SINTEF research activities on long-term hydrothermal scheduling

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Two main research areas

Hydrothermal optimization and simulation models

- For a region (e.g. northern Europe)
  - Price forecasting
  - System analysis
  - Security of supply
  - Investment analysis
  - Consequences of climate change
  - Hydro scheduling

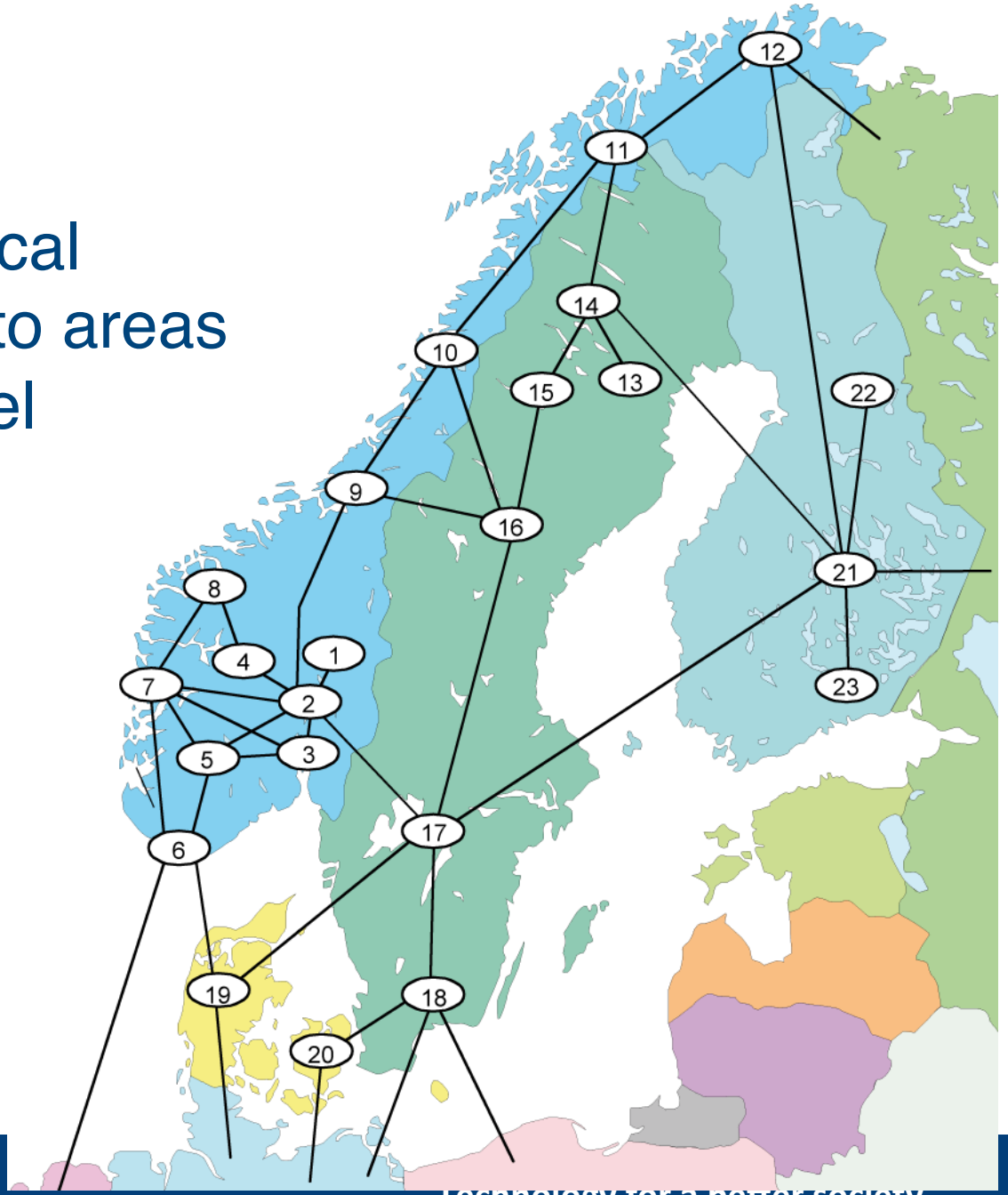
Long and medium-term hydro scheduling for a price taker

