Assessing Storage Value in Electricity Markets – a Literature Review

IEA Energy Storage Technology Roadmap Stakeholder Engagement Workshop

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Content

- Project background and scope
- Study classification
- Some key results
- Conclusion
The review addresses three main issues about power storage modelling:

- **Methodology**
  - Are there generally accepted methodologies to assess power storage?
  - What are the underlying hypotheses used?
  - Are there gaps inherent to the complexity and inadequacy of models?

- **Profitability**
  - Markets (geography, product) analysed
  - Economic approaches used
  - Value possibly not captured by the analysis
  - Presentation of the results in a harmonised way to ensure comparability

- **Regulation**
  - Impact of fees and technical requirements
  - Storage ownership, right of access
  - Alternative approaches to storage operation

Focus of this presentation
Content

- Project background and scope
- **Study classification**
- Some key results
- Conclusion
We divided the studies in two very broad groups

<table>
<thead>
<tr>
<th>Engineering Studies</th>
<th>Math. formulation</th>
<th>Typical application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximise profit resulting from (different) storage revenue streams</td>
<td>Assess the <em>profitability</em> of power storage from the asset’s point of view</td>
</tr>
<tr>
<td>System Studies</td>
<td>Minimise total costs of operating the power system</td>
<td>Assess <em>benefit</em> of adding storage to the generation system</td>
</tr>
</tbody>
</table>
Study figures had to be aligned in order to allow for comparability of different studies

<table>
<thead>
<tr>
<th>Topic</th>
<th>Complication</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currencies</td>
<td>• €, US$, AUS$, DKR… &lt;br&gt; • Different base years of the currency (inflation)</td>
<td>All currency units converted into €2012&lt;br&gt;&lt;br&gt;Separate discussion of CAES and PHS to take commodity price effects into account&lt;br&gt;&lt;br&gt;Compare storage net rev. with 4 combinations of CAPEX/WACC(^1) (min/max)</td>
</tr>
<tr>
<td>Technologies</td>
<td>• CAES (adiabatic, diabatic), PHS, Batteries &lt;br&gt; • Generic</td>
<td>Sorted studies according to services assessed</td>
</tr>
<tr>
<td>CAPEX</td>
<td>• Study specific CAPEX &lt;br&gt; • Different interest rates &lt;br&gt; • €/kW or component based</td>
<td></td>
</tr>
<tr>
<td>WACC</td>
<td>• Arbitrage (all) &lt;br&gt; • Reserve (&quot;regulation&quot;) &lt;br&gt; • Capacity payments</td>
<td></td>
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</tbody>
</table>

1) Lower value of 6% represents a typical TSO/regulated utility, upper value of 10% a deregulated power generator
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Majority of engineering studies assess arbitrage and reserve power revenue streams

Power system value chain

Generation → Trade → Transmission → Distribution → Retail & End Use

Power Market Arbitrage

Reserve Markets

- Tertiary Reserve: 15 min / 1 h
- Secondary Reserve: 5 min / 1 h
- Primary Reserve: 30 s / 5 min

Regulated domain

Activation / duration

Typical storage technologies

1) Compressed Air Energy Storage
2) Pumped Hydro Storage
Engineering studies showed wide range of results – comparing the incomparable?

CAES engineering study range of results

Key trends

- Net profit: 10 - 130 €/kW/a
- Sioshansi et al. 2011 includes capacity payments of 40$/kW
- Hessami 2011 only optimises sale of wind power (potential upside from allowing full arbitrage)
- Significant importance of reserve market revenues (36% for Drury et al. 2011, >50% for Fraunhofer 2009)
- Two studies used prices generated by stochastic financial model
System studies strongly diverge in their quantification of storage value

Key trends

• Value for individual services between -50 and >800 €/kW\(^1\)

• Generation remains most valuable part of the value chain (Strbac et al. 2012)

• Hydrogen storage can drive up generation CAPEX due to low round trip efficiency (VDE 2012)

• Storage can have negative value for the transmission system (Strbac et al., dena 2010 grid)

• Distribution grid value negative in DE if operated on arbitrage model (dena 2012 dist)

→ Mixed picture, many gaps!

1) Max. value for Strbac et al. 2012 not shown here
### Methodological approaches impact the study results and leave open questions

<table>
<thead>
<tr>
<th>Study and Author</th>
<th>Methodology</th>
<th>Impact &amp; Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dena II grid study (2010)</td>
<td>Massively deployed storage operated by power market</td>
<td>No relief of grid congestion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Impact of alternative rules (e.g. nodal prices)?</td>
</tr>
<tr>
<td>VDE 2012</td>
<td>H2 stores energy but does not transport it from North to South</td>
<td>No real value of H2 storage for the grid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Power2gas + injection?</td>
</tr>
<tr>
<td>Strbac et al. 2010¹</td>
<td>Explicit modelling of power prices</td>
<td>Very high storage values</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Does this hold in a world with capacity markets?</td>
</tr>
<tr>
<td>Denholm et al. 2013</td>
<td>Same storage case assessed using dispatch model vs price taker</td>
<td>34$/kW system vs 17$/kW arbitrage value</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Is this always so?</td>
</tr>
</tbody>
</table>

¹ See Gruenwald 2012
But regulation could change the picture even further...

- Grid fees in DE challenge viability of 110kV connected PHS plants (dena 2008)
- Bid size storage from tertiary reserve (VDE 2013)
- Paying RES-E feed in tariffs at very high negative prices might force storage into a market (Nicolosi 2011)
- RES-E to provide ancillary services? (VDE 2013, REservicesS 2013)
- On-going debate on TSO storage ownership in both Europe and US, yet very little studies on market impact
- Some attempts to model "mutualised storage" (He et al. 2011)
- Capacity markets → dynamics of investment planning
- Loss of FIT if mixing "green" and "grey" energy?
US studies identify very high x-value chain value for storage – valid in other legislations?

Storage value according to EPRI\(^1\) and SANDIA\(^2\) Study context

- Arb. value in the range of other US studies (Sioshansi, Drury)
- Reserve revenues anticipate higher 'efficiency based renumeration' for storage
- T&D invest deferrals based on 'mobile units' moved around US
- (Local) system capacity and transmission congestion based on existence of nodal pricing
- End user benefits mainly based on VOLL
- No simultaneous optimization unclear if services can be combined

→ Applicable to EU markets?

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1) EPRI 2010 – Electricity Energy Storage Technology Options - A White Paper ...
2) SANDIA 2010 – Energy Storage for the Electricity Grid: Benefits and Market Potential
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Conclusion

- No shortage on studies on storage profitability
- Two main approaches: engineering and system answer different question and give different figures
  - *Engineering studies* replicate investor view and often see **challenging business case**
  - *System studies* capture value for power system (as far as this is modeled), results vary wildly **from negative to very high** value
- Regulation can change everything

→ **No easy and general (quantitative) answer on the value of storage!**
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Thank you!