Short-term scheduling

SINTEF

Hans Ivar Skjelbred, Jiehong Kong, Christian Øyn Naversen, Per Aaslid, Ellen Krohn Aasgård, Michael Belsnes

SINTEF Energy Research

Short-term scheduling tools

SINTEF Energy Research delivers operational short-term hydropower scheduling tools. The general objective of the optimization tools is to maximize the profit within the planning period by exploiting the options for buying and selling energy or capacity in the markets, while fulfilling the firm load obligations.

The tools optimize unit commitment and production decisions for watercourses with hydropower. Pelton, Francis and Kaplan turbines are represented, as well as fixed speed and variable speed pumps. The delivery of ancillary services can also be optimally allocated among all types of units. A watercourse simulator is built into the tools to determine the physical consequences of manual re-planning.

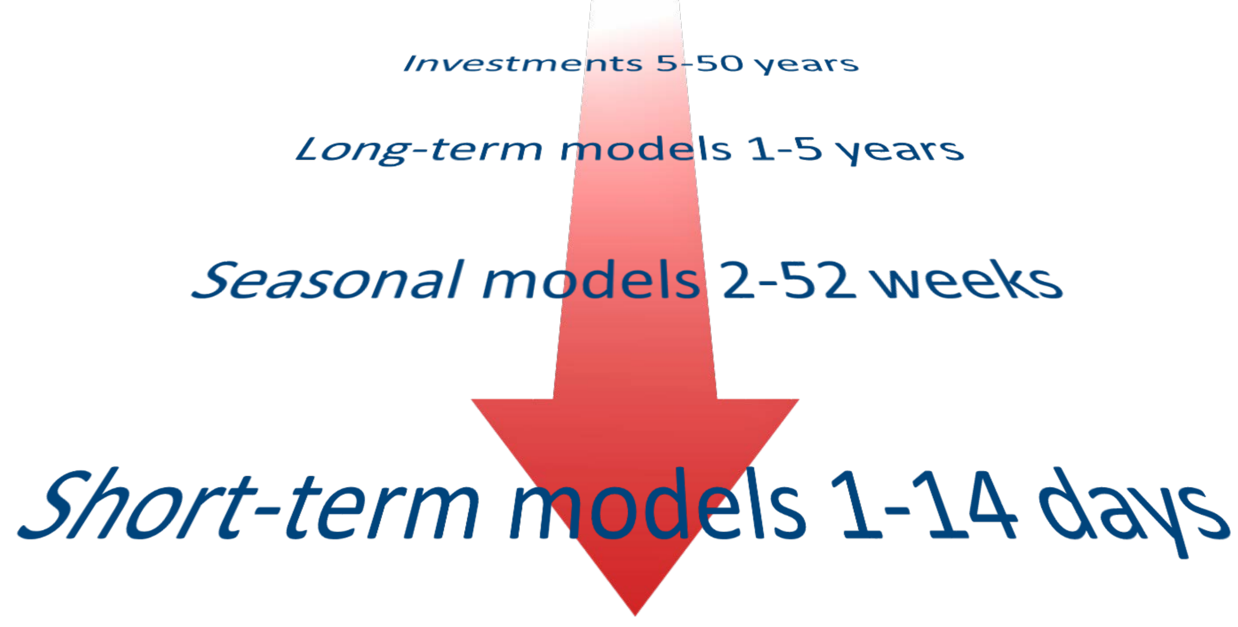
The short-term scheduling tools are also being used to evaluate costs and consequences of restrictions in watercourses as well as to assess the feasibility of capacity expansions. Policy questions regarding environmental impact of restrictions and investment planning can also be analysed.

The API (Application Programming Interface) of the short-term scheduling tools has been integrated with the APIs of the long-term tools developed by SINTEF Energy Research. The integration is done in Python and used to simulate the system in details over many years.

Most major hydropower producers in the Nordic region are using the short-term scheduling tools for daily operation. There are also users in Switzerland, Italy, Austria and Chile.

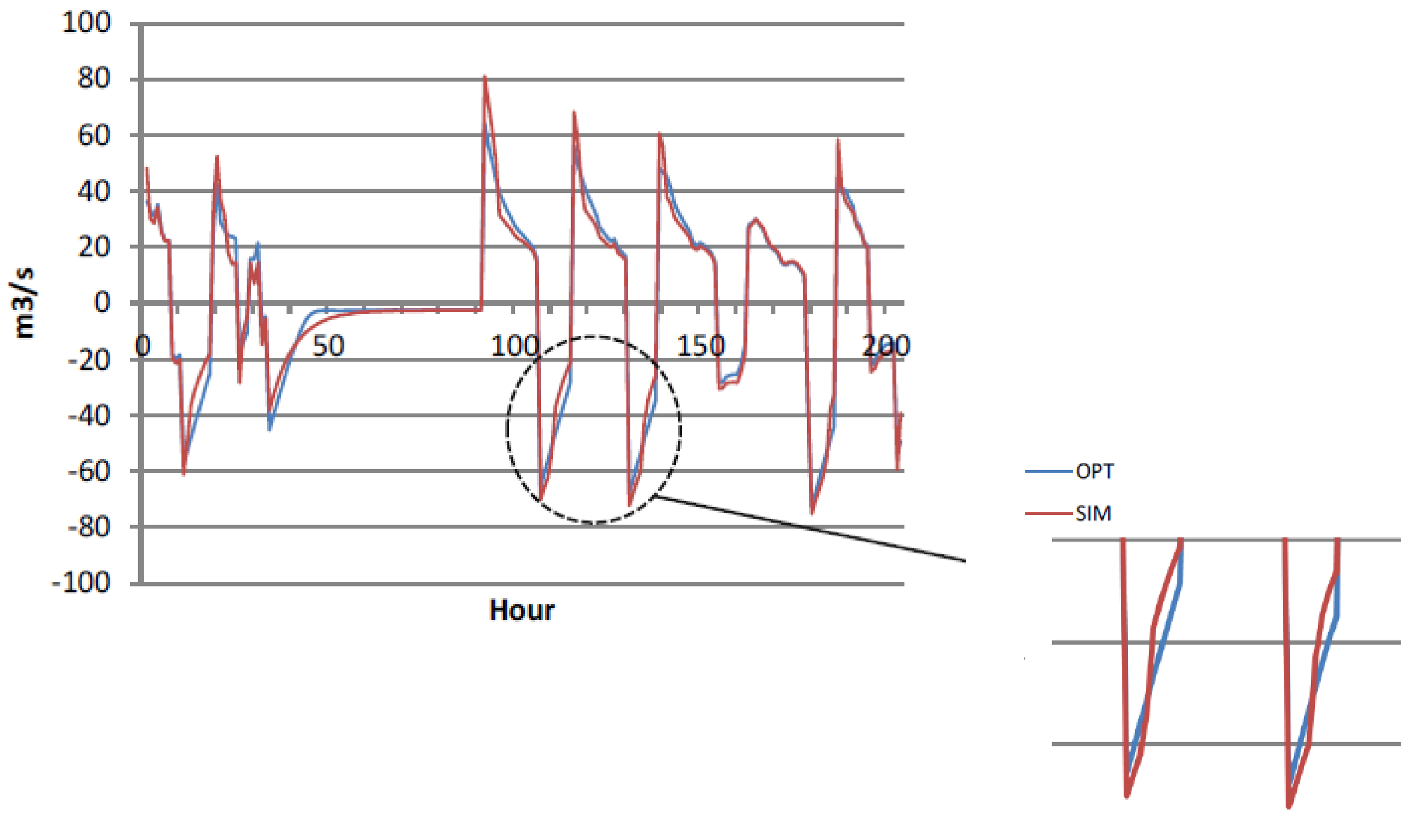
SHOP

SHOP is a deterministic optimization tool where complex hydraulic configurations of watercourses are modelled. It is able to handle any number of cascaded watercourses. SHOP includes all the main components such as reservoirs, hydro units, gates, junctions, creeks and thermal units. Optimization is based on successive linear programming and may include mixed integer formulation. CPLEX is most commonly used as solver, but Gurobi and COIN/CBC are also available as solvers.



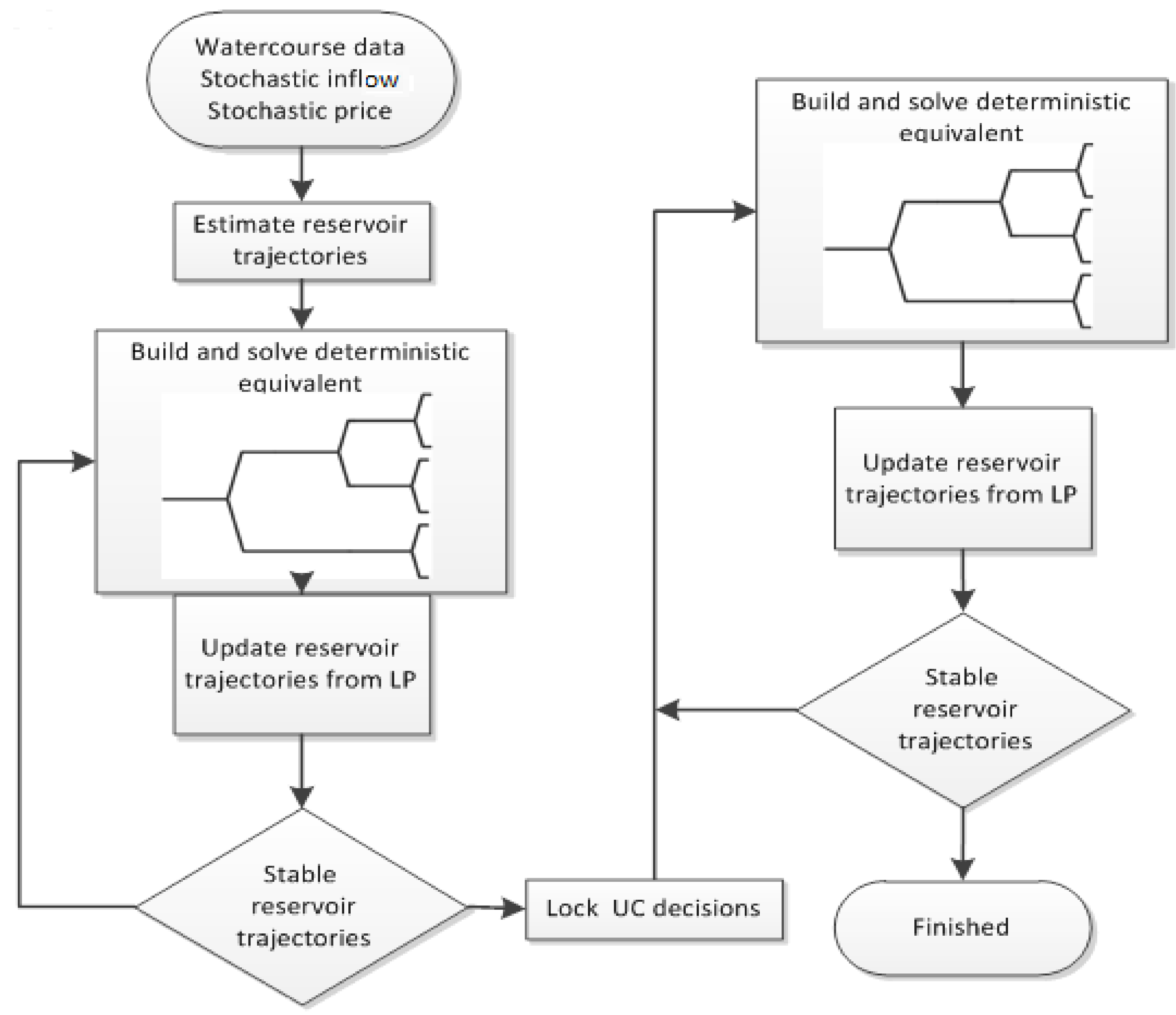
SHOP-SIM

SHOP-SIM is developed to simulate entire watercourses when all the user-controllable decisions are defined by schedules. The input is given in the same format as that for SHOP. The physical response of the system is sequentially calculated. Non-linear and state-dependent equations are solved directly in simulation while successive linearization is required in optimization. Therefore, SHOP-SIM can be used to validate the result from the optimization. Since the calculation time for most real-world cases is less than one second , SHOP-SIM is also well suited for manual re-planning.



