

Market Design for Future Systems With a High Share of Renewable Energy: **Fitness** or **Witless** for Purpose?

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Question:



Is the “standard” power market design “fit for purpose” today?...

...Given:

- **Rapid technology change?**
From dispatchable fossil resources to....
 - Zero (or less!) cost variable renewable energy (VRE)
 - Battery storage linking markets over time
 - Demand response, distributed resources
- **And ambitious decarbonization goals (IPCC 2022)?**



Future Power Markets Forum powermarkets.org

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Center on Global Energy Policy

**Which market design
issues are crucial to
discuss for the
transition?**

62 members reviewed the topics of the first 25 forums, and identified up to three that are worth updating or need new perspectives

- 19: RA; capacity/energy adequacy; adequacy criteria
- 11: Transmission policy & planning
- 8: Long-term procurement
- 7: DR and DERs
- 6: A/S & energy spot markets

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Outline

- I. Intro to power markets**
- II. Is the basic LMP framework still fit for purpose?**
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- IV. Some alternatives for future designs**
- V. Need sound transmission & carbon policy**

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I. Introduction: Markets for Power

➤ Why? Inefficiencies in:

- investment
- operations
- pricing

➤ Some Key Developments

- 1978 PURPA (US), Margaret Thatcher (UK)
- Fred Schweppe
- → Over half of US unbundled/deregulated
 - Then California Crisis!
 - Since then, incremental market reforms

Power systems '2000': hierarchical control strategies

Multilevel controls and home minis will enable utilities to buy and sell power at 'real time' rates determined by supply and demand



Thanks to Ignacio Perez-Arriaga

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How Principles Have Been Applied in US Markets: "Standard Market Design+" (SMD+)

➤ Short-run spot markets:

- Supply offers reflect internal costs & constraints
- Co-optimize energy, reserves, & transmission use
- 2+ settlements
- Energy settled at locational marginal prices (LMPs)

➤ Long-run investment:

- Capacity markets
- Renewable portfolio standards/tax credits
- Regional transmission planning



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Schweppe's Vision

- Theoretical efficiency results (given just a few assumptions...) (Bohn et al., 1986):

1. Solution to OPF = Solution to competitive market

Efficient dispatch...

...and long run investment!



2. Thus: LMPs “support” the optimal solution

Pay LMPs energy & reserves

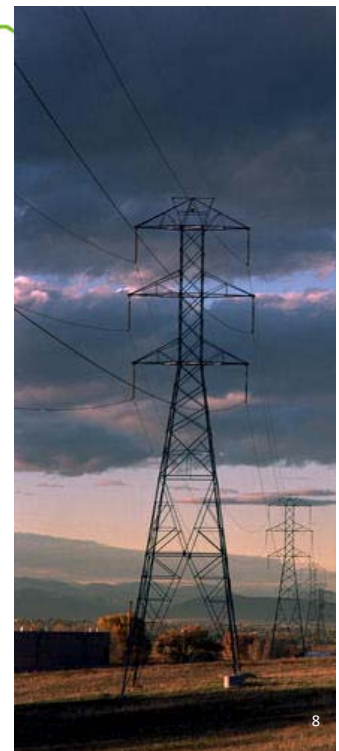
....Then the system-optimal schedule for each resource also maximizes their profit

... And revenue is adequate to cover capital costs

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Assumptions

- Market power mitigated
- No distortions in prices (from price caps, price averaging over time, ...)
- Perfect information
- Convex costs & constraint sets
- Solutions computable



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II. Today's LMP-Based Spot Market Design: *Fit for Purpose?*



<http://damanino.com/5-signs-of-a-poorly-made-suit/>

- Adequately incent **decarbonization**?
- Reward **flexibility** to back up VREs?
 - Now: Volatility suppressed by long settlement intervals & lack of uncertainty in market models (Lund et al. 2015)
- Engage **demand side**; consistent incentives for DER v. grid-scale **siting**?
- Right **horizons** for storage?
 - Now: Truncated horizons

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II.1 Where's the active demand-side?

