5th International Workshop on Hydro Scheduling in Competitive Electricity Markets

Economic analysis of large-scale pumped storage plant in Norway

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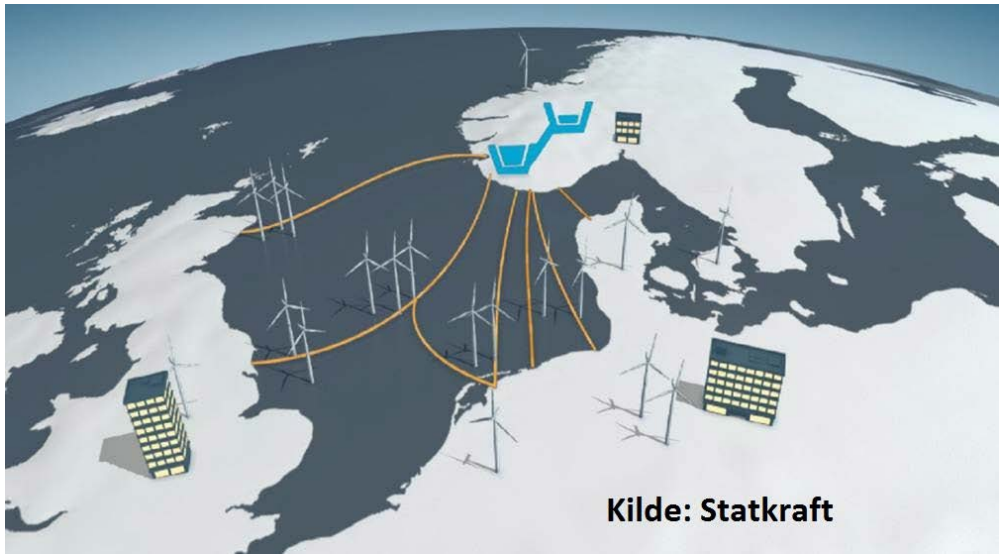
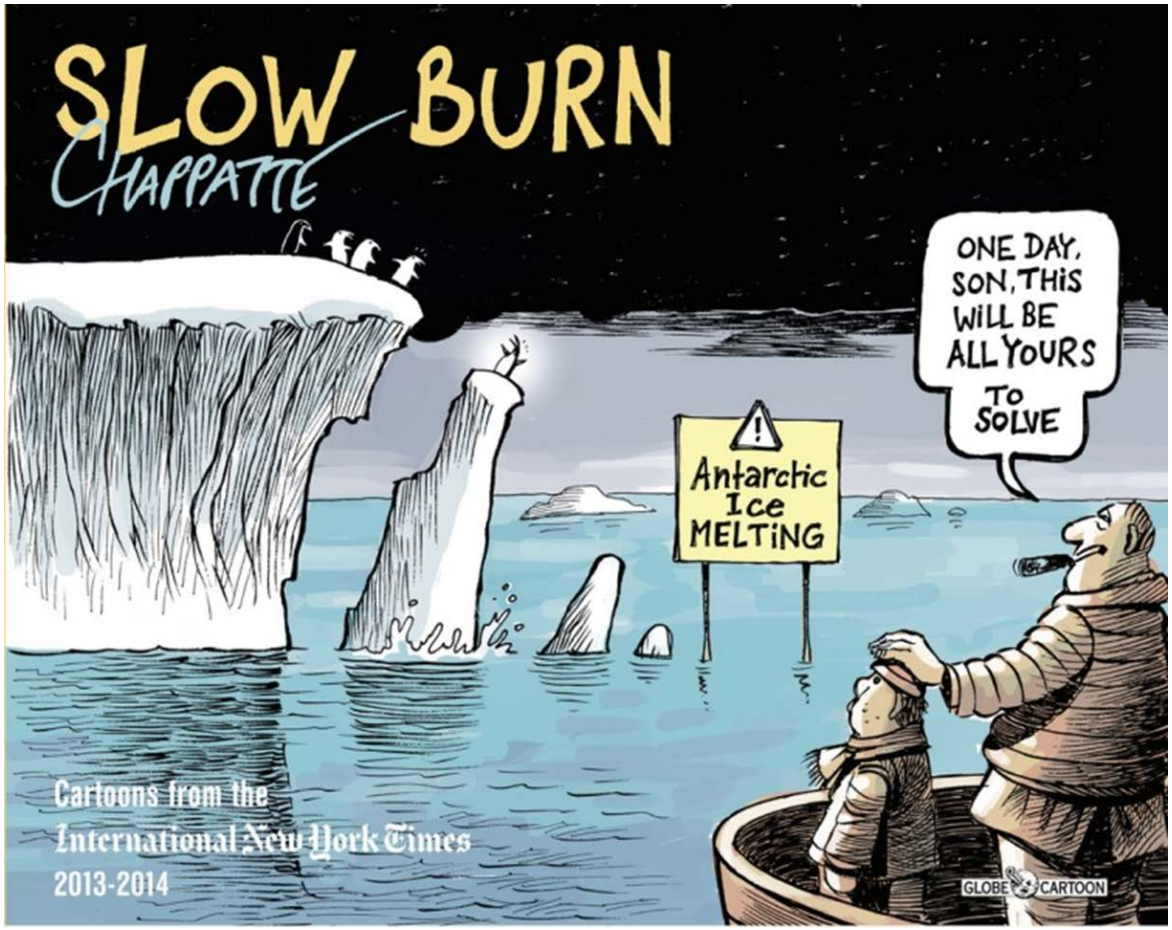


