2015
Workshop on Hydro Scheduling in Competitive Electricity Markets

THE VALUE OF STOCHASTIC SHORT-TERM SCHEDULING

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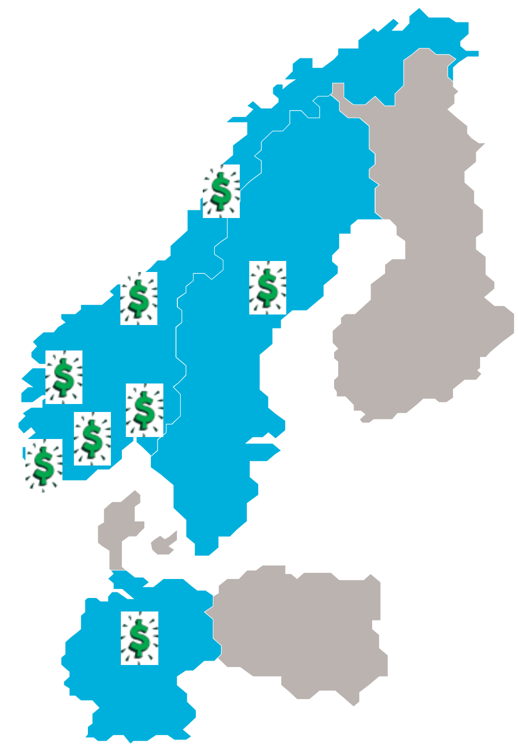
Introduction

- Statkraft has been using SHOP as an operative tool since 2008
  - Input to the daily short-term bidding and planning
  - SHOP = **S**hort-term **H**ydro **O**ptimization **P**rogram
    - Developed by SINTEF
    - Algorithm: Sequential Mixed Integer Linear Programming (deterministic optimization)
- Our use of SHOP has gradually increased
  - About 80 users in Norway, Sweden and Germany
  - Models of 40 watercourses, with 132 plants and 196 reservoirs

