NTNU – Trondheim
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Science and Technology

Norwegian pumped hydro for providing peak load power in Northern Europe

Cost comparison against OCGT

RERC, Oslo, 17. June 2014

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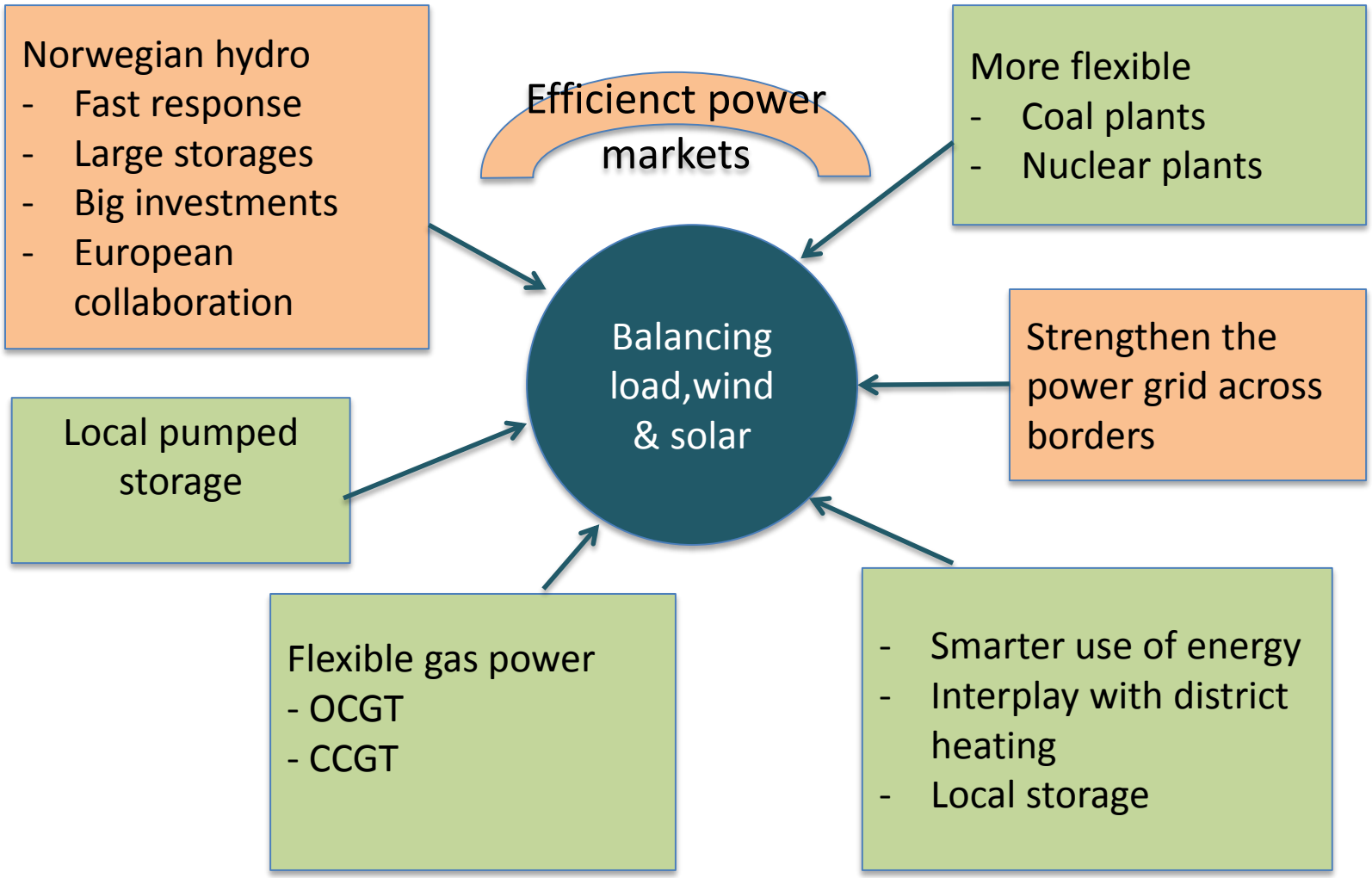
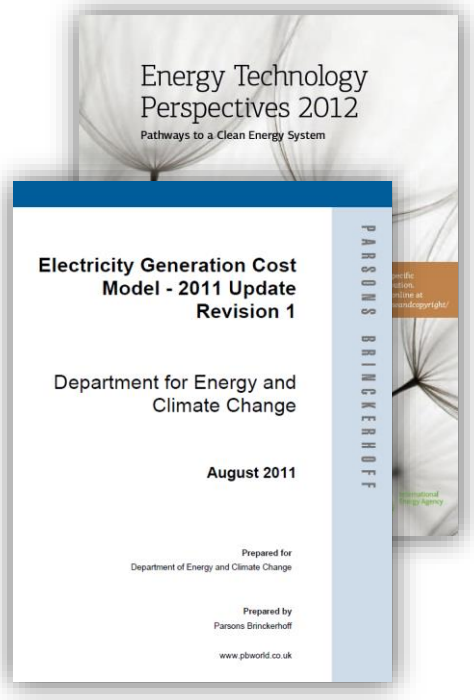
Balancing of renewables in Europe



