

Exploring the mechanics of hybrid markets in a context of deep decarbonization

Alexis Lebeau^{1,2}, Marie Petitet^{1,3}, Simon Quemin^{1,4,5}
Marcelo Saguan¹, Yannick Perez², Olivier Massol^{2,6}

¹EDF R&D, France ²LGI, CentraleSupélec, France ³Chaire European Electricity Markets, University Paris-Dauphine, France ⁴Potsdam Institute for Climate Impact Research, Germany ⁵Grantham Research Institute, London School of Economics, United Kingdom ⁶IFPEN, France

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Motivations

- Electricity Market Design has been vividly debated over the past two years in the public and political spheres.
- In the academic literature, some controversies have actually never settled since the beginning of electricity markets.
- The idea that the fully liberalized market model cannot meet the various objectives of the power sector – notably associated with deep decarbonization – has gained momentum.
- Some economists advocate for an evolution towards an **hybrid regime**, that still needs to be defined.



Figure 1: New EMD regulation proposal (11/09/2023)

What are hybrid markets?

Broad definition: *'liberalized markets with state intervention and long-term contracts, combining both short-term market mechanisms and planning and redistribution mechanisms'* (Roques and Burger 2023).

Different “generations” of hybrid markets, for different matters:

- Spontaneous (Correljé and De Vries 2008; Roques and Finon 2017)
 - Seen as an incomplete / disrupted liberalization process.
- “First generation” (Joskow 2022; Keppler et al. 2022)
 - main objective: allow investments at required pace (and reasonable cost) for security of supply and decarbonization in incomplete markets.
- “Second generation” (Fabra 2022; Neuhoff et al. 2023)
 - main objective: maintain affordability, mitigate distributive effects.

Research question

There is no consensus on how the Electricity Market Design should evolve.

Without attempting to be exhaustive, we identify open questions regarding contract design ([Newbery 2023](#); [Billimoria and Simshauser 2023](#); [Favre and Roques 2023](#)), auction design ([Iossa et al. 2022](#); [Fabra and Montero 2023](#)) and planning ([Corneli 2020](#); [Anderson and Zachary 2023](#)).

This paper seeks to gain insights on 'hybrid markets' by:

- Unpacking implementation details, thus going beyond general discussions.
- Understanding the overall mechanics by appreciating how its building blocks interact (physical and financial flows, short- and long-term dynamics)

Approach

To do so, we:

- describe **one possible** hybrid architecture based on recent literature and proposals (NB: we do not claim the superiority of this architecture over others)
- provide some elements of economic analysis on its building blocks
- simulate its functioning on one case study

Design studied in this work *à la* [Joskow 2022](#):

- The preservation of short-term markets for system operations
- A dedicated module to drive long-term decisions, with three attributes:
 - ① A partial return to planning
 - ② Long-term contracts with public counterparty
 - ③ Competitive procurement

- ① Motivations and research question
- ② Market design description and economic analysis
 - Overall architecture
 - Auctions
 - CfDs
- ③ Model
- ④ Case study and results
- ⑤ Policy discussion

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Overall architecture

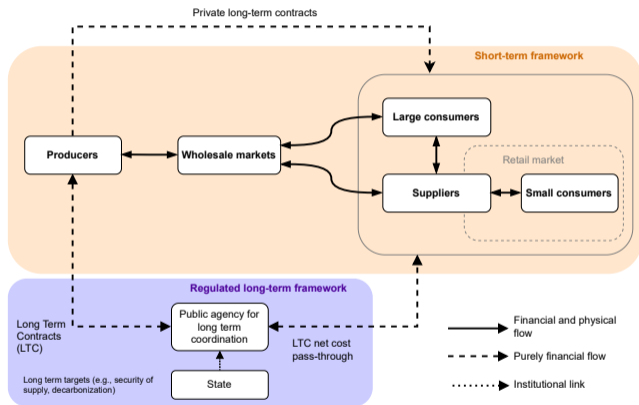


Figure 2: Hybrid market based on centralized procurement of long-term contracts

Simplified architecture in this work

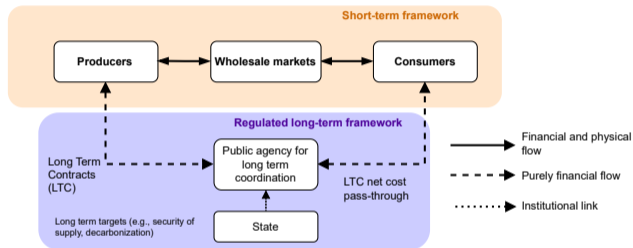


Figure 3: Simplified market design studied in this paper

We do not represent PPAs (Neuhoff et al. 2023; CEPR 2023). We focus on the wholesale market level.