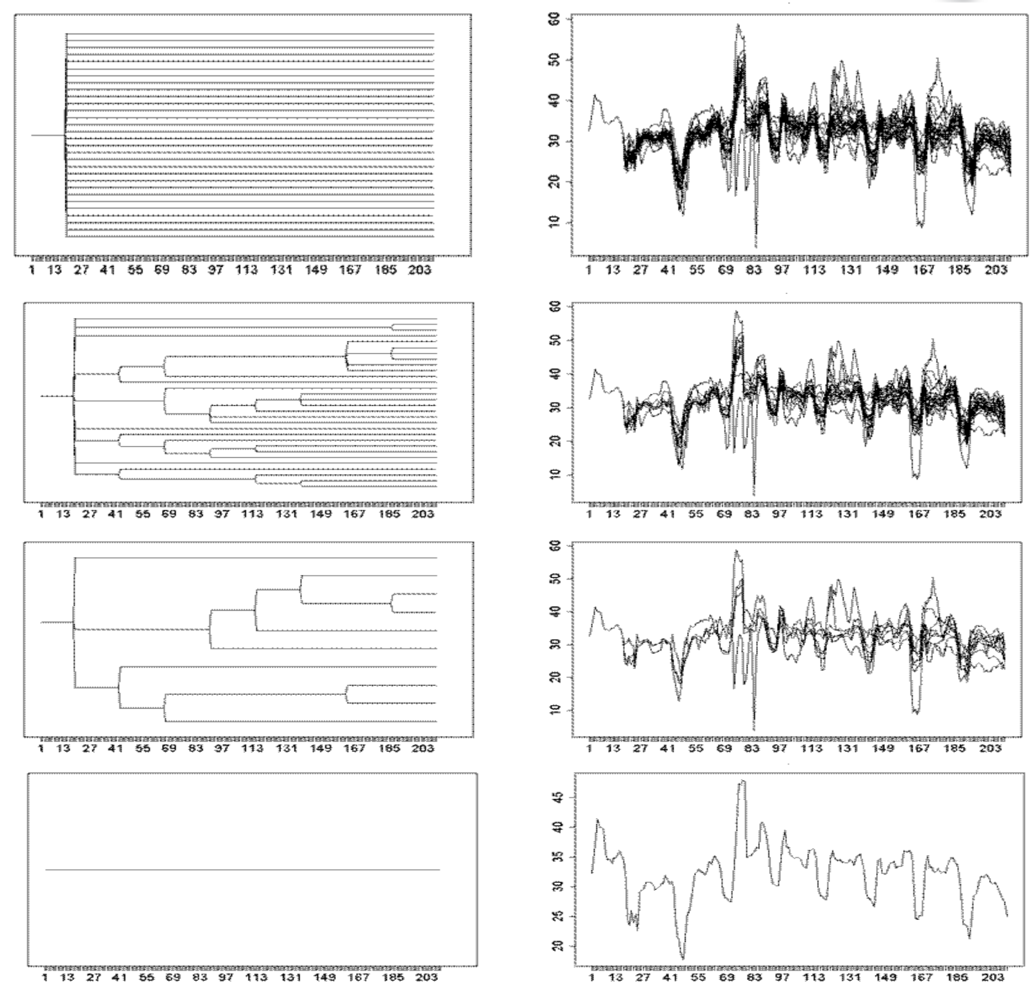


Background

- A stochastic short-term optimization model has been developed (SHARM)
- Developed by SINTEF in cooperation with 5 Norwegian power companies
- 2 projects
  - 2009-13: Prototype development. Presented at the conference in Bergen 2012
  - 2013-15: Evaluate the utility value (benefit) of stochastic short-term optimization
- This presentation shows the latest results of the evaluation in Statkraft

The SHARM-model

- SHARM is an expansion of the SHOP-model
- Both price and/or inflow can be modelled as stochastic inputs
- The uncertainty is represented by a scenario tree
  - Separate application for converting ensemble forecasts into scenario-trees with a user-defined branching
- Status SHARM
  - The SHARM-functionality is now implemented in SHOP
  - Will refer to SHARM as the stochastic SHOP



Utility value

- The primary goal of the project has been
  to estimate the utility value (economical benefit)
  of using stochastic short-term optimization instead of deterministic
- Typical questions we would like to answer are:
  - How much can modelling of uncertainty reduce the consequences of a bad forecast?
  - What is the pure value of stochastic optimization?
  - How much better (or worse) can the forecasting get?
  - How much does the calculation time increase when the tree size increase?
  - What is a good trade-off between increased calculation time and increased benefit?

Main challenge: Methodology

- Challenge
  Find a methodology suited for calculating the <u>incremental</u> benefit of modelling uncertainty
- Solution
  Use SHARM to calculate the value of different solutions made with different stochastic and deterministic representations of price and inflow
- Small differences
  - Needs high exactness => Puts SHARM to an ultimate test
- We have put much effort into
  - Tuning the methodology
  - Revealing errors and weaknesses in SHOP/SHARM
  - Developing an Excel-tool for automatic multi-run of SHARM

Proposed methodology

1. Plan calculations

- SHARM is run for different scenarios of price and inflow, both stochastic and deterministic variants
- The resulting plan for the next day of each scenario represents the decision that would be made using the corresponding price or inflow as a forecast

