TOWARDS ZERO-CARBON ELECTRICITY MARKETS: CHALLENGES AND SOLUTIONS FOR RESOURCE ADEQUACY

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U.S. DEPARTMENT OF ENERGY
Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

ESIG Fall Technical Workshop
Minneapolis, MN, Oct. 26, 2022

OUTLINE

- A review of electricity market design options for zero-carbon power systems (w/Zhi Zhou, Todd Levin, Argonne)

- Market equilibrium and cost recovery in zero-carbon systems: analytical insights (w/Guillaume Tarel (Hydro Quebéc), Magnus Korpås (NTNU))

HydroWIRES
U.S. DEPARTMENT OF ENERGY

https://www.anl.gov/esia/price-formation-in-zerocarbon-electricity-markets-the-role-of-hydropower

Price Formation in Zero-Carbon Electricity Markets

The Role of Hydropower

July 2022

Zhi Zhou
Audun Botterud
Todd Levin

ANL-22/31

MIT CEEPR MIT Center for Energy and Environmental Policy Research

Working Paper Series

Long-term Equilibrium in Electricity Markets with Renewables and Energy Storage Only

Guillaume Tarel, Magnus Korpås, and Audun Botterud

SEPTEMBER 2022
CEEPR WP 2022-012

https://ceepr.mit.edu/publications/working-papers/

A REVIEW OF ELECTRICITY MARKET DESIGN OPTIONS FOR ZERO-CARBON POWER SYSTEMS

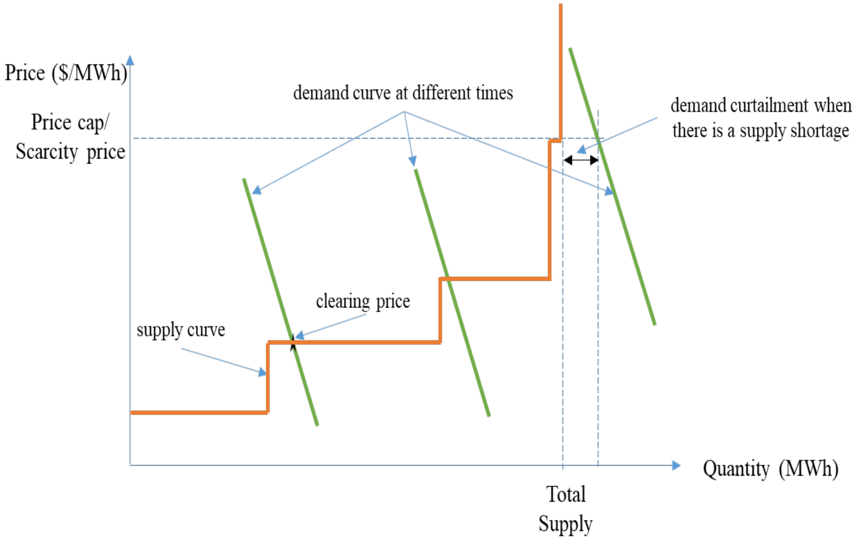
RESOURCES IN ZERO-CARBON ELECTRICITY SYSTEMS

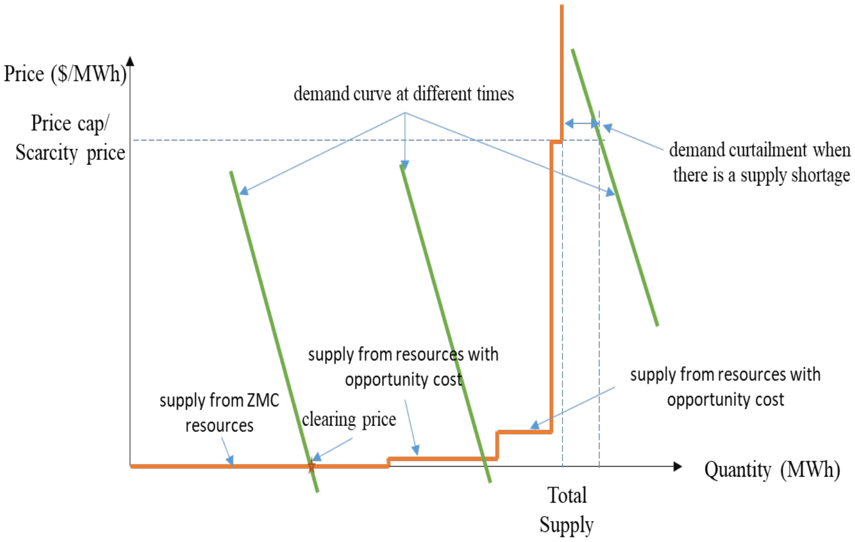
	Zero Fuel Cost	Non-Zero Fuel Cost
Non-Zero Marginal Cost	(Opportunity Cost) Reservoir hydro Pumped storage hydro Batteries Other Storage Demand Response	(Variable Fuel Cost) Bioenergy Hydrogen Gas w/CCS Coal w/CCS
Zero Marginal Cost	(No Opportunity Cost) Wind Solar Run-of-river Hydro Geothermal	(Fixed Fuel Cost) Nuclear

Zhou, Botterud, Levin, ANL-22/31.

