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Hierarchical planning for hydropower plant upgrades using semi-analytical policies

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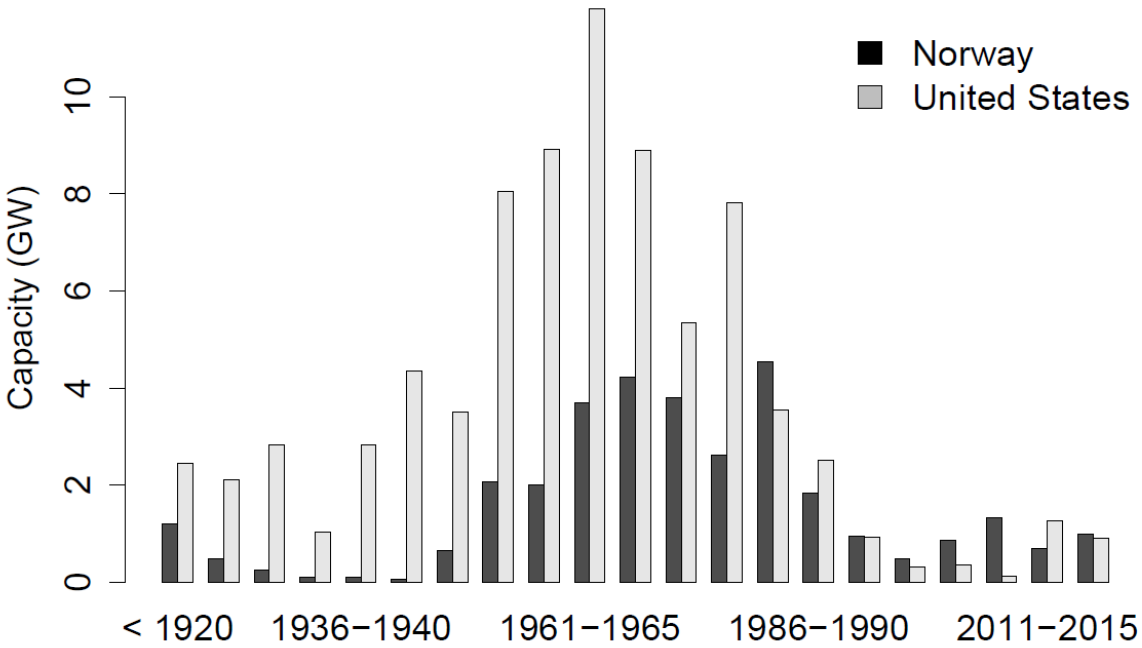
Background



Distribution of hydropower installed capacity by initial operating year

Contributions

- We include short-term operational aspects, provide bounds on the value of production schedules, and obtain semi-analytical investment policies for capacity upgrade
  - Compared to f.ex Bøckman et al (2008) and Andersson et al (2014)
  - Hierarchical planning (Anthony (1965), Dempster et al (1981), Lenstra et al (1984), Bitran and Tirupati (1993))
  - Reoptimization heuristic (Lai et al (2010), Nadarajah and Secomandi (2018)

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Refurbish/upgrade

- Large investment cost
- Increased capacity
  - Change in the operational pattern