- Individual river system
  - Water values for scheduling
  - Reservoir, production, profit forecasting
  - Planning maintenance
  - Investment analysis

Hydrothermal optimization and simulation

- (Hydro) characteristics for a typical hydrothermal model of the Nordic system
  - More than 1000 modelled reservoirs
  - About 400-500 hydro plants
  - About 100 statistically different inflow series
  - More than 100 individual river systems
  - Time resolution : from a few hours to week
  - Planning horizon: Several years
  - Model divided into about 20 areas
    - Hydro aggregation
    - Transmission constraints
  - Several thousand transmission nodes (if included)

The Nordic Electrical System divided into areas in the EMPS model



Hydrothermal optimization and simulation models - existing approach

- EMPS model
  - Strategy part and simulation part
- Strategy part
  - SDP (water value for aggregated hydro in each area)
  - Heuristics to handle connection to other markets
- Simulation
  - Formal optimization for each week using aggregated hydro models
  - Heuristics for hydro-disaggregation, feedback to aggregated description
- Used by most players in the NordPool market

- Relatively fast, very good results

Market development

- Stronger coupling to Europe
- More new renewables
- More often operation closer to capacity limits
- Both short-term and long-term variations and uncertainties are important for the value of storages, prices and price differences

- Current EMPS model drawbacks
  - Not formal optimization –possible inconsistencies for smaller investment decisions
  - Formal optimization for aggregate models give to high flexibility
  - Disaggregation not adapted to short-term pumped storage operation

Tested alternative approaches

- SDDP based method for aggregated hydro models
  - Disaggregation using EMPS method
- SDDP based method with detailed hydro modelling

- For both approaches
  - Much longer computation time than EMPS
  - Poorer results, especially for extreme scenarios
  - **NB!!!** Results are verified for observed inflows

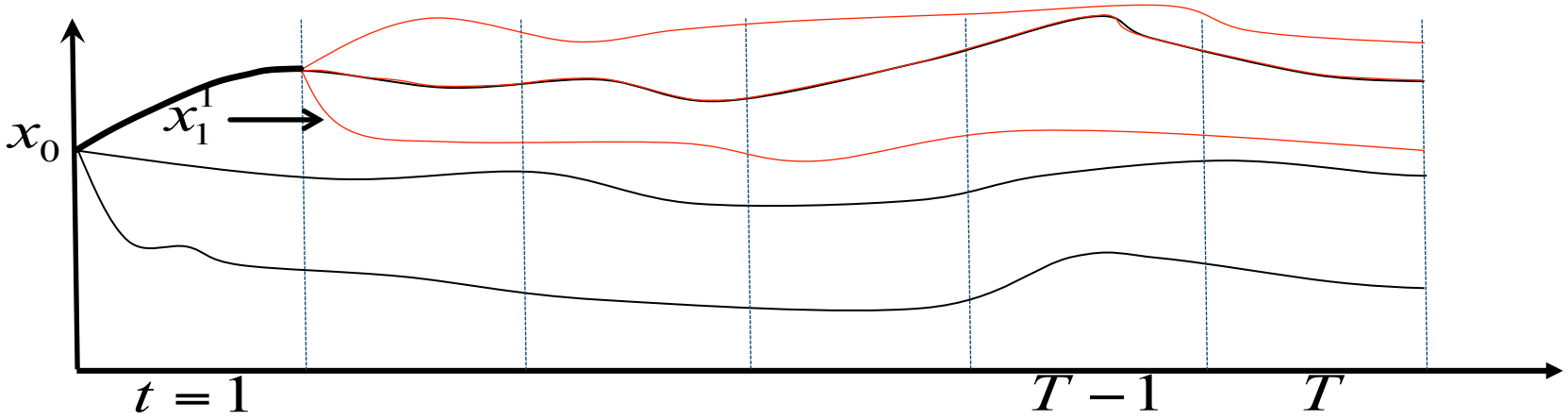
- SDDP modelling and statistical properties in time and space
- If simulation scenarios is sampled from the inflow model, the SDDP model give good results