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Auctions

We assume:

- Technology specific auctions
- Investors bid a strike price (given contract specifications). Assuming perfect competition, the strike price P^c verifies $NPV(P^c) = 0$.
- The tender process is implicit
- Auction rules
 - **One step** auction
 - **Pay as clear**
 - No price cap, reserve price or budget constraint.
- Demand curves (i.e. auctioned volumes) are inelastic and determined by a planning exercise (assumed to be perfect here).

CfDs (example for a zero-variable cost technology)

Financial Contract-for-Differences:

$$NPV = - \text{CAPEX} - \text{Fixed O\&M}$$

$$+ \underbrace{\sum_{n=0}^{\Delta_{\text{contract}}-1} \delta^n \left[\underbrace{Q_n^s P_n^s}_{\text{Spot revenues}} + \underbrace{Q_n^c (P^c - P_n^s)}_{\text{CfD payoff}} \right]}_{\text{Contract period}} + \underbrace{\sum_{n=\Delta_{\text{contract}}}^{\Delta_{\text{lifespan}}-1} \delta^n Q_n^s P_n^s}_{\text{Merchant tail}}$$

n is the year index, Δ_{contract} and Δ_{lifespan} are contract duration and project lifespan, CAPEX is the investment cost, Fixed O&M is fixed operating and maintenance cost, δ the discount factor, Q^s and Q^c are sold on the spot market and contracted volumes, P^s is the spot price and P^c the CfD strike price.

Focus on contractual mismatch

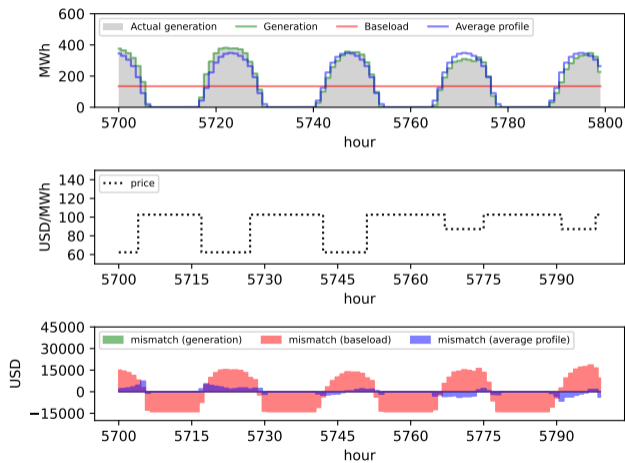


Figure 4: Illustration of contractual mismatch

CfDs (example for a storage technology)

Financial Contract-for-Differences:

$NPV = -\text{CAPEX} - \text{Fixed O\&M}$

$$\begin{aligned}
 & + \underbrace{\sum_{n=0}^{\Delta_{\text{contract}}-1} \delta^n \left[\underbrace{(Q_n^S - Q_n^{\text{charging}})' P_n^S}_{\text{Spot revenues}} + \underbrace{Q_n^C (P^C - P_n^S)}_{\text{CfD payoff}} \right]}_{\text{Contract period}} + \underbrace{\sum_{n=\Delta_{\text{contract}}}^{\Delta_{\text{lifespan}}-1} \delta^n (Q_n^S - Q_n^{\text{charging}})' P_n^S}_{\text{Merchant tail}}
 \end{aligned}$$

n is the year index, Δ_{contract} and Δ_{lifespan} are contract duration and project lifespan, CAPEX is the investment cost, Fixed O&M is fixed operating and maintenance cost, δ the discount factor, Q^S , $Q_{n,h}^{\text{charging}}$ and Q^C are respectively discharged, charged and contracted volumes, P^S is the spot price and P^C the CfD strike price.

NB: other options are possible ([DGEC 2023](#); [Billimoria and Simshauser 2023](#)).

