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MULTI-MARKET MODELING LONG- AND MEDIUM-TERM

Brukermøte Produksjonsplanlegging
10.05.2017
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SINTEF Projects on Multi-Market Topics

IBM

- Integrating Balancing Markets in Hydropower Scheduling Methods
- Producer's perspective

PRIBAS

- Pricing Balancing Services in the Future Nordic Power Market
- Fundamental market modelling

Supported by The Research Council of Norway

Integrating Balancing Markets in Hydropower Scheduling Methods (IBM)

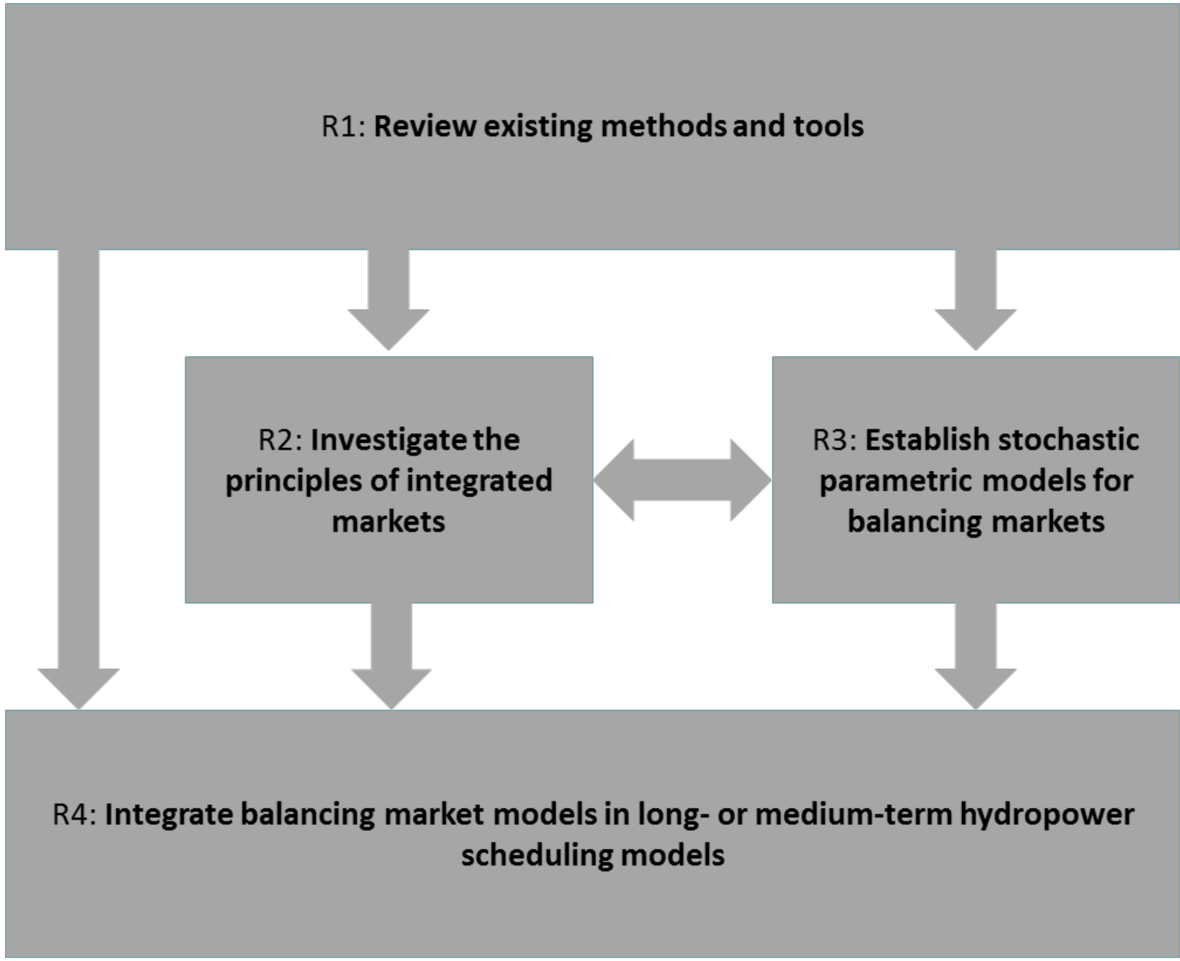
- Knowledge building project (KPN) 2014-2017
- 16 MNOK, research council supports 75 %
- One PhD at NTNU

Project Goal

Address the impact of integrating balancing markets in hydro scheduling methods by

- ✓ Reviewing existing approaches
- ✓ Illustrating concepts through simple models
- ✓ Extending current scheduling tools

How should the water values be calculated and interpreted?



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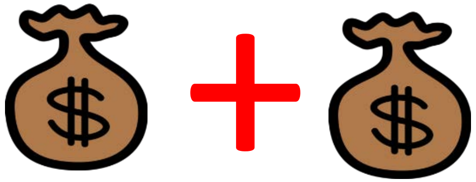
Hydropower producer's perspective

