Bidding hydropower into short-term markets

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Messages

- Optimization is useful in describing and supporting bidding operations

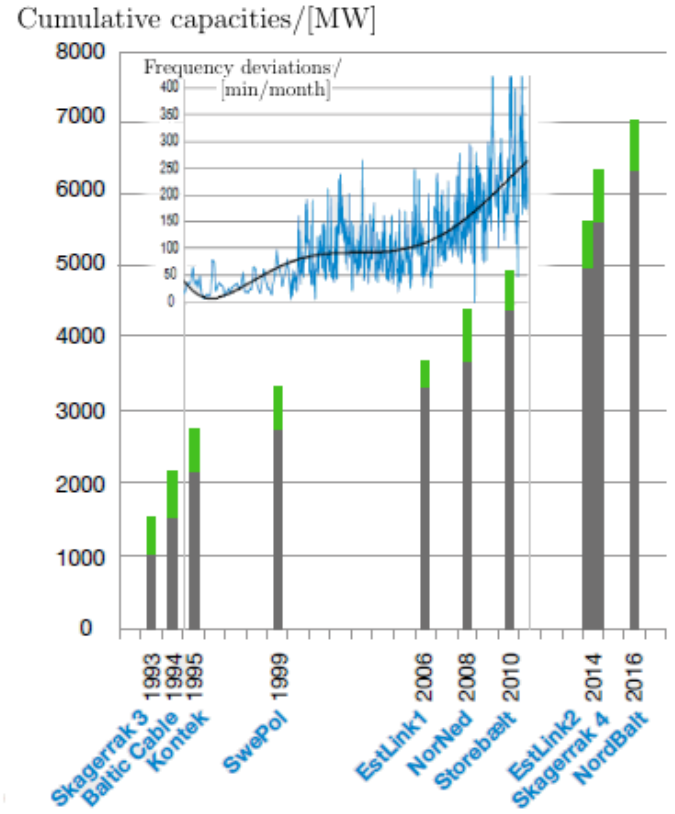
- Coordinated bidding (taking shorter term markets into account)
  - Size of coordination gains
  - If you are willing to break the rules: large
  - Higher model complexity

Where to feed the power?

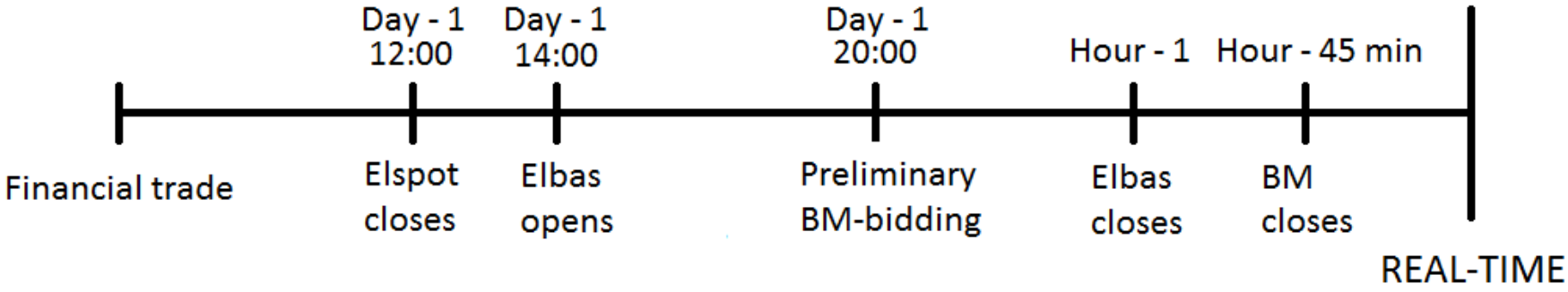
- European power producers are free to sell the power in various channels
  - Bilateral contracts (direct sales)
  - Day-Ahead auction
  - Intraday trading
  - Balancing market (up/down ramping on x minute notice)
  - Reserve markets (frequency support)

Where to feed the power?

- Nordic intraday market (Elbas) is small
  - ~0.1% of spot turnover
- Norwegian Balancing market (BM)
  - ~2% of spot turnover
- Intraday trading is increasing
  - Larger shares of non-flexible renewables
  - More interconnectors



Interconnection capacities (bars) and frequency deviations (line). Source: Statnett.



