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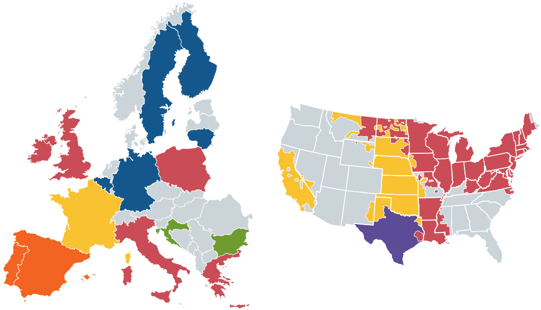
# On the Role of Electricity Storage in Capacity Remuneration Mechanisms

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

# Agenda

# Storage Participation in Capacity Mechanisms




(a) Europe (b) United States

*Source:* reproduced from Bublitz et al., 2019

**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)
  - Ireland & UK: derating factors (National Grid, 2017; Single Electricity Market Committee, 2016; Single Electricity Market Committee, 2018)

$\Rightarrow$ *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 $p^{\text{CRM}}$:

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

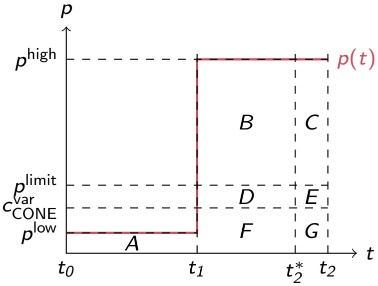
The resulting technology mix is driven by the relation of

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

$\Rightarrow$ *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




| Case | Strike price | Risk of empty storage | Power plant | Storage unit |
|---|---|---|---|---|
| 1 | No | Regulator | $B + C + D + E$ | $B + D + F - A$ |
| 2a | Yes | Storage operator | $D + E$ | $D + F - A - C$ |
| 2b | Yes | Regulator | $D + E$ | $D + F - A$ |

**Under some reasonable assumptions, storage units counterintuitively benefit from a strike price**

$$CM^{\text{stor}} > CM^{\text{conv}} \Leftrightarrow \begin{cases} p^{\text{high}} \left(1 - \eta^{\text{stor}}\right) < c^{\text{var}}_{\text{CONE}}, & \text{for Cases 1/2a} \\ p^{\text{limit}} \left(1 - \eta^{\text{stor}}\right) < c^{\text{var}}_{\text{CONE}}, & \text{for Case 2b} \end{cases}$$

$p^{\text{limit}}$ – strike price of call option, $c^{\text{var}}_{\text{CONE}}$ – variable cost of new entry, $CM$ – contribution margin, $\eta^{\text{stor}}$ – storage efficiency

# 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

# Agent-Based Electricity Market Simulation Model PowerACE

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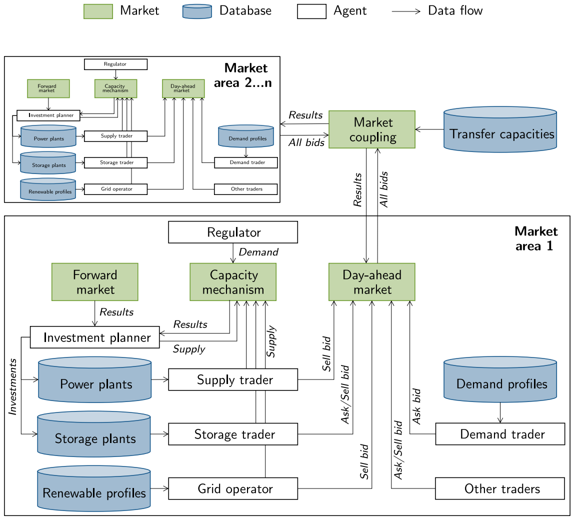


## Selected characteristics

- 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

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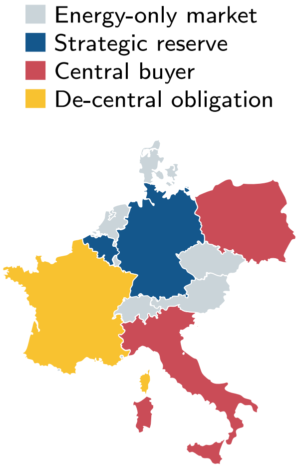
## Some key assumptions

- 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/$t_{CO_2}$ in 2050

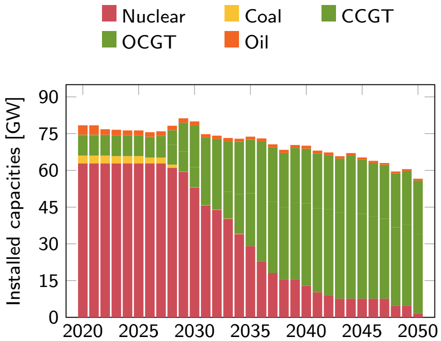
| Scenario | Electricity market designs | Strike price |
|---|---|---|
| EOM | European EOM | n/a |
| CRM | National CRM policies | none |
| CRM-limit_high | National CRM policies | $1.5 \cdot c^{var}_{CONE}$ |
| CRM-limit_low | National CRM policies | $c^{var}_{CONE}$ |

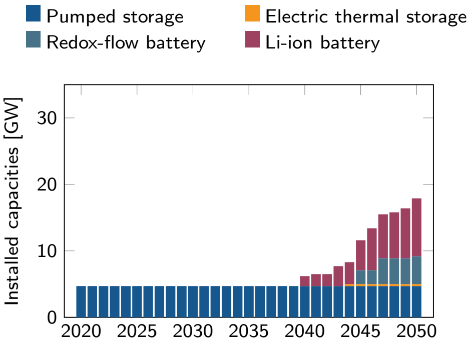
$c^{var}_{CONE}$ – variable cost of new entry, CRM – capacity remuneration mechanism, EOM – energy-only market