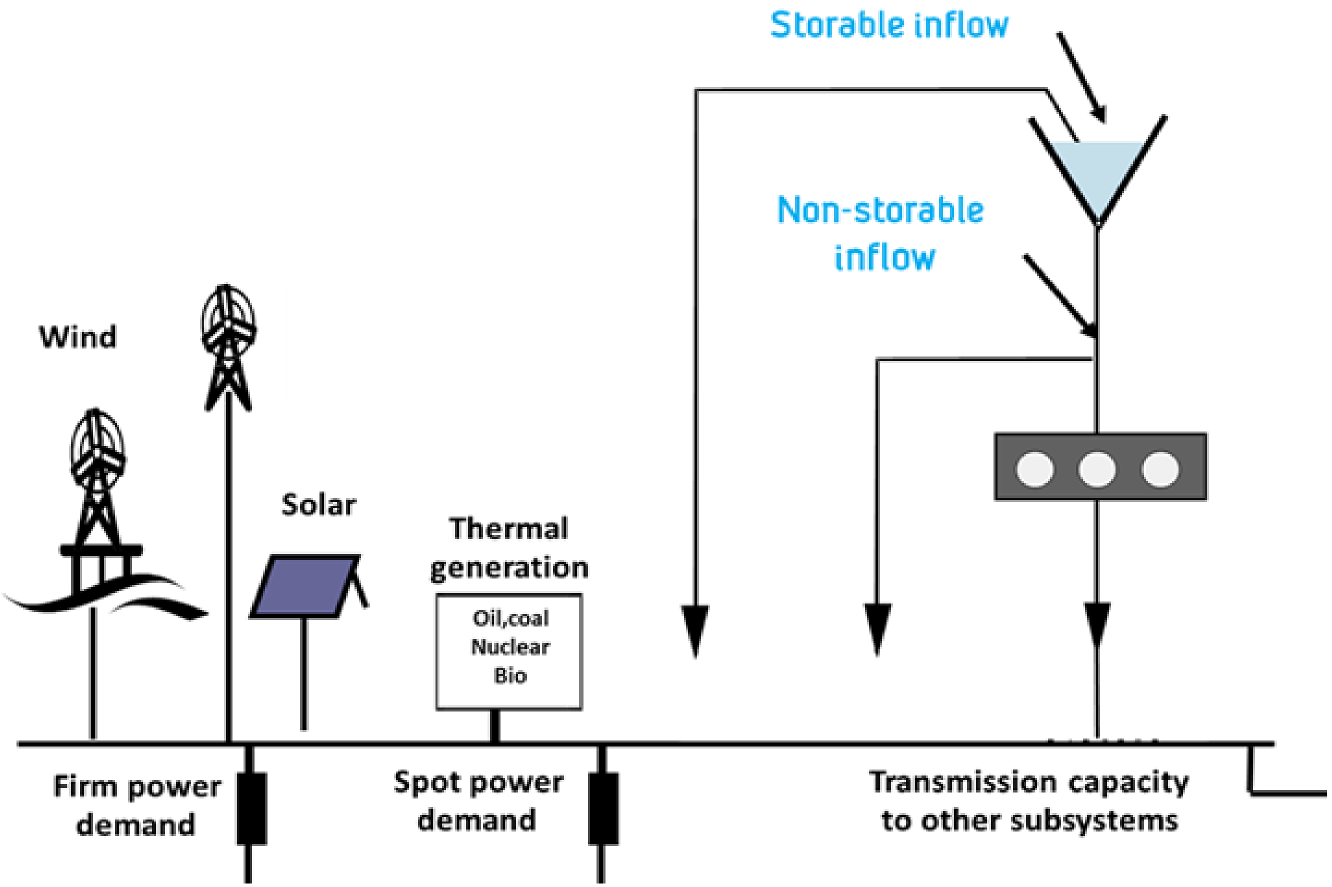
Energy only in the future?

- Multiple markets and prices
- More constraints
- Different decision stages

Impact on water values?

$$\max \mathrm{E}\left\{ \sum_{t=1}^{T} \mathbf{c}_t^{\mathrm{T}} \mathbf{x}_t + f\left(\mathbf{V}_t\right) \right\}$$





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Terminology & Assumptions

"Balancing markets"

- Reserve capacity
- Balancing energy

Producer

- Price taker
- Risk neutral

Reserve capacity

- Spinning
- Symmetric
- Sold in blocks

Table 6: Time-sequence for the different markets in Norway.

				October	Thursday	Thursday	Friday	Day-1	Day-1	Hour-1	Hour-0:45
					10:00	12:00	12:00	12:00	18:00		
Market	**Period**	**Resolution**	**Commodity**								
RKOM season	Winter	Season	Capacity	✓							
FRR-A	Week	N/D/E	Capacity		✓						
FCR-N week	Weekend	N/D/E	Capacity			✓					
RKOM week	Week	N/D	Capacity				✓				
FCR-N week	Weekday	N/D/E	Capacity				✓				
ELSPOT	Day	Hour	Energy					✓			
FCR-N/D day	Day	Hour	Capacity						✓		
ELBAS	Cont.	Hour	Energy							✓	
RKM	Hour	Hour	Energy								✓

Concerns & Challenges

Data:

- Balancing markets in the Nordics are 'under construction'
- Limited historical data
- Changing rules
- Low volumes
- Lack of fundamental models to create price forecasts for balancing markets

Modeling:

- ‘Linear’ unit commitment. Cannot strictly enforce minimum production in linear models
- Concave production function. Stations are allowed to generate electricity at low rates at an artificially high efficiency for the purpose of delivering reserves

Methodology Toolbox

Complexity

SDP

New Prototype

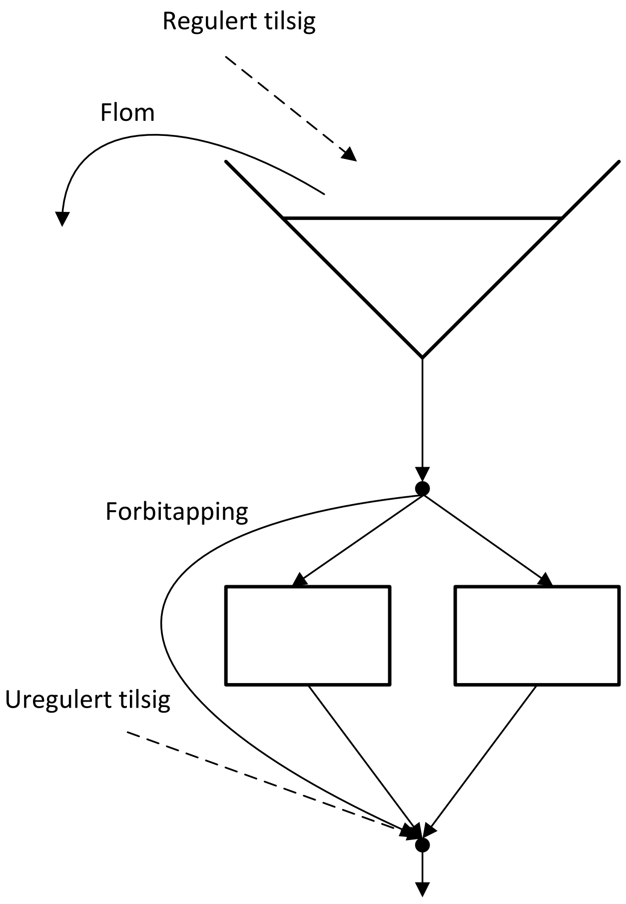
SDDP

SDDiP

SDP – Motivation

- Competence building & education
- Allows computing water values considering physical details
- Benchmark new functionality → what is the approximation error