Existing R&D projects

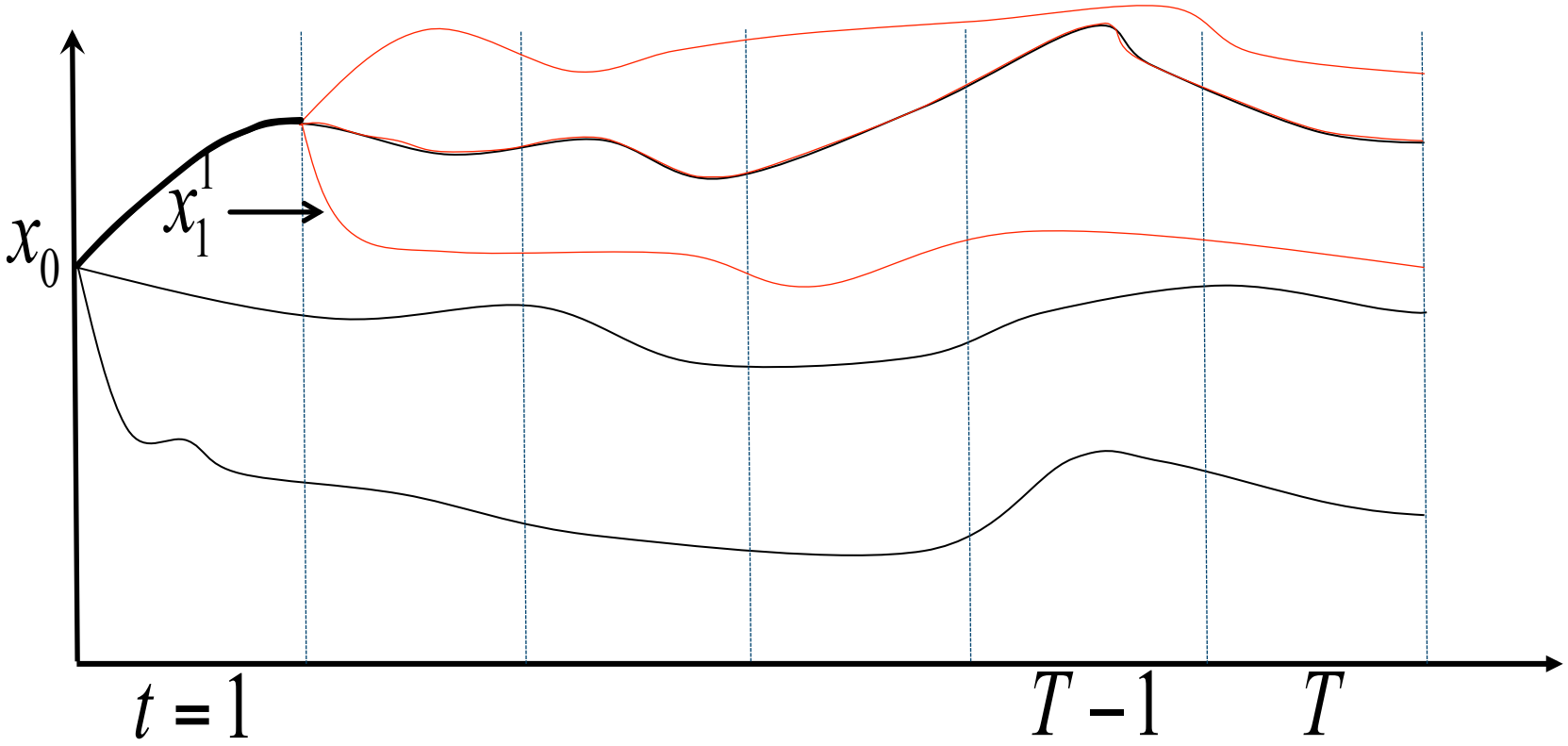
1. Simulator based on two-stage stochastic programming problems (SOVN)
   - Funding: Research Council of Norway and model users
   - Detailed hydro modelling
2. Price decoupling and use of local SDDP based models with exogenous stochastic price for each individual river system (ProdMarket)
   - Funding: SINTEF Energy Research
   - Detailed hydro modelling
3. Improving existing EMPS model
   - Funding: Research Council of Norway and model users
   - Heuristics
   - Aggregate model structure
   - Inflow used in water value calculation
     - Statistics
     - How is it calculated