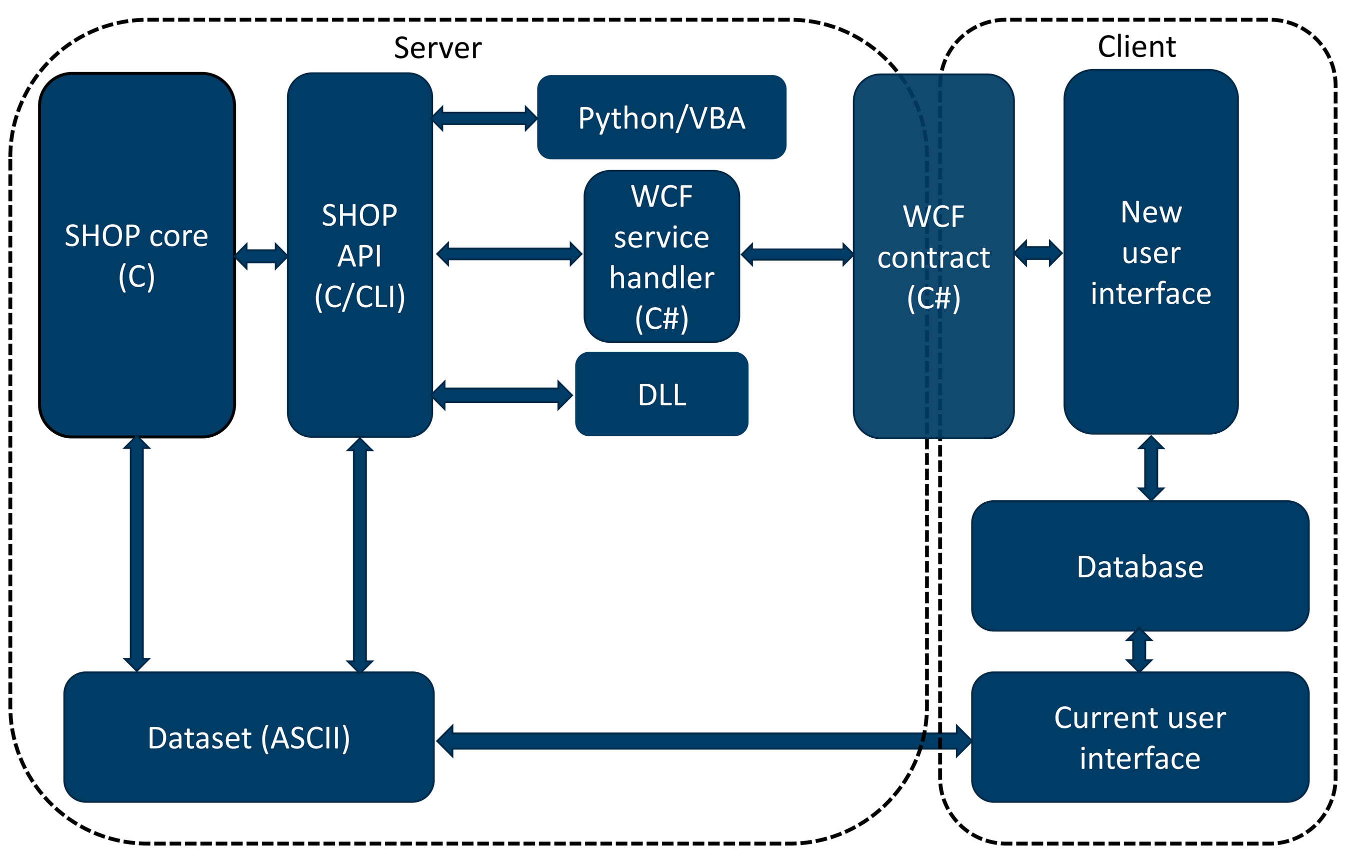
SHARM

SHARM is the stochastic version of successive linear programming that has been implemented within the framework of SHOP. The method is based on a discrete representation of uncertainty in the form of scenario trees. SHARM has been extended to include decision support for optimal bidding. The model can be solved by CPLEX, Gurobi or COIN/CBC.



API

The fundamental concept of the API is to provide basic functions with relatively simple data structures to transfer all data to and from the scheduling tools. The API can be flexibly integrated by different programming languages, such as Python, C# and VBA.



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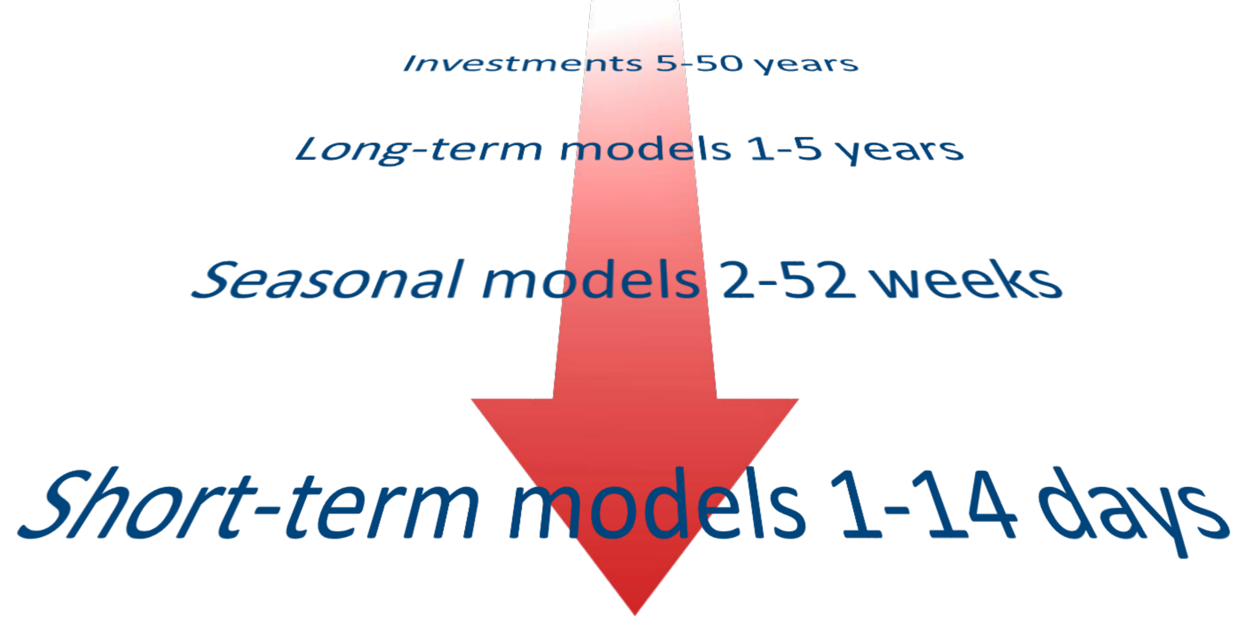

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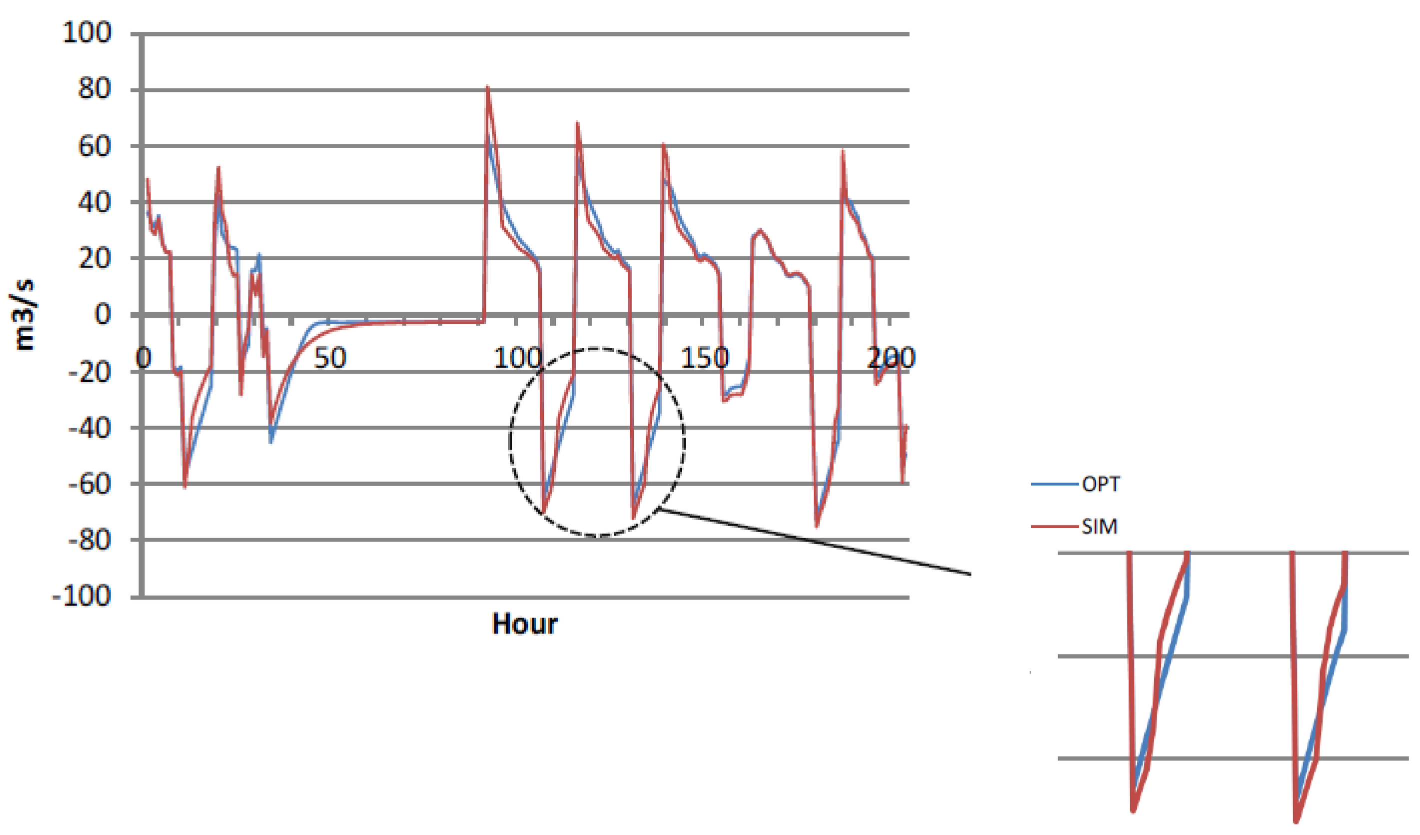