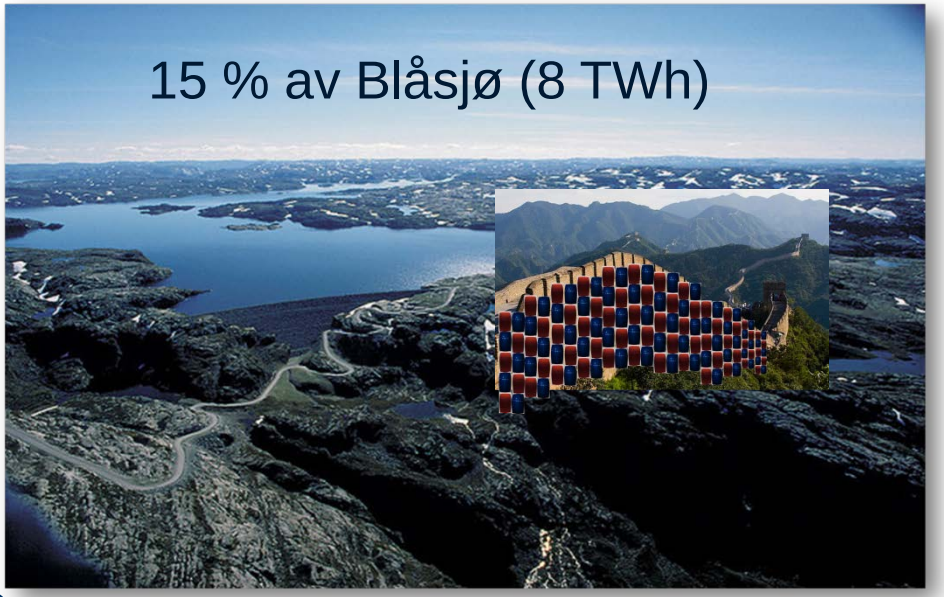
Outline

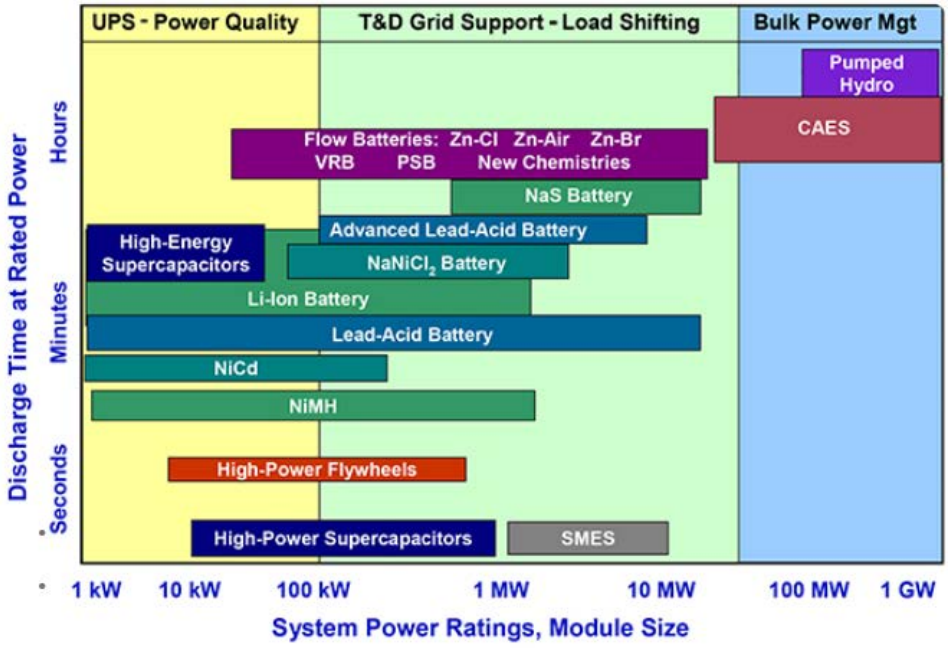
- Background
- Pumped storage
- Models
- Test case
- Results
- Conclusion