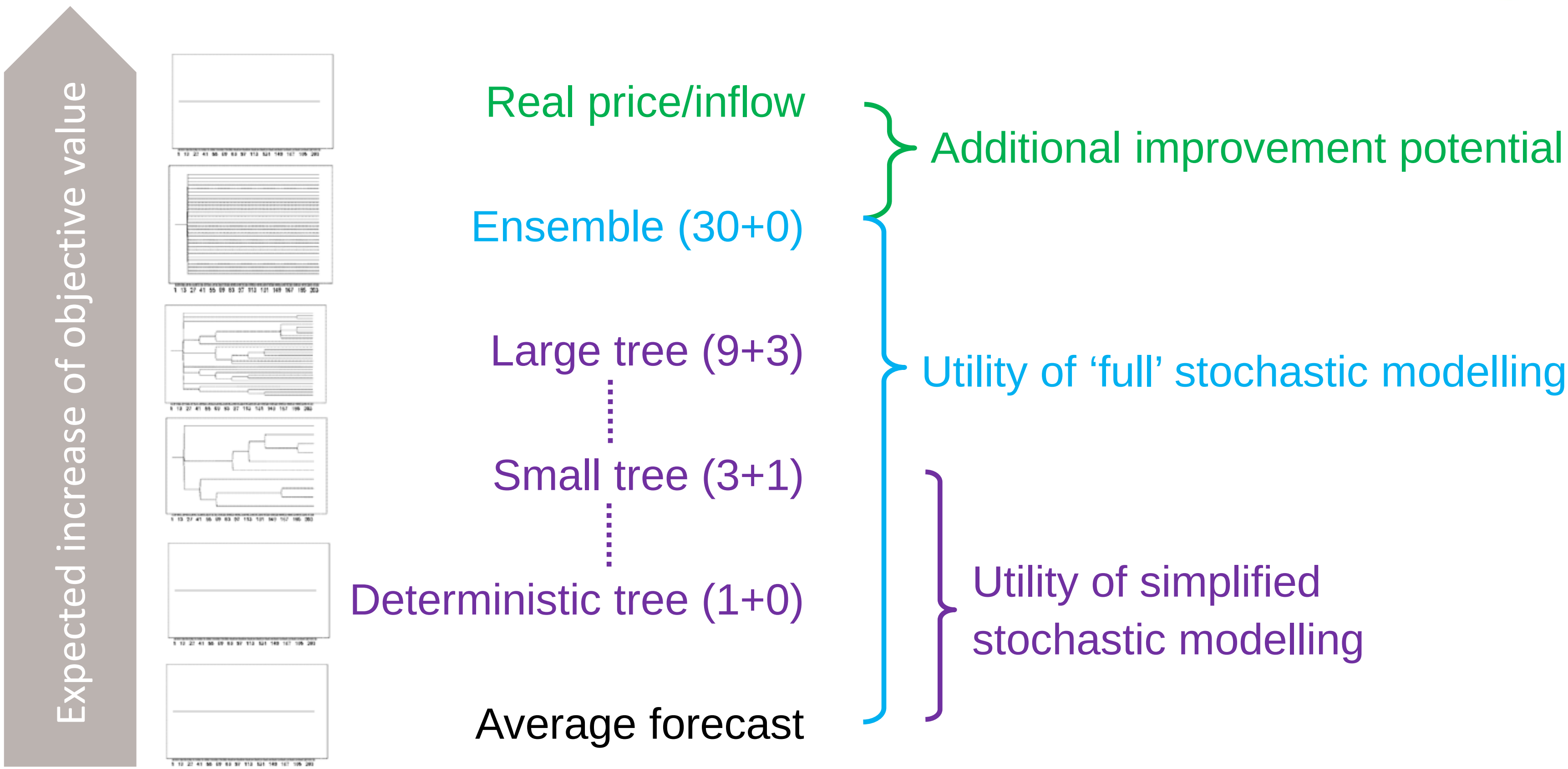
2. Value calculations

- The plan of each scenario is converted to a load requirement
- SHARM is run again twice for all scenarios (with the load requirement) for both:
  - the full ensemble
  - the real price/inflow
- The objective functions now represent the value of each plan/load decision

3. Utility calculations

- The differences in objective values give the relative utility values
- This method should give the utility value of
  - stochastic modelling
  - with and without influence of the forecast quality
  - for one single day
  - applied to 'price dependent bidding'

Calculating utility values



Nomenclature: 30+0 = 30 branches fist day, 0 new branches each day

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Analysis details

- One selected river system with high expected profit
  - A single plant with low discharge capacity
- Analysed for 12 random days of the past year, one day in each month
- Based on forecast ensembles with 30 scenarios (both for price and inflow)
  - Inflow with daily resolution, price with hourly resolution
- Price and inflow are analysed independently, not combined
- Optimization has 8 days horizon with stochastics
  - Stochastics starts next day (the day of planning)
  - Common plan requirement in the optimization
- MIP is not used

