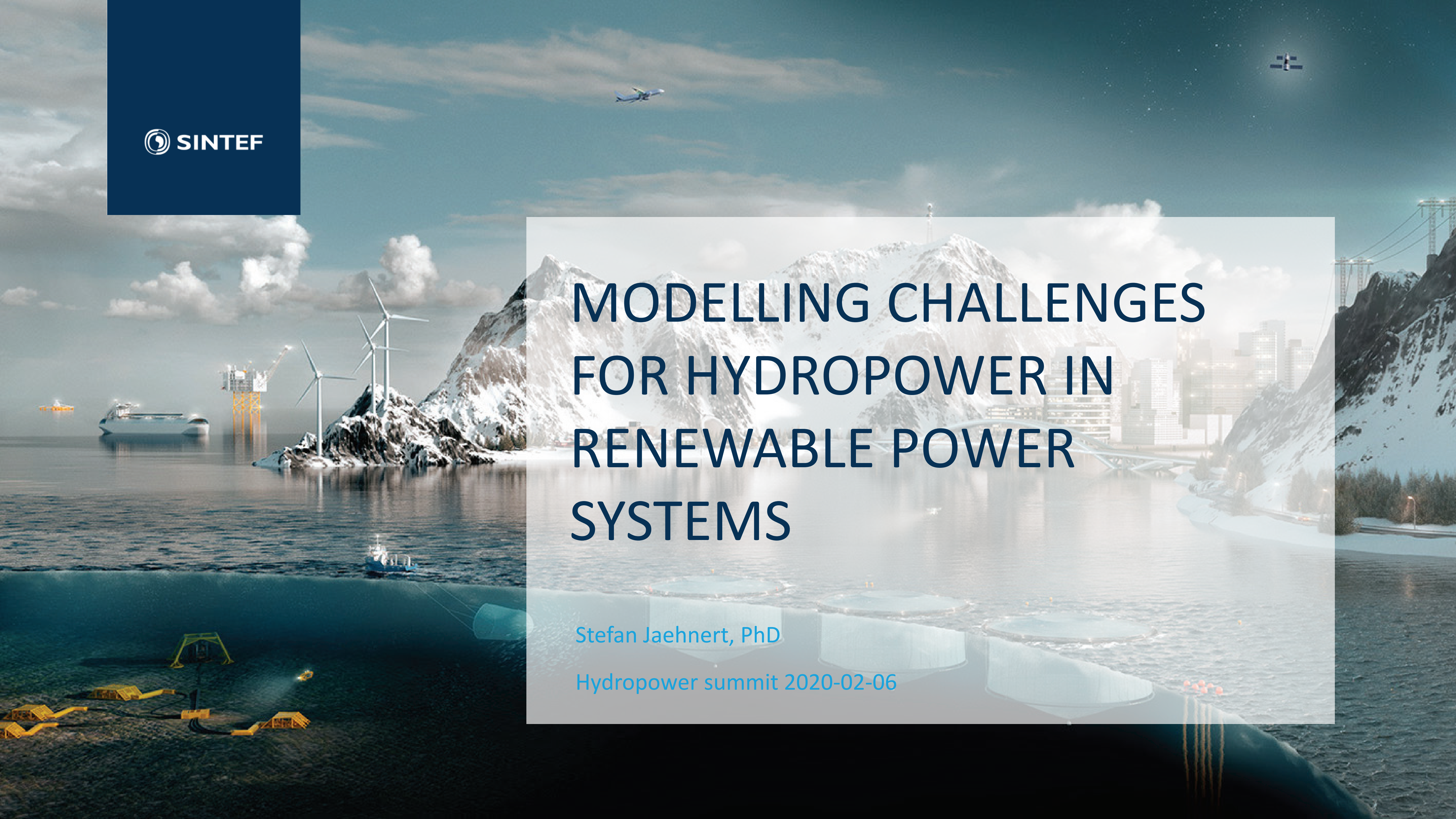

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MODELLING CHALLENGES FOR HYDROPOWER IN RENEWABLE POWER SYSTEMS

Stefan Jaehnert, PhD

Hydropower summit 2020-02-06

Future potential for large scale energy storage

Energy storage can supply more ***flexibility*** and ***balancing*** to the grid, providing a ***back-up*** to intermittent renewable energy.

European Commission, "DG Ener Working Paper The future role and challenges of Energy Storage", http://ec.europa.eu/energy/infrastructure/doc/energy-storage/2013/energy_storage.pdf

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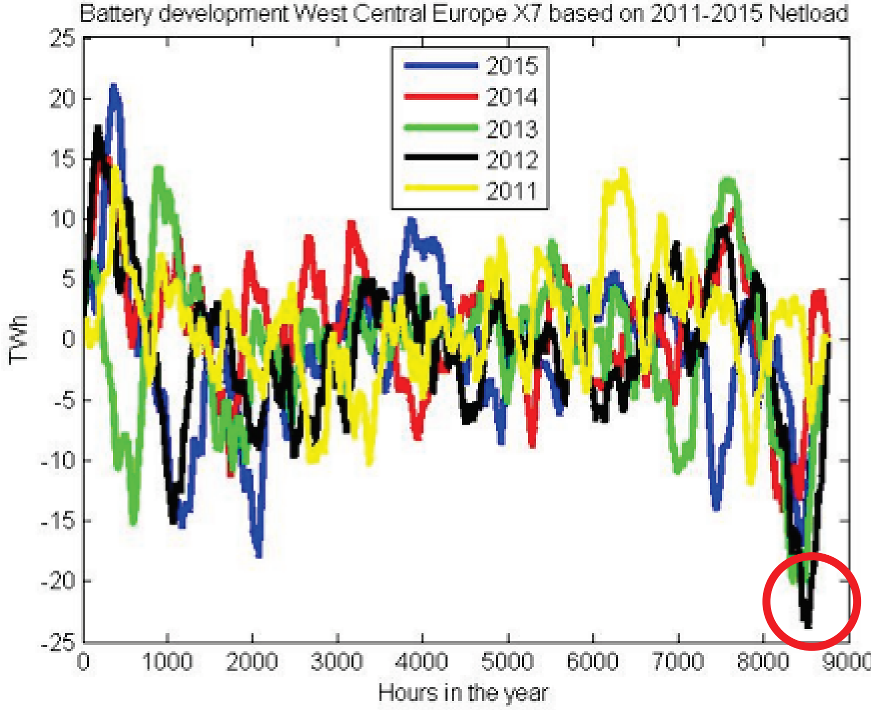
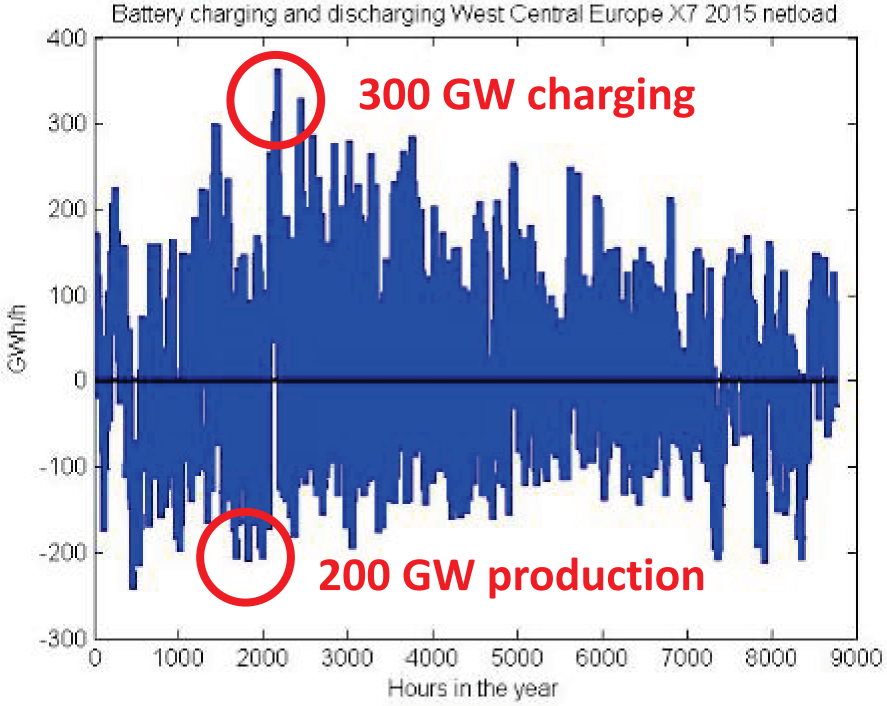
Need for balancing 2050 in West Central Europe





20-25 TWH storage needed

Includes: UK, Ireland, France, Benelux, Germany, West Denmark, Switzerland, Austria, Check Republic, Slovenia
Assumes no bottlenecks in transmission system in and between countries
eHighway Scenario X7: ~100% res, ~70% from wind and solar

Source: Graabak, Ingeborg. "Balancing of wind and solar power production in Northern Europe with Norwegian hydropower." (2018). PhD thesis, NTNU

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Norwegian hydropower for balancing

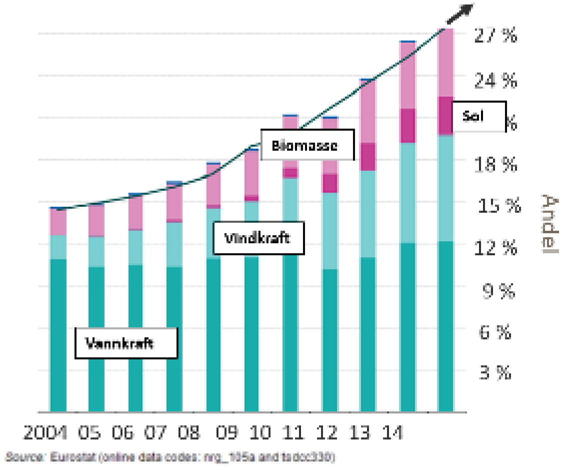
Reservoirs are natural lakes

Multi-year reservoirs

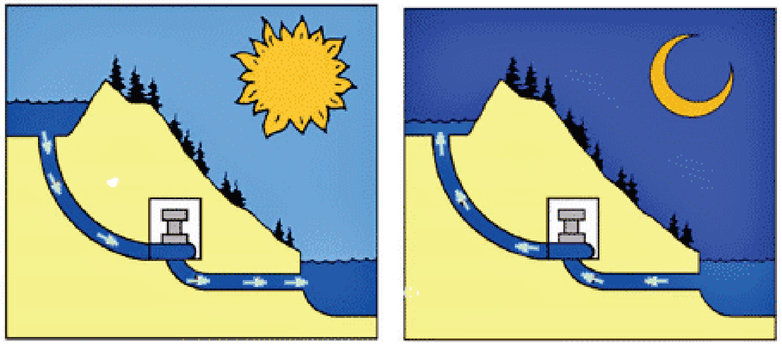
Largest lake stores 8 TWh

Total 84 TWh reservoir capacity

Increasing share of renewable power in EU. **Intermittent power from wind solar** with need for balancing



Huge possibilities for **more capacity** including **pump-storage** in existing reservoirs - Requires more transmission capacity