SOVN model

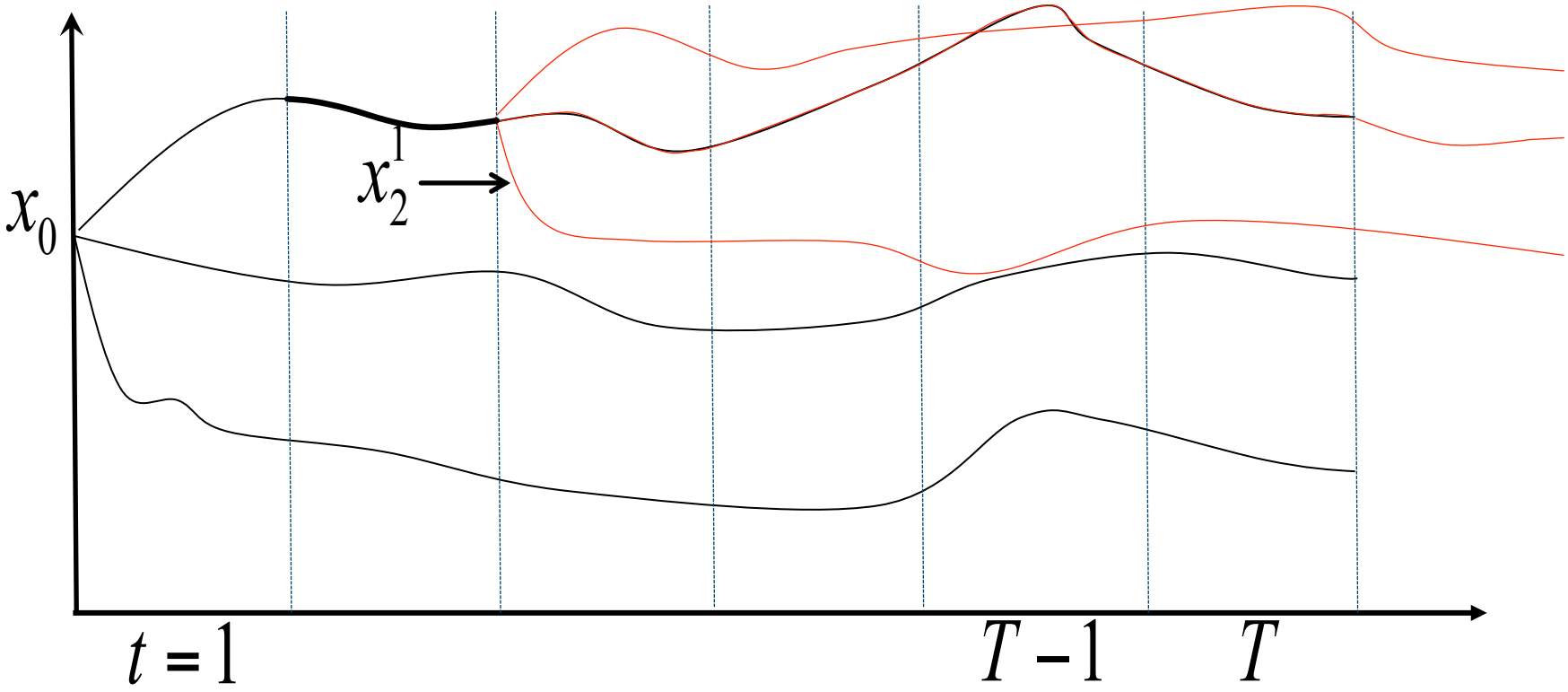
- Simulation along observed *weather scenarios* by solving a sequence of stochastic optimization problems
  - Two-stage stochastic problems
  - Uncertainties known in the first-stage (week)
  - All uncertainty is resolved in the second stage
  - First-stage decision is implemented and state variables are updated
  - Rolling horizon, fixed problem size