Inflow results - ensemble as reference*

Value of plan compared to ensemble (30+0)	[€/day]
Tree 30+0	-
Tree 9+3	-29
Tree 9+2	-16
Tree 9+1	-71
Tree 9+0	-60
Tree 5+3	-18
Tree 5+2	-38
Tree 5+1	-47
Tree 5+0	-78
Tree 3+3	-3
Tree 3+2	-52
Tree 3+1	-51
Tree 3+0	-87
Tree 1+3	-24
Tree 1+2	-46
Tree 1+1	-49
Tree 1+0	-123
Random	-282
Average	-180

- Increased branching 1. day improves the benefit
- Increased branching per day improves the benefit
- All variants of stochastic modelling are better than all variants of deterministic modelling!
- The deterministic equivalent (Tree1+0) is the best deterministic variant
- The random scenario gives the lowest benefit of the deterministic variants
- The value of full stochastic modelling compared to the deterministic average is 180 €/day (0,3% of the load value)

* Measures the pure benefit of stochastic optimization (with "perfect" knowledge of uncertainty)

Inflow results - real inflow as reference*

	Value of plan compared to real inflow [€/day]
Real inflow	-
Tree 30+0	-5 808
Tree 9+3	-6 208
Tree 9+2	-5 986
Tree 9+1	-6 479
Tree 9+0	-6 424
Tree 5+3	-6 078
Tree 5+2	-6 308
Tree 5+1	-6 355
Tree 5+0	-6 601
Tree 3+3	-5 696
Tree 3+2	-6 368
Tree 3+1	-6 204
Tree 3+0	-6 486
Tree 1+3	-5 495
Tree 1+2	-6 433
Tree 1+1	-6 300
Tree 1+0	-7 079
Random	-5 568
Average	-7 334

- No clear improvement with increased branching
  - The best tree is with branching 1+3
  - This is due to the tree construction algorithm
- The random scenario is the best deterministic variant
  - Even better than the full tree
  - This is due to luck in a few dominant analyses
- All variants of stochastic modelling are better than the deterministic equivalent (1+0) and the deterministic average
  - Stochastic modelling reduces the effect of bad forecasting!
- The value of full stochastic modelling compared to the deterministic average is ≈ 1500 €/day (2,6% of the load value)
- Even with full stochastic modelling the improvement potential of inflow forecasting is ≈5800 €/day

* Measures the benefit of stochastic optimization including the quality of the forecast model

Price results - ensemble as reference*

	Value of plan compared to ensemble (30+0) [€/day]
Tree 30+0	-
Tree 9+3	-7
Tree 9+2	-8
Tree 9+1	-13
Tree 9+0	-12
Tree 5+3	-18
Tree 5+2	-18
Tree 5+1	-19
Tree 5+0	-12
Tree 3+3	-17
Tree 3+2	-21
Tree 3+1	-22
Tree 3+0	-6
Tree 1+3	-15
Tree 1+2	-24
Tree 1+1	-17
Tree 1+0	-20
Random	-300
Average	-6

- All stochastic variants have small utility values, and has no significant variation with different branching
- A random scenario of the ensemble is much worse than all other variants
- The deterministic equivalent (1+0) and the average are equal to using stochastic equivalents
  - There is no value stochastic optimization!

* Measures the pure benefit of stochastic optimization (with "perfect" knowledge of uncertainty)

