hybrid) · reserved MW · activated MWh/h

MARKET	AVG MW	ACT MWH	PEAK MW	REVENUE	SHARE
Day-ahead energy	—	1,18	5,5	€ 165 259	51%
FCR-N reserve	0,23	0,02	2,0	€ 54 926	17%
FCR-D up	0,03	0,00	2,2	€ 2 776	1%
mFRR up / down	0,97	0,00	5,5	€ 83 653	26%
FFR profile + flex	0,11	0,00	1,1	€ 14 846	5%
<b>Total</b>				<b>€ 321 459</b>	

THE MARKET STRATEGIES · what each scenario co-optimises

- Day-ahead only**  
Spot-price optimised dispatch only — no reserves. The revenue baseline.
- DA + FCR-N (standalone)**  
Adds FCR-N (symmetric frequency reserve). Autonomous droop setpoint, capped at 10 % of capacity.
- DA + FCR + FFR (hybrid)**  
FCR-N + FCR-D up + fast frequency response (FFR). Assumes a small ESS hybrid for the sub-second products.
- DA + FCR-N + mFRR (standalone)**  
FCR-N plus manual restoration reserve (mFRR up/down) — TSO-activated, needs an operations function.
- All markets (hybrid)**  
Co-optimised across every balancing market (DA, FCR-N/D, mFRR, FFR) as a hybrid.

Day-ahead only	DA + FCR-N (standalone)	DA + FCR + FFR (hybrid)	DA + FCR-N + mFRR (standalone)	<b>All markets (hybrid)</b>
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**01 SCENARIO COMPARISON** - uplift vs. day-ahead only

STRATEGY	REVENUE	REVENUE (BAR) · Δ VS DAY-AHEAD	ENERGY (MWH)	CAPTURE RATE	CAP. FACTOR	RESERVE UTIL.
Day-ahead only	€ 193 665	—	13 974	58 %	29,1 %	0 %
DA + FCR-N (standalone)	€ 221 147	+14,2 %	12 128	66 %	25,2 %	4 %
DA + FCR + FFR (hybrid)	€ 267 018	+37,9 %	9 739	80 %	20,3 %	10 %
DA + FCR-N + mFRR (standalone)	€ 292 475	+51,0 %	11 400	87 %	23,7 %	25 %
<b>All markets (hybrid)</b>	<b>€ 321 459</b>	<b>+66,0 %</b>	<b>10 348</b>	<b>96 %</b>	<b>21,5 %</b>	<b>24 %</b>

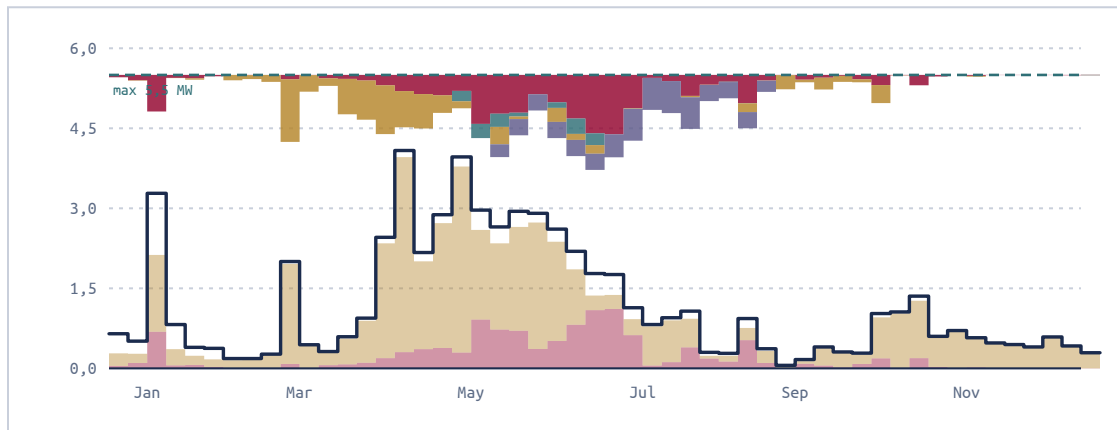
**02 WATER BALANCE & CAPTURE** - All markets (hybrid)

