Løvdalselva kraftverk

Run-of-river · · price zone **NO4** — full-year optimised dispatch, 1 Jan – 31 Dec 2025.

INSTALLED	MAX FLOW	RESERVOIR
1,5 MW	0,7 m³/s	0 h · 0,0 Mm³

WATERCOURSE & COMPONENTS · GRATANGEN

THE HEADLINE · 2025

Co-optimising Løvdalselva kraftverk across **all balancing markets** lifted modelled revenue **+173 %** over day-ahead-only dispatch — almost entirely from reserve capacity, not extra energy.

+173 % REVENUE UPLIFT

€ 48 500 ADDITIONAL / YEAR

PERFORMANCE — ALL MARKETS (HYBRID)

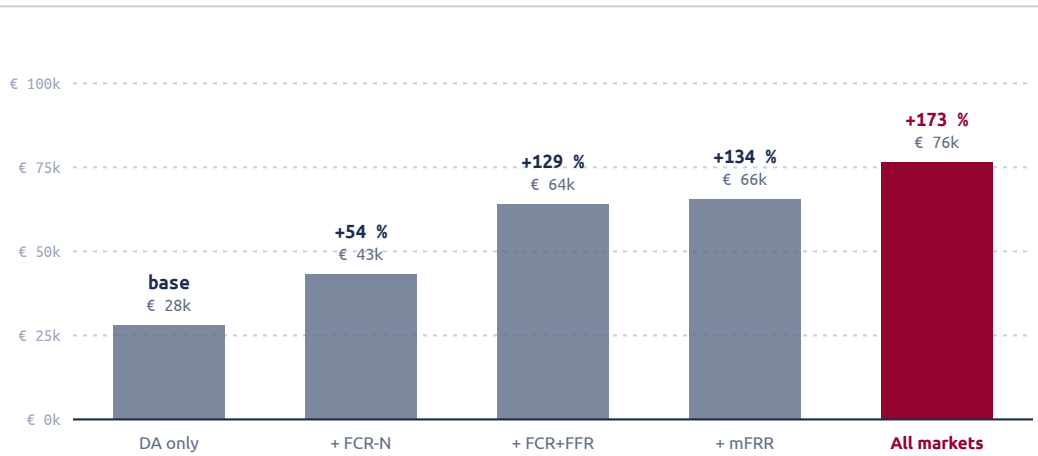
SELECT MARKET STRATEGY ↓

Day-ahead only	DA + FCR-N (standalone)	DA + FCR + FFR (hybrid)	DA + FCR-N + mFRR (standalone)	**All markets (hybrid)**

TOTAL REVENUE	ENERGY	CAPACITY FACTOR	CAPTURE RATE	RESERVOIR CYCLES	SPILL
€ 76 494	3 658	27,8 %	145 %	n/a	4,3
+173,3 % vs. DA only	MWh to grid	of 1,5 MW	20,9 €/MWh realised (all markets ÷ energy)	full equiv. / yr	Mm³ · 39,7 %

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	–	0,42	1,5	€ 21 475	28%
FCR-N reserve	0,12	0,01	0,6	€ 26 676	35%
FCR-D up	0,02	0,00	0,6	€ 1 656	2%
mFRR up / down	0,28	0,00	1,5	€ 22 630	30%
FFR profile + flex	0,03	0,00	0,3	€ 4 056	5%
Total				**€ 76 494**	

THE MARKET STRATEGIES · what each scenario co-optimises

1 **Day-ahead only**
Spot-price optimised dispatch only — no reserves. The revenue baseline.

2 **DA + FCR-N (standalone)**
Adds FCR-N (symmetric frequency reserve). Autonomous droop setpoint, capped at 10 % of capacity.

3 **DA + FCR + FFR (hybrid)**
FCR-N + FCR-D up + fast frequency response (FFR). Assumes a small ESS hybrid for the sub-second products.

4 **DA + FCR-N + mFRR (standalone)**
FCR-N plus manual restoration reserve (mFRR up/down) — TSO-activated, needs an operations function.