Study of power production cost in Europe

- Only cost is considered
  - Market simulation not included
  - Assessment of the most cost-effective solutions in the near term
- In-house study
  - Time period 2025-2050
  - Based on IEA ETP scenarios and figures
  - Gas, Coal and Nuclear cost model according to report for UK Dept. of Energy and Climate Change
  - Pumped hydro storage and grid data based on Norwegian figures; NVE and Statnett

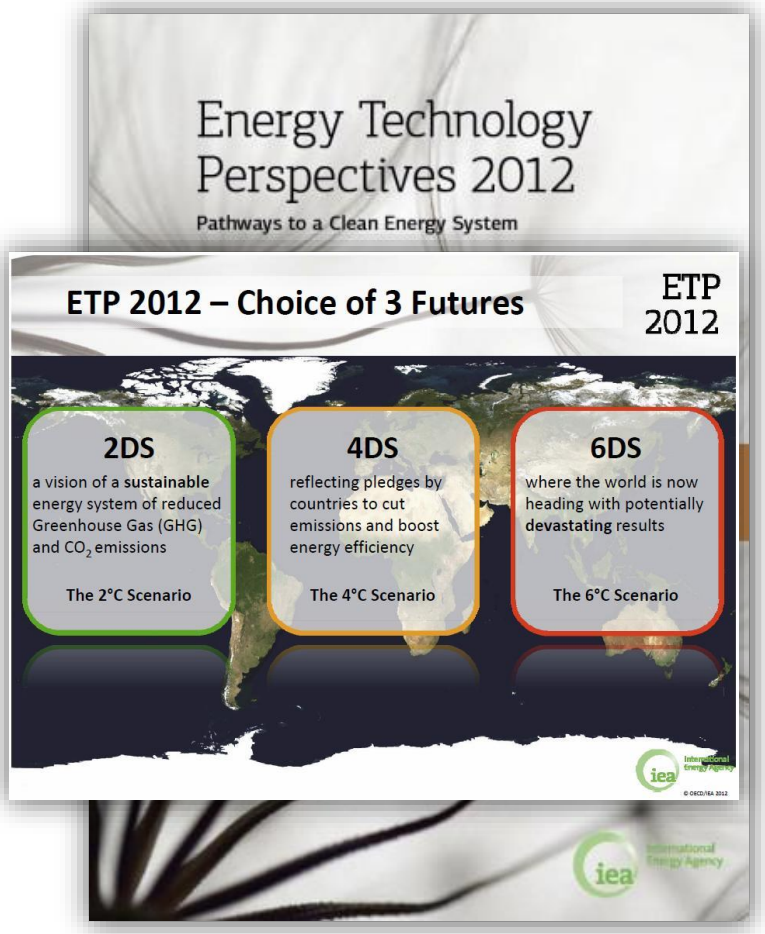


Three scenarios
2025 – 2050 perspective

1. 2DS – IEA 450 Scenario:
   - Gas price 29.5 € /MWh
   - CO_2 price 93.9 €/ton

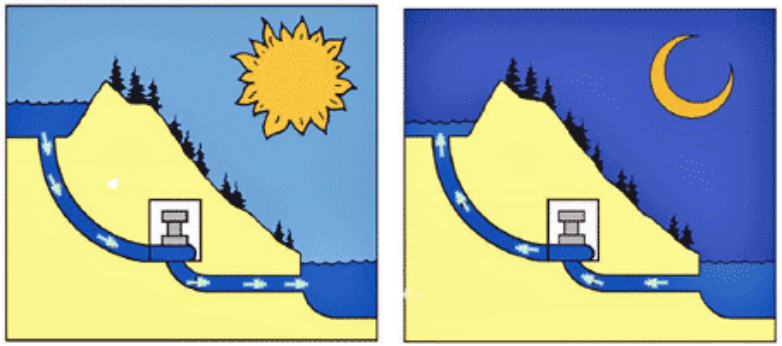
2. 4DS – IEA New Policy Scenario:
   - Gas price 34.8 €/MWh
   - CO_2 price 35.2 €/ton

