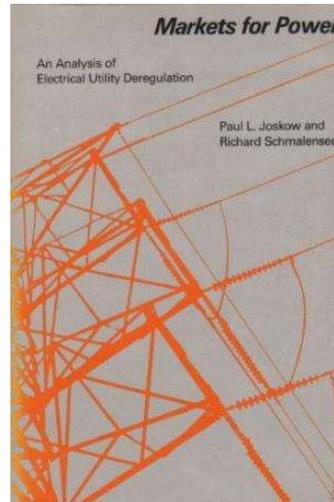ELECTRICITY MARKETS

FIRST AND SECOND-BEST PRICING AND HEDGING

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ELECTRICITY MARKET
Electricity Restructuring

The evolution of electricity restructuring contains a thread of issues related to counterintuitive market design requirements requiring coordination for competition.
MIT led the way.

Markets for Power, 1983.

Joskow and Schmalensee. Addressed the possibility and problems of introducing competition and markets in the power sector. (Joskow and Schmalensee, 1983)
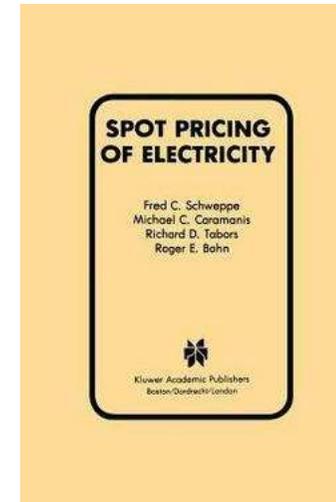
Spot Pricing of Electricity

Kluwer. Using prices to direct the dispatch. (Schweppe et al., 1988)

"The practice of ignoring the critical functions played by the transmission system in many discussions of deregulation almost certainly leads to incorrect conclusions about the optimal structure of an electric power system." (p.63)

Energy Reform Challenges

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A core challenge for all electricity systems is between monopoly provision and market operations. Electricity market design depends on critical choices. There is no escape from the fundamentals.

INTEGRATED MON

- Mandated
- Closed Access
- Discrimination
- Central Planning
- Few Choices
- Spending Other People's Money
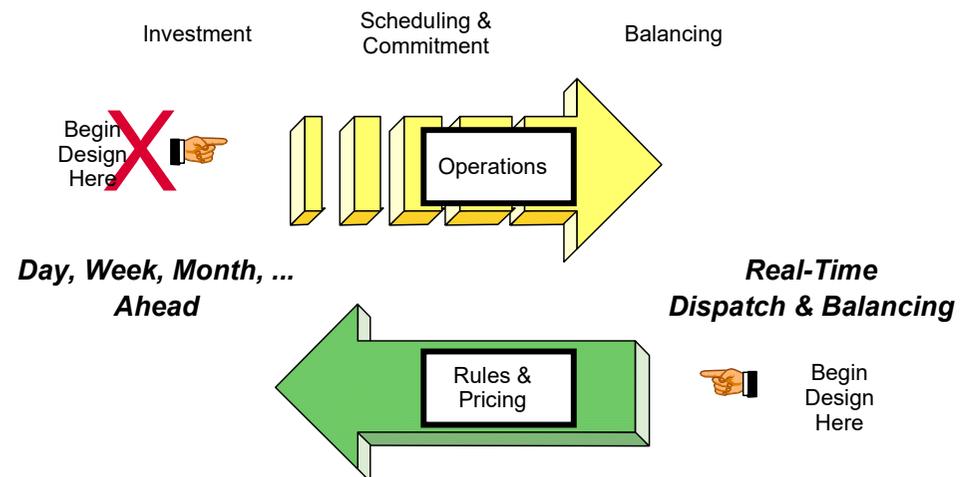- Average Cost Pricing

COMPETITIVE MARKETS

- Voluntary
- Open Access
- Non-discrimination
- Independent Investment
- Many Choices
- Spending Your Own Money
- Marginal Cost Pricing

A Key Market Design Objective

Supporting the Solution: Given the prices and settlement payments, individual optimal behavior is consistent with the aggregate optimal solution.

Focus on Balancing Markets First

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## False Starts for the Electricity Market

The solution to open access and non-discrimination inherently involves market design. Good design begins with the real-time market and works backward. A common failure mode starts with the forward market, without specifying the rules and prices that would apply in real time.

Investment

Scheduling & Commitment

Balancing

Begin Design Here

Operations

Day, Week, Month, ... Ahead

Real-Time Dispatch & Balancing

Rules & Pricing

Begin Design Here

Market expectations determine incentives. Start at the end. Work backward, not forward, in setting market design.