- What will planning, operations and market prices look like in a zero-carbon system?

PRICE FORMATION IN CURRENT AND FUTURE MARKETS





Traditional System

Zero Carbon System

CHALLENGES FOR RESOURCE ADEQUACY AND REVENUE SUFFICIENCY

- Can price dynamics from current dispatch logic provide adequate signals for operations, investments, and retirements?
- What reliability criteria do we need in future systems?
  – From capacity to energy constrained systems
- Do we need to rethink mechanisms to ensure reliability?
  – Capacity procurement methods
  – Operating reserve requirements
- What are adequate instruments/mechanisms to hedge against future price uncertainty?

ELECTRICITY MARKET DESIGN OPTIONS (I)

Enhanced Energy Only Markets

Proposed Solution	Goal of solution	Potential challenges	Reference
Scarcity pricing	Improve incentives for flexible resources Mitigate missing money problem	Set appropriate scarcity pricing rules	Leslie et al. (2020), Aaslid et al. (2021)
Price floor	Mitigate over generation and low/negative prices	Could distort price signals and operational incentives	CAISO (2020b), NYISO (2018)
Long-term marginal cost	Incorporate capital cost to ensure revenue adequacy	Negatively impacts operational efficiency of system dispatch	Stevenson et al. (2018), MBIE (2019), Pierpont and Nelson (2017)
Improved representation of opportunity cost	More realistically reflect operational costs	Opportunity cost is hard to estimate, may require an extended dispatch horizon accounting for uncertainty7	Aaslid et al. (2021)

ELECTRICITY MARKET DESIGN OPTIONS (II)

Long-term Contracts or Auctions

Proposed Solution	Goal of solution	Potential challenges	References
Long-term energy market	Reduce investor price risk in short-term market	Forecast energy demand for multiple years into the future	Pierpont and Nelson (2017)
Long-term contract auctions	Reduce generation investors' exposure to electricity market price risk Drive forward prices down to the average costs of the best available technologies	Determine future capacity needs May need centralized planning to determine capacity demand	Wolak (2021), Fabra (2021) Joskow (2021)

ELECTRICITY MARKET DESIGN OPTIONS (III)

Improved Capacity Markets

Proposed Solution	Goal of solution	Potential challenges	References
Enhanced capacity market	Better ensure capacity adequacy, e.g., through: (1) flexible capacity adequacy requirements; and (2) local resource adequacy requirements	Determine future capacity and flexibility needs. Relies on administrative parameters. Limited consumer interaction.	Tierney (2018)
Capacity subscription	Capacity to cover peak demand based on customer preferences. Capacity prices to reflect consumer choice. Implemented through long-term contracts or a market framework.	Need ability to physically curtail individual consumers during scarcity situations. Potential concerns about energy equity.	Doorman (2005), Gui et al. (2020)

ELECTRICITY MARKET DESIGN OPTIONS (III)

Other Solutions

Proposed Solution	Goal of solution	Potential challenges	Reference
Linked swing contract based energy and ancillary service market	Improve market efficiency, enable higher VRE levels, through market products better aligned with the physical needs of the system.	Significant departure from current market designs. Greater responsibilities on resources to reflect their operational characteristics and costs.	Tesfatsion (2020)
Partial return to cost based regulation	Eliminate investor exposure to volatile and depressed short-term prices in zero-carbon systems.	Determine optimal investment pathways through centralized planning. Provide economically efficient signals for new investment.	Joskow (2021)

SOLUTIONS IN U.S. ISO/RTO MARKETS

Current/emerging initiatives include:

- Operating reserve demand curves
- Accommodate state policies and clean energy initiatives (e.g. carbon pricing or clean energy procurement)
- New market products to meet flexibility requirements
- Resource adequacy accreditation

Table 12. Recent market changes and proposed plans related to energy price formation