# Reference Scenario (European Energy-Only Market)

Simulated development of conventional power plant and storage capacities in France




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

⇒ *Fuel switch towards gas-fired power plants and expansion of utility-scale storages*

# Capacity Auctions Bundled with Call Options

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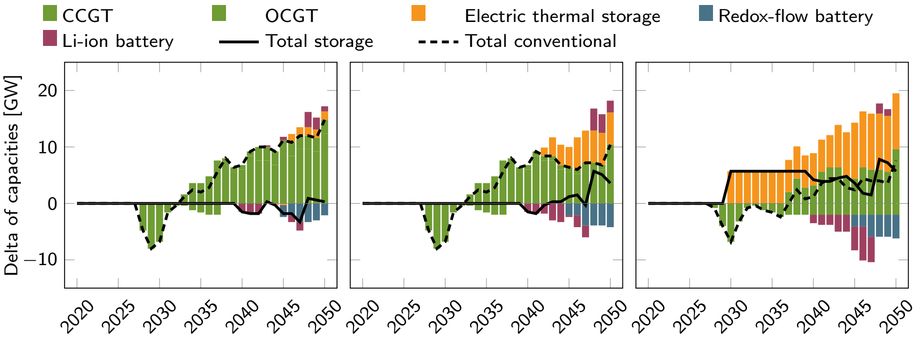
Simulated development of conventional power plant and storage capacities in France




(a) no strike price (b) high strike price (c) low strike price

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

⇒ *Technology composition affects both renewable integration and generation adequacy*

# Impact of Technology Composition on Generation Adequacy

Deterministic indicators describing generation adequacy level in France (∅ 2020–2050)

| Scenario | Strike price | No market clearing | Energy not served |
|---|---|---|---|
| EOM | n/a | 10.7 h/a | 60.5 GWh/a |
| CRM | none | 0.0 h/a | 0.0 GWh/a |
| CRM-limit_high | $1.5 \cdot c^{\text{var}}_{\text{CONE}}$ | 1.6 h/a | 3.7 GWh/a |
| CRM-limit_low | $c^{\text{var}}_{\text{CONE}}$ | 5.1 h/a | 16.2 GWh/a |

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

⇒ *Nameplate capacity of electricity storage should be adequately derated (for details see paper)*

# Agenda

# Conclusion and Policy Implications

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## 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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On the role of electricity storage in capacity remuneration mechanisms

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ABSTRACT

In electricity markets around the world, the substantial increase of intermittent renewable electricity generation has intensified concerns about generation adequacy, ultimately driving the implementation of capacity remuneration mechanisms. Although formally technology-neutral, substantial barriers often exist in these mechanisms for non-conventional capacity such as electricity storage. In this article, we provide a rigorous theoretical discussion on design parameters and show that the concrete design of a capacity remuneration mechanism always creates a bias towards one technology or the other. In particular, we can identify the bundling of capacity auctions with call options and the definition of the storage capacity credit as essential drivers affecting the future technology mix as well as generation adequacy. In order to illustrate and confirm our theoretical findings, we apply an agent-based electricity market model and run a number of simulations. Our results show that electricity storage has a capacity value and should therefore be allowed to participate in any capacity remuneration mechanism. Moreover, we find the implementation of a capacity remuneration mechanism with call options and a strike price to increase the competitiveness of storages against conventional power plants. However, determining the amount of *firm* capacity an electricity storage unit can provide remains a challenging task.

1. **Introduction**

The substantial increase of renewable electricity generation in countries around the world brings along new challenges for the appropriate design of electricity markets. Due to the highly intermittent nature of solar and wind power, a certain amount of dispatchable capacity will likely also be required in the future, i.e., even under very high shares of renewables. At the same time, however, the reduced number of hours with scarcity and therefore price spikes leads to substantial risks for investments in this *firm* capacity.

Driven by such considerations, so-called capacity remuneration mechanisms (CRMs) have been implemented in several regions of the world as an extension to the energy-only market (EOM), in which capacity providers are solely compensated for the amount of electricity they sell on the markets. In the US, the earliest such mechanisms date back to the late 1990s. In recent years, also several European countries have started implementing different kinds of CRMs (Bublitz et al., 2019). All of these mechanisms typically aim to reduce the risks for new investments by offering capacity providers supplementary income on top of the earnings from selling electricity on the market. The additional generation, storage or demand side management (DSM) capacity may then in turn help to improve generation adequacy, i.e., avoid shortage situations.

Critical voices claim that CRMs are nothing but hidden subsidies to operators of conventional power plants while other alternative capacity providers, such as electricity storage or DSM, barely face any chance of successfully participating in these mechanisms. Formally, the European Commission requires full technology neutrality from any CRM to be implemented in Europe (European Commission, 2013). The situation is similar in the US, where the Federal Energy Regulatory Commission has recently directed grid operators to remove barriers that hinder storage from participating in wholesale energy, capacity and ancillary services markets and to define rules for their efficient remuneration taking into account physical and operational characteristics of such units (Sakti et al., 2018).

However, while most CRMs in Europe and the US generally allow the participation of storage and demand side units, the concrete rules applied differ substantially (Sakti et al., 2018; Usera et al., 2017). This is mostly due to the non-trivial question of whether and how much *firm* capacity such units can contribute to system adequacy. While conventional power plants can provide full power output throughout scarcity periods of whatever length, storage units are not able to do so due to

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# Literature III

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