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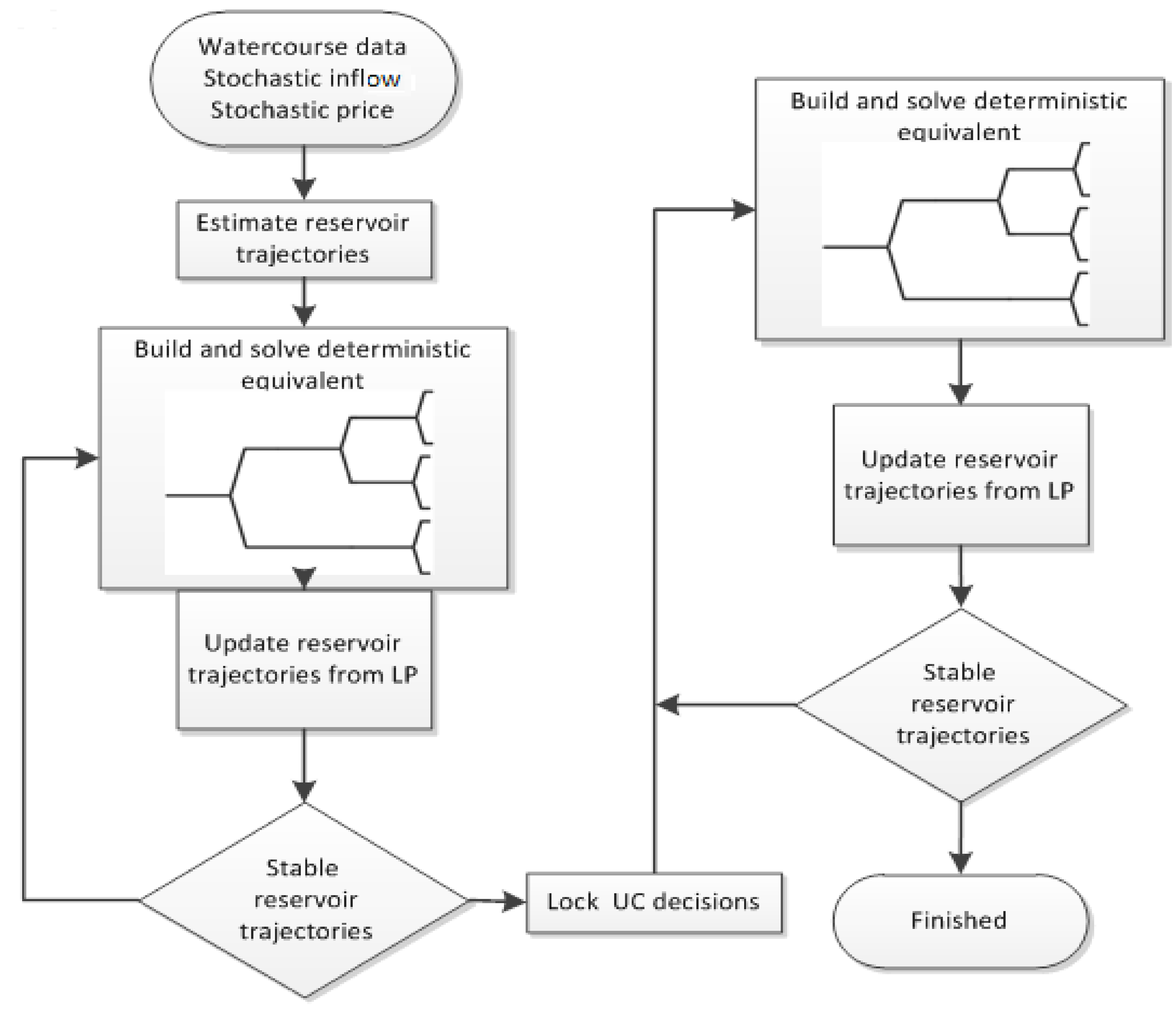

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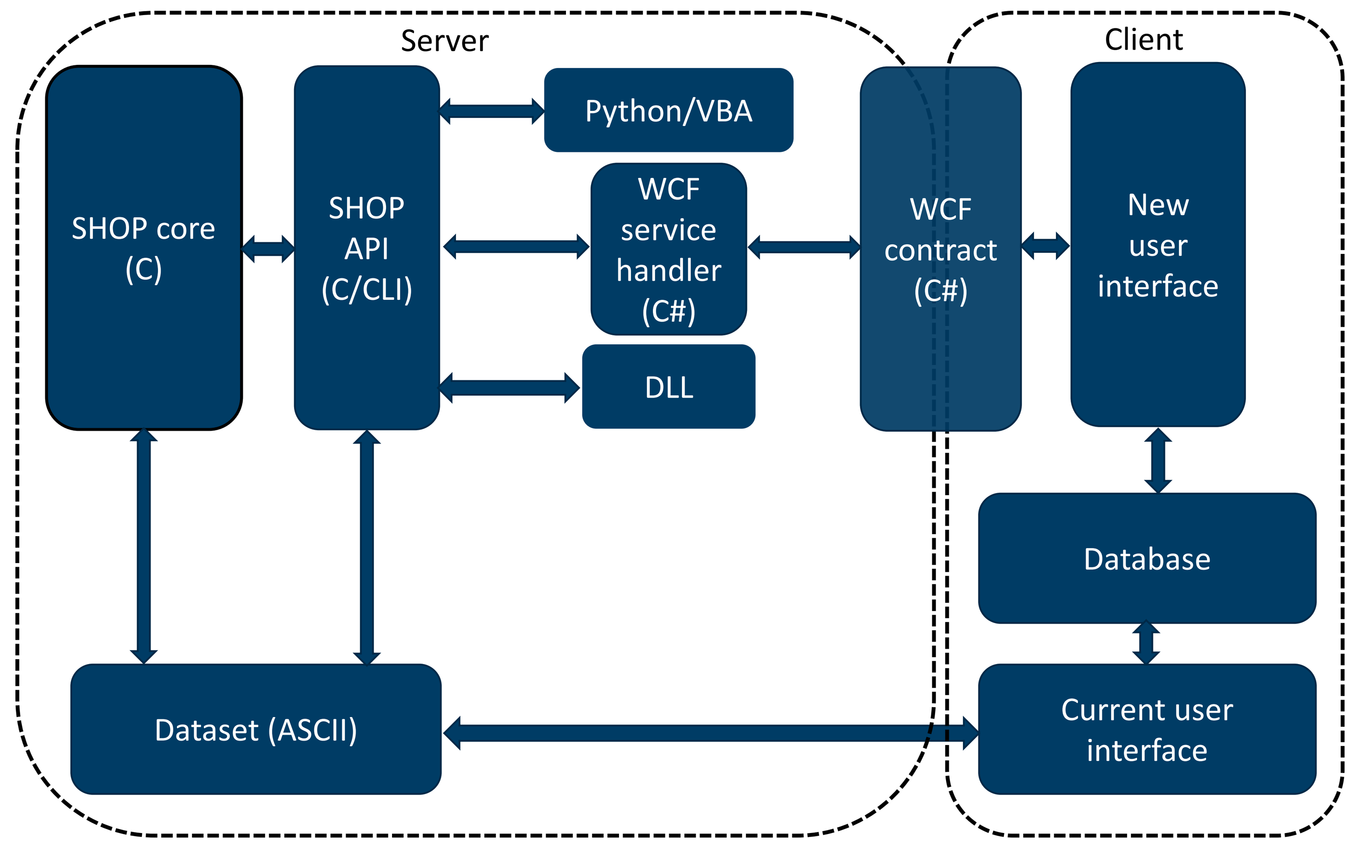

LTM release 9.9 and 10.0

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LTM release 9.9 and 10.0

Release 9.9. Delivered 1. Mars 2017
Release 10.0. Beginning of 2018.

Release 9.9

Main functionality

New free functionality

- Time dependent calibration factors

Freed functionality

- Feedback to water value calculation from revisions and pumping
- Soft reservoir constraints
- Automatic calculation of revision costs
- Calibration using minimum production constraints
- HBV forecast in EMPS
- Seasonal model in EOPS; Water values for each scenario, overflow

Licensed functionality

- Parallel processing of Kopl
- Several improvements of system price calculations
- Water value calculation with energy inflow including overflow
- Separate presentation of bypass and overflow
- Improved seasonal model in EMPS
- Presentation of flow between hydraulic coupled reservoirs.

Release 10

Main functionality

New free functionality

- All EMPS results on HDF5 files
- Input API for (new) time series
  - Firm and price dependent contracts
  - Inflow forecast for whole planning period
  - Non-controlled production and exogenous stochastic prices
  - Transmission constraints
- A domain model

New applications (LTM and EOPS) replaces Vansimtap application

- Allows for running using XML input (not data input)

Licensed functionality

- Calendar correct input and output

Prototype Vansimtap/ProdRisk API

- Free functionality
- A complete API for the models but with a bit reduced functionality
  - Input
  - Running the models
  - Output
  - Price taker assumption
  - Only available for ProdRisk 9.6

Vansimtap API example using Python

```
vansimtap = vansimtapAPI(runID,silentConsole)

vansimtap.SetOptimizationPeriod("20170102","20180416")
vansimtap.ReadXmlInputData(vansimtapInputFiles)
IO.SetString(vansimtap,"setting","setting","prodriskPath",vansimtapRunPath)
IO.SetInt(vansimtap, "setting","setting","startWeek",1)

vansimtap.GenerateVansimtapFiles()
vansimtap.RunVansimtap()

production = IO.GetSTxySeries(vansimtap, "module", "mod1", "production")
discharge = IO.GetSTxySeries(vansimtap, "module", "mod1", "discharge")
writeResultsToFile("vansimtap_"+runID+"_results.txt",production, discharge
```

MultiSHARM

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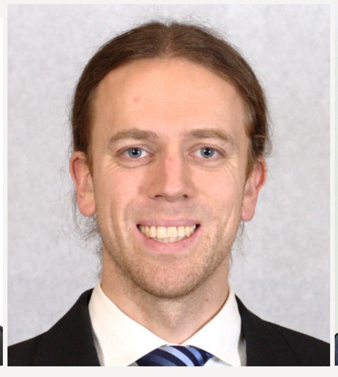


Day-ahead Bidding with Multiple Short-term Markets

How can hydropower producers optimize their strategy across multiple, sequential energy and reserve markets?

Participation in markets other than the day-ahead energy market may offer producers increased profits or more flexible production schedules.

Coordinating the trading strategy across several markets may thus be a competitive advantage for producers.

The project aims to develop methods for optimal hydropower scheduling to support bidding in the day-ahead market as part of a sequence of markets. Developments are sought included in current SINTEF tools such as SHOP/SHARM.

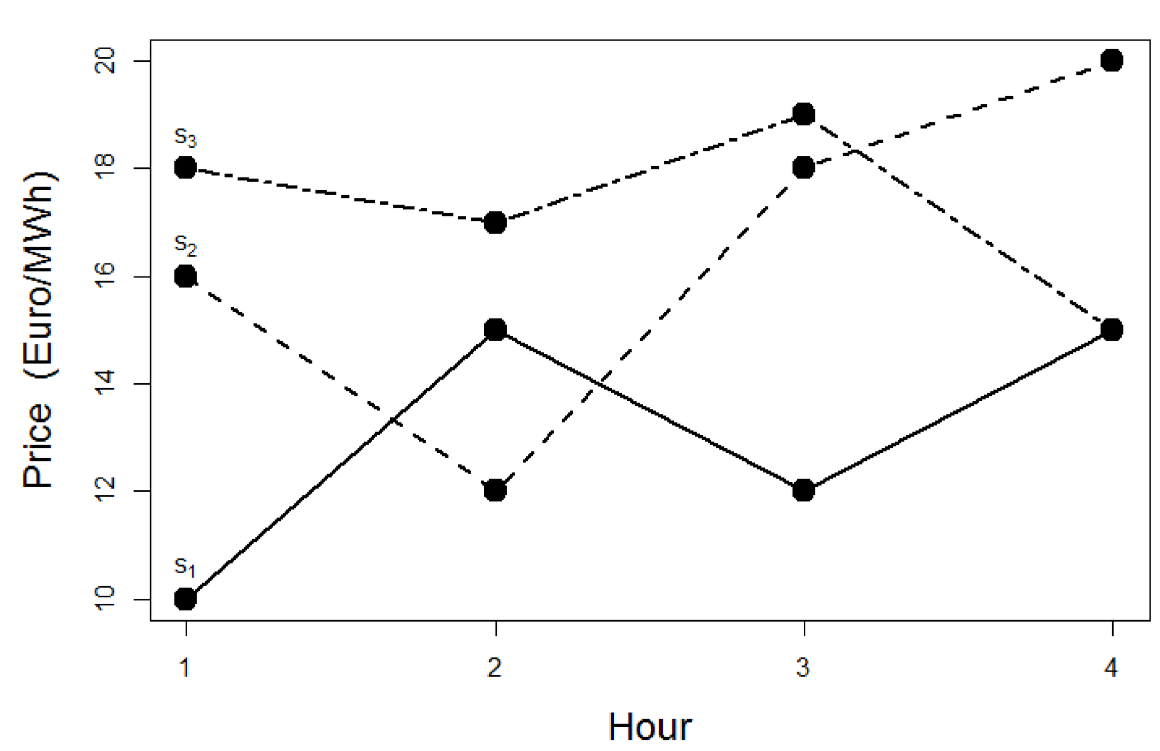
The project is a joint effort with SINTEF Applied Economics, NTNU and industry partners. The project started in 2015 as a continuation of the former SHARM projects, and will run until 2018.