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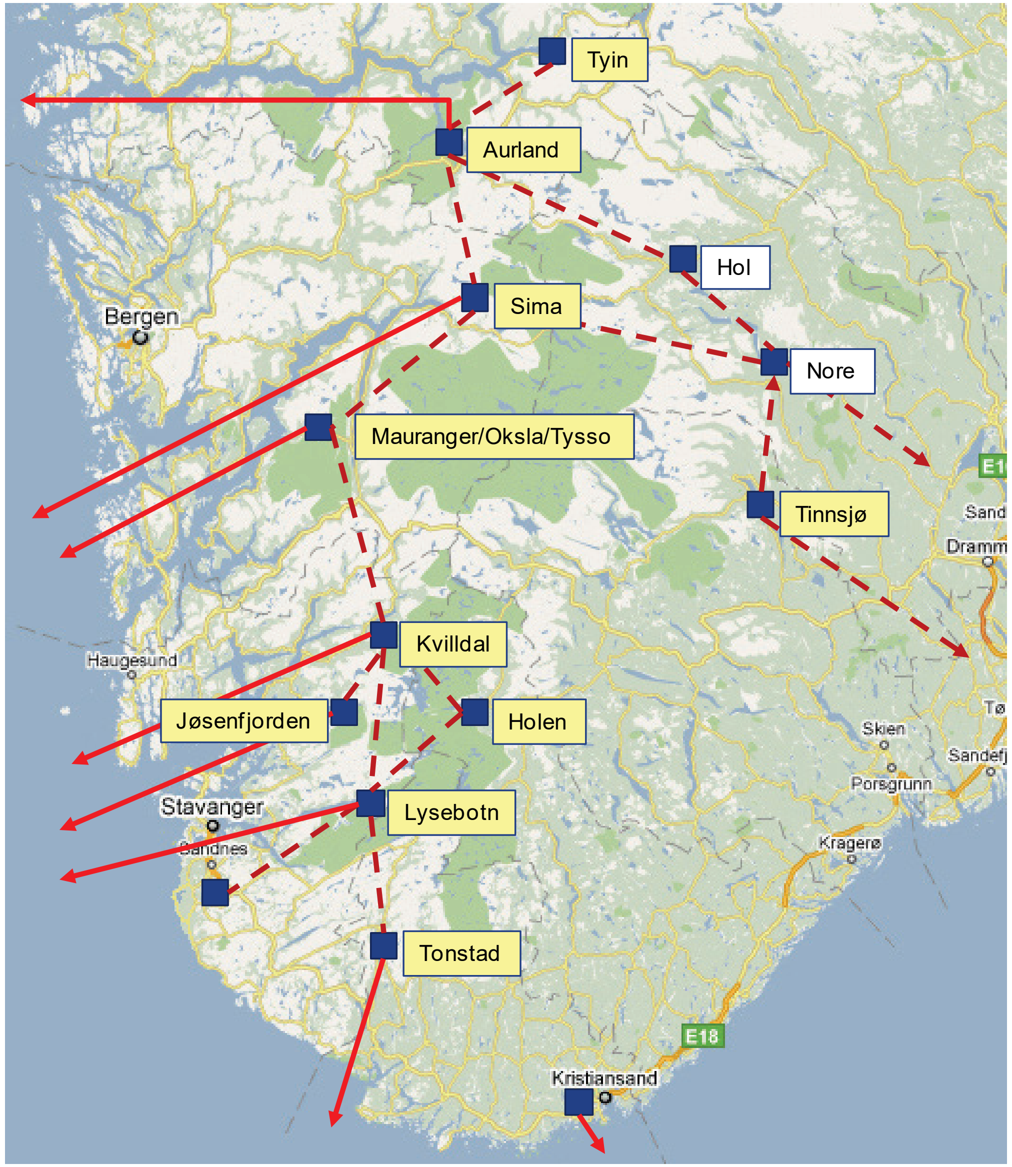
Case study 2030



10-20 GW new pumping and generation capacity using existing reservoirs

2012, Eivind Solvang et al., Increasing balance power capacity in Norwegian hydroelectric power stations, SINTEF Report TR A7195

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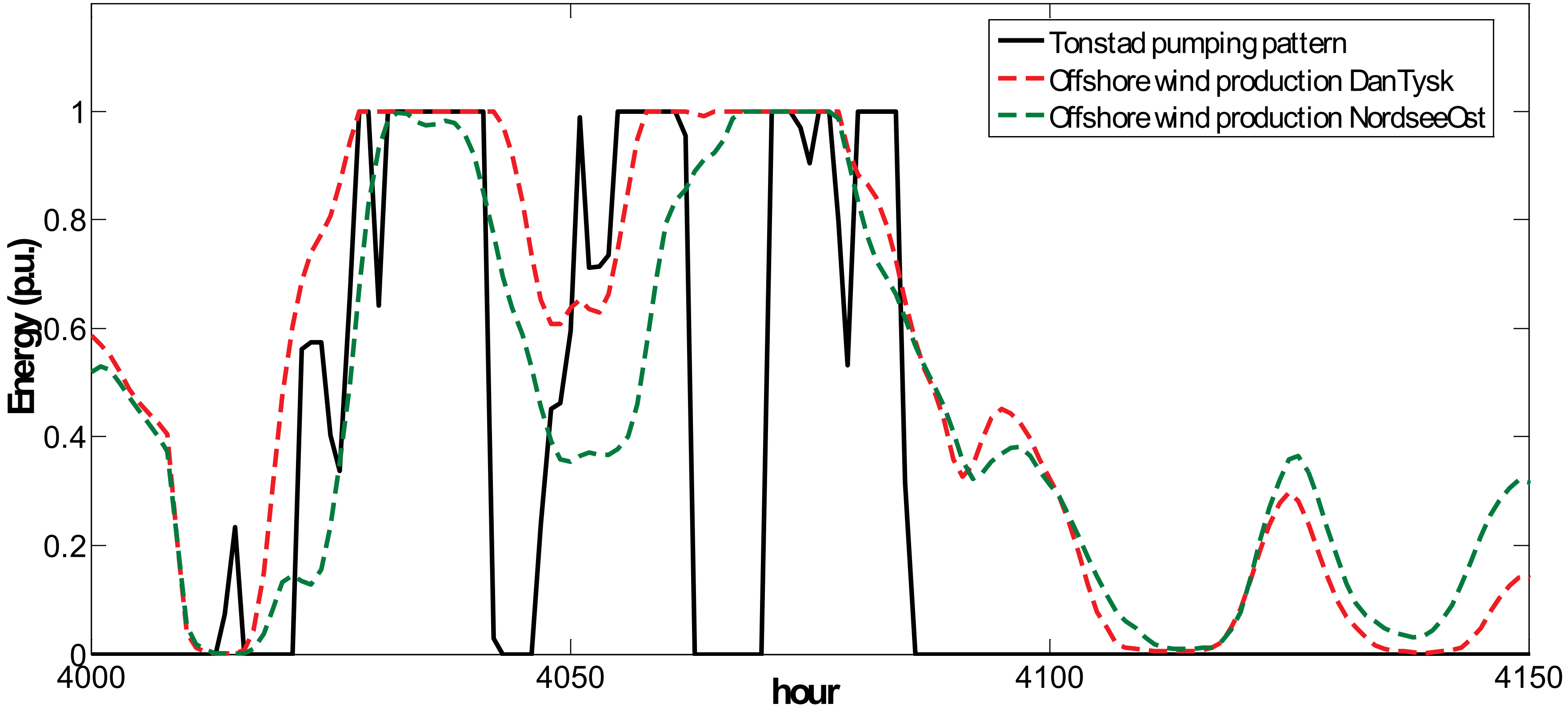
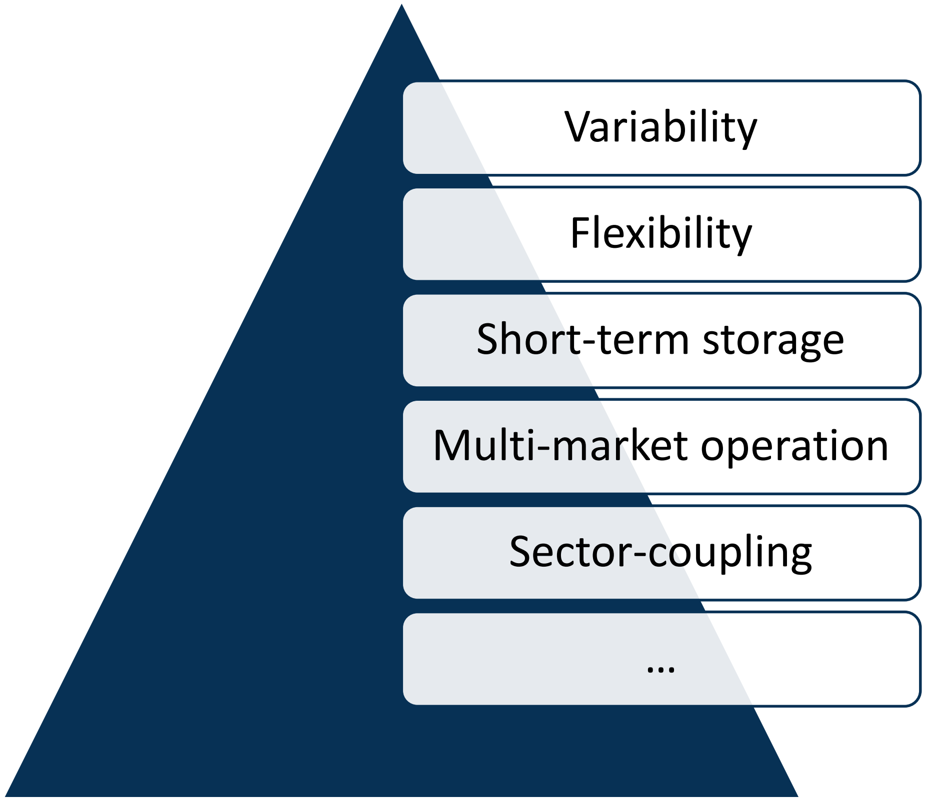
Tonstad – pumping pattern



TWENTIES - Task 16.3, " Possibilities of Nordic hydro power generation flexibility and transmission capacity expansion to support the integration of Northern European wind power production: 2020 and 2030 case studies", http://www.twenties-project.eu

Power system challenges



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Project overview

PriBas	FanSi	VannFly	IBM
MAD	Rakett	Vilkårs-revisjoner	Hydro Balance

The Nordic Power System

General:

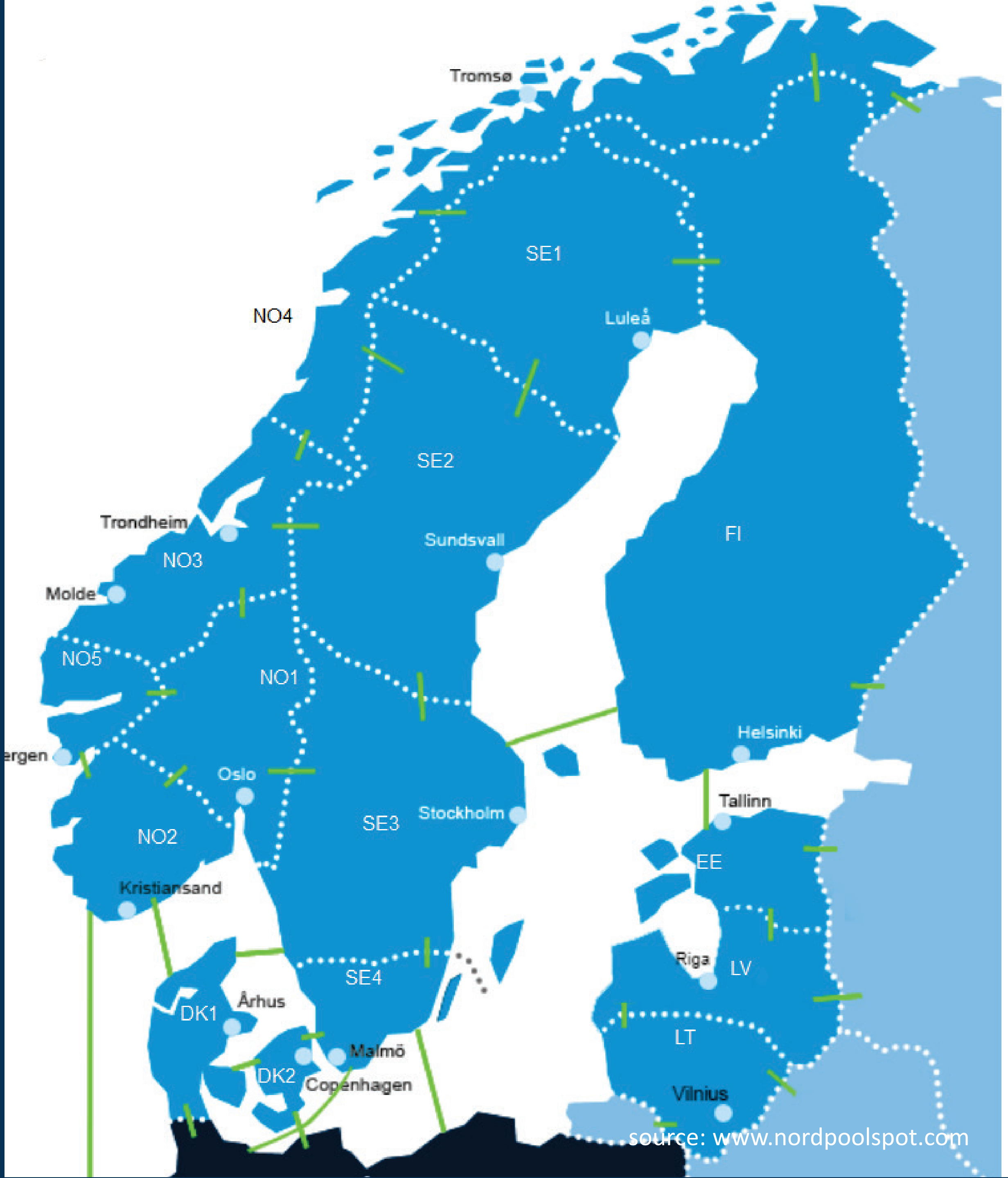
- Mixture of generation sources
- Liberalized market
- Interconnectors to central and eastern Europe

