Large scale balancing and storage from Norwegian hydropower

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Centre for Environmental Design of Renewable Energy
Norwegian hydropower for balancing

Reservoirs are natural lakes
Multi-year reservoirs
Largest lake stores 8 TWh
**Total 84 TWh reservoir capacity**
**32 GW installed with max load 25 GW**

Increasing share of renewable power in EU.
**Intermittent power from wind solar** with need for balancing

Huge possibilities for **more capacity** including **pump-storage** in existing reservoirs - Requires more transmission capacity
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: Roadmap 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
HydroBalance Roadmap

Contents

- Key Findings
  1. Cost comparison of hydropower
  2. Demand for balancing
  3. Flexibility as a multi-market commodity
  4. Sustainable storage
  5. Acceptance of storage

- Innovations
- Key Actions
- Research needs
1. Tech. competition: gass power vs. pump-storage

"Levelized Cost Of Energy (LCOE) incl HVDC cables"

Input data ref: 2040
Based on IEA WEO scenarios and figures
Gas plant models and costs according to report for UK Dept. of Energy and Climate Change
Pumped hydro storage and grid data based on Norwegian figures; Producers, Regulator, TSO, Univ.

Increasing CO₂ prices
Increasing spot prices
1. Tech. competition: Optimal energy system

- Uses data from ENTSO-E and e-Highway assuming 80% RES in 2050
- Investment cost and variable cost for thermal units included
- Investment cost and cycle cost for energy storage included.
- With a fixed C02 quota, what is the consequences with different use of energy storage.

![Diagram](https://example.com/diagram.png)

![Bar Graph](https://example.com/bar_graph.png)

<table>
<thead>
<tr>
<th></th>
<th>Case 5</th>
<th>Case 6 Limited PHES</th>
<th>Case 7 No PHES</th>
<th>Case 8 No storage</th>
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<tbody>
<tr>
<td>Wind [MW]</td>
<td>372 618</td>
<td>345 922</td>
<td>332 852</td>
<td>372 495</td>
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<tr>
<td>Solar [MW]</td>
<td>146 091</td>
<td>220 570</td>
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<td>146 435</td>
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<tr>
<td>Thermal [MW]</td>
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<td>139 318</td>
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<td>24 224</td>
<td>40 964</td>
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<td>PHES [MW]</td>
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<td>20 000</td>
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<td>RES curt [GWh]</td>
<td>45 021</td>
<td>84 178</td>
<td>116 394</td>
<td>159 666</td>
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<tr>
<td>Emissions [kton]</td>
<td>32 335</td>
<td>32 335</td>
<td>32 335</td>
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<tr>
<td>Tax [EUR/ton]</td>
<td>76</td>
<td>115</td>
<td>126</td>
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</table>
2. Need for balancing 2050 West Central Europe

- **20-25 TWH storage needed**
- **2-300 GW capacity needed**

Includes: UK, Ireland, France, Benelux, Germany, West Denmark, Switzerland, Austria, Check Republic, Slovenia

Assumes no bottlenecks in transmission system in and between countries

*eHighway Scenario X7: ~100% res, ~70% from wind and solar*
3. Business models: Revenues multiple markets

Case study:

1 GW pump-storage

24 M€/year annuity with 5% interest
3. Case study: Revenues from flexible hydropower assets

DA: Day-ahead
ID: Intra-day
RR: procurement of reserves
RES: activation of reserves
3. Case study: Revenues from pump

- Annuity 24 M€
- + 300% Multi market
- + 32% with pump

<table>
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<th>Scenario</th>
<th>Extra profits with a pump (in M€ per year)</th>
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<td>Only DA</td>
<td>41,0</td>
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<td>DA,ID</td>
<td>63,4</td>
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<td>DA,ID,RR</td>
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<tr>
<td>DA,ID,RR,RES</td>
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4. Modelling potential impacts of water level fluctuations in reservoirs

- Qualitative scenarios
  - Assumptions
- Power system simulation
- Prices
- Hydropower optimization
  - Discharge
- Lake
  - Hydrodynamic modeling
  - Temperature

Future environmental impact in reservoirs

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4. Case study: Change in water temperature
5. Barriers and drivers for large-scale balancing

**Method**

**Informants where:**
- National authorities
- Members of Parliament
- Environmental NGO’s
- Energy intensive industry
- Hydro power companies

**Topics for the interviews:**
- Current legislation
- Infrastructure/grid lines
- Commercial potential
- Societal legitimacy
- Environmental impacts

**Main findings**

**EU-level:**
Need of a system for exchanging and valuing balancing services

**National level:**
Need of political strategies and necessary measures to realize hydrobalancing

**Community level:**
Compensation and early involvement of stakeholders
Key actions: National policy makers

- Establish an multi-disciplinary advisory board on how to best develop Norwegian hydropower, including transmission lines and interconnectors.
- Develop plans and strategies for Norwegian hydropower in the common integrated European electricity.
- Develop a benefit sharing schemes
- Create a transnational level playing field for flexibility
- Implement a new regulatory framework for hydropower production with updated restrictions adapted to flexible services in future markets.
Key actions: Norwegian TSO

- Make and maintain a rolling plan for realizing the next cables from Norway.

- Coordinate plans with neighbouring countries to remove local bottlenecks and agree on sharing of investments, profits, and risks. (ACER is also a component)

- Ensure that new domestic and international transmission cables are constructed with minimal impact on landscape and biodiversity.
Key actions: National authorities (OED, NVE)

- Develop a coherent and comprehensive planning framework concerning the potential for balancing services and related grid development.

- Create an overall plan for how to identify which hydropower plants that are the most suitable for balancing services, and which that are not.

- Integrate the concept of environmental design of hydropower in license revisions and implementation of the water framework directive but keeping in mind impact on available flexibility from hydro.

- Initiate a dialogue including politicians, authorities, and public and private stakeholders, with the aim of formulating common goals that encompass and balance different societal interests and concerns related to further hydropower development.
Key actions: Producers

- Make a strategy to increase the ability to provide balancing services.

- Replace fish stockings with habitat improvements and water level regulation patterns that facilitate natural recruitment and improved ecological status of the reservoirs.

- Collect data such as bathymetric maps and spatial and temporal water temperature variations enabling improved modelling of future operation patterns.

- Give local groups the opportunity to provide direct input during the planning and construction phase and, specify how community benefits and costs are allocated.
Thank you for your attention!

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