5 **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)	**All markets (hybrid)**

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	€ 27 994	–	5 419	53 %	41,2 %	0 %
DA + FCR-N (standalone)	€ 43 120	+54,0 %	4 432	82 %	33,7 %	7 %
DA + FCR + FFR (hybrid)	€ 64 122	+129,1 %	2 940	122 %	22,4 %	18 %
DA + FCR-N + mFRR (standalone)	€ 65 639	+134,5 %	4 525	124 %	34,4 %	36 %
All markets (hybrid)	€ 76 494	+173,3 %	3 658	145 %	27,8 %	30 %

02 WATER BALANCE & CAPTURE · All markets (hybrid)

TOTAL INFLOW
10,9
Mm³ · Sildre (Øvrevatn) × 0.01 — scaled so capped-turbinable energy matches the NVE concession estimate (5.6 GWh; beta)

TURBINED
6,6
Mm³ through turbine

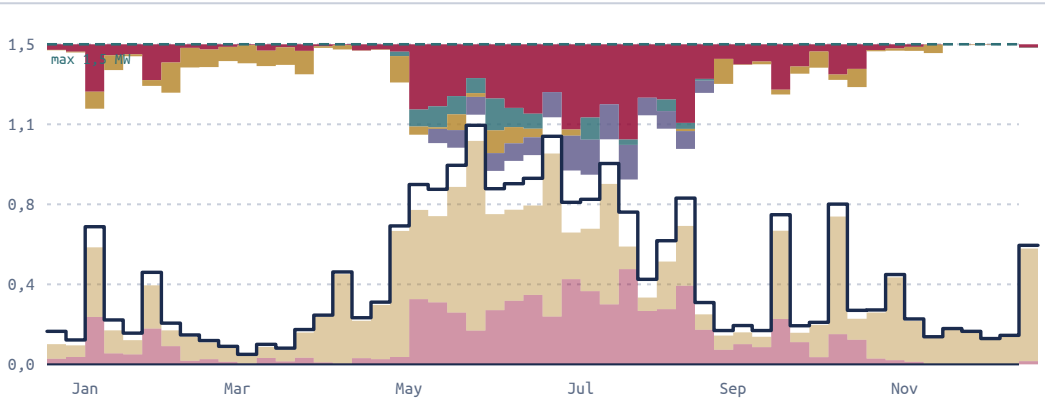
SPILL (LOST)
4,3
Mm³ · 39,7 % of inflow

AVG RESERVOIR
n/a
% of usable volume

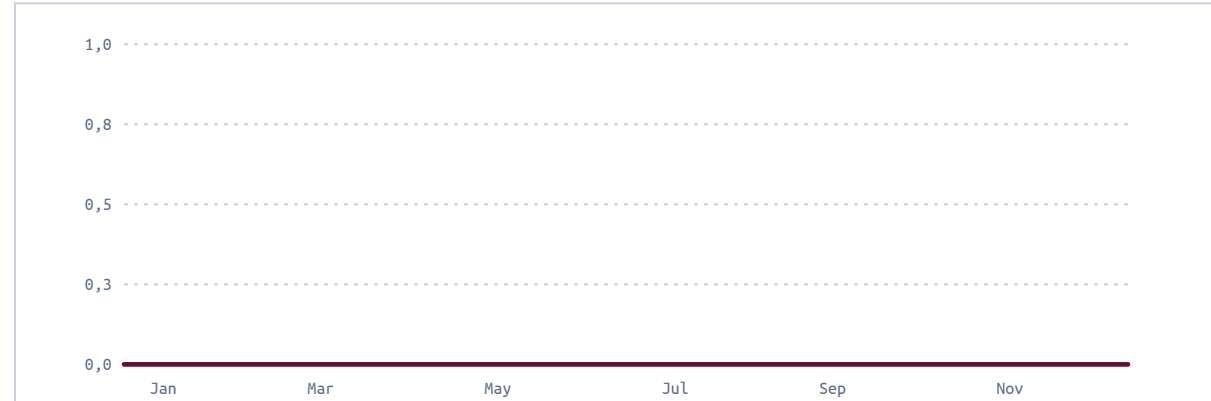
CAPTURE RATE
145 %
revenue ÷ (inflow energy × 8,7 €/MWh)

