Economic Potential for an Extension of Pump Storages in Norway

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1. Introduction

2. Presentation of the models applied

3. Scenario description

4. Results

5. Conclusions
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Introduction

• Rising shares of volatile electricity production from RES in Europe

• In the upcoming future, especially the potentials of off-shore-wind power in the north and baltic sea are scheduled to be developed

• In order to guarantee serving of the load also in times of lower RES-production, flexible production has to be provided to the grid
  – Flexibility due to extension of transmission capacities
  – Flexibility from flexible power plants (e.g. Natural Gas but also Hydro storages)
  – Flexibility from electricity storages (e.g. Pump storages)

• Linking the offshore-production with a north-sea grid to the storage potentials in Norway seem to be of great advantage
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2. Presentation of the models applied
   1. Overview
   2. E2M2s
   3. JMM

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Interaction of the models

![Diagram]

- **Input – data base**
- **European Electricity Market Model E2M2s**
  - Production capacities, seasonal usage of hydro storages; Type days: Electricity prices, electricity production and electricity exchange between countries
- **Joint Market Model JMM**
  - Hourly electricity prices, electricity production and electricity exchange between countries
- **Output – data base**
Basic considerations of the models (I)

- **Minimization of system costs**
  - Fundamental model
  - LP as well as MIP equations

- **Cost components taken into account**
  - fuel cost for electricity production and for start – ups
  - CO2 – costs for electricity production and for start – ups
  - other variable cost (e.g. Operation and maintenance, Shedding of RES,...)

- **Further restrictions:**
  - Electricity production from additional RES capacities (wind and solar)
  - Reserve requirements
  - Grid bottlenecks ...
Basic considerations of the models (II)

• Models include all European countries

• Including electricity and district heating markets

• Variable degree of detail:
  – whole of Europe or
  – European regions or/and
  – several regions within one country

• Possible stochastic modeling of load, wind, solar and water fluctuations
  - increasing share of solar and wind power production in European System
  - fluctuating production induces additional load flows
  - changes in hydrological conditions have also to be foreseen
E2M2s – Methodology

- Long term investment model based on Peak-Load-pricing approach

- Typically modelling a series of years

- Representation of each year in typical days and typical hours
  - In each quarter of the year
  - One work day and one weekend day
  - Each day is represented by 7 hours
  - Total of 56 representative hours

- Stochastic optimization using recombining trees
E2M2s – Results

- Optimal dispatch of production technologies
- Optimal investment in power plant capacities
- Optimal exchange of electricity
- Fundamental prices of electricity production
  → shadow prices of the demand restriction
- CO₂-prices
  → shadow prices of the emission bound
- Total system costs
JMM – methodology

• Short term unit dispatch model using a rolling planning approach
• Hourly Optimization of 2 markets:
  – day-ahead (unit dispatch up to 36 hours)
  – Intraday (redispatching the day-ahead results if new information available)
• Very detailed representation of technical restrictions (e.g. efficiency factors, availabilities, ramp rates, CHP unit types etc.)
• Detailed grid representation: NTC, PTDF and DCLF depiction is possible
• Recombining wait and see decision structure if stochastic is included
• Stochastic option for wind, sun, water and load is in place
• Developed within the EU project WILMAR in 2004
• Applied in the EU-projects EWIS and SUPWIND but also in several industry projects
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Basic considerations

- **Time horizon:** 2030 and 2050
- **Considered overall developments:** „Environmental friendly“
  - High Prices for fossil fuels
  - High CO2-prices (2030: 35 EUR/t CO2; 2050: 90 EUR/t CO2)
  - Excessive built-up of RES – capacities
  - Low development of electricity demand
- **Geographic scope:** Europe
  - incl. Norway, Switzerland and 2-3 offshore-nodes
  - excluding south-eastern Europe
  - Representation of Germany in 7 regions
    → In total 49 regions included
    → Presentation of results only for the mainly affected regions
Geographical Scope
Considered scenarios

- **Scenario 1:**
  - Moderate extension of the north sea grid
  - Only 2 offshore nodes
  - Less installed wind capacities connected to these nodes
  - More offshore-wind capacities connected bidirectional to the countries
  - No extension of pumping capacities in Norway
Considered scenarios

