How Wholesale Power Markets Work

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100% CLEAN ENERGY COLLABORATIVE

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About the 100% Clean Energy Collaborative

The Clean Energy States Alliance (CESA) created the Collaborative to assist states (and other entities) that have 100% clean energy goals by providing knowledge-sharing activities and analysis so that together they can address program challenges and opportunities. The Collaborative also provides information and technical assistance to states that may consider establishing similar goals. The primary participants in the 100% Clean Energy Collaborative are state agency officials with responsibilities for achieving their state's zero-carbon goals, as well as policymakers in other states that may consider establishing similar goals. Through the Collaborative, participants share program insights, engage with analysts who are studying solutions to technical challenges, and participate in Collaborative meetings. The Collaborative offers individualized technical assistance to the 100% states.

To ensure the success of the Collaborative, CESA has entered into a partnership with the U.S. Climate Alliance (USCA), a bipartisan coalition of governors committed to reducing greenhouse gas emissions consistent with the goals of the Paris Agreement. CESA and USCA are coordinating their respective activities to create synergies and avoid duplication.

About the Clean Energy States Alliance

CESA is a national, nonprofit coalition of public agencies and organizations working together to advance clean energy. CESA members— mostly state agencies—include many of the most innovative, successful, and influential public funders of clean energy initiatives in the country. CESA facilitates information sharing, provides technical assistance, coordinates multi-state collaborative projects, and communicates the views and achievements of its members.

About the Author

Bentham Paulos is the principal of PaulosAnalysis, providing consulting on energy policy, advocacy, communications, and research. PaulosAnalysis clients have included government agencies, nonprofits, foundations, consulting firms, trade associations, and media. Paulos is a CESA board member, a commissioner on the Berkeley Energy Commission, and an Affiliate in the Electricity Markets & Policy Group at Lawrence Berkeley National Lab.

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> ***The transition to a 100% clean electric supply will likely involve a very large amount of wind and solar power generation. These resources, with very low operating costs, fit poorly in wholesale electricity markets premised on the marginal cost of production—mostly fuel costs. To understand how this might play out, we first turn to how power markets work today.***

Although electricity seems very different from other consumer products, it is similar in some ways. The electricity market has producers, distributors, and intermediaries, wholesalers and retailers. As with other products, fluctuations in supply and demand result in price variations. But in other ways, electricity markets are unique and can be quite complex.

In this explainer we look at the electricity markets run by regional transmission organizations (RTOs), also known as independent system operators (ISOs). An RTO is a non-profit corporation that operates a region's electricity grid, administers the region's wholesale electricity markets, and provides reliability planning for the region's bulk electricity system. Membership in the RTO, by utilities, grid owners, and generation companies, is voluntary. About two thirds of US demand is served by competitive wholesale electricity markets.