3. Low Gas price Europe:
   - Gas price 19.7 €/MWh (USA level)
   - CO_2 price 35.2 €/ton (as 4DS)

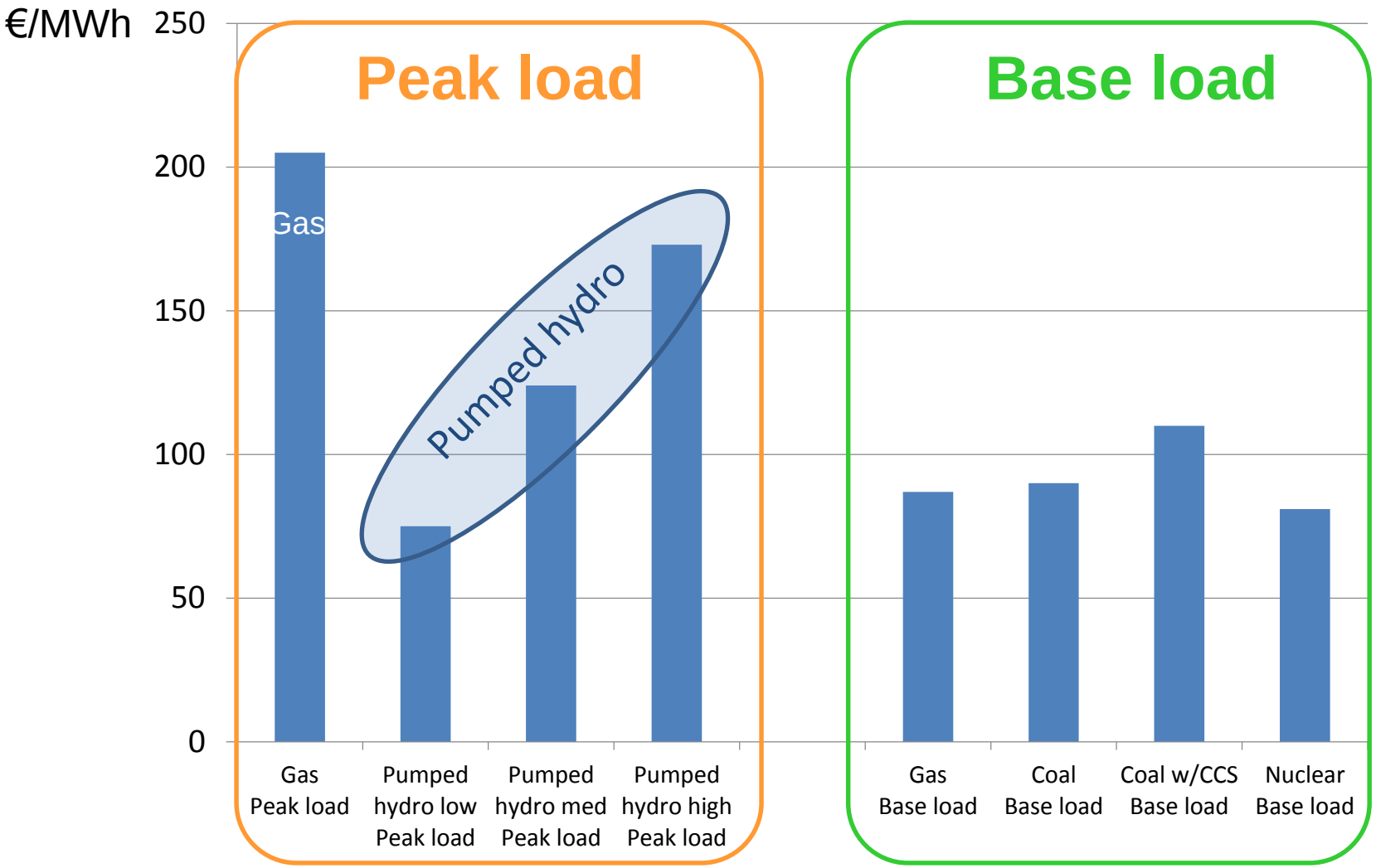


Norwegian hydropower for balancing

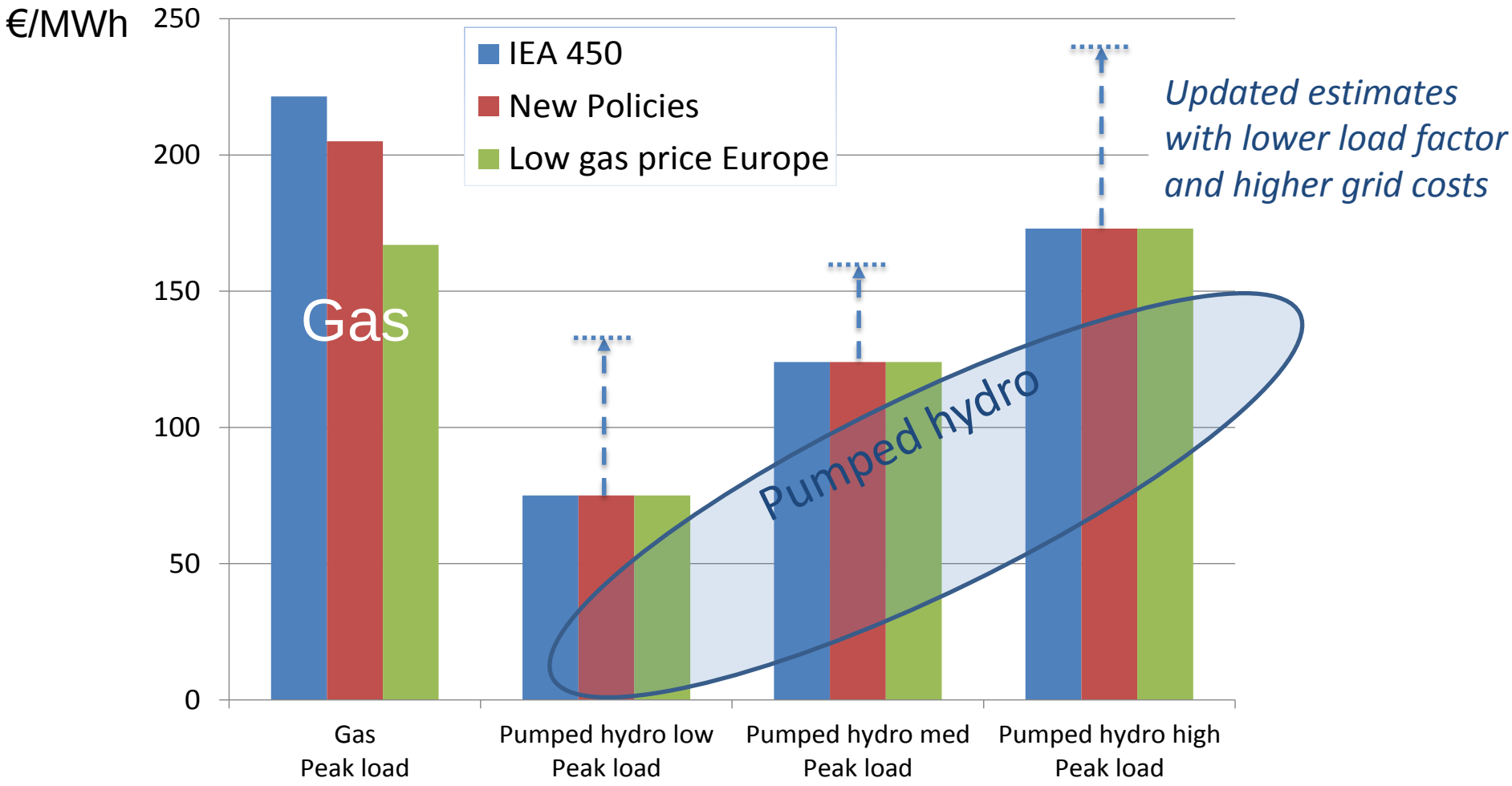
- The reservoirs are natural lakes
  - Multi-year reservoirs
  - Largest lake stores 8 TWh
  - Total 84 TWh reservior capacity
- Balancing capacity estimates 2030
  - 29 GW installed at present
  - + 10 GW with larger tunnels and generators