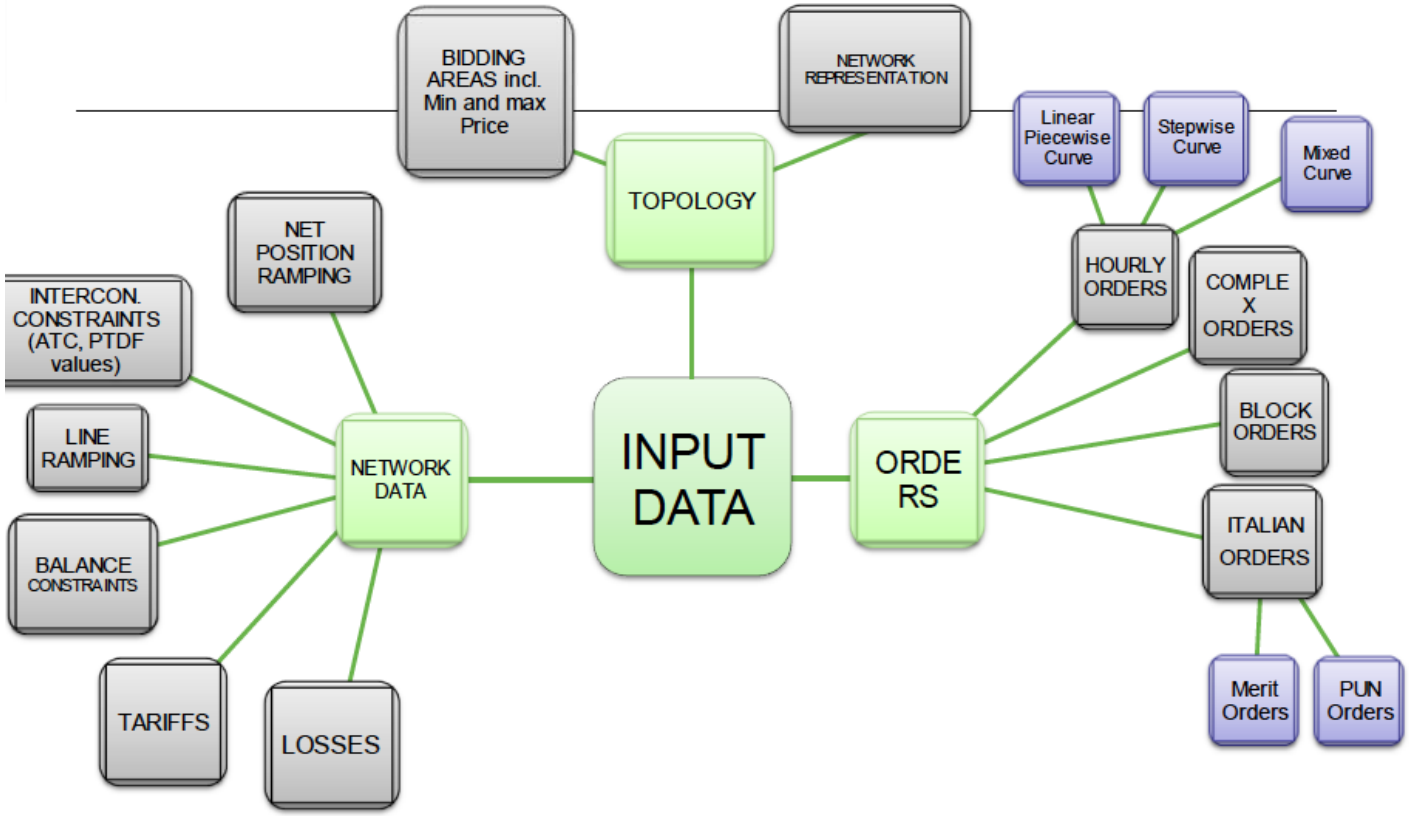
NTNU

Hydropower bidding problem

- Determine bids in (European) day-ahead auction
- Maximize future profit
- Hydropower reservoirs are capable of storing energy
- Account for intraday/balancing trading?
  - Boomsma, Juul and F. (2014) , Faria and F. (2011), Klæboe, Braathen, Eriksrud, F. (2015)
- System Operator requires unbiased spot bidding, i.e., expected deviations from spot market commitment should equal zero
- The market prices and inflows are uncertain
- Studied in detail in F. and Kristoffersen (2007)

Day-ahead auction: EUPHEMIA

- Which type of bid to use?



Day-ahead market bidding

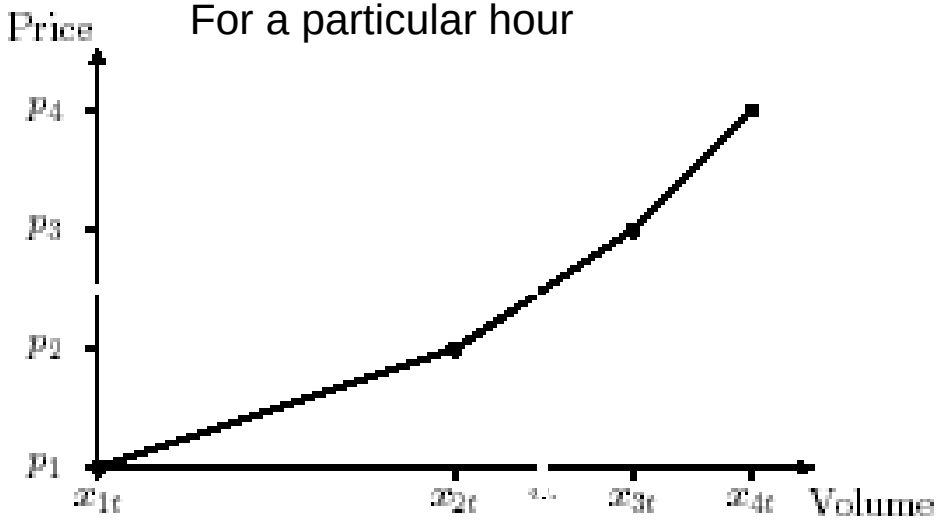
- Hourly bids: prices and volumes
  - Piecewise linear
  - Submit a table
  - 64 price points allowed

