SHOP

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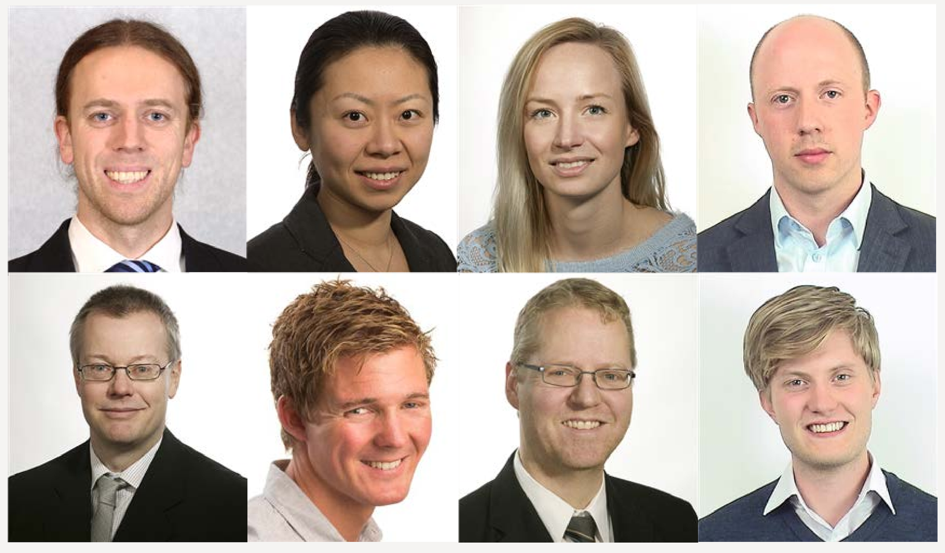

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30-year Development of Short-term Hydro Optimization Program (SHOP)

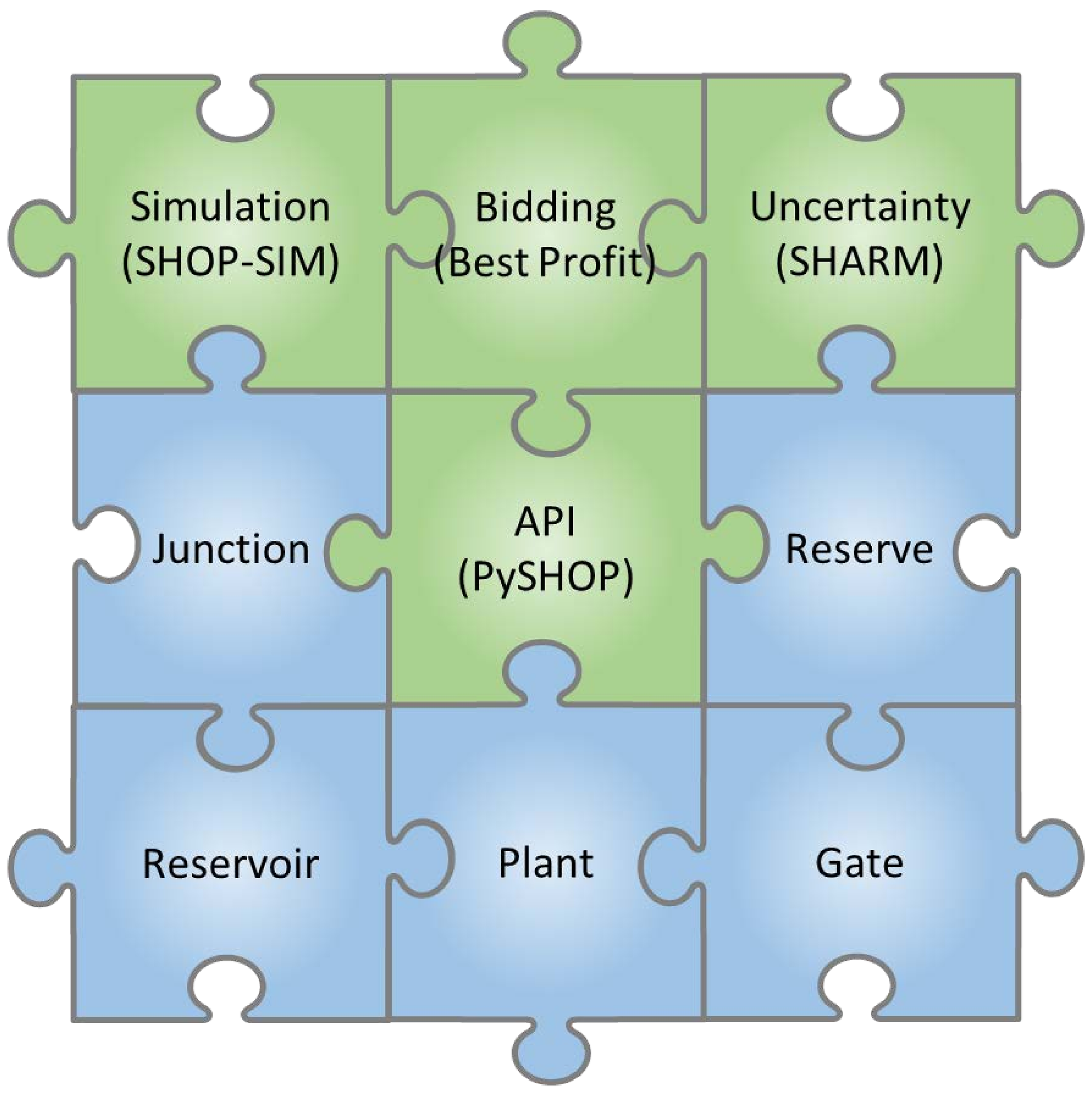
The state-owned power and grid company Statkraftverkene financed the initial prototype of SHOP in 1989. The first operational version was delivered in 1996 to Harris Controls who licensed SHOP to hydropower producers in India and Egypt. Further research on algorithmic development, the breakthrough of computer hardware, and result validation supported by the industry lead to the first operational use of SHOP in Norway at Statkraft in 2003. Since then SHOP has been taken into use by more than 25 major hydropower producers in Norway, Sweden, Switzerland, Italy, Austria, and Chile. At the same time, SHOP has facilitated numerous research projects on hydro scheduling. To keep SHOP start-of-the-art, the problem formulation, solution methods, and data input structure were redesigned in 1996, 2008, and 2016, respectively.

SHOP optimizes unit commitment and load dispatch decision for cascade hydropower plants. Pelton, Francis and Kaplan turbines are represented, as well as fixed speed and variable speed pumps. In addition to the common reservoir, plant, gate, junction, and reserve modules, recently, a watercourse simulator (SHOP-SIM) is built into SHOP to validate the result from the optimization model and to determine the physical consequences of manual re-planning. The uncertainty in market price and inflow (SHARM) has been implemented within the framework of SHOP. The method is based on a discrete representation of uncertainty in the form of scenario trees. A new bidding module (Best profit) is developed to support the real-time energy trading in both reserve activation market and the intraday market.

SHOP is coded in the C/C++ programming language. The optimization program can by solved by commercial solvers CPLEX and GUROBI or open source solvers like CBC. The optimization process is designed to be carried out either locally, on an in-house server, or in cloud services. Originally, all input data and output results in SHOP are listed in ASCII files. Now, an application programming interface (API) is developed. It allows the user to input and update data, execute the model, and examine results in their own applications.

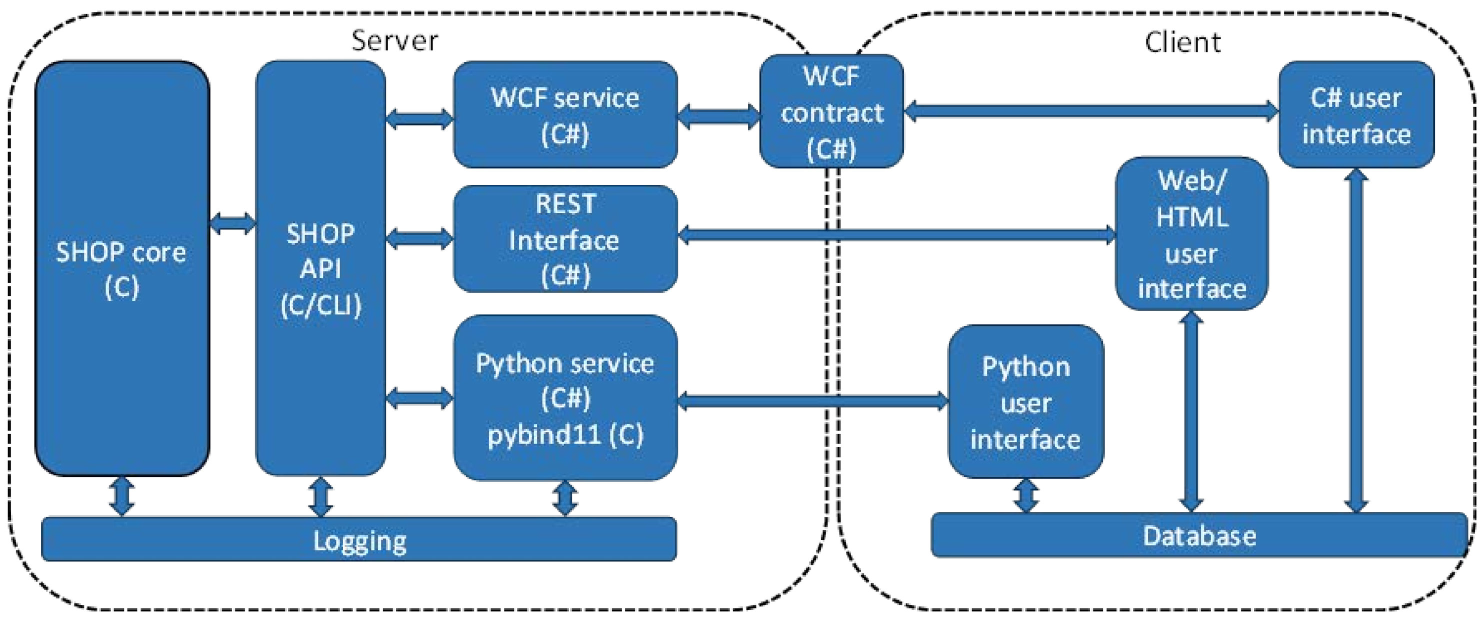
Current Modules in SHOP

SHOP comprises modules that are consistent with the real-world hydraulic systems and market conditions. Different functionalities have been developed to meet the requirements posed from the real-life operation.