  - + 20 GW pumped storage
  - 30 GW total new capacity
    - Within todays environmental limits
  - Requires more transmission capacity



Peak load and base load have different cost



Pumped hydro power is cost-effective for balancing in all scenarios



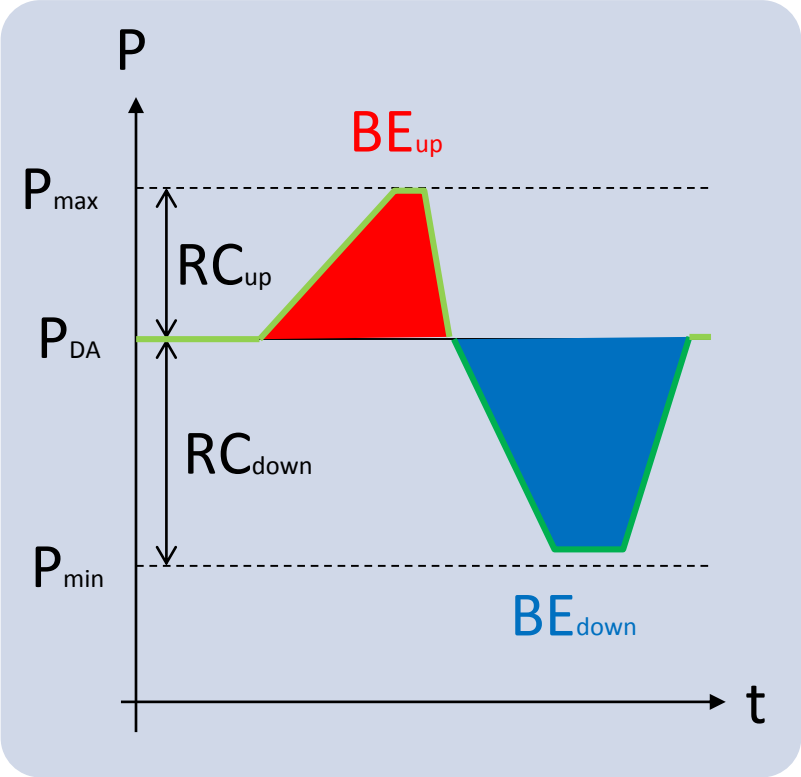
Balancing Reserve Capacity vs Energy

Reserve procurement

- Reserve capacity (RC) [EUR/MW]
- TSOs ensure sufficient reserves in the system during operation