ISO/RTO	Recent and Proposed Market Changes
PJM	PJM currently has a form of alternative pricing narrowly applied to resources and has proposed updates to its pricing methodology in accordance with a FERC order (Giacomoni 2018). Recent filings focused on ancillary service pricing, including an ORDC with changes to the level of shortage pricing for each of its reserve products. PJM has also been evaluating several carbon-pricing leakage mitigation mechanisms in its region.
NYISO	Because of the large number of gas turbines in its system, NYISO has long used a hybrid-pricing methodology that includes a physical and economic pass that relaxes minimum operating limits to allow start-up costs of block-loaded units to be reflected in energy prices. Following FERC orders, NYISO extended this pricing methodology to all fast-start units, starting in December 2020. NYISO also has issued a proposal to include additional carbon pricing in its region.
ISO-NE	ISO-NE has implemented alternative modeling for fast-start resources and is currently evaluating opportunity cost-adders and multi-day energy markets with strike prices and options because of long-term energy security issues.
MISO	MISO was early to implement alternative pricing for fast-start units and continues to make improvements to the calculation method behind its ELMP formulation (MISO 2019c).
SPP	SPP had no alternative pricing and has recently proposed new methods because of a FERC order that creates a separate pricing run and sets fast-start eligibility requirements.
CAISO	Although CAISO offers a COG resource category with associated pricing, no resources have opted to use this voluntary categorization.
ERCOT	ERCOT was not affected by the FERC ruling, and has implemented different adjustments over time. The operator offers fast-start resources the ability to set prices based on the inclusion of commitment costs.

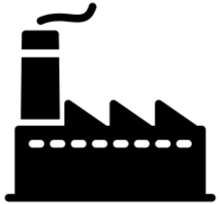
KEY FINDINGS

- Market prices will not necessarily drop to zero for extended periods due to opportunity costs and scarcity pricing mechanisms
- Many studies suggest market enhancements to current practices, e.g. with
  - Long-term energy procurement (contracts, markets, auctions)
  - Adjustments to long-term capacity compensation mechanisms
- Flexible resources (e.g. hydro) likely to play a critical role in zero-carbon systems
  - Support system flexibility, storage requirements, price formation
  - May take advantage of new price dynamics
  - Increasing importance of opportunity costs and demand response
- Interactions between resource adequacy mechanisms and low-carbon incentives
- Few quantitative studies of electricity market design in zero-carbon systems

MARKET EQUILIBRIUM AND COST RECOVERY IN ZERO-CARBON SYSTEMS: ANALYTICAL INSIGHTS

Marginal cost pricing and market equilibrium: Simple case with thermal generators

High fixed costs F_b
Low variable costs v_b



Low fixed costs F_p
High variable costs v_p

Load shedding
(value of lost load VOLL)

- Central planner problem
- Minimization of fixed (F_i) and variable (v_j) costs

$$\min_{x_i, q_k(t), q_{e-}(t)} C = \sum_i F_i x_i + \sum_j v_j \int_0^T q_j(t)\, dt$$

Marginal cost pricing and market equilibrium: Simple case with thermal generators

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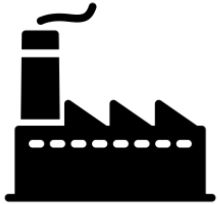

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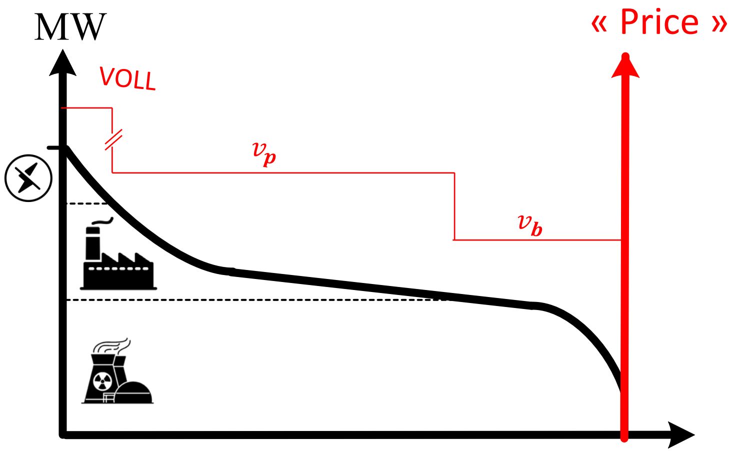
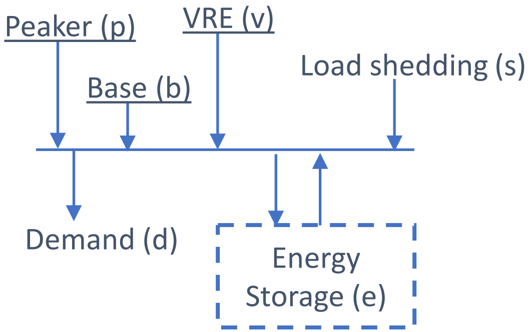