Hydropower:

- Accounts for more than 50 % of the total capacity
- More than 1000 hydro reservoirs in the system
- Annual inflow ranging from 174 – 241 TWh

Trends:

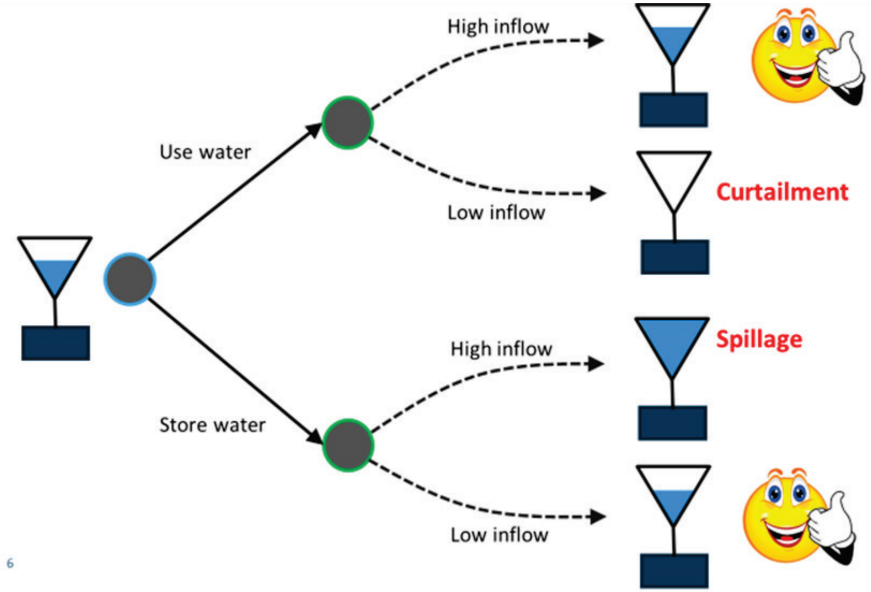
- Stronger interconnections to other European markets
- Increasing share of renewables in Europe
- Hydropower has great potential for balancing "unpredictable" generation from solar and wind



source: www.nordpoolspot.com

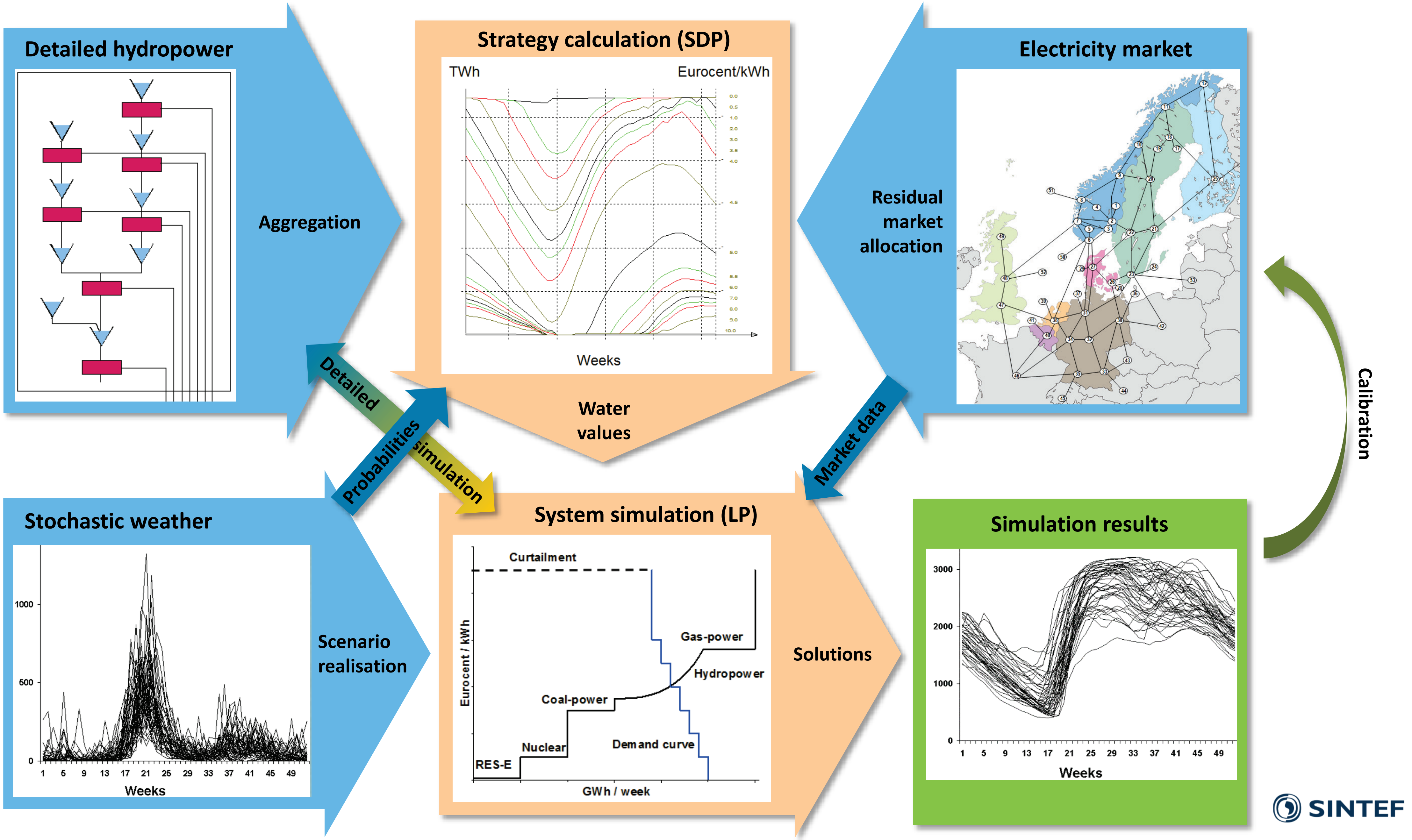
The Overall Scheduling Problem

- A large-scale multi-stage stochastic optimization problem
- Characterized by:
  - A large number of state variables (> 1000 hydro reservoirs)
  - Time horizon of 3-5 years
  - Weekly stochastic time-resolution
  - Hourly time resolution within the week



- Inflow is the most important stochastic variable, and is correlated in time and space
- The strategy will be simulated using historical inflow scenarios (de facto standard among players in the Nordic Power market).

=> How to find the optimal strategy for handling reservoirs



Detailed hydropower
Aggregation
Strategy calculation (SDP)
TWh
Eurocent/kWh
Weeks
Water values
Electricity market
Residual market allocation
Calibration
Detailed simulation
Probabilities
Market data
Stochastic weather
1000
500
0
1 5 9 13 17 21 25 29 33 37 41 45 49
Weeks
Scenario realisation
System simulation (LP)
Curtailment
Eurocent / kWh
Gas-power
Hydropower
Coal-power
Nuclear
RES-E
Demand curve
GWh / week
Solutions
Simulation results
3000
2000
1000
0
1 5 9 13 17 21 25 29 33 37 41 45 49
Weeks
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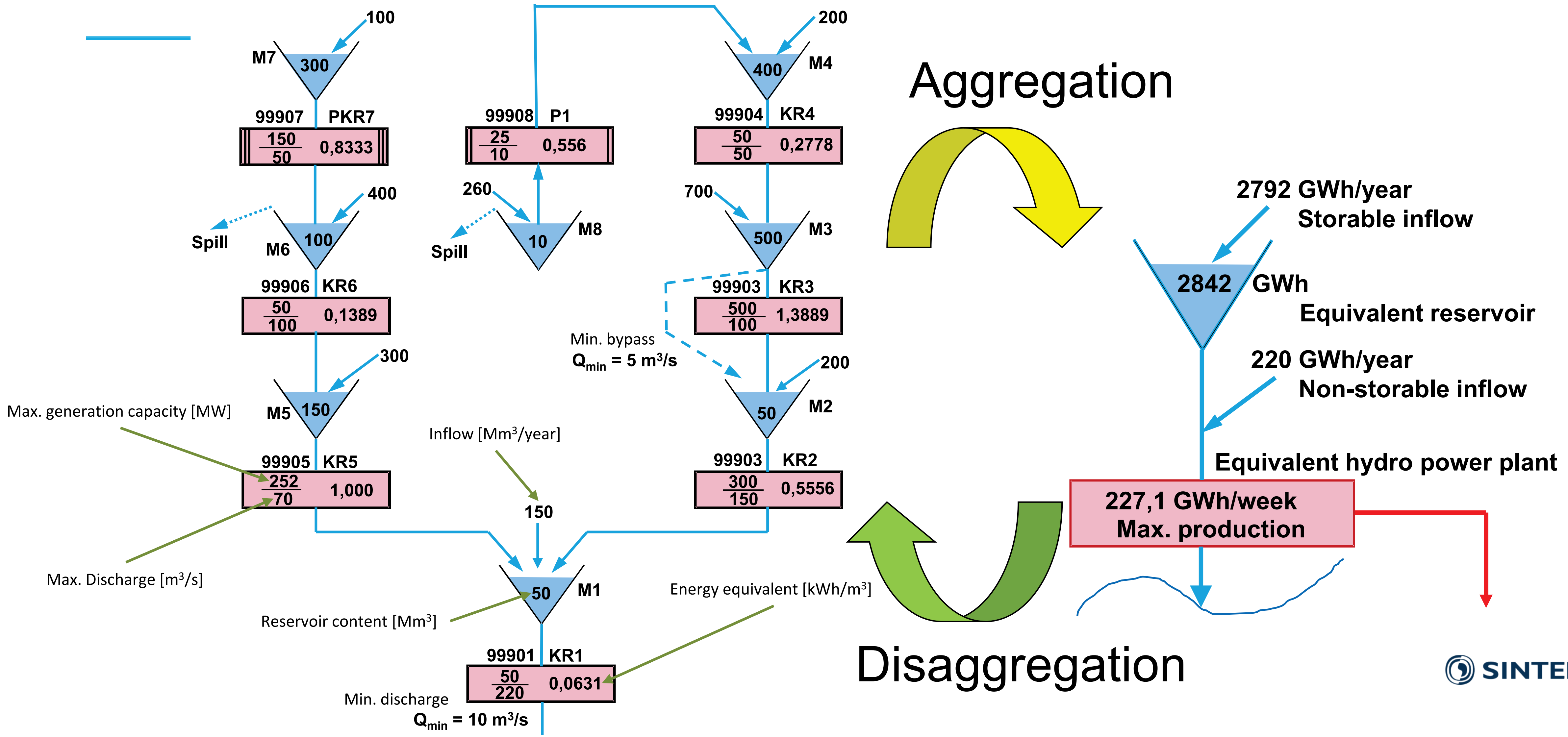
Hydropower water course



