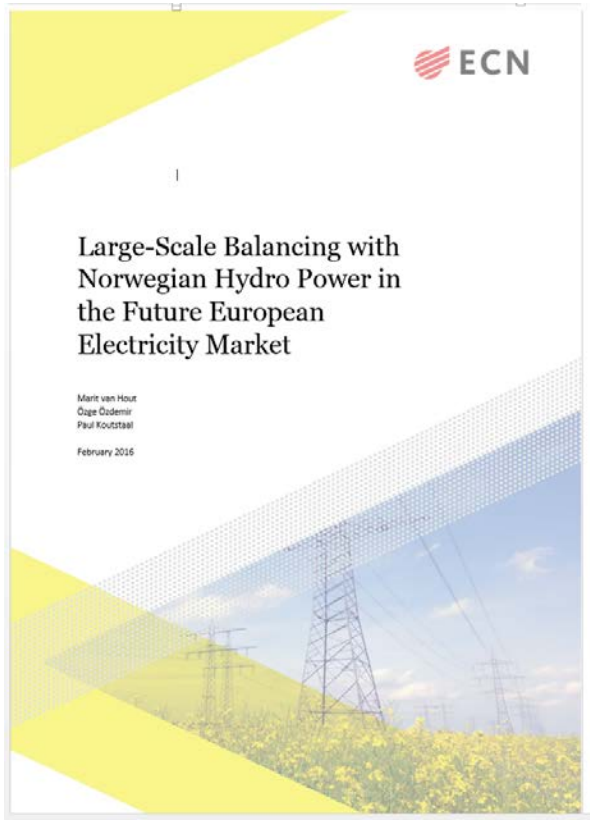
WP3
Modelling and analyses to develop relevant business models: summary of activities

Ove Wolfgang and Arild Lote Henden

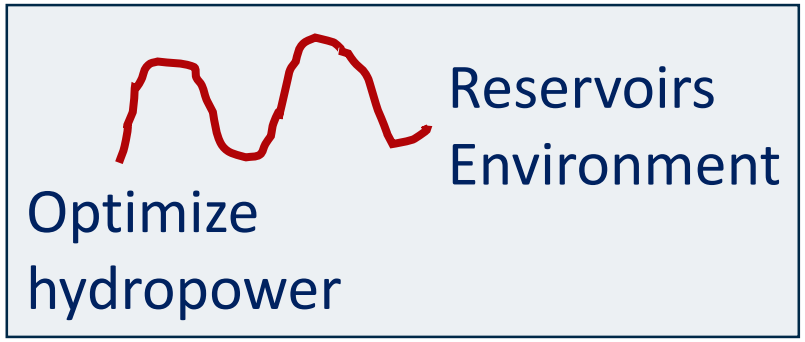
User-meeting Hydrobalance 2016

Main activities

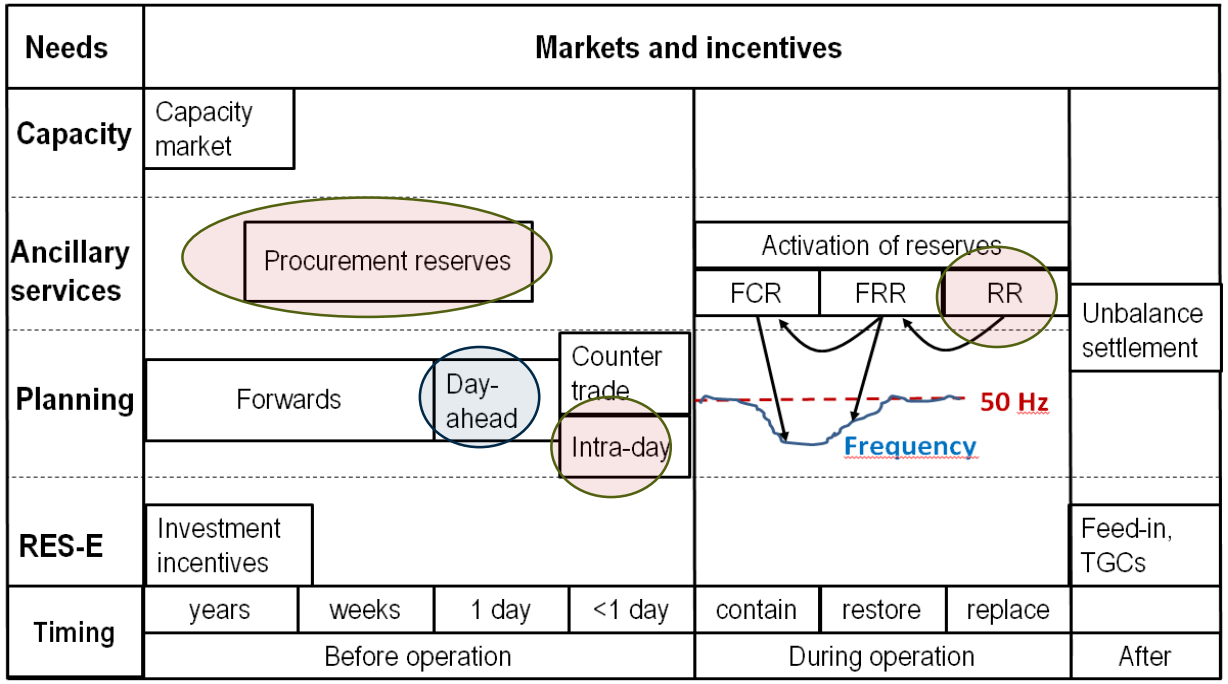
(1) ECN study

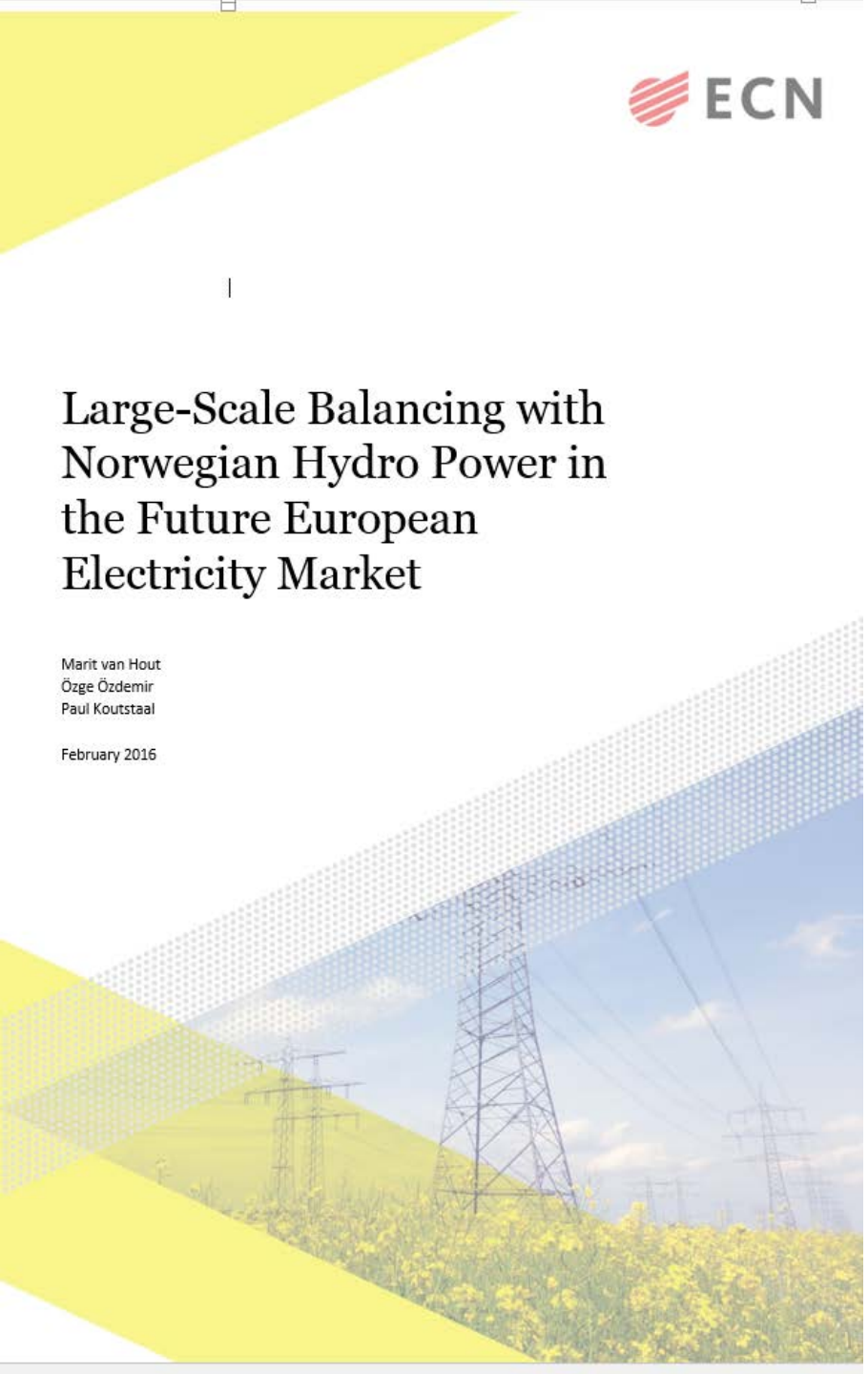


(2) SINTEF/Nina case study



(3) Model implementation: Prodrisk One2Many



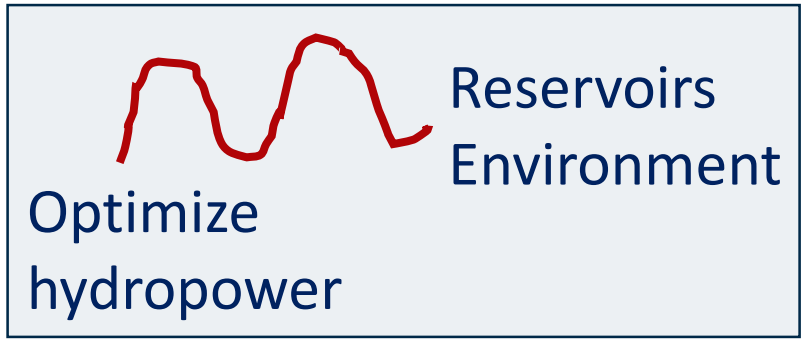


(1) ECN Study

- Initiated to calcluate consistent market prices for Day-ahead + intraday in Hydrobalance scenario
- Prices are input to local optimization tools
- <u>To be presented by ECN</u>

