Large scale balancing and storage from Norwegian hydro

*HydroBalance project*


*Julie Charmasson*, SINTEF Energy Research, Trondheim, Norway
Case study 2030

10-20 GW new pumping and generation capacity using existing reservoirs

2012, Eivind Solvang et al., Increasing balance power capacity in Norwegian hydroelectric power stations, SINTEF Report TR A7195

www.cedren.no/Projects/HydroBalance
Centre for Environmental Design of Renewable Energy
Norwegian hydropower for balancing

- The reservoirs are **natural** lakes
  - Multi-year reservoirs
  - Total **84 TWh** reservoir capacity
  - Largest lake stores 8 TWh

- Balancing capacity estimates 2030
  - **29 GW installed at present**
  - **30 GW total new capacity** (+10 GW upgrading + 20 GW pump storage)
    - Within today’s environmental limits
  - Requires more transmission capacity
1. CEDREN HydroBalance: Facts

Feasibility of large scale development of energy balancing and storage from Norwegian hydropower in the future European electricity market with respect to the power system, environmental aspects, economic viability and social acceptance.

WP 1 Roadmaps for balancing from Norwegian hydropower

WP 2 Demand for energy balancing storage

WP 3 Analyses to develop relevant business models

WP 4 Environmental impact of operation schemes for balancing

WP 5 Social acceptance and regulatory framework
WP1. Scenario building methodology

WP 1
Roadmaps for balancing from Norwegian hydropower

Scenarios development
WP1. Scenario building methodology

Scenarios

Integration of Norway with grid and markets of Central EU+UK

High

Small storage

Niche storage

Nordic storage

Low

Big storage

Legend
Bubble size:

Balancing on - all time scales

- long time horizons only

Amount of balancing from Norway

Small

Large

2015, Sauteuleute et al., Scenarios for large scale balancing and storage from Norwegian hydro
WP3. Central research questions

WP 3
Analyses to develop relevant business models
WP3. Overview of work

Develop methodology
- Hydropower optimization
- SINTEF's optimization tools for hydropower
- With several markets

Forecast prices
- HydroBalance scenario
- 2050
- Several markets

Case-study
- Real river system
- Relevant **pumped-storage project**
WP3. Overview of work

Scenario and prices simulation

- **Statistics**
- **Big Storage**
- **Niche Storage**
- **Multi-market**

Supply only for day-ahead market

day-ahead + RR activation

→ All scenarios: With and without investment in additional pump
WP3. Case-study: Pumped storage investment

- 1000 MW: extra generation capacity and pump
- Reservoirs: 15 days to empty/fill
- Total efficiency (pump x generation): 72.2 % (conservative, cf. Ibrahim 2007)
- Estimated total costs: 416 M € (Henden, 2014)
### WP3. Case-study: Economic results (in M € per year)

<table>
<thead>
<tr>
<th></th>
<th>Day-ahead only</th>
<th>German prices</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Climate years 2007-2011)</td>
<td>(Climate year 2008)</td>
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<tr>
<td></td>
<td>Statistics</td>
<td>Niche Storage</td>
</tr>
<tr>
<td>Average yearly income</td>
<td>205</td>
<td>474</td>
</tr>
<tr>
<td>Additional operating profits</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>Investment cost *)</td>
<td>-24</td>
<td>-24</td>
</tr>
<tr>
<td>Investment profits *)</td>
<td>-15</td>
<td>-2</td>
</tr>
<tr>
<td>Break even interest rate</td>
<td>-0.5%</td>
<td>4.5%</td>
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</tbody>
</table>

*) With 5% annual interest rate
2. Levelised Cost of Electricity (LCOE)

WP 2
Demand for energy balancing storage
Norwegian pumped hydro has a relatively low LCOE …

even when grid and cable costs are included.
2. Levelised Cost of Electricity (LCOE)

Levelised Cost of Peak Generation (LCPG)

- New metric for the cost of providing electricity when fluctuating renewables and inflexible thermal generation cannot meet the (fixed) demand
  - Peak generation must cover the residual load
  - It's no longer the load itself that determines the need for peaking power but the residual load

Natural gas:

\[
LCPG_{ng} = \frac{i_{ng} \cdot (\delta_{ng \cdot r} + OM_{ng}) - P_{cap}}{\alpha_{ng} \cdot T_{ng}} + \left(\frac{p_{ng} + p_{CO_2} \cdot e_{ng}}{\eta_{ng}}\right)
\]
2. Levelised Cost of Electricity (LCOE)

Conclusion so far..