Background

- Global environment
- Renewable energy
  - Sun, wind, tide, etc.
  - Variable and unpredictable
- Storage technology
  - Compressed air energy
  - Pumped storage





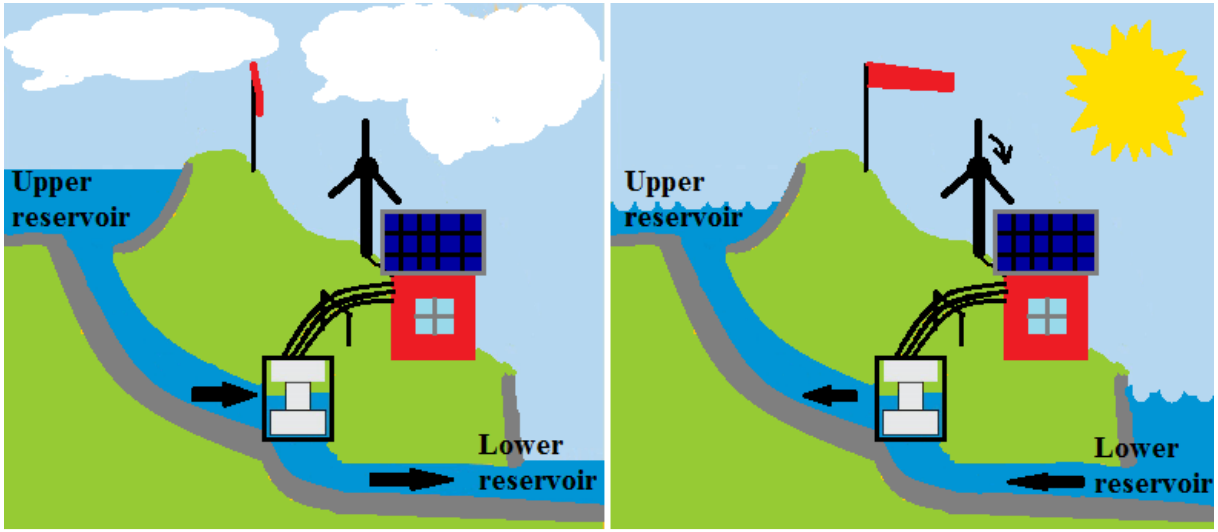
Todd Heinrichs, "Energy and climate", 2013, Sandia National Laboratories

Potential in Norway

- High altitude
- Reservoir
  - Numerous
  - Large
  - 85 TWh
  - 50 % of the capacity in Europe

Pumped storage

- Seasonal or daily
- Income from price arbitrage
  - Covered the losses
- Total efficient from 65 to 80 %
- Lifetime 40-60 years



