Benchmarking hydro operation by use of a simulator

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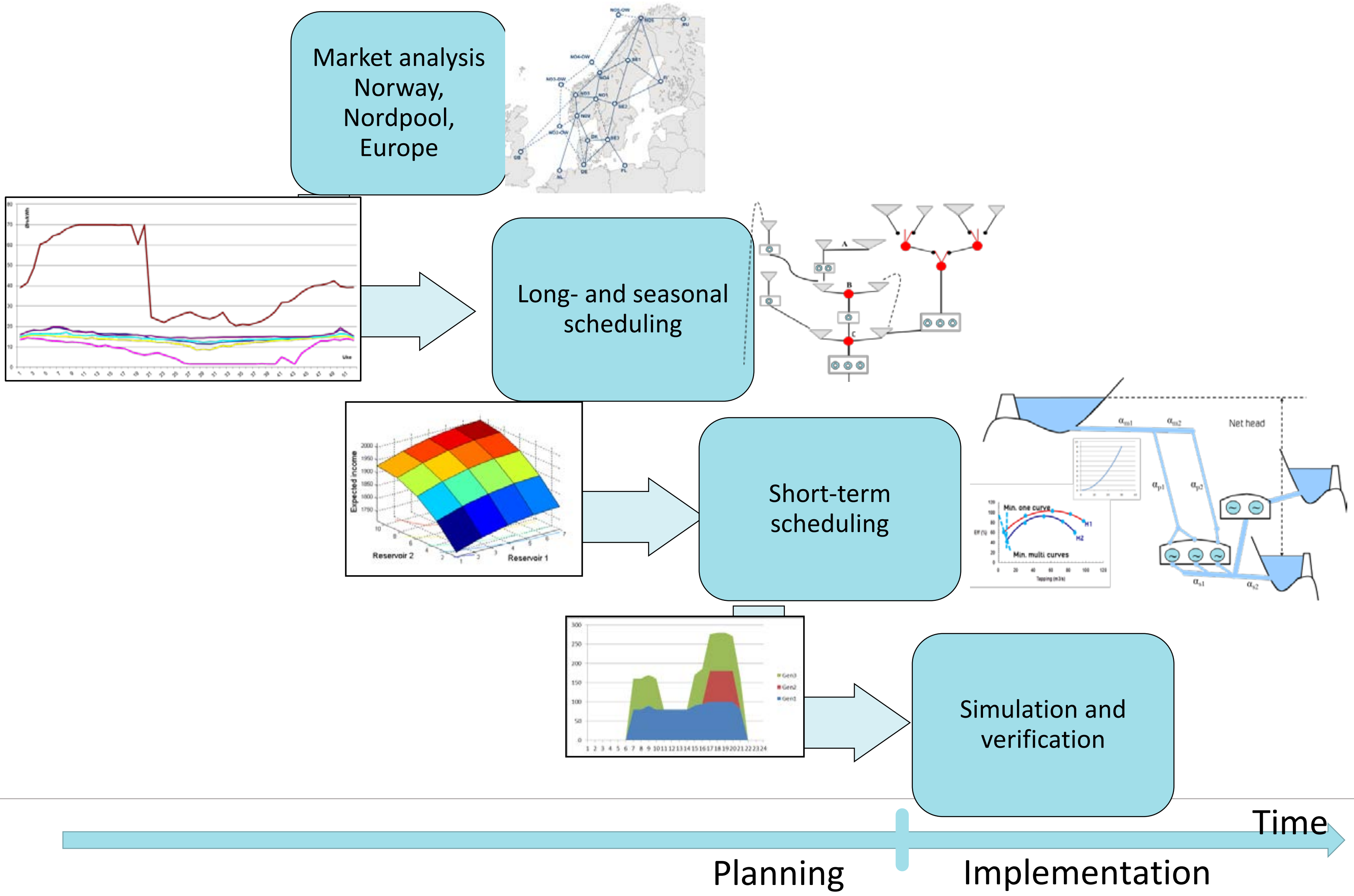
Hydro Scheduling

- Main purpose
  - Supply hourly bids to the spot market for the next day
  - Schedule spot market obligations
  - Supply bids and perform balancing according to obligations

