On the Role of Electricity Storage in Capacity Remuneration Mechanisms

Christoph Fraunholz, Dogan Keles, Wolf Fichtner | IAEE Online Conference – 8 June 2021
Agenda

1. Storage Participation in Capacity Mechanisms
2. Theoretical Discussion on Relevant Design Parameters
3. Selected Results of a Large-Scale Simulation Study
4. Conclusion and Policy Implications
Regulatory framework

- Capacity mechanisms are used around the world to secure sufficient firm capacity
- Formally, technology neutrality is a requirement in Europe and the US (European Commission, 2013; Sakti, Botterud, and O’Sullivan, 2018)
- In practice, rules for storage participation differ
  - PJM: like conventional units (Chen et al., 2017)
  - CAISO: full output for 4 h (Usera et al., 2017)

⇒ In what way does the parametrization of capacity mechanisms affect the future technology mix and long-term generation adequacy?
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**Generic Capacity Auction Mechanism**

Central buyer mechanism with reliability options (used in, e.g., Italy, Ireland)

### Characteristics
- Regulator determines firm capacity requirement and other parameters
- Successful participants are rewarded with the marginal capacity price of the auction
- Capacity derating factors may be used, e.g., for storage units
- Combination with call options
  - Price cap on the day-ahead market
  - Regulator collects peak energy rent
  - Implicit penalty for non-availability during scarcity periods

### Bidding strategy

Capacity remuneration should cover the difference costs $DC$:

$$DC = \max \left( -NPV, 0 \right)$$

With some simplifications follows the indifference bid price $p^{CRM}$:

$$p^{CRM} = \frac{k_1}{f^{derate}} \cdot \max \left( k_2 \cdot c^{invest} - CM(p^{limit}), 0 \right)$$

The resulting technology mix is driven by the relation of

- investment expenses $c^{invest}$,
- contribution margin $CM$ (indirectly: strike price $p^{limit}$),
- derating factor $f^{derate}$.

⇒ *Focus of this talk: Combination with call options and variation of the strike price*
Combination with Call Options

Contribution margins in a stylized example of the day-ahead market in the future

- Contribution margin: $CM = p - c_{\text{var}}$
- Break-even point: $p = c_{\text{var}}$
- Strike price: $p^\text{limit}$
- Storage capacity: $C^{\text{stor}}$
- Storage efficiency: $\eta^{\text{stor}}$

\[CM^{\text{stor}} > CM^{\text{conv}} \iff \begin{cases} p^\text{high} (1 - \eta^{\text{stor}}) < c_{\text{var}}^{\text{CONE}}, & \text{for Cases 1/2a} \\ p^\text{limit} (1 - \eta^{\text{stor}}) < c_{\text{var}}^{\text{CONE}}, & \text{for Case 2b} \end{cases} \]

- Case 1: No Regulator
  - Storage unit: $B + D + F - A$
- Case 2a: Yes Storage operator
  - Storage unit: $D + F - A - C$
- Case 2b: Yes Regulator
  - Storage unit: $D + F - A$

Under some reasonable assumptions, storage units counterintuitively benefit from a strike price.
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Agent-Based Electricity Market Simulation Model PowerACE

Selected characteristics
- Time horizon 2020–2050 with 8760 h/a
- Day-ahead market simulation (daily)
- Investment decisions (yearly)

Input
- Power plant fleets of the base year
- Fuel and carbon prices
- Hourly electricity demand
- Hourly renewable feed-in
- Transfer capacities between market areas

Output
- Hourly day-ahead market prices
- Hourly dispatch (power plants, storages)
- Investment decisions (power plants, storages)
## Model Assumptions and Scenario Setup

### Some key assumptions

- Simulation period: 2020–2050 at hourly resolution (8760 h/a)
- Regional scope: Selection of ten European countries with diverse electricity market designs
- Renewable share in electricity demand reaching 80% by 2050
- Carbon prices increasing to 150 EUR/t\(\text{CO}_2\) in 2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Electricity market designs</th>
<th>Strike price</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOM</td>
<td>European EOM</td>
<td>n/a</td>
</tr>
<tr>
<td>CRM</td>
<td>National CRM policies</td>
<td>none</td>
</tr>
<tr>
<td>CRM-limit_high</td>
<td>National CRM policies</td>
<td>(1.5 \cdot c_{\text{var}}^{\text{CONE}})</td>
</tr>
<tr>
<td>CRM-limit_low</td>
<td>National CRM policies</td>
<td>(c_{\text{var}}^{\text{CONE}})</td>
</tr>
</tbody>
</table>

\(c_{\text{var}}^{\text{CONE}}\) – variable cost of new entry, CRM – capacity remuneration mechanism, EOM – energy-only market
Reference Scenario (European Energy-Only Market)

Simulated development of conventional power plant and storage capacities in France

⇒ Fuel switch towards gas-fired power plants and expansion of utility-scale storages
Simulated development of conventional power plant and storage capacities in France

CCGT—combined cycle gas turbine, OCGT—open cycle gas turbine

Technology composition affects both renewable integration and generation adequacy
**Deterministic indicators describing generation adequacy level in France (Ø 2020–2050)**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Strike price</th>
<th>No market clearing</th>
<th>Energy not served</th>
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</thead>
<tbody>
<tr>
<td>EOM</td>
<td>n/a</td>
<td>10.7 h/a</td>
<td>60.5 GWh/a</td>
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<tr>
<td>CRM</td>
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<td>0.0 h/a</td>
<td>0.0 GWh/a</td>
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<td>1.6 h/a</td>
<td>3.7 GWh/a</td>
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<td>$c_{\text{CONE}}^{\text{var}}$</td>
<td>5.1 h/a</td>
<td>16.2 GWh/a</td>
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</table>

$c_{\text{CONE}}^{\text{var}}$ – variable cost of new entry, CRM – capacity remuneration mechanism, EOM – energy-only market

$\Rightarrow$ *Nameplate capacity of electricity storage should be adequately derated (for details see paper)*
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Conclusion and Policy Implications

Key take-aways of this talk

- Design of capacity remuneration mechanisms inevitably creates a bias towards one technology or the other
- Linking the capacity auctions with call options increases the competitiveness of storages against conventional power plants
- Determining the capacity credit of non-conventional resources is challenging and can strongly affect generation adequacy
- For additional details see paper on the right (open access)

Contact details – feel free to get in touch

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⇒ Thank you for the attention! Any questions or comments?

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Literature I


Literature II