TOTAL INFLOW <b>120,8</b> Mm³ · Sildre (Gisnås) × 1.41 — scaled so capped-turbinable energy matches the NVE concession estimate (14.2 GWh; beta)	TURBINED <b>78,5</b> Mm³ through turbine	SPILL (LOST) <b>42,4</b> Mm³ · 35,1 % of inflow	AVG RESERVOIR <b>n/a</b> % of usable volume	CAPTURE RATE <b>96 %</b> revenue ÷ (inflow energy × 21,1 €/MWh)
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**03 HOW THE PLANT WAS DISPATCHED** - optimised dispatch for the selected strategy

**RESERVE CAPACITY HELD**

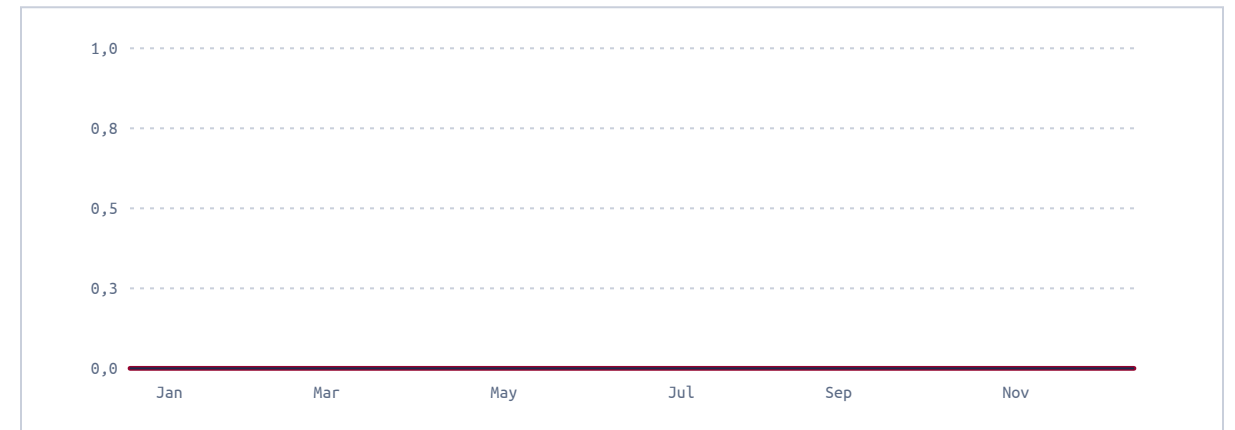
All markets (hybrid) · up from top, down from bottom



FCR-N FCR-D mFRR FFR Plant output Max capacity

**RESERVOIR TRAJECTORY**

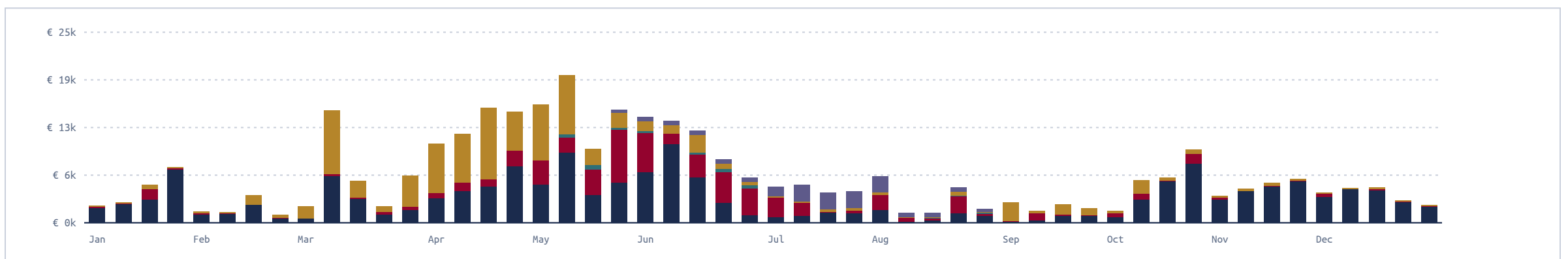
weekly · Mm³ · all strategies, selected highlighted