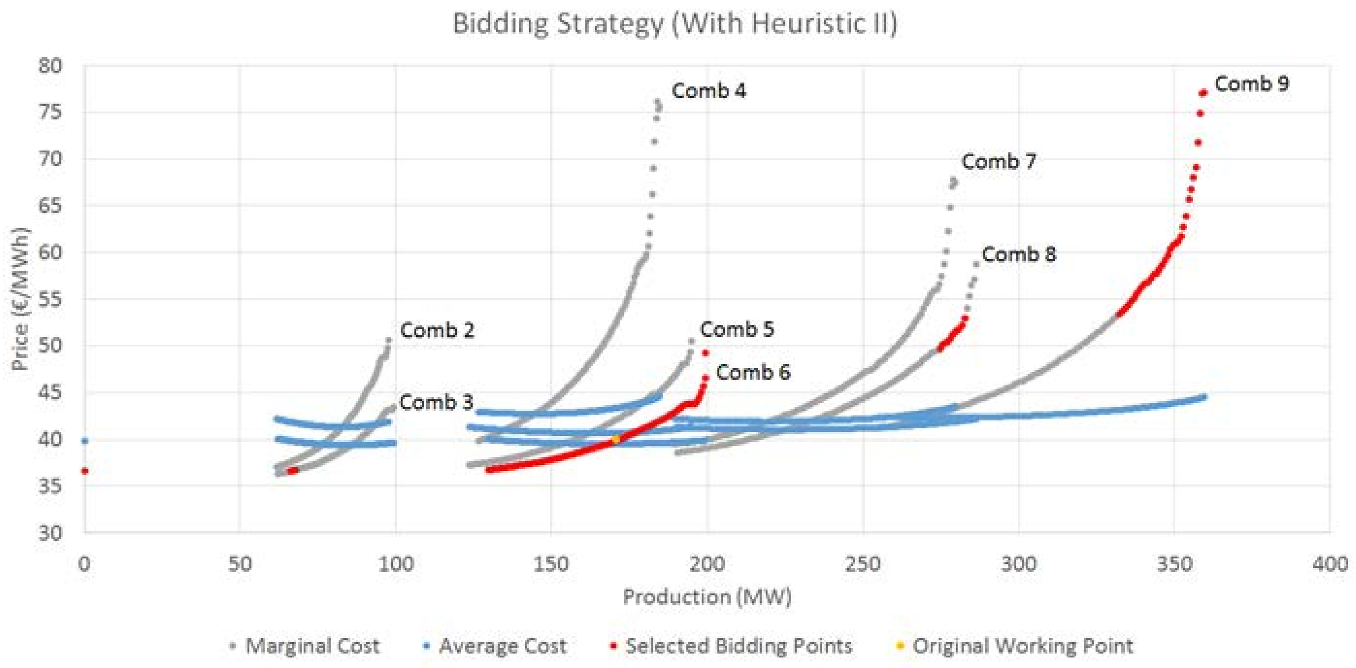
API/PySHOP

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



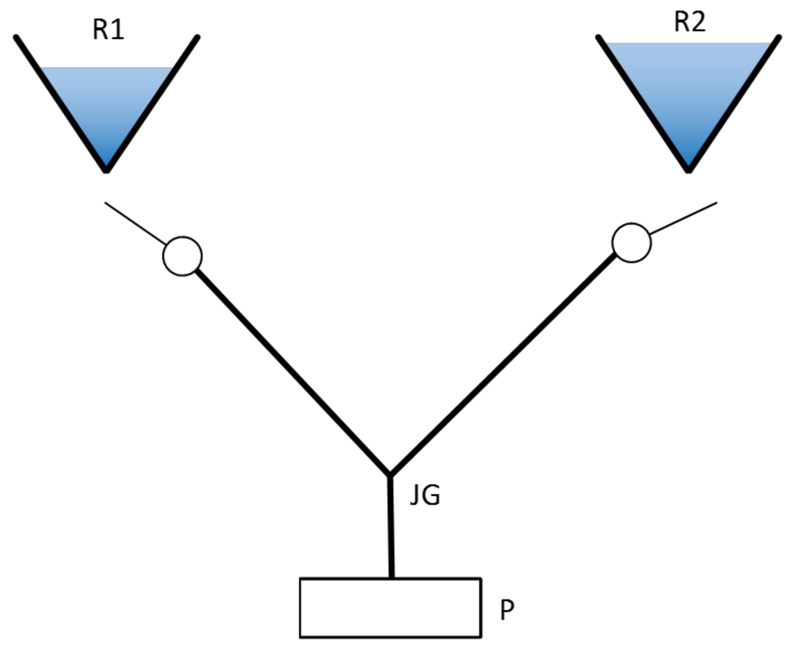
Bidding (Best Profit)

Best Profit is a curve that shows optimal plant production as a function of the market price in a single time step. Production must monotonously increase with price. Start-/stop-costs of units are taken into account. Best Profit is primarily developed for bidding in mFRR, but can in principle be used for bidding in other energy markets.



Junction Gate Optimization

The flow in pressurized tunnels can be modelled by junctions and junction gates in SHOP. A junction is always open for all tunnels connected to it. A junction gate can have an additional schedule to predefine the gate state, i.e. whether Tunnel 1 or Tunnel 2 or both tunnels are open/closed. The goal of Junction Gate Optimization is to optimize the state of the binary gates inside pressurized tunnels. The flow in each tunnel is modelled by friction coefficients. Restrictions for down-time after each change in the gate state are specified as input data. The output is a time series per tunnel with the optimized discharge. In addition, a time series per tunnel with gate state is also given as result. The cost for changing gate state is added to the overall objective.



SHARM

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Functionality for including stochastics in short-term scheduling

The SHARM functionality in SHOP allows for modelling the stochastic nature of prices and inflow in short-term scheduling. The SHARM functionality builds a stochastic version of the successive linear programming algorithm that is used inn SHOP. The method is based on a discrete representation of uncertainty in the form of scenario trees.

The SHARM functionality also include decision support for optimal day-ahead bidding. As a result, bid curves can be obtained as a direct result from the optimization.

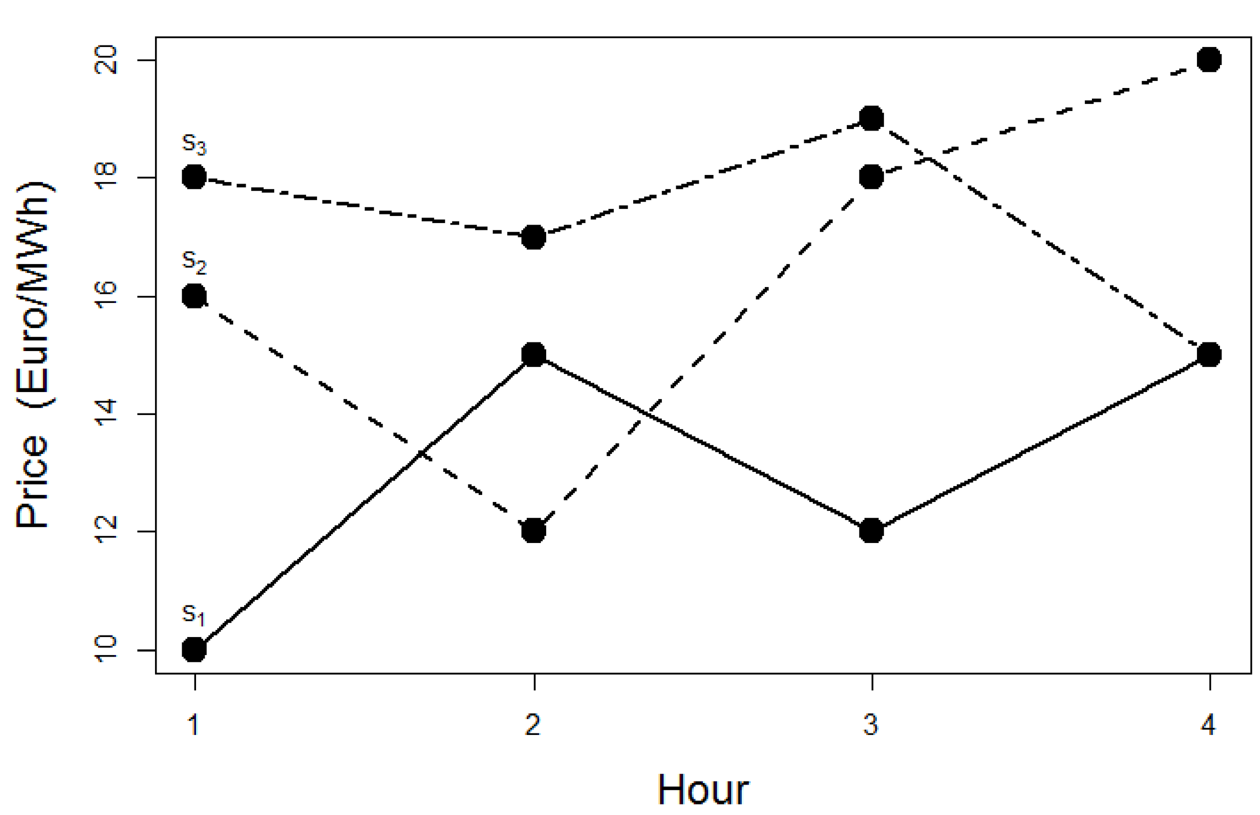
Participation in markets other than the day-ahead market may offer producers increased profits or more flexible production schedules. How can hydropower producers optimize their strategy for multiple services and products? Coordinating the trading strategy across several markets may be a competitive advantage for producers. The SHARM functionality allows for stochastic representation of multiple markets.

The SHARM functionality has been developed in a series of research projects funded by the Research Council and industry partners.