Strike price formation depending on contract design

$$P^c = \frac{\text{CAPEX} + \text{Fixed O\&M}}{\text{Total contracted volume}} + \frac{\text{Contractual mismatch}}{\text{Total contracted volume}} - \frac{\text{Merchant tail}}{\text{Total contracted volume}} \left(+ \frac{\text{Charging cost}}{\text{Total contracted volume}} \right)_{\text{for storage}}$$

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Modeling framework

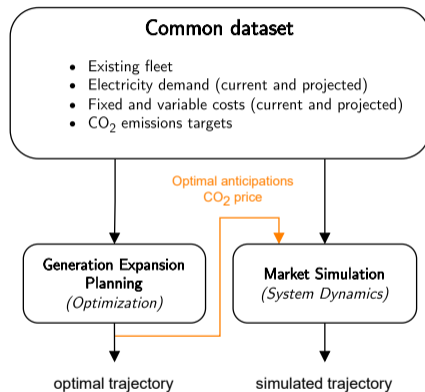


Figure 5: Modeling framework used in this article

Focus on the simulation model for the hybrid market design

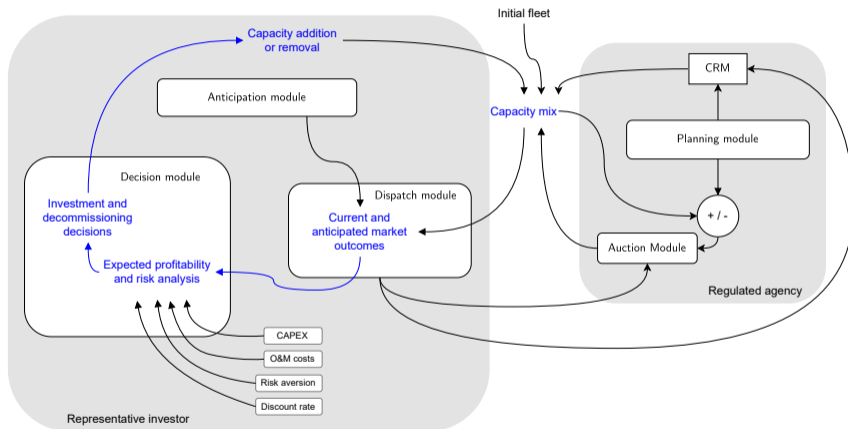


Figure 6: System Dynamics causal diagram

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Stylized California case study (1/2)

Why California? (i) data availability, (ii) relatively simple (small number of candidate technologies, limited cross-border trade) and (iii) typical decarbonization + electrification case study starting with a fossil brownfield fleet.

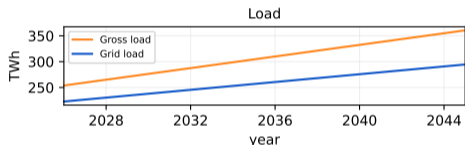


Figure 7: Load assumption (NB: two weather scenarios are modeled)

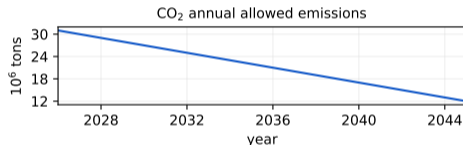


Figure 8: CO₂ annual emissions targets

Data sources

All data adapted by authors from CPUC's RESOLVE (CPUC 2019), NINJA Renewables (Ninja Renewables 2021, Staffell and Pfenninger 2016, Pfenninger and Staffell 2016) and historical data.

Stylized California case study (2/2)

Four technologies endogenously represented (investment or decommissioning decisions).

Technology	Available decision	CAPEX [USD/kW-Yr]	Fixed O&M [USD/kW-Yr]	Fuel Cost [USD/MWh]	Carbon intensity [tCO ₂ /MWh]
CCGT	Decommissioning	117	30	Average: 31 ▶ see app.	0.37
Peaker	Decommissioning	43	20	Average: 51 ▶ see app.	0.61
PV	Investment & decommissioning	72	9	0	0
Storage	Investment & decommissioning	108	13	0	0

- Units have a discrete size of 500 MW.
- The storage technology is assumed to have a 6 hours duration and a 85% round-trip efficiency.
- Common WACC: 8 %
- Price cap on the energy market: 15 USD/kWh
- Other (exogenous) generation: wind, nuclear, CHP, biomass, small hydro, etc.