SINTEF

(2) SINTEF / NINA case study



- Case
  - Which reservoirs can we carry out environmental assessments for? (measurements needed).
  - Hydropower optimization (Prodrisk) for watercourse
  - Prices: Historical vs. Hydrobalance 2050, and more markets
- Presented by NINA yesterday

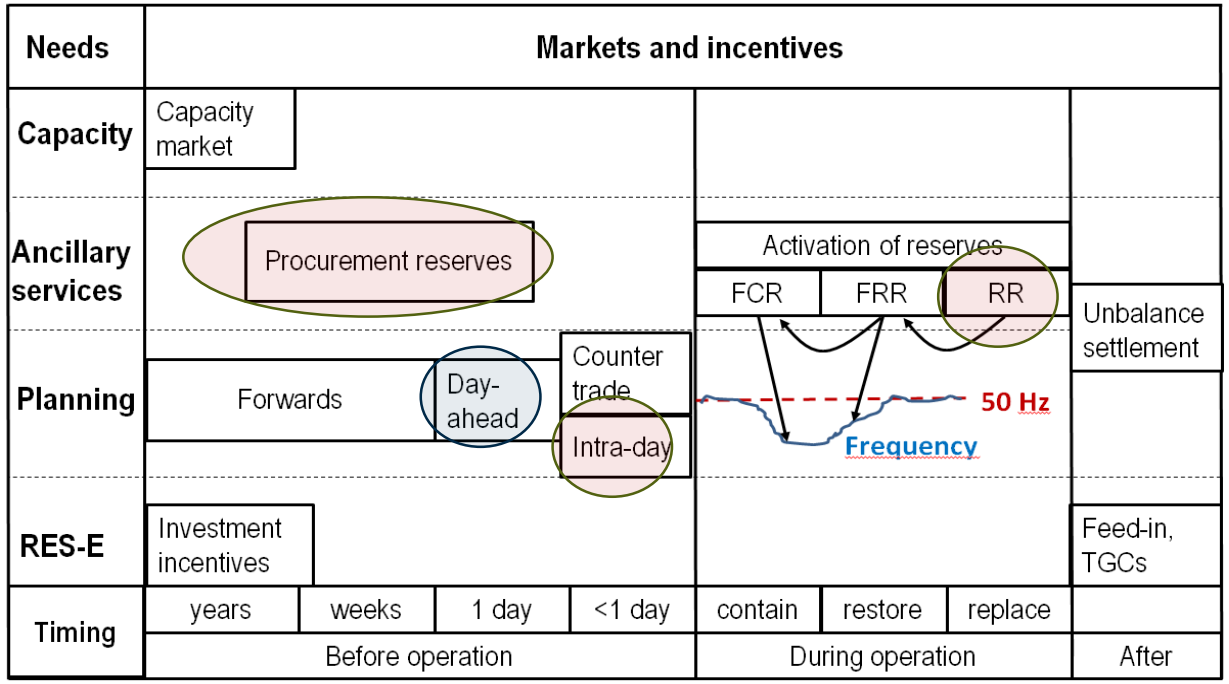
SINTEF

(3) Model implementation: Prodrisk One2Many

- What?
- Why?
- How?

What have we developed?

- A multi-market version of a detailed planning tool for hydropower scheduling (PRODRISK)
- As far as we know: The first example of this



- Before Hydrobalance: Only day-ahead
- 2015: Two markets, manual steps
- 2016: Flexible number, 'one push'
- Prototype exists
- We will make user-manual

Why did we implement this?

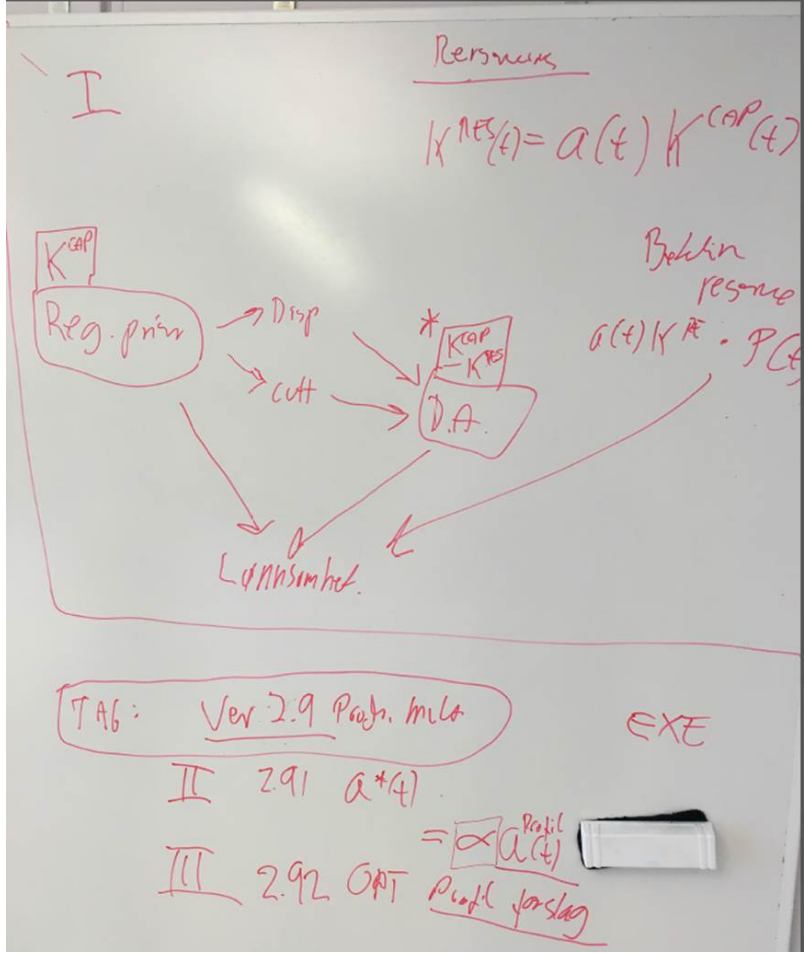
Central research questions in WP3

1. How will hydropower be operated in the future?
2. How large share of the income will come from different markets?
3. Will investments in new pumped storage be profitable in Norway?

- A multi-market approach was needed to study this
- Methodology was developed, but included manual several steps
- Goal for WP3 includes*: Streamline methodology so others can use it*

How did we do it?

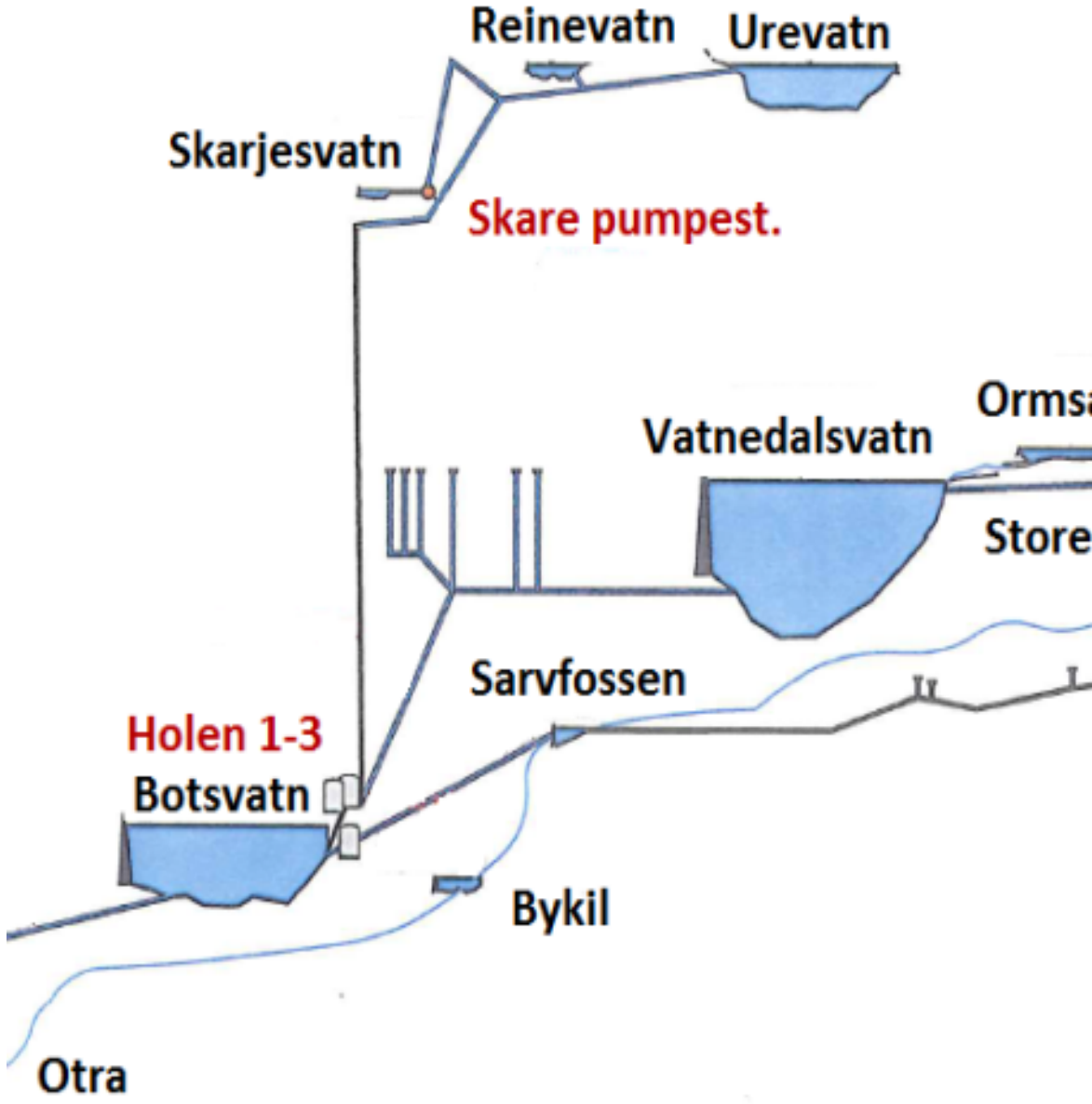
- Brief intro to Prodrisk
- Philosophy for multi-market simulation
- Small numerical example