Optimization and Efficient Pricing

**The economic paradigm for efficient markets coincides with the principles of economic dispatch. Efficient prices support the solution.
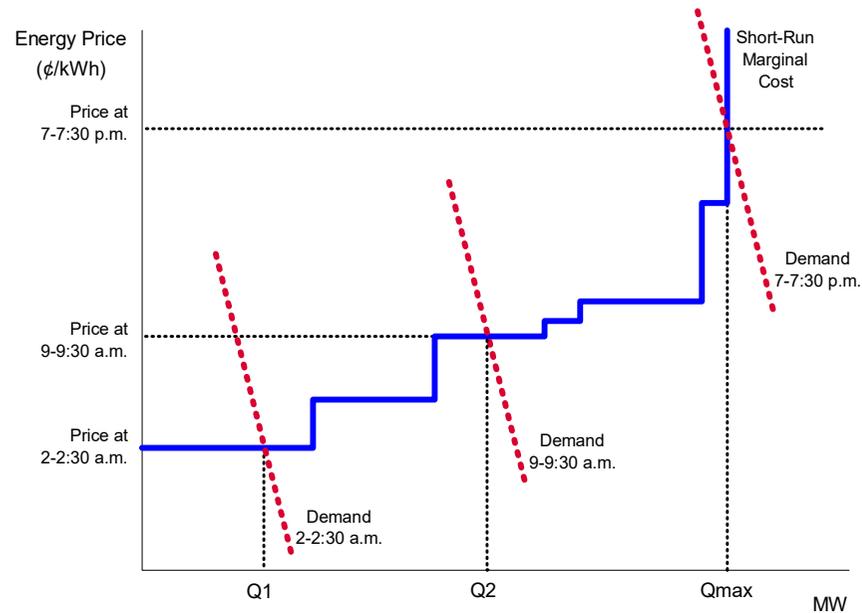This underlying framework guides practical implementation.**

EFFICIENT ELECTRICITY MARKET
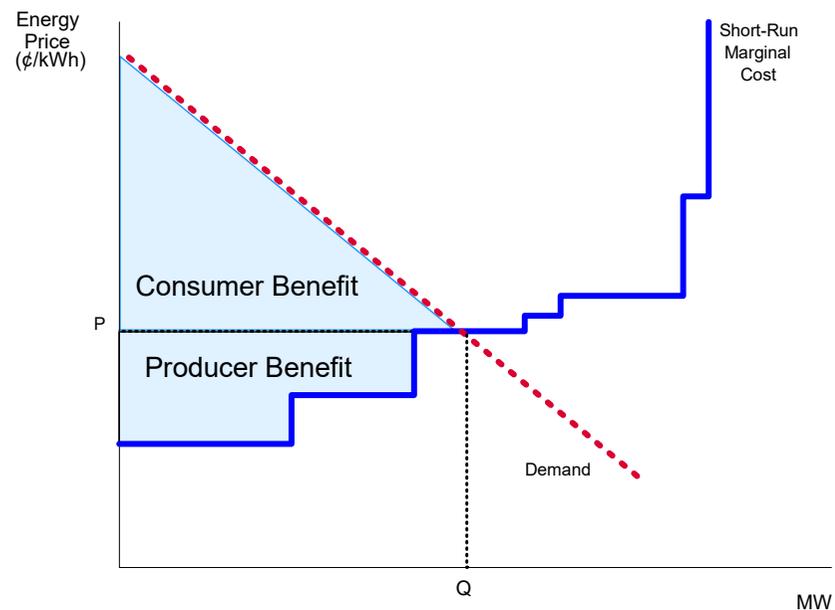
Equilibrium Prices Support Maximum Benefits

Pool Dispatch

An efficient short-run electricity market determines a market clearing price based on conditions of supply and demand balanced in an economic dispatch. Everyone pays or is paid the same price.

The illustration depicts the copper-plate model that ignores network interactions.
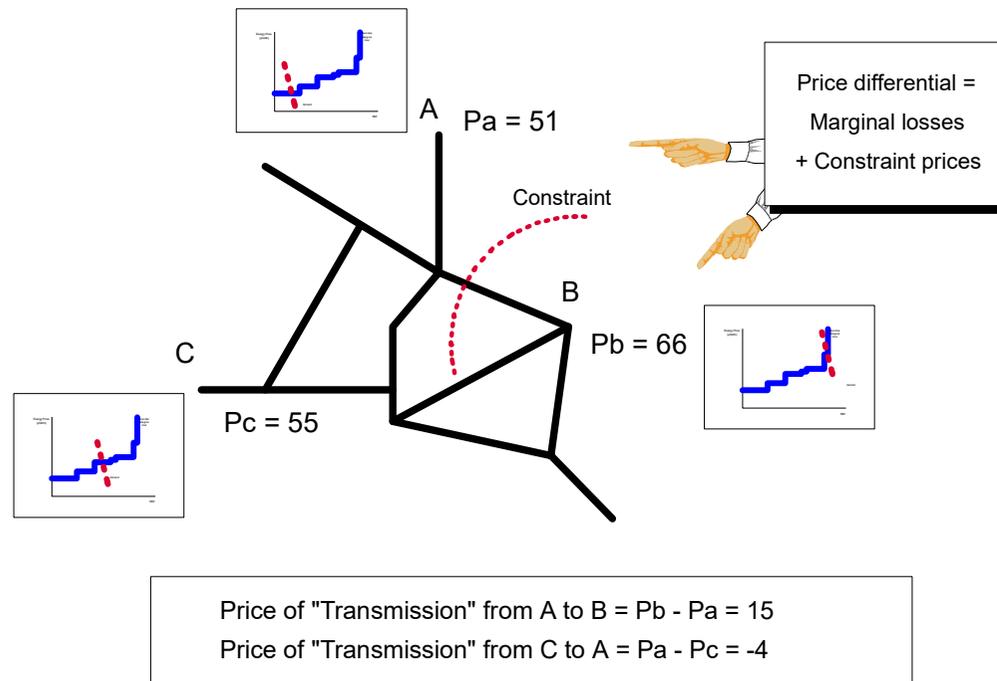
SHORT-RUN ELECTRICITY MARKET
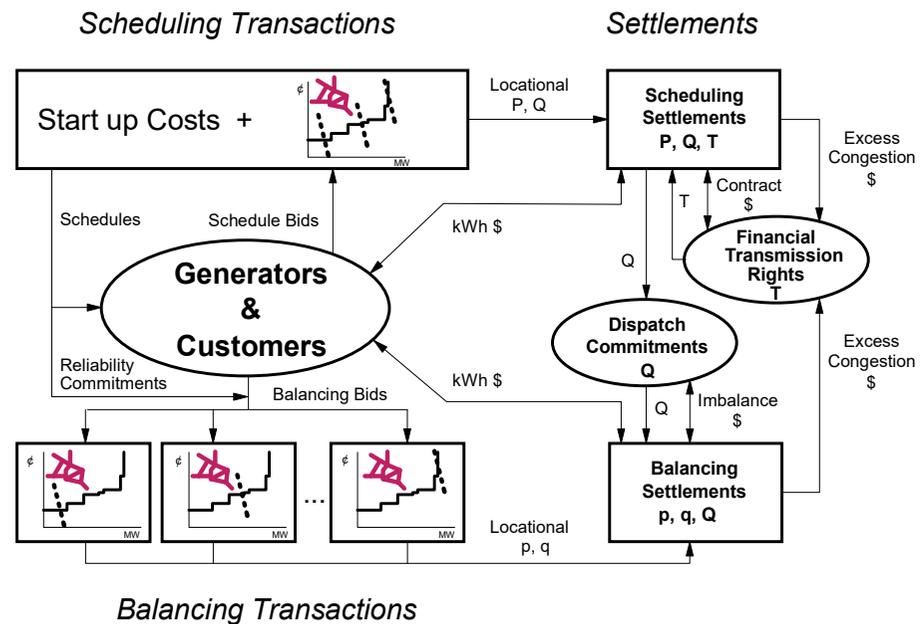
Locational Spot Prices