Results from the GEP model

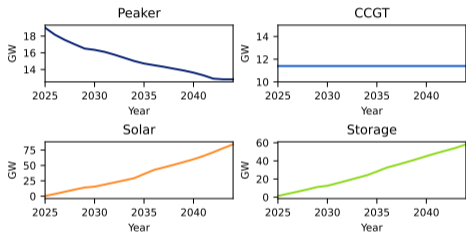


Figure 9: Optimal capacity trajectories from the GEP model

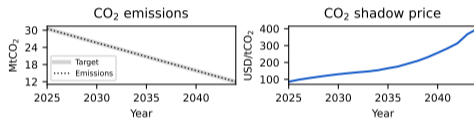


Figure 10: CO₂ shadow price from the GEP model

Simulated cases

	Risk Aversion	Auction module		CRM
		Volume	Duration	
EOM				
EOM	No			
EOM + RA	Yes			
Auctions				
Y_25	No	Yardstick	25	
AP_25	No	Average profile	25	
Y_15	No	Yardstick	15	
Y_15 + RA	Yes	Yardstick	15	
Y_10 + RA	No	Yardstick	10	
Auctions + CRM				
Y_25 + RA + CRM	Yes	Yardstick	25	Yes

Table 1: Simulated cases

Following [Newbery 2018](#) – drawing on [Newbery and Stiglitz 1981](#), we substitute market completeness by the combination of risk neutrality and rational expectations.

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Simulated outcome under EOM design

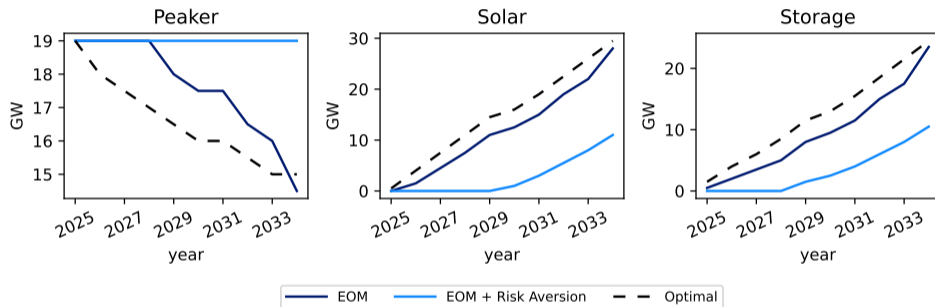


Figure 11: Capacity trajectories with EOM design

- In an almost ideal case (except lumpiness), the EOM yields trajectories close to the optimal ones
- Assuming risk aversion, 'classic' outcome of under-investment for new entrants, and no decommissioning of the fossil fleet.

Impact of different market designs on capacity outcome

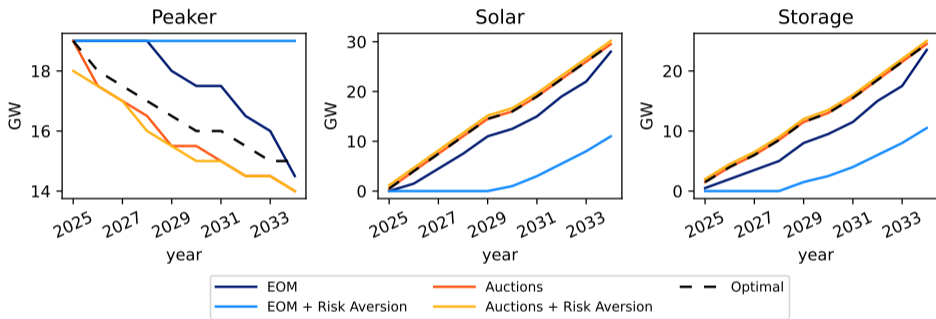


Figure 12: Capacity trajectories with auctions for new entrants

- With auctions for new entrants, capacity trajectories are determined by auctioned volumes (with or without risk aversion)
- The fossil fleet capacity is now below optimal level (lumpiness + risk aversion)

Impact of different market designs on capacity outcome

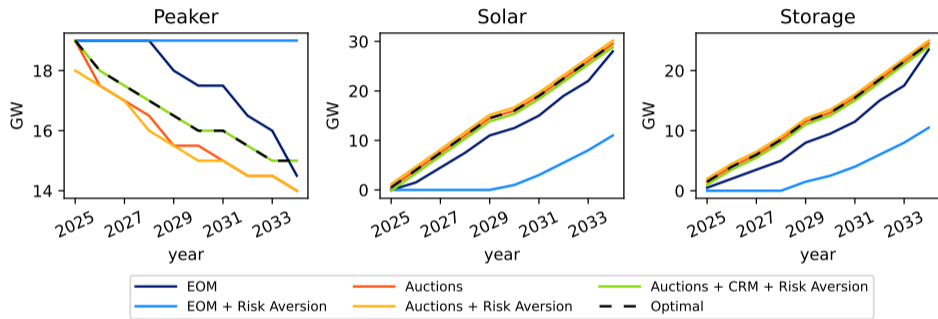


Figure 13: Capacity with auctions for new entrants and CRM

- A CRM (not detailed here) maintains the optimal level of fossil capacity (should it be consistent with the auction module)