Bidder: Storfossen AB
Week no.: 40/95
Price area: C

Hour From - To	Price									
	0	100	101	150	151	170	171	200	201	900
1 - 6	50	50	20	10	0	0	-10	-20	-30	-30
7	80		80		30	0	-20	-30	-30	-20
8	80			80	50	0	-20	-20	-30	-30
9	80			80	70	0	-20	-20	-30	-30
10	80				80	0	-10	-10	-30	-30
11-16	100	100	100	100	80	0	-10	-10	-30	-30
17	80	70	70	60	50	0	-20	-30	-30	-30
18	80	70	69	20	19	0	-20	-20	-30	-30
19	80	70	60	40	0	0	-20	-20	-30	-30
20	80	70	40	30	0	0	-20	-20	-30	-30
21	70	70	30	20	0	0	-20	-20	-30	-30
22-14	50	50	20	10	0	0	-10	-20	-30	-30

Shading indicates 80 MW

For a particular hour



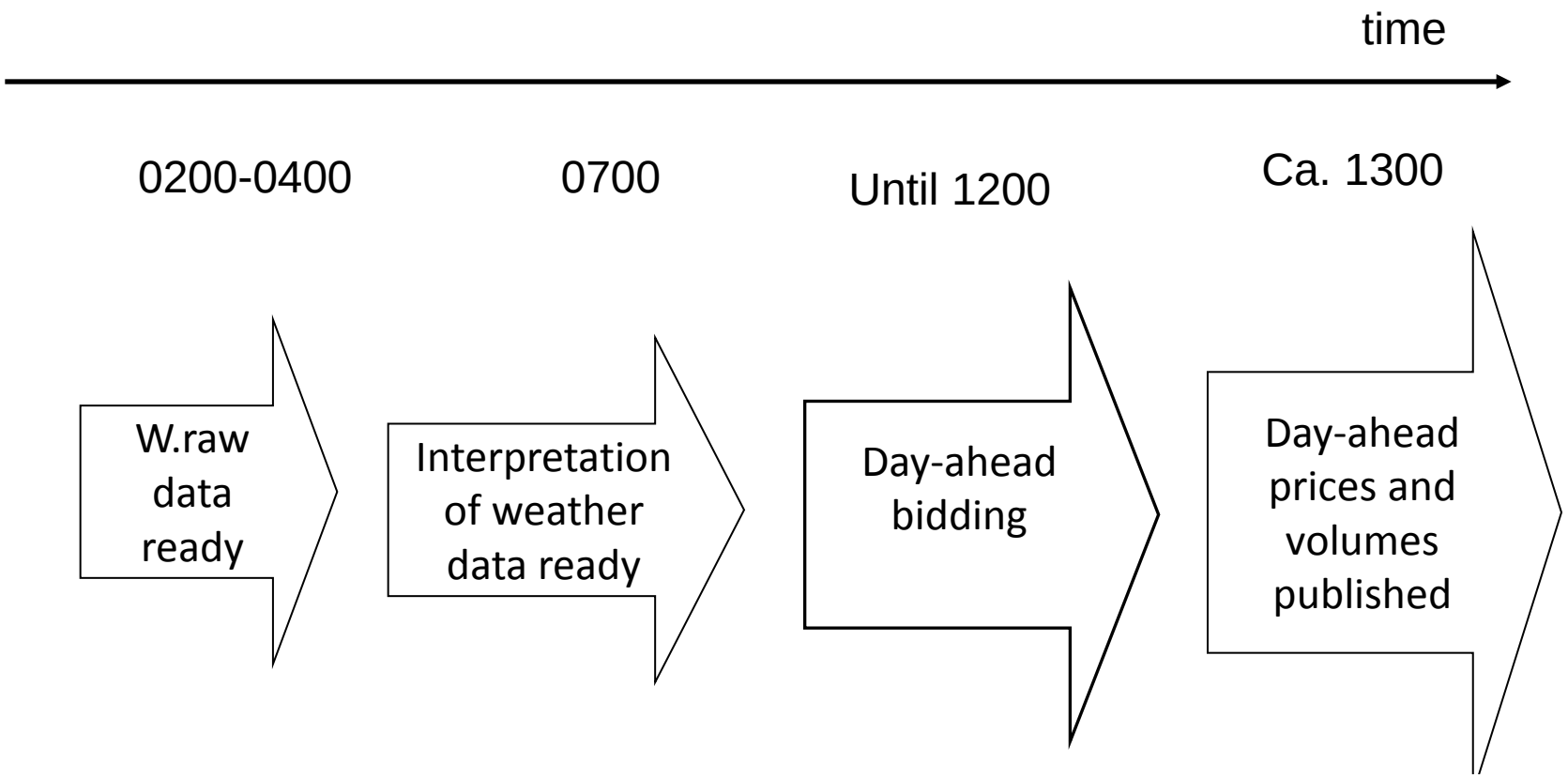
After market clearing calculations, announces ρ_t

- y_t given

$$y_{sh} = \frac{\rho_{sh} - P_{i-1}}{P_i - P_{i-1}} x_{ih} + \frac{P_i - \rho_{sh}}{P_i - P_{i-1}} x_{i-1h}$$

$$P_{i-1} \leq \rho_{sh} \leq P_i, \qquad h \in H,\ i \in I.$$

Information structure



Major weather forecast every morning,
Inflow forecasting model updated up to every hour

Information structure

$x_t =$

	Spot prices first day	Inflow hour t	Inflow hour t	Inflow and spot price hour t	Inflow and spot price hour t
Spot market bidding decisions first day	Spot market commitments first day	Unit commitment, discharges, imbalances, spill hour t	Unit commitment, discharges, imbalances, spil hour t	Spot market commitment, unit commitment, discharges, imbalances, spill hour t	Spot market commitment, unit commitment, discharges, imbalances, spill hour t