- **Scenario 2a:**
  - Extensive grid extension
  - 3 offshore nodes
  - More offshore-wind capacities connected to the offshore-nodes
  - Less installed wind capacities connected bidirectional to the countries
  - No extension of pumping capacities in Norway
Considered scenarios

- **Scenario 2b:**
  - Higher grid extension
  - 3 offshore nodes
  - More offshore-wind capacities connected to the offshore-nodes
  - Less installed wind capacities connected bidirectional to the countries
  - Installation of pump capacities in Norwegian water reservoirs (9GW)
  - The total considered capacity for Norwegian water reservoirs is much higher (27GW)
  - Only 1/3 of these capacities do fulfill the geographical preconditions which qualify them for an extension
  - In this case, only pumps would be applied (lower investment costs)
Considered scenarios

- **Scenario 2c:**
  - Higher grid extension
  - 3 offshore nodes
  - More offshore-wind capacities connected to the offshore-nodes
  - Less installed wind capacities connected bidirectional to the countries
  - Installation of pump & production capacities in Norwegian water reservoirs (9GW)
  - Same selection of water reservoirs as before
  - Locating the additional turbines in the existing structures (into the dams or caverns) that they are also able to produce (higher investment cost)
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Installed capacities for 2030

Installed capacities (GW)

- Nuclear
- Lignite
- Coal
- Natural gas
- Oil
- Pump storage
- Water power
- Biomass
- Waste
- Sun
- Wind onshore
- Wind offshore

Legend:
- Scen1
- Scen2a
- Scen2b
- Scen2c
Installed capacities in Scenario 1 for 2030

- nuclear
- lignite
- coal
- natural gas
- oil
- pump storage
- water power
- biomass
- sun
- waste
- Wind onshore
- Wind offshore
Installed capacities in Scenario 2a for 2030

- Nuclear
- Lignite
- Coal
- Natural gas
- Oil
- Pump storage
- Water power
- Biomass
- Sun
- Waste
- Renewable energy sources (wind onshore, wind offshore)
Production by fuel and region in Scenario 1 for 2030

Legend:
- SUN
- Biomass
- COAL
- FUELOIL
- GEOTHHEAT
- LIGNITE
- Misc
- MUNI_WASTE
- NAT_GAS
- NUCLEAR
- PUMP_HYD
- WATER
- WATER_RES
- WIND

Production (TWh)
Production by fuel and region in Scenario 2a for 2030
Comparison of average base prices – 2030

Base prices (EUR/MWh)

Scen1
Scen2a
Scen2b
Scen2c
Comparison of average base prices – 2030

• The high price level for France and Poland is set by the connected markets
  – In case of France by Spain and Italy
  – In case of Poland by Czech Republic and Hungary

• Strong dependency of the Nordic countries

• Scen 1 vs Scen 2a-c:
  – Leveling effect of additional transmission capacities still observable

• Scen 2a vs 2b vs 2c:
  – Only marginal differences between the scenarios indicate marginal effects
Comparison of average base prices – 2050
Comparison of average base prices – 2050

- Massive rises of price levels due to changes in fuel and CO2 prices as well as lowering effects due to rising share of RES
  - First effect especially observable in case of Poland
  - Second effect especially in case of Denmark

- Scen 1 vs Scen 2a-c:
  - The price levels are levelising due to the higher transmission capacities
  - The average base price level in countries linking to NO and SE decrease while the prices in NO and SE itself do rise
Production from water reservoirs – 2030 and 2050

Production (TWh)

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario</th>
<th>R_FR</th>
<th>R_NO</th>
<th>R_PL</th>
<th>R_SE</th>
<th>R_UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>Scen1</td>
<td>15</td>
<td>20</td>
<td>10</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>2030</td>
<td>Scen2a</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>2030</td>
<td>Scen2b</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>3</td>
</tr>
<tr>
<td>2030</td>
<td>Scen2c</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>2050</td>
<td>Scen1</td>
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<td>70</td>
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<td>70</td>
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<tr>
<td>2050</td>
<td>Scen2a</td>
<td>40</td>
<td>60</td>
<td>40</td>
<td>60</td>
<td>15</td>
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<tr>
<td>2050</td>
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<td>40</td>
<td>20</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>2050</td>
<td>Scen2c</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>20</td>
<td>5</td>
</tr>
</tbody>
</table>
Production from water reservoirs – 2030 and 2050