All markets (selected) Other strategies Min / max bounds

**WEEKLY REVENUE BY MARKET**

All markets (hybrid) · 52 equal periods



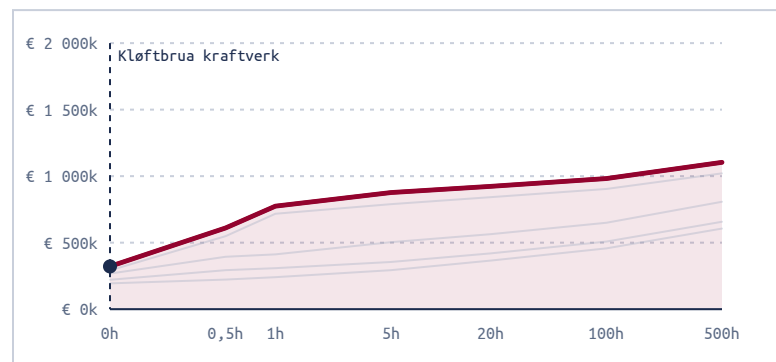
Day-ahead FCR-N FCR-D mFRR FFR

Day-ahead only	DA + FCR-N (standalone)	DA + FCR + FFR (hybrid)	DA + FCR-N + mFRR (standalone)	<b>All markets (hybrid)</b>
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### 01 WHERE THE MARGINAL VALUE IS

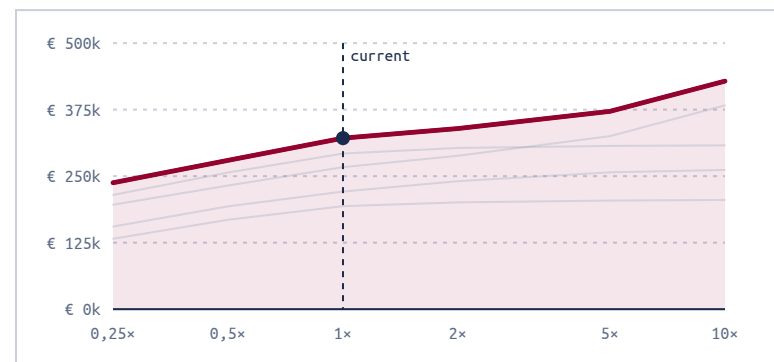
Sensitivity of optimised revenue to the plant's physical envelope, under each market strategy. The **highlighted line is the selected strategy**; the dashed marker is Kløftbrua kraftverk's current operating point.

#### STORAGE DISCHARGE DURATION



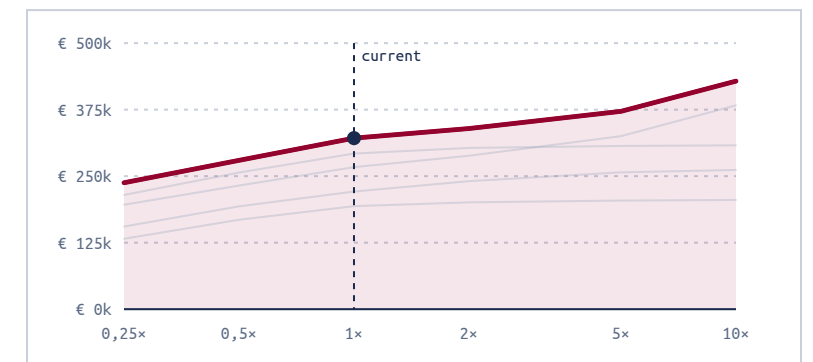
Annual revenue vs. usable storage hours (log). Marker = as-built.