The natural extension of a single price electricity market is to operate a market with locational spot prices. (Schweppe et al., 1988)

- It is a straightforward matter to compute "Schweppe" spot prices based on marginal costs at each location.

- Transmission spot prices arise as the difference in the locational prices.

LOCATIONAL SPOT PRICE OF "TRANSMISSION"

A   Pa = 51

Constraint

Price differential =
Marginal losses
+ Constraint prices

B
Pb = 66

C

Pc = 55

Price of "Transmission" from A to B = Pb - Pa = 15

Price of "Transmission" from C to A = Pa - Pc = -4
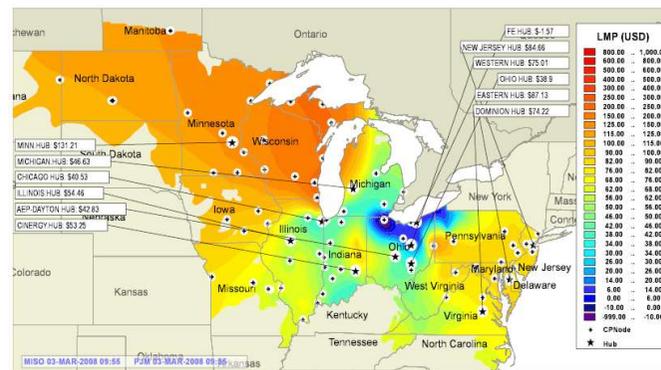
7

Day-Ahead Commitments

Organized electricity markets utilize day-ahead markets with bid-in loads, generation offers and virtual bidding for financial contracts. In addition, day-ahead markets include a reliability commitment to ensure that adequate capacity will be available in real time to meet the actual load.
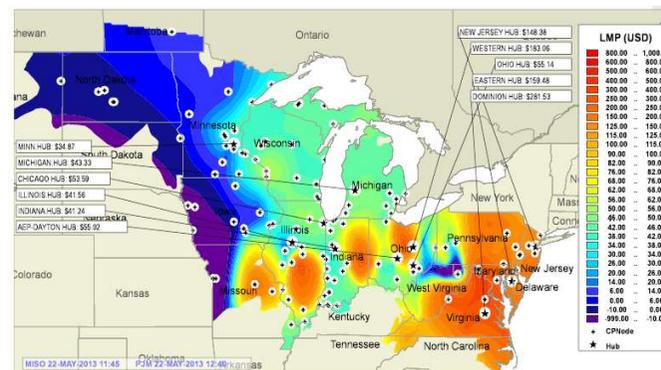
A Structure for Forward Market Scheduling, Spot Market Dispatch & Settlements

Day-Ahead Commitments

Minnesota Hub: $131.21/MWh.
First Energy Hub: $-1.57/MWh.
March 3, 2008, 9:55am

RTOs operate spot markets with locational prices.
For example, PJM updates prices and dispatch every five minutes for over 12,000 locations.
Locational spot prices for electricity exhibit substantial dynamic variability and persistent long-term average differences.

Missouri MPS -$71.25,
Dominion Hub $281.53.
May 22, 2013, 12:40pm.