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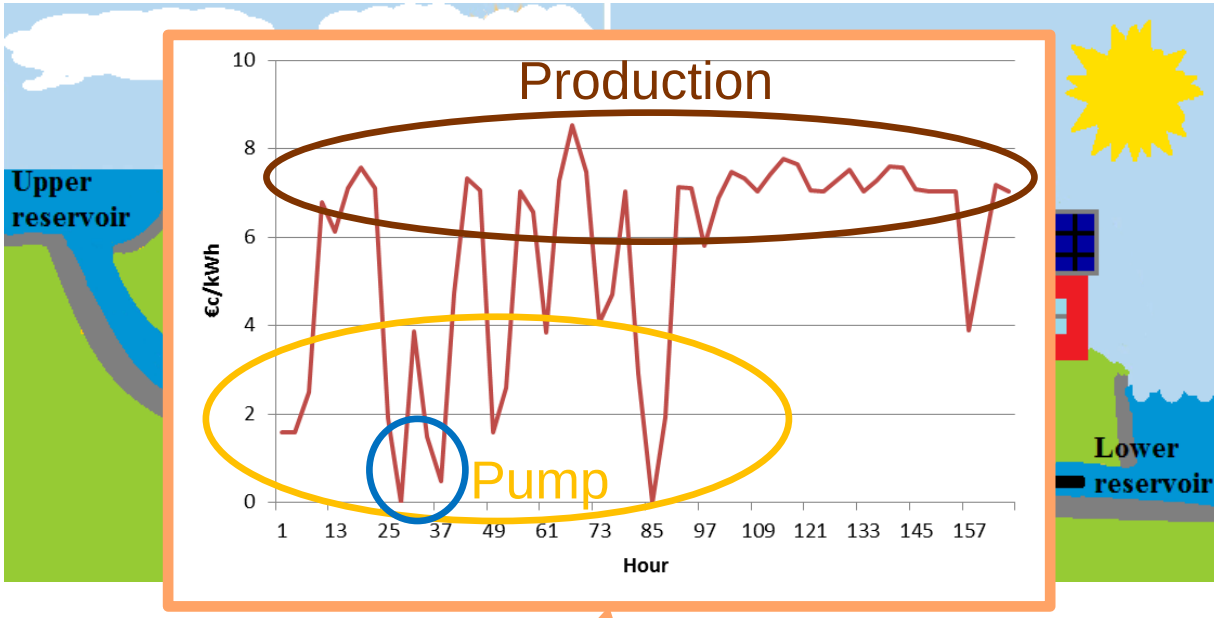
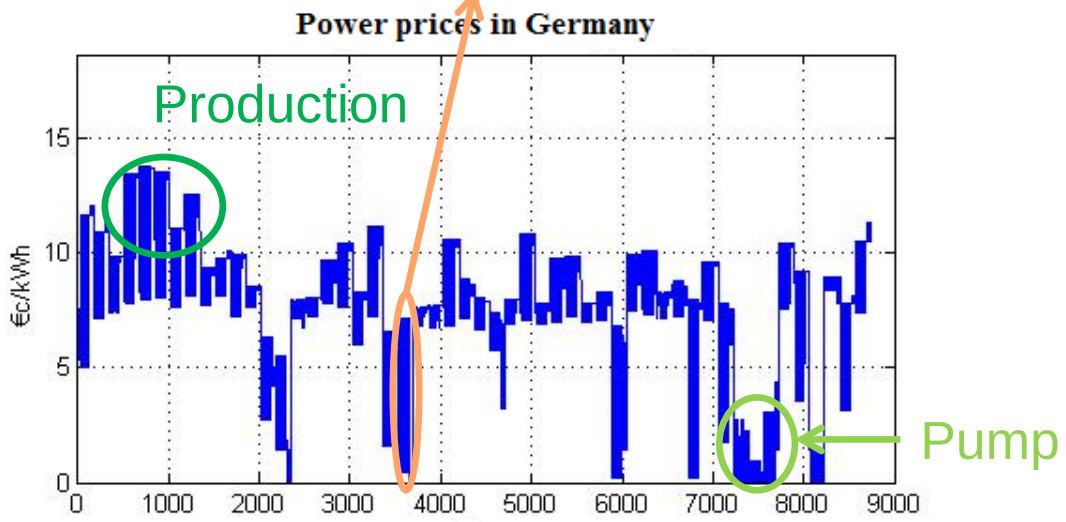