SINTEF

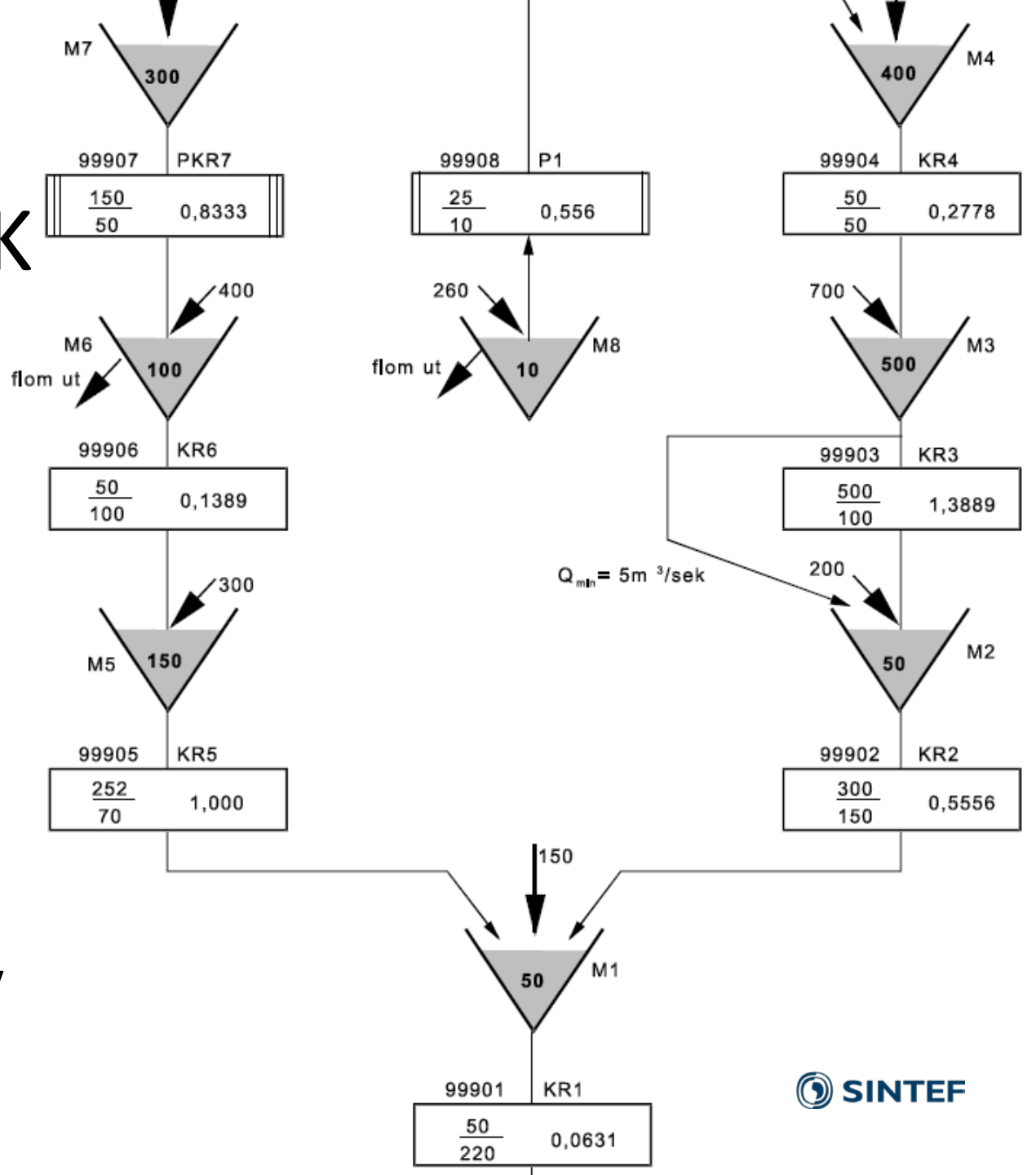
Introduciton to PRODRISK

- One of SINTEF's optimization tools for hydropower
  - For one given watercourse / river system
  - Stochastic variables: inflow, prices
  - Time-resolution/horizon: e.g. hour/year
- Maximize income in planning period, subject to all constraints
- However, standard version of model is only for one power market (day-ahead)



Introduciton to PRODRISK

- One of SINTEF's optimization tools for hydropower
  - For one given watercourse / river system
  - Stochastic variables: inflow, prices
  - Time-resolution/horizon: e.g. hour/year
- Maximize income in planning period, subject to all constraints
- However, standard version of model is only for one power market (day-ahead)



Philosophy for multi-market simulation

1) Day-ahead market is treated as the main market
   - Available capacity is bid as-if it was the only market.
   - Fairly reasonable, but *not fully optimized strategy*.
2) However, producers *react upon* prices in subsequent markets
   - Intraday, balancing energy ("regulerkraft")
   - Increase or decrease production; price-takers
3) The same water-value is applied when optimizing for different markets.
4) Reserve power (up and down) is roughly optimized per week;
   iterative algorithm runs through a set defined by user, and select the best.

Comments to model implementation

- Reference scenario
  - Full standard PRODRISK optimization
  - For prices in the final market (to get correct reservoir levels)
  - Water-values are calculated for each week and scenario

- Optimal supply per market segment, for given hour/scenario
  - The water-value has already been calculated by reference scenario
  - Optimal generation is calculated for price in corresopnding market-segment
  - Supply in market segment is "change" in generation compared to prevous segment

Example (one given hour/scenario)

Market segment	Price (€/MWh)	Supply*) (MWh)	Supply for segment (MWh)	Income (€)
Day-ahead	20	80	80	20x80=1600
Intra-day	30	90	90-80=10	30x10=300
Balancing energy	40	100	100-90=10	40x10=400
Total		**100**	**80+10+10=100**	**2300**

*) Optimized generation for scenario/hour in Prodrisk, for given price in market-segment.
Note: The same startegy/water-value is applied for all market-segments.

Coming research activities

- Run case-study with several markets
  - Check profitability of pumped storage in Hydrobalance scenario, when several markets are taken into account (e.g. DA, ID and reserves)
  - Identify extra profits of participating in different markets
- Publish model / case-study
- User manual for multi-market version of PRODRISIK

Case study: Arild Lote Henden

HydroBalance

WP3 – Results September 2016

Price-scenario and strategies

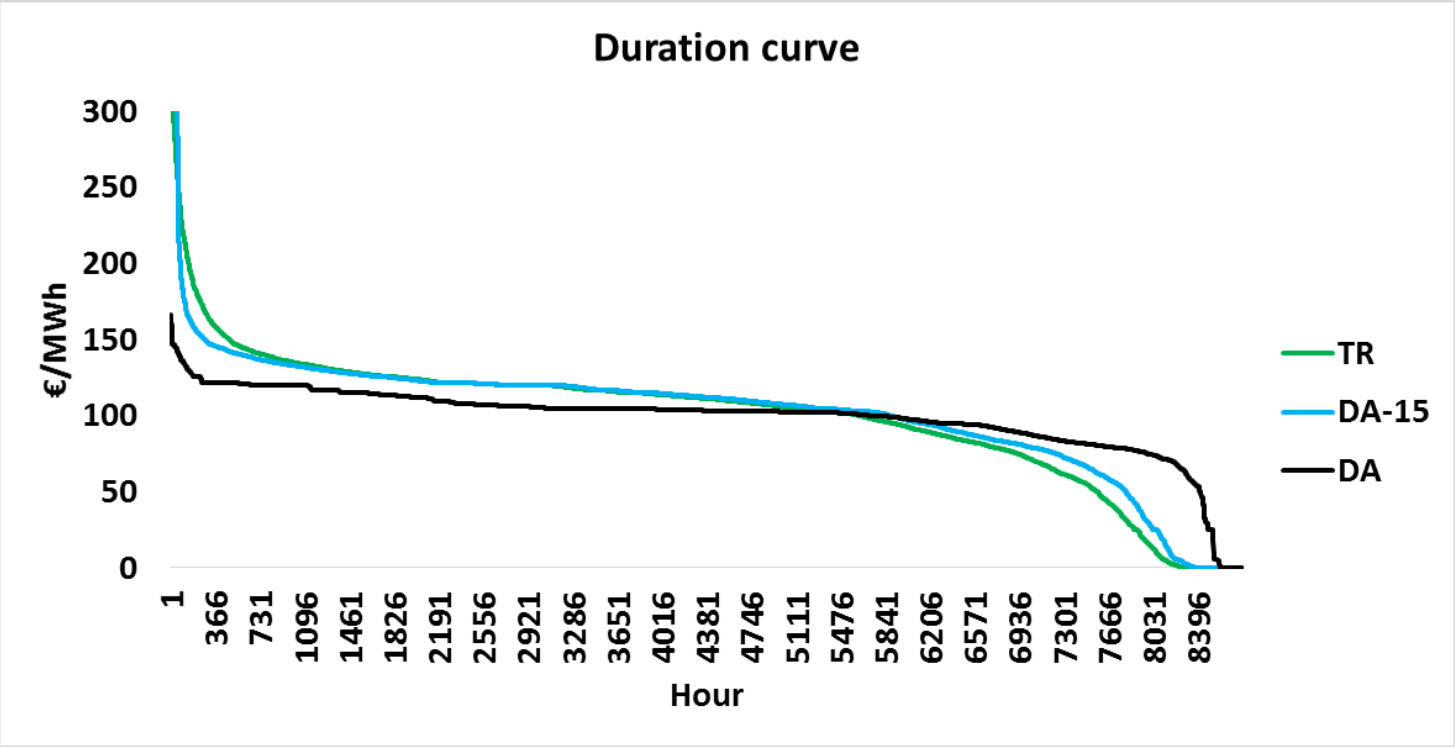
- Future prices calculated by IAEW
- Several markets from detailed study of Germany (2008 weather year)
  - Results for 10 market:
    - Day ahead, energy – DA
    - Day ahead 15 minutes, energy – DA15/≈Intraday
    - Secondary reserve, energy – SR
    - Tertiary/replacement reserved, energy – TR/RR/RK
    - Reserved power in PR: Up and Down – PR/FCR
    - Reserved power in SR: Up and Down – SR/FRRA
    - Reserved power in TR: Up and Down – ResTR/FRRM/RKOM