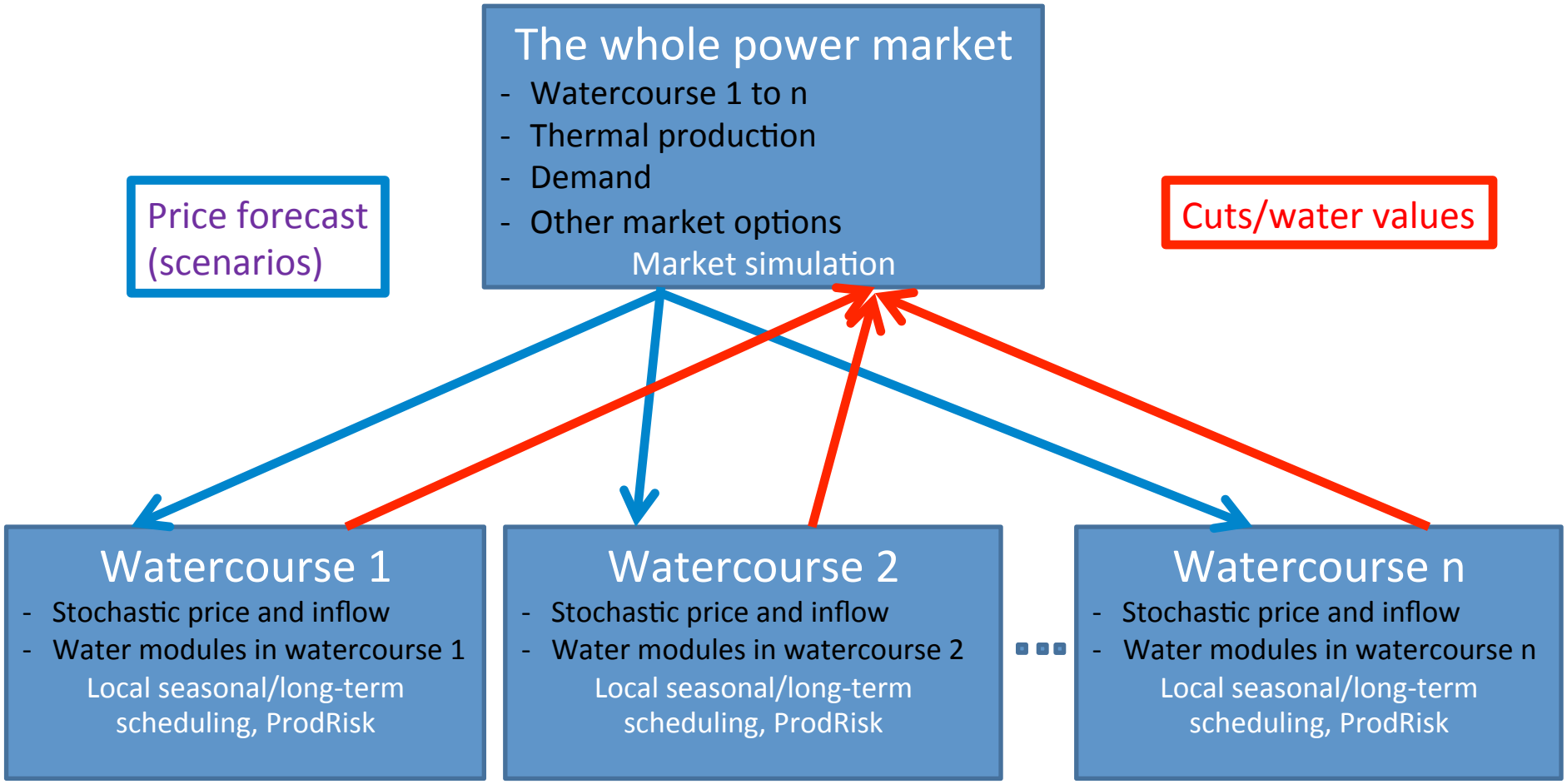
Simulator Scheme



Simulator Scheme



Principle of the ProdMarket model

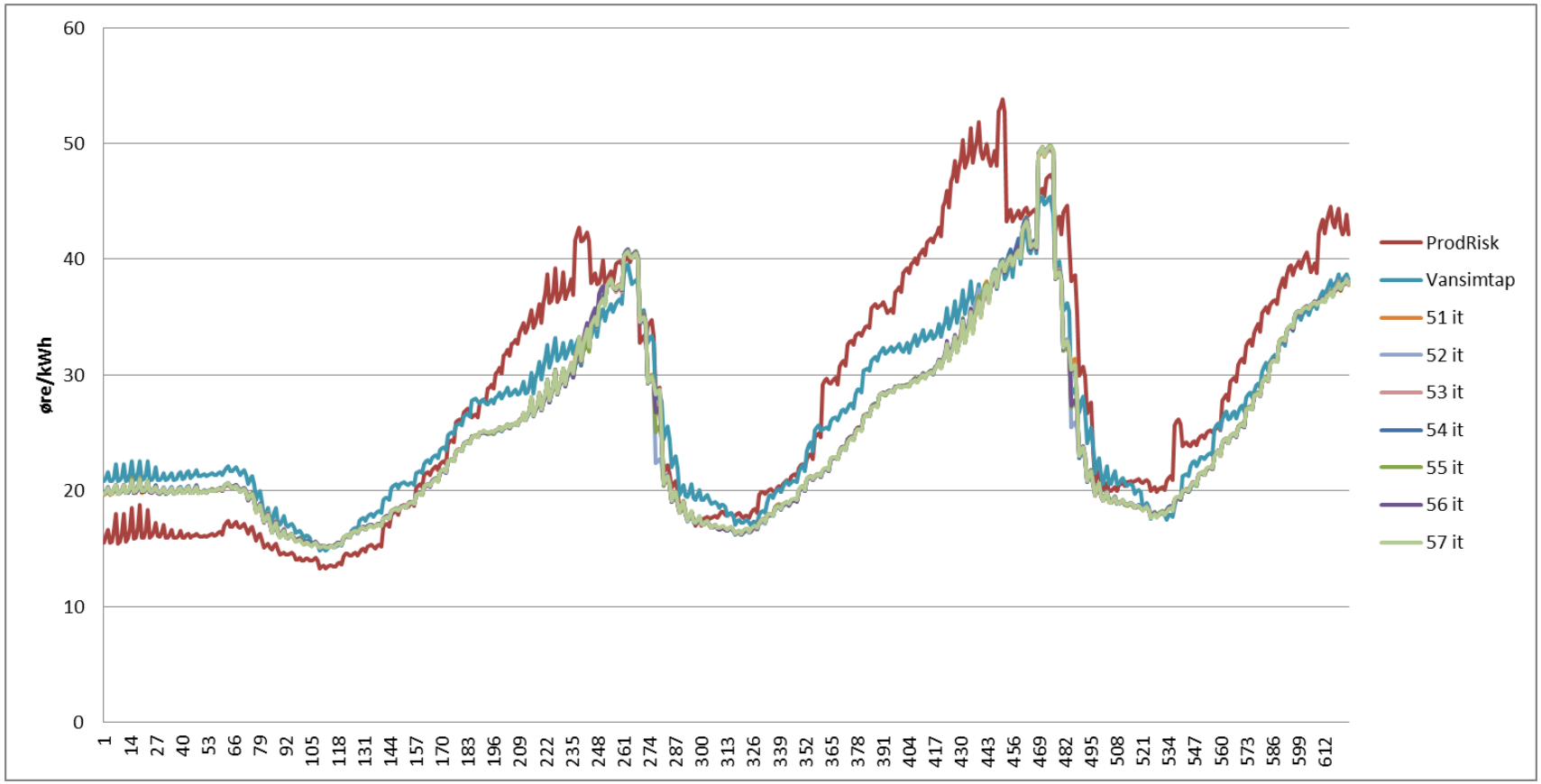


Case study – case description

- A small Nordic system
- 50 water modules, reservoirs
  - Three watercourses
  - 2 064 MW production capacity
  - 6 000 GWh total storage capacity
- No restriction on transmission capacity
- 4 load periods within the week
- 156 weeks in simulation period
- 50 years in the inflow statistics