Day-ahead bid optimization

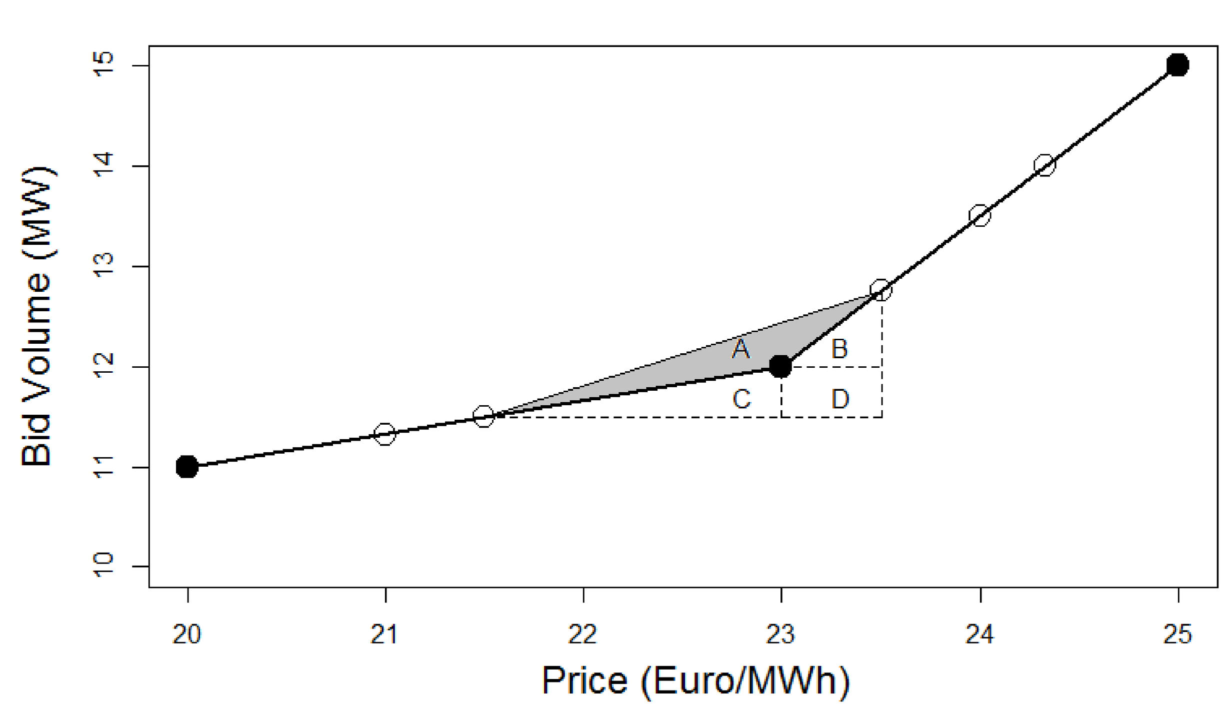
The MultiSHARM project has extended the SHARM functionality to support optimization of bids to the day-ahead energy market.

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.

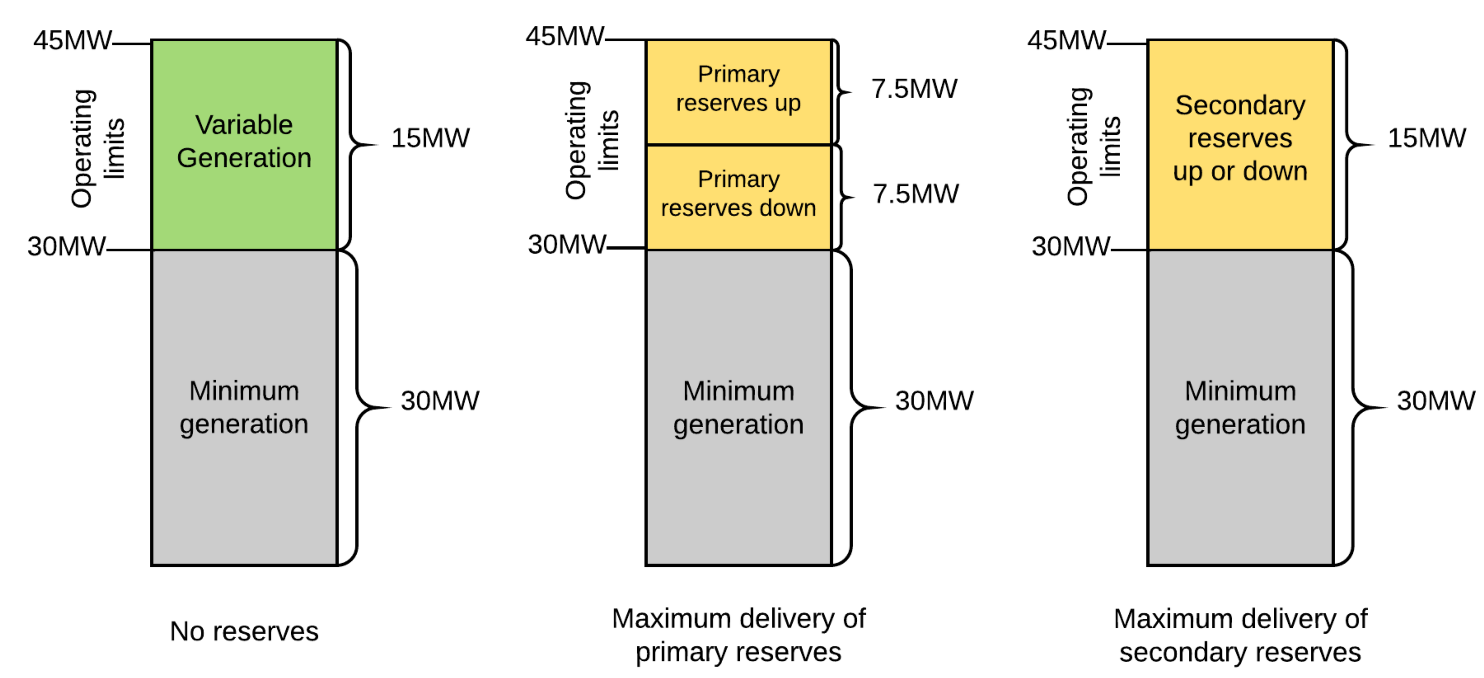
The bid curve may need to be reduced to comply with the size limitations set by market rules. This is done by a greedy heuristic that removes the least important columns of the bid matrix.



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

Multiple markets: Energy and reserves

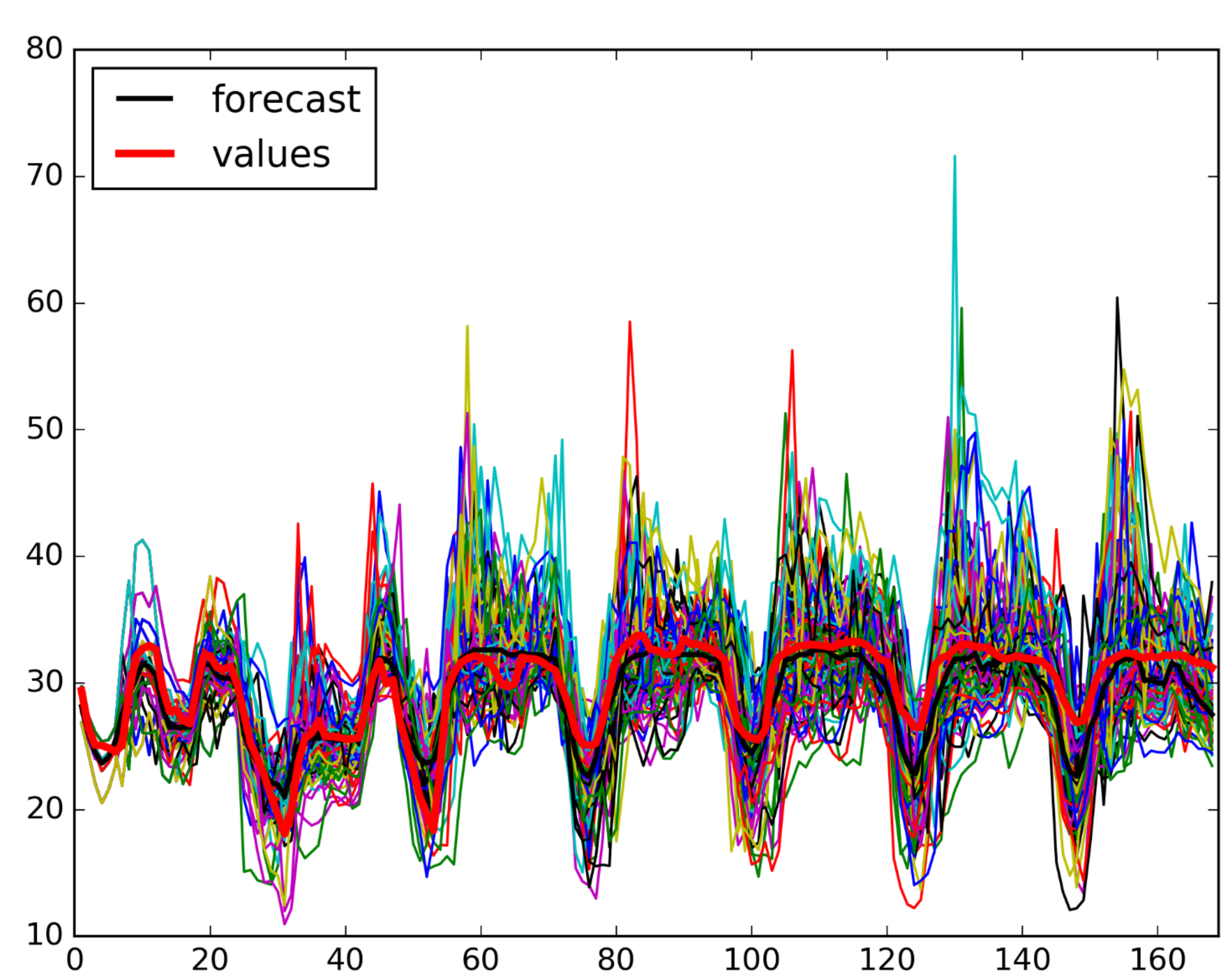
It is possible to optimize sales of both energy and reserves in SHOP. This functionality is also available with stochastic inflows, prices and market depth with the SHARM functionality.



SHOP offers support on how to allocate production between energy and reserves. With SHARM functionality, it is also possible to stochastic prices and market depth for multiple products.

Scenario generation

The representation of uncertainty is important in stochastic models. 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.

HydroCen WP3: Market and Services

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Main goal

The main objective of WP 3 in HydroCen is to develop methods and prototype models to maximize the value potential for hydropower in a future with changing markets and restrictions, rapid technology development and increasing needs for renewal and upgrades.

The work is structured in five tasks, where Task 3.1 and 3.2 will provide data and information into Task 3.3 and 3.4.

Task 3.1
Future market structures and prices

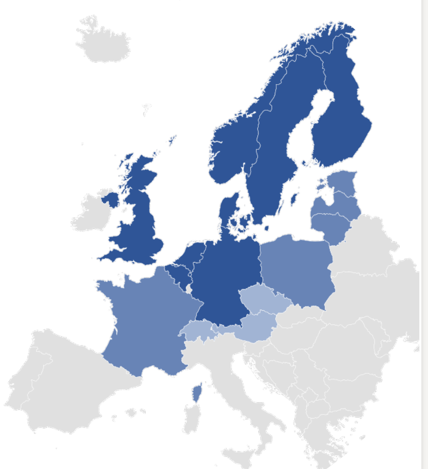
Task 3.2
Remaining useful life, failure probability

Task 3.3
Optimal hydro design in the future power system

Task 3.4
Environmental constraints and uncertainties – impact on revenues

Task 3.5
Water resources assessment tool

HydroCen scenarios (Task 3.1)



Reference scenario 2030

Moderate assumptions for 2030.