- US Power Markets still (mainly) half a market
 - “Dumb meters/grid” (average cost pricing, uninformed consumers)
 - Despite \$5B in smart meter investment
 - Just 3% of US residential customers on time-varying rates
 - (Hledik et al. 2017). E.g., California:
 - Retail TOU rates are, e.g., 17-30 \$/MWh
 - Wholesale prices can be -300 to +2000 (or more) \$/MWh
 - High volumetric rates skew solar investment to high-cost residential installations



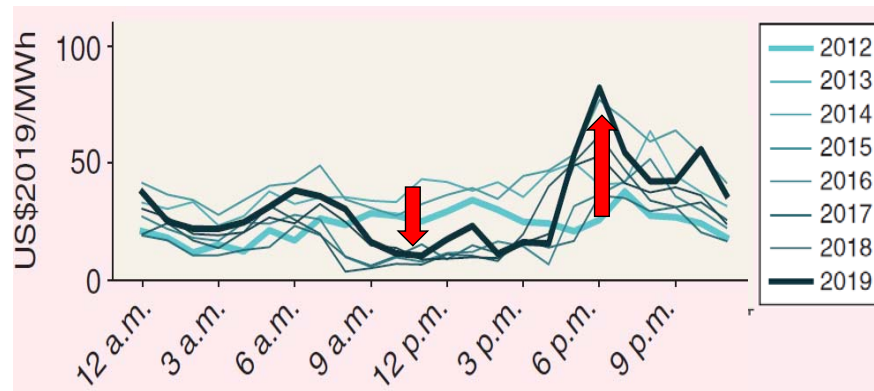
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II.2 How will High VRE Penetration affect LMPs?

(Ela et al. 2021; Mills et al. 2020; OECD, Nuclear Energy Agency 2019)

➤ Will spot prices be “bipolar”?

CAISO Energy Prices: Spring



- Will instability discourage investment?
- Will back-up flexible power sources revenue-inadequate?

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How will High VRE Penetration affect LMPs?

➤ **The Reality:** price distributions will change by 2040-2050, but prices will often be at intermediate levels. Why?

- **Backup power running costs:** Fuel costs (bioenergy, CCS-fossil) will often set prices (Sepulveda et al., 2020)
- **Sectoral coupling (“Power to X”):** methanation, Fischer-Tropsch, H₂ could drop long-run VRE curtailment from ~33% to ~5% (Evolved Energy, 2021)
- **Scarcity:**
 - “Operating reserve demand curves” goose prices gradually when capacity short (Frew et al., 2021; Mehrtani et al. 2022)
 - Realizing Schweppe’s dream: demand response *at all times* – EVs, building thermal storage etc. (Cruz et al. 2018)
- **Storage:**
 - Correct storage degradation models will smooth price variations due to cost of deep drawdowns (Padmanabhan et al. 2019, Zheng et al. 2022)
 - Opportunity costs rise smoothly, accounting for uncertain scarcity (E.g., Ontario Hydro; Ela et al. 2021)

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VREs & storage don’t change Schweppe’s basic conclusion: In theory, LMPs can support optimal operations & investment

Extending classic analyses (Bohn et al. 1986, Stoft 2002), Korpas & Botterud (2020) consider optimal investment & dispatch of VREs & storage, as well as thermal capacity, given varying load:

- **In markets with scarcity pricing/no price caps:** LMPs enable all capacity, including VREs & storage, to:
 - recover all costs
 - be optimally sized & operated
- **Other show that social goals can be efficiently accommodated, if policy constraints priced** (Baldick, Bushnell, Hobbs, Wolak, 2011)

⇒ “Think twice before embarking on complete re-design of electricity markets”

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III. Today's Capacity Market-Based Designs: *Fit for Purpose?*



NEW OR ASSUMED AWAY CHALLENGES:

1. **New technologies:** How to handle correlated outputs of variable renewables / storage?
2. **Extreme events/profound uncertainty?**
3. **Missing demand-side, and retail/wholesale divide:** How to engage demand side & avoid skewed investment?