Day-ahead bid optimization

The MultiSHARM project has extended the SHARM model to support optimization of bids to the day-ahead energy market.

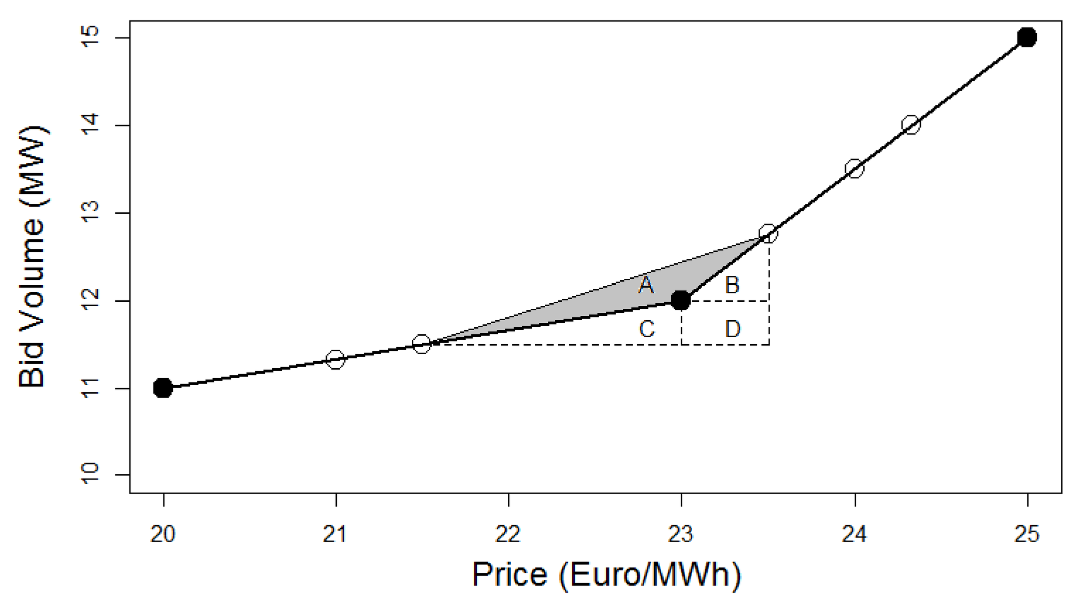
SHARM is a stochastic programming model that builds on the same successive linear programming technique as SHOP. Both prices and inflows may be represented as stochastic parameters.

Bids are calculated from optimal production schedules for each scenario. To get a non-decreasing curve, bids in any scenario has to be lower than or equal to bids in scenarios with higher price.



To build an increasing bid curve, we must compare the production quantity across scenarios.

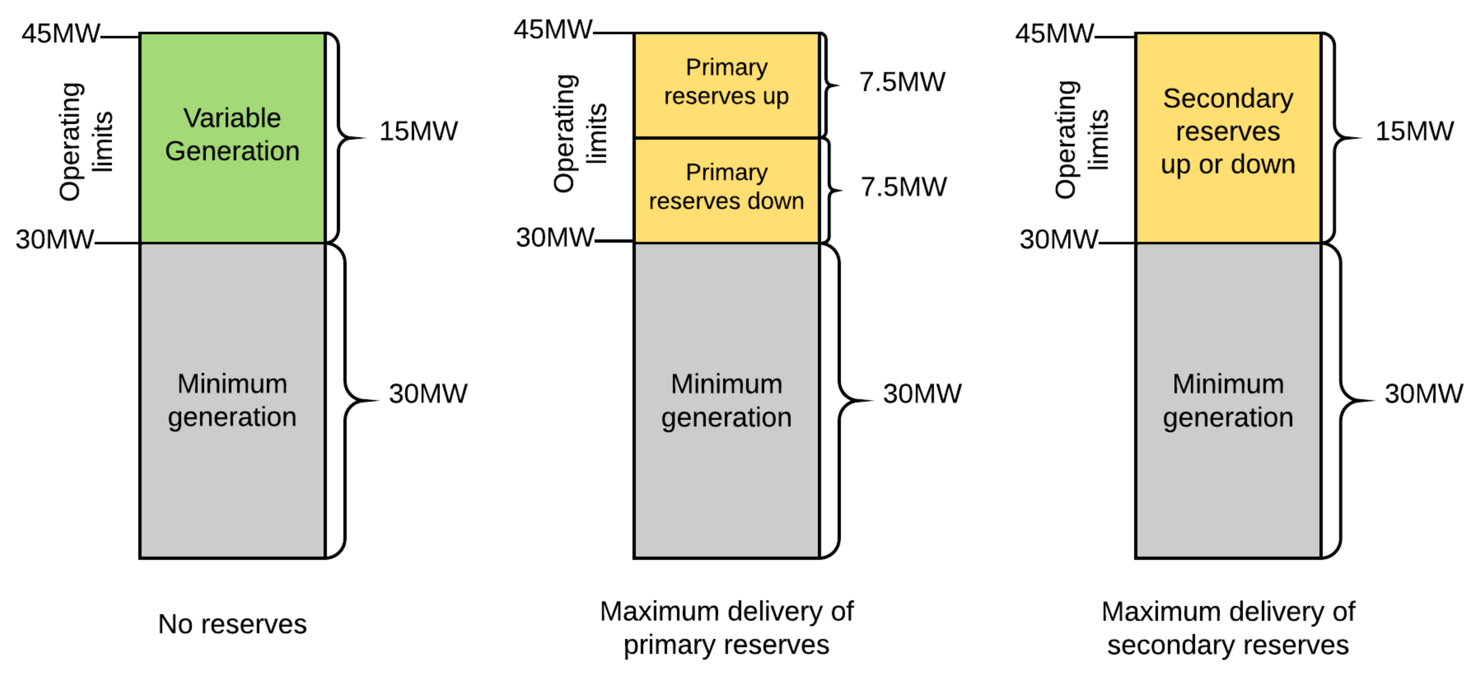
The bid curve may need to be reduced to comply with the size limitations set by market rules. This is done by a greedy heuristic that removes the least important columns of the bid matrix.



The bid curve is reduced by removing the columns which give the minimal change in shape of the curve.

Multiple markets: Energy and reserves

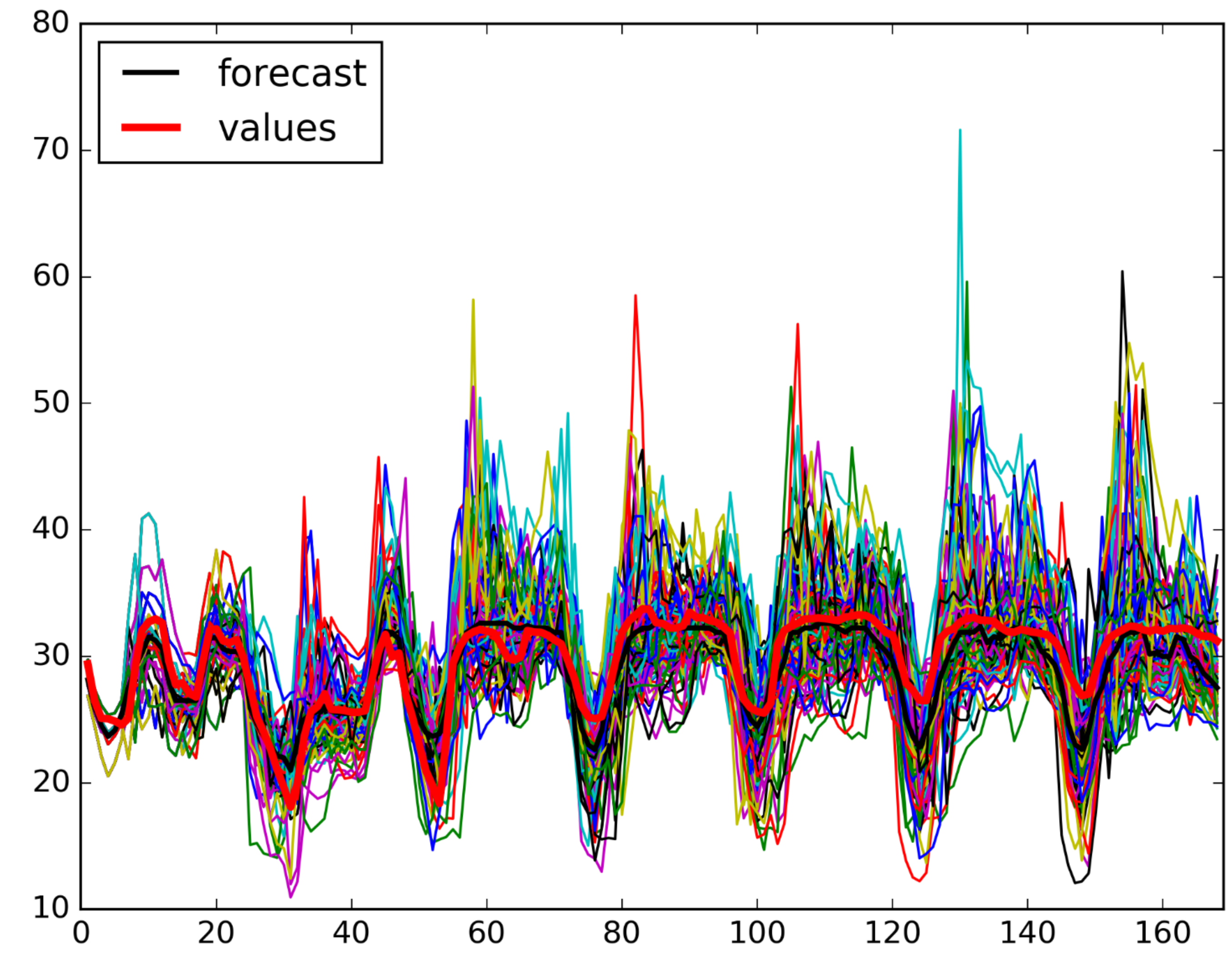
It is possible to optimize sales of both energy and reserves in SHOP. This functionality is also available with stochastic inflows and prices in the MultiSHARM project.



The model offer support on how to allocate production between energy and reserves.

Scenario generation

The MultiSHARM project has developed a new method for scenario generation based on historical forecasts and forecasts errors.



Plot of 100 generated scenarios. The black curve shows the forecast, the red curve shows the realized market prices.