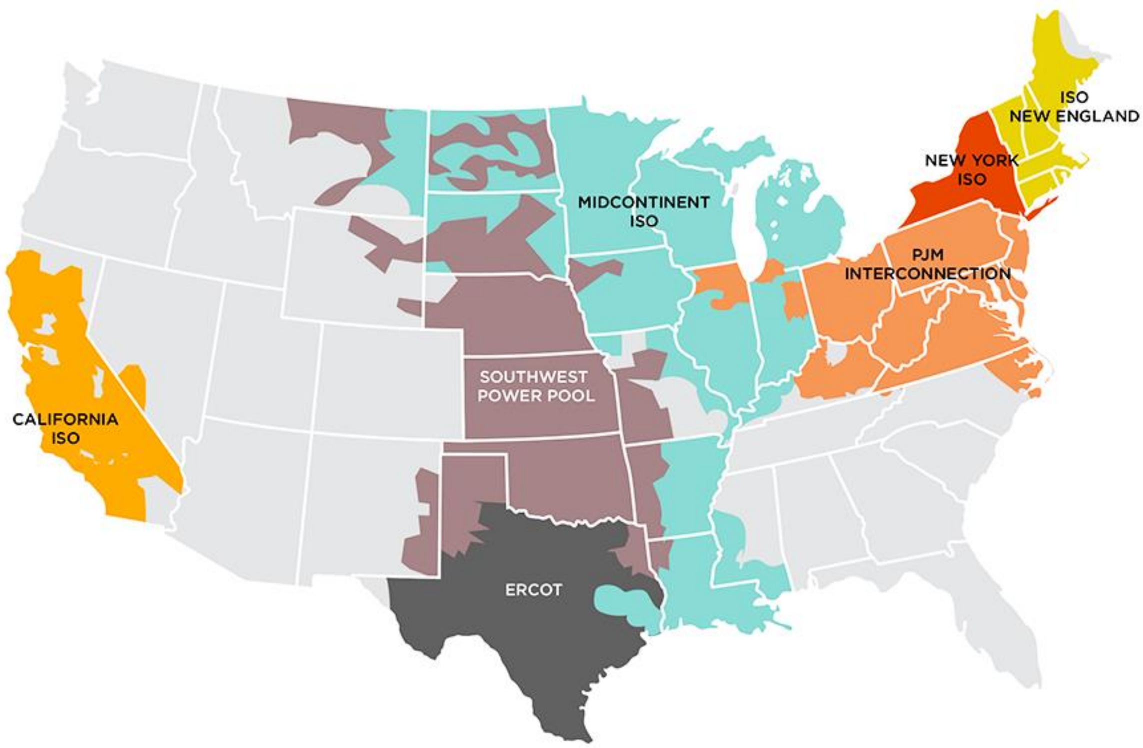
RTO markets are a fundamental part of the move toward wholesale competition that has affected much of America since the 1990s (see Figure 1, p.4). They are where electricity generators compete to sell power to wholesale buyers, such as utilities, energy retailers, and large commercial and industrial customers. For power sellers, being a least-cost power supplier, at the right time and place, is the key to success).

Outside of Markets

Outside of RTO markets, customers are served by regulated utilities which generate their own power or buy from independent producers through long-term contracts. While these utilities might buy power from neighboring utilities when they are short, they are not directly subject to the competitive price dynamics of an RTO.

In non-RTO regions such as much of the West or Southeast, "imbalance markets" are being developed to make last-minute trading more formal and competitive. Imbalance markets provide at least some of the economic efficiency of a regional market by lowering costs and cutting the need for duplicative power plants.