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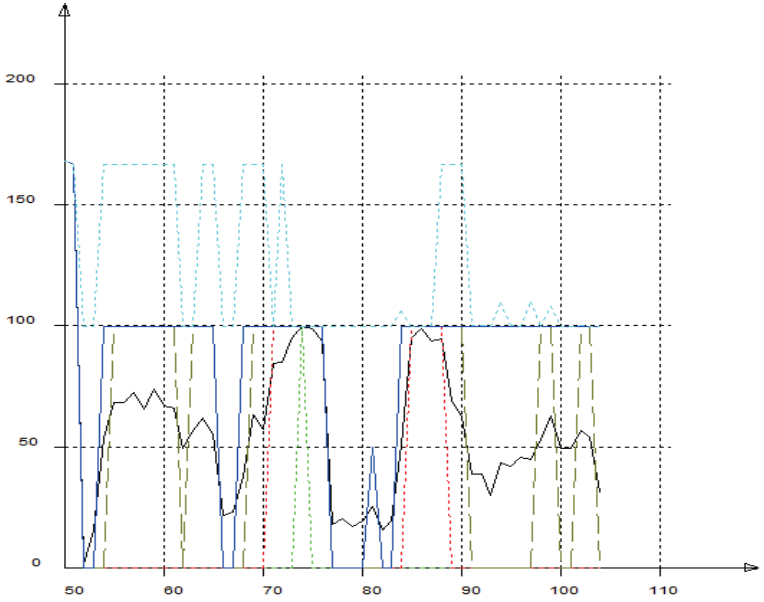
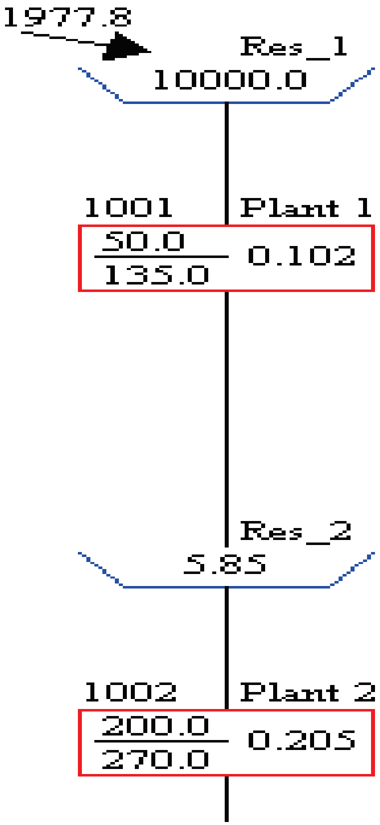
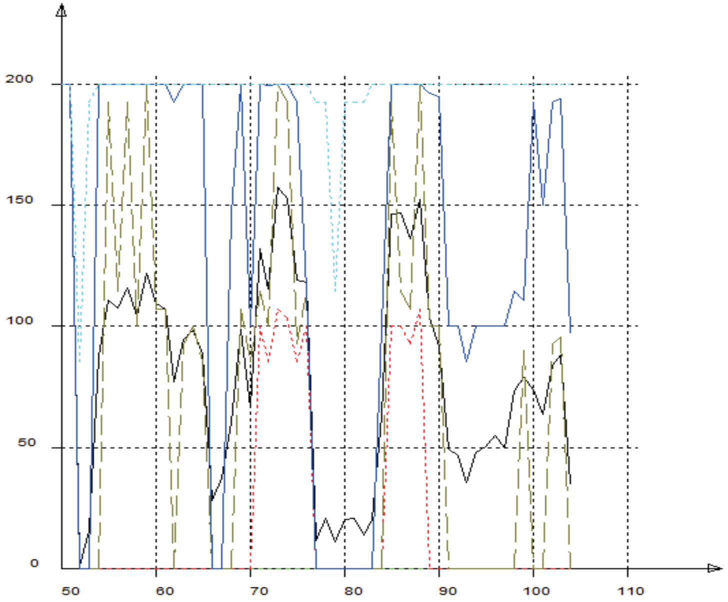
Optimal production in serial water courses

Drawdown heuristic (Vansimtap)

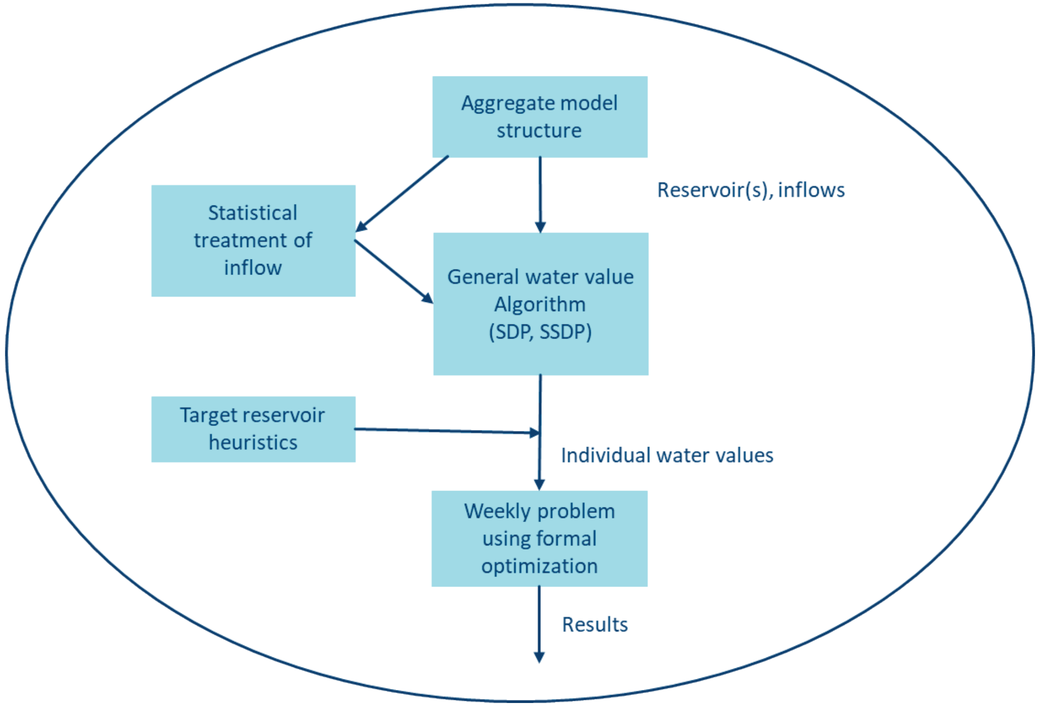


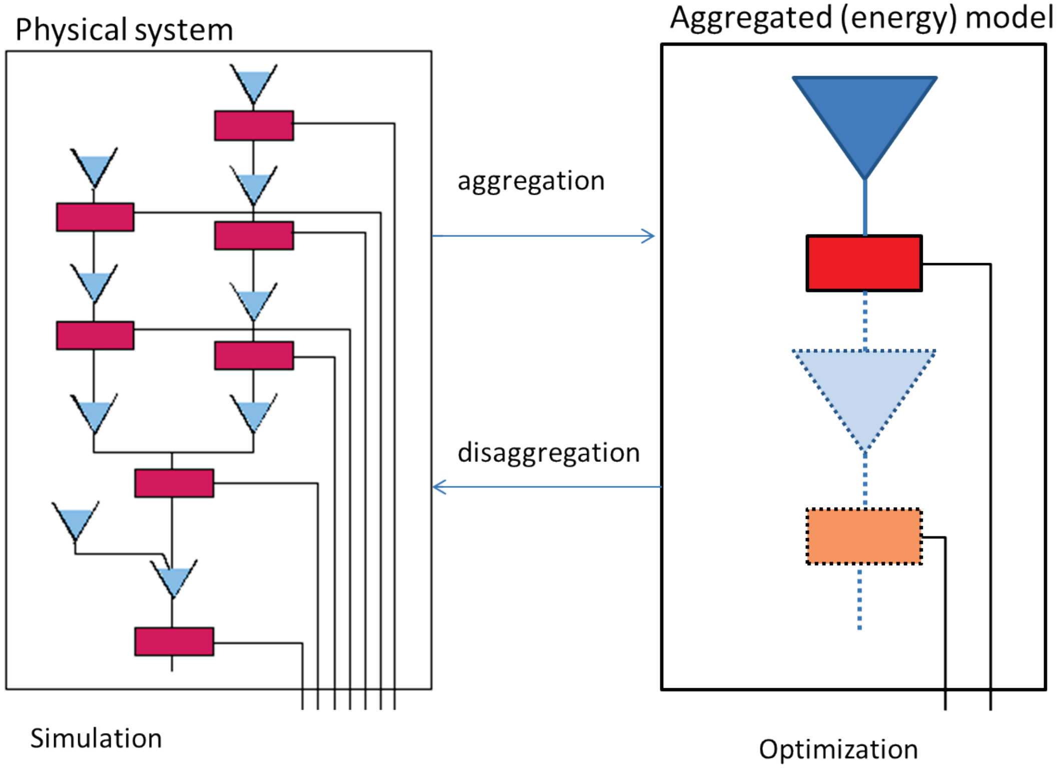


Optimization (ProdRisk)

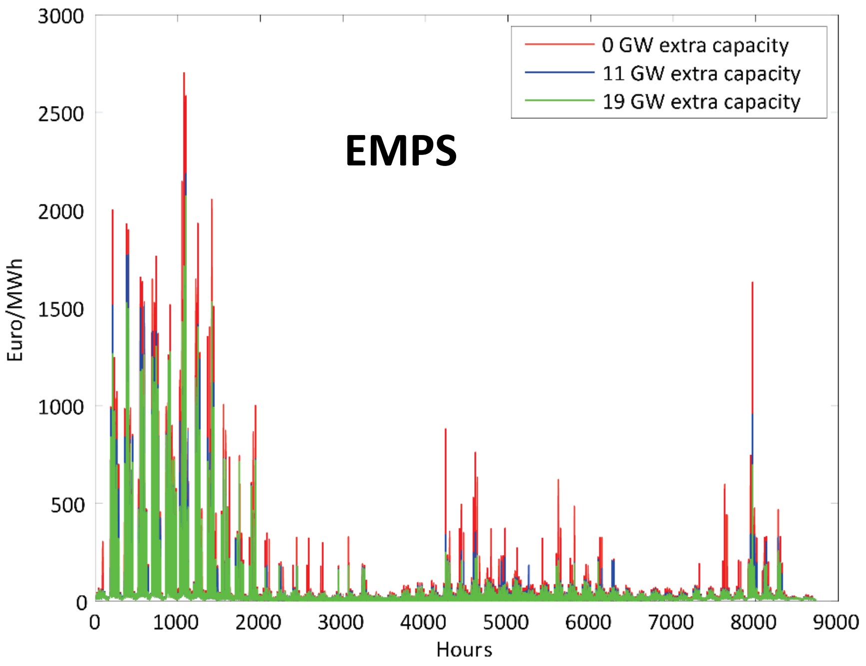


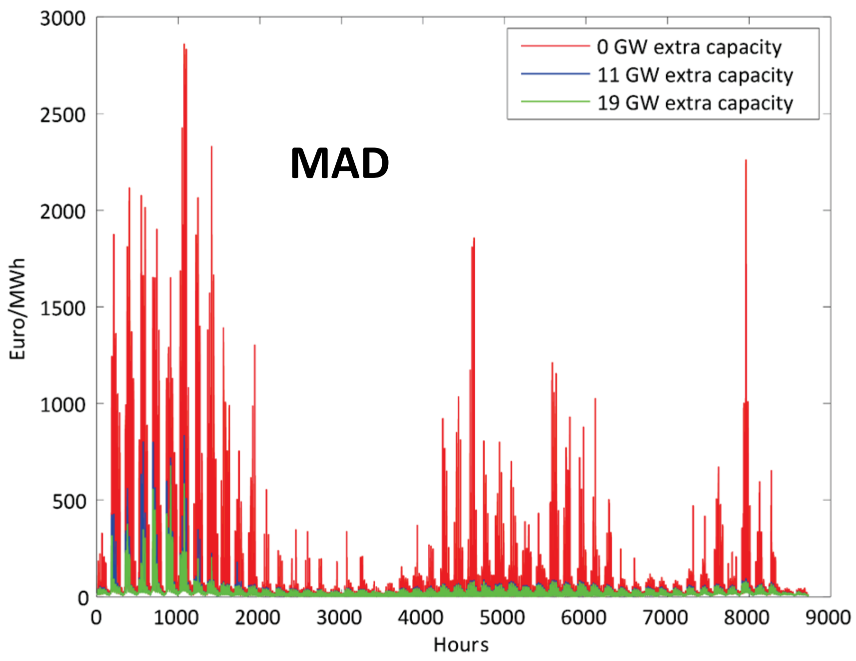
Methods of Aggregation and Disaggregation





Impacts on the power prices in the Netherlands "100% RES" scenario with extra nuclear





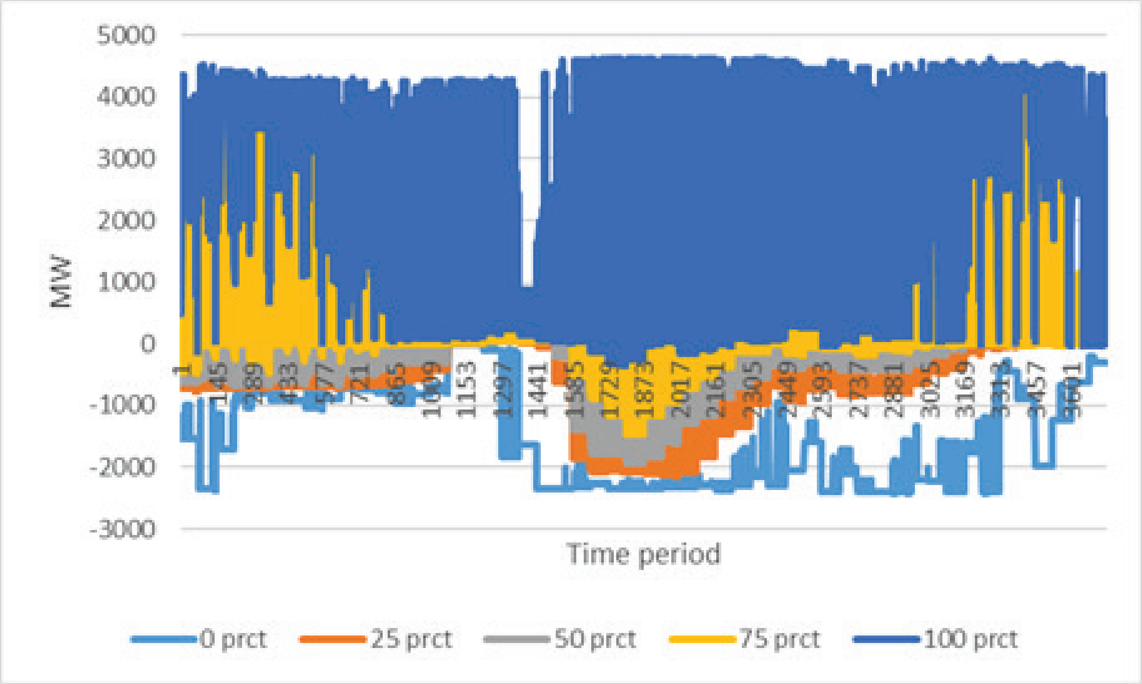
Prices hour-by-hour averaged for 75 years with stochastic weather data
Rationing prices of 10000 Euro/MWh sets the price in periods

Paper 6: I Graabak, M Korpås, S Jaehnert, M Belsnes. "**Balancing future variable wind and solar power production in Northern Europe with Norwegian hydropower**". Submitted to Elsevier Energy. 1st round of comments received.