Wait

Common industry practice

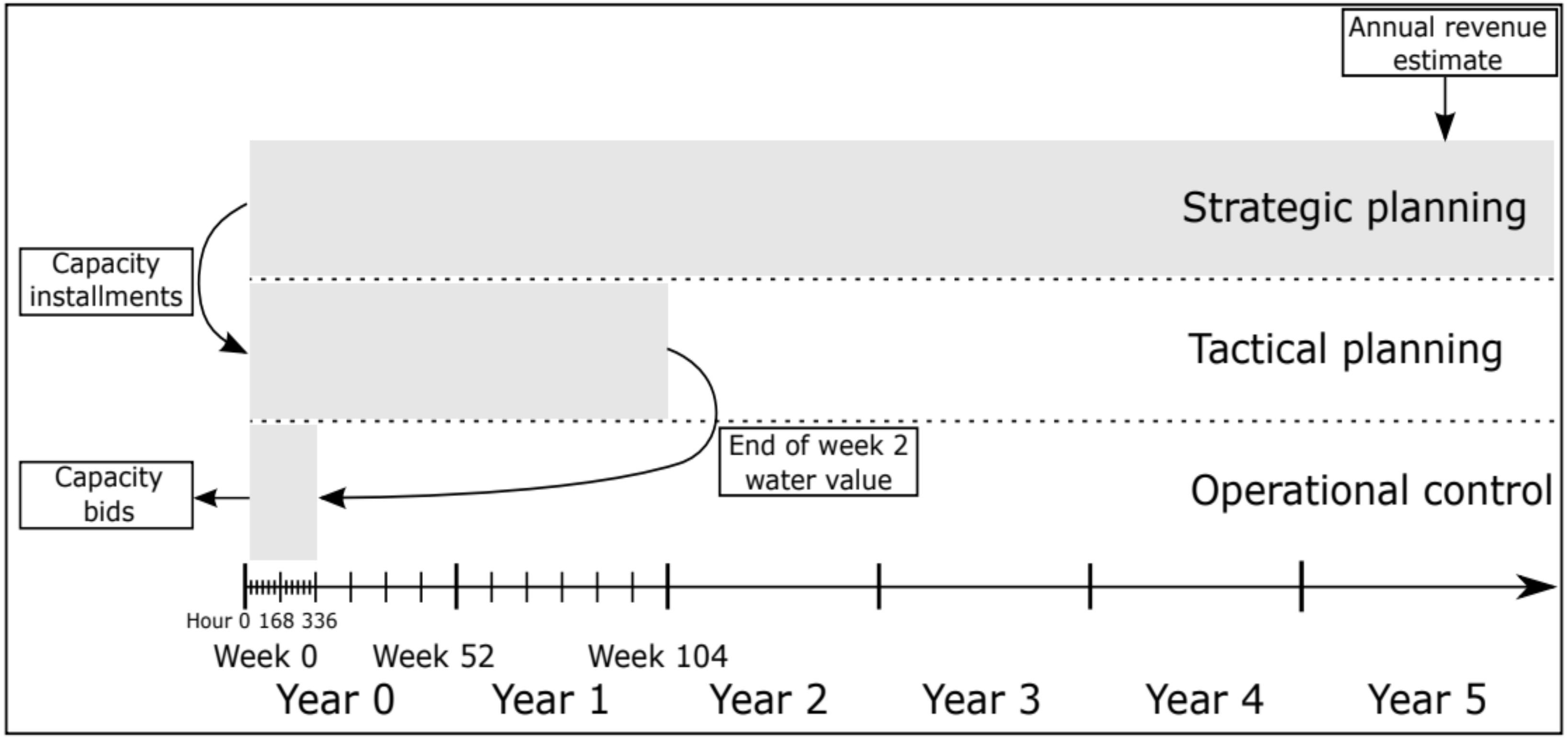
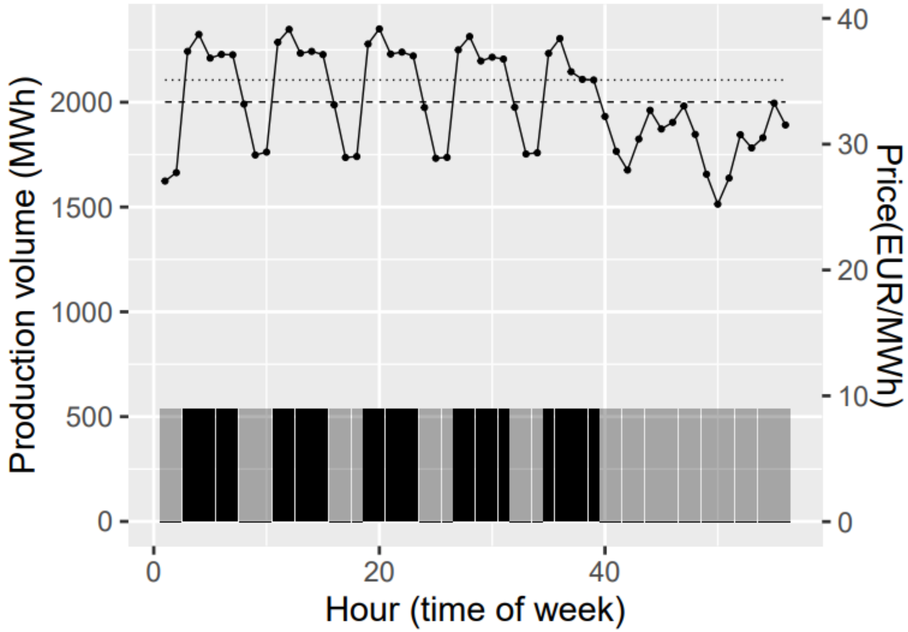