<http://damanino.com/5-signs-of-a-poorly-made-suit/>

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Making Tomorrow's Capacity Markets *Fit for Purpose*



1. **New technologies:** How to handle correlated loads and outputs of variable renewables / storage

➤ *Approach:* rigorous capacity credits ("effective load carrying capability"), with strengthened scarcity pricing in spot markets

2. **Extreme events/profound uncertainty?**

➤ NERC/Federal/State Regulatory standards, with nondistortionary cost recovery

3. **Missing demand-side; retail/wholesale divide:**

➤ *Approaches:* Include dynamic marginal component in retail rates; careful evaluation of demand-based capacity programs

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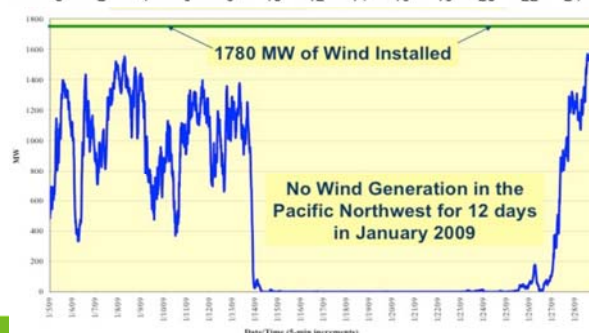
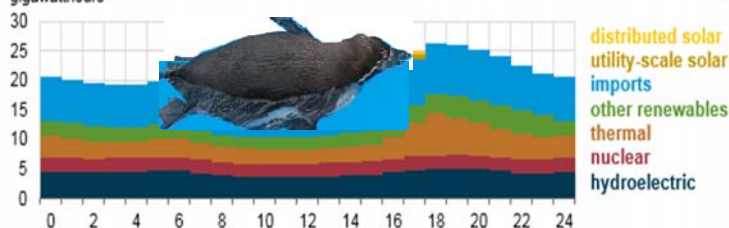


III.1 New and Highly Correlated Resources

► Complications from renewable correlations

- CAISO Duck (?) curve
- Long tails of distribution (*dunkelflaute*)
- Other issues as renewables grow:
 - Timing of system stress shifts & is less predictable
 - Marginal contribution of renewable capacity declines

California Independent System Operator net generation, March 11, 2017
gigawatt-hours



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Equivalent Firm Capacity Method (EFC)

(S. Wang, B. Hobbs, et al. *IEEE TPWRS*, 2022)

THEORY: For a system with correlated variable renewables, storage, and dispatchable gen:

- IF RA market pays accurate marginal capacity credit for all resources, and the reserve margin is adjusted appropriately to reflect the value of lost load,
- THEN a capacity market can duplicate the efficiency of the ideal Schweppe/LMP spot market solution

PROCEDURE

- **Step 1:** Define the target unserved energy and a starting point CAP^0 (close likely optimum)
- **Step 2:** Use finite differences in a dispatch model to evaluate $\partial UE / \partial cap_i$ and the resulting $EFC_i = (\partial UE / \partial cap_i) / (\partial UE / \partial EFC)$, and the implied target equivalent capacity $\sum_i cap_i^0 * EFC_i$
- **Step 3:** Implement resulting capacity credit market $\rightarrow$ Prices support optimal investment
- **Step 4:** iterate if necessary