From MISO-PJM Joint and Common Market, ++
http://www.jointandcommon.com

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A Consistent Framework

(IRC Council and CAISO maps)

The basic model covers
all the existing Regional
Transmission Organizations
in North America and
is expanding through
the Western Energy
Imbalance Market.

www.westerneim.com
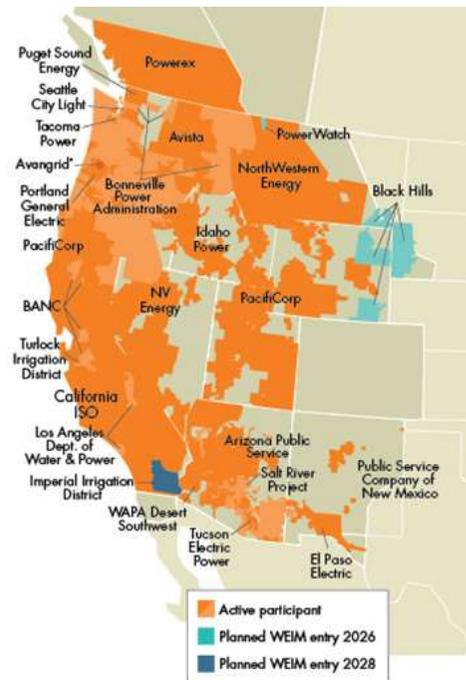
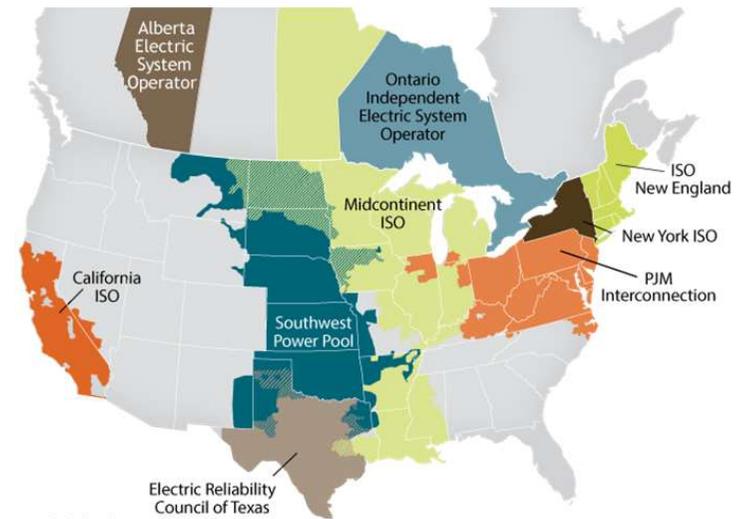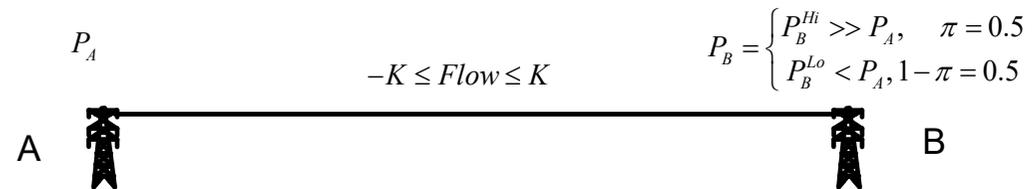*Avangrid office; generation only BAA with distribution across multiple states.
Map boundaries are approximate and for illustrative purposes only.
Copyright © 2025 California ISO

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Day-Ahead Price Equilibrium

Equilibration of day-ahead prices and expected real-time prices does not mean that expected dispatch in real-time will be the same as the dispatch day-ahead, nor does it imply that the same transmission constraints will be binding or have the same congestion costs.

(Hogan, 2016)

P_A

$$-K \leq Flow \leq K$$

$$P_B = \begin{cases} P_B^{Hi} \gg P_A, & \pi = 0.5 \\ P_B^{Lo} < P_A, & 1-\pi = 0.5 \end{cases}$$

A   B

Expected Values

$$E(P_A) = P_A$$
$$E(\mu_{ab}) = 0.5(P_B^{Hi} - P_A)$$
$$E(\mu_{ba}) = 0.5(P_A - P_B^{Lo})$$
$$E(P_B) = 0.5(P_B^{Lo} + P_B^{Hi}) > P_A$$
$$E(Flow) = 0.5(K) + 0.5(-K) = 0$$

Day-Ahead Dispatch

$$P_A^{DA} = P_A$$
$$P_B^{DA} = E(P_B)$$
$$\mu_{ab}^{DA} = E(P_B) - P_A < E(\mu_{ab})$$
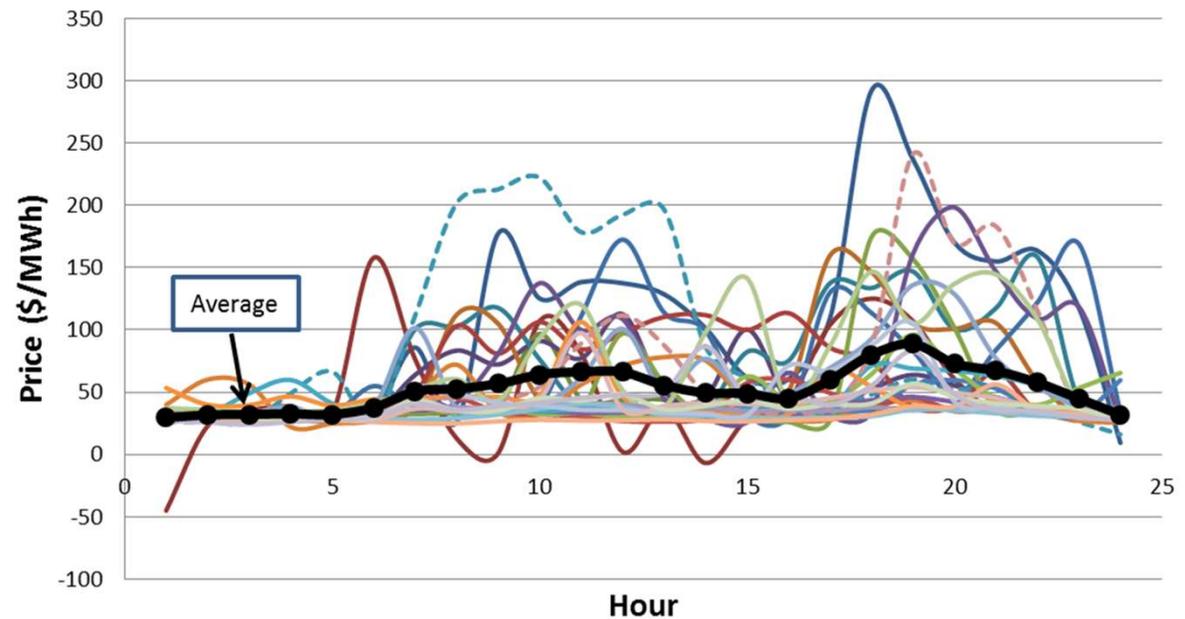$$\mu_{ba}^{DA} = 0 < E(\mu_{ba})$$
$$Flow^{DA} = K$$