Natural stage structure

Main model elements

$$y_{sh} = \frac{\rho_{sh} - P_{i-1}}{P_i - P_{i-1}} x_{ih} + \frac{P_i - \rho_{sh}}{P_i - P_{i-1}} x_{i-1h}$$
$$P_{i-1} \leq \rho_{sh} \leq P_i, \qquad h \in H,\, i \in I.$$

Bidding

$$x_{hi} \leq x_{hi+1}$$

$$\sum_{r \in R} w_{srh} - y_{sh} + z^+_{sh} - z^-_{sh} = 0, \quad s \in S,\, h \in H.$$

Tying day-ahead commitment to production

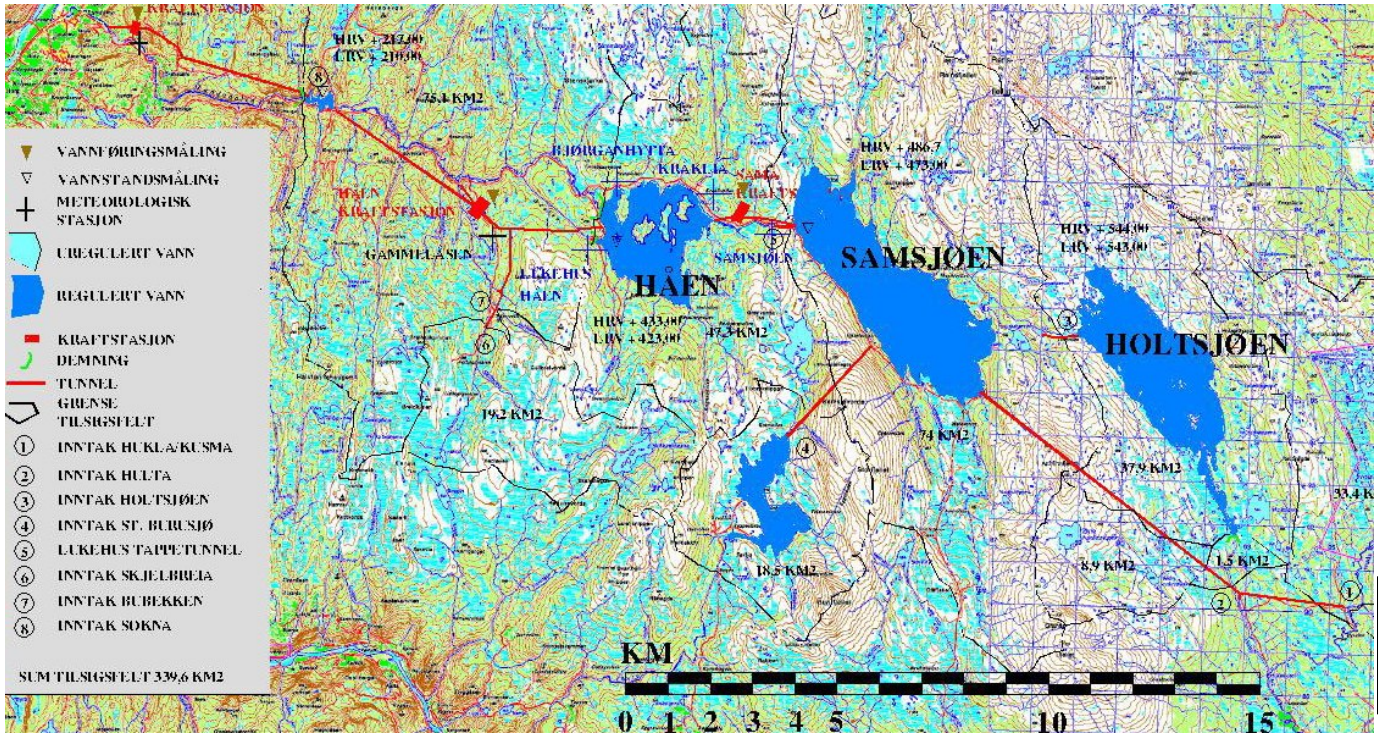
$$\max \sum_{s \in S} \pi_s \left(\sum_{h \in H} \rho_{sh} y_{sh} + m_s \right.$$
$$\left. -G \sum_{h \in H} (z^+_{sh} + z^-_{sh}) - \sum_{h \in H} \sum_{j \in J} S_j d_{shj} \right)$$

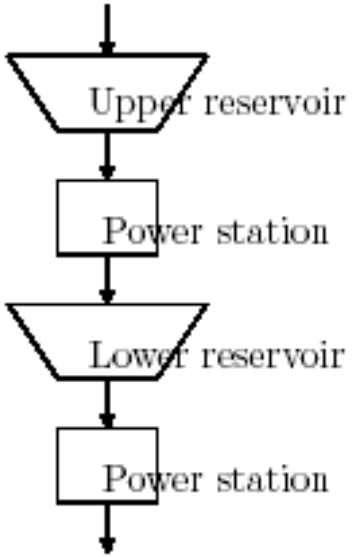
Objective

Plus hydropower constraints

Power plant case 1: Lundesokna

- Owner: TrønderEnergi. Thanks to L.O. Hoset and colleagues, and to Fosso/Belsnes at NTNU
- 278 GWh per year, 61 MW capacity
- 136 GWh storage, two main reservoirs
- Fleten & Kristoffersen (2007, 2008), modelling block bids etc.