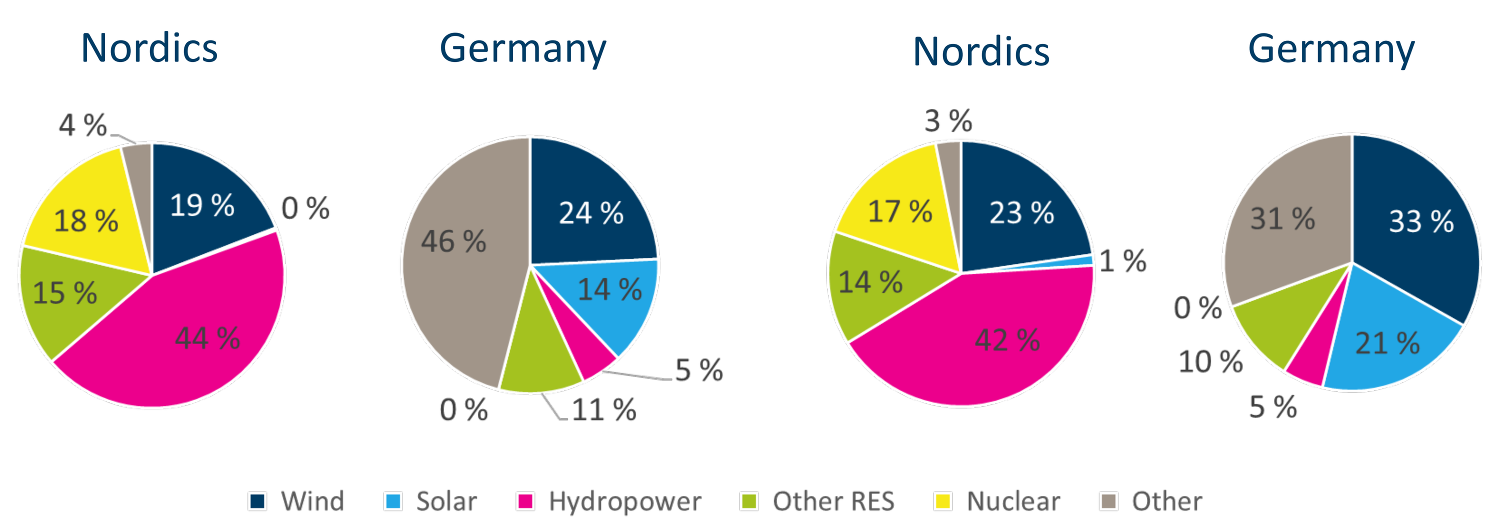
- Planned increase in transmission
- Thermal power generation modelled with start costs
- Fuel- and CO2- prices based on expectations for 2030
- Phase out of coal in many countries and increase in RES

Low emission scenario 2030

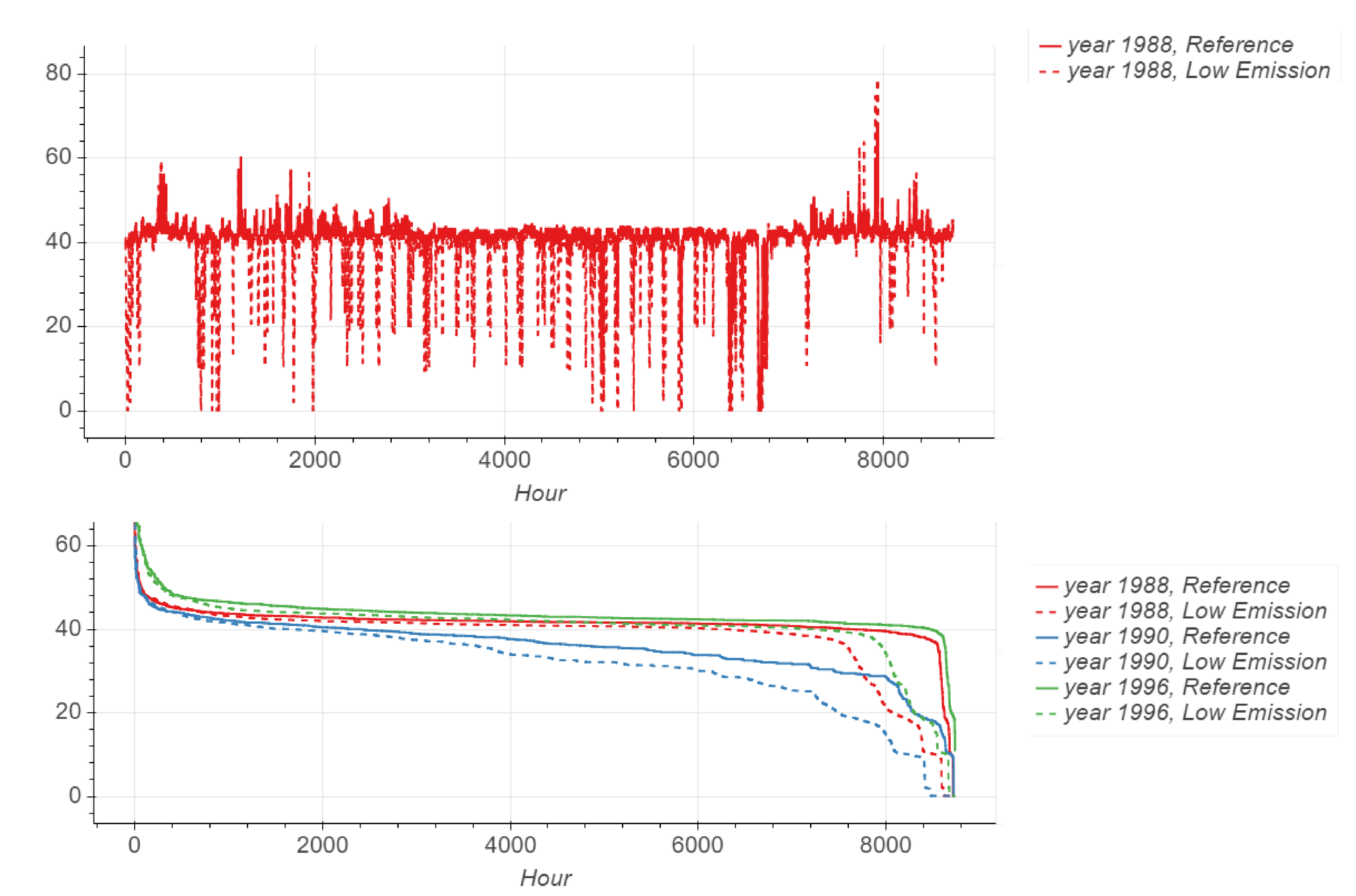
- Reference scenario
  - + Increased WPP and SPP (~ 20%)
  - + Lignite phased out in Germany
  - + Increased transmisison capacity NO-GB and DE (1400 MW)

Electricity generation mix 2030

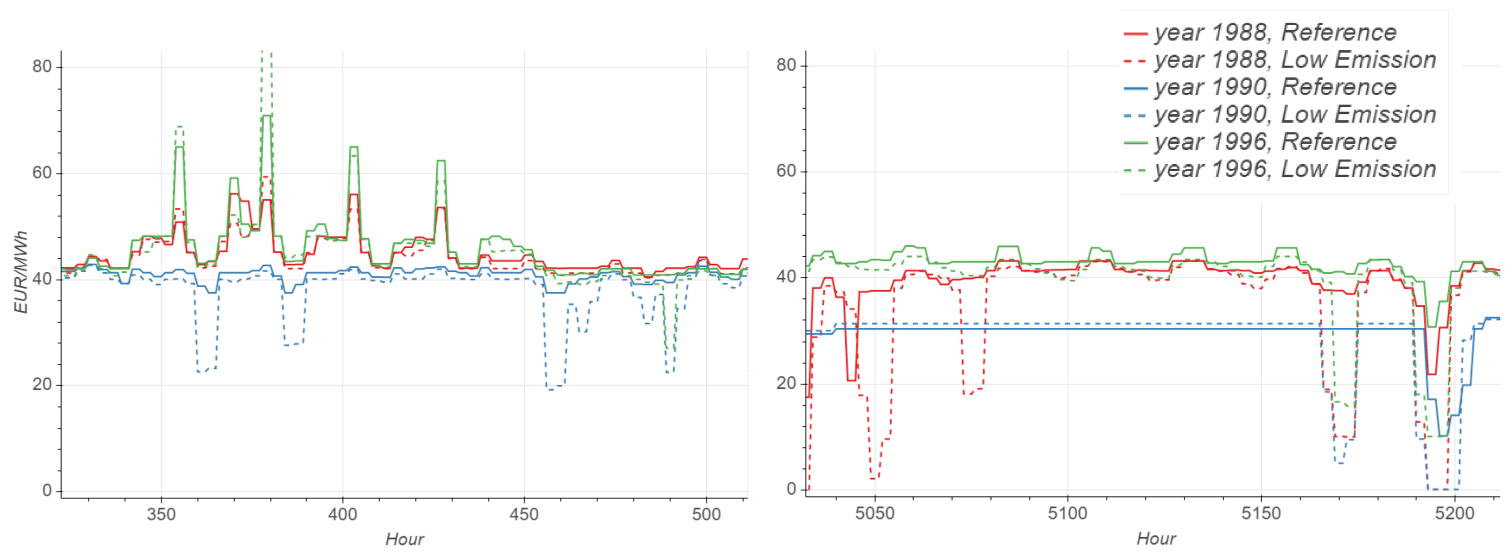
Reference Scenario			Low Emission Scenario		
Nordics:	79 % RES	(19 % VRES)	Nordics:	80 % RES	(24 % VRES)
Germany:	54 % RES	(38 % VRES)	Germany:	69 % RES	(54 % VRES)