03 HOW THE PLANT WAS DISPATCHED · optimised dispatch for the selected strategy

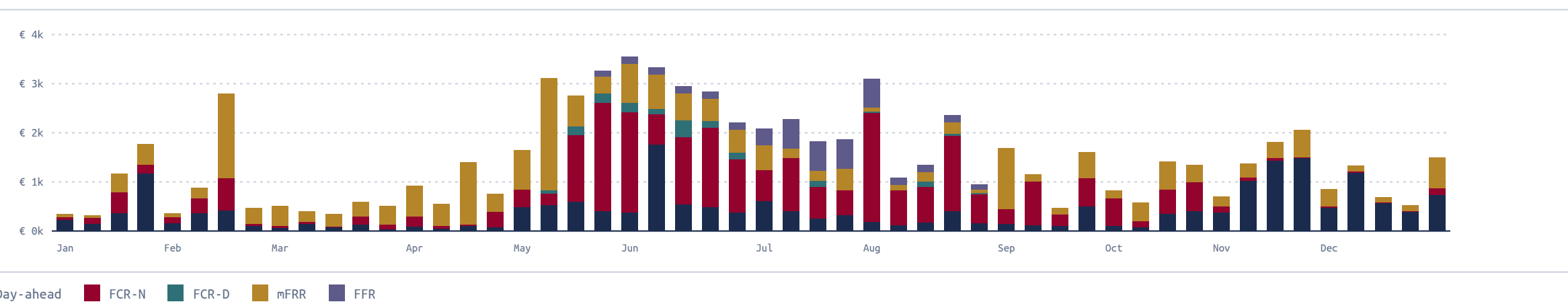
RESERVE CAPACITY HELD
All markets (hybrid) · up from top, down from bottom



RESERVOIR TRAJECTORY
weekly · Mm³ · all strategies, selected highlighted



WEEKLY REVENUE BY MARKET
All markets (hybrid) · 52 equal periods

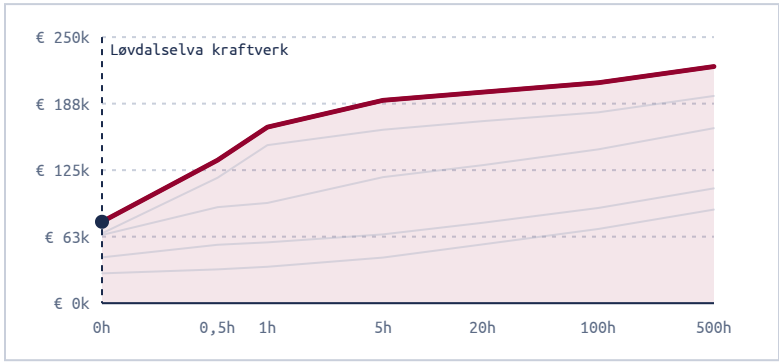


Day-ahead only	DA + FCR-N (standalone)	DA + FCR + FFR (hybrid)	DA + FCR-N + mFRR (standalone)	**All markets (hybrid)**

01 WHERE THE MARGINAL VALUE IS

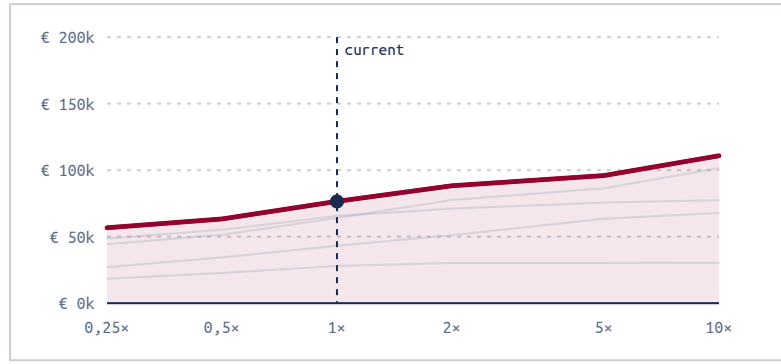
Sensitivity of optimised revenue to the plant's physical envelope, under each market strategy. The **highlighted line is the selected strategy**; the dashed marker is Løvdalselva kraftverk's current operating point.