IBM

Integrating balancing Markets in hydropower scheduling

2014 – 2017

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SINTEF

Project Goal

- Identify how balancing markets may impact water values
- Develop suitable methods for assessing this impact

Motivation

- Increasing importance of balancing markets in the future
- Income potential from balancing markets

Assumptions

- Price taker
- Risk neutral
- Sales of energy and reserve capacity

Challenges

- Prices and volumes are difficult to predict
- Nonlinear and non-convex relationships, e.g. unit commitment

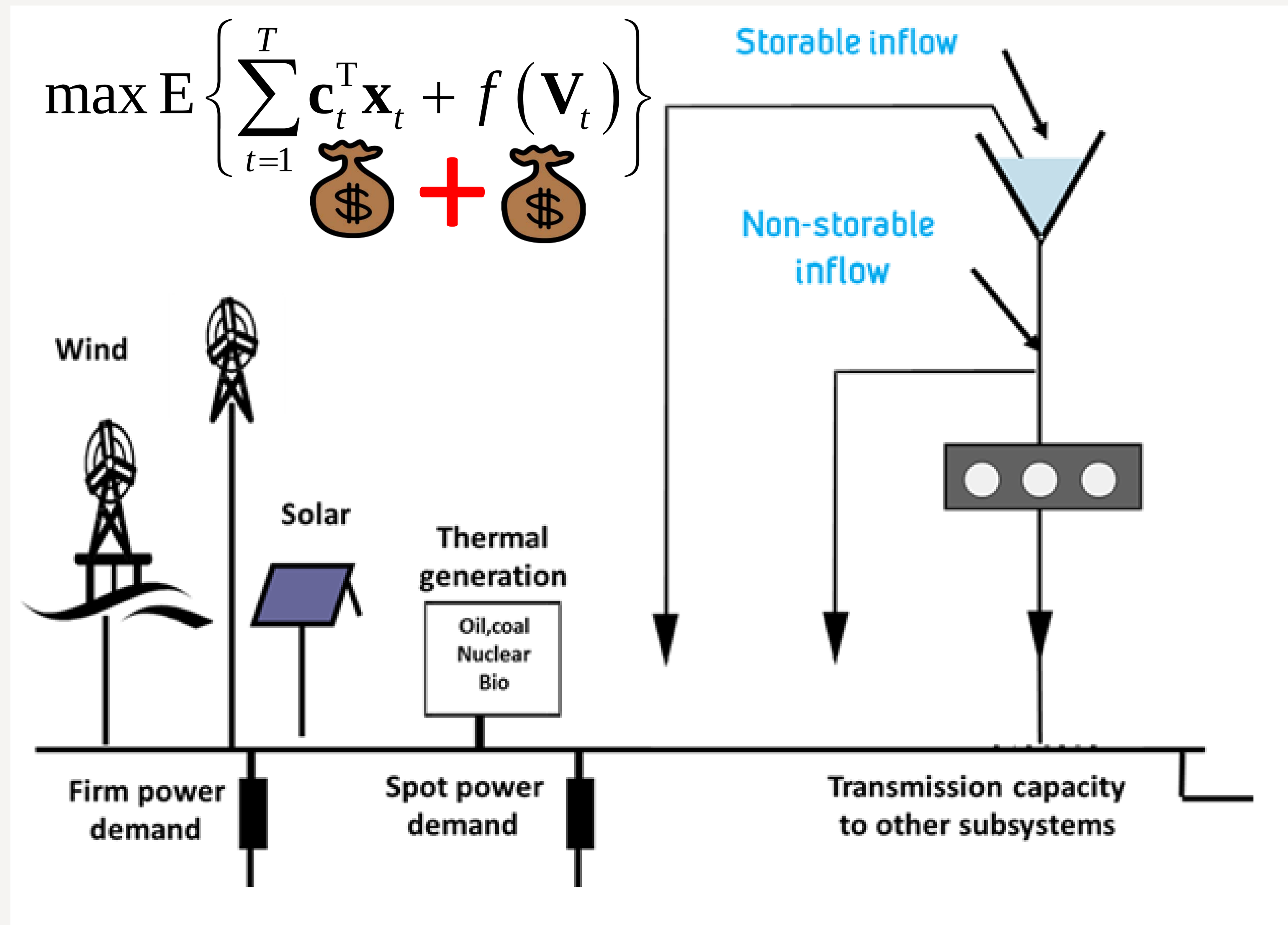
Methods

- Stochastic Dynamic Programming (SDP)
- Stochastic Dual Dynamic Programming (SDDP)
- Stochastic Dual Dynamic Integer Programming (SDDiP)

Experiments

How do water values differ when comparing…

- Approximate (LP) and detailed (MIP) modelling of nonconvex relationships
- Simultaneous vs. sequential market clearing of energy and reserve capacity
- Linearized vs. accurate start-stop modeling
- Zero and full energy requirement for sold reserve capacity



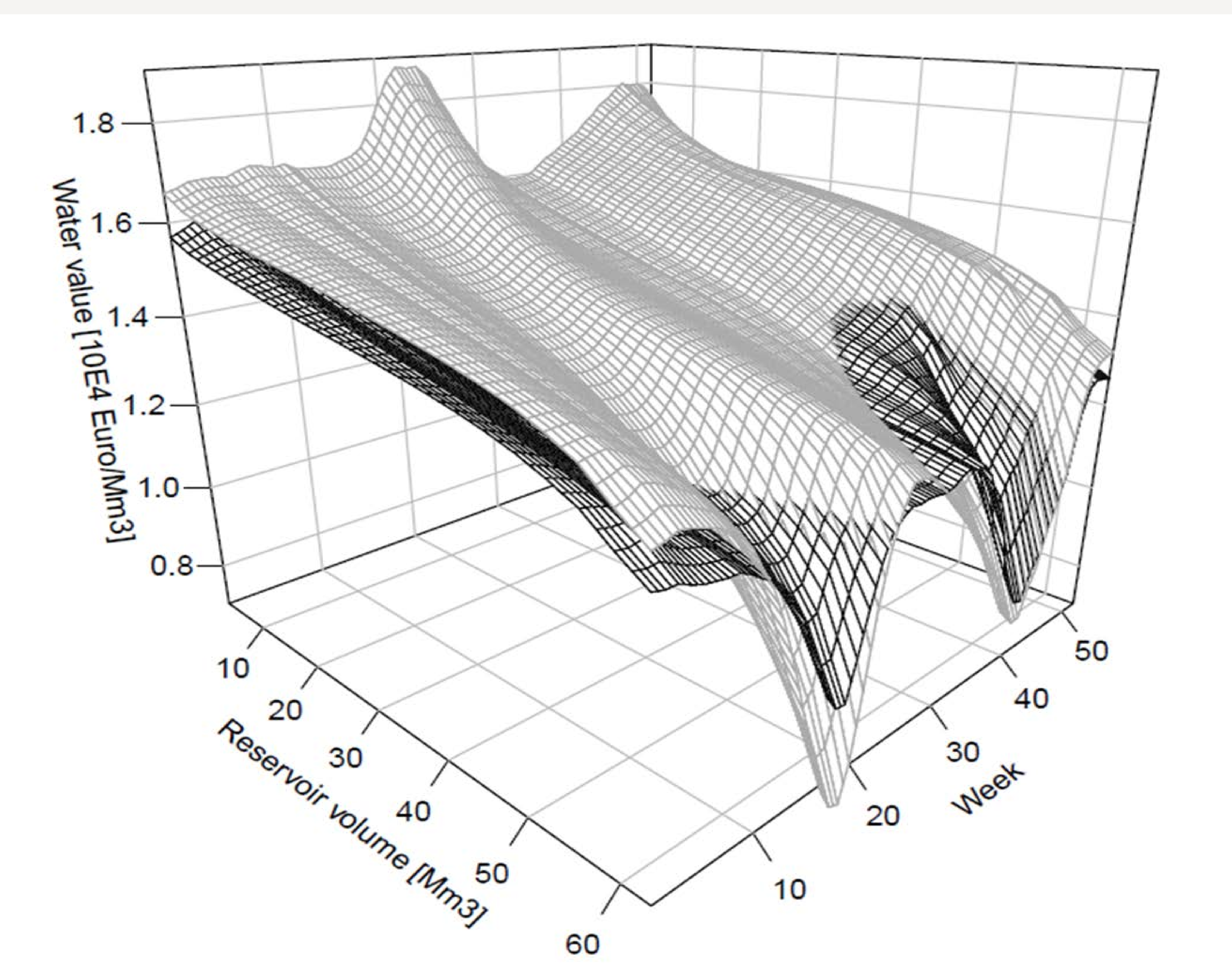
ProdRisk Improvements

New ProdRisk functionality

- Start-up cost (linear)
- Price mark-up on power plant (e.g. green certificates)
- Improved final simulation

ProdRisk prototype with sales of reserve capacity

- ✓ Multiple markets for reserve capacity
- ✓ Capacity sold at a deterministic price
- ✓ Symmetric and separate up- and down regulation
- ✓ Co-optimal and sequential market clearing
- ✓ Minimum production limits
- ✓ Linearized start-stop cost



With (grey) and without (black) reserve capacity market

Conclusions

- We have developed a ***modeling toolbox*** for computing water values in future electricity markets
- Separate between the generic products *energy* and *reserve capacity*

- Down-regulation capacity → Higher water values
- Up-regulation capacity → Lower water values

Forskningsrådet
agder energi
HYDRO
Lyse
NTNU
ECO
Statkraft
VATTENFALL

MAD – Methods for Aggregation and Disaggregation

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Ole Martin Hansen, OleMartin.Hansen@sintef.no

Project goals

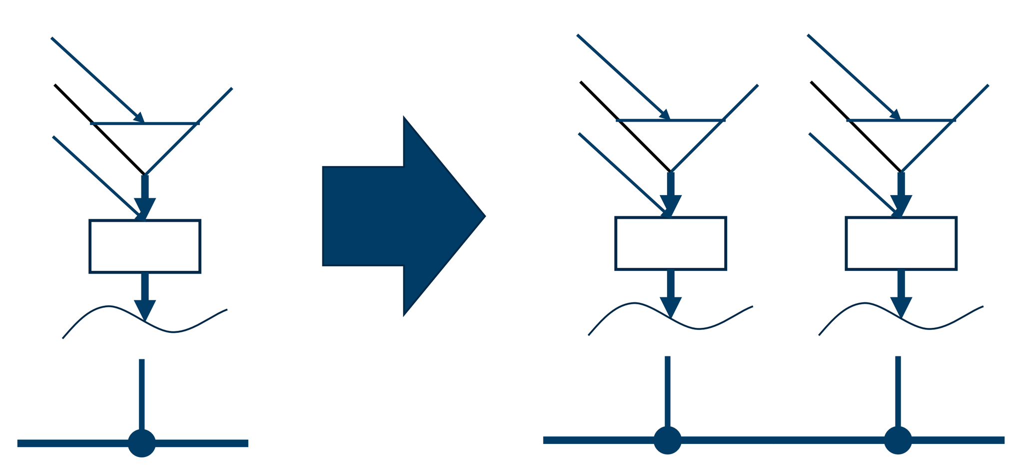
Improve the EMPS model
Improved aggregation method
New aggregation structure

Improved disaggregation method
Heuristics based solution => Formal optimisation based solution

Aggregation

Aggregation of hydropower systems is used to reduce problem size and calculation time. Replace the aggregated one reservoir structure with an aggregation to two reservoirs.

One reservoir   Two reservoirs

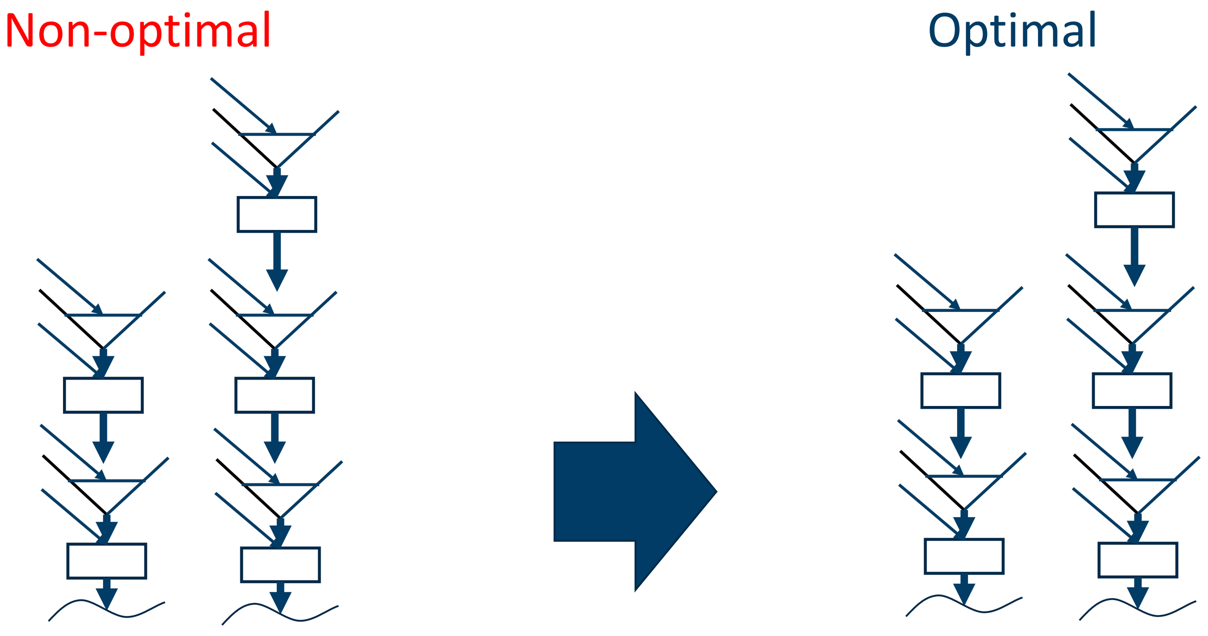


Disaggregation

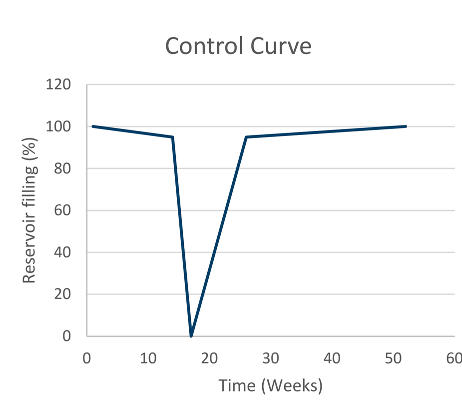
The non-optimal heuristics based disaggregation techniques will be replaced by formal optimisation. The new disaggregation will allow for the modelling of optimal intra-week production from uncontrollable renewables and a stronger coupling with Europe.