System balancing

- Balancing energy (BE) [EUR/MWh]
- TSOs activate reserves to counteract system imbalances



Source: Doorman (NTNU)

Study model 1 – Integration of balancing markets

Fundamental model

Detailed water course description
About 300 thermal power plants
Transmission corridors (NTC)

Northern Europe

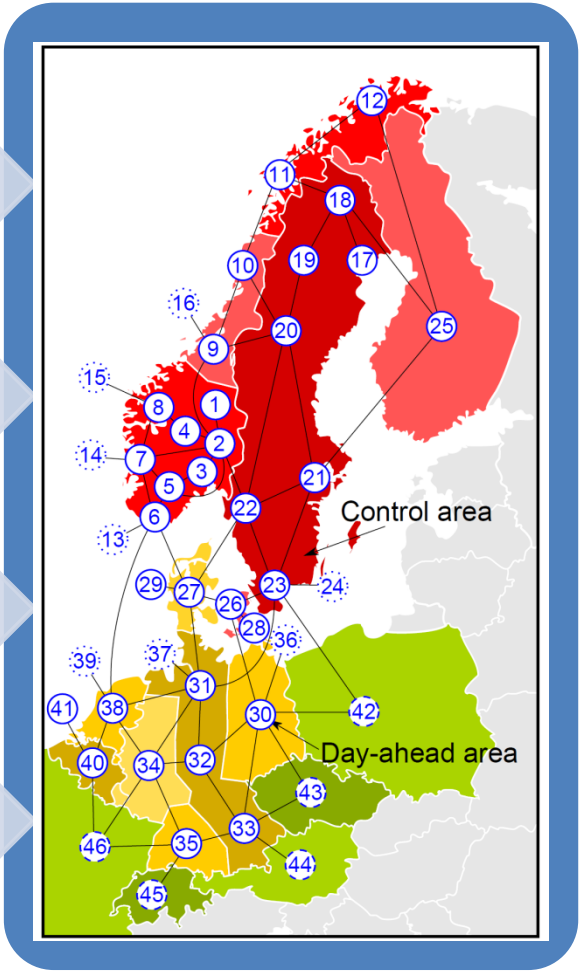
Denmark, Finland, Norway, Sweden
Germany, Netherlands, Belgium