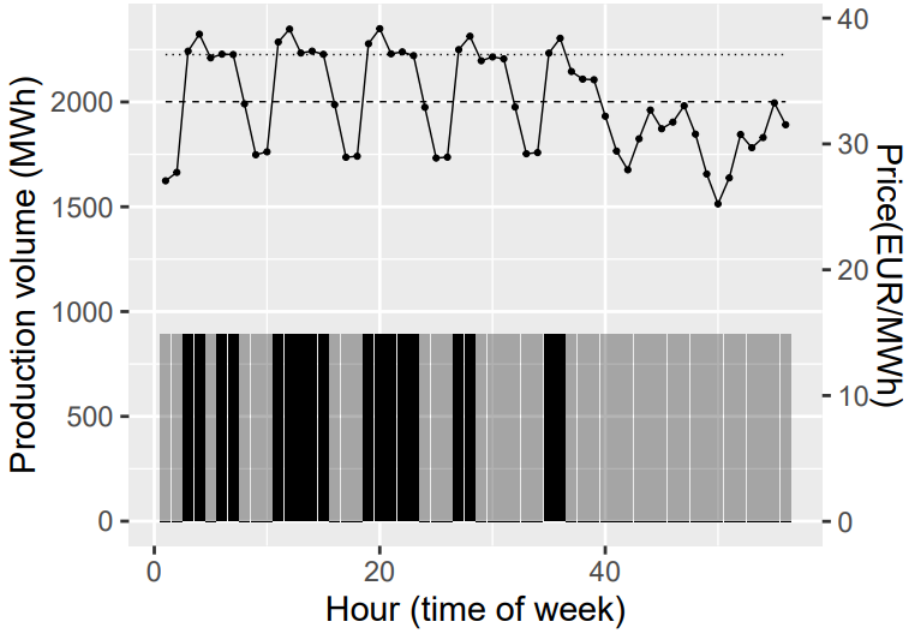
Figure 1: Common industry practice for hydropower planning.

When and how much additional capacity to install?

And how does the decision to install additional capacity depend on assumptions on future short-term price variations?



(a) Low capacity.



(b) High capacity.

Key assumption

- Strategic decisions (i.e. upgrading) are unaffected by the level of the short-term factors
  - Short term price deviation from the equilibrium level
  - Inflow state
  - Reservoir level

- So only the movement of equilibrium price level affects the value of the investment

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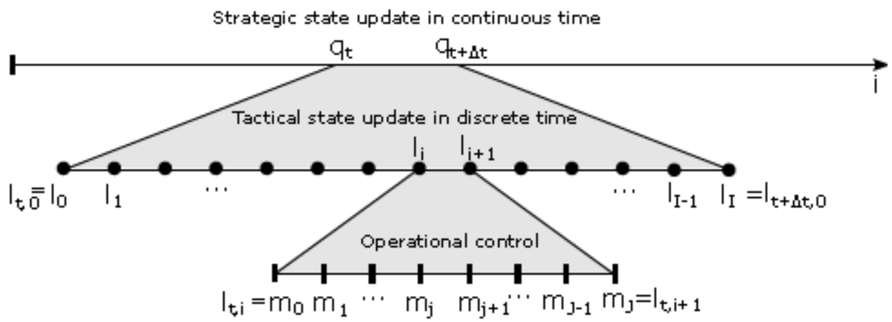
Decomposition

- Upper level: Investment
  - Continuous time
  - When (=at what equilibrium price level) and at what size
  - Capacity size Q is the main linking parameter
- Lower level
  - Tactical and operational decisions/values



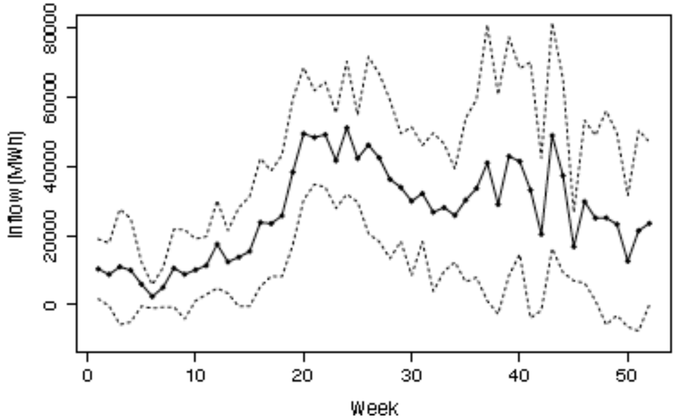
Methods

- Problem is cast as a Markov decision process
- Model-based reinforcement learning
  - Stochastic dynamic programming for the tactical-operational problem
  - Reoptimization heuristic (RH) for obtaining tactical-operational policies for different capacity upgrade alternatives
- Tactical-operational value as a function of capacity
  - Solve the investment timing problem as a joint capacity choice and real options problem