#### TURBINE CAPACITY



Annual revenue vs. turbine flow capacity (x as-built, log). Marker = as-built.

#### PLANT SCALE



Revenue vs. scaling turbine + reservoir together (x as-built, fixed inflow). Saturates when the plant outgrows its water.

— All markets (selected) — Other strategies — Kløftbrua kraftverk as-built

#### MARGINAL VALUES & BINDING CONSTRAINTS

as-built · All markets (hybrid)

Marginal water value	27,1 €/MWh	Extra revenue from one more MWh of stored water
Turbine capacity (+1 MW)	3 279 €/yr	Extra annual revenue from a turbine uprate at current scale
Storage (+1 MWh)	131 352 €/yr	Extra annual revenue from more usable storage (≈0 when over-provisioned)
Reserve-cap headroom (+1 MW)	3,2 €/MW·h	Extra €/MW·h from relaxing the binding reserve reservation cap
Day-ahead spot (reference)	21,1 €/MWh	Avg. zone NO3 day-ahead price
Reservoir upper bound	binds 100 %	Share of hours at the cap — spill risk in the melt

#### READING MARGINAL (SHADOW) PRICES

A marginal (shadow) price is the extra revenue the optimiser would earn from **one more unit** of a scarce resource — an MWh of stored water, +1 MW of turbine, +1 MWh of storage, or +1 MW of reserve-cap headroom — holding everything else fixed.

A value near **zero** means that limit isn't binding: loosening it wouldn't help, so don't invest there. A **large** value flags the binding bottleneck — where a relaxed limit or an upgrade would pay back, and roughly how much it is worth per year. They answer: *what is holding this plant back, and what is it worth to change it?* (Values are for the selected strategy at the as-built size.)

#### RECOMMENDATIONS

- NO3 2025: spot down a quarter, reserves up — +66 % uplift**  
NO3 spot averaged 21,0 €/MWh in 2025 (28,2 in 2024); day-ahead alone earned €194 000 and full participation €321 000/yr. mFRR led with €84 000, FCR-N €55 000 (standalone +€27 000/+14 %). The NO3 story is milder than NO4's collapse but points the same way: reserve capability stabilises revenue across price years. Perfect-foresight upper bounds.
- mFRR route ahead in 2025 (€292 000 vs €267 000 hybrid)**  
mFRR alone rose to €93 000/yr — the largest single mFRR line in the portfolio. Locus Hydro's Rennebu location sits in the same bidding zone as several established balancing actors; an outsourced agreement should be straightforward to price. FCR-N first regardless.
- The buffer finding survives the zone change**  
0,5 h of pondage prices at €609 000/yr against the as-built €321 000 (and 34 % of inflow spills at full reserves against the 55 m<sup>3</sup>/11,5 m<sup>3</sup>/s configuration). Two years, two zones, same conclusion as the rest of the portfolio: modest buffering is the highest-value design change available. Model-preliminary (LER assumptions).

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#### SIMULATION SETUP & ASSUMPTIONS

<b>MODEL</b>		<b>HORIZON</b>		<b>HYDROLOGY</b>		<b>CAPS</b>	
Method	MILP co-opt.	Period	2025 full-year	Inflow source	Sildre (Gisnås) × 1.41 – scaled so capped-turbinable energy matches the NVE concession estimate (14.2 GWh; beta)	FCR-N	10% / 40% hyb.
Solver	CBC	Resolution	60 min MTU	Station	Gisnås	FCR-D	40%
Segments	5	Hours	8 760	Total inflow	120,8 Mm <sup>3</sup>	FFR	10%
Boundary	cycling res.	Storage bounds	concession	Usable res.	0,0 Mm <sup>3</sup> · 0 h	mFRR	100%
<b>MARKETS &amp; PRICES</b>							
Strategies	DA · FCR-N/D						
	mFRR · FFR						
Price zone	NO3						
Avg spot	21,1 €/MWh						