Price-scenario and strategies

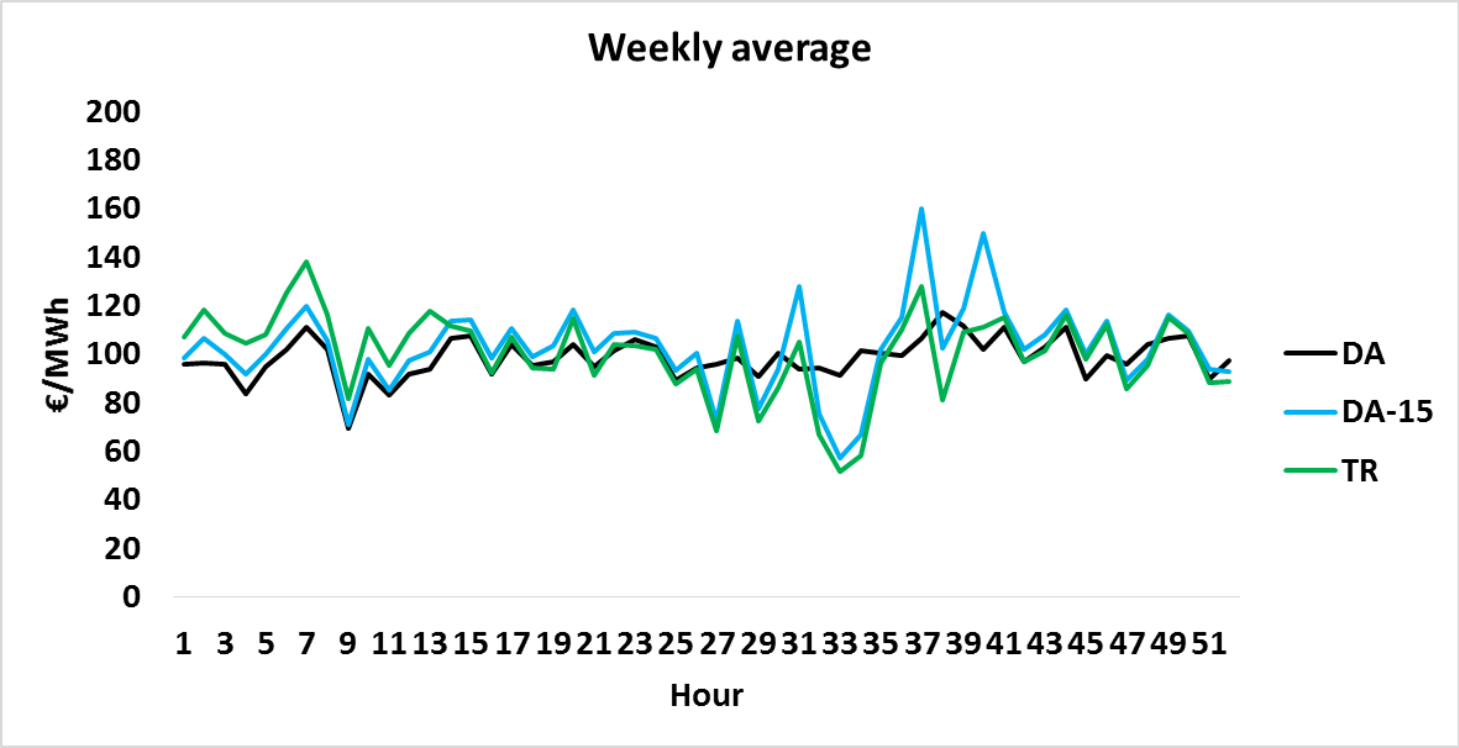
- Future prices calculated by IAEW
- Several markets from detailed study of Germany (2008 weather year)
  - Results for 10 market:

• Day ahead, energy	– DA
• Day ahead 15 minutes, energy	– DA15/≈Intraday
• Secondary reserve, energy	– SR
• Tertiary/replacement reserved, energy	– TR/RR/RK
• Reserved power in PR: Up and Down	– PR/FCR
• Reserved power in SR: Up and Down	– SR/FRRA
• Reserved power in TR: Up and Down	– ResTR/FRRM/RKOM