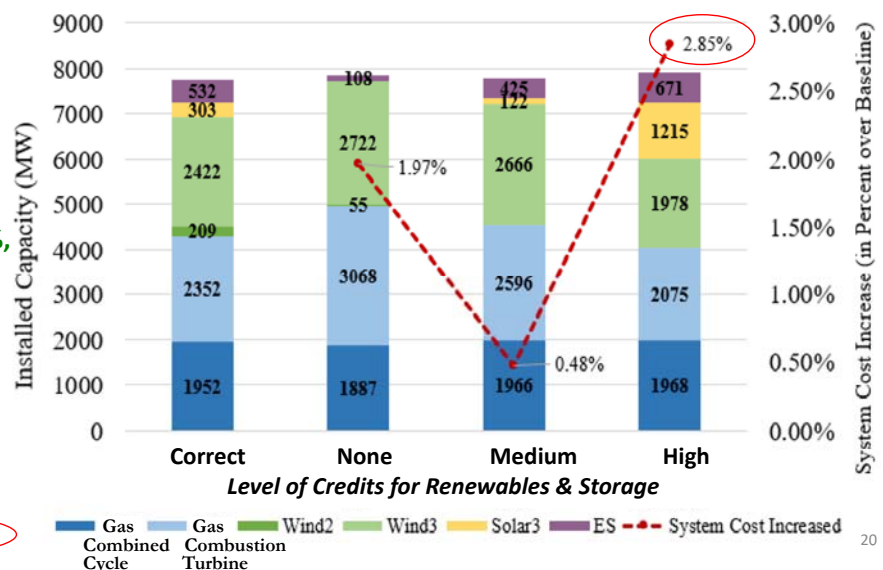
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What if we get capacity credits wrong?

► **Distortions in Texas-like system with different credits under 40% renewable penetration (portfolio standard), \$1K/MWh price cap, and \$10K/MWh VOLL:**

- Correct (Wind2 22%, Wind3 1.5%, Solar3 48%, Storage 82%)
- None (No capacity constraint; energy- only market)
- Medium (Wind 15%, Solar 40%, Storage 60%)
- High (Wind 25%, Solar 100%, Storage 100%)

\$360M/y loss in worst case



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II.2 Common mode failures & extreme events

... In theory can be included in capacity markets if with known probabilities and a credible model... but many involve profound uncertainty

Operational Fuel-Security Analysis



For Discussion

JANUARY 17, 2018
ISO-NE PUBLIC



Resource Retirements



LNG Availability



Oil Tank Inventories

i
id



Imported Electricity



Renewable Resources

➔ Energy shortfalls due to inadequate fuel would occur with almost every fuel-mix scenario in winter 2024/2025, requiring frequent use of **emergency actions** to keep power flowing and protect the grid. Emergency actions that would be visible to the public range from requests for energy conservation to load shedding (rolling blackouts affecting blocks of customers).

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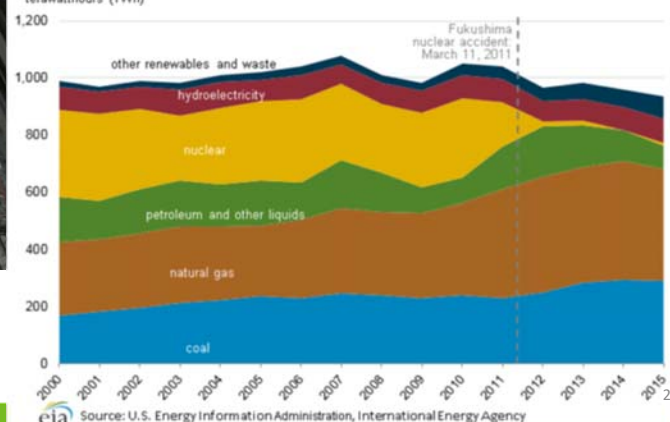
Extreme events/profound uncertainties



www.carbonbrief.org/analysis-the-legacy-of-the-fukushima-nuclear-disaster

Fukushima:
17% of Japan's
capacity lost

Figure 7. Japan's net electricity generation by fuel, 2000-2015
terawatt-hours (TWh)



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Correlations Among Different Stressors

"When sorrows come, they come not single spies. But in battalions."

King Claudius, *Hamlet* (Thx to Roger Cooke et al.)