Figure 1 - RTOs / ISOs in the United States



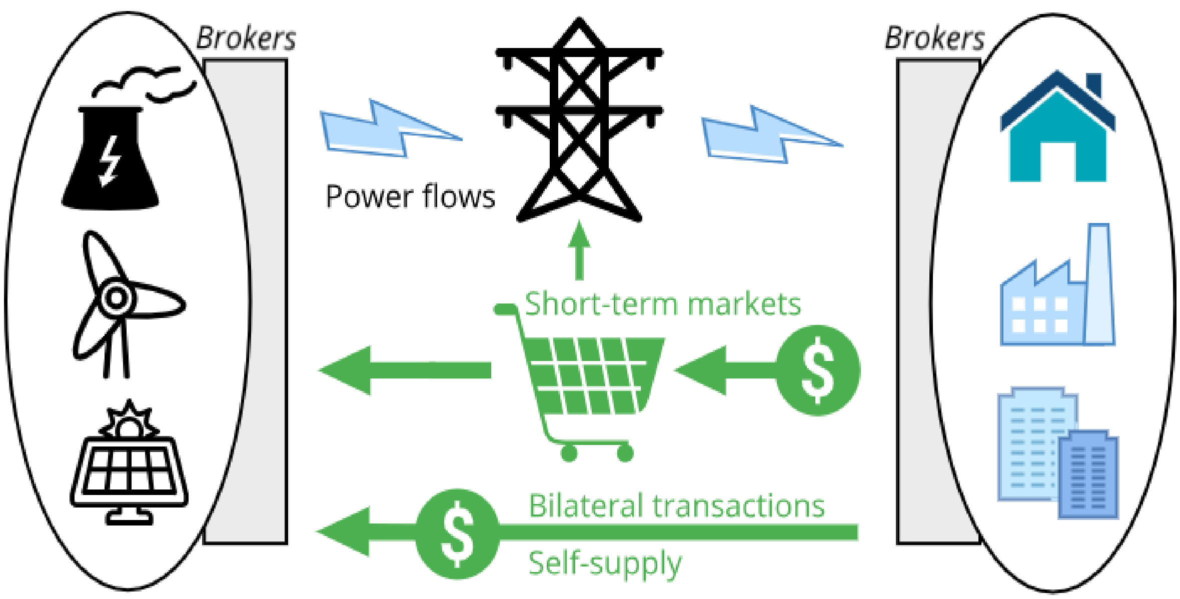
Source: ISO/RTO Council

Market Functions

RTOs are responsible for the reliable operation of the grid at a reasonable cost for customers, and for the efficient management of regional wholesale electricity markets. They send dispatch signals to generators, forecast demand in their region, and manage congestion over the transmission system using price signals. Their markets seek to ensure there is sufficient investment in new generation to provide power reliably in all hours of the year.

In short, they manage both the flow of electricity and the flow of money in a regional power system, to and from generators, the owners of transmission and distribution systems, energy resellers, and end-use customers. See Figure 2.

Figure 2 - Electricity and Dollar Flows



Source: Clean Energy States Alliance

Electricity flows from generators to customers, while dollars flow in reverse. Some money flows through short-term markets (day ahead and real time) while most flows through a direct transaction between two parties (bilateral) or from a retailer that has its own power plants (self-supply). Brokers and resellers facilitate the transactions.

Reliable electricity systems must balance supply and demand at all times. Imbalances can quickly lead to cascading equipment failure and system-wide blackouts.

To balance supply and demand, RTOs operate centralized wholesale electricity markets, where generators in the territory compete to serve demand. Markets cover a variety of products, such as energy, transmission rights, capacity, and support (or "ancillary") services. They function in three timeframes – long-term, short-term, and real-time.

The largest volume of electricity is sold not in the short-term markets but by retailers that generate their own power (called "self-supply"), or through long-term contracts between retailers and separate generation companies. These bilateral contracts specify prices, plus time and place of delivery. Since electricity retailers offer relatively fixed retail rates to their customers, they lock up most of their supply with their own plants or with bilateral contracts, to protect against the volatility of short-term markets.

In PJM last year, for example, self-supply accounted for 59.2 percent of total sales, bilateral contracts accounted for 16.1 percent, and 24.7 percent were from spot market purchases.[1]

Because the market needs to see all transactions to provide a complete picture of supply and demand, even self-supply and bilateral transactions are reported into the short-term markets. The buyer and seller settle their costs, adjusting the difference between their contract price and the market price through a "contract for differences."

The main function of short-term RTO power markets is to make up for inaccurate planning. Retailers are rarely able to predict precisely how much power they will need during a given hour, so short-term markets let them make up for shortages or sell excess power from their bilateral contracts. Buyers and sellers can do all their transactions on short-term markets if they want, though this can be a risky strategy since prices can be volatile.

[1] Monitoring Analytics, LLC (Independent Market Monitor for PJM, (March 11, 2021), State of the Market Report for PJM, Volume 2: Detailed Analysis.

Of the two short-term markets, most transactions happen on the day-ahead market, selling or buying power to be delivered the following day. Real-time markets, with bids placed on 5-to-15-minute intervals, are largely used to make small adjustments to day-ahead orders.