SDP – Stochastic Dynamic Programming



Products:
- Energy
- Reserve capacity

Discretize State Variables

- Limited to systems with "a few" reservoirs

Nonlinearities

- Piecewise linear production function
- Head dependency
- Exact unit commitment

Uncertainty - Markov model

- Inflow
- Energy price
- Reserve capacity price

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SDP – Test Case

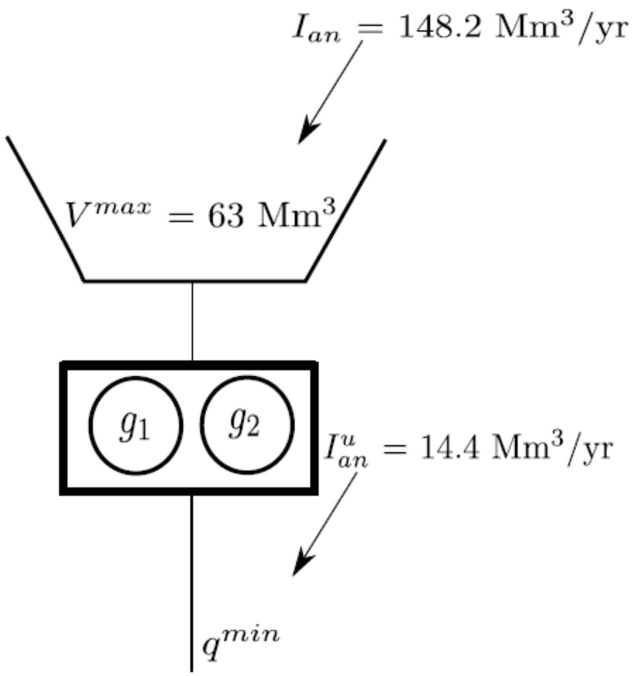

Table 1: Simulated cases

Case	unit no.	P^{max}	P^{min}	Type
A	g_1	21.11	6.57	Francis
A	g_2	3.71	0.49	Pelton
B	g_1	16.06	2.34	Pelton
B	g_2	8.79	0.97	Pelton

Products:

- Energy
- Reserve capacity
  - FCR – symmetric
  - NO2 prices

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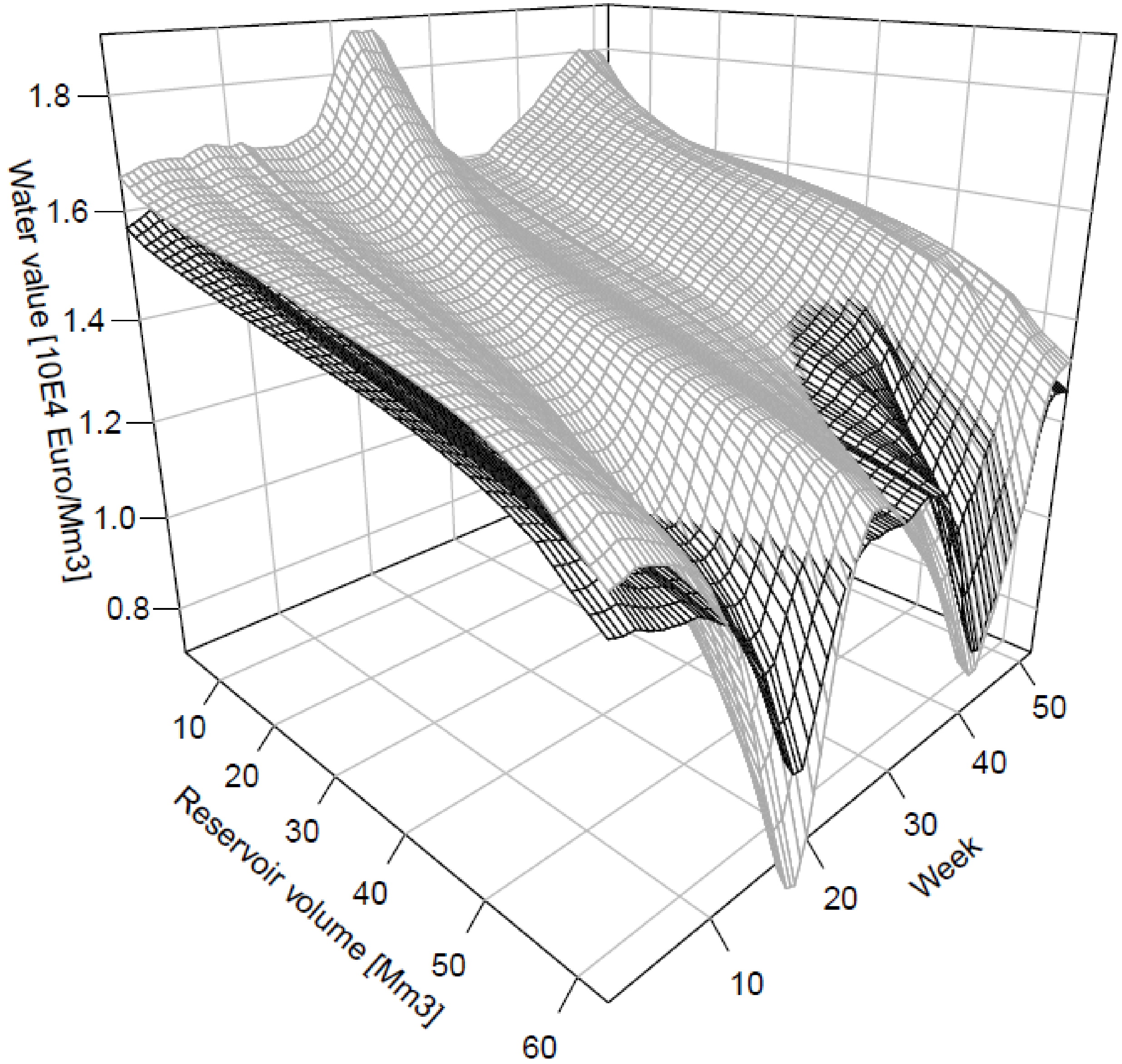
SDP – Test Case