- Complicated for a system with long-term reservoirs
  - Market analysis/price forecasting
  - Long-term hydro scheduling
  - Seasonal scheduling
  - Short-term scheduling

Market and scheduling tasks



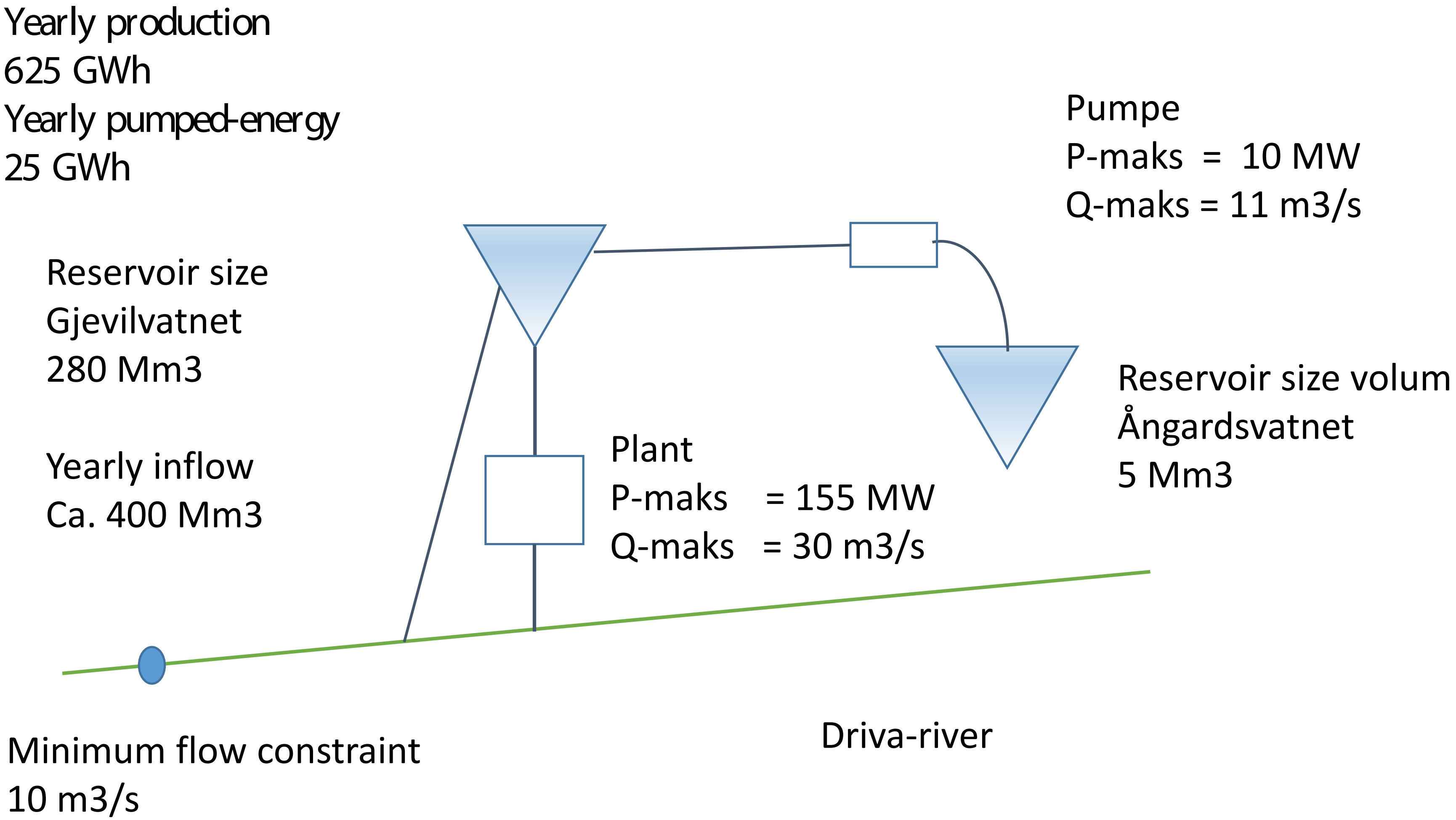
Why do a benchmarking of the production-planning process