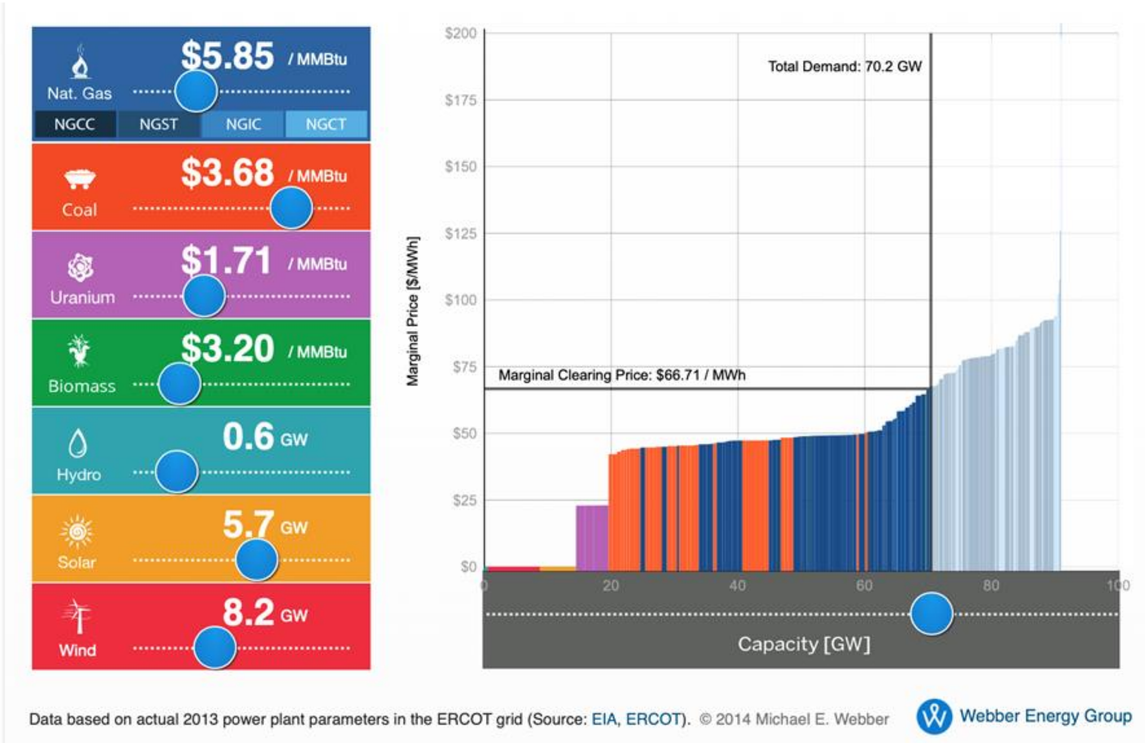
PRICE DISCOVERY

To discover the price of electricity on the market, generator bids are sorted by price (known as the "merit order") and all bids up to the amount of demand needed at that time slot are selected. The market-clearing price is set when demand is met, which is paid to all winning bidders and collected from all participating electricity retailers (often known as "load-serving entities"). Those winning bidders then generate and deliver energy for that price and time period.

Market rules are set up to encourage power generators to bid their marginal cost of production, or the cost of producing the next megawatt-hour of electricity. For coal and gas plants, that is essentially the cost of fuel plus short-term operations and maintenance (O&M) costs. Generators with no or low fuel costs, such as wind, solar, and nuclear, are called "price takers," that is, they typically bid very low or even $0 and take whatever the market clearing price is.

Figure 3 (p.8) shows how a merit order might work, as illustrated in an online tool developed by the Webber Energy Group depicting the ERCOT market in 2013. The user can adjust the total demand using the slider on the bottom, and the fuel cost or quantity of various sources using the sliders on the left. The resulting bid prices are lined up in order, showing variation by generator type, up to the point of demand. In the case shown in the figure, wind and solar bid zero while nuclear bids a low price. Coal and gas combined cycle units compete for most of the rest of supply. Demand at this given time is about 70 giga-watts (GW), resulting in a market-clearing price of $66.71 per megawatt-hour (MWh).

Figure 3 - Merit Order Calculator



Source: Webber Energy Group

A merit order calculator, showing how winning bids are selected. An interactive version is online at http://www.energy101.com/calculators.

The chart leads to a few observations:

- First, price rises with demand, as plants further up the merit order are dispatched.
- Second, given the large amount of natural gas generation in the Texas market and the volatility of gas prices, the market clearing price is almost always set by gas prices. With the fuel prices selected on the graph, there are about 40 GW of coal and gas units with similar operating costs, resulting in a predictable price across a wide range of demand.
- Third, because nuclear, hydro and renewables offer at very low marginal cost, competition at the margin is typically between coal and gas, and rests largely on fuel prices. An increase in either fuel price can dramatically change the merit order. Because natural gas relies on real-time delivery, it typically has a more volatile cost.

- And lastly, larger amounts of wind and solar will drive down the market clearing price, by pushing more expensive units out of the merit-order—known as the "merit-order" effect.

Even though plant owners only bid their short-term marginal operating cost, any profits they make when the clearing price exceeds their marginal cost go toward covering their longer-term costs, such as capital and fixed O&M. When energy prices get very high, like during hot summer days, plants with low operating costs can reap substantial rewards. Generators can also recover costs by selling capacity, ancillary services, and other products, as mentioned below.