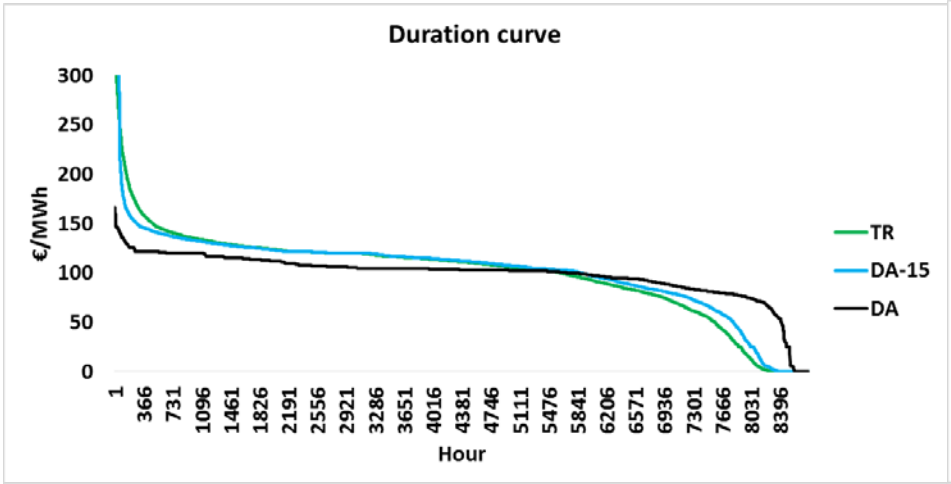
Energy prices

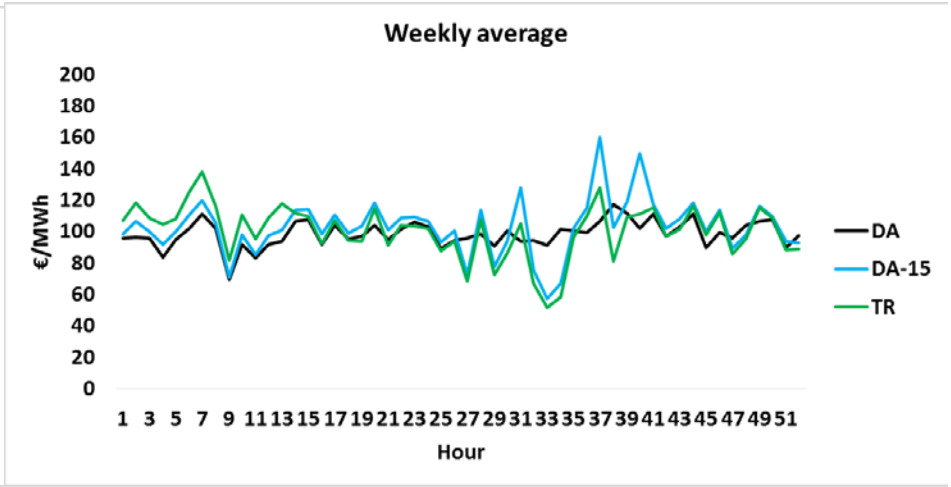


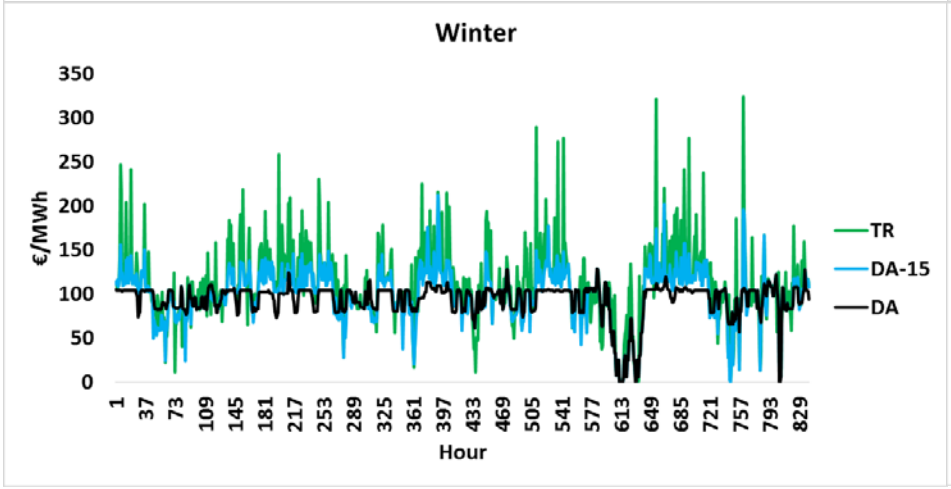
Energy prices

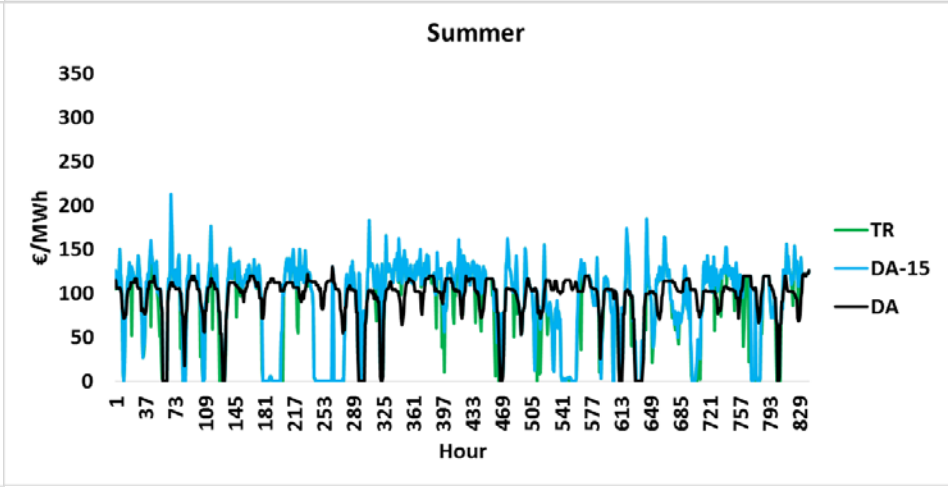


Energy prices

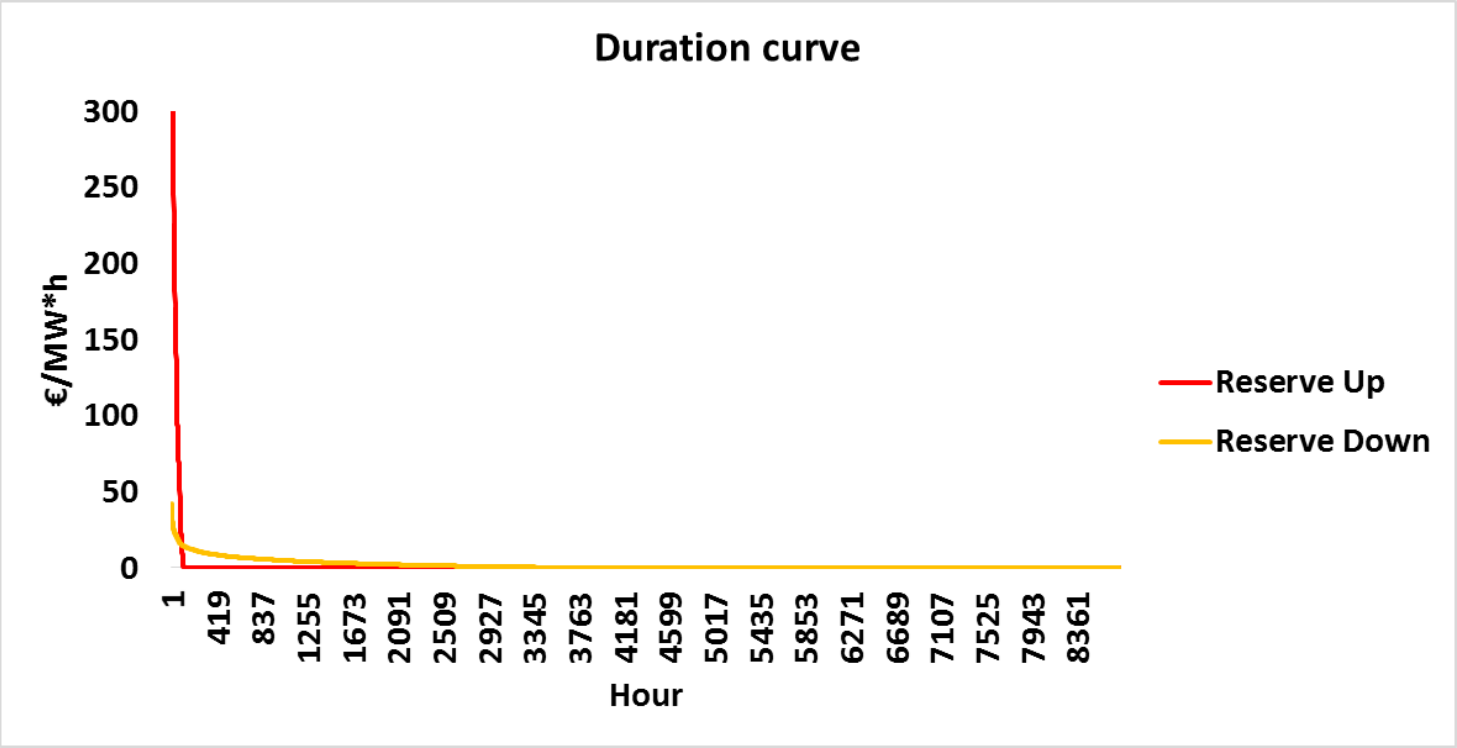




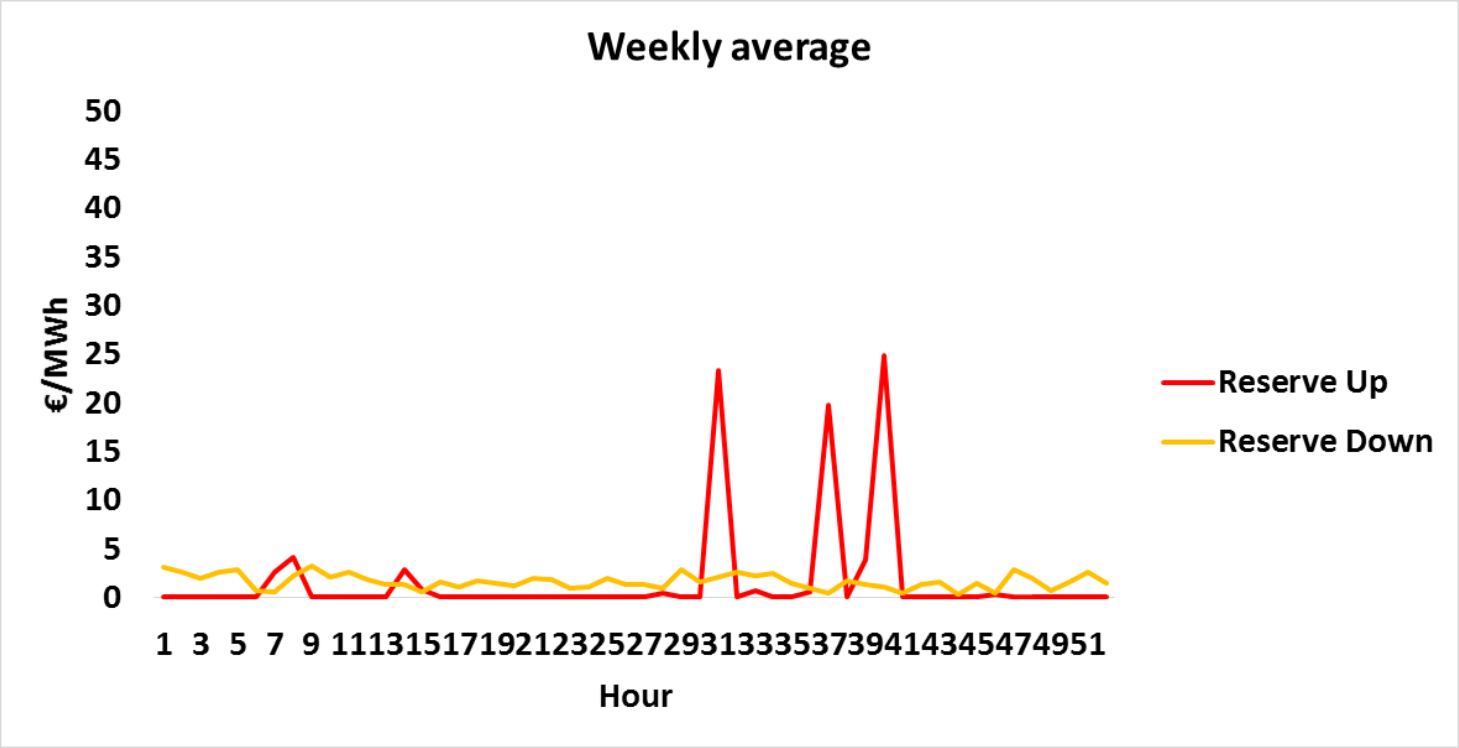




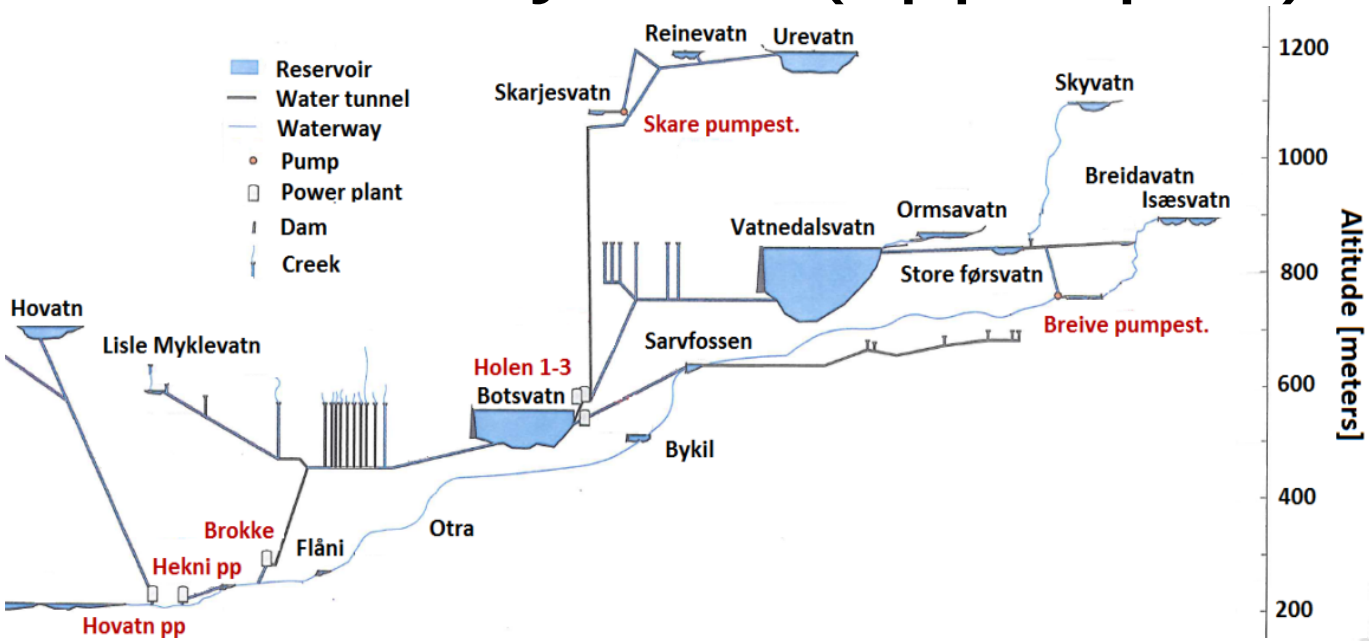
Power prices



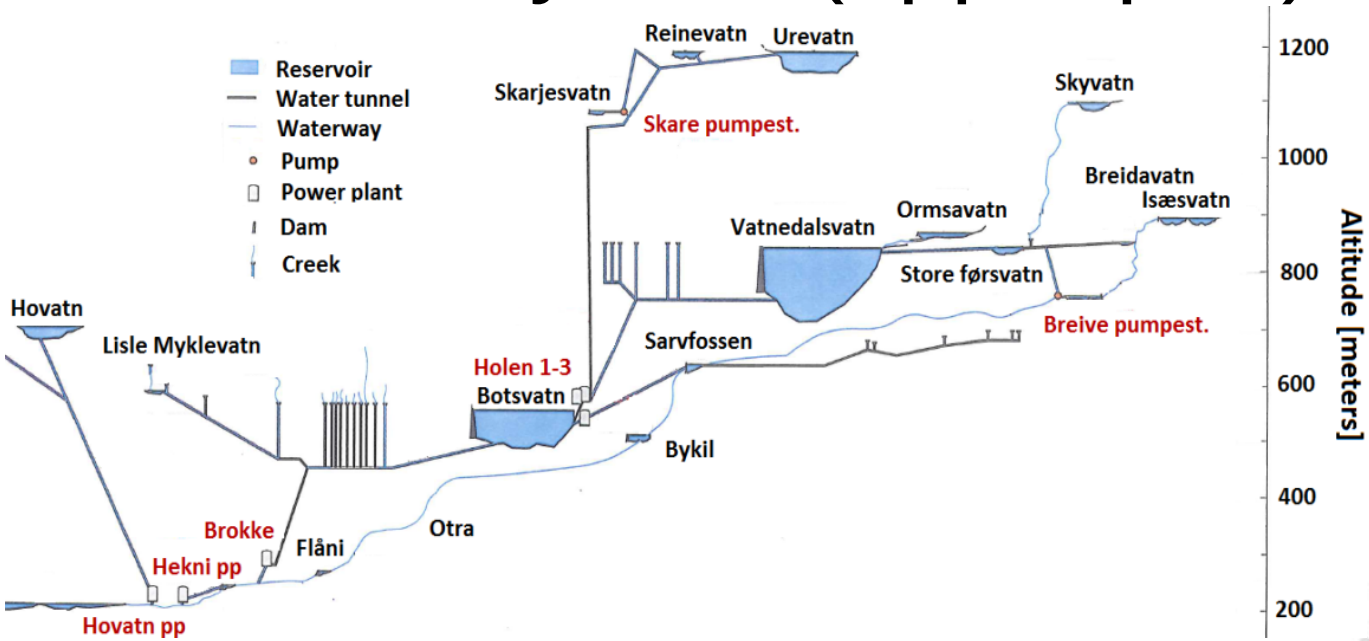
Power prices



Otra river system (upper part)