- Increasing our own knowledge about benchmarking and later on utilizing the results from this project to create/develop new and better benchmarking methods.
- Management require and expect more precise measurement of performance onwards
- Operating revenue around 400-700 MNOK, hence small increases in performance yield large return!
- A must have to measure effect of changes done in the optimization-process
- A tool used to prioritize among different improvement projects, we are currently using Lean as methods for improvement work within TrønderEnergi AS.
- Contribute to improved internal understanding of the use and value of optimization within hydropower scheduling
- We are currently developing a new set of benchmark's for both short- and long-term optimizations models and processes.

TrønderEnergi's existing hydro scheduling benchmark

- Includes the whole value chain from market analysis to actual production.
- Difficult to evaluate improvements of individual parts of the decision process
  - E.g. price forecasting, inflow forecasting etc.
- Depends on flexibility (Inflow)

Driva- hydropower system



Simulator

- A computer program that simulates TrønderEnergis daily hydro scheduling tasks for the Driva system for the period 2005-2015
- + A simulator of the physical water course

- Implemented in Python and uses APIs to the different hydro scheduling model

- Well suited to teste consequences:
  - Different calculation methods and modelling
  - Value of information (price forecasts, snow storage/long-term inflow forecasts, uncertainty in short-term weather forecasts)

Assumptions

- Historical forecasts (price and snow storage) for the whole benchmarking period
- Actual availability and forecasted availability for the whole period
- Historical production, inflows and prices (spot and futures)

- The simulator uses the same information that was available at each decision stage during the period 2005-2015.