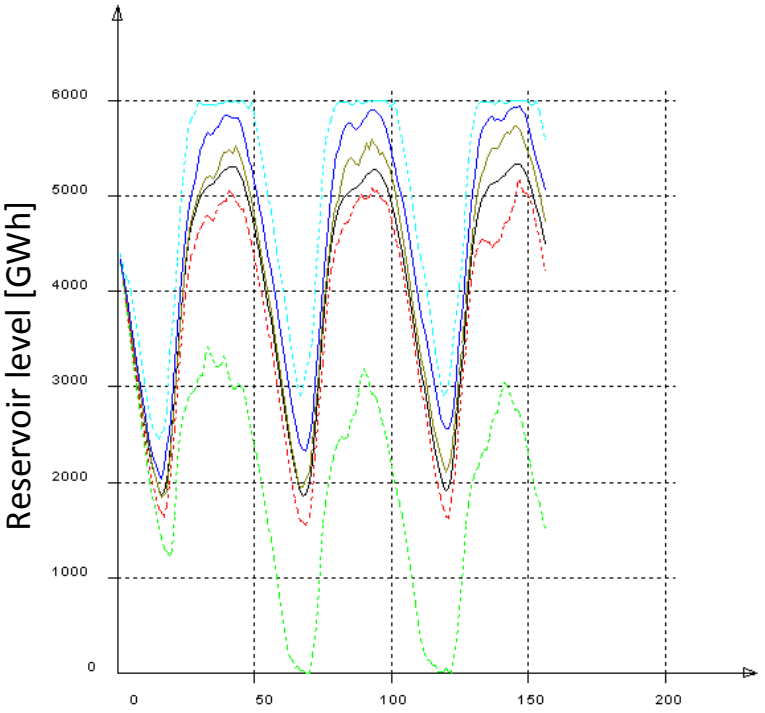
- High risk for rationing

Average simulated prices



Reservoir level –
Percentiles for sum of all reservoirs

ProdMarket



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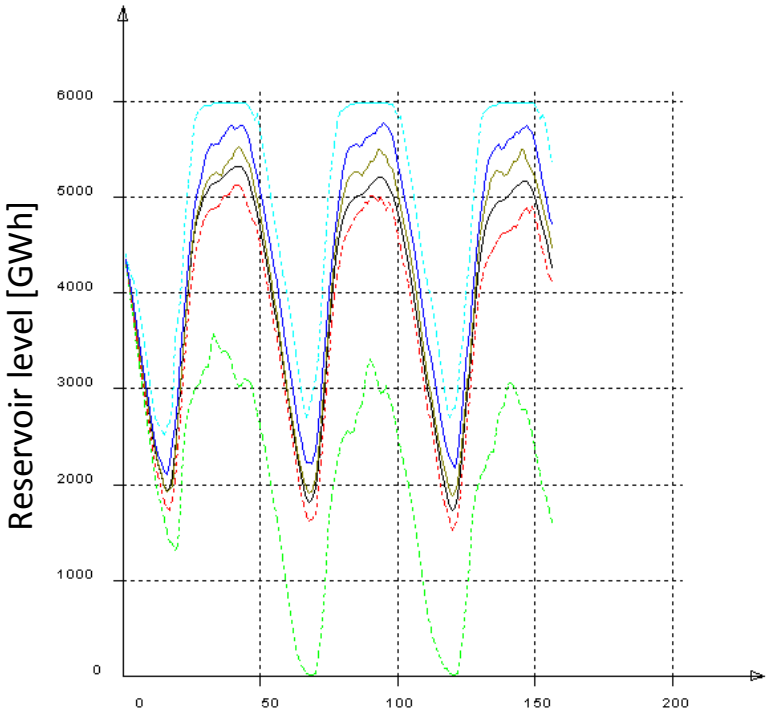
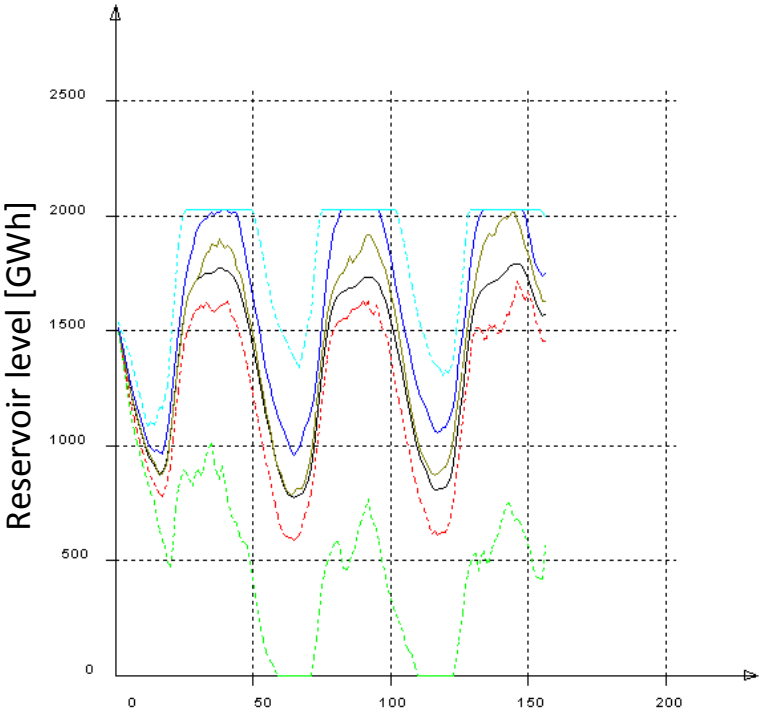