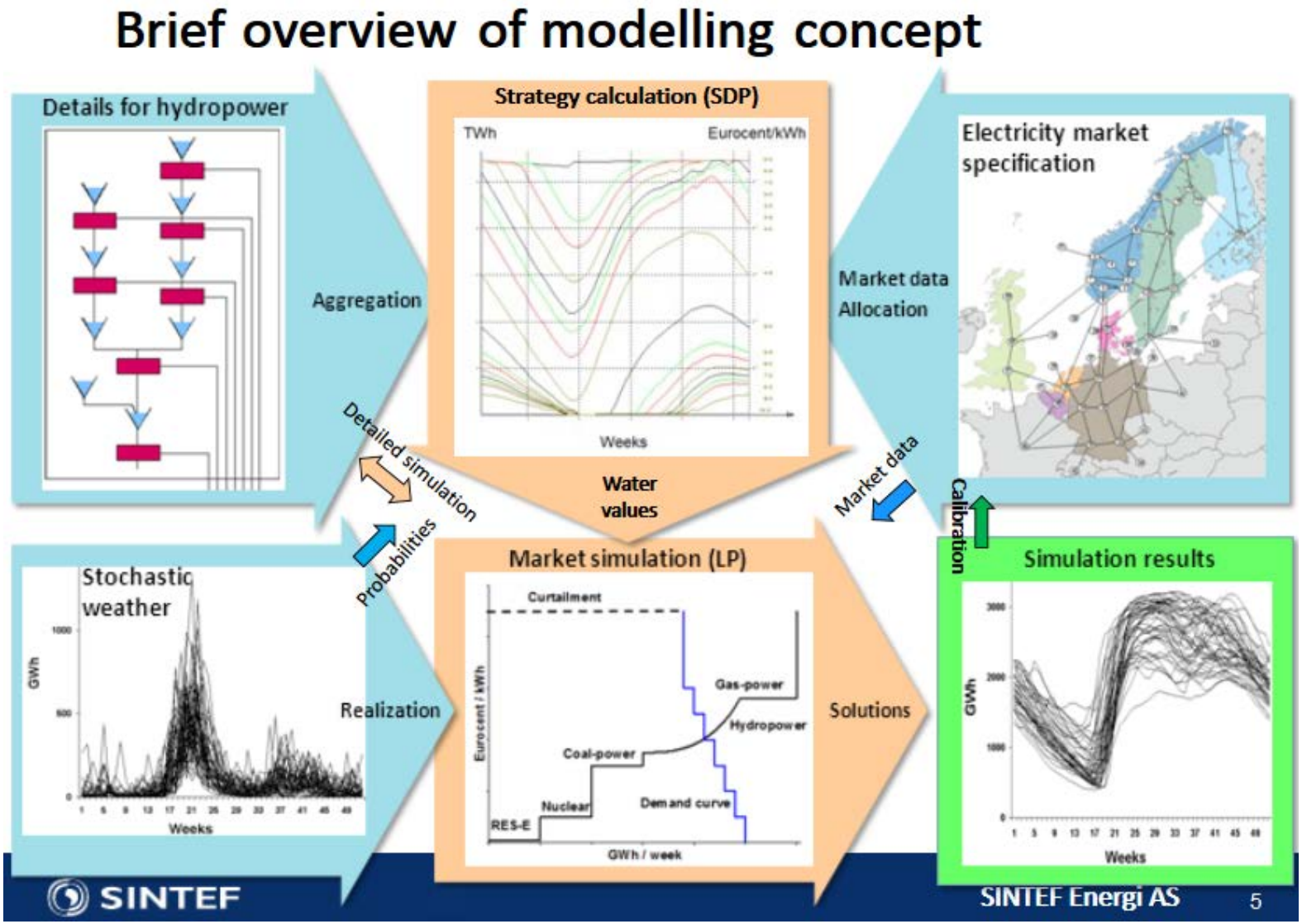
EMPS model and ReOpt

- Long term analyses of hydro-thermal power system
- Maximizing socio-economic surplus

- Input:
  - Stochastic description; Inflow, temperature and wind
  - Detailed description; Thermal- and hydro power plants, transmission corridors between regions, demand, etc.

- Results:
  - Power prices
  - Exchange between areas
  - Production on each power plant
  - Etc.

EMPS model


Brief overview of modelling concept
Details for hydropower
Aggregation
Strategy calculation (SDP)
TWh
Eurocent/kWh
Weeks
Water values
Detailed simulation
Probabilities
Stochastic weather
GWh
Weeks
Realization
Market simulation (LP)
Curtailment
Gas-power
Hydropower
Coal-power
Nuclear
Demand curve
RES-E
Eurocent / kWh
GWh / week
Solutions
Market data
Allocation
Electricity market specification
Market data
Calibration
Simulation results
GWh
Weeks
SINTEF
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EMPS - Samkjøringsmodellen

- Weekly subproblems
  - Heuristics
  - Water values
- Pumping
  - Long time, seasonal
- Established model in Scandinavia

ReOpt

- Weekly subproblems
  - Optimizing
  - Target reservoir level from EMPS
- Pumping
  - Long time, seasonal
  - Short time, daily/week
- Power system with a lot of renewable energy
- Prototype

Data set, Northern Europe

- Approximation of 2030
- Historical weather years from 1962 to 2008
- 56 time step in each week

- Scandinavia is detailed described
- Baltic partial described
- Central Europe and UK
  - Exogenous - Fixed prices
  - Calculate in BID by Statnett