Strike price formula (reminder)

$$P^c = \frac{\text{CAPEX} + \text{Fixed O\&M}}{\text{Total contracted volume}} + \frac{\text{Contractual mismatch}}{\text{Total contracted volume}} - \frac{\text{Merchant tail}}{\text{Total contracted volume}} \left(+ \frac{\text{Charging cost}}{\text{Total contracted volume}} \right)_{\text{for storage}}$$

Strike price formation for PV under different contract designs

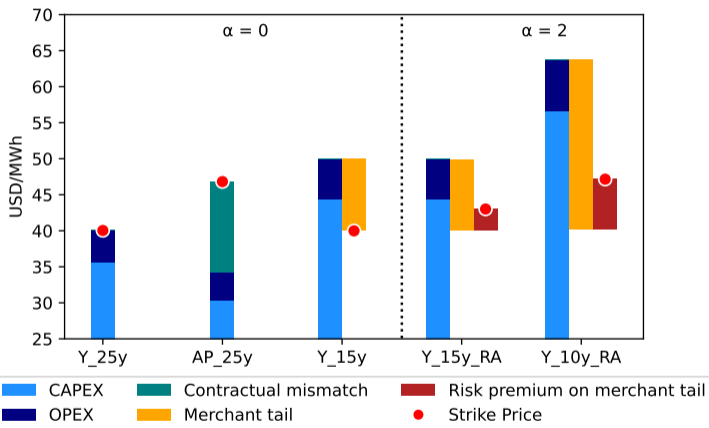


Figure 14: PV strike price formation for different contract designs without and with risk aversion (resp. $\alpha = 0$ and $\alpha = 2$)

Strike price formation for storage under different contract designs

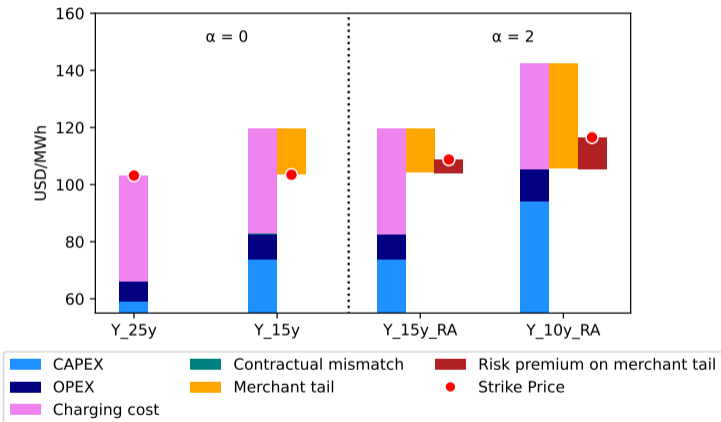


Figure 15: Storage strike price formation for different contract designs without and with risk aversion (resp. $\alpha = 0$ and $\alpha = 2$)

Other findings

- Price stabilization effect between the different weather scenarios (assuming a pass-through mechanism to retail prices)
- Price hedging is not revenue hedging (relevant if capacity outcome differs from what developers expected when bidding strike prices)

Limitations

- contractual mismatch and charging costs are uncertain (and difficult to hedge) → increase the strike price.
- capital structure is exogenous ([Gohdes et al. 2023](#))

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Policy discussion

- In this type of market design, capacity trajectories are determined by long-term regulated mechanisms: auction module (for new entrants) and CRM.
 - The planning process should be transparent.
 - The different modules need to be coherent (e.g. to achieve the different policy objectives, avoid double remuneration)
- The strike price depends on contract design (contracted volume, duration). Leaving (unhedgeable) market exposure increases it (without accounting for cost of capital impacts).

Further work

- Add PPAs
- Interactions LTCs v. carbon price
- Interactions LTCs v. CRM
- Discuss the planning exercise
- Test other contract designs (price formation, incentives)
- Test other datasets

Thank you for your attention !
alexis.lebeau@edf.fr