Otra river system (upper part)

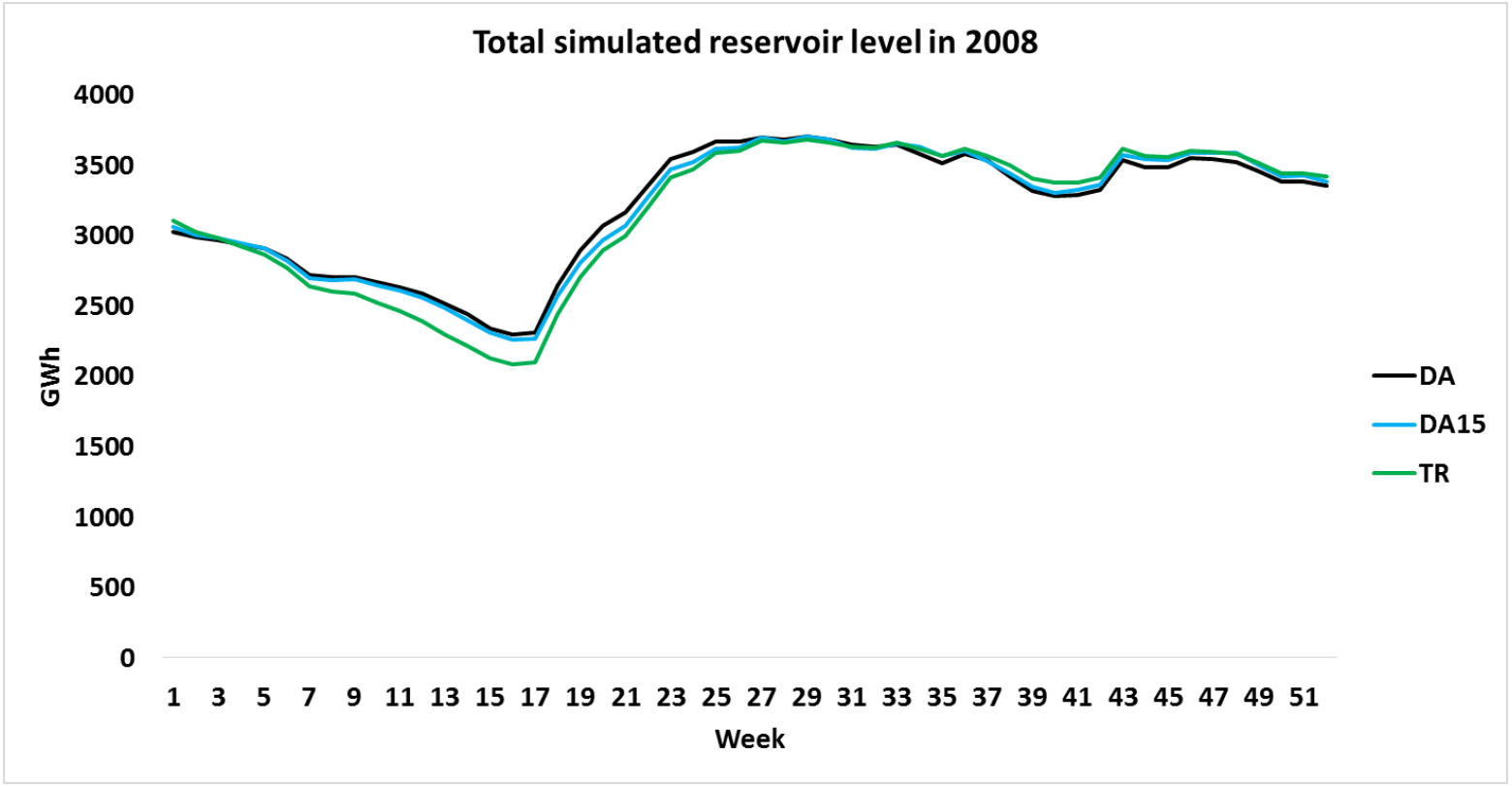


- 1 122 MW production capacity – 14 plants
- 36 MW pumped capacity – 2 pumps
- 3.75 TWh storage capacity – 13 reservoirs
- 5 TWh average annual production
- Complex river system

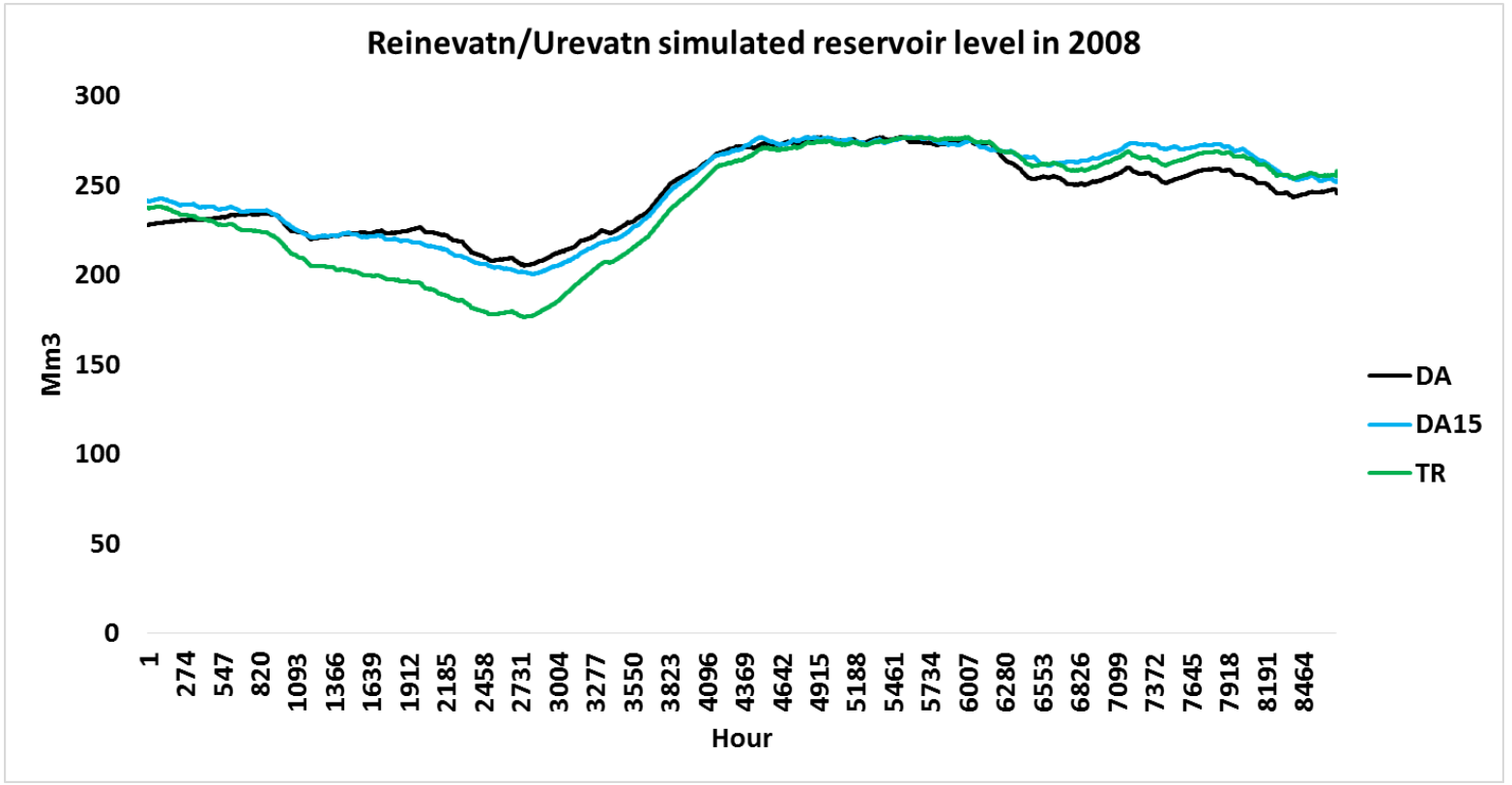
Results

- Reservoir level
  - Only 2008
- Production result
  - 2007 to 2011
  - Winter and summer weeks in 2008
- Reserved power
  - Same volume is reserved for all year and each week
- Economic result
  - Average of 2007 to 2011