Instances

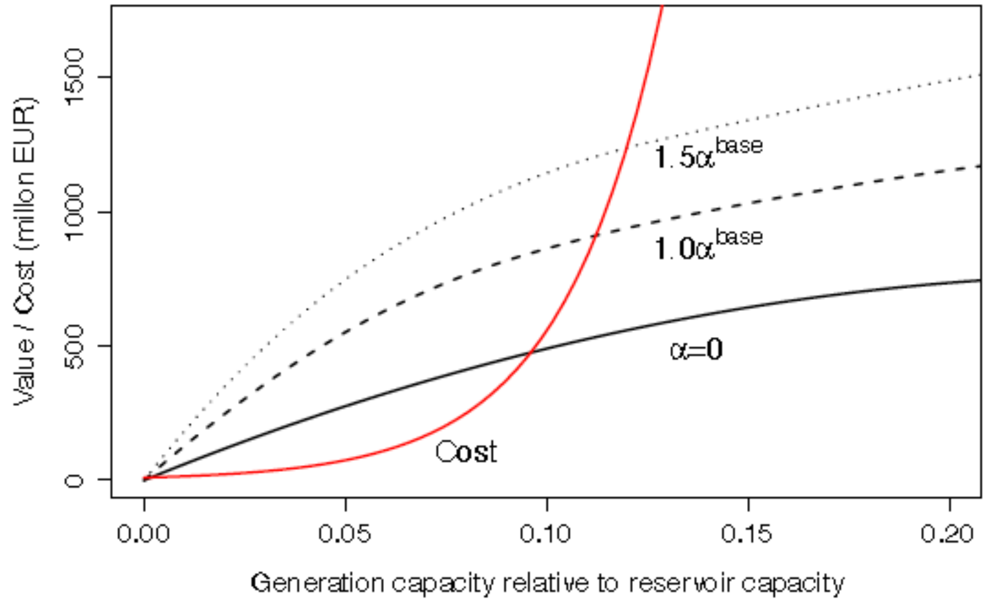
- Reservoir capacity 335 GWh
- Initial generation capacity 166 MW (8.3%/week)
- Average annual inflow 1354 GWh/year (~4x reservoir)
- Spot prices 2013-2018
- Start level equilibrium price 30 €/MWh, drift 0.012, volatility 0.146

Instance	Description	Spot price data
$\alpha_{t,i} = 0$	Weekly decision periods	Zero variations
$\alpha_{t,i} = 1.0\alpha^{base}$	3-hourly decision periods	Variations in 2013-2018
$\alpha_{t,i} = 1.5\alpha^{base}$	3-hourly decision periods	1.5 × variations 2013-2018