Spot price results 2030 – Sorland

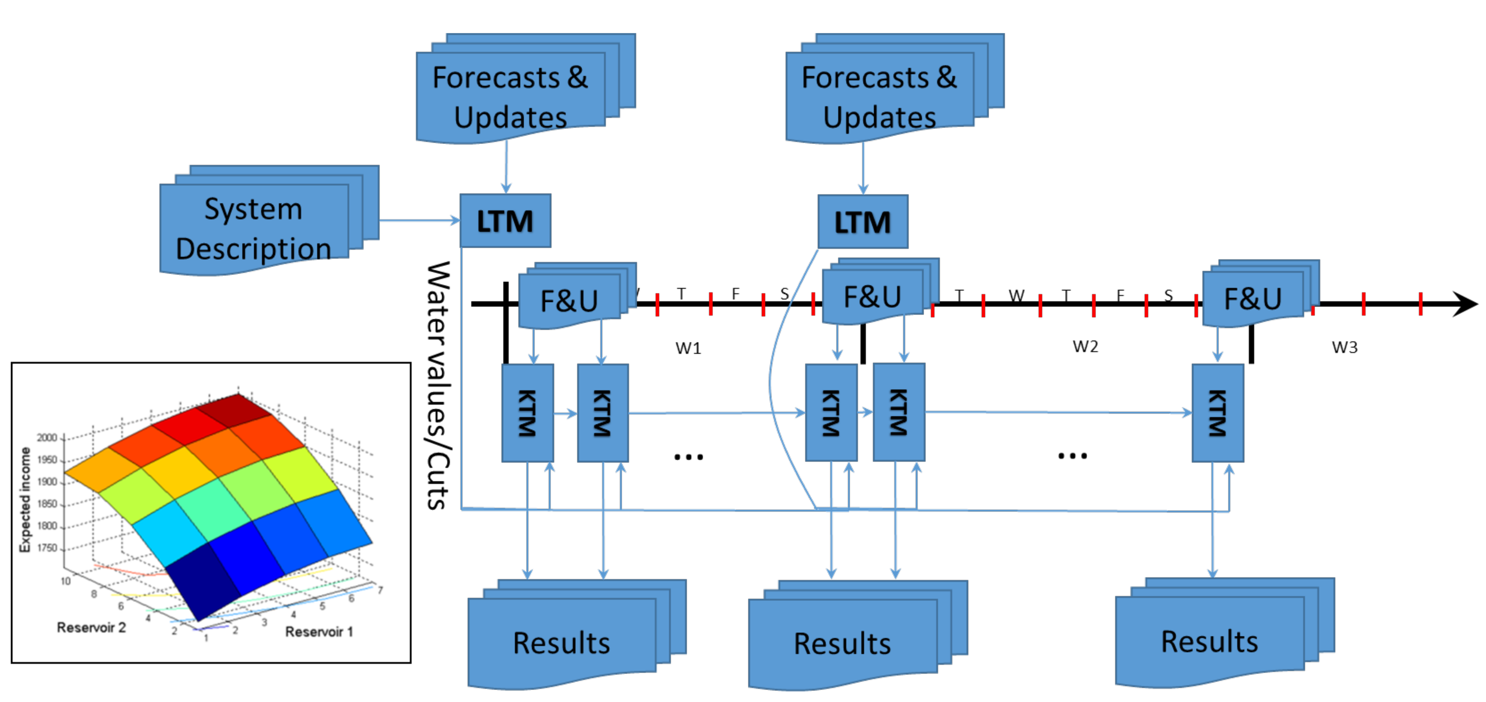


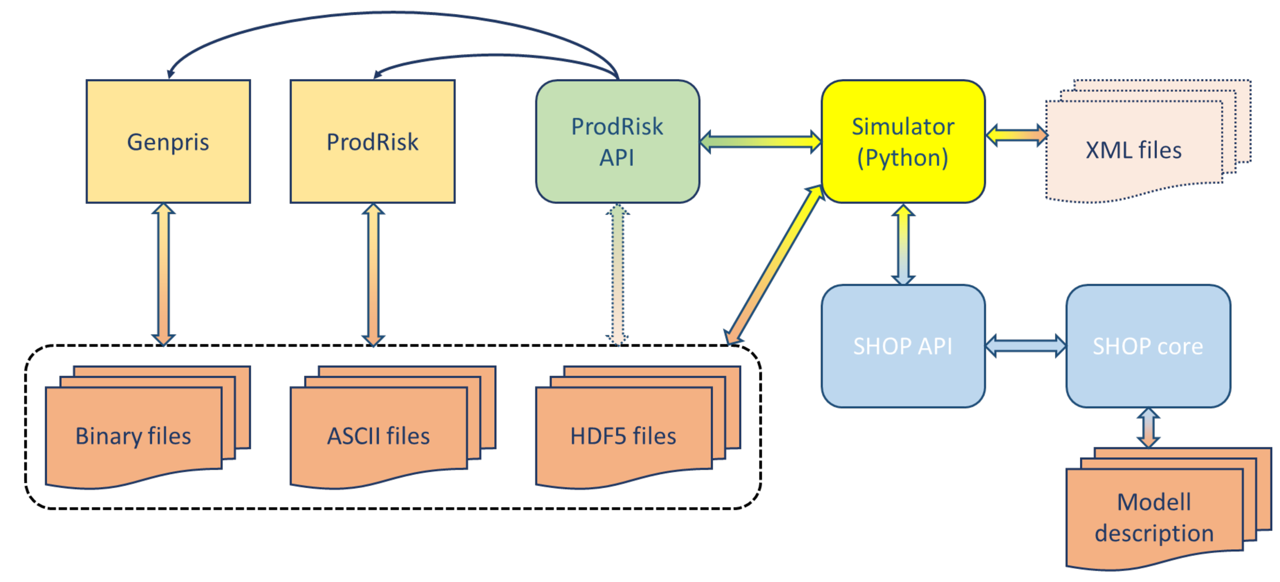
The plots show the power price (top) and duration curve for the power price (bottom) for a full year in Sorland, Reference and Low Emission Scenario



The plots show the power price for a winter week (left) and a summer week (right) in Sorland for three historical weather years in the Reference and Low Emission Scenario.

Simulator (Task 3.3 and 3.4)





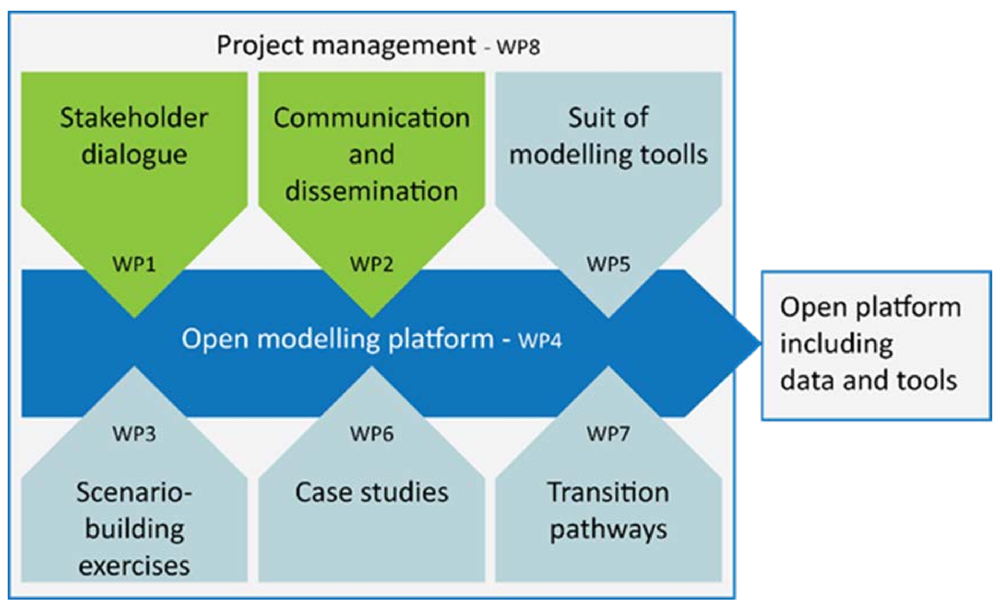
The illustrations show the simulator concept (top) and setup (bottom).

New H2020 project: Open ENTRANCE Modelling in support to the transition to a Low-Carbon Energy System in Europe

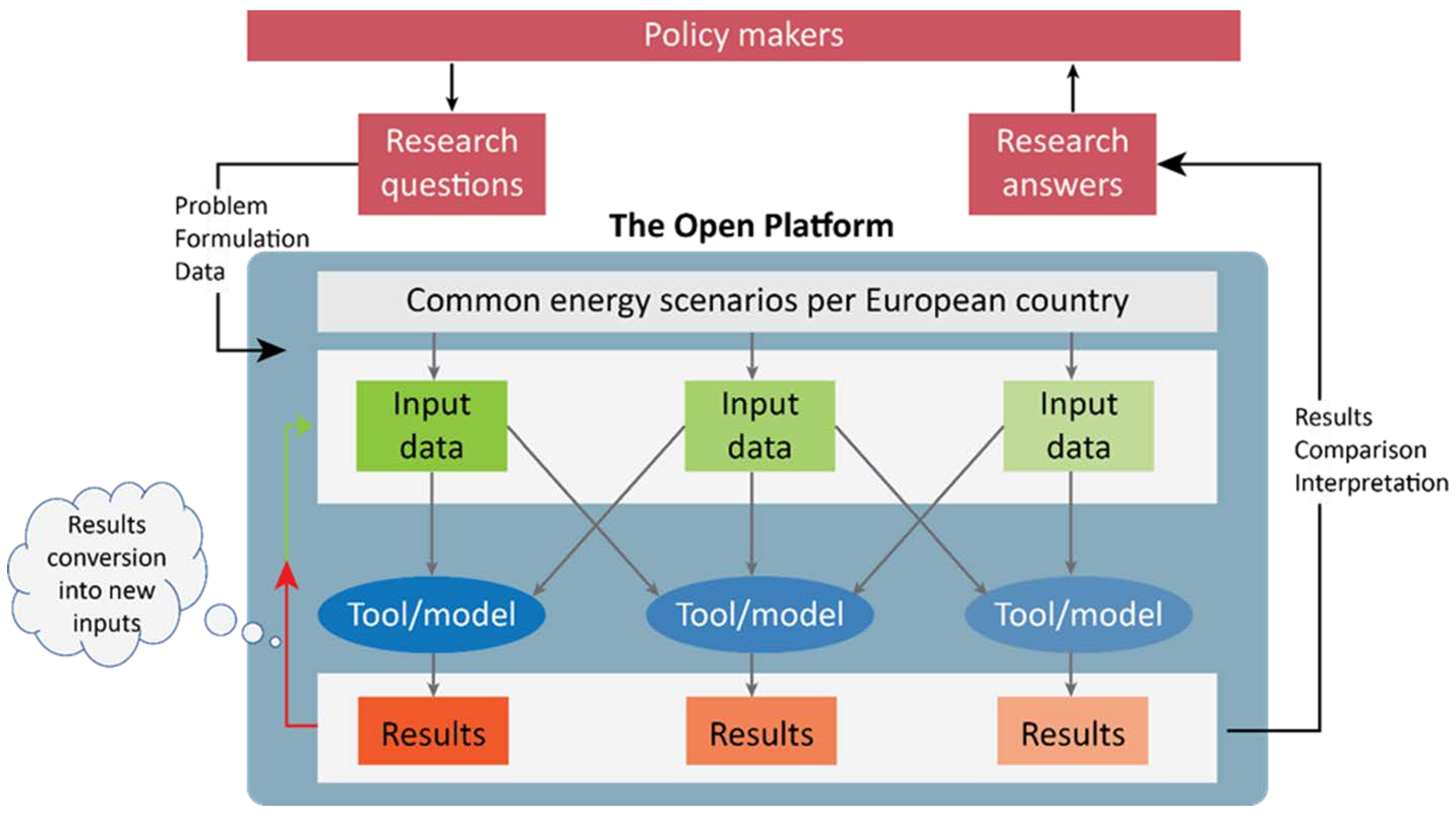
Coordinated by SINTEF Energy Research,
Ingeborg Graabak, Ingeborg.Graabak@sintef.no

Objectives

The primary objective of Open ENTRANCE is to contribute to an improved and robust understanding of the transition to a low carbon energy system in Europe by developing, demonstrating and using an Open platform. The platform will be populated with a suite of open integrated modelling tools and a common database including all necessary data for conducting among other scenario building exercises and macro-economic analyses of pathways to a low-carbon energy system at regional, national and pan-European level.