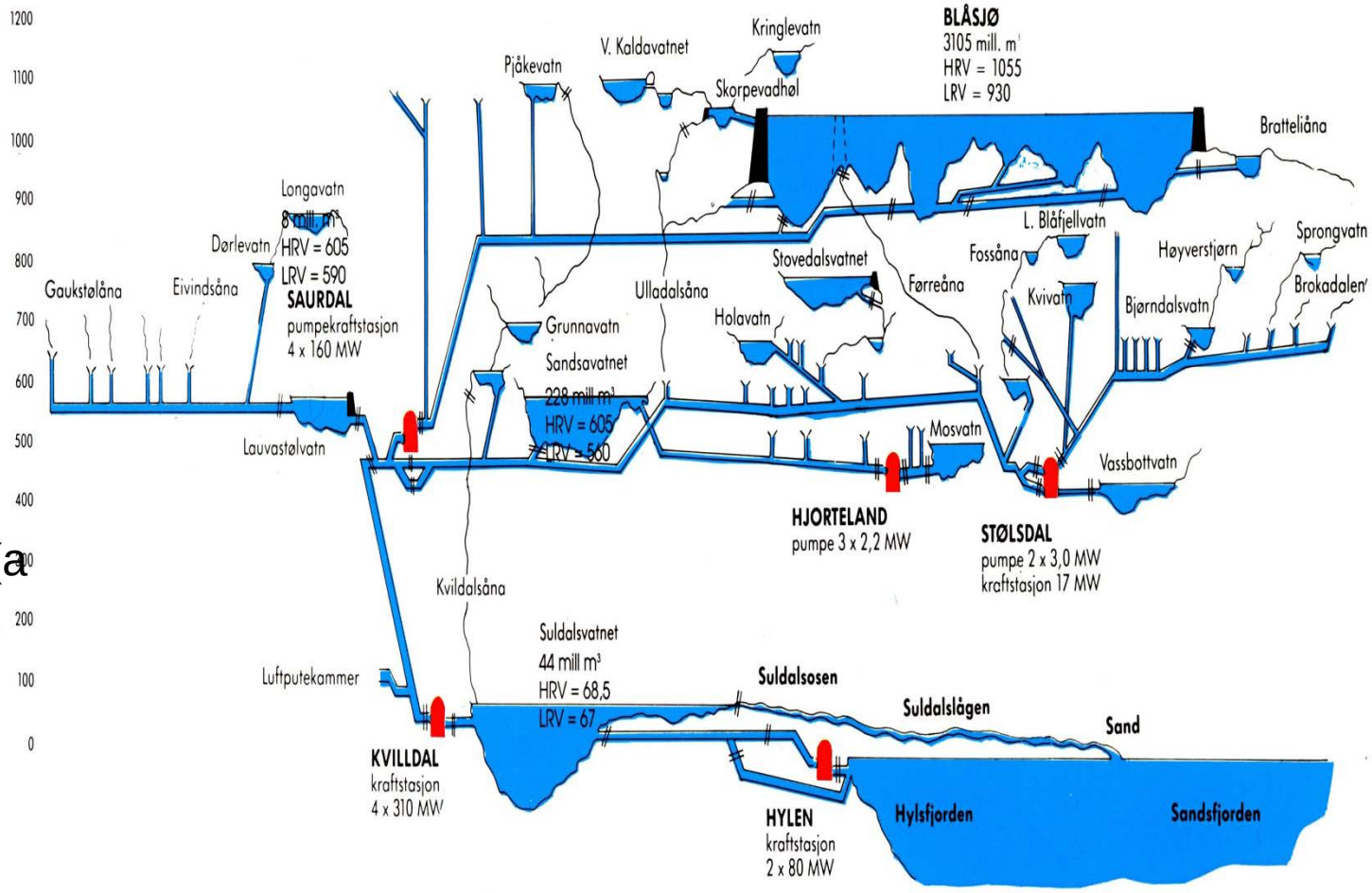


TRØNDERENERGI

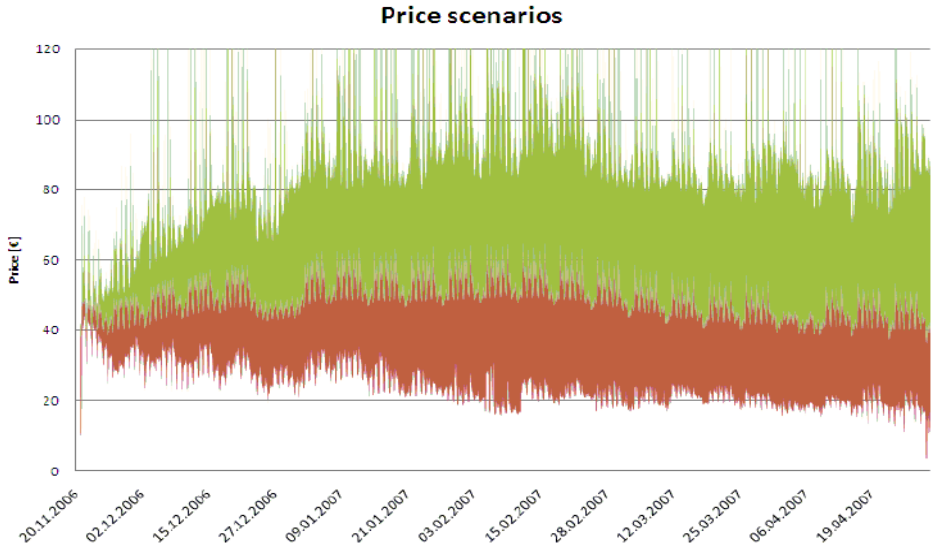
Lundesokna

Case 2: Ulla-Førre

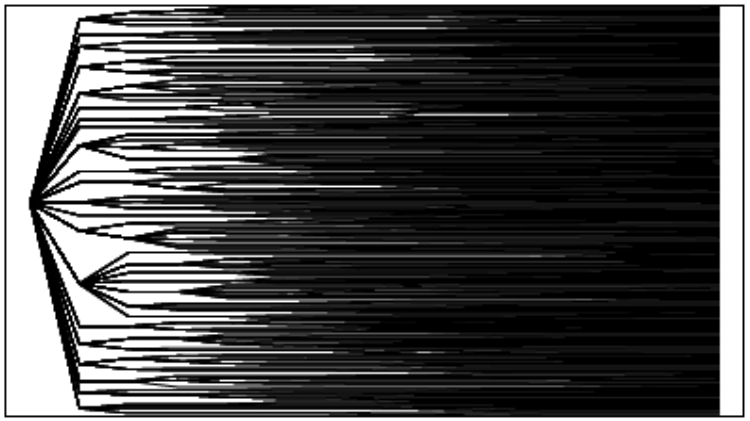
- Two-stage
- First stage: spot price and inflow unknown, decide on bidding
- Second stage: hydropower generation
- Linear approximation of unit commitment (a la C. Weber (2004))
- Lumb & Weiss (2006)