Reservoir level –
Percentiles for the Vatnedal reservoir

ProdMarket



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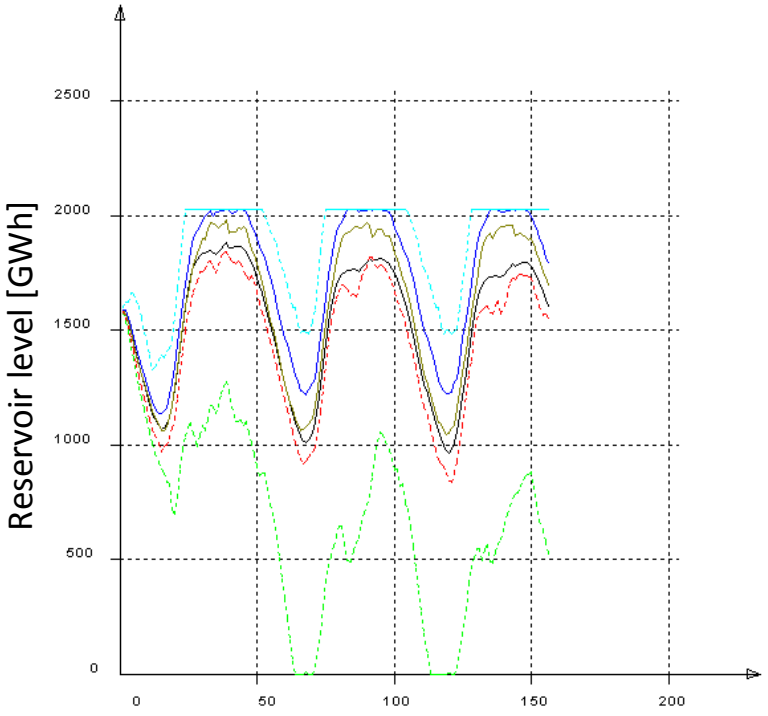

Long and medium-term hydro-scheduling for a price taker

- Activities related to a SDDP based model with exogenous stochastic price (ProdRisk)
  - Linear model
  - Some non-linear features in simulation (head dependencies, PQ description)
- Two main research areas:
  - Consequences of new markets on long-term operation strategy and water values
    - Reserve capacity markets
    - Balancing energy markets
  - State and inflow dependent constraints
    - E.g. discharge capacity dependent on head
- Other: Time resolution, time delays, start-up costs

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Technology for a better society

Aggregation and disaggregation