Concept



Consortium of 14 partners

TU Wien, Austria
IIASA, Austria
TU Berlin, Germany
EDF, France
Comillas, Spain
KHAS, Turkey
NTNU, Norway
Energi Institute, Austria
Fraunhofer, Germany
TNO, The Netherlands
DIW Berlin, Germany
DTU Denmark
WFC, Germany
SINTEF Energi, Norway

and 45 stakeholders including some of the largest energy companies in Europe

List of case studies

1. Assess how demand-response from household consumers (based on real large-scale data) will impact the European power system
2. Assess how demand-response from communities of actors partly being self-supplied will impact the European power system
3. Compare the flexibility provided by pumped hydro storage and batteries for the future European power system
4. Assess flexibility provided by electric vehicle to the European power system.
5. Compare different levels of geographic coordination for investment decisions, both at regional and European level, focusing on the topic of decentralisation.
6. Study the use of innovative technology in terms of underground rocks for seasonal storage of heat from summer to winter in a district in Oslo, Norway.
7. Evaluate how the use of flexibility from the heating sector at different time scales may have an impact on the power system operation costs and network expansion needs.
8. Investigate the role of natural gas storage in current and future energy systems in transition.

Models available through the Open Platform

MODEL	LEAD PARTNER	DESCRIPTION	ELEC-TRICTY	HEAT	GAS	TRAN-SPORT
GENeSYS-MOD	TU Berlin	Energy System Model, cost-optimizing linear program, focusing on long-term developments	x	x	x	x
REMES	NTNU/ SINTEF	Regional Economic Modelling with focus on the Energy System	x	x		x
EXIMOD 2.0	TNO	Multisector multi region CGE model, measures the environmental and economic impacts of policies.	x	x	x	x
EMPIRE	NTNU	Power infrastructure investment model	x			
TEPES	Comillas	Power infrastructure investment model	x			
HERO	TU Wien	Optimal capacity allocation and dispatch of distributed generation and battery storage for meeting the energy services needs of local energy communities	x	x	x	x
OSCARS	TU Wien	Optimal utilization of small battery storages and flexible loads on prosumer level under various operation strategies	x	x		
Plan4RES	EDF	Modelling suite for the electricity system: i/ a capacity expansion model ii/ a seasonal storage valuation tool iii/ an European operational dispatch model	x			
FRESH:COM	TU Wien	FaiR Energy SHaring in Local COMmunities: Multi-objective optimization tool for local RES technology portfolio dimensioning	x			x

Facts

Financed by the European Commission
Budget: 5 mill Euros
Project period: 2019-2021

Norwegian Energy Road Map 2050 – KPN project

SINTEF Energy Research, IFE, SINTEF Building and Infrastructure, NTNU Indøk

Objective

Develop a knowledge basis
Establish a knowledge basis about how a low carbon future will impact the energy, the power and the transmission systems and the overall economy in Norway. Provide recommendations on how policy measures can be implemented within a Norwegian societal and political context.

Develop a framework for consistent analyses
Establish a holistic framework for consistent analyses in and beyond the project. The framework shall include linked energy- and power models as well as a general equilibrium model and a cross-disciplinary research team.

We have 12 years to limit climate change catastrophe, warns UN (October 2018)

The world's leading climate scientists have warned there is only a dozen years for global warming to be kept to a maximum of 1.5C, beyond which even half a degree will significantly worsen the risks of drought, floods, extreme heat and poverty for hundreds of millions of people.

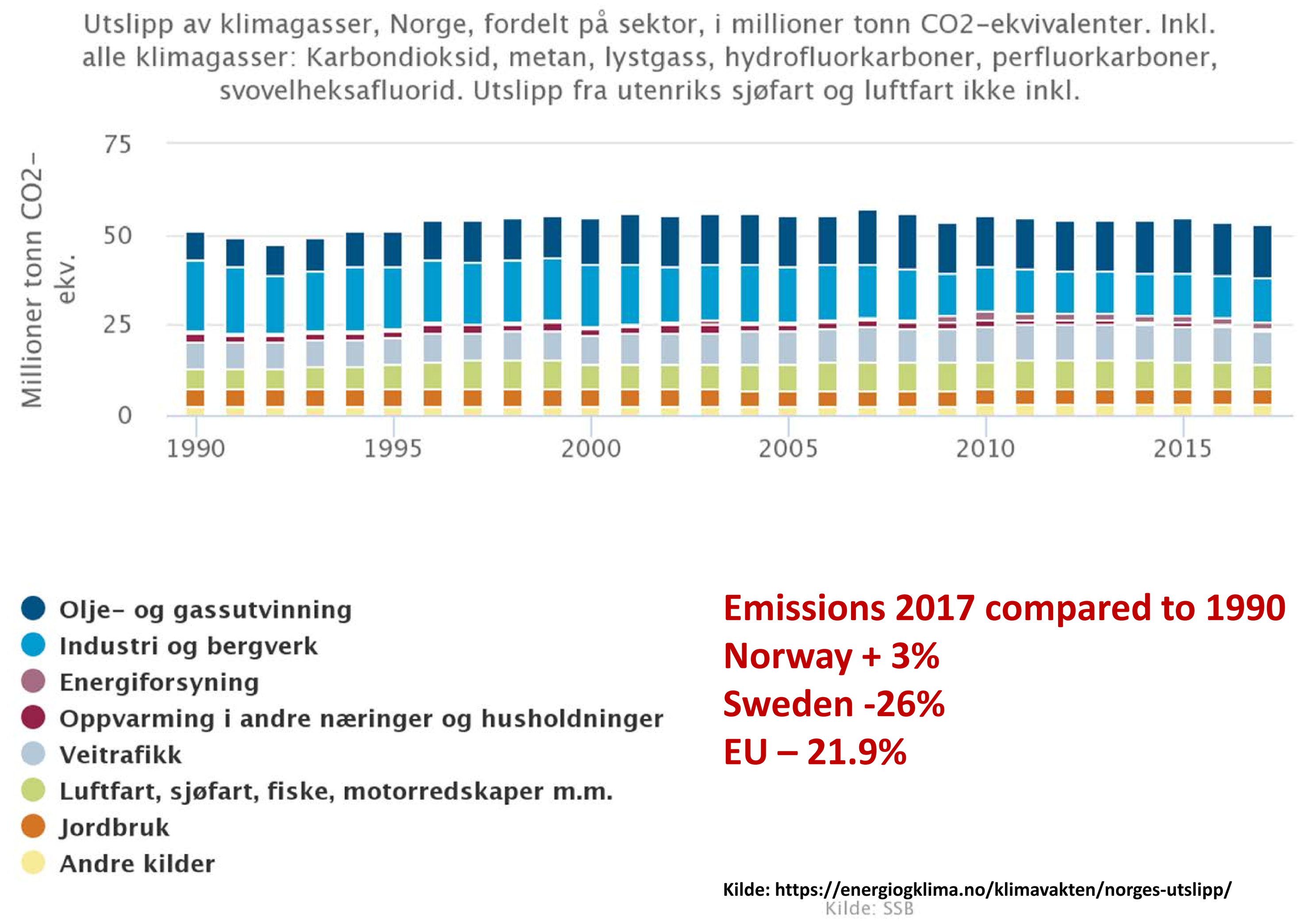
The authors of the landmark report by the UN Intergovernmental Panel on Climate Change (IPCC) released on Monday say urgent and unprecedented changes are needed to reach the target, which they say is affordable and feasible although it lies at the most ambitious end of the Paris agreement pledge to keep temperatures between 1.5C and 2C.

A firefighter battles a fire in California. The world is currently 1C warmer than preindustrial levels. Photograph: Ringo HW Chiu/AP

Source: The Guardian

The climate law in Norway

§ 4. Climate target for 2050: Norway shall be a low emission society. The green-house gas emissions shall be reduced with 80-95% compared to the Reference year 1990.



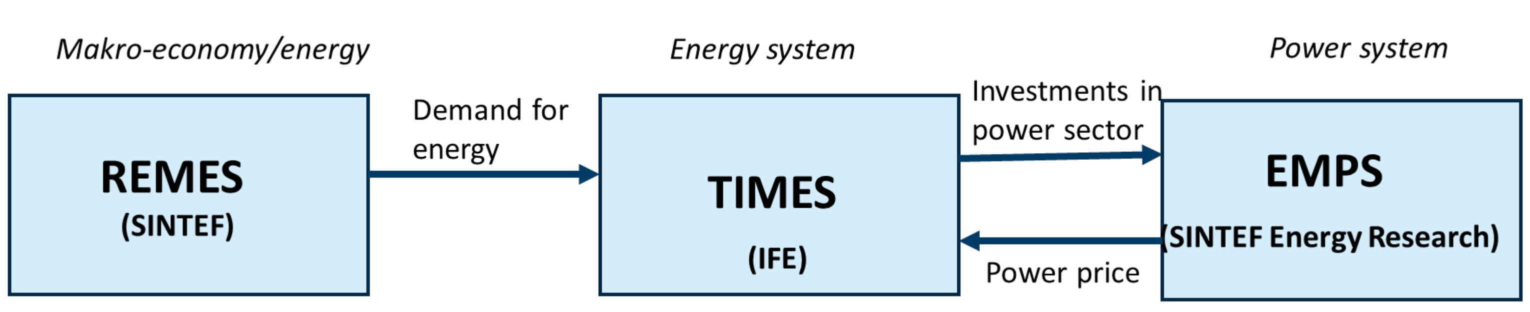
Emissions 2017 compared to 1990
Norway + 3%
Sweden -26%
EU – 21.9%

Kilde: https://energiogklima.no/klimavakten/norges-utslipp/

Scenarios

Industry and service sector grow equally	Reference scenario	Industry scenario	Service scenario
GDP	Increase 0% pr capita per year. Sensitivity 0.8%	Increase 0% per capita per year. Sensitivity: 0.8%	Increase 0% per capita per year.
Business sector	Present mix	Present mix	Present trend
Oil- and gas	Sector grows based on "Perspektivmelding"	Oil sector decommissioned. Gas sector transformed	Oil and gas sector decommissioned
Industry- and service	Industry and service sector grow equally. Energy consumption in industry sector as in 2015	Industry and service sector grow equally	Service sector grows
Transport			
Demand	CENSES REF (NTP)	CENSES REF (NTP)	Person car km as in 2015. Increased use of public transport
Teknology	Fossile	El and hydrogen	El and bio
	Not CCS	CCS	Not CCS
Residentals	Limited energy efficiency	CENSES reference scenario, energy efficiency	Lower energy demand due to environmentally conscious consumers reduced consumption of goods, 7 TWh PV