Prices can be affected by the location of both buyers and sellers, and whether the grid is congested between them. Power markets are subdivided into hundreds of "nodes" with prices that reflect conditions at that location. These prices are used to make adjustments to each sale.

After the power is delivered, the parties settle up, with the prices and quantities determining the invoices that are sent to buyers.

Market Products

Energy is not the only product of power markets. Other resources are needed to operate the grid and are therefore traded. Power market products include:

- **Energy**: measured in megawatt-hours (MWh).

- **Transmission**: Fees to deliver energy from the generator to customers. When a transaction crosses more than one transmission territory, it can accrue multiple fees, known as "pancaked" fees. An advantage of RTOs is they offer a single fee for transmission and offer transmission access to new market entrants without discrimination, but pancaking can happen between RTOs and in non-RTO territories.

- **Capacity**: Ensuring there is enough generation capacity available to meet demand at all times. Some regions require capacity to be purchased for up to three years in advance. Not all markets have a capacity product.

- **Ancillary Services**: Supplemental services that support grid operations, such as voltage and frequency regulation. There are four types of ancillary services products: regulation up and regulation down (to manage changes in demand) and spinning reserve and non-spinning reserve (to respond to fast changes in grid conditions).

- **Renewable energy certificates (RECs)**: RECs prove that electricity was generated from an eligible renewable source, and they are used for compliance with state laws or to verify a "green power" purchase. They can be sold either with or separately from the electricity.

To give a sense of the relative values of these products, the components of electricity price in PJM in 2020 are shown in Figure 4, p.11. Of an average price of $44.57 per megawatt-hour, energy made up about half, with transmission and capacity making up most of the rest. Ancillary services, administrative fees, and other costs made up the last 3 percent.[2] REC prices vary widely by state and category, from $1 to $40 per MWh.[3]

To see online trackers of real-time activity in RTOs / ISOs, click on the following:

- Electric Reliability Council of Texas (ERCOT)
- California ISO (CAISO)
- Midcontinent ISO (MISO)
- Southwest Power Pool (SPP)
- PJM Interconnection (PJM)
- ISO New England (ISO-NE)
- New York ISO (NYISO)

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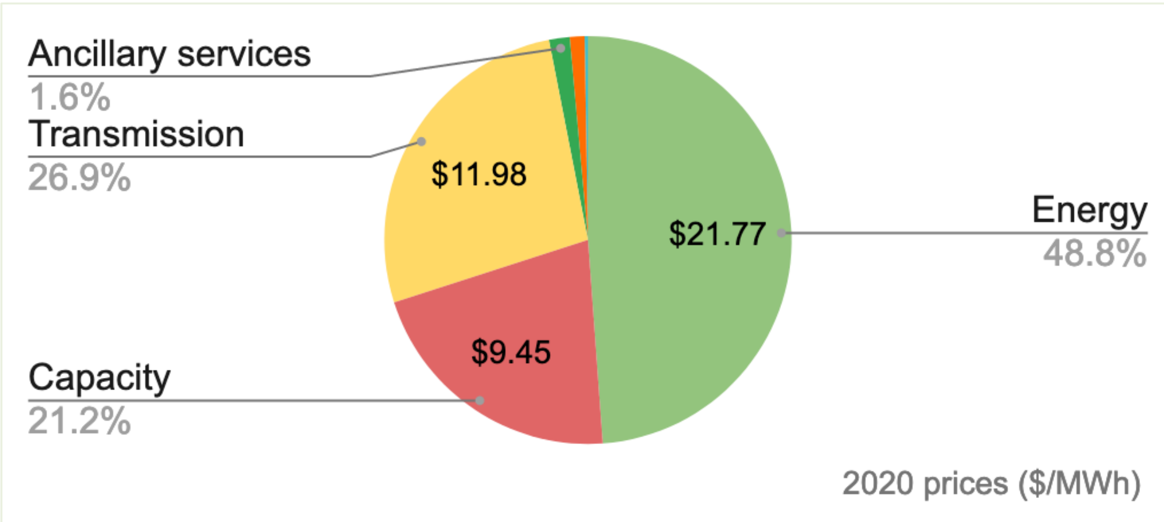
[2] Monitoring Analytics, LLC

[3] Galen Barbose, Berkeley Lab, *U.S. Renewables Portfolio Standards 2021 Status Update: Early Release*, February 2021.