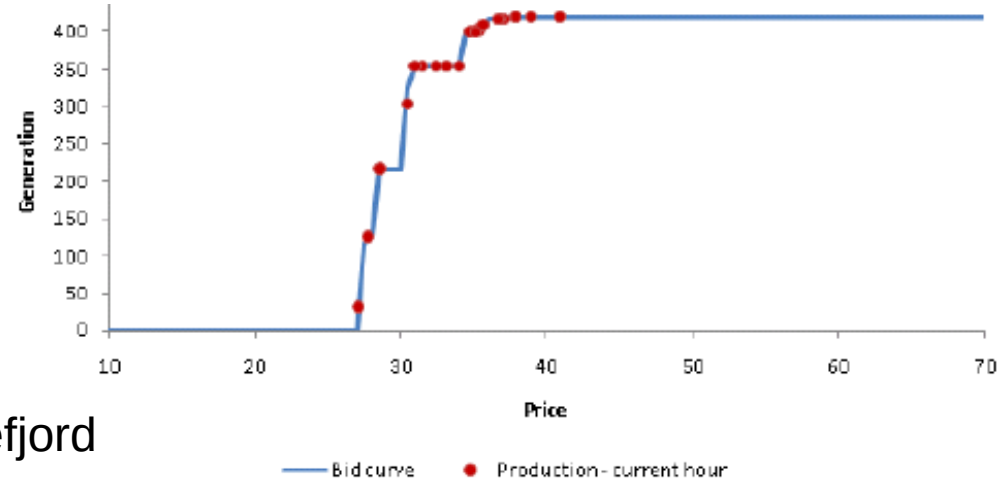
Case 3: Røssåga



Price and inflow scenario tree using scenario reduction

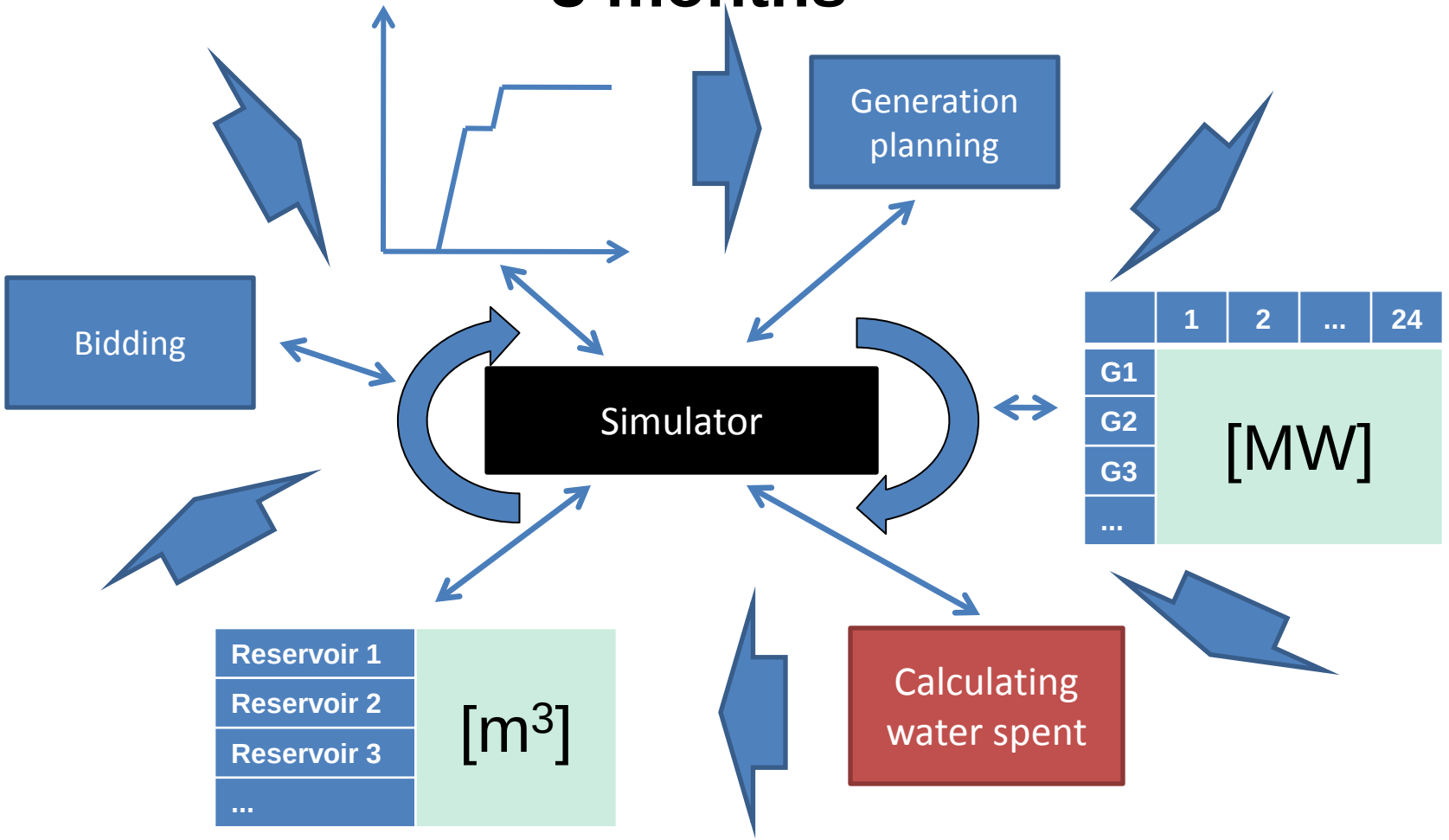


Steinsbø (2008)
Resulting bid curve



Thanks to Statkraft esp. L. Holmefjord

Simulation model – validating the optimization model by running Røssåga over 3 months



Simulated generation pattern

Three month period beginning of 2006

Both simulated and actual production near max