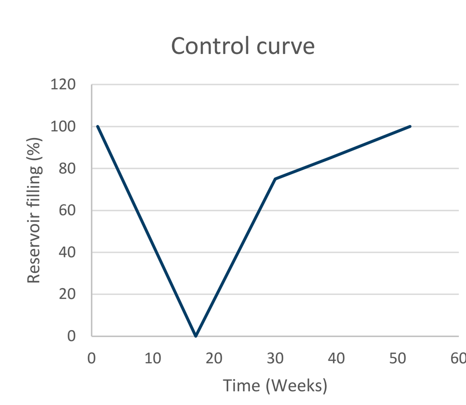
Heuristics based
Non-optimal

Formal optimisation
Optimal



$$\begin{array}{ll} \text{maximize} & \mathbf{c}^{\mathrm{T}}\mathbf{x} \\ \text{subject to} & A\mathbf{x} \leq \mathbf{b} \\ \text{and} & \mathbf{x} \geq \mathbf{0} \end{array}$$

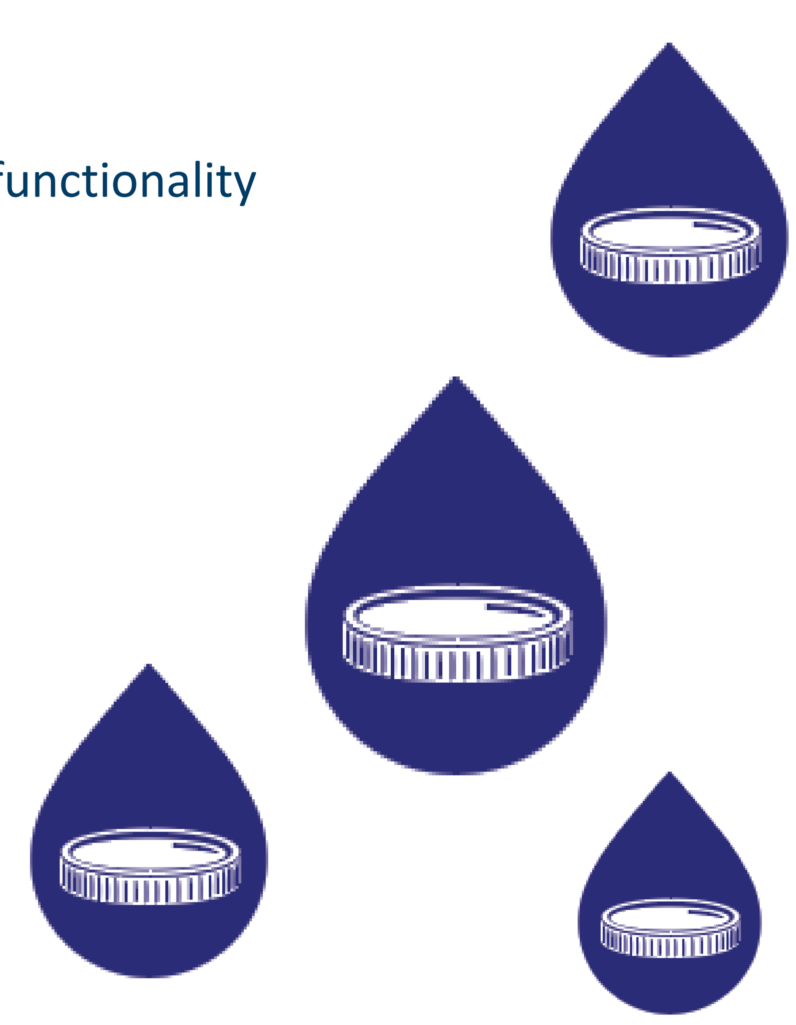




Pros and cons

Pros
- Better results
- Less complex code
- Easier to debug
- Easier to understand
- Easier to include new functionality

Cons
- Computation time



Partners

Energy System Analyses – Future Scenarios

SINTEF

FME CenSES RA5 and KPN Norwegian Energy Road Map 2050

SINTEF Energi, SINTEF Teknologi og samfunn, NTNU Indøk, NTNU Elkraft, NTNU KULT, IFE, NVE, Statnett, Statkraft, Statoil, Hydro, Sør-Trøndelag Fylkeskommune, Enova, Trønderenergi, ...

Objective

How can the future Norwegian energy system contribute and adapt to a low-carbon society

What?

- Long term scenario analyses with a horizon of 2030 to 2050
- Overall energy system with multiple energy carriers

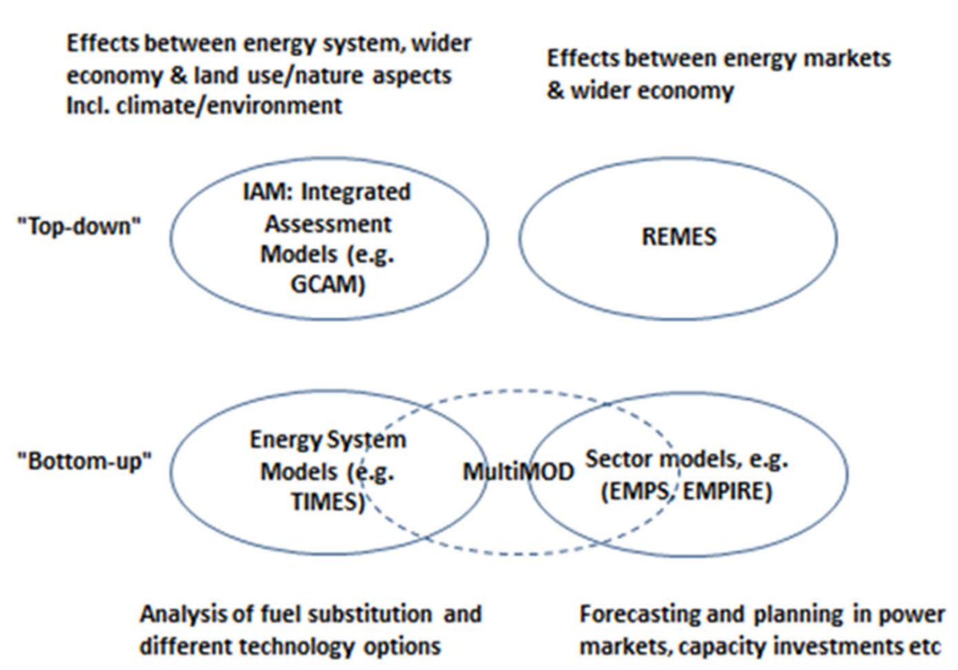
How?

- Describing a framework of multiple possible future scenarios, not forecasting the one most likely
- Cross-disciplinary – quantitative and qualitative analyses to build and evaluate scenarios
- Application and linking of multiple energy system models

Coordinated use of multiple models

- A comprehensive analysis of the Norwegian energy system is targeted
- Scenarios will be assessed with a number of different energy system models
- A linking of the various energy system models is intended

- An infrastructure project is planned in order to build up a Norwegian Analysis Platform for Energy Systems

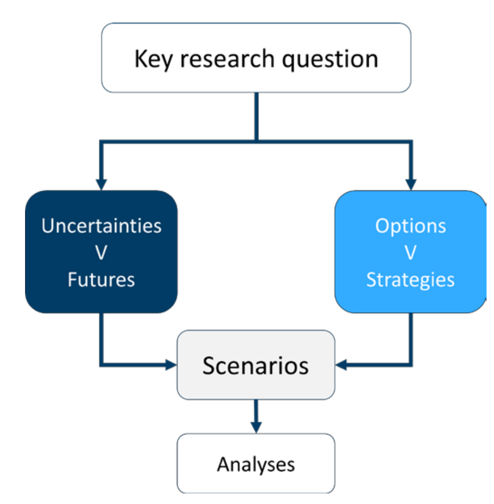


Model overview

CenSES scenario development process

Combination of ***Futures*** and ***Strategies*** defines ***Scenarios***

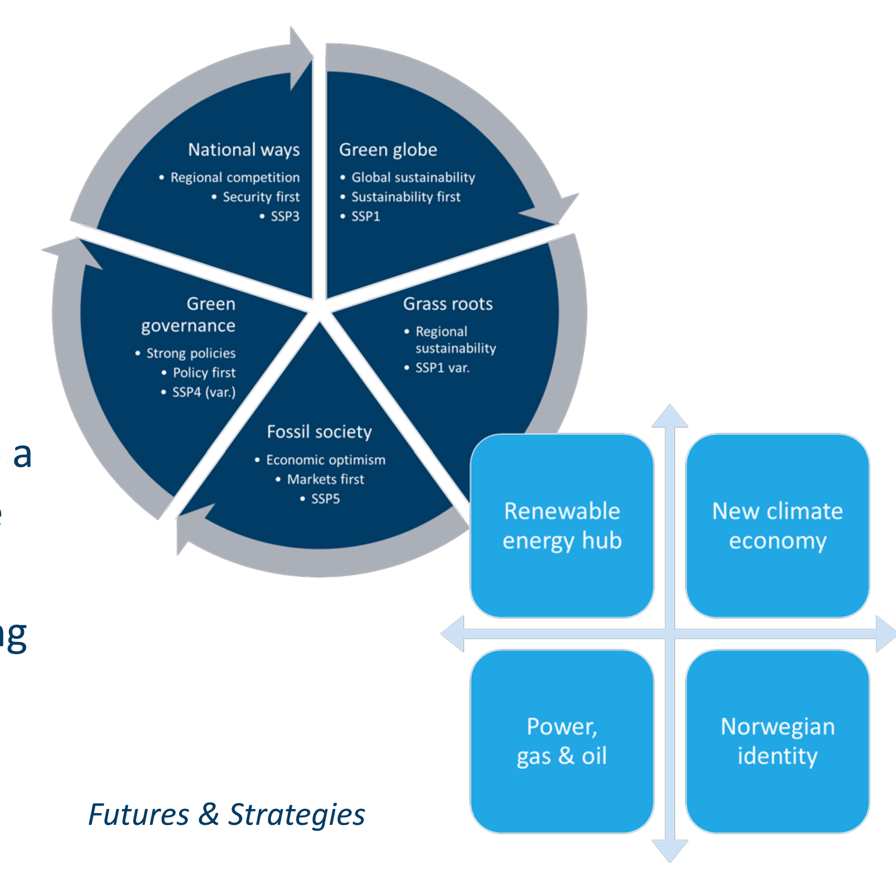
(Bottom-up methodology)



What is the research objective?
Which factors are important?
Which aspects are controllable?

Methodology

Key research question:
How can Norway contribute to a global reduction of GHG, while meeting its climate targets for 2030 and 2050 and contributing to value creation?



