Electricity storage demand in European long-term energy scenarios

A sensitivity analysis

Felix Cebulla
1. Motivation & Aim
2. Methodology
   - Model
   - Scenario
   - Assumptions
3. Results
4. Conclusion & Outlook
Motivation & Aim

- Research on future electricity storage demand result in broad ranges regarding the capacities and the power.

Discharge power [GW]

Storage capacity [TWh]
Different methodological as well as techno-economic assumptions

<table>
<thead>
<tr>
<th>Methodological assumptions</th>
<th>Techno-economic assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different model types: optimization, simulation, top-down, bottom-up, agent-based modeling etc.</td>
<td>Total share of renewable generation</td>
</tr>
<tr>
<td>Normative scenarios, predefined capacity structures</td>
<td>Ratio of fluctuating to dispatchable generation</td>
</tr>
<tr>
<td>Open capacity expansion, greenfield approach</td>
<td>Structure of volatile generation (e.g. wind to pv ratio)</td>
</tr>
<tr>
<td>Combined approach: predefined capacity (scenario) and und capacity expansion</td>
<td>Costs and price paths (fuel, CO₂ and investment costs)</td>
</tr>
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</tbody>
</table>
In how far are model-based results of future storage demand robust with regard to uncertain energy economic, political and technical frameworks?

⇒ Sensitivity analysis

Testing the influence of:

a) Fuel and emission costs
b) Grid expansion scenarios
c) Constraints on curtailment of fluctuating renewable generation
d) Scenario vs. greenfield approach
Methodology - model

- Linear bottom-up optimization model REMix
- Cost minimizing dispatch and expansion optimization
- Electricity, heat and transport sector; H₂-infrastructure
- High temporal (1h) and spatial resolution

- Around 20 technology modules which enable different applications:
  - Validation and construction of long-term energy scenarios
  - Validation of balancing options
  - Short-term capacity expansion
Methodology - scenario I
Model nodes/spatial resolution

- 9 European and 20 German model regions
Methodology - Scenario II
Grid scenarios

- Bi-directional mean electricity line utilization over 3 months
- Example links: Tennet2 ↔ Amprion2, Tennet1 ↔ EnBW1

<table>
<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
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</thead>
<tbody>
<tr>
<td>Mean util. [%]</td>
<td>97</td>
<td>83</td>
</tr>
<tr>
<td>Numb. of util &gt; 0.98</td>
<td>8,175</td>
<td>4,942</td>
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<thead>
<tr>
<th></th>
<th>(a)</th>
<th>(b)</th>
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</thead>
<tbody>
<tr>
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<td>48</td>
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<tr>
<td>Numb. of util &gt; 0.98</td>
<td>838</td>
<td>9</td>
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</tbody>
</table>
Methodology- Scenario III
Scenario capacities

- Installed power for Germany based on lead study 2011 scenario A

- Installed power for Europe based on Trans-CSP study (modified)

- Normative target: 80% Renewable generation with regard to the annual gross electricity generation (year 2050)
Methodology - Scenario IV
Other assumptions

- 3 curtailment scenarios: 100%, 10%, 3% shedding of annual electricity generation allowed (cur.100, cur.10, cur.3), technology specific

- 5 storages: adiabatic compressed air storage, hydrogen storage (electrification in CCGT), lithium-ion battery, pumped storage, redox-flow battery

- One weather year (2006) and the associated load time series from ENTSO-E

- Expansion options (endogenous): storages and gas turbines
Methodology - Scenario V

Scenario tree

Fuel costs
- High

Emission costs
- Low

Allowed curtailments
- 100%

Grid scenario
- Expanded (G+)
  - Expanded (G+)
  - Restricted (G-)
Results I

Total storage and gas turbine expansion

Influence of fuel and emissions costs

- Base scenario: expanded grid + unlimited curtailments

- High fuel costs can quadruple the added storage power, while high emission costs only increase the model endogenous expansion by factor 2

- With lower FC- and EC costs storages are substituted by gas turbines

<table>
<thead>
<tr>
<th>Fuel costs (FC)</th>
<th>Emission costs (EC)</th>
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<tbody>
<tr>
<td>low-med-high [€/MWh]</td>
<td>low-med-high [€/t CO₂]</td>
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<tr>
<td>Coal</td>
<td>14 - 21 - 35</td>
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<tr>
<td>Lignite</td>
<td>8 - 9 - 10</td>
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<tr>
<td>Nat. Gas</td>
<td>33 - 48 - 73</td>
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</table>
Results II

Regional storage and gas turbine expansion

Influence of grid and curtailment constraints

- CCGT
- Coal
- Wind on
- Wind off
- Biomass
- PV
- Hydro

50 GW

G+ cur.3
G+ cur.10
G- cur.100
G+ cur.100

10 GW
Results III
Scenario specific storage expansion

Discharge power [GW]

Storage capacity [TWh]
Results IV
Comparison of model results with exiting research

Discharge power [GW]

Storage capacity [TWh]

2013, Bert Droste-Franke, Future Storage and Balancing Demand – Ranges, Significance and Potential Improvements of Estimations
Results V
Region specific storage utilization

Regional storage expansion

Node specific correlation coefficient between discharge power and wind/pv generation

- Storage operation is mainly used for balancing wind power (region A, B), apart from model region C where high PV potentials foster the storage capacity expansion.
Results VII

Yearly storage utilization

Restricted grid (G-)

- Grid expansion substitutes long term storages, such as hydrogen
- Storage utilization decreases significantly within the G+ scenarios (mean util., numb. Of util. > 0.9)

<table>
<thead>
<tr>
<th></th>
<th>CAES</th>
<th>Li-Ion</th>
<th>Hydro</th>
<th>Hydrogen</th>
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<td>Mean util. [%]</td>
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<td>1,430</td>
<td>1,017</td>
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<td>1,615</td>
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<td>E2P ratio [h]</td>
<td>22</td>
<td>6</td>
<td>13</td>
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<td>37</td>
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<tr>
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<td>596</td>
<td>33</td>
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<tr>
<td>E2P ratio [h]</td>
<td>14</td>
<td>6</td>
<td>15</td>
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</tbody>
</table>
Results VI
Seasonal storage utilization

Winter (h 0-240)

Summer (h 4320-4560)
Conclusion & Outlook

- Both storage power as well as storage capacity are robust with regard to changes of fuel and CO\textsubscript{2} certificate costs.
- Storage demand is more sensitive to the chosen grid scenario and the allowed curtailments.
- These results have to be tested for an open capacity expansion (greenfield).

- Further analysis could include cost related and node specific curtailments.
- A review of the robustness of the storage demand is essential with regard to the following sensitivities:
  - Different weather year
  - Load times series
  - Further flexibility options
  - Power plant modeling approach (MILP vs. LP)
Thanks for your attention!

Questions?