- No time delay and ramping constrains

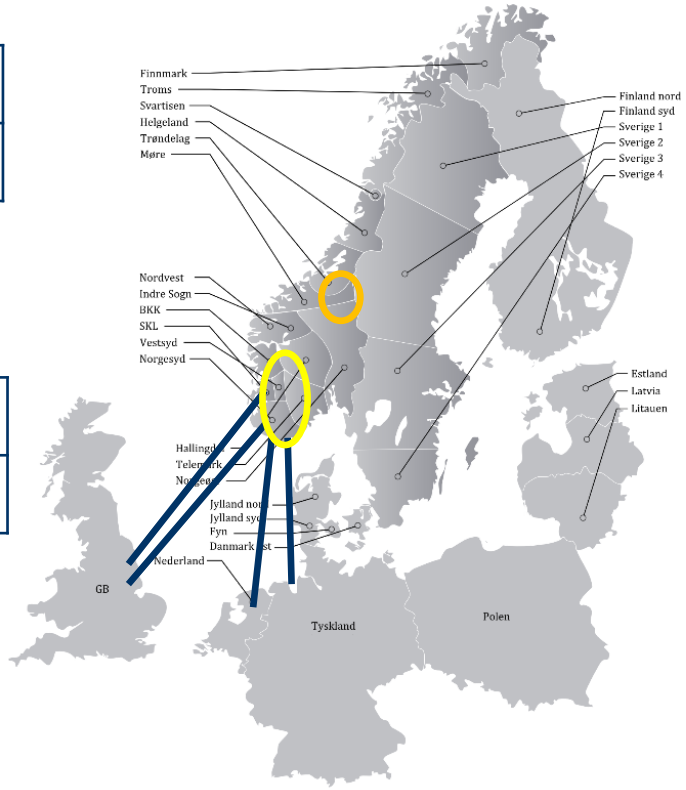
Test cases

- PSP
  - 15 power plant each 950 MW
  - Cost from 0.25 M€/MW to 0.5 M€/MW

Install capacity [MW]	0	950	6 650	9 500	14 250
Investment cost [M€]	0	343	2 413	3 133	5 251

- Transmission
  - From Southern Norway to Europe

Install capacity [MW]	4 900	7 700	10 500	14 100	18 300
Investment cost [M€]	0	4 065	8 220	13 255	19 400

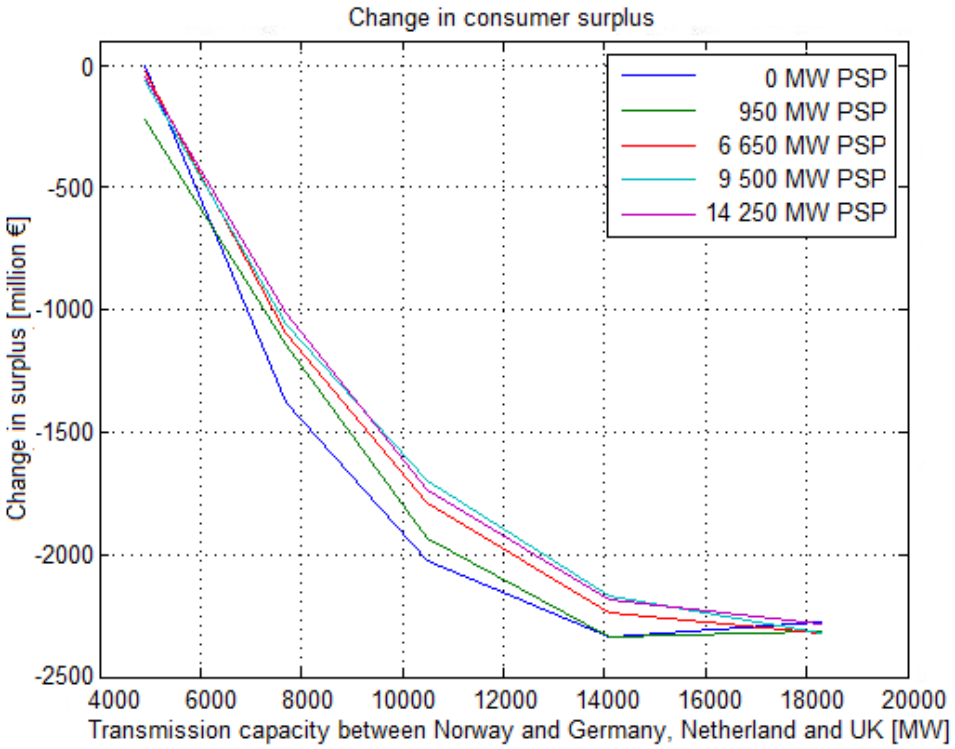


- Total 25 cases
- Base case (reference):