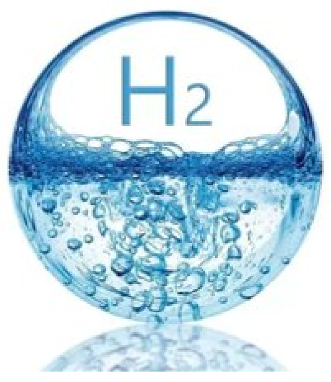
Models



Case study hydrogen production

- Potentials and barriers for upscaling of production
- How to facilitate for hydrogen as an energy carrier?
- Qualitative study based on interviews with many different actors

Intervjuer		Workshops	Andre prosjekter	
Norsk H2	MDIR	Unleashing the H2 market	MoZEES	
Varanger kraft	ZERO	Scandria2act	HyLAW	
Equinor	Bellona	HyLAW, Brüssel	TRAZEPO	
Greenstat	OED (?)	H2fc 2018 Trondheim	Mission H2	
Statkraft	KLD (?)	TBU: H2 - ny industri i Norge		
Gasnor/SKL	Enova	Klimapartnere Rogaland	etc.	
Glomfjord Hydrogen AS				
Technip (Deep Purple)	Hordaland FK			
HYPER (prosj)	Trøndelag FK			
NEL	Rogaland FK			
Praxair				
UnoX	Meløy Kommune			Samt dokumentstudier!
Hexagon	Berlevåg Kommune			
Statnett	Matre Kommune			
Hydrogenforum				
Innovasjon Norge				
BaneNor				
NHO-LT				
Norges Taxiforbund				
Tizir				
Yara				



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Duration 2016 - 2019

PRIBAS Pricing Balancing Services in the Future Nordic Power Market

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Project goal

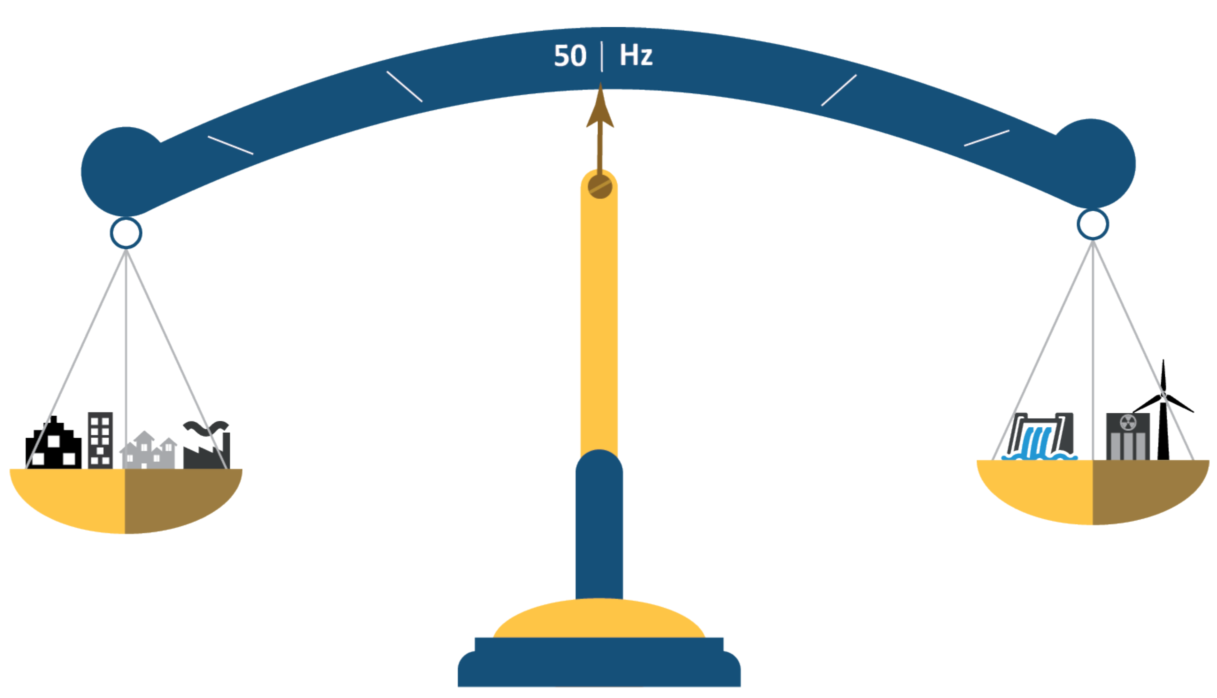
- Develop a fundamental multi-market model for the Nordic power system
- Compute marginal prices for all electricity products
- Including reserve capacity and balancing energy

Motivation

- The European power market is in transition
- More volatile prices and lager volumes in balancing markets
- Increased need for flexibility in the power market
- Changing market designs

Current market models are not customized for the future power system

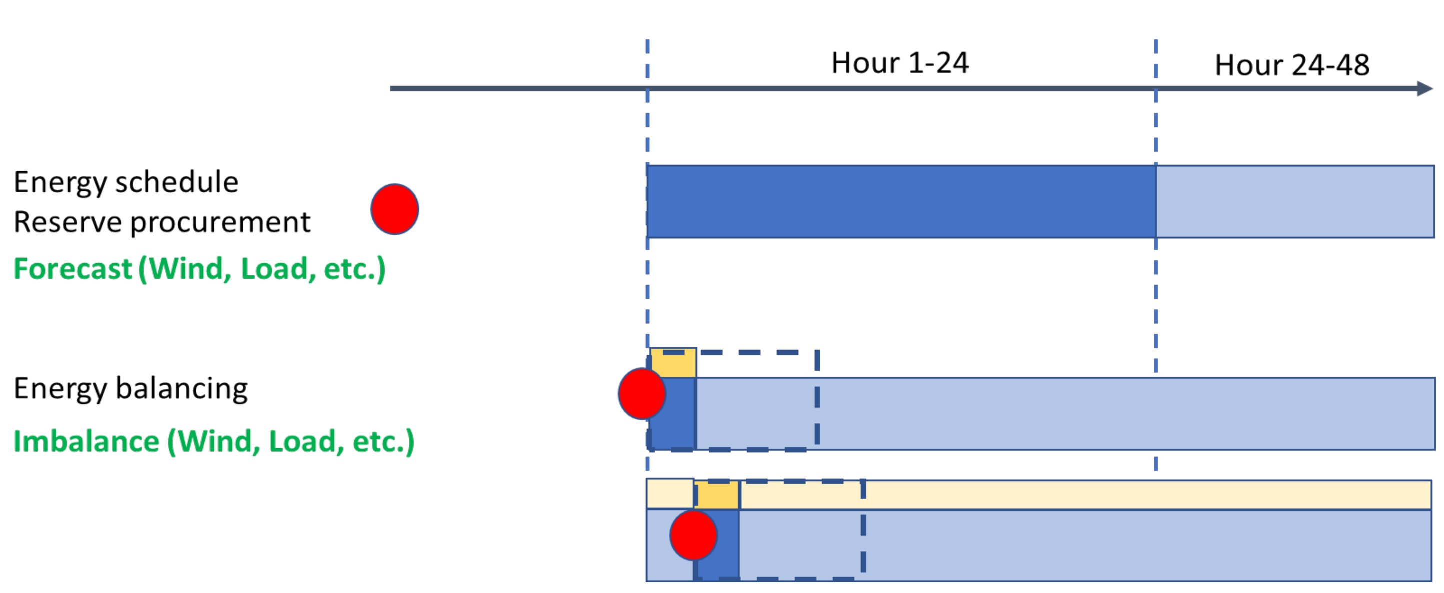
- Technical details and fine time-resolution become more important
- Short-term uncertainty needs to be considered



Model concept

- Compatible with V10 EMPS data
- Optimize daily decision problems with interpolation in weekly cuts or water values from Fansi or EMPS
- 15 minute time-resolution
- Rolling-horizon

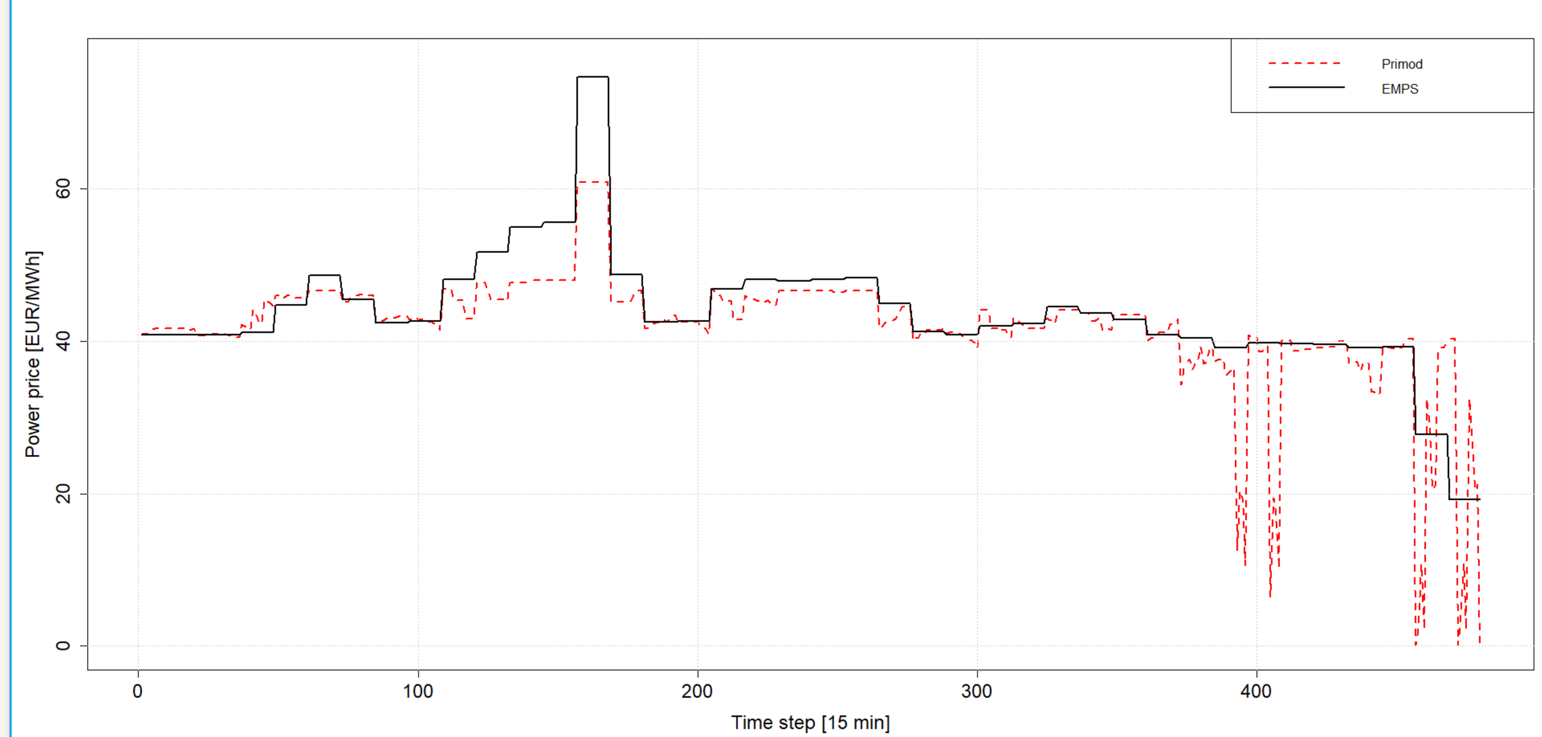
1) Clearing of energy and reserve capacity (first-stage decision)
2) Deviations in forecasts (e.g. wind and load)
3) Balancing using the procured resources (second-stage decision)