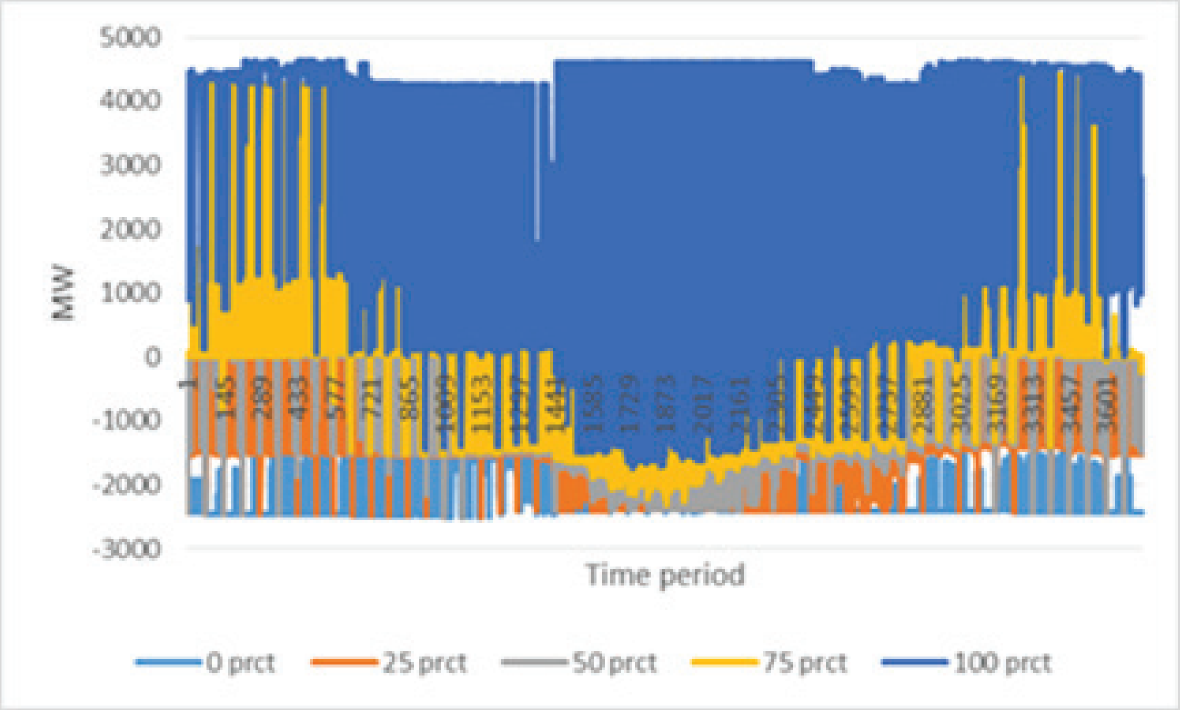
Kvilldal plant in VESTSYD

Generation capacity increased from 1.2 GW in present system to 4.6 GW (19 GW increase in Norway). New pump capacity with 2.4 GW. Capacity of upstream reservoir: 237 MM

EMPS



MAD



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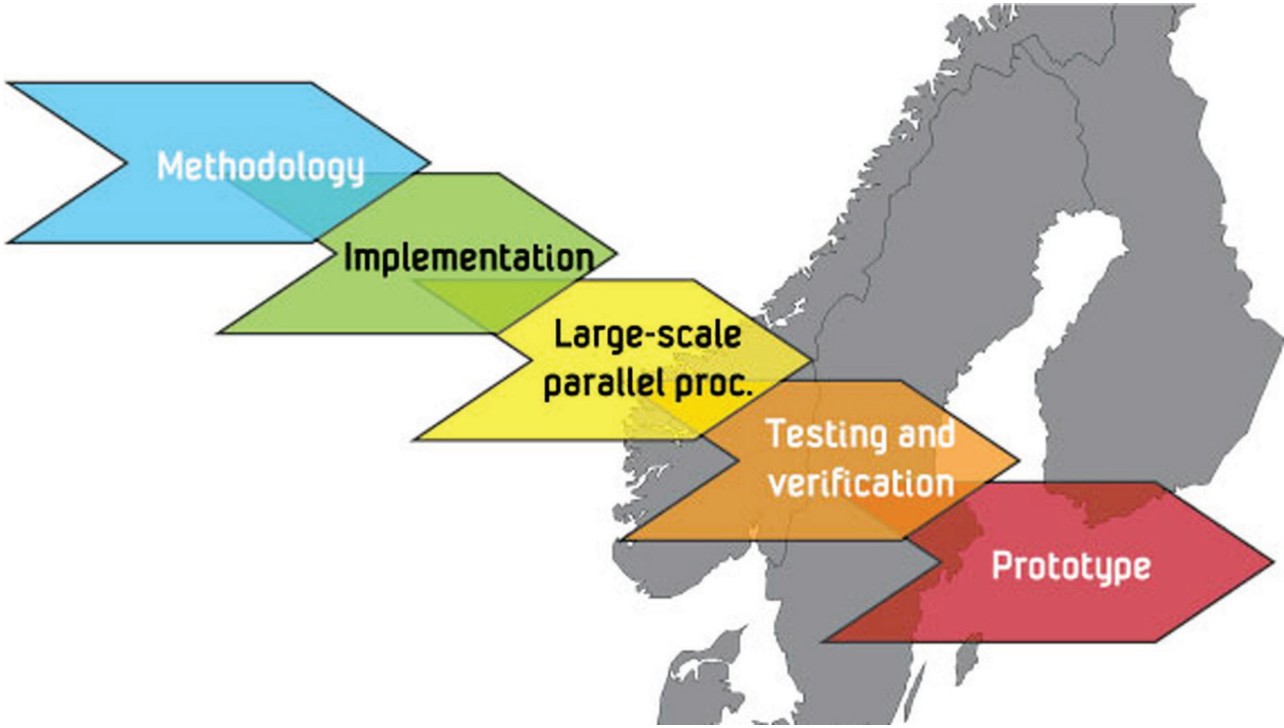
Full formal optimisation - FanSi

- Multi-stage stochastic optimization
- Large-scale (Europe)
- Detailed description of hydropower
- Transmission system and representation of physical flow
- No calibration and no heuristic
  - No aggregation and No disaggregation



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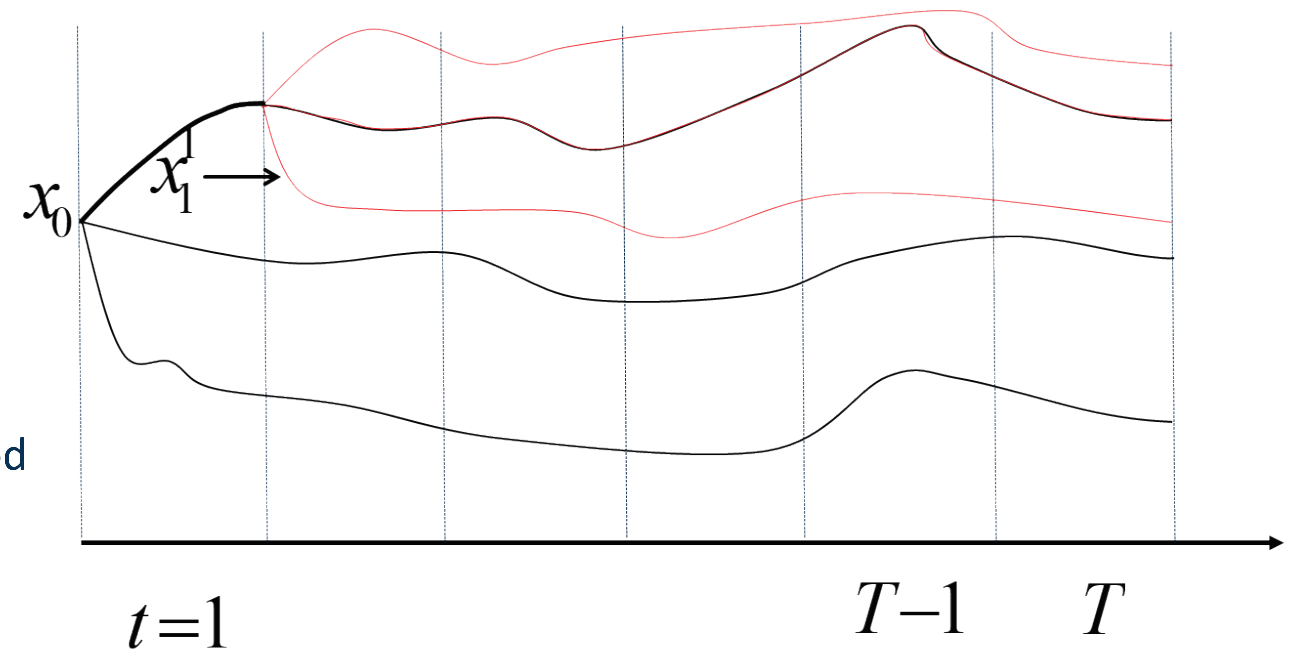
Scenario Fan Simulator

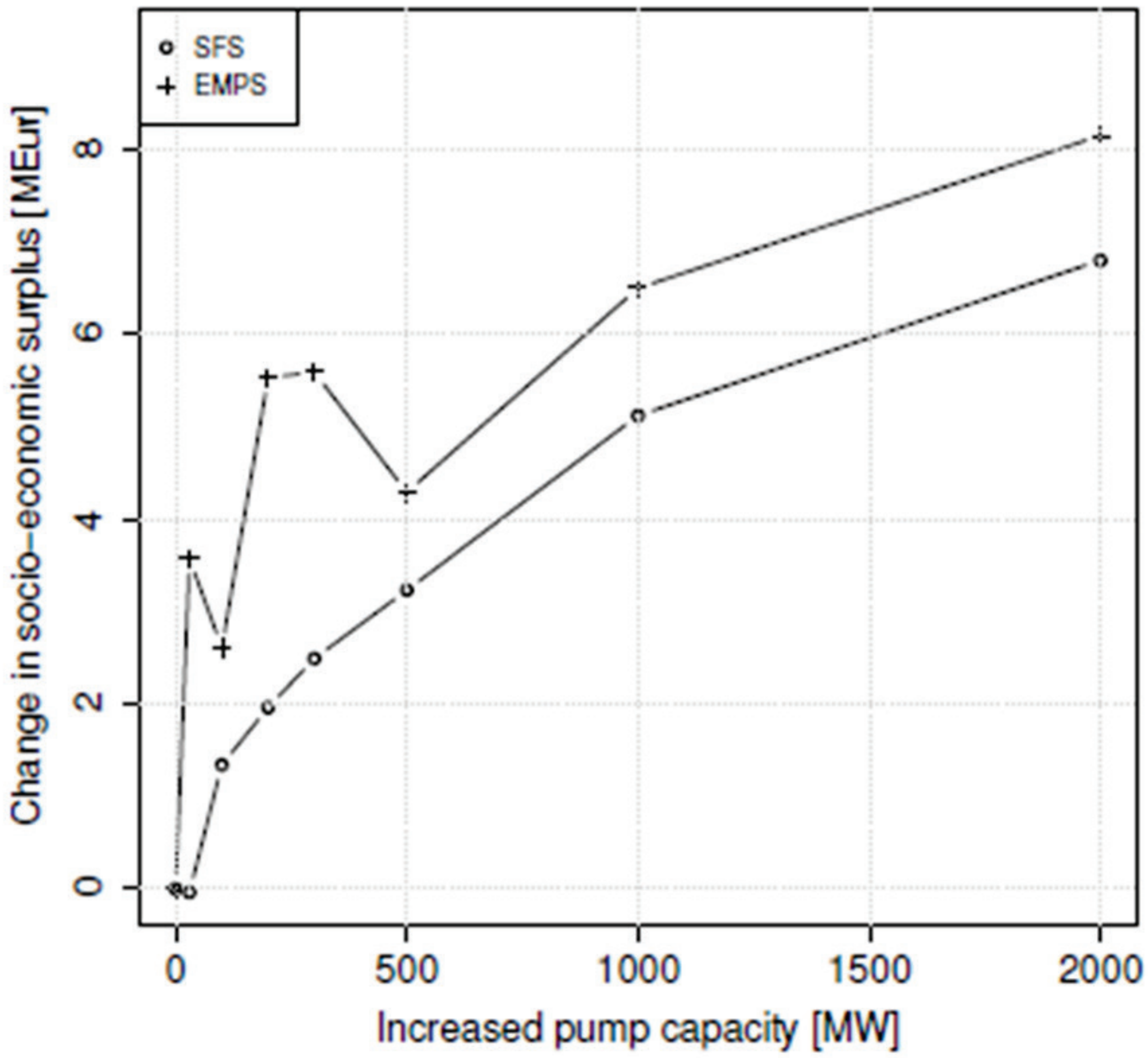
- Simulation by solving a sequence of optimization problems
  - Two-stage stochastic problems
  - Uncertainty known in the first-stage (week)
  - All uncertainty is resolved in second (time) stage
  - Solution by decomposition, e.g. L-shaped method
  - First-stage decision passed on to next stage
  - Rolling horizon, fixed problem size