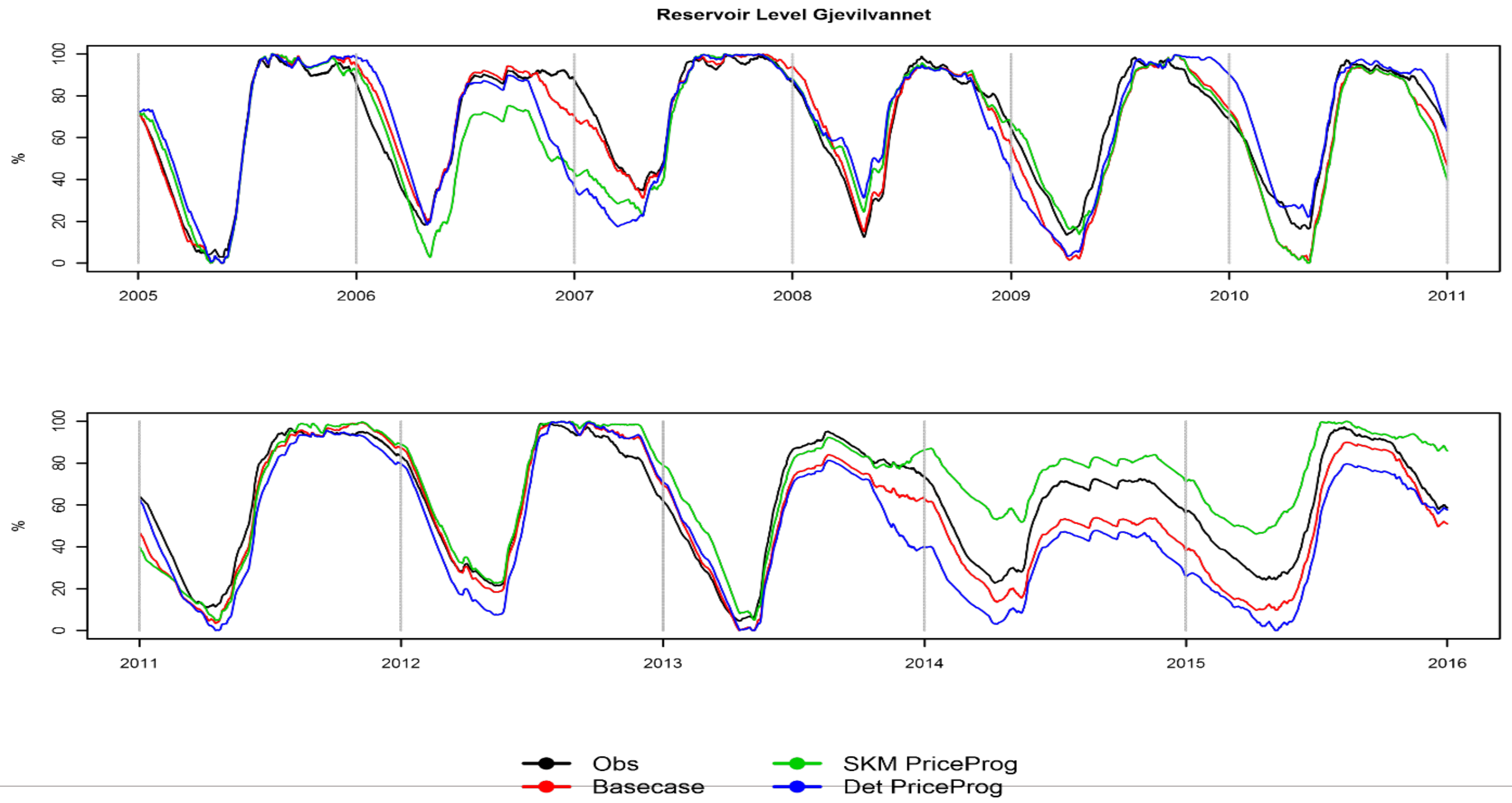
Simulator used for benchmarking

- Compares observed operation with results from simulator for different assumptions
- Calculates income from production, verifies that simulated production is feasible
- Performed tests:
  - Direct use of models, no manual adjustments
  - Different types of long-term price forecasts
    - Based on fundamental models
    - Average corrected to forward market
    - Deterministic with perfect information
  - Different types of long-term inflow forecasts
    - Based on "measured" snow storage
    - No snow storage information
    - "Perfect" snow storage
  - Coupling between medium and short-term model
    - Cuts or constant water values
  - Market price resolution for long and medium term hydro scheduling models