Water values

Depends more on reservoir level when selling two products

- Down-regulation gives increase
- Up-regulation gives decrease

More exposed to risk of

- Emptying reservoir (limit flexibility)
- Spillage

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SDP – Test Case

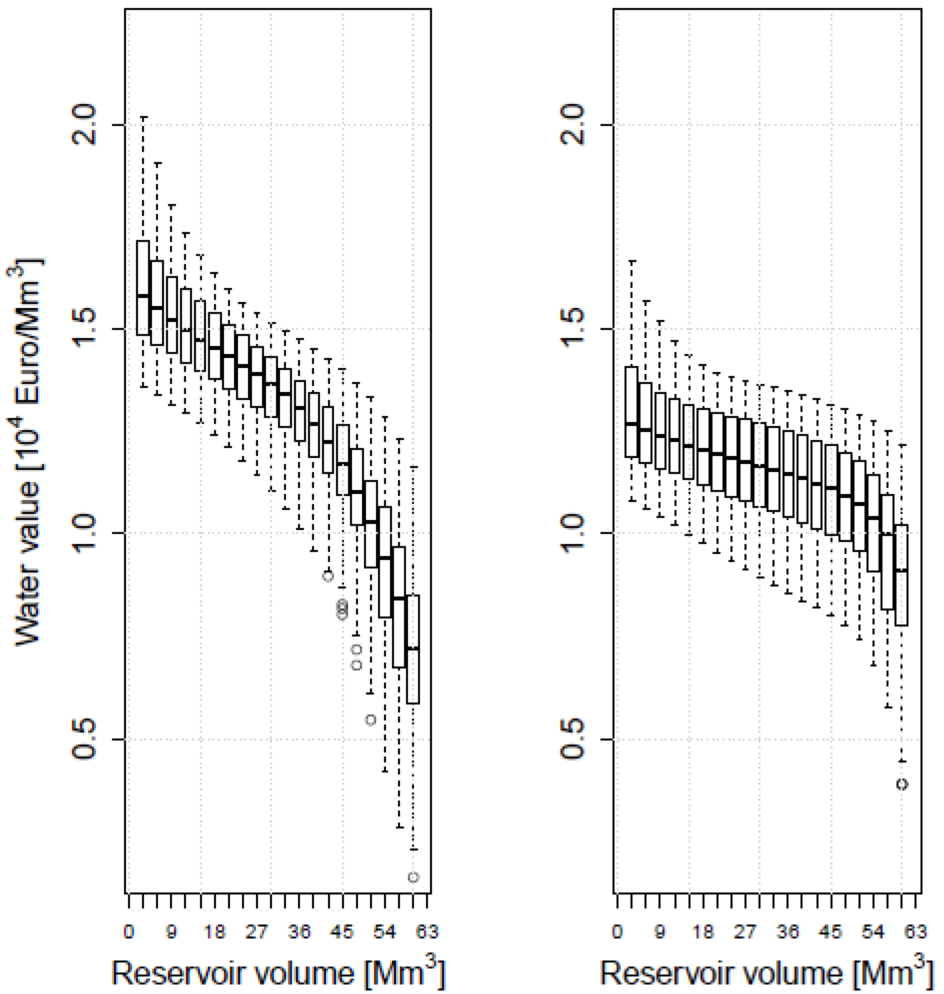

Figure 3: Water values for case B for week 15. Values for the E+C mode (left) and the E