  0 MW PSP and 4900 MW transmission

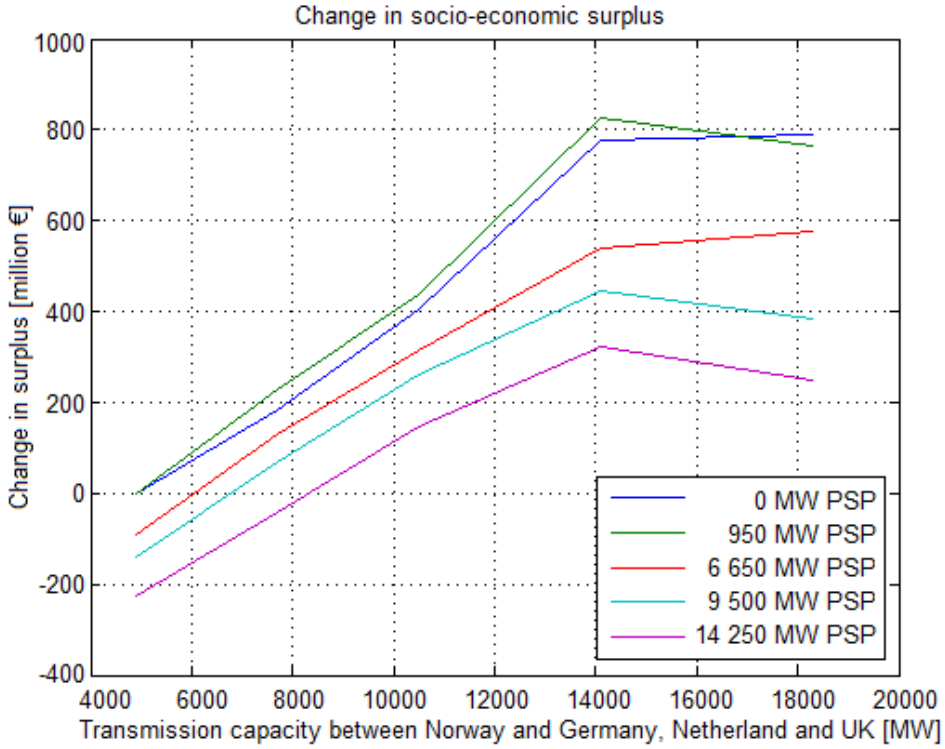
Consumers surpluses

- Average annual surpluses



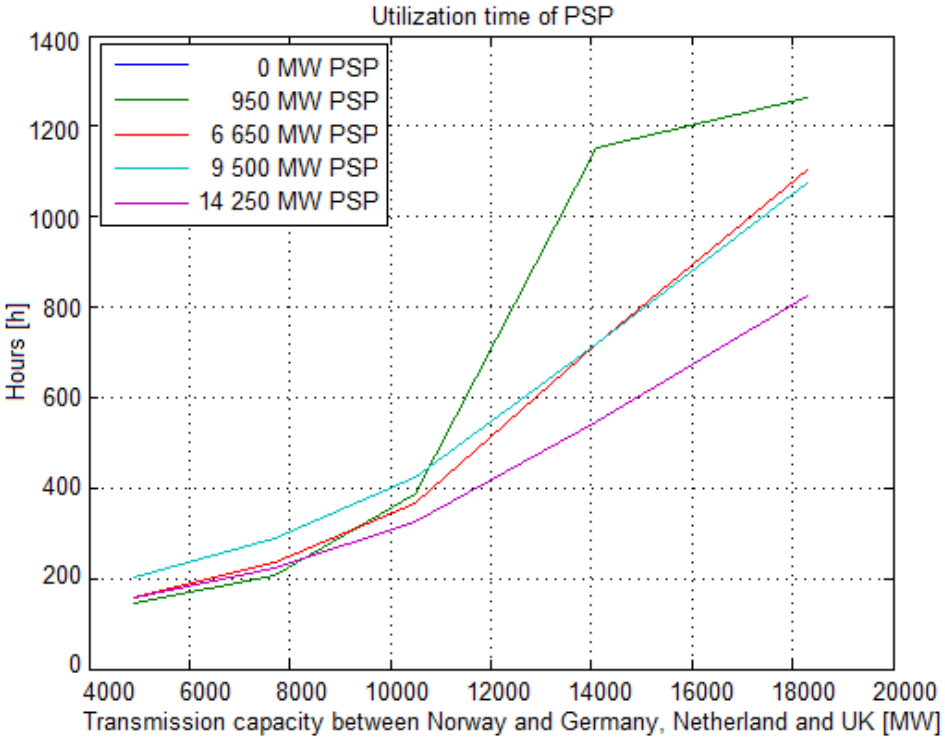
Socio-economics surpluses

- Include investments cost on PSP and transmission
- Include half the congestion rent between Norway and Europe
- Average annual surpluses