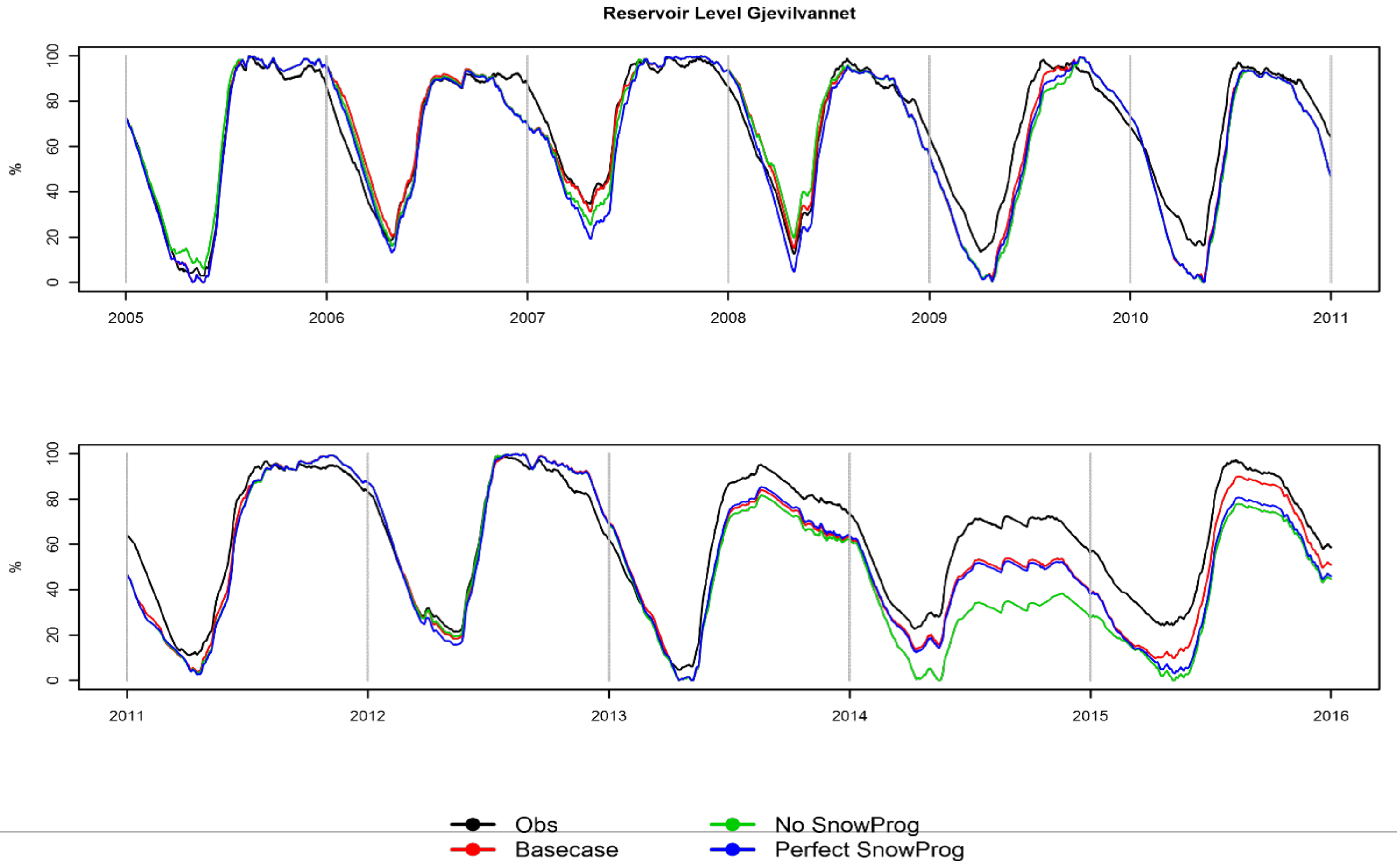
Simulator applied to the Driva system

- Advantages
    - A system with few reservoirs and plants – shorter computation time about 6 hours.
- Challenges
    - Many complex state dependent constraints
    - E.g. discharge constraints dependent on storage levels and previous discharges
    - Important to verify that simulator results with all physical and judicial constraints