Water values

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Methodology Toolbox

Complexity

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SDDP

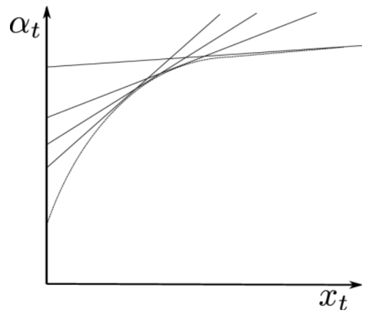
ProdRisk

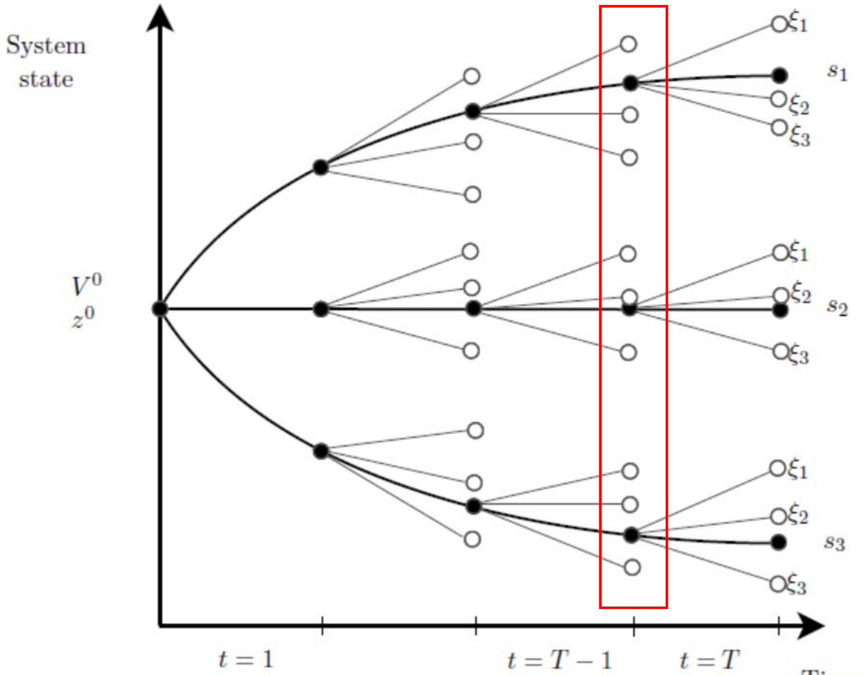
Prototyper

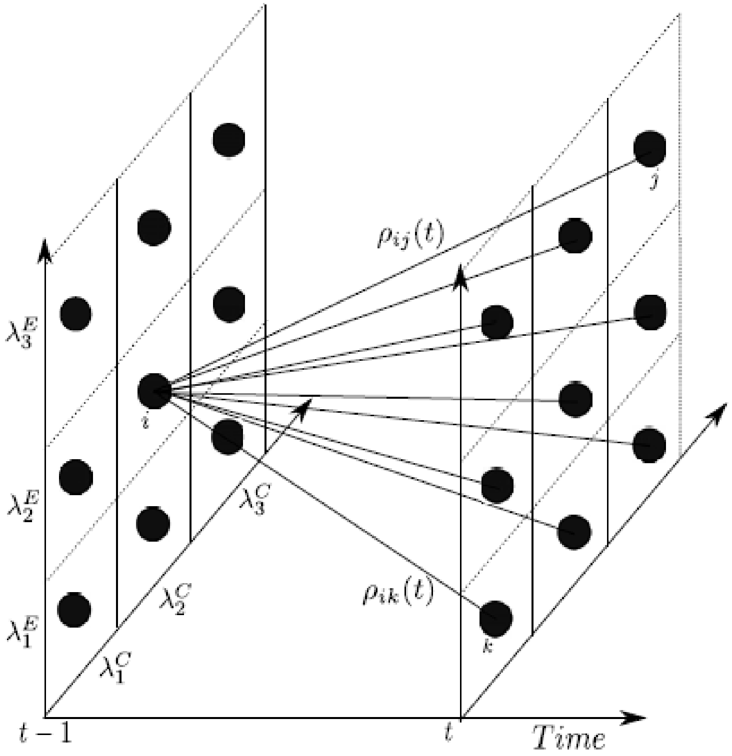
SDDiP

SDDP – Stochastic Dual Dynamic Programming

- Combined SDP-SDDP Used in ProdRisk
- Based on linear programming
- We add to the methodology:
  - ✓ sales of reserve capacity
  - ✓ corresponding constraints and prices







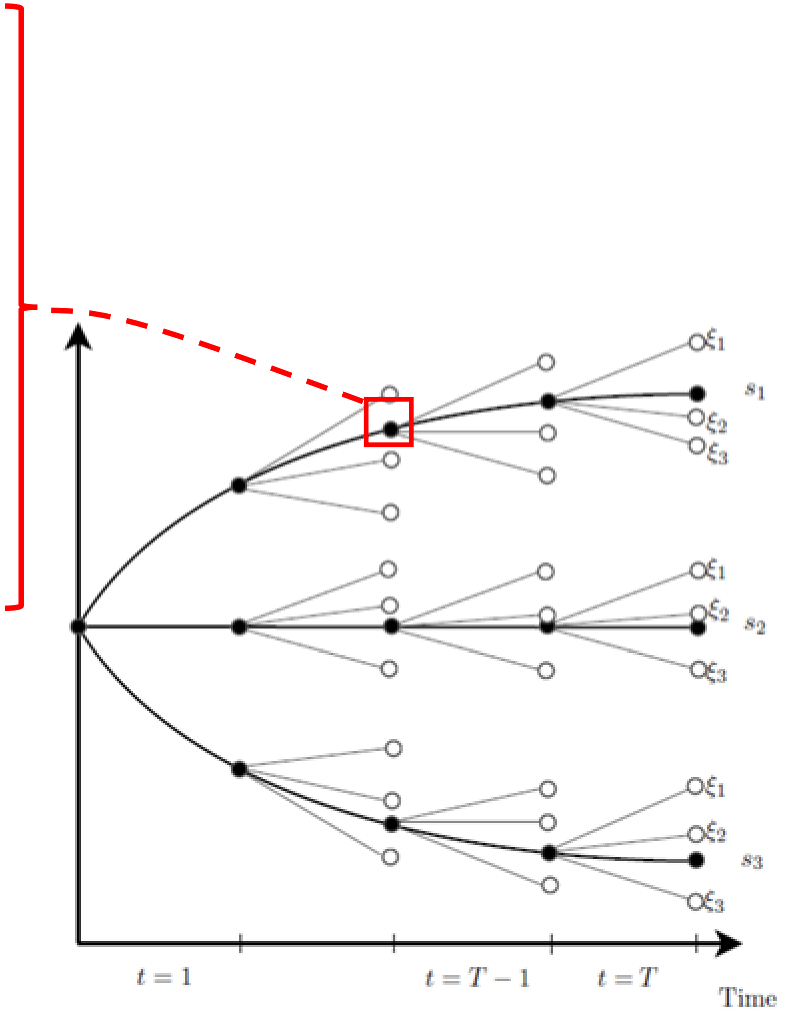
The Decomposed Weekly Decision Problem

Given {energy price, inflow}

Maximize profit from sales of energy + expected future profit

Constraints:

- Reservoir balance
- Energy balance
- Cuts



The Decomposed Weekly Decision Problem

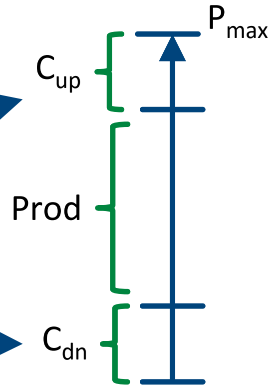
Simultaneous Sales of Energy and Reserve Capacity

Given {energy price, reserve capacity price, inflow}

Maximize profit from sales of energy & reserve capacity + expected future profit

Constraints:

- Reservoir balance
- Energy balance
- Cuts
- Capacity balance
- Distribute capacity to power stations that
  - Do not run at maximum output
  - Generate electricity ("spinning")



The Decomposed Weekly Decision Problem

Sequential Sales of Energy and Reserve Capacity

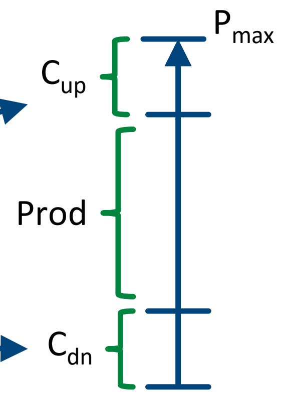
Given {energy price, reserve capacity price (t+1), inflow}

Maximize profit from sales of energy & reserve capacity(t+1) + expected future profit

Constraints:

- Reservoir balance
- Energy balance
- Cuts
- Capacity balance
- Distribute capacity to power stations that
  - Do not run at maximum output
  - Generate electricity ("spinning")