• Grid extensions have especially an effect on the production of Norwegian water reservoirs

• Scen 1 vs Scen 2a-c:
  – In 2030, the grid extensions seem to lower the need from flexible production...
  – ... while in 2050 the need for flexible production triggered by even more installed capacities of RES seem to exceed the flexibility offered by grid extensions

• Scen 2a vs 2b vs 2c:
  – Additional pumping respectively production capacities are used

<table>
<thead>
<tr>
<th>Year</th>
<th>Scen1 (TWh)</th>
<th>Scen2a (TWh)</th>
<th>Scen2b (TWh)</th>
<th>Scen2c (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>85.8</td>
<td>83.7</td>
<td>90.1</td>
<td>91.6</td>
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<tr>
<td>2050</td>
<td>74.2</td>
<td>104.4</td>
<td>111.05</td>
<td>111.73</td>
</tr>
</tbody>
</table>
Pumping activities of mayor providers in Europe – 2030

- Scen1
- Scen2a
- Scen2b
- Scen2c
Pumping activities of mayor providers in Europe – 2050

- R_AT
- R_AT_Tirol
- R_AT_Vorarlberg
- R_BE
- R_CH
- R_DE
- R_FR
- R_IT
- R_LU_Vlinden
- R_NO
- R_PL
- R_UK

Legend:
- Scen1
- Scen2a
- Scen2b
- Scen2c
Pumping activities of mayor providers in Europe – 2030 and 2050

• Various influences cause different pumping behaviors of the mayor producers in Europe between the two base years
  – France: While in 2030, no mayor differences occur, the grid extensions cause a more drastic change in behavior

• Pumping activities in Norway
  – In both base years, pumping in Norway seems reasonable
  – There are no mayor differences between scenario 2b and 2c
  – This indicates, that the much higher investment costs in scenario 2c could not be justified
  – In general, the pumps have a total of about 1100/1200 full load hours for 2030/2050

<table>
<thead>
<tr>
<th>Year</th>
<th>Scen2b (TWh)</th>
<th>Scen2c (TWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030</td>
<td>9.7</td>
<td>9.9</td>
</tr>
<tr>
<td>2050</td>
<td>10.8</td>
<td>11.1</td>
</tr>
</tbody>
</table>
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Conclusions

- An extension of the north sea grid seams to have greater impact than the additional installation of pumping capacities or combined pumping and production capacities in Norwegian water reservoirs.

- The existing hydro storages are already very flexible – a shifting of the production to hours of high prices is already possible and by the extension of the grid even more applicable.

- Still, the additional capacities would be dispatched within expected values.

- Marginal differences between Scenario 2b and 2c indicate that the high investment needs for extending production capacities are not justified.
Thank you for your attention!

Any questions or remarks?

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Backup
Comparison of standard deviations of base prices – 2030

Diagram showing the comparison of standard deviations of base prices for different scenarios (Scen1, Scen2a, Scen2b, Scen2c) for various countries and regions (DK_E, DK_W, R_50HZA, R_BE, R_FR, R_NL, R_NO, R_PL, R_SE, R_TPA, R_UK).
Comparison of standard deviations of base prices – 2030

• Similar picture to the previously show base prices

• Scen 1 vs Scen 2a-c:
  – Due to the grid extension, the standard deviation of the base prices is levelizing

• Scen 2a vs 2b vs 2c:
  – With additional pumping or even production capacities, the standard deviation is lower
Comparison of standard deviations of base prices – 2050

The chart shows the comparison of standard deviations of base prices for various regions in 2050. The x-axis represents different regions, and the y-axis shows the standard deviation of base prices (EUR). The regions are color-coded as follows:

- Scen1 (Blue)
- Scen2a (Red)
- Scen2b (Green)
- Scen2c (Purple)

Each region has three bars representing different scenarios, illustrating the variability in base prices across these regions.
Wind shedding – 2030 and 2050