Challenge: Keeping lower reservoir within limits

- New model does well
- Lowers production weekends instead of night

Runtime optimization: ca. 3 minutes

Deterministic equivalent using XPRESS 64 bit on a 2.60 GHz dual-core AMD Opteron® processor and 8 GB of RAM

Runtime simulation: 8.4 hours

Same spillage risk as in reality

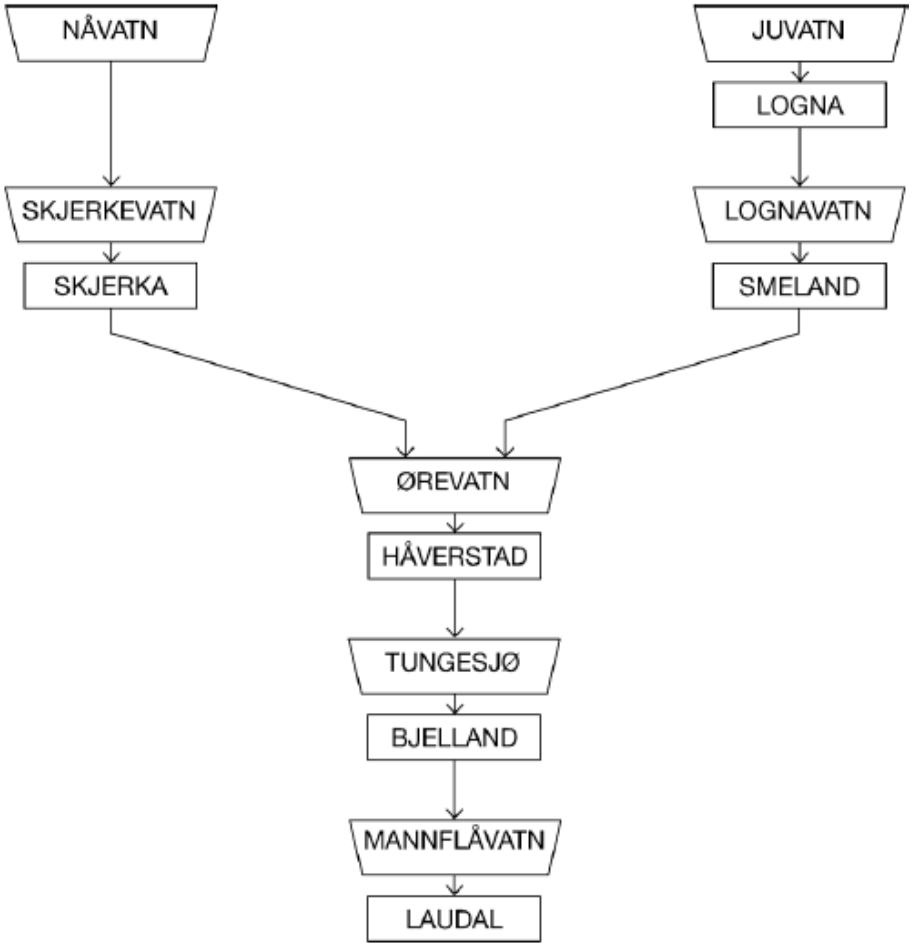
Simulation indicates a possible small benefit