Sold capacity in (t-1)



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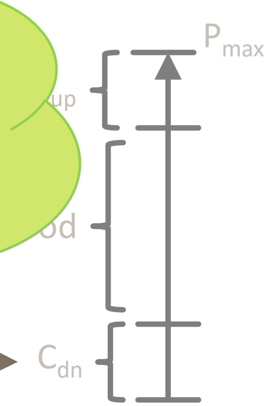
Sold capacity in (t-1)

Marginal cost of reserve capacity as a by-product

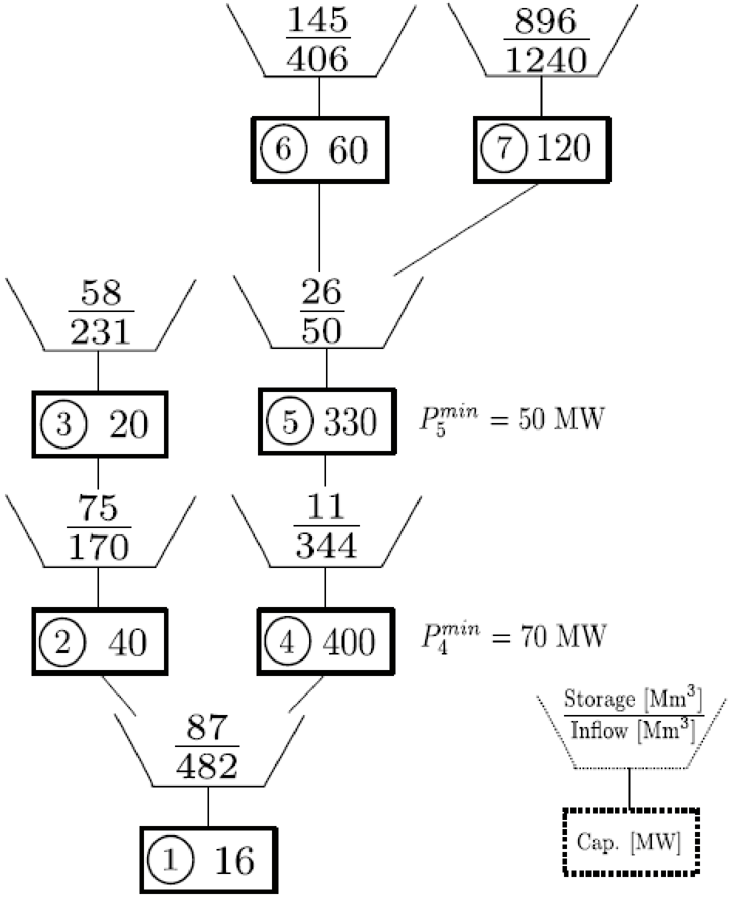


Conducted Experiments & Conclusions

- Stochastic and deterministic reserve capacity prices
- Reserve capacity volume constraint (maximum droop)
- Additional constraints and penalties to enforce minimum production requirement
- Require water "behind" sold reserve capacity
- Simulate with all details (MIP)

Findings:

- ✓ Water values (cut coefficients) changes as previously explained
- ✓ Additional profit low in today's market
- ✓ Linear models significantly overestimate revenue potential



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Methodology Toolbox

Complexity

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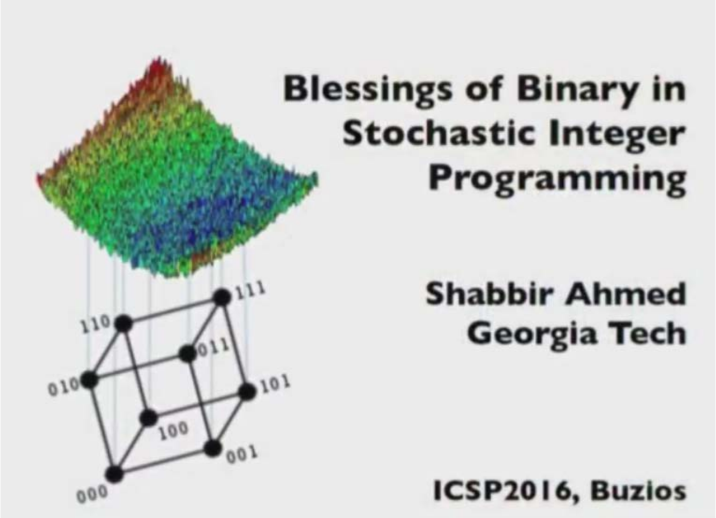
SDDP

SDDiP

PhD

Stochastic Dual Dynamic Integer Programming

- Developed by researchers at Georgia Tech University
- Applied to the hydropower scheduling problem by IBM project's PhD-student



https://www.youtube.com/watch?v=Ewr2Boj0Jgs

Algorithm in brief:

- Allow solving the weekly decision problem as a MIP and still create valid cuts
- Requires all state variables to be binary
- Several types of cuts are combined to improve performance
- Allows cut sharing