Figure 4 - Components of Price in PJM in 2020



Source: Monitoring Analytics, LLC, Independent Market Monitor for PJM

Components of wholesale prices for 2020. Of a total average price of $44.57 per MWh, energy makes up about half.

The risk of price volatility can be a major factor in electricity markets. Risk can happen over time and by location. Market actors use a variety of hedging instruments to manage the risk, including a few listed here. These instruments can be traded on the market or can happen directly between buyers and sellers.

- Financial transmission rights: Congestion can cause big price differences between locations on a grid. To avoid the risk of paying unknown congestion charges, a marketer can buy FTRs that entitle the owner to earn or pay the difference in price between two or more nodes. This makes the cost of a transaction between nodes more certain in advance.
- Virtual bidding: Market participants can buy or sell energy in the day-ahead market with the explicit requirement to buy or sell it back in the real-time market, thus ensuring that day-ahead and spot market prices are similar.
- Contracts for Differences: A buyer and seller make a direct agreement with each other for a transaction at a fixed price (called a "strike" price). If the spot market price is higher or lower than the strike price, the buyer or seller reimburses the other party for the difference.

Price Dynamics

Electricity is difficult to store in large quantities, which makes it challenging for grid operators to ensure the right amount of electricity is generated and available at all times.

Power demand can fluctuate widely, especially due to changes in the weather. For example, millions of air conditioners on hot summer days can drive electricity demand to three or four times the average level in some regions.

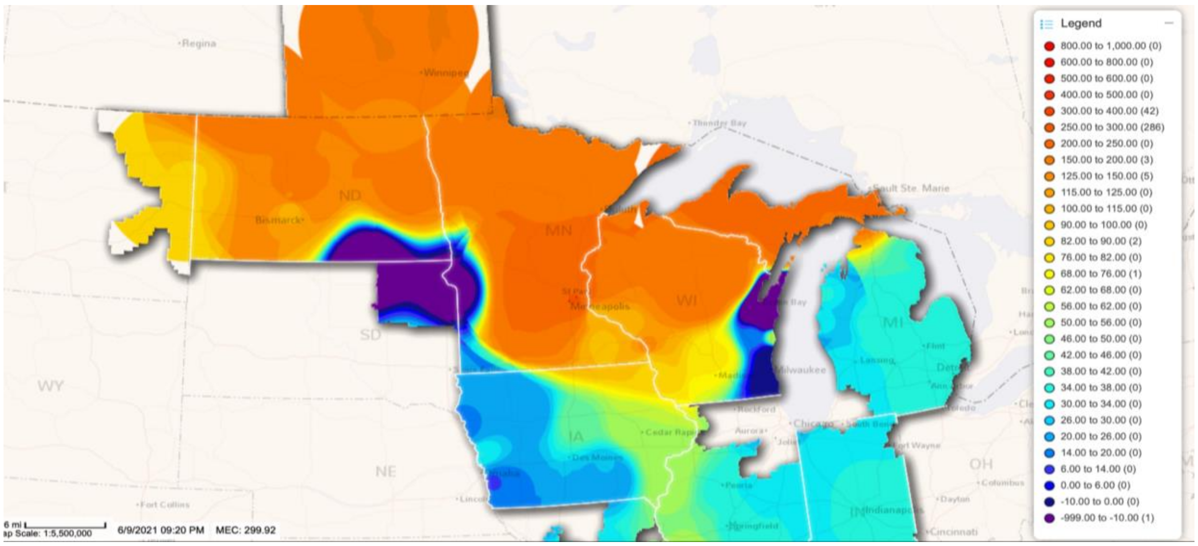
Variations in supply can come from severe storms or heat or cold, daily and hourly changes to wind and solar power output, or from equipment failures at power plants and transmission lines. Over longer time frames, drought can greatly affect hydropower output, and fuel prices or availability can limit natural gas or coal generation. With this volatility of supply and demand comes volatile pricing. High prices signal to generators to increase output to meet demand, and signal to electricity buyers to reduce their consumption.

