Norwegian pumped hydro for providing peak load power in Northern Europe
Cost comparison against OCGT

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Balancing of renewables in Europe

Norwegian hydro
- Fast response
- Large storages
- Big investments
- European collaboration

Local pumped storage

Efficient power markets

Balancing load, wind & solar

More flexible
- Coal plants
- Nuclear plants

Strengthen the power grid across borders

Flexible gas power
- OCGT
- CCGT

- Smarter use of energy
- Interplay with district heating
- Local storage

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SINTEF
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
   – CO₂ price 93.9 €/ton

2. 4DS – IEA New Policy Scenario:
   – Gas price 34.8 €/MWh
   – CO₂ price 35.2 €/ton

3. Low Gas price Europe:
   – Gas price 19.7 €/MWh (USA level)
   – CO₂ 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 reservoir 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 today's environmental limits
  • Requires more transmission capacity
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Peak load and base load have different cost

€/MWh

Peak load

Gas
Pumped hydro low
Pumped hydro med
Pumped hydro high

Base load
Gas
Coal
Coal w/CCS
Nuclear

Gas
Coal
Coal w/CCS
Nuclear
Pumped hydro power is cost-effective for balancing in all scenarios

Updated estimates with lower load factor and higher grid costs
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

Source: Jaehnert (NTNU)
Total balancing market costs for different wind forecast horizons

(a) 2010

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

(b) 2020

Source: Jaehnert (NTNU)
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 schedules 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)

<table>
<thead>
<tr>
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<th>2030</th>
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<tbody>
<tr>
<td>Reserve procurement costs</td>
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<td>Balance settlement costs</td>
<td>1700</td>
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</tbody>
</table>

Source: Farahmand (NTNU/SINTEF)
Significant additional savings are achieved with intra-day markets

Total annual balancing cost savings

- 2010: Without Intraday = 250, With Intraday = 175
- 2020: Without Intraday = 500, With Intraday = 100

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