System scenarios

2010 – current state of the system
2020 – a future state of the system

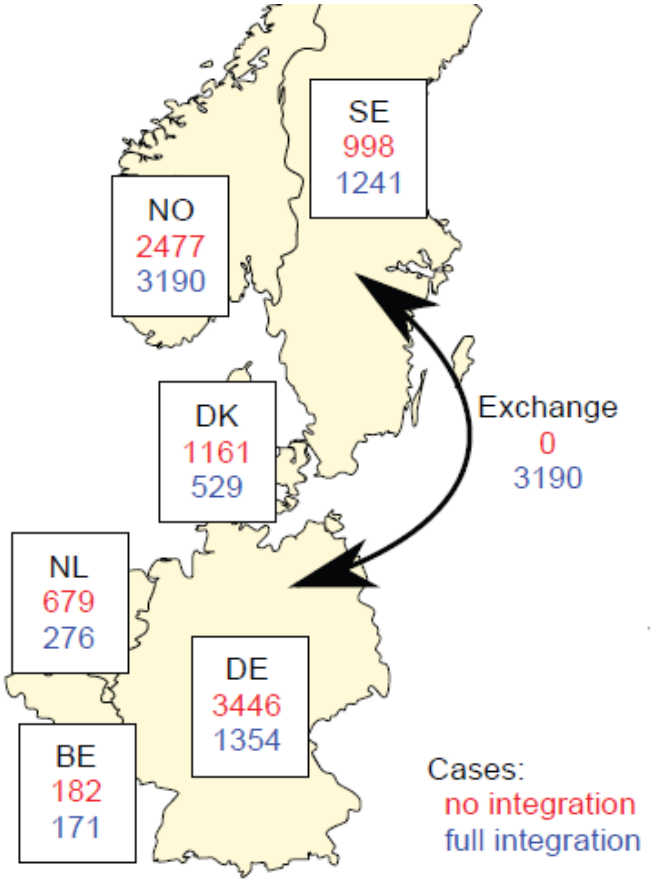
Several climatic years

Hydrology (Inflow)
Temperature
Wind speed

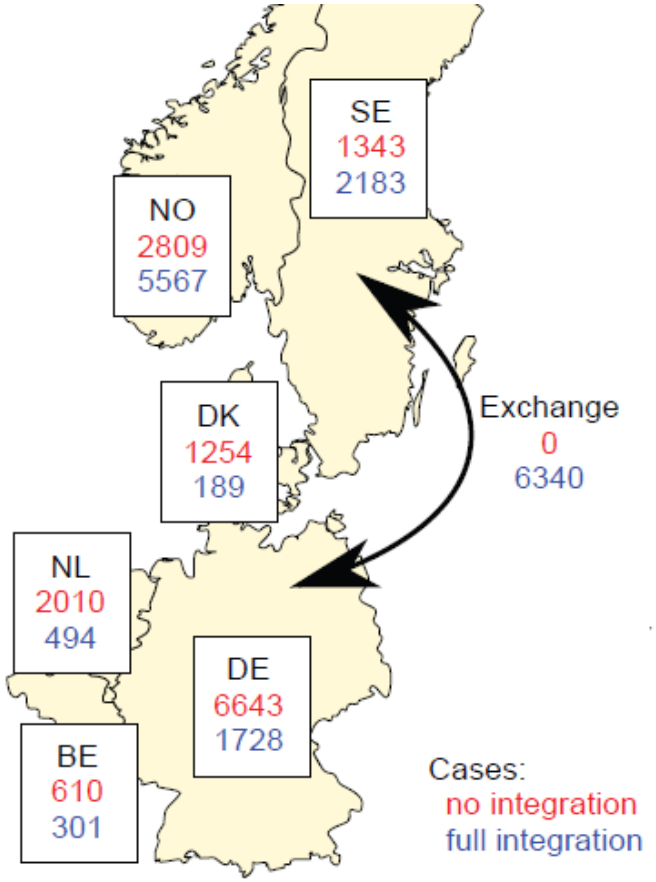


Source: Doorman (NTNU)

Country wise annual balancing reserve allocation (GWh/yr)

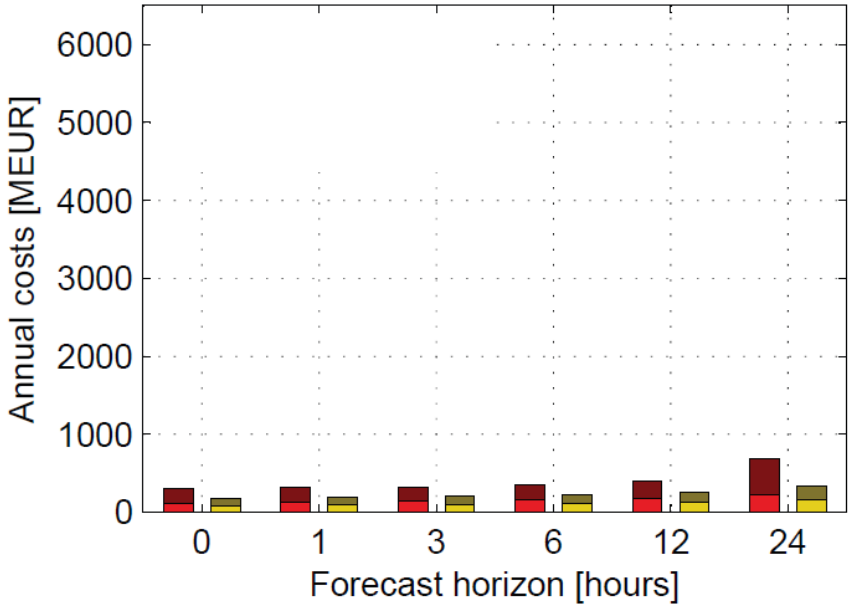


(a) 2010

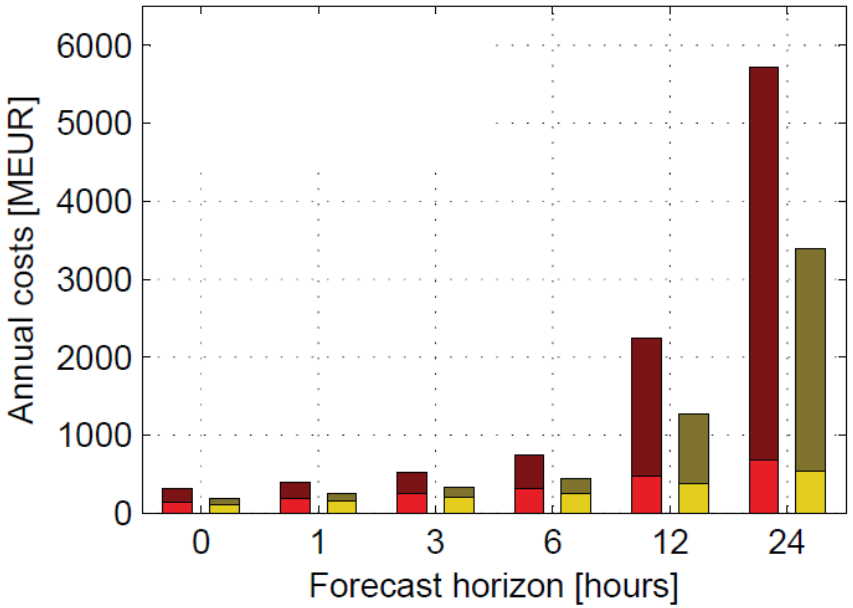


(b) 2020

Total balancing market costs for different wind forecast horizons



(a) 2010



(b) 2020

No integration : Reserve procurement
No integration : System balancing
Full integration: Reserve procurement
Full integration: System balancing