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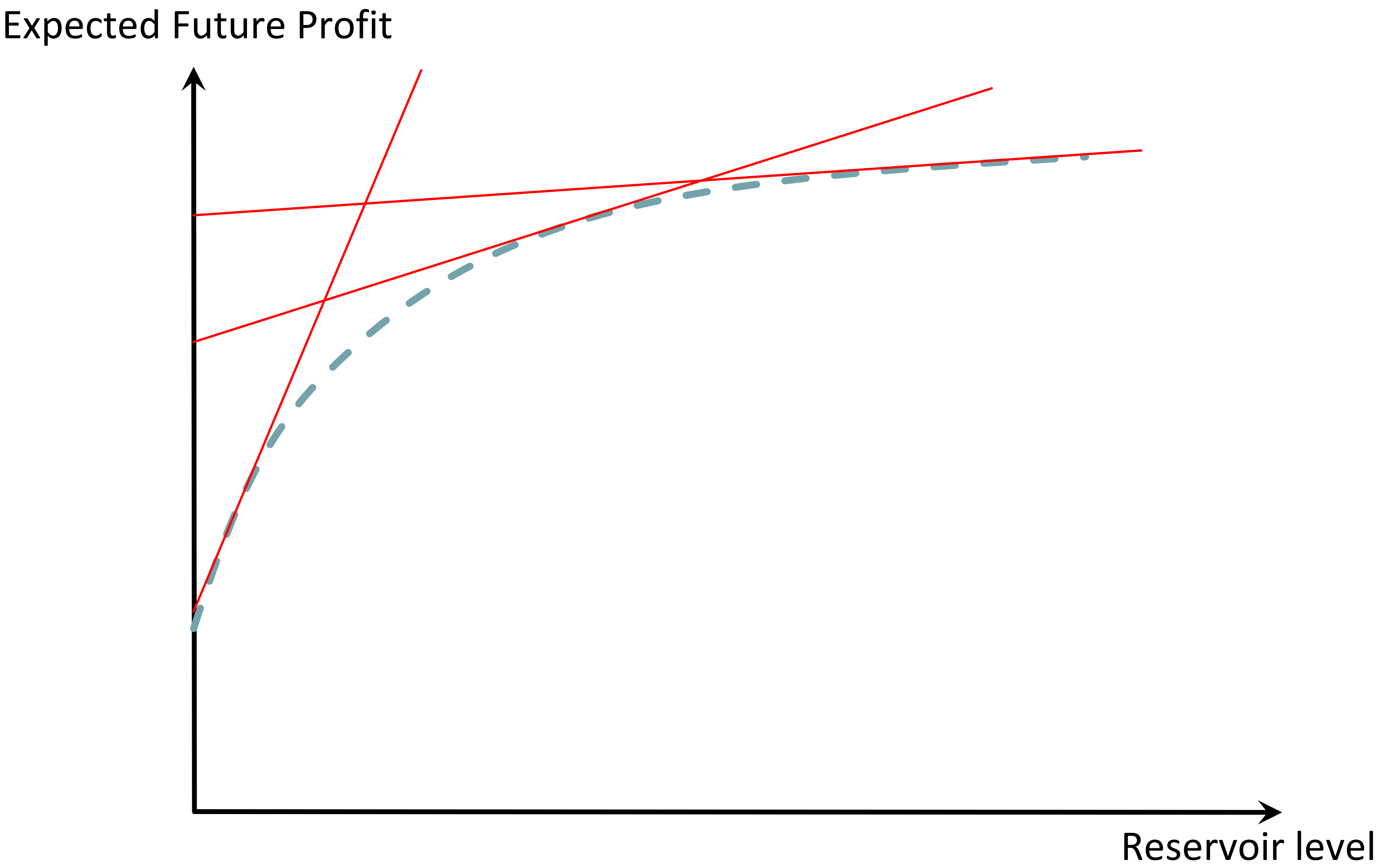
Stochastic Dual Dynamic Integer Programming

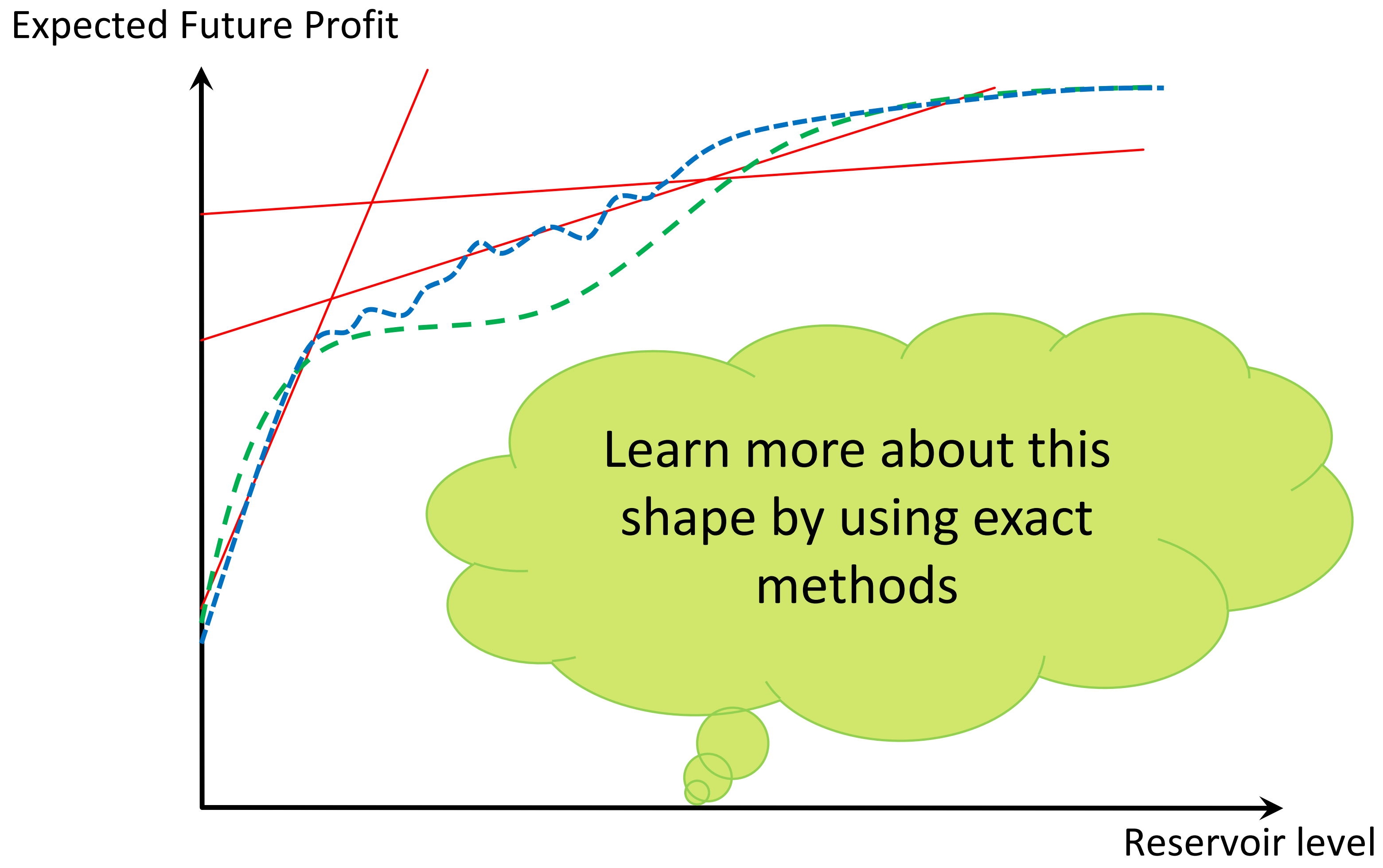
Our experiences so far:

- Extremely computationally demanding!
- Has the potential to quantify approximation errors in linear models, e.g. related to:
  - ✓ Unit commitment
  - ✓ Head dependent production functions
  - ✓ State-dependent constraints
- New types of cuts can improve current scheduling models, e.g. strengthened Benders cuts

The Expected Future Profit Function



The Expected Future Profit Function



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Pricing Balancing Services in the Future Nordic Power Market (PRIBAS)

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- 17 MNOK, research council supports 67 %
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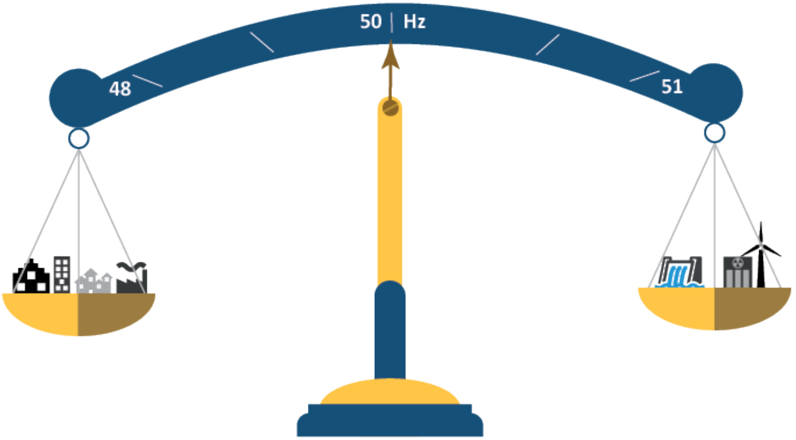

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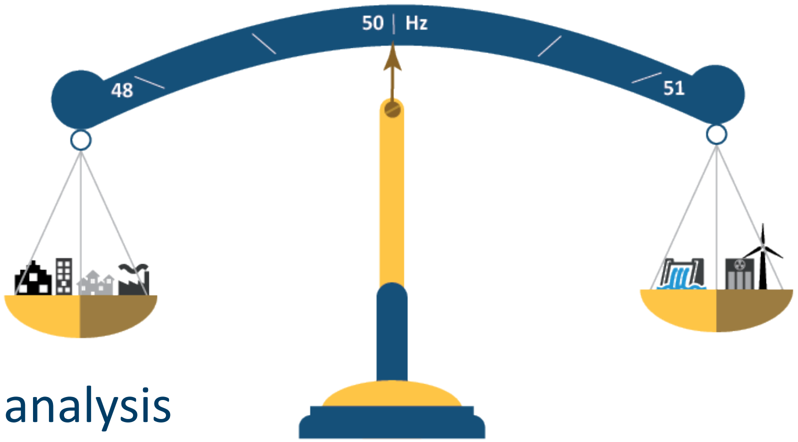
Project Goal

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

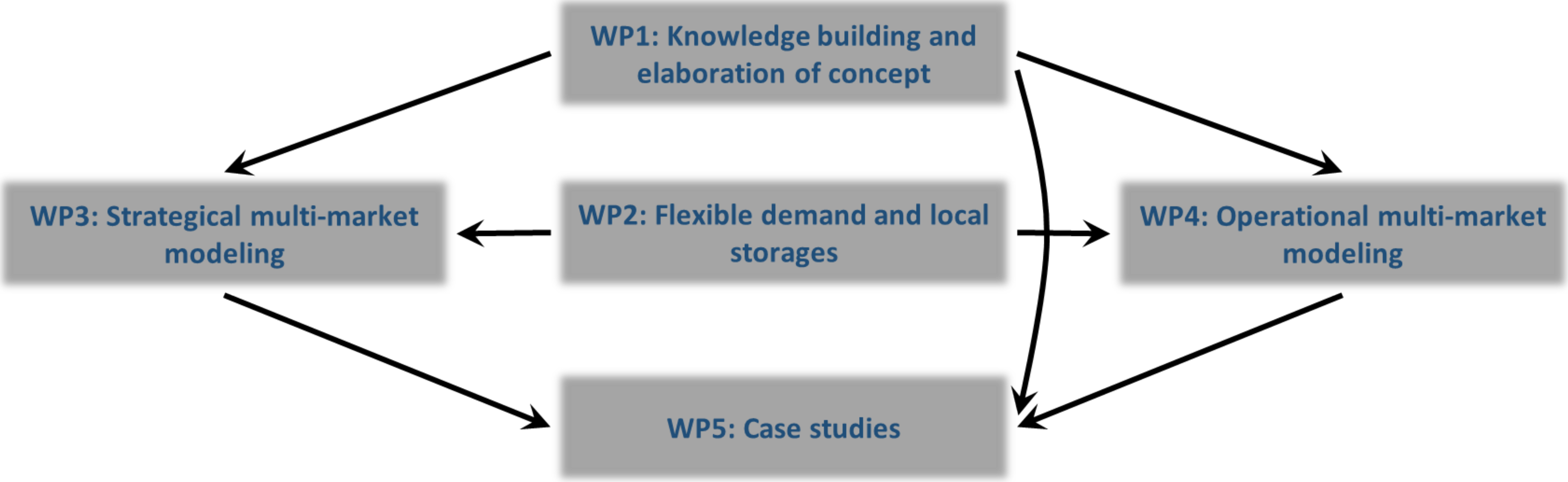
- ✓ Compute marginal prices for all electricity products
- ✓ Including reserve capacity and balancing energy
- ✓ Including flexible consumption and local storages



Expected use

- 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

Work Packages



balancing concept costs decision demand design developed different electricity energy european flexible forecasts fundamental future generation hydropower including increased integrated international knowledge local market methods model multi-market nordic ntnu operational partners power price products project prototype provide relevant representing research reserve results scheduling services sintef-er storages strategical system workshops wp

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