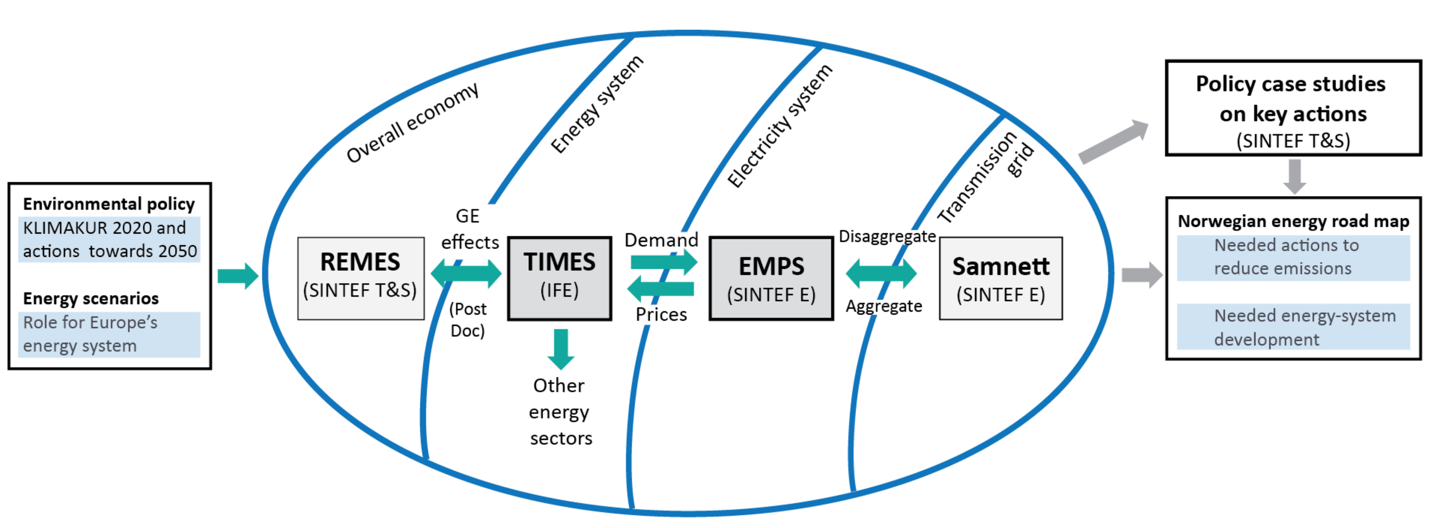
Futures & Strategies

Norwegian Energy Road Map 2050

Primary project objectives:

- Develop Norwegian Road Map – knowledge basis for understanding how a low carbon future can impact the energy and power systems, assess economic spillover effects and provide policy implementation recommendations

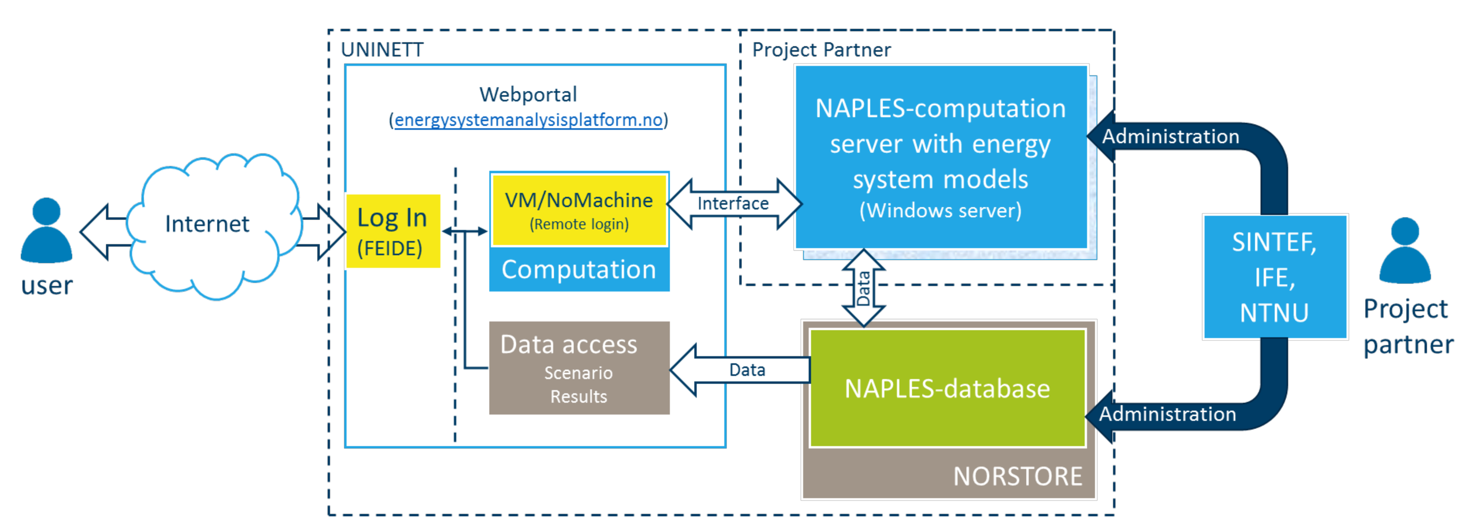
- Establish analysis framework –holistic model framework and cross-disciplinary research team



- Duration: 2016-2019

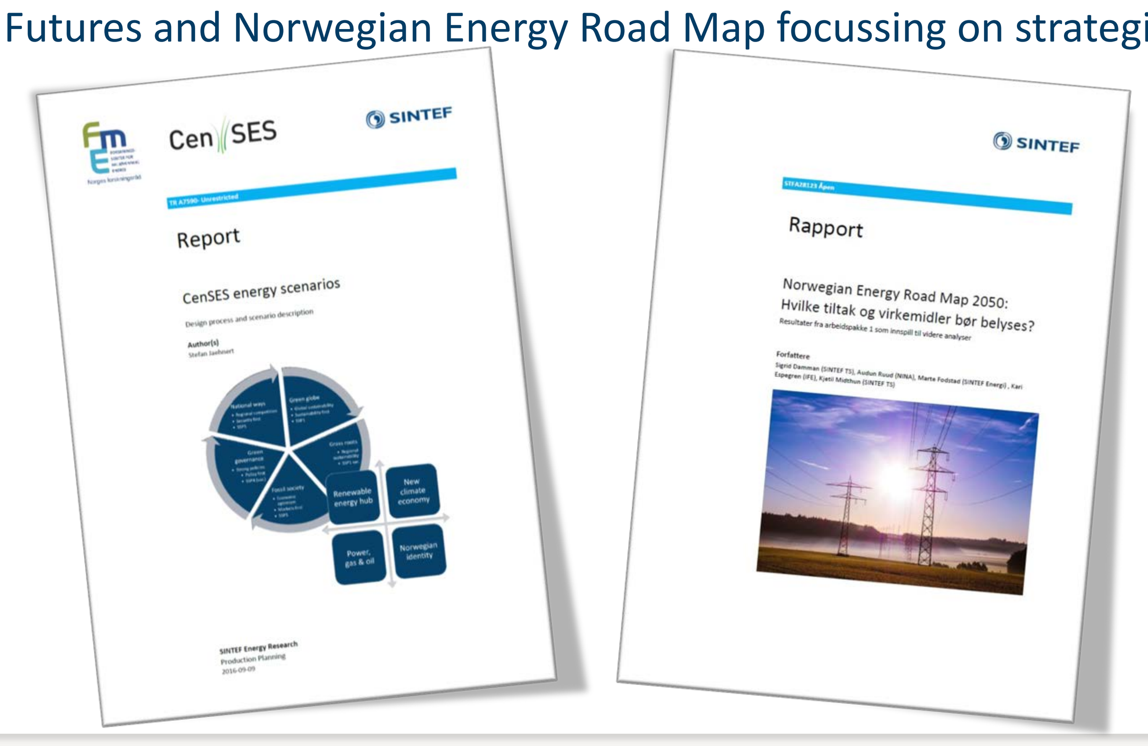
EnergyMap Project overview

Analysis Platform



Status

- The basis for the scenarios are defined and are under quantification
- Reports for scenario definitions are available, with CenSES RA5 focussing on Futures and Norwegian Energy Road Map focussing on strategies



Contacts

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PRIBAS

Pricing Balancing Services in the Future Nordic Power Market

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Project Goal

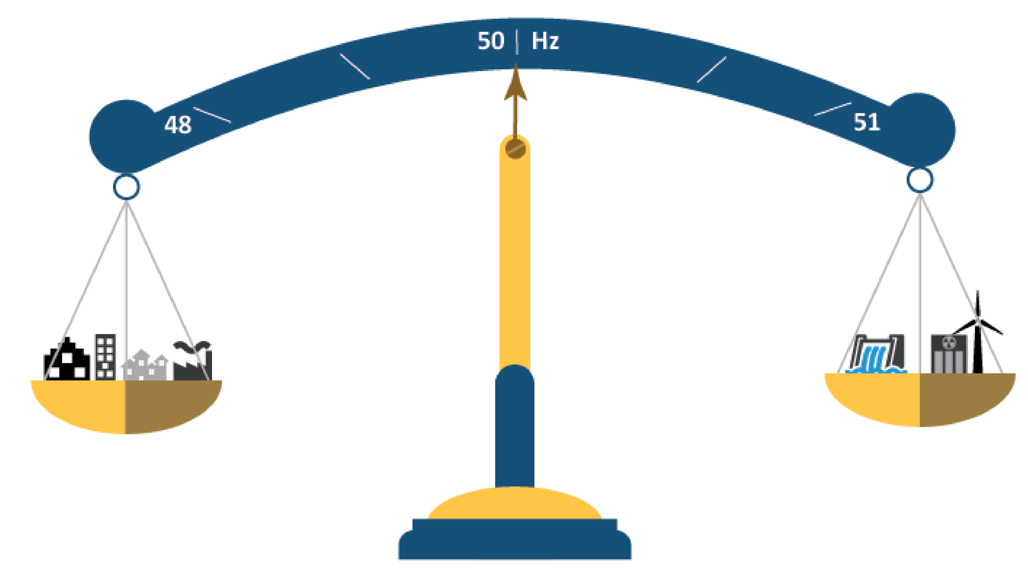
- Develop a fundamental multi-market model for the Nordic power system
- Compute marginal prices for all electricity products
- Including reserve capacity and balancing energy

Motivation

- The European power market is in transition
- Current market models are not customized for the future power system
- Need for long-term price forecasts for all electricity products
- Increased need for flexibility in the power market
- More volatile prices and lager volumes in balancing markets
- The future role of Norwegian hydropower
- More challenging to maximize the value of the water
- Supporting tool: robust and correct investment decisions

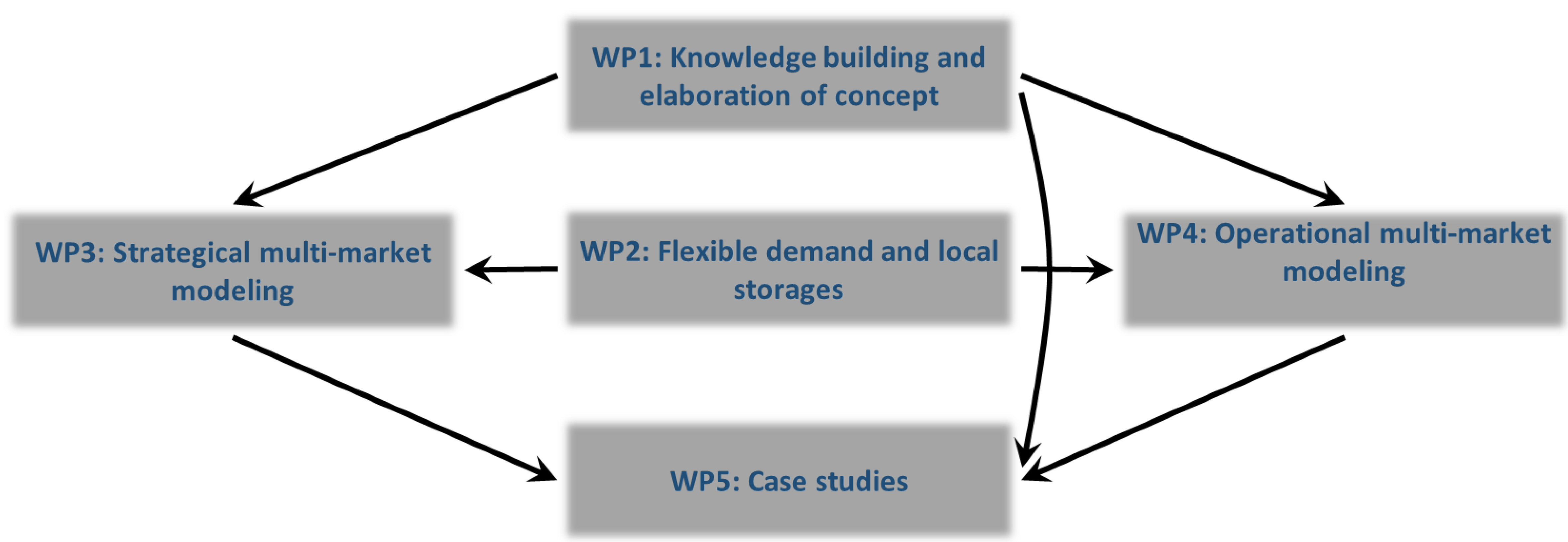
Increased need for flexibility

+ More renewable power generation
+ Decommission of nuclear generation capacity
+ New cables from Norway to Great Britain and Europe
- Advanced Metering Infrastructure (AMI) introduces opportunity for load control and for consumers to react on variations in prices
- Small scale local storage



Balance between production and consumption is vital to the power system.