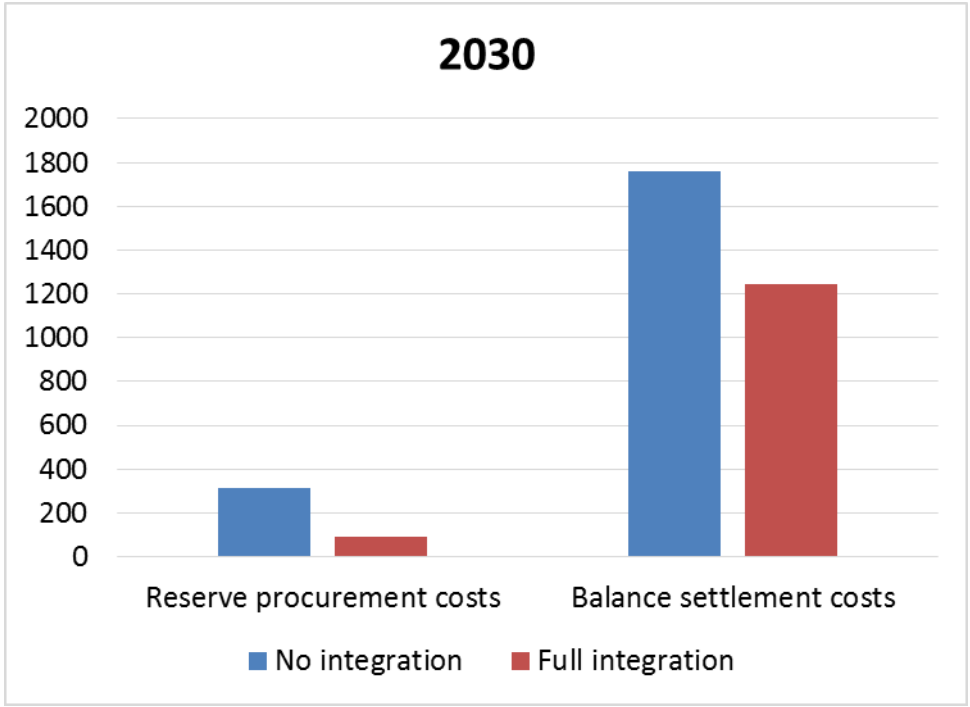
Study model 2 – Integration of balancing markets

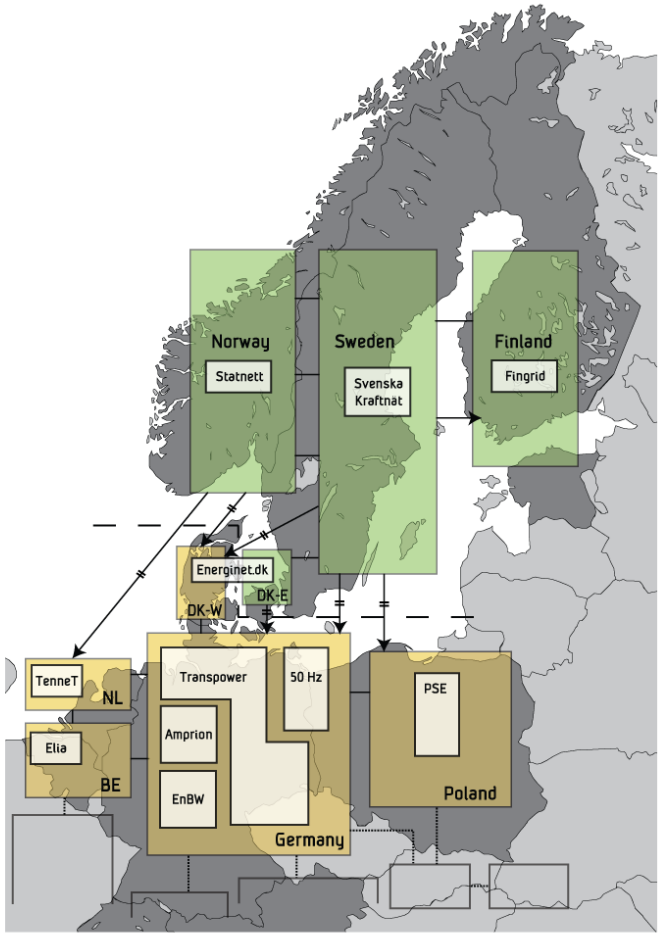
- Detailed European grid model based on DC power flow
- Representation of day-ahead, intra-day and balancing markets
- Co-optimizating day-ahead scheduels and reserve procurements based on forecasts
- Scenarios for load, generation and grid capacity year 2020 and 2030