$\mu :$ Constraint Shadow Price

$\pi :$ Scenario Probability

The hourly average prices capture very little of the total real-time price variation.

Newark Bay Real-Time LMP, Days in Feb. 2013

(Source: www.pjm.com) (W. Hogan, "Time-of-Use Rates and Real-Time Prices," August 23, 2014, www.whogan.com)

Green Agenda

The arrival of large volumes of intermittent, zero-variable-cost renewables raises questions about possible effects and needs for expansion or modification of successful market design.

Zero Marginal Cost	Intermittent Resources	Capacity Contributions	Matching Production and Consumption	Reducing Carbon Emissions
How can markets support efficient use or investment when there are resources with zero marginal costs?	How must operating principles change to deal with the expansion of intermittent resources?	What changes are needed to identify and support the capacity contributions of intermittent resources?	What do we need to change in support of 24/7 matching of individual loads and renewables?	How do renewables affect carbon emissions?

Pool Dispatch

An efficient short-run electricity market determines a market clearing price based on conditions of supply and demand balanced in an economic dispatch. Everyone at the same location pays or is paid the same price. The thought experiment of a no-carbon/zero-variable-cost, green energy supply reveals that the basic efficiency principles still apply. The same principles apply in an electric network. Storage will be important, but does not change the basic design analysis. (Korpås and Botterud, 2020) (Hogan, 2022) (Harvey and Hogan, 2023)

SHORT-RUN ELECTRICITY MARKET

SHORT-RUN ELECTRICITY MARKET
With zero marginal cost renewables
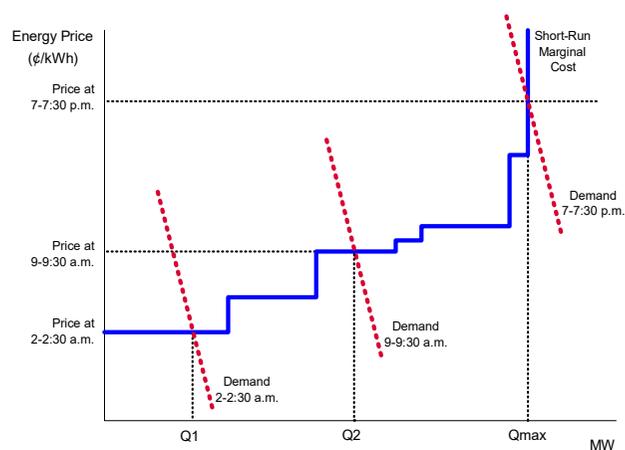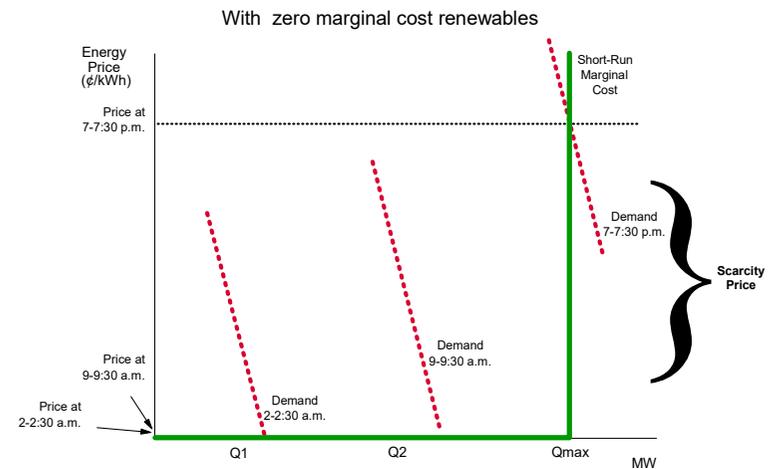
A key feature would be to increase the importance of scarcity pricing.

Environmental impacts

A typical assumption for implied carbon prices is that the subsidized entities are perfect or close substitutes for the carbon emitting activities. However, transmission constraints and local conditions in the electricity system induce material differences across locations.