Work Packages (WP)



Our partners

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Statkraft
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HYDRO
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agder energi

Challenges

- Uncertainty modelling
- Establishing data
- Computational time
- Time resolution requirements
- Type of mathematical modelling (LP, MIP)
- Storage and consumption modelling

Contact

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SOVN

Individual water values and power flow constraints in a new fundamental market model

2013 to 2017 mars

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Project goal

- Multi-stage stochastic optimization
- Large-scale (Europe)
- Detailed description of hydropower

Motivation

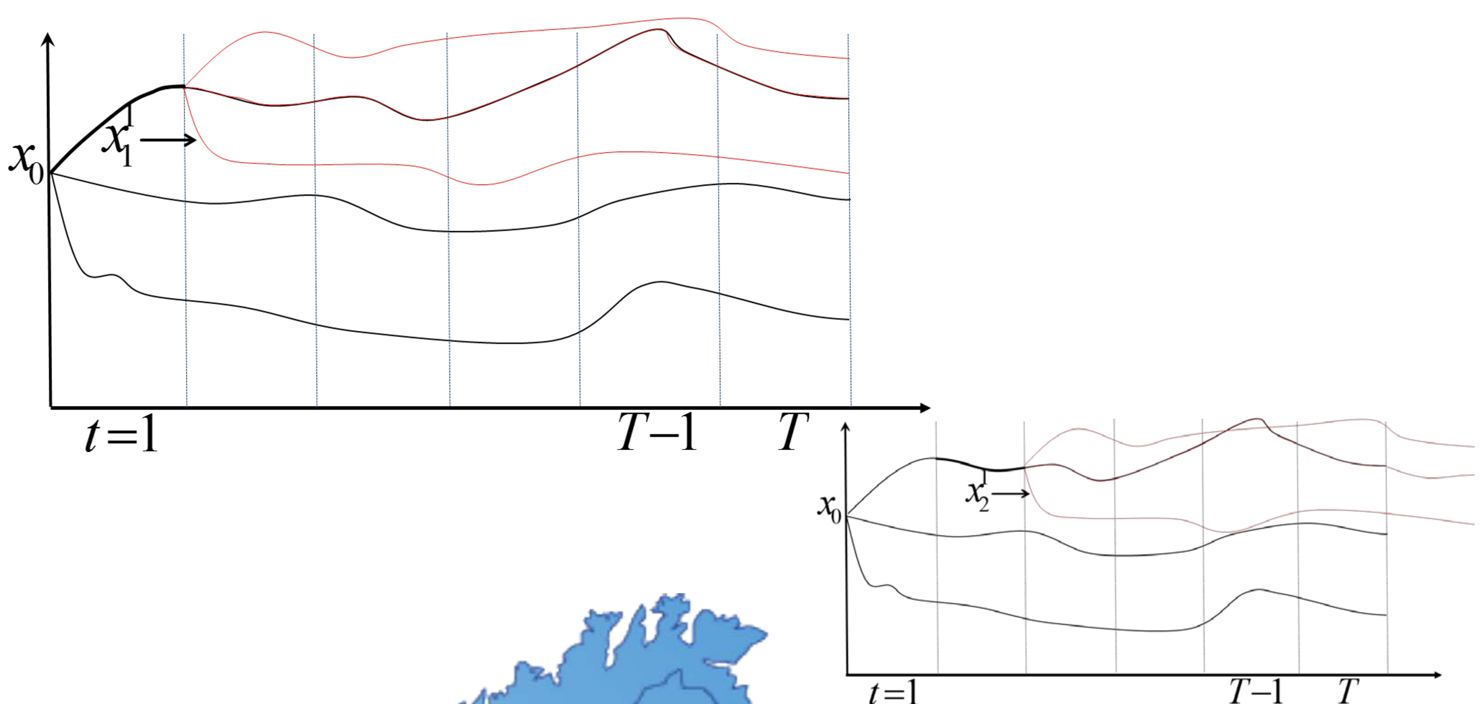
- Individual water values
- High variations in production (wind, sun)
- Investment decisions

Relation to existing models

- Same problem as: EMPS, Samlast, Samnett and ReOpt

Method – scenario tree

- Simulator scheme: two-stage stochastic problems
  - No uncertainty in first-stage (week, X1)
  - Uncertainty (weather, price) in second-stage
- Benefit
  - Formal optimization – optimum
  - Easy to build and extend
- Challenge: calculation time
  - Full parallelization
  - Scenario reduction
  - Calibration is not necessary

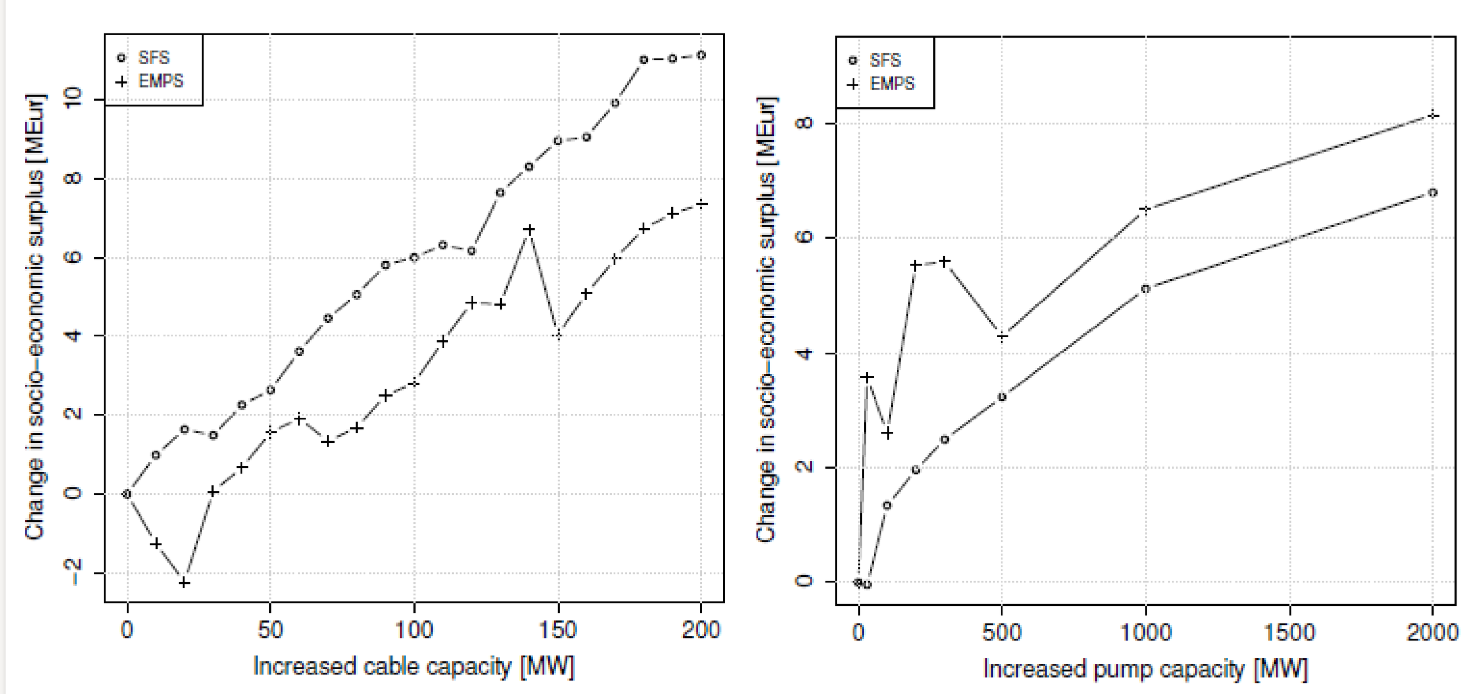


Extra functionality (ref EMPS)

- Hydro description:
  - Head correction in strategy
  - Time delay on flows
  - Ramping on production
  - Season and daily pumping
- Grid:
  - Aggregated or detailed PTDFs
  - Ramping
- Reservation of capacity: up and down
- Challenge
  - Obtaining input
  - Calculation time

Conclusion and result

- Works very well
  - Consistent results (figures)
  - Improved socio economic surplus (277 M€/year in Nordic compared to EMPS)



Methodology → Implementation → Large-scale parallel processing → Testing and verification → Prototype

NVE · Forskningsrådet · Statkraft · BKK · Statnett

Program Brukermøte Produksjonsplanlegging

SINTEF

10. MAI

Tid	Innlegg
09:00	Innsjekk
10:00	Velkommen - SINTEF
10:15	Vannkraftsprodusentenes muligheter i fremtidens markeder - Asbjørn Høivik - Lyse
10:45	Pause
11:00	Nyheter og forskning langtidsmodellene - Birger Mo - SINTEF
11:45	Comparing stochastic and deterministic optimalization using ProdRisk - Toumas Pykkonen - Fortum
12:30	Lunsj
13:30	Pressure links i avanserte topologier - Sigri Scott Bale - Hydro
14:00	Pause og postersesjon
14:40	SINTEFs arbeid med multimarkedsmodellering del 1 - Marte Fodstad - SINTEF
15:00	SINTEFs arbeid med multimarkedsmodellering del 2 - Arild Helseth - SINTEF
15:30	Pause
15:45	Exploring the 'Black box' with market curves - Ivar Døskeland - Statnett
16:15	Programslutt
17:30	Kieglekroa - Sjoelbak
19:00	Middag - Emilies ELD

11. MAI

Tid	Innlegg
09:00	Benchmarking av driften i Drivasystemet - Gunnar Aronsen - Trønder Energi
09:30	Forskning og nyheter korttidsmodellene - Hans Ivar Skjelbred - SINTEF
10:00	Pause
10:15	Modellering av svenske vassdrag i SHOP - Fredd Kristiansen - Statkraft
10:45	Ny markedsmodell SOVN - erfaringer og resultater - Arild Lote Henden - SINTEF
11:30	Lunsj
12:20	API utvikling til Samkjøringsmodellen - erfaringer og status - Arve Tveter Iversen - Statkraft
12:50	Status for API-utvikling for langtidsmodellene og planer for videre implementasjon - Birger Mo og Geir Warland - SINTEF
13:20	Felles grensesnitt til SHOP, Vansimtap og ProdRisk - Erik Lien Johnsen - Powel
13:30	Pause
13:45	Best Profits i intraday - Tellef J. Larsen - Statkraft
14:15	Investeringsanalyser ved bruk av Vansimtap og ProdRisk - Magnus Landstad - Lyse
14:45	Avslutning
15:00	Programslutt