- At optimality for the system (e.g. Green 2000, Stoft 2002)
  - Energy must be priced at the marginal cost
  - Except during shedding: then it must be VOLL
  - All individual generators are able to recover their cost (« zero » profit)
- Valid under perfect market conditions, including no barriers to exit and entry
- **No fixed costs in resulting market prices**

Marginal cost pricing and market equilibrium: Keeping thermal generators, adding VRE and storage

- an optimal solution with prices based on variable costs, ***and energy storage efficiency***, still exists under certain conditions
    - fossil generators are still present
    - renewables can be curtailed
    - no subsidie
    - simplified energy storage model
- **No fixed costs in resulting market prices**



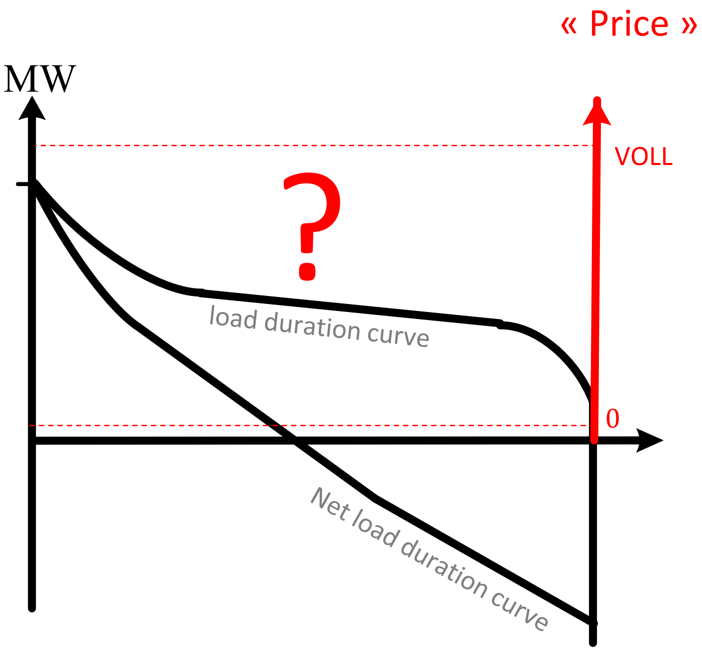
M. Korpås, A. Botterud. *Optimality Conditions and Cost Recovery in Electricity Markets with Variable Renewable Energy and Energy Storage*, MIT CEEPR Working Paper 2020-005, March 2020.

What happens with no thermal generators ?

Relatively low fixed costs
No variable costs

Relatively high fixed costs
No variable costs

Load shedding
(value of lost load VOLL)



- case with storage expensive compared to wind generation (in $/MW)
- If energy is priced using variable costs, will it will be 0 all the time ? VOLL all the time ? A combination of both ?

Renewables and energy storage only: Mathematical problem

$$\min_{x_e, x_v, q_k(t)} C = F_e x_e + F_v x_v + v_s \int_0^T q_s(t)\,dt,\ k \in \{s, v, e, e-\}$$

s.t. $$q_d(t) - q_v(t) - q_e(t) + q_{e-}(t) - q_s(t) = 0$$

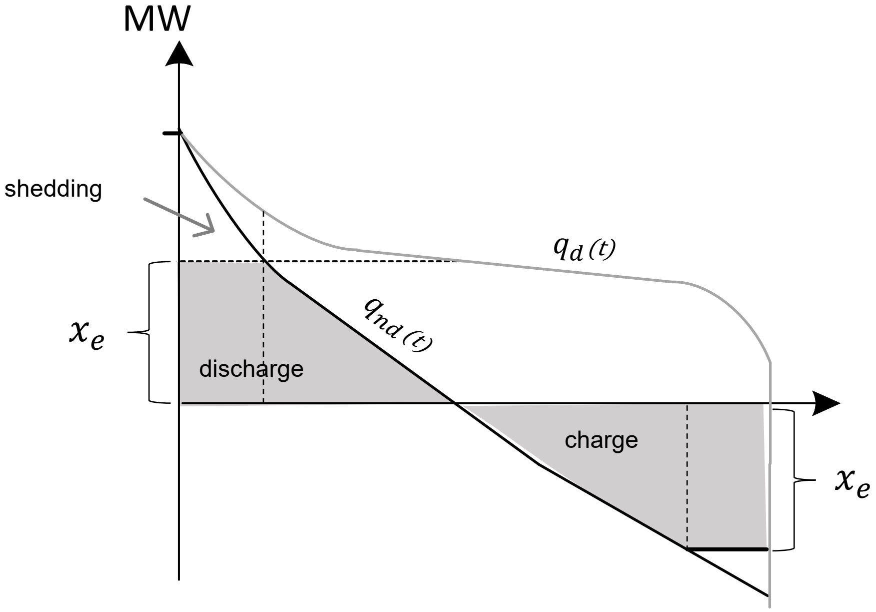
$$-q_k(t) \leq 0\ ,\ k \in \{s, v, e, e-\}$$