► Ten Plagues of Egypt: *California 2000-01*

- Fuel (gas compressor station outage)
- Hydro shortage
- NO_x allowance shortages
- Kelp

► Interdependent infrastructure: Texas 2021: Gas-electricity interdependency, compounded by inability to efficiently ration

► *In theory* model-able



www.powermag.com/prepare-your-gas-plant-for-cold-weather-operations/

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Role of Markets for Managing Extreme Risks

For extreme events:

- Probability estimates are unreliable
- Insurance is unlikely to be available or very expensive

...three particular phenomena of climate related risks that will require a change in our thinking about risk management: global micro-correlations, fat tails, and tail dependence. (Their) consideration ...will be particularly important for natural disaster insurance, as they call into question traditional methods of securitization and diversification (Kousky & Cooke, RFF-DP-09-03-REV.pdf, 2009)

Public good of network reliability → central planning, FERC/NERC rules, ...

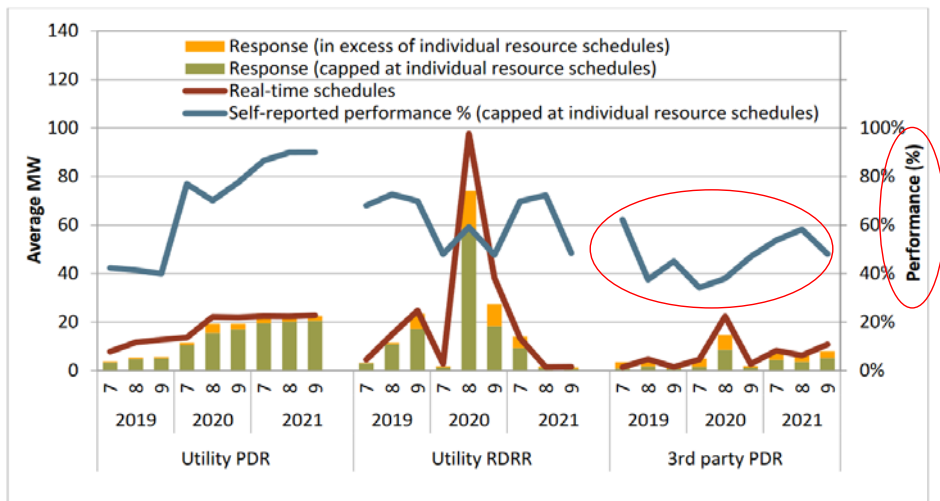
(Quasi) market roles:

- Bidding to provide equipment, services
- Performance-based ratemaking for infrastructure owners

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III.3 Uncertain and so-far disappointing performance of demand-response programs in capacity markets

Demand response resource adequacy performance - July to September (4-9 p.m.)



Source: CAISO Dept. Market Monitoring Annual Report for 2021

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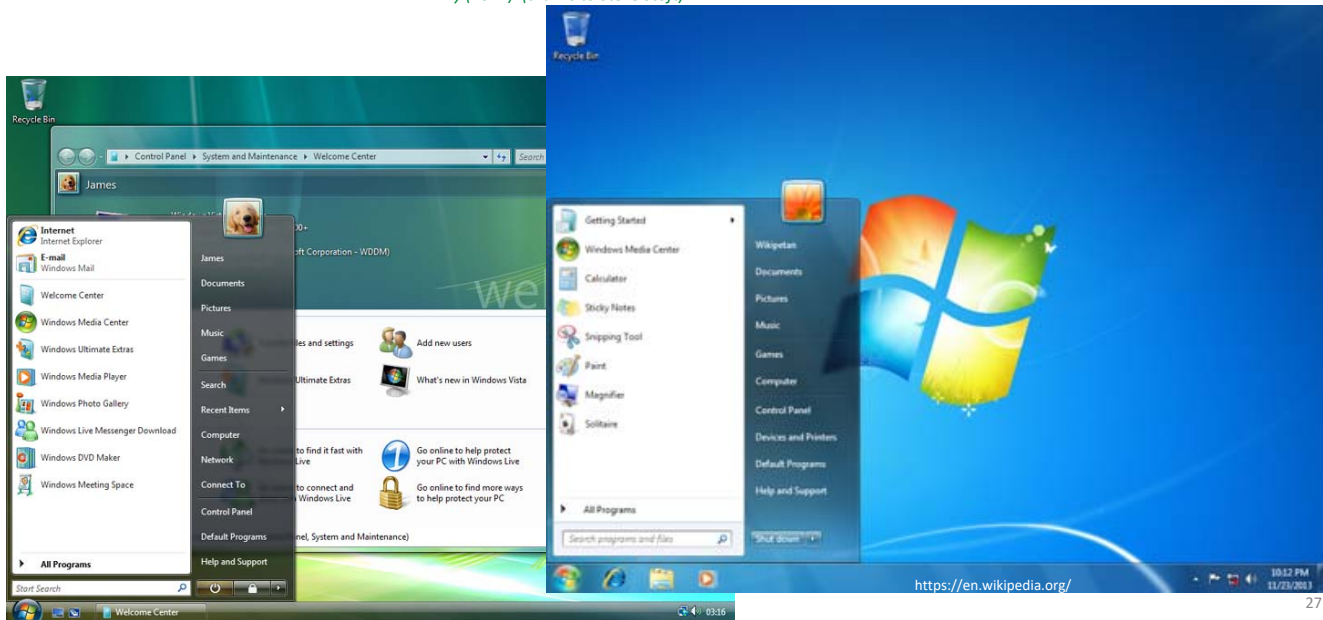
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III. When ought you kludge ... and when start from scratch?