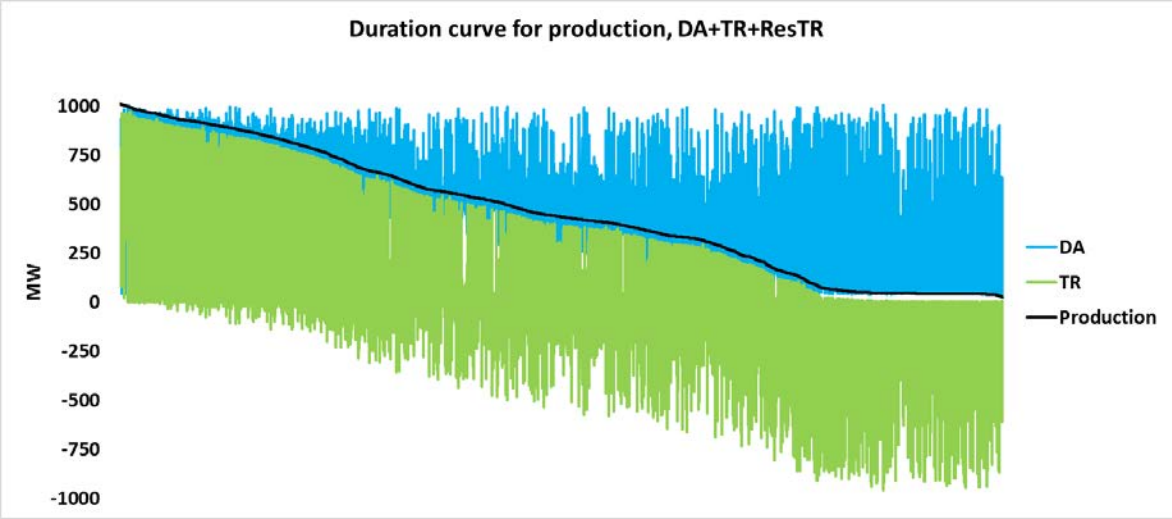
Total reservoir

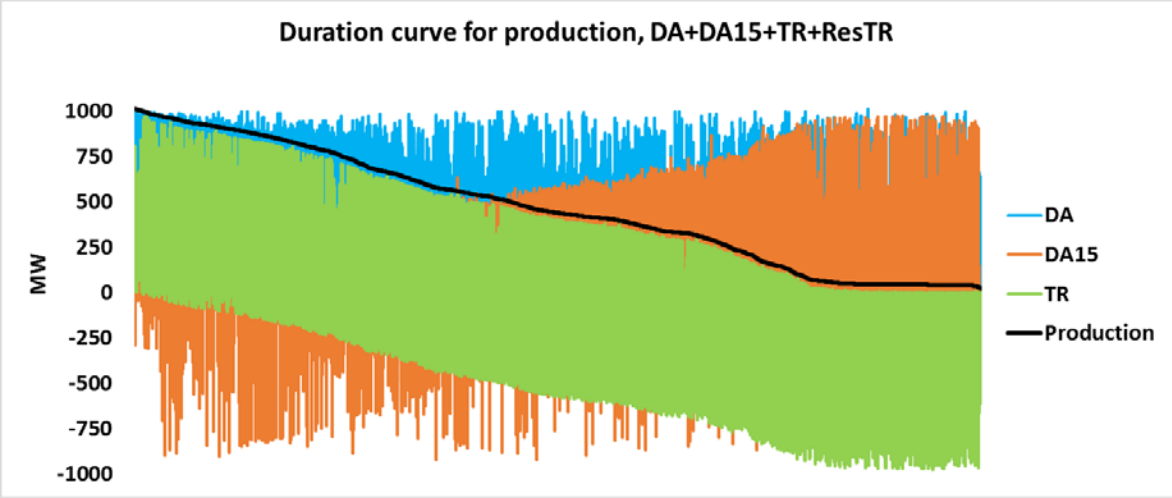


Reinevatn and Urevatn reservoir

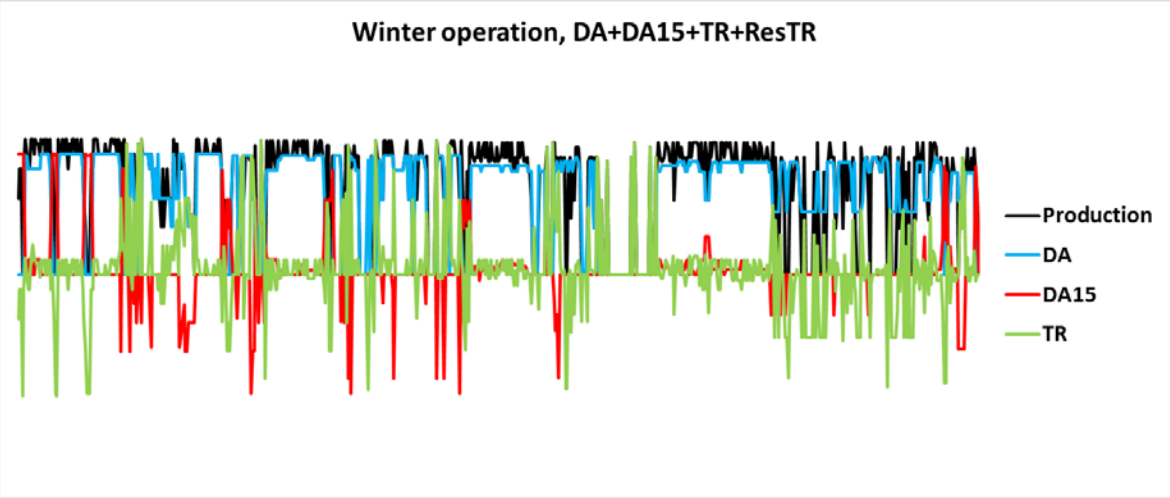


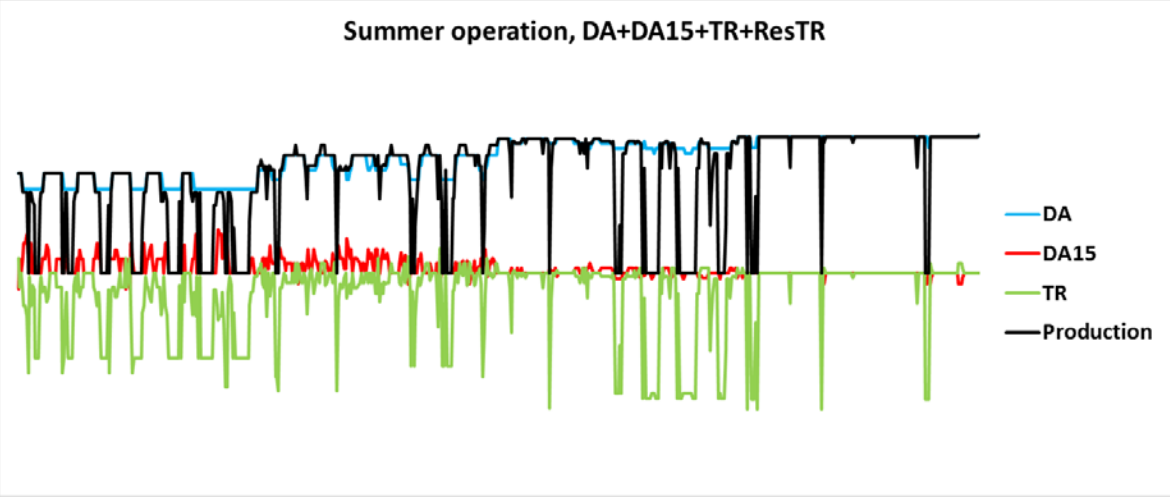
Total production in river system





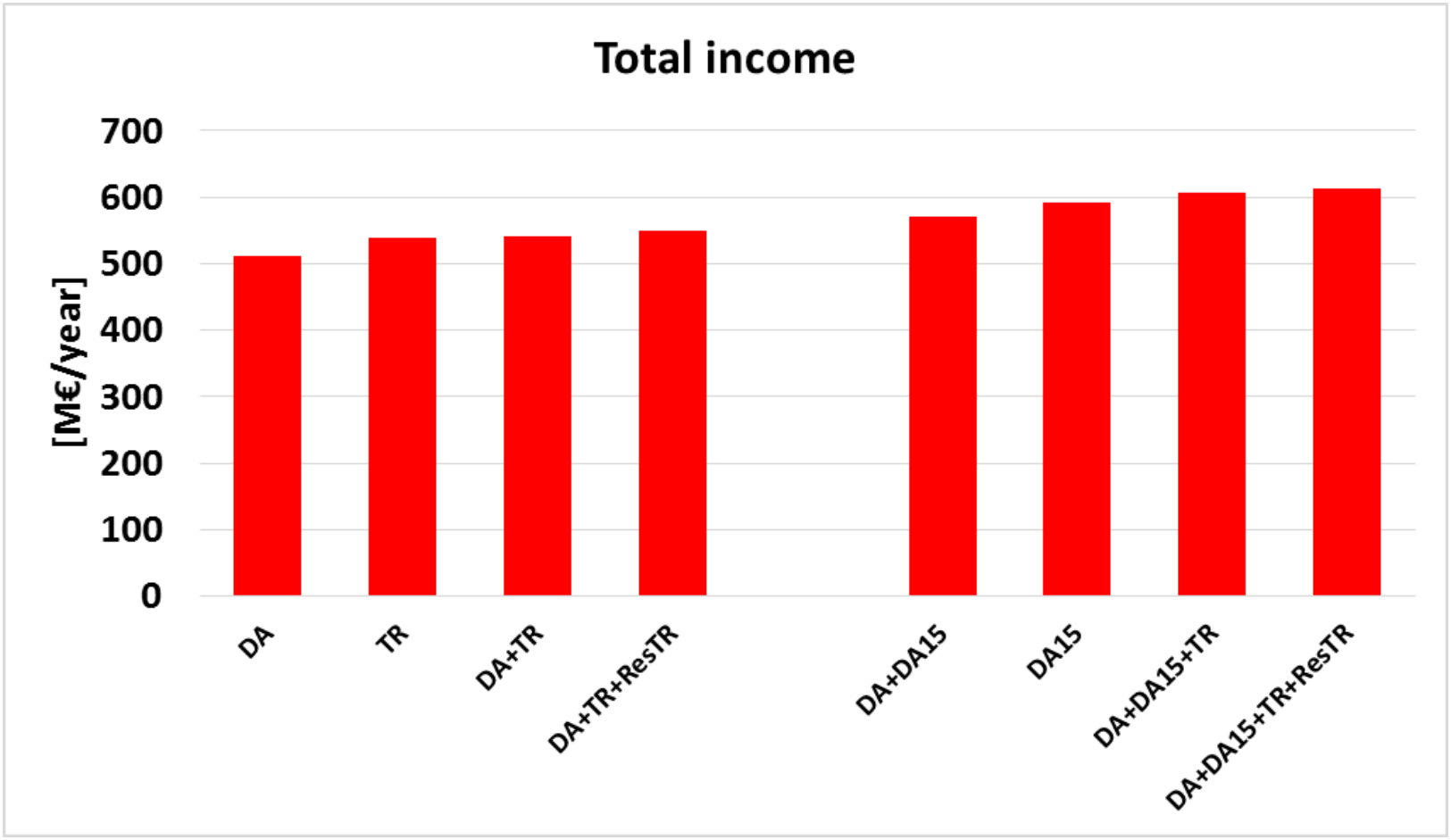
Production for given unit



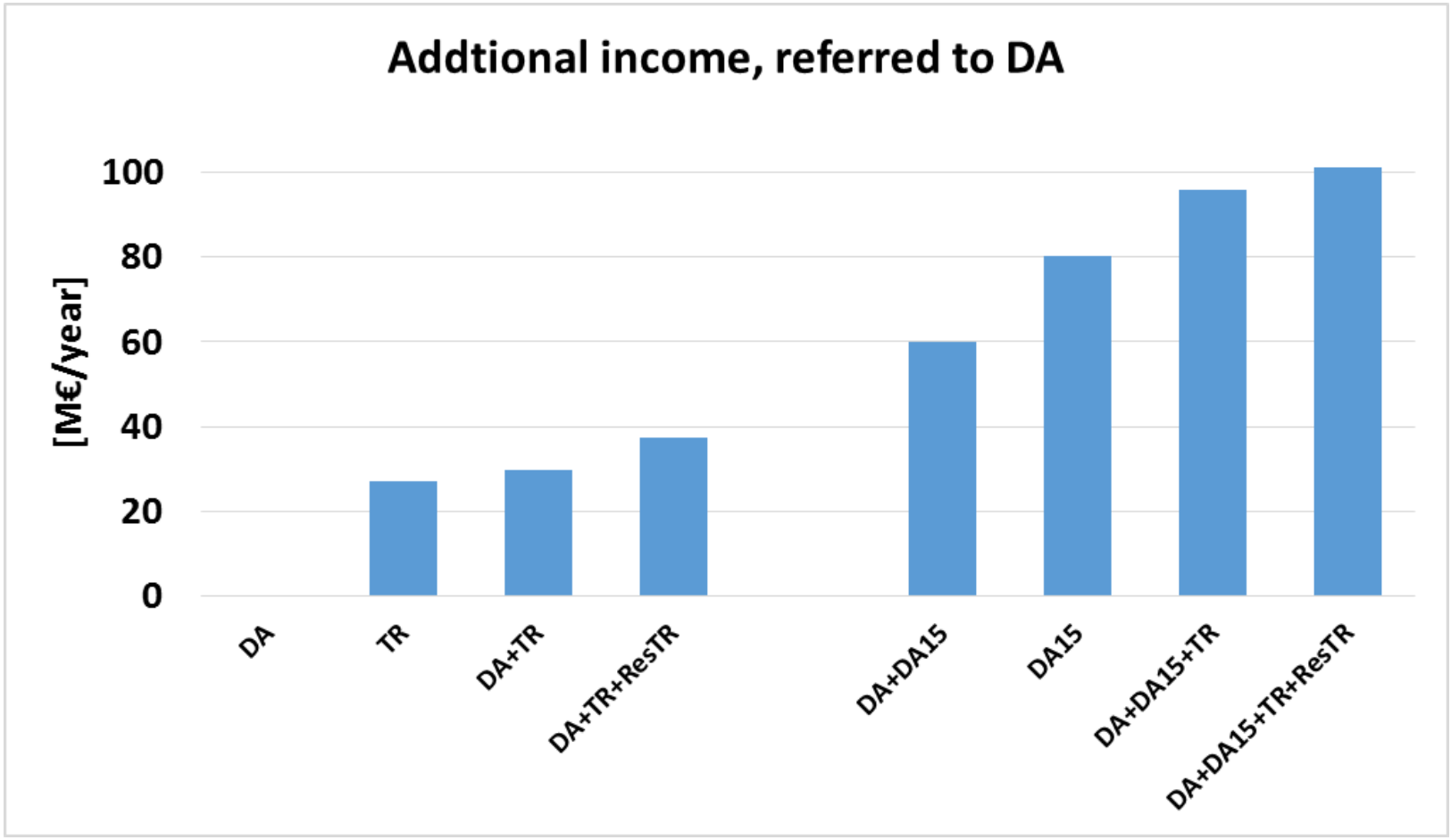


Reserved power in river system

Economic results



Economic results



Economic results

Market, numbers in [M€/year]	Total income	**Addtional income, referred to DA**	DA	DA15	TR	ResTR	Reservoir change	**Addtional income, referred to DA [%]**
DA	511,5	**0,0**	528,5				-17,0	**0,0**
TR	538,6	**27,1**			538,7		-0,1	**5,0**
DA+TR	541,2	**29,7**	496,5		44,8		-0,1	**5,5**
DA+TR+ResTR	548,8	**37,2**	499,9		43,1	5,8	-0,1	**6,8**
DA+DA15	571,6	**60,1**	359,4	212,7			-0,5	**10,5**
DA15	591,7	**80,2**		592,2			-0,5	**13,5**
DA+DA15+TR	607,5	**95,9**	524,4	170,0	-86,9		-0,1	**15,8**
DA+DA15+TR+ResTR	612,7	**101,1**	543,3	143,7	-76,3	2,1	-0,1	**16,5**

Summery of results

- Small or non change in reservoir operation
- Can analyse all type of energy market in sequence
  - Estimate production in each market
  - Use one market for strategy calculation and another (also same) in reservoir operation
- Reservation of power in TR market works
  - To god optimization with only one price series
  - Only one price for each week
- Income
  - Highest when operating in all market
  - 5 to 6 % extra income with operating in all markets
  - Use deterministic price series, but several weather years

Further work

Testing

- Different type of river system
  - Pump storage plant
- Test with several price scenarios in all marked
- Back testing

Development

- Included more reserve power marked in optimization
  - Included now fixed power reservation on given units in FCR and FRRA
  - FCR and FRRA as a part of optimization, change the strategy
- Should all reserved power be activated?

Article of method and analyse

User manual for how to use the new ProdRisk

Included method in existing ProdRisk?

Fornybar energi
på lag med naturen

Contact:
post@cedren.no

www.cedren.no

Files

Input

- MultiMarket.xml
- Reserve power prices

Output

- Econimic results for each iteration step
  - Income in different markets
  - Reserved power
  - Dual value (skyggepris), value of next MW reserved
- Reserved power for each week
- Optional: Reservoir curve for all load periode
- Optional: Production in each market and total

MultiMarket.xml

```
<MULTIMARKET>
   <Variable> <NAME> UseMultiMarket   </NAME> <VALUE>  T      </VALUE> <COMMENT> If MultiMarket should be used     </COMMENT> </Variable>
   <Variable> <NAME> RefPriceStrategy </NAME> <VALUE>  3      </VALUE> <COMMENT> Referanse price stragy calculation</COMMENT> </Variable>
   <Variable> <NAME> RefPriceReservoir </NAME> <VALUE>  3     </VALUE> <COMMENT> Referanse price reservoir operation</COMMENT> </Variable>
   <Variable> <NAME> PriorityPrice    </NAME> <VALUE>  1,2,3  </VALUE> <COMMENT> Priority of price scenarios in calc  </COMMENT> </Variable>
   <Variable> <NAME> MarketName       </NAME> <VALUE>  DA,DA15,RK    </VALUE> <COMMENT> Energy market name     </COMMENT> </Variable>
   <Variable> <NAME> WriteReservoir   </NAME> <VALUE>  T      </VALUE> <COMMENT> Write reference reservoir        </COMMENT> </Variable>