Marginal Damages Distribution ($/MWh)
(PJM 4:25pm 10/14/21)

PJM SO2 vs CO2 Marginal Emissions Across Locations
(lbs/MWH 4:25pm 10/14/21)
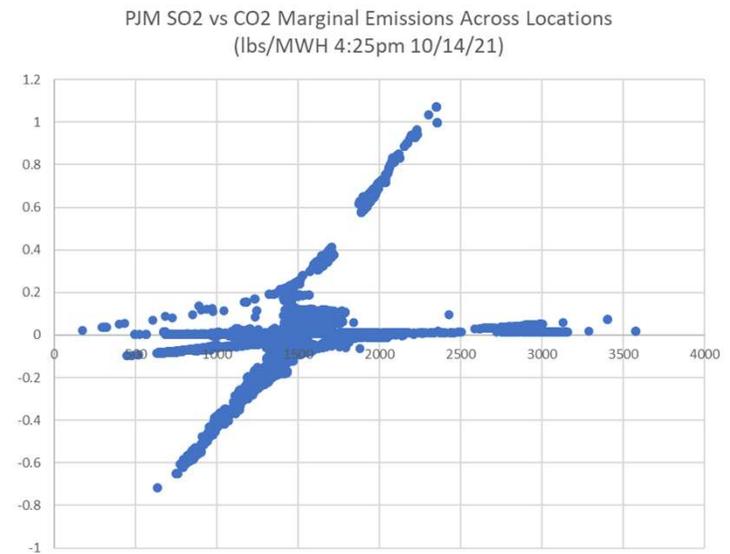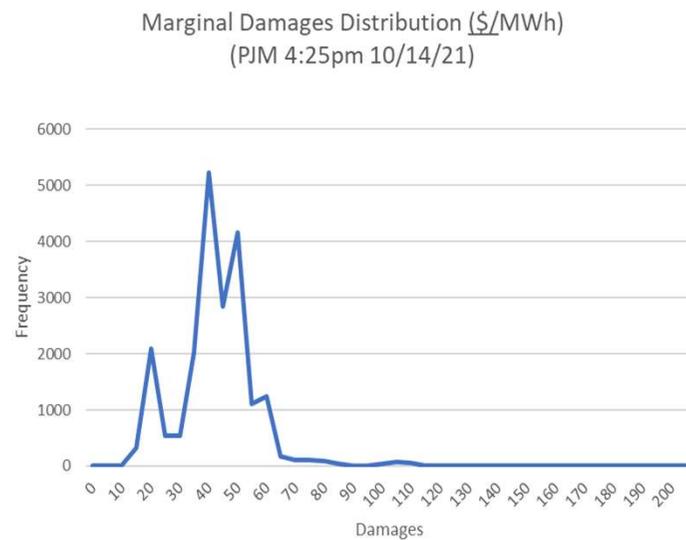
There can be a wide difference of impact on marginal emissions for different pollutants across the PJM footprint.
(https://dataminer2.pjm.com/feed/fivemin_marginal_emissions) (PJM-Interconnection, 2021)

Subsidies and Prices

The variations across space in the PJM balancing accompany significant variation across time.
(across time at the same locations)

Marginal_CO2_rate (lbs/MWh)
PJM Nodes, 5/1/23-5/15/23; 15:00 EPT

Marginal_Damages [CO2, SO2, Nox]($/MWh)
PJM Nodes, 5/1/23-5/15/23; 15:00 EPT
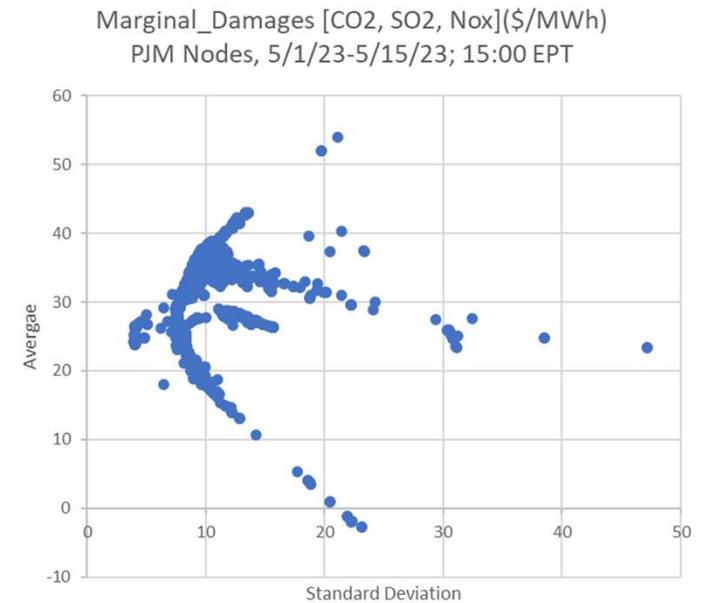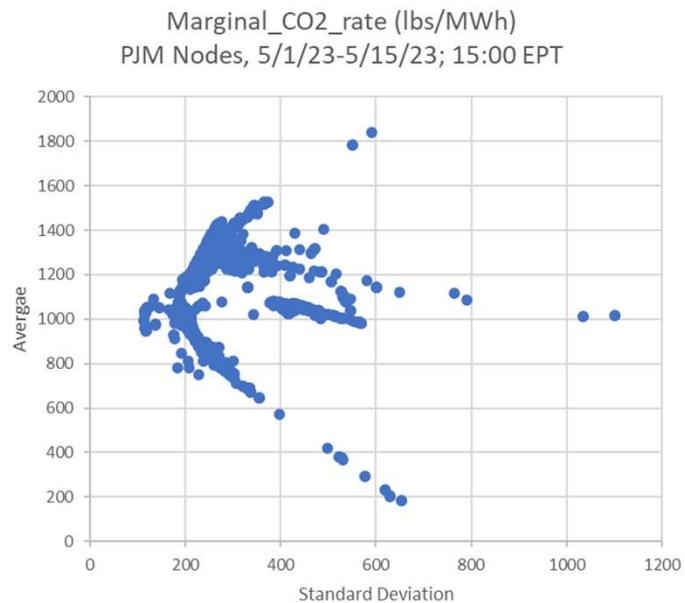
(https://dataminer2.pjm.com/feed/fivemin_marginal_emissions)

An important advantage of carbon emissions pricing, as opposed to subsidies, is the automatic ability to accommodate these wide variations and provide better incentives for operations and investments.