[Helseth, Mo and Warland 2010]: "Long-term scheduling of hydro-thermal power systems using scenario fans"

Results
pump investment

- +345 M€/year for socioeconomic surplus in Nordic
- Consistent results
- 5000MW cable from Norway to Germany



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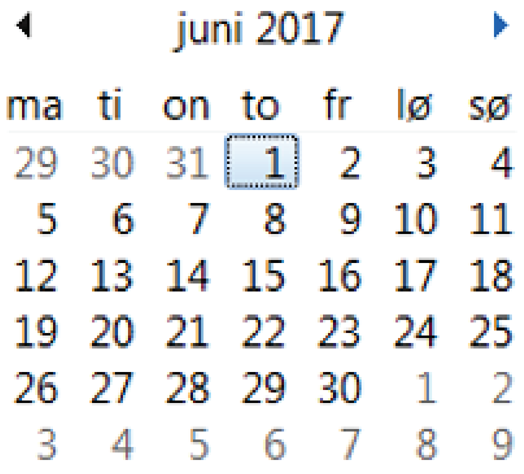
Challenges

- Calculation time
  - 50 hours on test case
    - EMPS 10 min without calibration
  - 156 hours with finer time resolution
    - 56 time step in week problem
    - 92 time step in scenario fan



- Depend on time resolution, detailed description and size of power system
- Increases with more restrictions
  - Not head correction, time delay and snow

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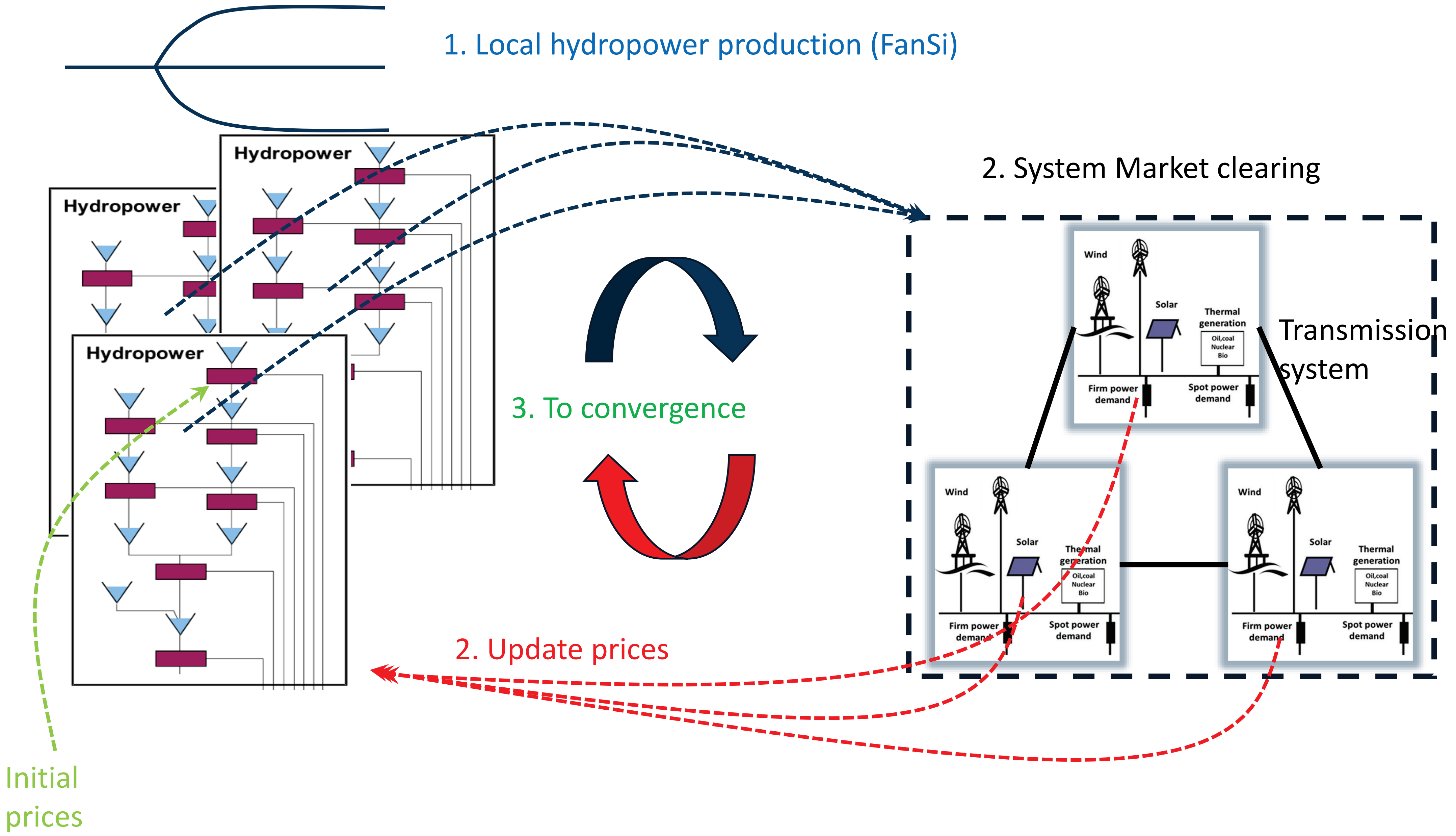
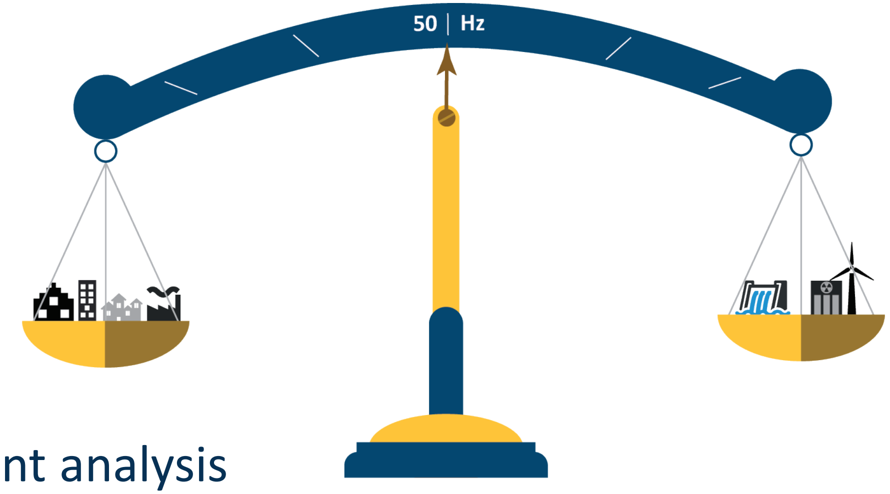
Price – volume decomposition



Project Goal

Develop a fundamental multi-market ***model concept*** for the Nordic power system

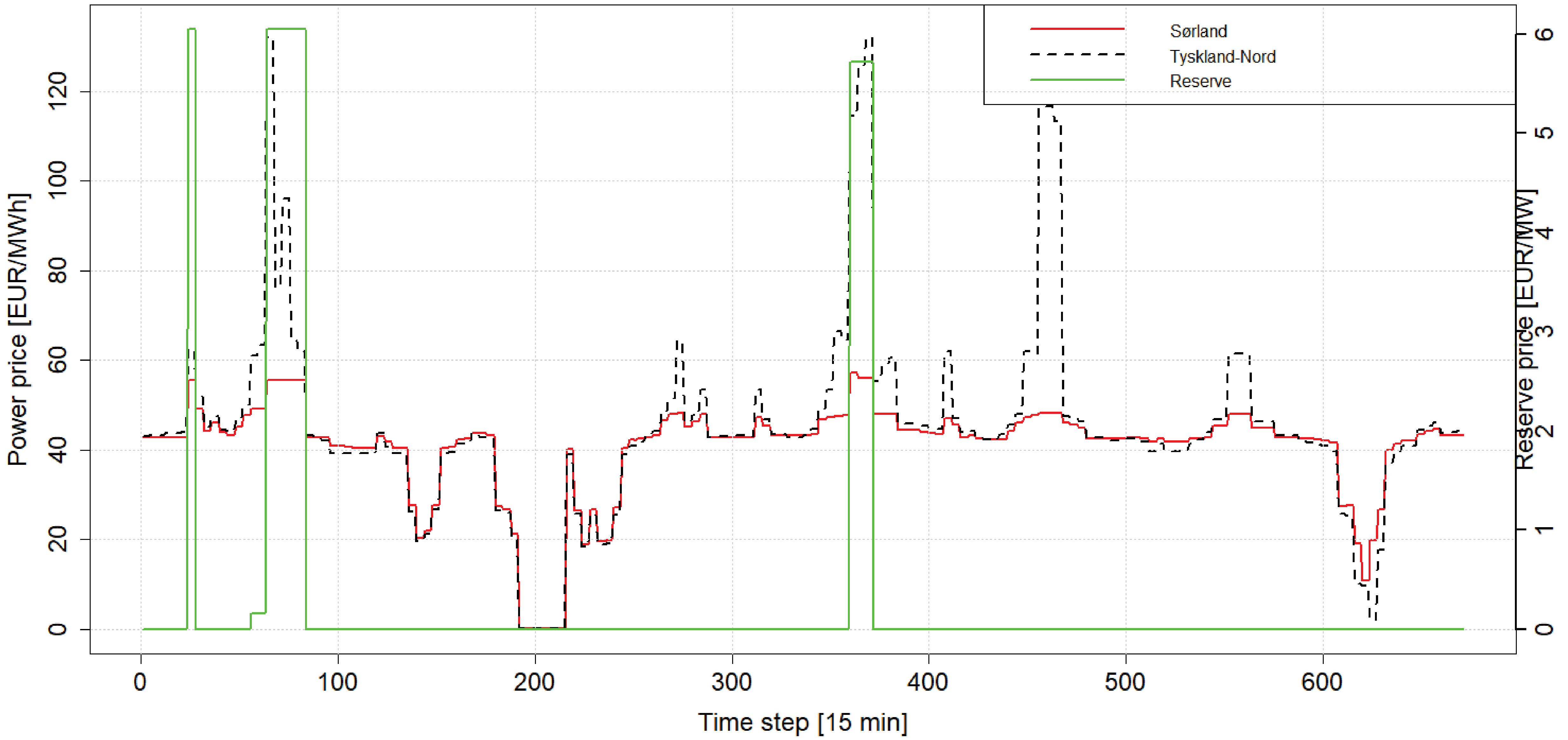
- ✓ Compute marginal prices for all electricity products
- ✓ Including reserve capacity and balancing energy
- ✓ Including flexible consumption and local storages