- Reproducing identical information is impossible

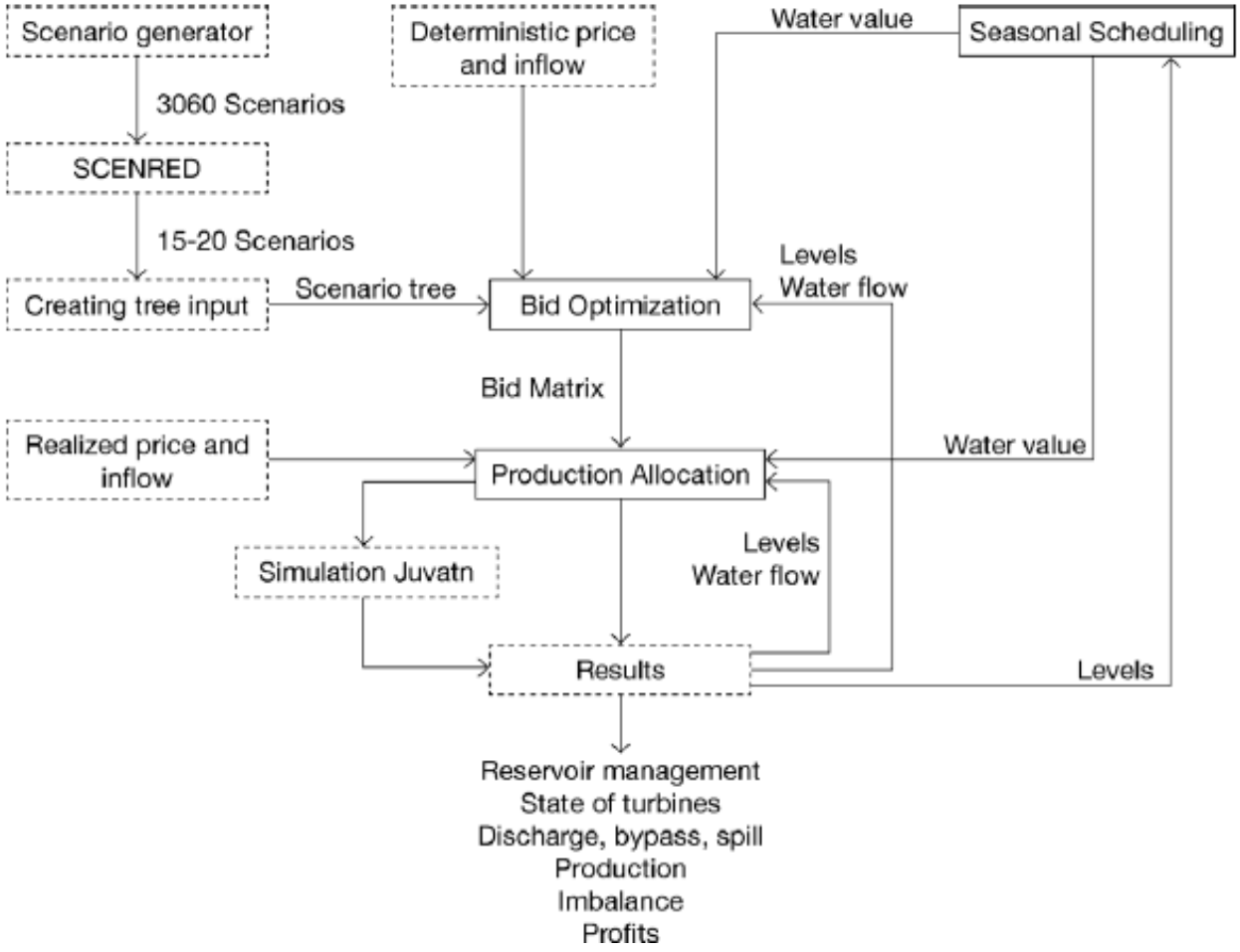
Overall: new model manages reservoirs well and operates the system reasonably, also on medium scale time horizons

Case 4: Mandalsvassdraget

Aasgård, Andresen, F, Haugstvedt (2014)



Case 4: Mandalsvassdraget



Actual day-ahead bidding

- Alnæs, Grøndahl, Boomsma, F, ENSYMORA special issue
- 3 different producers each gave bidding curves for 4x 14 days
- Actual bid curves and model-optimized curves align pretty well, but:
  - Conditions such as the efficiency of units are accounted for in a good way by the producers
  - Other elements, such as feed-in fees, are not that well accounted for in the bidding, even though this can imply a large marginal cost
  - Marginal costs seem in some cases to be overestimated at high production levels

Coordinated bidding

- Should the day-ahead bidding decisions take into account intraday and/or balancing markets?
- Intraday is meant for adjusting day-ahead
- Balancing markets are meant to take care of unexpected imbalances
- ”Bid your expected production day-ahead”
- Faria and F. (2011)
  - Fixed limits on the use of the intraday market
  - Modest coordination gains
- Boomsma, Juul, F. (2014)
  - Assume that this rule can be ignored.
  - Small balancing market – modelled via a price responsive demand
  - Large gains from coordination: 8-25%
- Klæboe, Braathen, Eriksrud, F. (2015)
  - Expected imbalance restricted to zero
  - No coordination gains found, however, bid curves are different and allow for more profitable balancing market participation

Summary

- Nice insights into bidding practices
- Good foundation for industry application
  - 2 new projects in Norway ; Multimarket (Powel, NTNU, Hydro, Axpo) and Multisharm (NTNU, SINTEF, Hydro, Statkraft, TrønderEnergi, E-CO, Agder Energi)

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