Price constantly varies over time, even changing in 5-minute intervals in the real-time market. It tends to be higher when demand is high, or supply is low. When supplies are tight, prices can be extremely high. In the Texas winter power crisis of February 2021, prices hit a price cap of $9,000 per MWh, or $9 per kWh, about 200 times higher than normal.

Price also changes by location within a market, based on where power is generated or consumed. Transmission congestion between “nodes” can greatly affect the locational value of electricity and isolated “load pockets” can see much higher or lower prices, depending on the ability to move power into or out of the area.

Figure 5 (p.13) shows how prices varied on a hot day in June 2021 in the Upper Midwest. This snapshot was taken at 9:20 pm, and it shows prices ranging from less than negative $10 per MWh to over $200 per MWh. Large amounts of wind power output in the Dakotas and Wisconsin caused pockets of very low prices, while transmission constraints between northern states (MN and WI) and southern states (IL and IN) caused a large price differential.

Figure 5 - Locational marginal prices in MISO, June 9, 2021 at 9:20 pm



Source: MISO

For an animated map of locational marginal prices, click the "playback" button here.

This variation by location sends a signal to the market and to planners to take steps to solve the condition, such as through new transmission lines, more flexible generation, plant retirements, or new generation in a load pocket that has recurring high prices.

Negative prices occur when supply exceeds demand, essentially paying suppliers to reduce output in order to maintain reliability. How can prices go negative? Wind generators, which get a federal tax credit based on energy generated, can be willing to accept negative prices up to the value of the tax credit. Sometimes thermal generators will not want to turn down for a few hours since they lack the flexibility to ramp back up quickly and want to be available in subsequent hours when prices rise. Hydroelectric plants may need to keep operating to meet irrigation, fish, and recreational needs.

When oversupply occurs, an RTO first asks for bids from generators to turn down, known as "decremental" bids. If that doesn't get a sufficient response, an RTO can order some generators to be curtailed. Since thermal generators are already getting the signal of very low or negative prices, well below their operating costs, decremental bids and curtailment usually applies only to wind and solar generators.[4]

While momentary spikes in prices can get a lot of attention, they are not signs of an ill-functioning market. In fact, a lack of energy price volatility can be a sign that markets are over-supplied, with customers paying too much in capacity payments to maintain un-needed generation. More accurate measures of an affordable power system are average annual wholesale energy prices and average customer bills. So long as a sufficient number of market participants can react to changes in prices, markets can provide the most fundamental signals about what resources and behavior are needed.

Conclusion

Ultimately, wholesale power markets serve two functions. First, they match buyers and sellers in a competitive marketplace to drive down costs and increase economic efficiency. Second, markets can provide clear and tangible signals to all market actors—power plant owners, marketers, buyers, planners, and regulators—about the actions needed to improve efficiency, grid operations, infrastructure, and reliability. Well-designed markets allocate risk to the parties most able to manage it.

By bundling small markets or single utilities into larger regional markets, RTOs capture a number of benefits. A larger market creates more geographic diversity of generation and load, less need for redundancy, more competition from a larger pool of resources, and easier integration of renewables.

PJM has estimated that its competitive market saves consumers $3.2 to $4 billion per year, especially from avoiding investment in duplicative power plants and from more efficiently integrating resources.[5] When markets fail, however, costs can be extremely high. When

[4] Bentham Paulos, "Too Much of a Good Thing? An Illustrated Guide to Solar Curtailment on California's Grid," Greentech Media, April 3, 2017
[5] PJM Interconnection, *PJM Value Proposition*, 2019.

winter storm Uri hit Texas in February 2021, electricity prices in ERCOT rose by an estimated $16 to $26 billion, not counting the costs of power outages.[6]

While markets are never perfect, well-designed markets offer substantial improvements over past systems. However, as we will describe in an upcoming paper, traditional power markets may not be compatible with the shift to very large amounts of wind and solar power.

Further Reading

American Public Power Association (APPA), Wholesale Electricity Markets and Regional Transmission Organizations: Electricity Markets Issue Brief, June 2021.

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[6] Robert Bryce, "Texas Ratepayers Are Being Saddled With Nearly $38 Billion In Excess Energy Costs From Winter Storm Uri," Forbes, June 11, 2021.

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