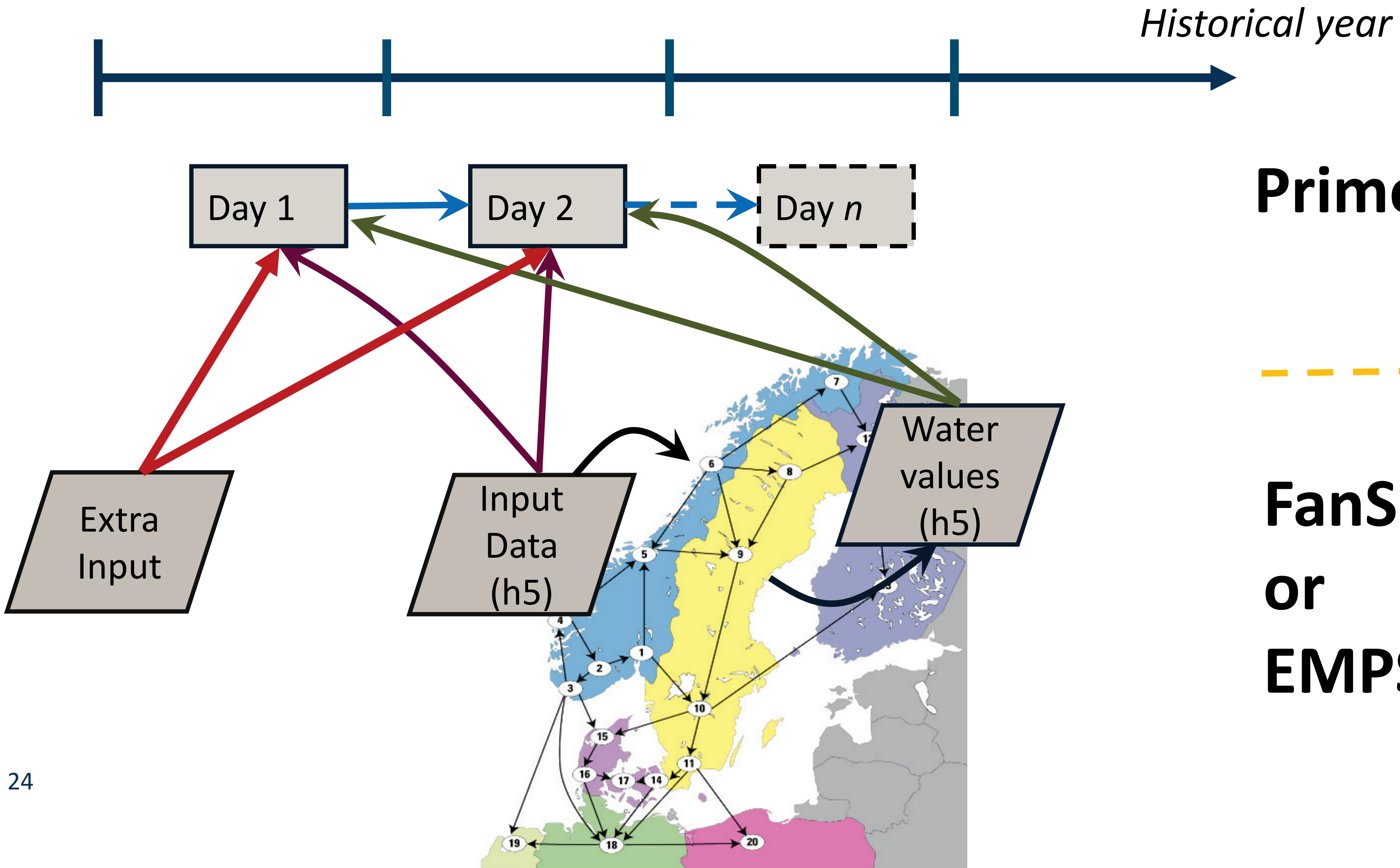
Expected application of model concept

- Compute simultaneous market price time series, e.g. for investment analysis
- Estimate the value of flexibility in different market designs, e.g.
  - Spot market clearing closer to real time
  - Common reserve markets in the Nordics

High-load week



Model Concept: PriMod



Primod

- *Research prototype*
- *Python/Pyomo*
- *Rapid prototyping*

FanSi or EMPS

- *Compiled*
- *Computational speed*

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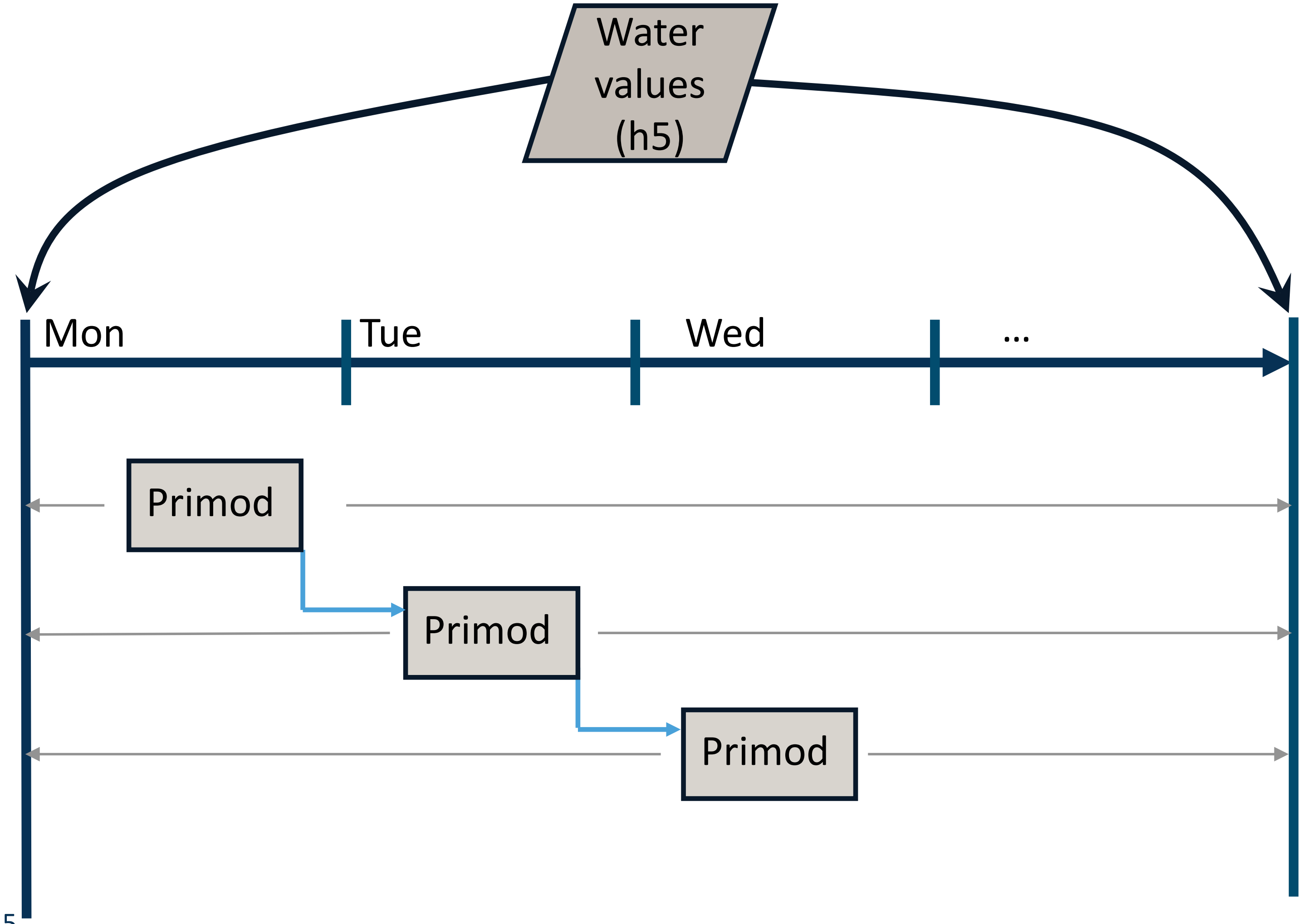
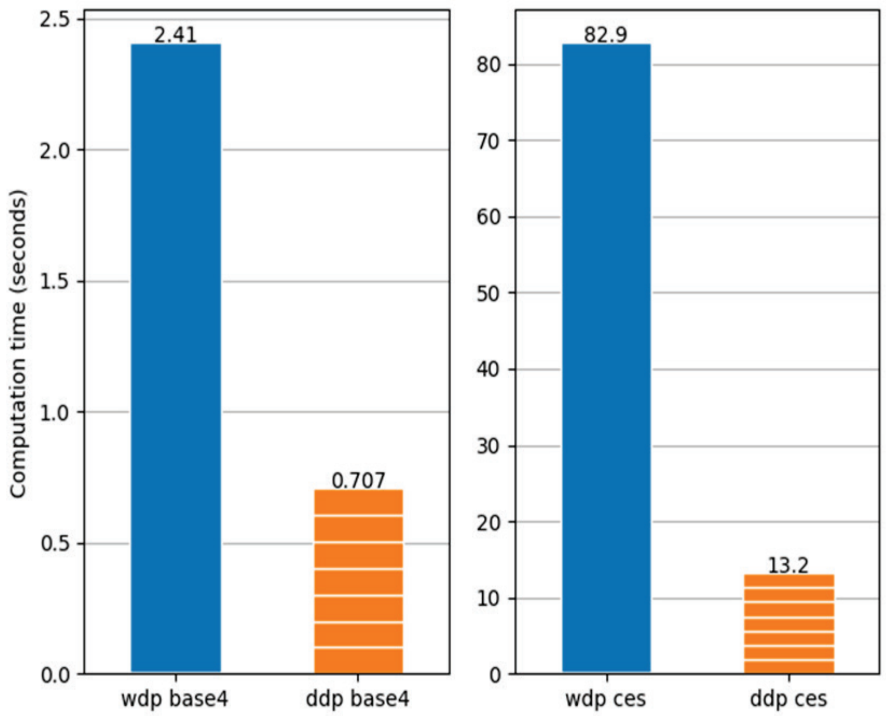
Decomposition, weekly →daily



Interpolation in cost functions:

- Rolling horizon towards end-of-week
- Capture seasonal trends
- Break the "deterministic structure"



Daily problem with end-value setting per week

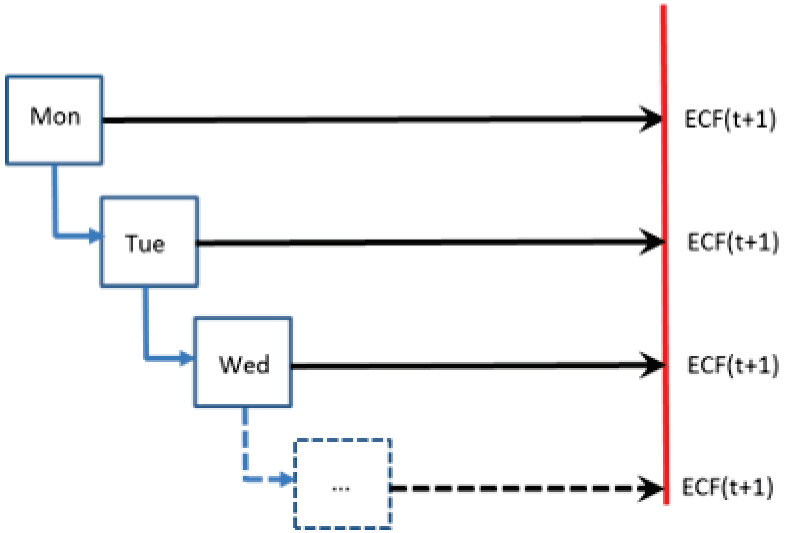


Figure 3 Illustration of rolling horizon towards a fixed end-valuation.

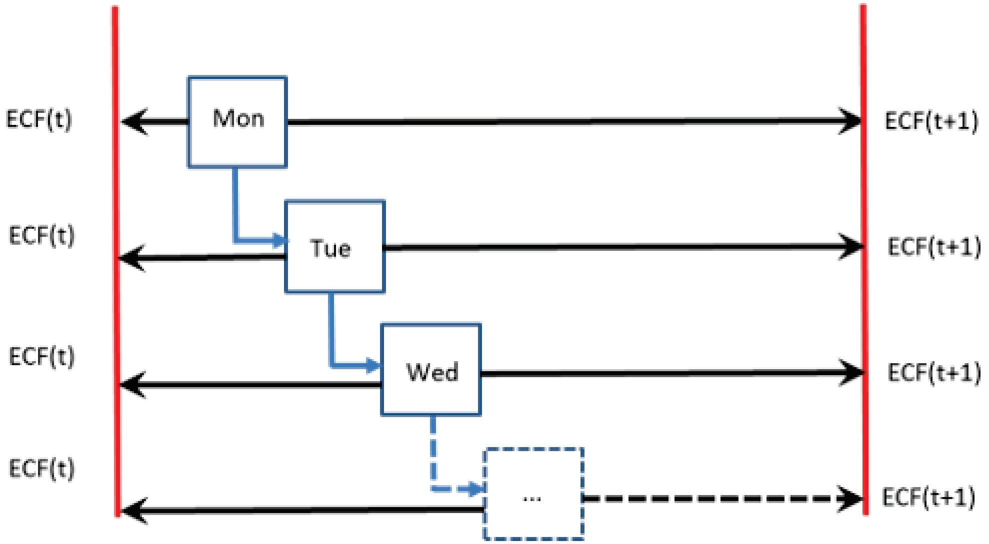


Figure 4 Illustration of rolling horizon towards an interpolated end-valuation.