Ely (2011) (thanks to Steve Stoft)



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Some Possible Long-Run Market Design Strategies



1. *Incrementalism* (ISOs)

- Easiest
- But danger of kludges

2. *"A la EU"*: Increase # settlements & time horizon, but omit details on internal resource constraints (e.g., Matt White ISO-NE)

- Better reflects updated forecasts
- Gives up on verifying costs, nixing US-style market power mitigation



3. *Capacity-based retail contracts* (ZOMEHOME; Lo et al. 2019)

- Consumers like; fits zero short-run cost world
- But spot prices actually will be significant

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Alternative Long-Run Design Strategies

4. *Investment auctions*: Decades-ahead resource & transmission auctions, with clean energy constraint (Ela et al. 2021; Corneli 2020; Gimon 2020)

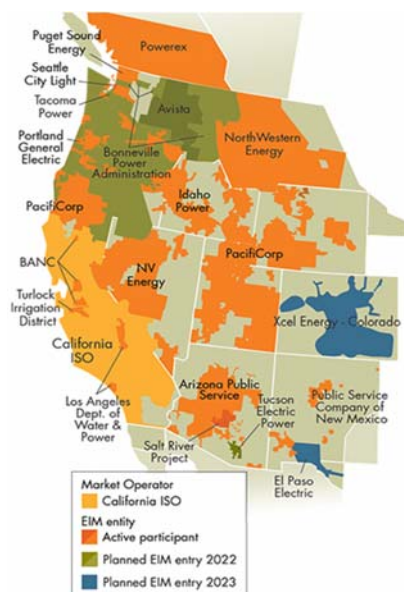
- Long contracts might better incent investment
- But:
 - unclear alignment with spot markets;
 - counter-party risks;
 - relies on uber-IRP models

5. *Clean Energy forward procurement* (Spees et al. 2021)

- Add *clean* energy auction, complementing energy & capacity:
 - Oblige load-serving entities to buy
- Similar to “emissions cap-and-trade”, but more complex (Hobbs, Bushnell, Wolak, 2010)

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Examples of California ISO's Incremental Design Changes



➤ “Energy Imbalance market” (westerneim.com)

- Day-Ahead “EDAM” next

➤ Capacity market reforms (CAISO, CEC, CPUC 2021)

➤ Resource internal constraints

- “State-of-charge” models
stakeholdercenter.caiso.com/StakeholderInitiatives/Energy-storage-and-distributed-energy-resources

➤ New reliability services/products

- Network-constrained “ramp product”
stakeholdercenter.caiso.com/StakeholderInitiatives/Flexible-ramping-product-refinements

➤ Aggressive renewable targets



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V. Non-market Planning & Policy Need Reform, Too!