*Interconnectors* must be given full access to all markets, including capacity markets, for utilization of the most economical viable sources of storage and flexible power in Europe

Credit: Statkraft
2. Levelised Cost of Electricity (LCOE)

Analysis of Cost of flexibility

- Levelized cost of electricity (LCOE) study
  - Comparison of competitiveness of several different generating technologies (cost, performance and ability for flexibility)
  - Development of a method for general use with simple clear metrics based on up-to-date information and future scenarios from reliable sources.

- Technologies:
  - PHS,
  - Conventional hydro,
  - CCGT, OCGT with/without CCS
  - Coal power plants with/without CCS
  - Nuclear

- Main sources: IEA, DECC, EIA, NVE
2. Levelised Cost of Electricity (LCOE)

Analysis of Cost of flexibility
WP4. Future energy demand and water level fluctuations

WP4
Environmental impact of operation schemes for balancing
WP4 focuses on HP reservoirs

- Most of studies in rivers
- > 900 reservoirs (lakes) in Norway
  Also used as recreational area
- **Environmental impacts of new operational regimes in reservoirs**

**Abiotic consequences**
- Water temperature
- Stratification period/duration/intensity
- Ice cover thickness/period/duration...
- Water quality

**Biotic consequences**
- Biological productivity
- Species composition
- Fish diet
- Growth and reproduction...
WP4. Focus on fish

Fish as **top predator**: bio-indicator for **ecological status**
WP4. How to separate effects from hydropower from natural variation?

Lake morphology

- Area
- Altitude
- Shape

Climate

- Ice cover
- Summer Temp.

Fish growth

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WP4. Data collection and Statistical analysis and modelling of interactions

[Graphs and images showing data analysis and interactions]
3. Modelling hydro-dynamics consequences from new operational regimes

1. 2D hydrodynamic modelling reservoir
   - water temperature and stratification characteristics
   - Ice cover period-thickness-duration

2. For a large range of synthetic cases
   - Regulated amplitude
   - Area
   - Mean depth
   - Climate region

3. Run simulations of future operational regimes
   - (present regime)
   - Big Storage
   - Niche Storage
WP 5: Research questions

WP 5
Social acceptance and regulatory framework
## WP 5: Results from interviews

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<thead>
<tr>
<th>National level</th>
<th>Drivers</th>
<th>Barriers</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>• Hydropower <strong>reservoirs</strong></td>
<td>• <strong>Environmental consequences</strong> due to new operational regimes</td>
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<td></td>
<td>• <strong>EU</strong>'s climate ambitions</td>
<td>• <strong>Uncertainties</strong> about both development of an integrated energy system and demand for Norwegian balancing power</td>
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<td>• <strong>Demand</strong> for balancing services</td>
<td>• Cables ownership</td>
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<td></td>
<td>• <strong>Cables</strong> to EU</td>
<td>• <strong>Profitability</strong></td>
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<td>• <strong>Export/import</strong> possibilities</td>
<td>• Electricity prices</td>
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<td></td>
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<td>• <strong>Grid</strong> capacity and flexibility</td>
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<table>
<thead>
<tr>
<th>Local level</th>
<th>Drivers</th>
<th>Barriers</th>
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<tbody>
<tr>
<td></td>
<td>• Early <strong>involvement</strong></td>
<td>• <strong>Visual</strong> impacts (low water level),</td>
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<td>• <strong>Information</strong></td>
<td>• <strong>Environmental</strong> impacts</td>
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<td></td>
<td>• Identification of local inconveniences consequences</td>
<td>• <strong>Economic</strong> impacts (electricity prices)</td>
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<tr>
<td></td>
<td>• <strong>Compensation measures:</strong> Investment in local infrastructures (roads, internet access,...)</td>
<td>• Consequences for <strong>local infrastructures</strong> (unstable ice and passage, quay and boat traffic)</td>
</tr>
<tr>
<td></td>
<td>• <strong>Compensation measures:</strong> Electronic warning system</td>
<td>• <strong>Security issues</strong> related to reservoir and ice cover</td>
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Roadmap

- Detailed plan to guide progress from a defined starting point towards a goal

NOW

Society

Environment

Market

Systems

2050
Use NO hydropower to provide flexibility and storage to the EU energy system
Thank you for your attention!

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