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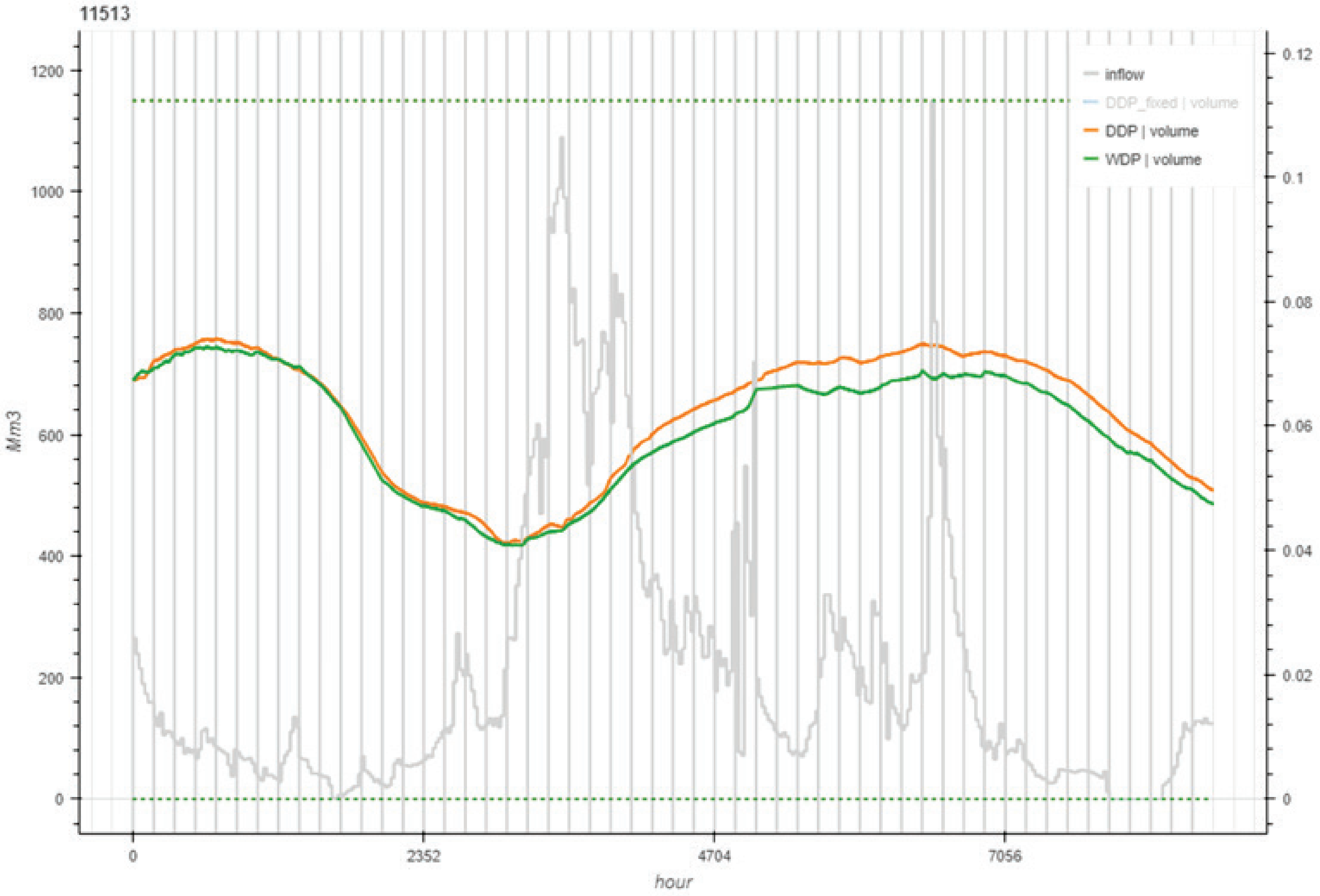

Figure 7 Reservoir level (in MM3) for Otras reservoir 11513 (Vatnedal) obtained from WDP and DDP. Inflow is indicated in grey.

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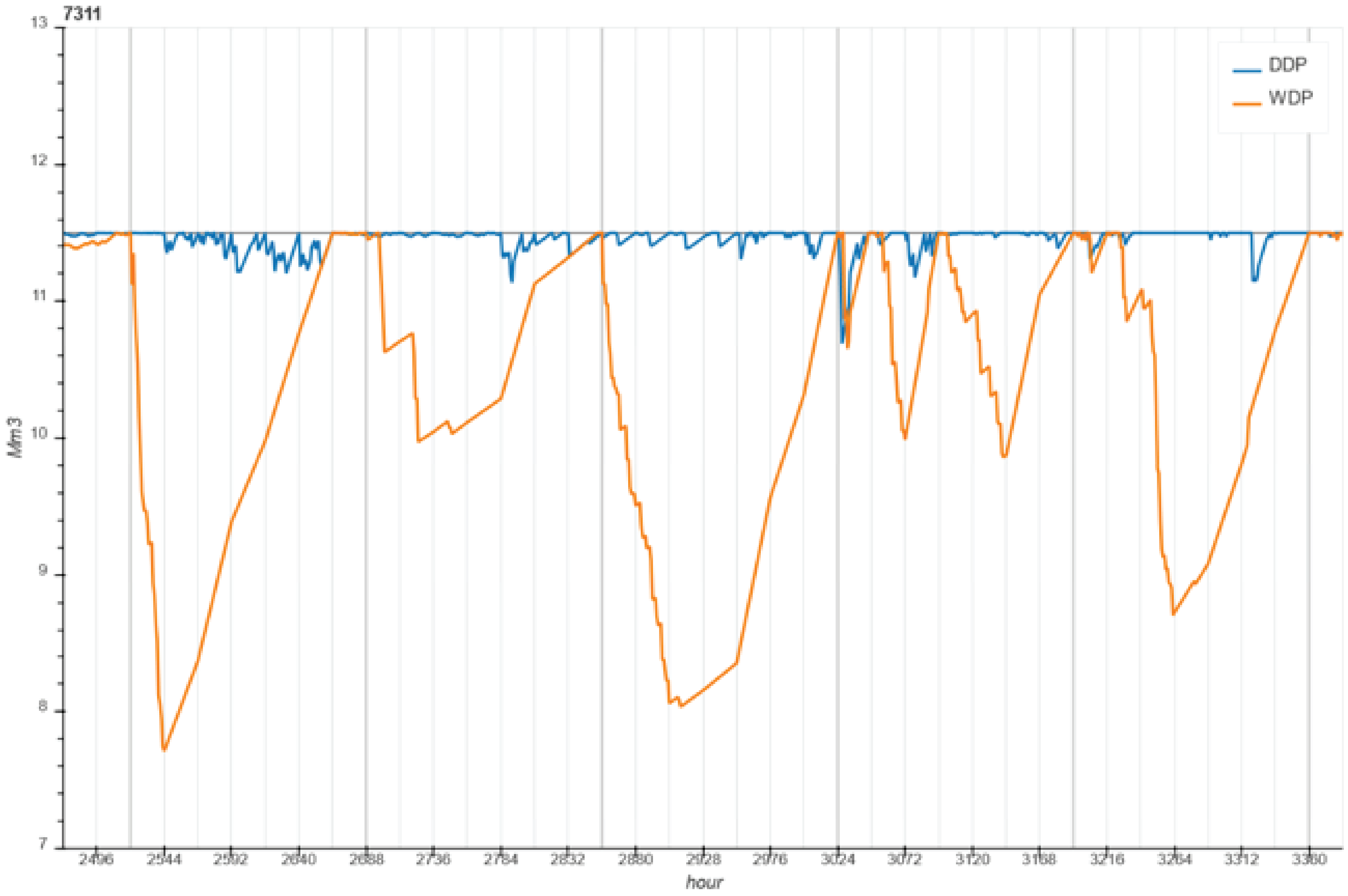
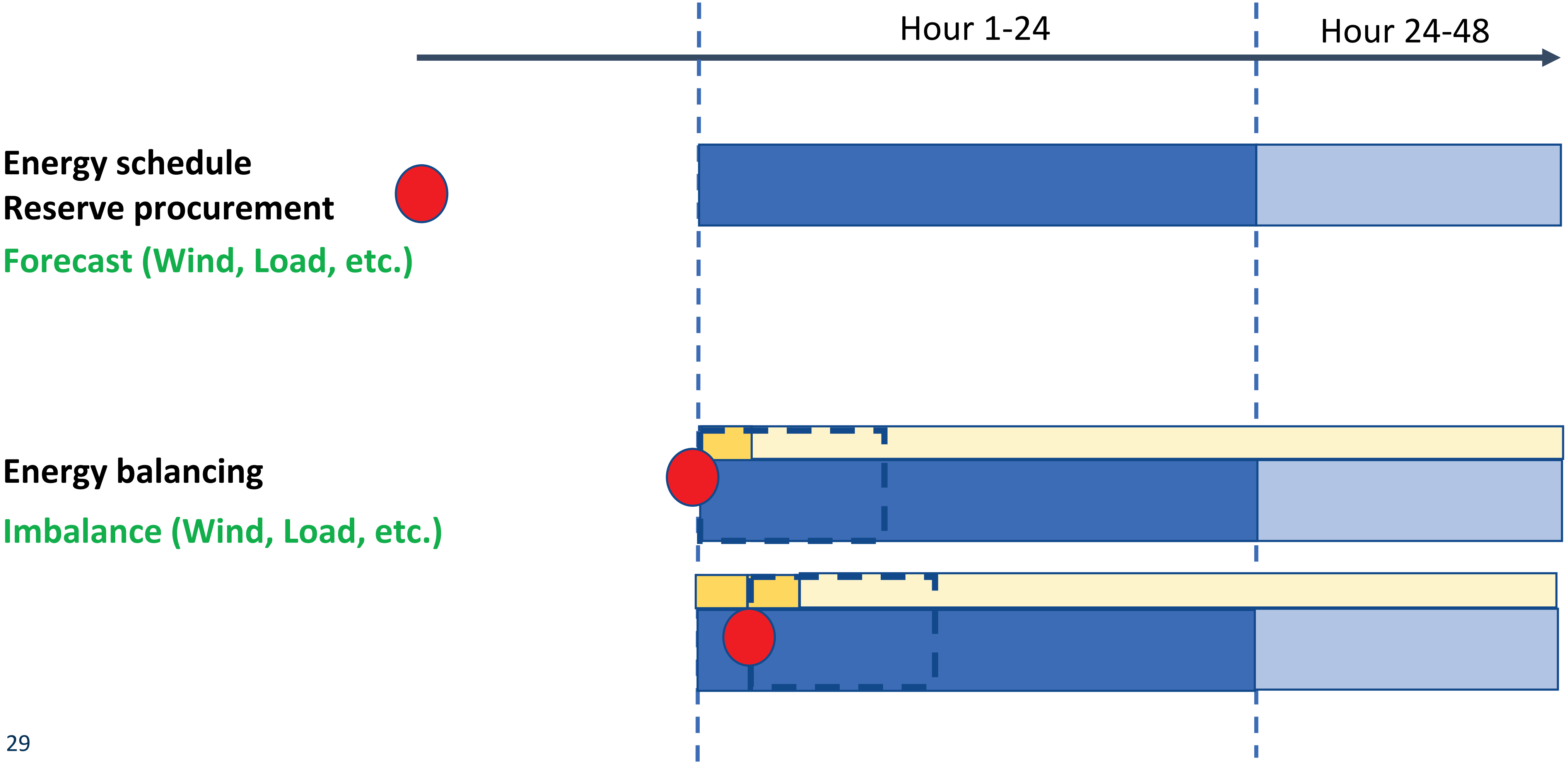


Figure 9 Reservoir level for reservoir 7311 (Vrenga) in area Numedal obtained from WDP and DDP. The vertical grey lines indicates the end of each day, and the thick vertical grey lines the end of each week.

Short-term model design



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