$$q_e(t) - x_e \leq 0\,, \qquad q_{e-}(t) - x_e \leq 0$$

$$q_v(t) - AF_v(t)x_v \leq 0$$

$$\frac{dE_e(t)}{dt} = \eta_e \cdot q_{e-}(t) - \frac{q_{e+}(t)}{\eta_{e+}}$$

$$\eta_e \int_0^T q_{e-}(t)dt - \int_0^T q_e(t)dt = 0$$



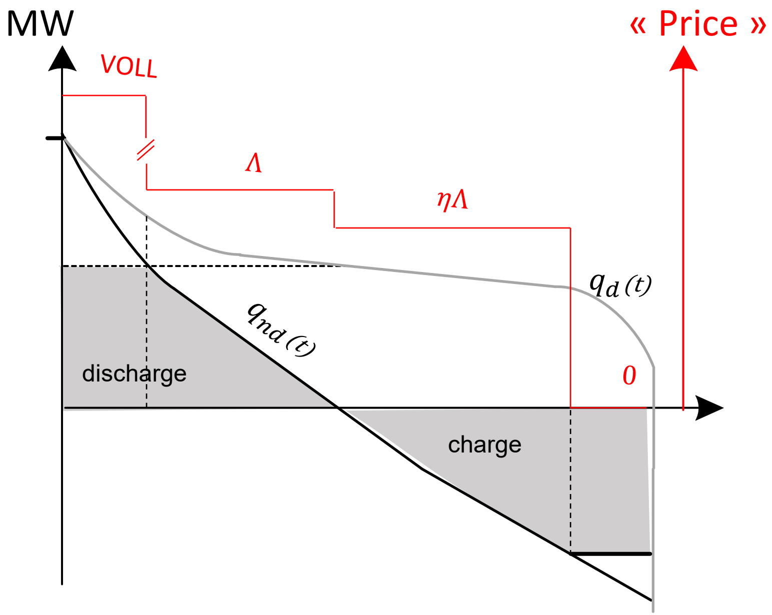
Renewables and energy storage only: Equilibrium results

- We find a mathematically acceptable solution: cost recovery, minimized cost
- It is an equilibrium, with « prices » during charge and discharge periods based on parameter Λ

$$\frac{F_v}{t_e AF_v^{[0,t_e]} + \eta_e(t_v - t_e)AF_v^{[t_v,t_e]}} = \Lambda = \frac{F_e}{\eta_e(T - t_v)}$$

VRE condition — Storage condition

- **Time-dependent « prices » that depend on fixed costs**, F_v, F_e



CONCLUSIONS

CONCLUDING REMARKS

- Electricity market design for resource adequacy
  – Evolution or revolution?
  – Multiple options proposed in literature
  – Majority are enhancements to current market designs
  – Opportunity costs increasingly important

- Market equilibrium with renewables and storage only
  – Equilibrium prices directly reflect investment costs
  – Operations and investments cannot be separated
  – Allow offers to reflect investment costs?

- What happens to market power monitoring?

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- Z. Zhou, A. Botterud, T. Levin, “Price Formation in Zero-Carbon Electricity Markets: The Role of Hydropower,” Report ANL 22/31, July 2022.
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ACKNOWLEDGEMENTS

- DOE Water Power Technologies Office (WPTO)
- Hydro Quebéc

THANKS!

OPEN RESEARCH QUESTIONS

- To what extent can energy-only markets ensure market efficiency, resource adequacy and provide incentives for new investment in a zero-carbon system?
- What is the role of a long-term energy market or capacity remuneration mechanism in contributing to resource adequacy and cost recovery?
- How can remuneration mechanisms for resource adequacy best be designed in a future system, which may be more constrained by energy than capacity?
- How can effective market power mitigation strategies be implemented for resources whose optimal operational strategy depends on its opportunity costs?
- How can opportunity costs for flexible resources be calculated in systems that lack conventional thermal resources with a well-defined marginal cost of generation?

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