   <Variable> <NAME> WriteProduction  </NAME> <VALUE>  T      </VALUE> <COMMENT> Write production                 </COMMENT> </Variable>
 </MULTIMARKET>

 <POWER>
   <Variable> <NAME> ControlAll       </NAME> <VALUE>  T      </VALUE> <COMMENT> Control all iteration            </COMMENT> </Variable>
   <Variable> <NAME> NIt              </NAME> <VALUE>  15     </VALUE> <COMMENT> Number of iteration              </COMMENT> </Variable>
   <Variable> <NAME> ItStepUp         </NAME> <VALUE>  0,10,20,30,40, 0, 0, 0, 0,20,30,40,20,30,40  </VALUE> <COMMENT> Up reservation in % of
total capacity </COMMENT> </Variable>
   <Variable> <NAME> ItStepDown       </NAME> <VALUE>  0, 0, 0, 0, 0,10,20,30,40,10,10,10,20,20,20 </VALUE> <COMMENT> Down reservation in % of
total capacity </COMMENT> </Variable>
   <Variable> <NAME> NamePowerPrice </NAME> <VALUE>  PowerPrice.csv   </VALUE> <COMMENT> File name with power prices</COMMENT> </Variable>
   <Variable> <NAME> DimWeek      </NAME> <VALUE>  52       </VALUE> <COMMENT> Number of week in power prices file  </COMMENT> </Variable>
 </POWER>

<Market>
 <POWERSYSTEM>
   <Variable> <NAME> ModNr   </NAME> <VALUE>  11512    </VALUE> <COMMENT> Unit number include in reserved market </COMMENT> </Variable>
   <Variable> <NAME> ModNr   </NAME> <VALUE>  11525    </VALUE> <COMMENT> Unit number include in reserved market </COMMENT> </Variable>
   <Variable> <NAME> ModNr   </NAME> <VALUE>  11540    </VALUE> <COMMENT> Unit number include in reserved market </COMMENT> </Variable>
   <Variable> <NAME> ModNr   </NAME> <VALUE>  11549    </VALUE> <COMMENT> Unit number include in reserved market </COMMENT> </Variable>
   <Variable> <NAME> Column  </NAME> <VALUE>  5        </VALUE> <COMMENT> Column where power price are saved   </COMMENT> </Variable>
 </POWERSYSTEM>
<FCR>
   <Variable> <NAME> Column  </NAME> <VALUE>  1        </VALUE> <COMMENT> Column where FCR price are saved     </COMMENT> </Variable>
 </FCR>
 <FRRA>
   <Variable> <NAME> Column  </NAME> <VALUE>  3        </VALUE> <COMMENT> Column where FRRA price are saved    </COMMENT> </Variable>
 </FRRA>
</Market>
```

Economic results

Week	Market name	Avg. income[Mill/pa]					
1	DA		8.880		8.880		8.880
1	DA15		1.721		1.483		1.143
1	RK		0.768		1.031		1.392
1	PowerSystem		0.000		0.000		0.000
1	Total		11.369		11.394		11.415
1	PI [€/MW]-DA	0.000	0.000	0.000	0.000	0.000	0.000
1	PI [€/MW]-DA15	0.000	0.000	-2.475	0.000	-2.897	0.000
1	PI [€/MW]-RK	0.000	0.000	0.000	0.000	0.000	0.000
1	Power tested [MW]	0.000	0.000	75.947	0.000	151.894	0.000
2	DA		8.673		8.665		8.642
2	DA15		3.760		3.426		2.925
2	RK		0.350		0.693		1.224
2	PowerSystem		0.000		0.000		0.000
2	Total		12.783		12.784		12.791
2	PI [€/MW]-DA	0.000	0.000	-0.074	0.000	-0.105	0.000
2	PI [€/MW]-DA15	0.000	0.000	-3.457	0.000	-4.241	0.000
2	PI [€/MW]-RK	0.000	0.000	0.000	0.000	0.000	0.000
2	Power tested [MW]	0.000	0.000	75.821	0.000	151.642	0.000
3	DA		8.945		8.928		8.901
3	DA15		1.679		1.402		1.046
3	RK		1.568		1.870		2.266
3	PowerSystem		0.000		0.000		0.000
3	Total		12.193		12.200		12.213
3	PI [€/MW]-DA	0.000	0.000	-0.129	0.000	-0.174	0.000
3	PI [€/MW]-DA15	0.000	0.000	-3.794	0.000	-4.452	0.000
3	PI [€/MW]-RK	0.000	0.000	0.000	0.000	0.000	0.000
3	Power tested [MW]	0.000	0.000	75.546	0.000	151.091	0.000