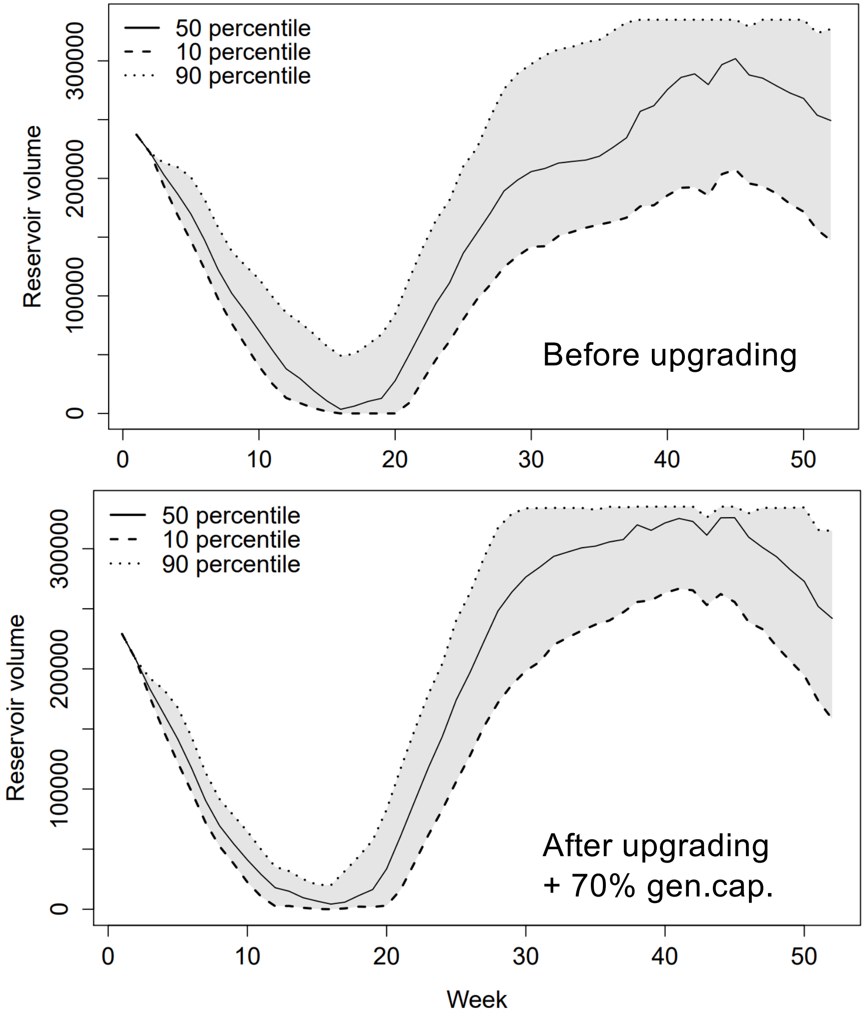


Results

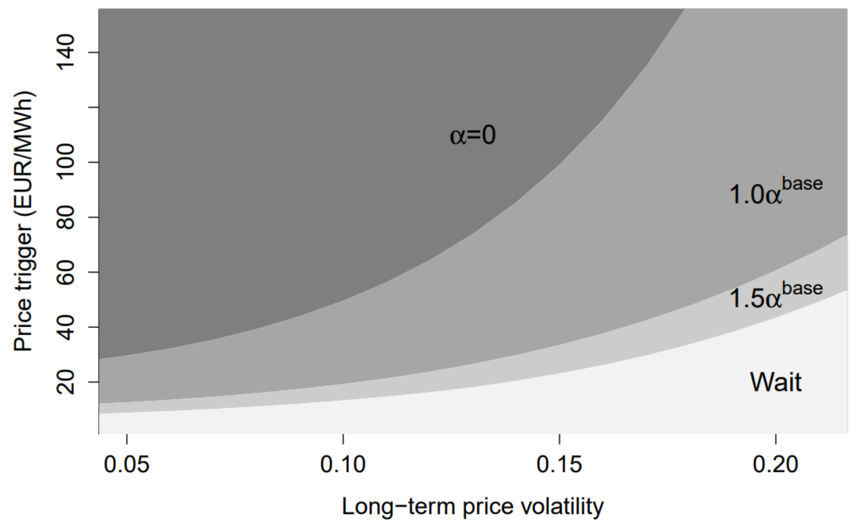
- Value of additional capacity
  - Given an equilibrium price of 32 €/MWh



Results



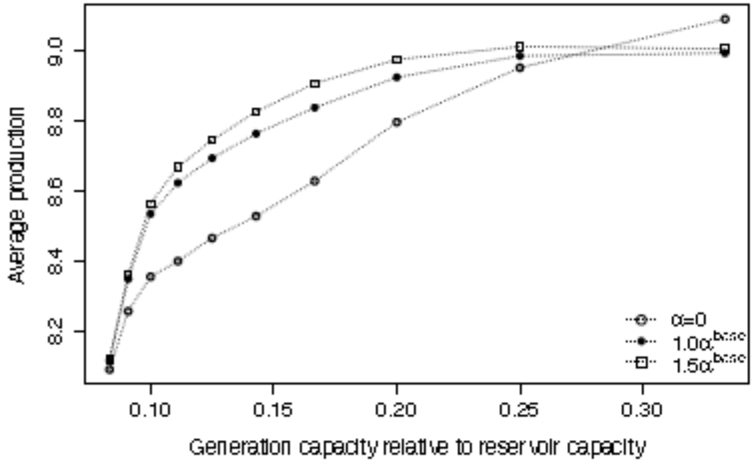
50 percentile
10 percentile
90 percentile
Reservoir volume
Before upgrading
After upgrading
+ 70% gen.cap.
Week