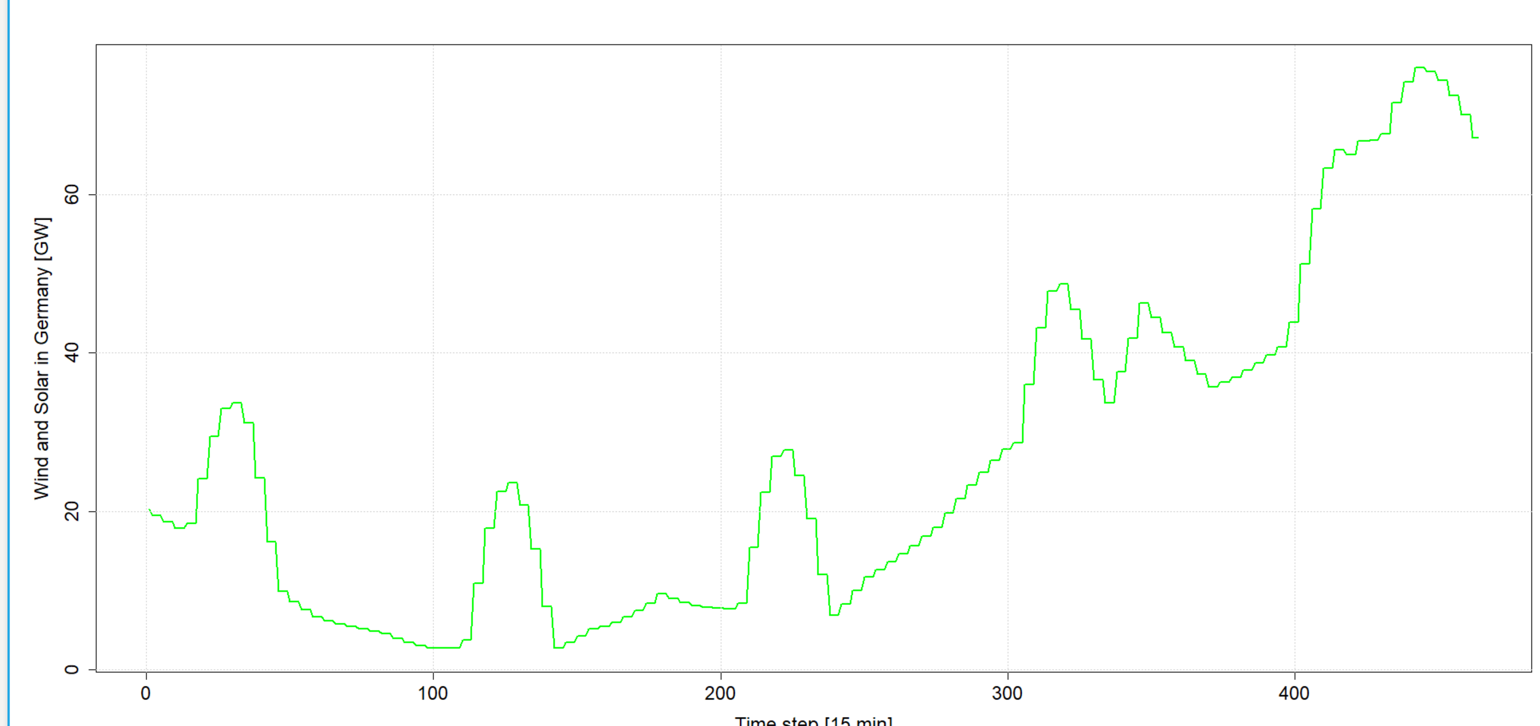
Results day-ahead prices

- The model was run on the Low emission 2030 dataset from HydroCen
- The results are compared with results from the EMPS model
- Inflow year 1958
- Monday to Friday week 1

Prices for South-Norway



Wind and solar power for Germany



Our partners

Forskningsrådet, agder energi, Lyse, Svenska Kraftnät, ECO, Hydro, Statkraft, Statnett

MAD – Methods for Aggregation and Disaggregation

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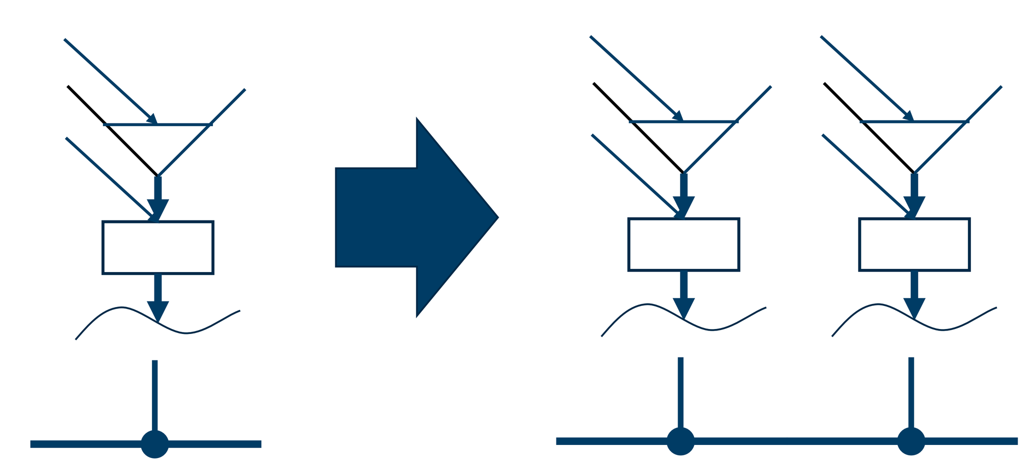
Project goals

Improve the EMPS model
Improved aggregation method
New aggregation structure

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

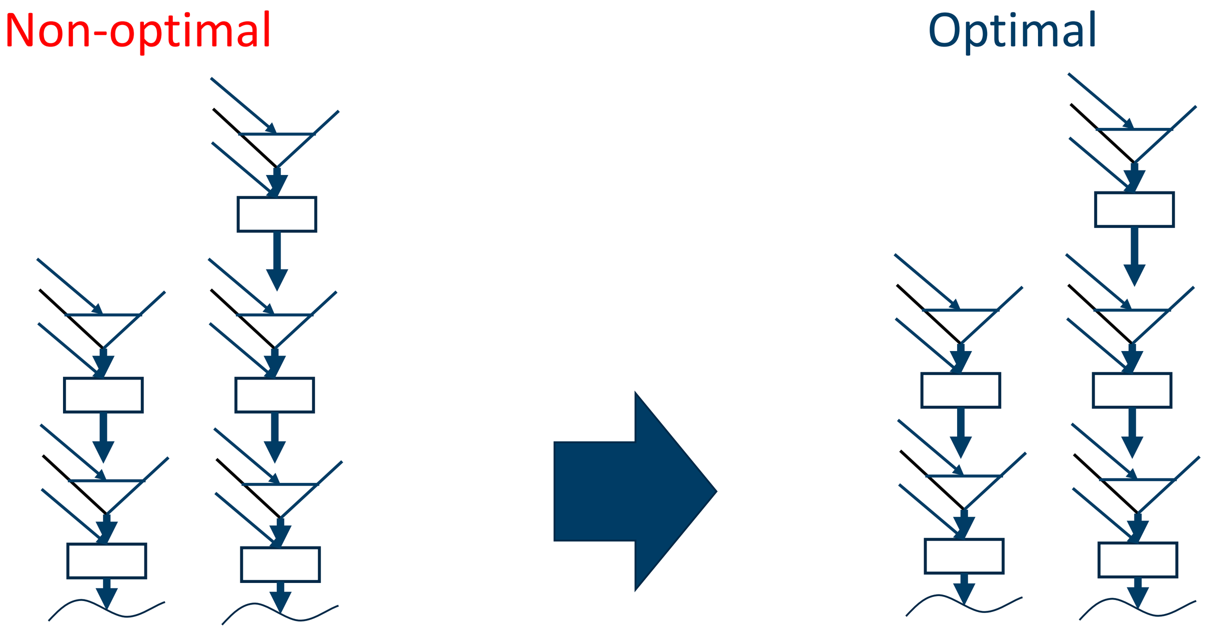
Aggregation

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.

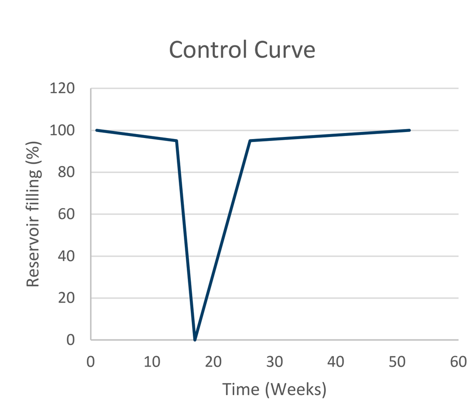


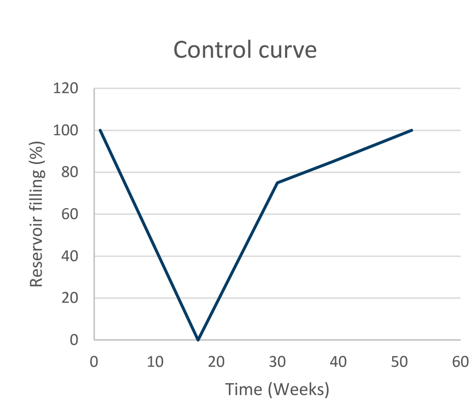
Disaggregation

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.



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





Pros and cons

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

Cons
- Computation time

Partners

Forskningsrådet
HYDRO
Statnett
Statkraft
BKK
agder energi
ECO
Lyse
VATTENFALL