ERCOT Scarcity Pricing

ERCOT launched implementation of the ORDC in in 2014.
The summer peak is the most important period. The first five years of results show recent scarcity of reserves and higher reserve prices.

Legend: Jun2014-Aug 2014 · Jun2015-Aug2015 · Jun2016-Aug2016 · Jun2017-Aug2017 · ERCOT ORDC · Jun2018 - Aug2018 · Jun2019-24Aug2019

X-axis: 5 min SCED ORDC On-Line Reserve (MW). Y-axis: 5 min SCED ORDC On-Line Price Adder ($/MWh).
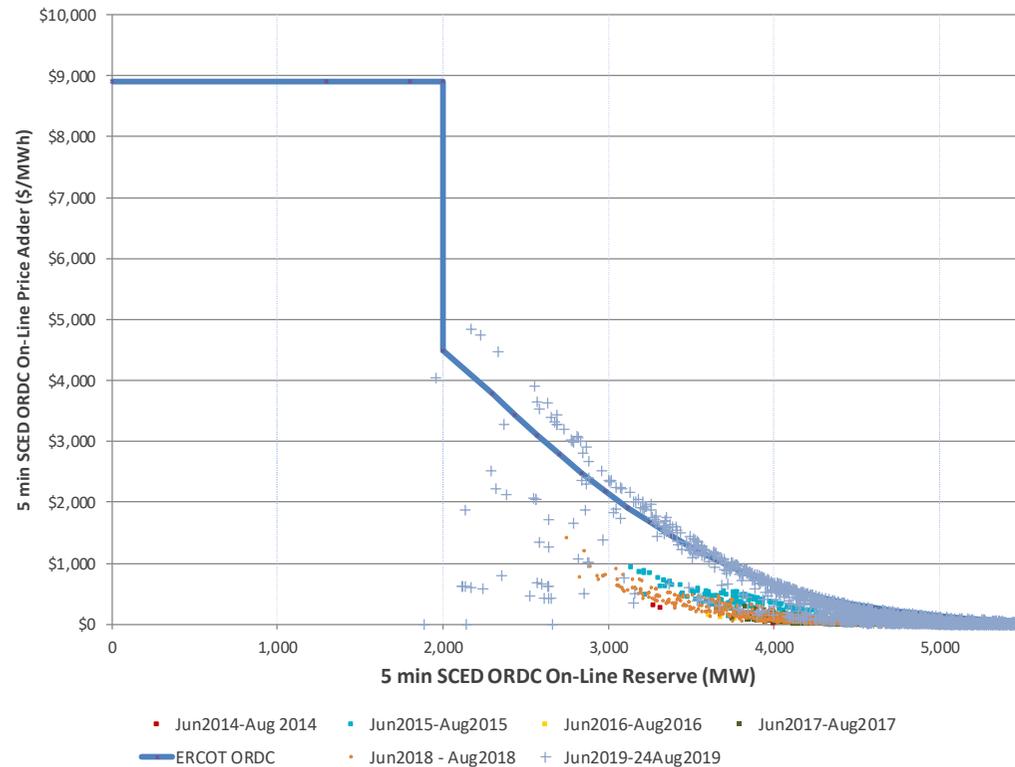
Source: Resmi Surendran, ERCOT, EUCI Presentation, Updated 8/31/2019. The ORDC is illustrative. See also (Hogan and Pope, 2019)

Hedging Requirements

Forward contracts can in principle connect long-term investors in generation with the hedging needs for loads. There is a debate over the nature markets failures and the choice of second-best hedging.

Mandated Capacity Markets

"The original sin of electricity market design."

Forward Energy Markets

Focus on the delivered product at locational prices.

Generators

Forward contracts can support investments based on incentives in the energy market.

Small Customers

The large volume of small loads presents a different problem of potential market failures.

- Large Transaction Costs. Too difficult to arrange contracts.

- Moral Hazard. Customers may assume regulators will intervene in the case of very high prices, undermining the incentive for hedging and investment.

Large Customers

In principle, large customers have the capability and interest to enter into long-term contracts.

Financial Participants

Financial participants can enter to provide liquidity in the forward contracting market.

Default Service

The New Jersey Basic Generation Service is a default service that can be seen as addressing these problems.

Default Service Arrangements

**New Jersey operates a Basic Generation Service (BGS) to set default rates for residential and small commercial customers.
The BGS design incorporates the risks in the auction pricing and leaves the utility arranging the service without any exposure and without any discretion.**

Financial Contract

The BGS is a financial contract with no connection to the generation source of the power. In effect, this is a contract for differences.

Delivered Prices

The contract is set in terms of the price of energy at the customers' location. The problem of arranging "delivery" or hedging locational prices rests with the suppliers.

Tranche Auction

Suppliers compete in a "descending block" auction to meet the requirements across multiple locations.