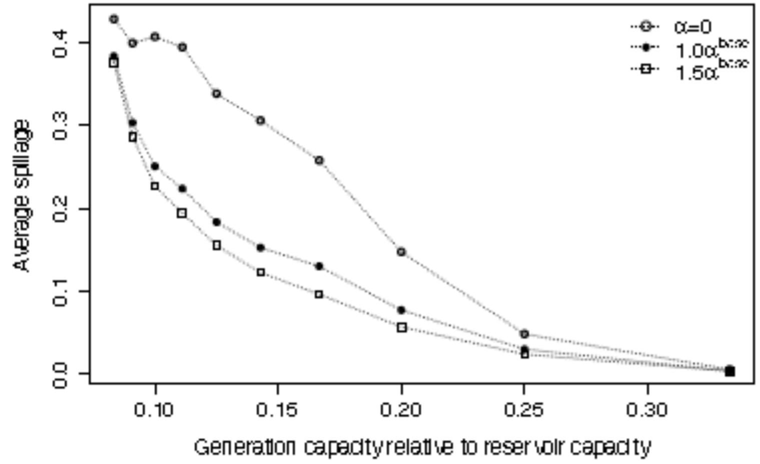
α=0
1.0α base
1.5α base
Wait
Price trigger (EUR/MWh)
Long−term price volatility

Results: Generation and spill

- Total average generation and spill as a function of capacity alternatives.
- The curves are plotted relative to the maximum reservoir capacity.



(a) Average generation.

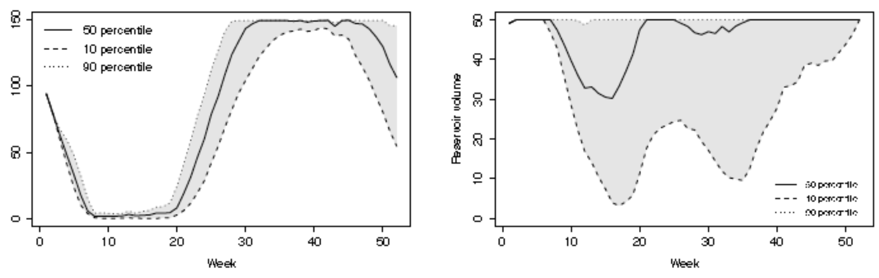


(b) Average spill

- Most of the value of upgrading comes from the ability to exploit within-week price variations

Scalability

- Multiple reservoirs
  - Affects the tactical-operational subproblem
  - Reservoir levels are not discretized
  - Have tested multireservoir cases
    - Reoptimization heuristic is scalable
- Multiple upgrade dimensions
  - F ex increasing generation capacity in several plants
  - Should be doable
- Multiple long-term uncertainty factors
  - No. Requires a complete redesign of the framework



(a) Upstream (b) Downstream

Figure 24: Reservoir management with high capacity and $\alpha - \alpha^{base}$.

Results

- The investment policy and value under different assumptions regarding within week price variations: 0, 1 and 1.5 times the variation the most recent 5 years. Values are reported in million €
- Additional capacity installments are reported as a percentage of current capacity

		$\alpha = 0$	$1.0\alpha^{base}$	$1.5\alpha^{base}$
NPV (no investment)		5 039.7	5 219.0	5 294.8
NPV (investment)		5 231.5	5 711.9	6 009.3
Real options value	$H(q_0, \xi_0)$	5 256.3	5 712.1	6 009.3
Capacity upgrade (invest now)	$u^*(\xi_0)$	71.3%	82.3%	87.6%
Capacity upgrade (at trigger)	$u^*(\xi^*)$	101%	83.7%	80.4%
Price trigger	$\exp(\xi^*)$	93.3 €/MWh	32.0 €/MWh	22.0 €/MWh
Investment probability (10 years)		1.3%	85.0%	100%

Conclusions

- We present an approach for capacity upgrade analysis
  - Capacity affects operational pattern from which the value of the investment originates
  - Investment timing and capacity choice interacts
  - Investment is supported at lower prices when the short-term variability of these prices increases
- Future work: market effects of upgrades
  - Which plant to upgrade?
  - Flexibility value vs aggregate investment