STORAGE DISCHARGE DURATION



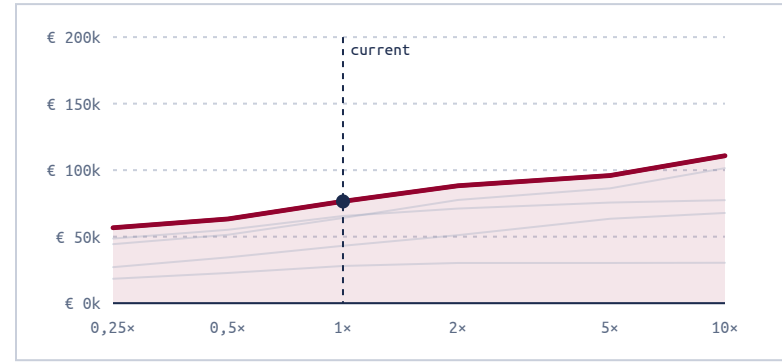
Annual revenue vs. usable storage hours (log). Marker = as-built.

TURBINE CAPACITY



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

PLANT SCALE



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

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

MARGINAL VALUES & BINDING CONSTRAINTS

as-built · All markets (hybrid)

Marginal water value	15,5 €/MWh	Extra revenue from one more MWh of stored water
Turbine capacity (+1 MW)	7 896 €/yr	Extra annual revenue from a turbine uprate at current scale
Storage (+1 MWh)	96 560 €/yr	Extra annual revenue from more usable storage (≈0 when over-provisioned)
Reserve-cap headroom (+1 MW)	1,8 €/MW·h	Extra €/MW·h from relaxing the binding reserve reservation cap
Day-ahead spot (reference)	8,7 €/MWh	Avg. zone NO4 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

1 **2025: +173 % — reserves kept the smallest prospect alive**

At NO4's 8,6 €/MWh, day-ahead alone earned €28 000/yr — marginal against any realistic O&M budget. Full participation earned €77 000, with FCR-N standalone contributing +€15 000 (+54 %) autonomously. For a 1,5 MW plant, reserve capability is the difference between viable and not in a low-price year. Perfect-foresight upper bounds.

2 **FCR-N is half the reserve story; the rest needs aggregation**

In the full strategy FCR-N reaches €27 000/yr and mFRR €23 000 — but mFRR presupposes a 24/7 balancing function no 1,5 MW plant carries alone. The Gratangen/Lavangen cluster (Løvdalselva, Hilleshamn, Sandneselva, Plasselva, Foldvik) is the natural aggregation unit; one shared agreement changes the economics for all of them.

3 **Undersized turbine + no buffer = the two design findings stand**

Capture price fell to 69 % of spot (5,9 vs 8,6 €/MWh) and 40 % of inflow spills at full reserves — the swallow is the bottleneck in both years. The sweep prices 0,5 h of pondage at €134 000/yr versus €77 000 as-built. Fix the physics before the byggefrist; the markets will still be there.

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SIMULATION SETUP & ASSUMPTIONS

MODEL

Method	MILP co-opt.
Solver	CBC
Segments	5
Boundary	cycling res.

HORIZON

Period	2025 full-year
Resolution	60 min MTU
Hours	8 760
Storage bounds	concession

HYDROLOGY

Inflow source	Sildre (Øvrevatn) × 0.01 — scaled so capped-turbinable energy matches the NVE concession estimate (5.6 GWh; beta)
Station	Øvrevatn
Total inflow	10,9 Mm³
Usable res.	0,0 Mm³ · 0 h

CAPS

FCR-N	10% / 40% hyb.
FCR-D	40%
FFR	10%
mFRR	100%

MARKETS & PRICES

Strategies	DA · FCR-N/D mFRR · FFR
Price zone	NO4
Avg spot	8,7 €/MWh