Source: Farahmand (NTNU/SINTEF)

Large benefits of integrating the Northern and continental balancing markets

Total annual balancing cost savings (Mill.EURO)

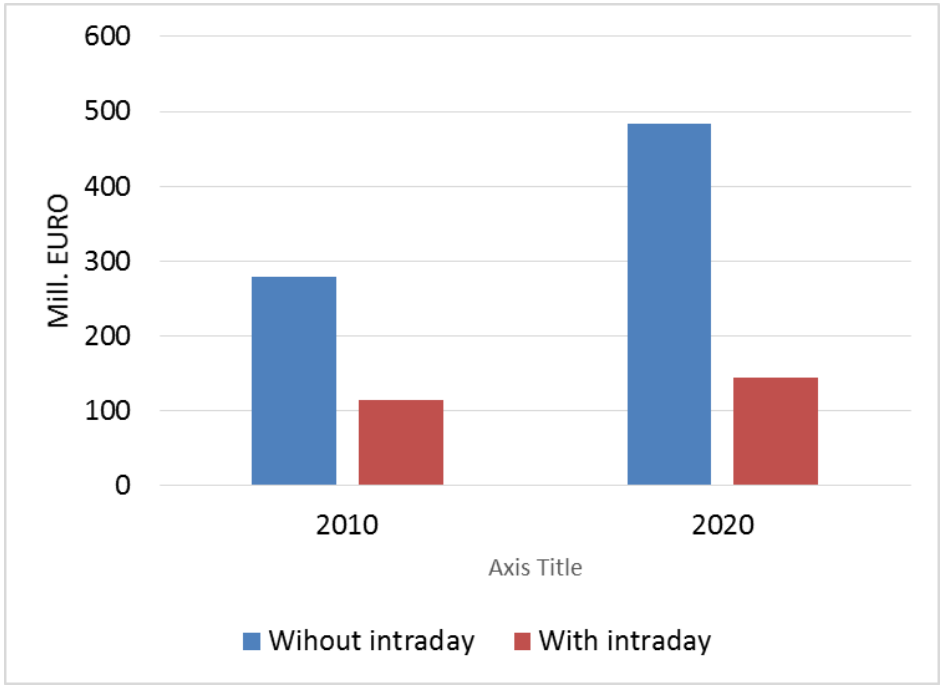




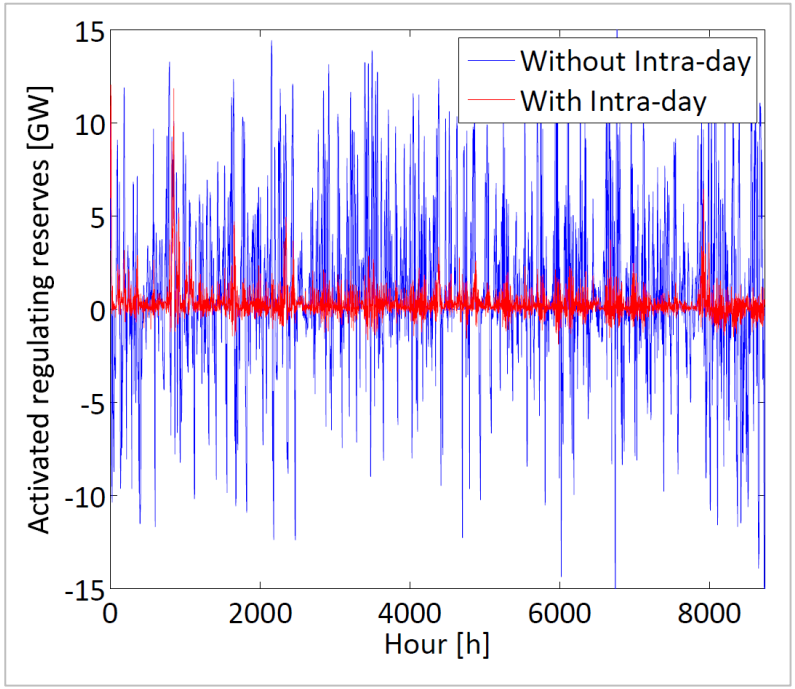
Source: Farahmand (NTNU/SINTEF)

Significant additional savings are achieved with intra-day markets

Total annual balancing cost savings



Activated reserves



Source: Aigner (NTNU)

Summary

- Norwegian pumped hydro is cost-effective for balancing
  - Large potential
  - Large flexibility and multiple uses
  - Requires European collaboration
- An efficient and integrated power market is an enabler for high RE penetration
  - Reduces the need for expensive storage
  - Reduces the need for expensive reserves
- Comprehensive studies of balancing markets in Northern Europe
  - Large benefits of integrated markets for balancing resources
  - Large benefits of integrated markets for intra-day trading