Because transmission, storage, DR, and supply can be interchangeable, grid reinforcements should be planned recognizing:

- How transmission availability & pricing affect incentives for investment in resources: “*Proactive planning*” (Sauma & Oren, 2006)

Lau & Hobbs (2021)

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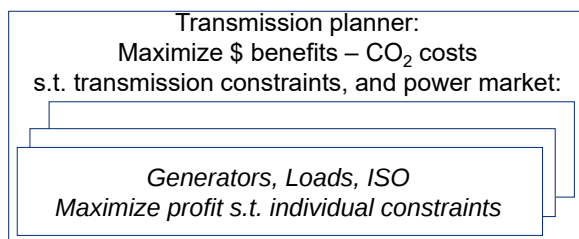
Can transmission planning facilitate C reductions?

Given uncoordinated state C policies in West, can weighing CO₂ emissions in WECC transmission planning yield different plans & lower CO₂? (Yinong Sun, Ph.D.)

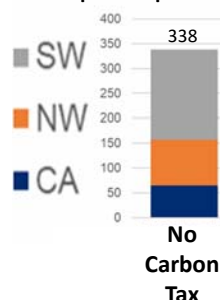
Dissertation, JHU, in process)

Multilevel "second-best" model: choose transmission additions to MIN annualized WECC-wide costs + weighted CO₂ emissions in 2034, subject to market response ("co-optimization")

- Assume: \$40/ton social cost of CO₂



Example Comparison (Preliminary): System-wide CO₂ emissions (Mton)



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Designing effective policy: WECC Example



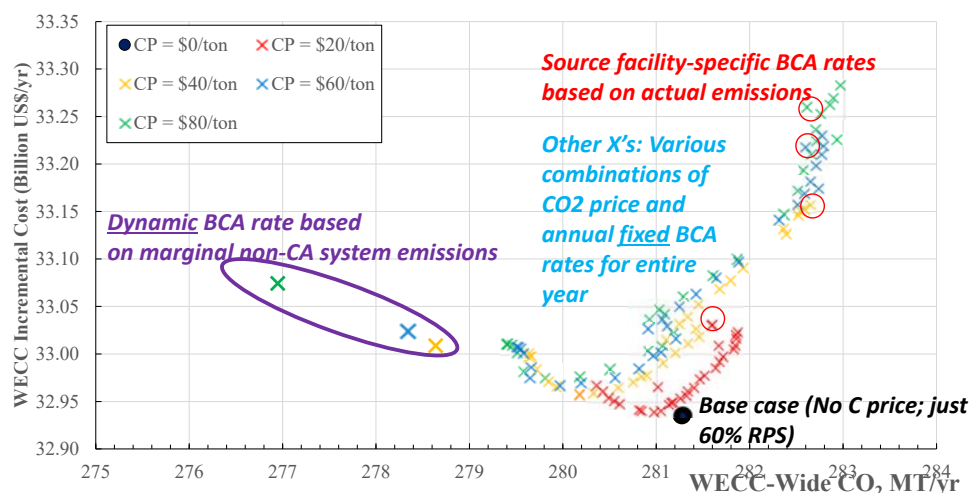
Border Carbon Adjustments (BCA): Can a state increase its C policy impact by penalizing "dirty" imports?

Year 2034: WECC-wide CO₂ emissions & incremental power cost, under a Calif. 60% Renewable Portfolio Standard, and various:

- Calif. CO₂ prices
- BCA policies for CAISO Extended DA Market

Lesson:

- Only dynamic BCAs (based on marginal non-Calif CO₂) reduce emissions



Q. Xu, B. Hobbs, 2021

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Conclusions

- **The SMD+ principles are still fit: New technologies don't fundamentally challenge LMP & RA theory**
 - Although new implementation challenges join the old ones
 - Incremental approach of CAISO justified
 - RA can be adapted to VER & storage resources availability; managing extreme events require regulatory involvement
- **Clean energy auctions: easiest way to inject carbon targets in long- & short-run markets**
 - Can't afford to be wasteful!
- **Market designs need to be complemented with effective & cost-efficient:**
 - Infrastructure planning
 - Carbon policy

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