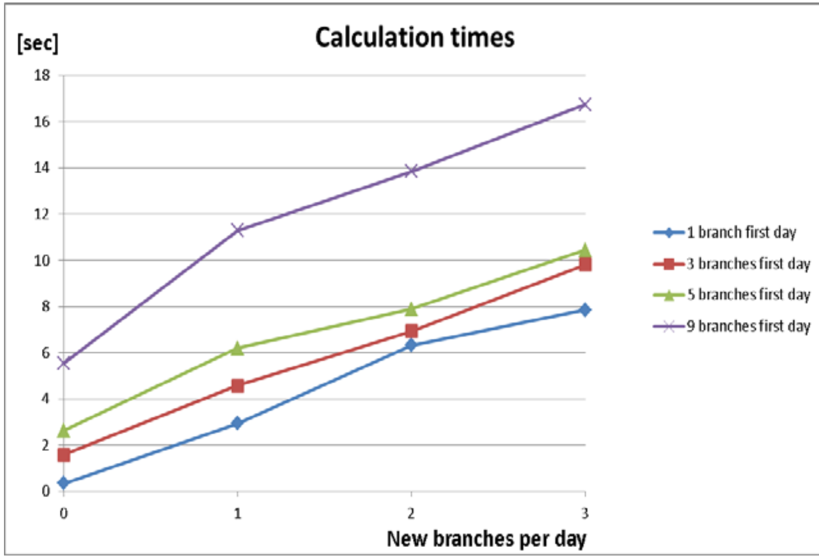
Price results - real price as reference*

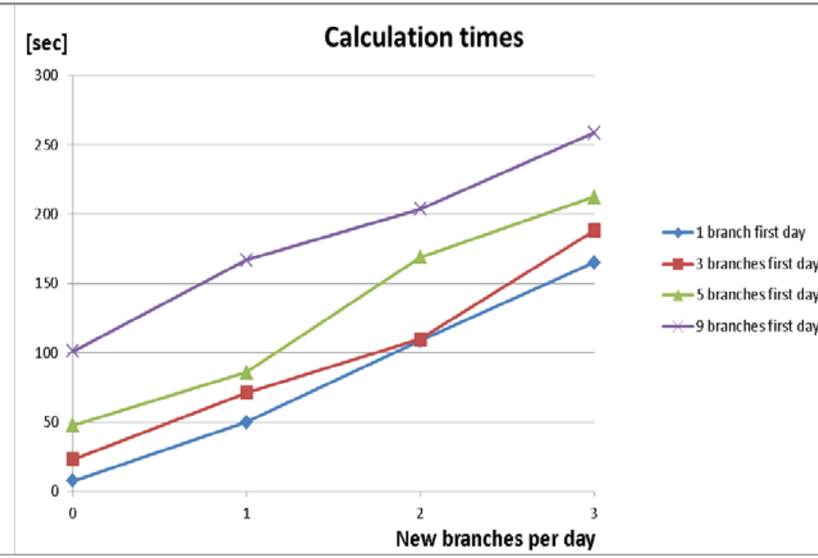
	Value of plan compared to real price [€/day]
Real price	-
Tree 30+0	-46
Tree 9+3	-45
Tree 9+2	-45
Tree 9+1	-92
Tree 9+0	-89
Tree 5+3	-74
Tree 5+2	-92
Tree 5+1	-74
Tree 5+0	-82
Tree 3+3	-54
Tree 3+2	-77
Tree 3+1	-84
Tree 3+0	-79
Tree 1+3	-55
Tree 1+2	-51
Tree 1+1	-64
Tree 1+0	-94
Random	-623
Average	-85

- Again small utility values with no significant variation of different branching
  - A weak suggestion that increased branching per day improves the utility value
- The random scenario is still much worse than all other variants
- The value of full stochastic modelling compared to the deterministic average is ≈40 €/day
  - The consequences of a bad forecast has little improvement
- With full stochastic modelling the improvement potential of inflow forecasting is only ≈50 €/day
  - The forecast model is good

* Measures the benefit of stochastic optimization including the quality of the forecast model

Calculation times





- The calculation time increases almost linearly
  - with the number of new branches per day
  - with the number of branches first day

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Conclusions

- Stochastic optimization in SHOP is working!
  - Stochastic modelling can reduce the effect of bad forecasting
  - Stochastic modelling of price seems to unnecessary (in this case)
  - The tree size seems to be of little importance
  - SHOP is pretty accurate (despite the successive linearization)

- Still some concerns
  - Calculation times increases fast with branching (even without MIP)
  - Simple analysis: One river system, only 12 days
  - The results are only valid for price dependent bidding
  - Still some unsolved inconsistencies in other analyses
- More testing is recommended
  - Other topologies
  - On real areas of use (not price dependent bidding)
  - With combined and correlated price and inflow

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SHARM results