Storage in Gjevilvatnet for different market price assumptions

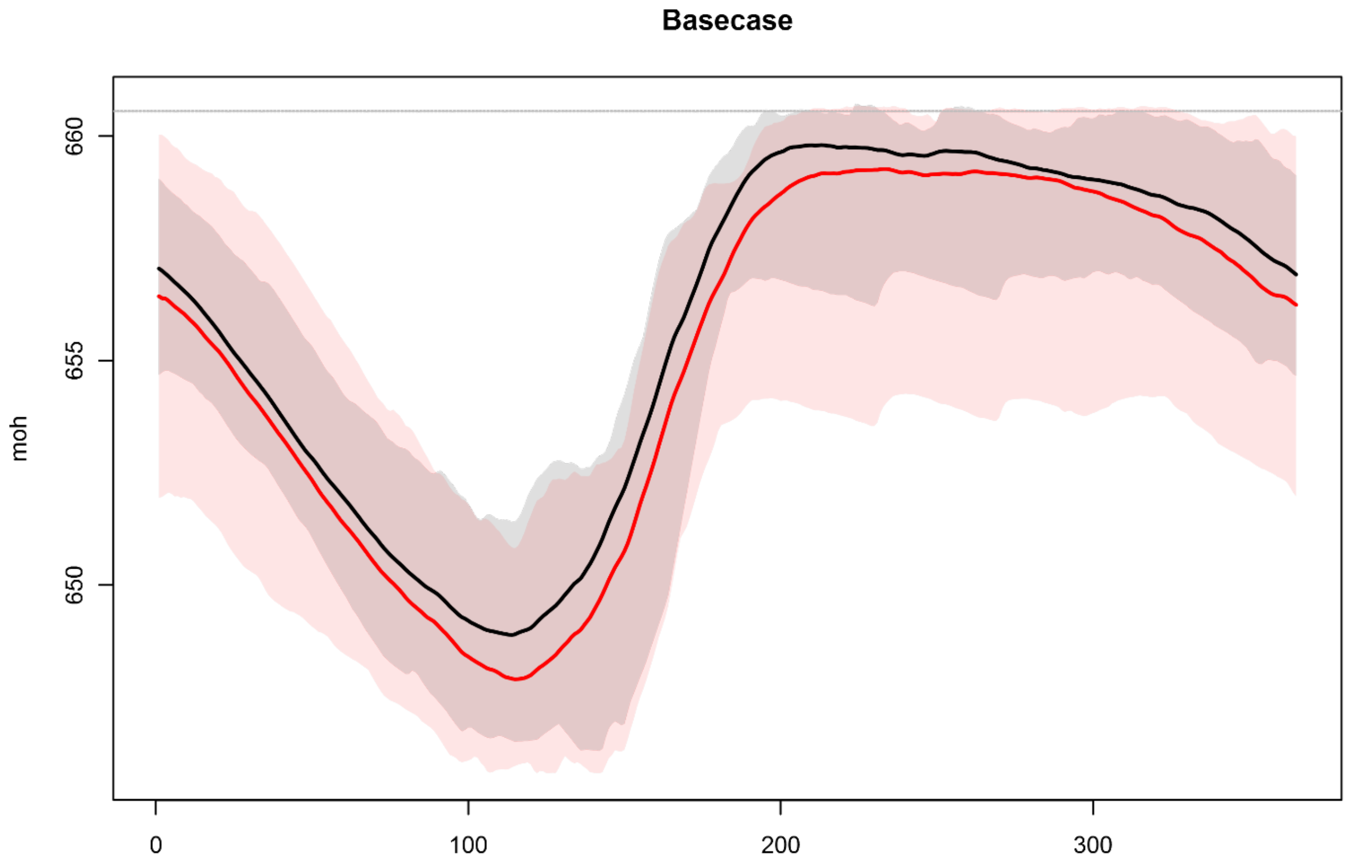


Storage in Gjevilvatnet for different assumptions about snow storage



Reservoir utilization (model and observed)

993



Simulator results (sum 2005-2015)

	Sales income (MEUR)	Value of end storage (MEUR)	Sum (MEUR)
Observed	253.5	3.5	257.0
Base case	259.2	3.0	262.2
Price forecast	255.4	5.1	260.5
Perfect price forecast	267.6	3.4	271.0
No snow	261.1	2.7	263.8
Constant water values	258.6	2.9	261.5
Increased market resolution– perfect price	267.4	3.4	270.8

Yearly results for two cases

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Tot
Observed	19.9 (11.2) [335.8]	24.6 (10.2) [342]	21.3 (14.3) [337.8]	34.9 (10.5) [251.4]	18.8 (11.2) [268]	34.8 (21.4) [251.8]	29.3 (10.9) [325.9]	24.8 (8) [242.4]	19.5 (8.2) [286.3]	14.4 (6.4) [221.4]	11.2 (3.5) [229.9]	253.5
Base case	18.5 (12.3) [369]	29.6 (8.1) [274.6]	18.1 (15.5) [365.8]	36.9 (9.1) [218]	17.5 (12) [285.3]	41.6 (15.5) [181.9]	25.2 (11.4) [339.4]	24.3 (9) [270.6]	22.7 (7) [244.3]	14.5 (4.3) [149.5]	10.3 (3) [198.5]	259.2

- Historical income 253,5 MEUR
- Model result 259,2 MEUR

2,2 % higher

- Including efficiency deviation ca. 3 %!!!
- Assuming same difference for all of TrønderEnergis hydro plants, yearly improvement 10-15 MNOK.

TrønderEnergi's conclusion

- Remaining improvement potential using out-of-the box functionality in the software used within the simulator is still significant
- Quite surprising results from scenarios related to inflow/snow-pack input. Uncertain if this is a effect of certain year's with very special combination of high summer prices in combination with expected high inflow during the summer.
- Certain effects in how to structure price-input not as significant as first expected.

Gains from the project

- Experience from such projects makes it easier to make operational KPI’s that capture the effects that are wanted. Hence less explaining of deviation in the KPI’s from desired/planned goals.
- Model results used in developing KPI’s for the optimization process within TrønderEnergi AS.
- Previously assumption within the organization about upper-bounds one the potential within how well the optimization actually can be done is reconsidered