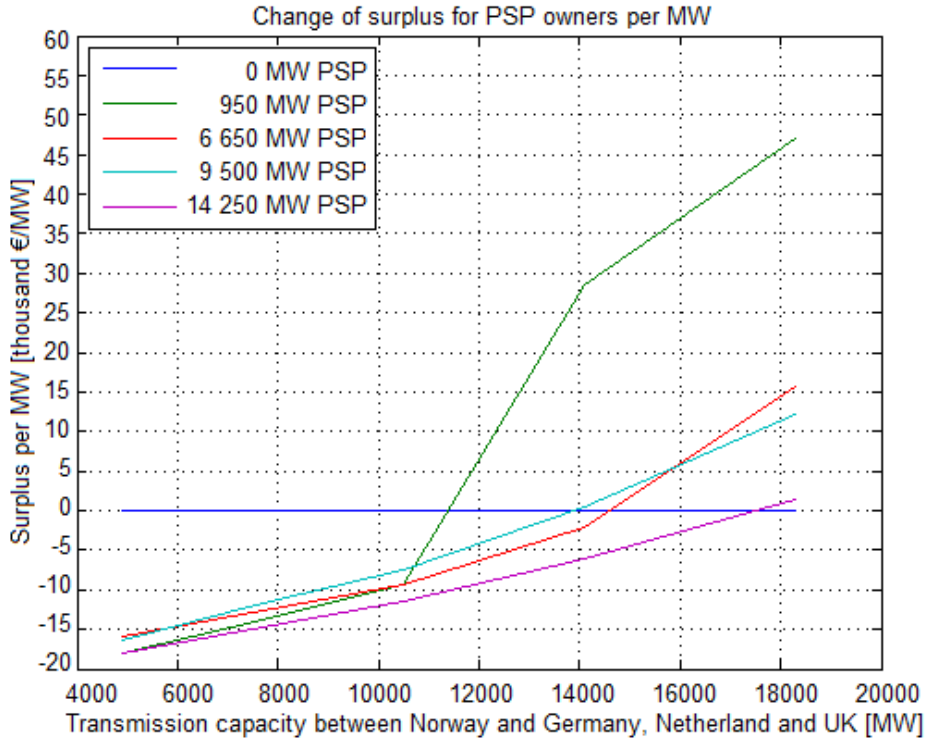
Utilization time of PSP

- Only pump
- Average annual utilization



Surpluses to PSP owners

- Include investments cost on PSP
- Average annual surpluses



Conclusion

- Consumer will lose if PSP should be relevant
- Producer will get a benefit if PSP should be relevant
- Large-scale PSP will depress the high and increase the low energy prices

- With todays power market results suggest to develop little or no new PSP
- Transmission capacity have to be much larger than PSP capacity

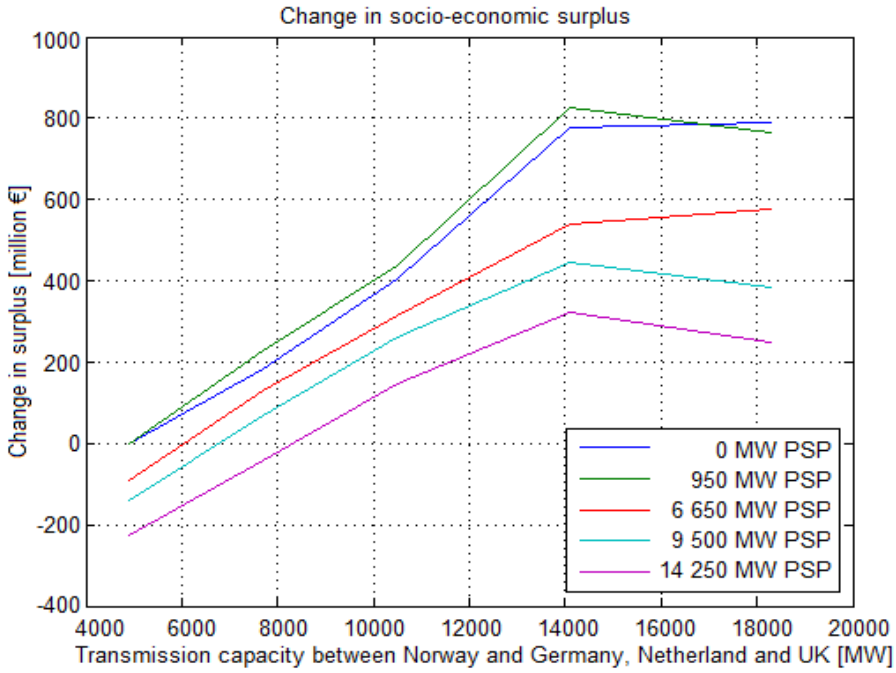
- Result will change if:
  - Other parties take the investment costs
  - Physical constrains as ramping and time delay have been included
  - Intraday market and real time balancing market have been included

Technology for a better society

Socio-economics surpluses

- Include half the congestion rent between Norway and Europe
- Average annual surpluses

With investment cost



Without investment cost