- **Three Year Rolling Auction.** The steady state auction procures one-third of the next three-year requirement. This keeps prices connected to expected spot-market prices, but substantial reduces price volatility.
- **Tranche Auction.** The contract awards are for a fraction of the full requirements ("a tranche") of the customers who do not opt out. The contract quantity risk is incorporated in the offers of the suppliers.

(http://www.bgs-auction.com/bgs.auction.overview.asp)

Full Requirements Service

The contract is for the full energy and ancillary services requirements.

Successful Operation

The BGS auction has been operating for many years. Most eligible customers accept the default. Evaluations have concluded that the auction prices results are competitive.

Continued

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Other issues address new and old problems in electricity markets.

Operating Demand Curves
Pricing scarcity and related ancillary services. (Hogan, 2013)

Co-Optimization
Energy and ancillary services.

Extended Location Marginal Pricing
Commitment and related fixed costs. (Andrianesis et al., 2022)

Ramping Constraints
Rolling models for real-time dispatch. (Hua et al., 2019)

Forward Hedging
Contracts for differences and financial transmission rights.

Default Service
Hedging for small commercial and residential customers as in the New Jersey Basic Generation Service auctions.

http://www.bgs-auction.com/bgs.auction.overview.asp

Resource Adequacy
Capacity market challenges and a changing resource mix.

Carbon Pricing
Pricing carbon emissions is not the same thing as subsidizing renewable production.

Other ...

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William W. Hogan is the Raymond Plank Research Professor of Global Energy Policy (Emeritus), John F. Kennedy School of Government, Harvard University. This paper draws on research for the Harvard Electricity Policy Group and for the Harvard-Japan Project on Energy and the Environment. The author is or has been a consultant on electric market reform and transmission issues for Allegheny Electric Global Market, American Electric Power, American National Power, Aquila, AQUIND Limited, Atlantic Wind Connection, Australian Gas Light Company, Avista Corporation, Avista Utilities, Avista Energy, Barclays Bank PLC, Brazil Power Exchange Administrator (ASMAE), British National Grid Company, California Independent Energy Producers Association, California Independent System Operator, California Suppliers Group, Calpine Corporation, CAM Energy, Canadian Imperial Bank of Commerce, Centerpoint Energy, Central Maine Power Company, Chubu Electric Power Company, Citigroup, City Power Marketing LLC, Cobalt Capital Management LLC, Comision Reguladora De Energia (CRE, Mexico), Commonwealth Edison Company, COMPETE Coalition, Conectiv, Constellation Energy, Constellation Energy Commodities Group, Constellation Power Source, Coral Power, Credit First Suisse Boston, DC Energy, Detroit Edison Company, Deutsche Bank, Deutsche Bank Energy Trading LLC, Duquesne Light Company, Dyon LLC, Dynegy, Edison Electric Institute, Edison Mission Energy, Electricity Authority New Zealand, Electricity Corporation of New Zealand, Electric Power Supply Association, El Paso Electric, Energy Endeavors LP, Energy Security Board Australia, Exelon, Financial Marketers Coalition, FirstEnergy Corporation, FTI Consulting, GenOn Energy, GPU Inc. (and the Supporting Companies of PJM), GPU PowerNet Pty Ltd., GDF SUEZ Energy Resources NA, Great Bay Energy LLC, GWF Energy, Independent Energy Producers Assn, ISO New England, Israel Public Utility Authority-Electricity, Koch Energy Trading, Inc., JP Morgan, LECG LLC, Luz del Sur, Maine Public Advocate, Maine Public Utilities Commission, Merrill Lynch, Midwest ISO, Mirant Corporation, MIT Grid Study, Monterey Enterprises LLC, MPS Merchant Services, Inc. (f/k/a Aquila Power Corporation), JP Morgan Ventures Energy Corp., Morgan Stanley Capital Group, Morrison & Foerster LLP, National Independent Energy Producers, New England Power Company, New York Independent System Operator, New York Power Pool, New York Utilities Collaborative, Niagara Mohawk Corporation, North Dakota Public Service Commission, NRG Energy, Inc., Ontario Attorney General, Ontario IMO, Ontario Ministries of Energy and Infrastructure, Pepco, Pinpoint Power, PJM Office of Interconnection, PJM Power Provider (P3) Group, Powerex Corp., Powhatan Energy Fund LLC, PPL Corporation, PPL Montana LLC, PPL EnergyPlus LLC, Public Service Company of Colorado, Public Service Electric & Gas Company, Public Service New Mexico, PSEG Companies, Red Wolf Energy Trading, Reliant Energy, Rhode Island Public Utilities Commission, Round Rock Energy LP, San Diego Gas & Electric Company, Secretaría de Energía (SENER, Mexico), Sempra Energy, SESCO LLC, Shell Energy North America (U.S.) L.P., SPP, Texas Genco, Texas Utilities Co, Tokyo Electric Power Company, Toronto Dominion Bank, Total Gas & Power North America, Transalta, TransAlta Energy Marketing (California), TransAlta Energy Marketing (U.S.) Inc., Transcanada, TransCanada Energy LTD., TransÉnergie, Transpower of New Zealand, Tucson Electric Power, Twin Cities Power LLC, Vitol Inc., Westbrook Power, Western Power Trading Forum, Williams Energy Group, Wisconsin Electric Power Company, and XO Energy. The views presented here are not necessarily attributable to any of those mentioned, and any remaining errors are solely the responsibility of the author. (Related papers can be found on the web at www.whogan.com).