MIT Center for Energy and Environmental Policy Research

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Research Brief

Electricity Pricing Problems in Future Renewables – Dominant Power Systems

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Constraints on electric power system carbon emissions will make optimal increased reliance on variable renewable energy (VRE, mainly wind and solar generation), which has near zero marginal operating costs. Using capacity expansion modeling of electric power systems in three US regions, we show that under a wide range of plausible demand and supply-side technology assumptions, efficient, deeply decarbonized systems will have many more hours of very low marginal values of electricity (MVEs) and more hours of relatively high MVEs, than today. This result stems from the shift away from systems dominated by thermal generators with well-defined marginal costs to systems dominated by VRE with near zero marginal operating costs. To minimize the cost of electricity and to encourage cost-effective economy-wide decarbonization, economic theory prescribes that wholesale and retail prices of electricity should equal MVEs. However, the sharply increased variability of MVEs compared to today means that setting wholesale and retail prices equal to MVEs would likely impose politically intolerable risks at both levels. The following paper proposes potential solutions to this fundamental problem.

Tightening constraints on power system carbon emissions will make optimal increased reliance on variable renewable energy (VRE, mainly wind and solar generation), which has near zero marginal operating costs. Both because the electric power sector will grow in relative importance and because electricity prices will affect the vital process of economy-wide decarbonization, the costs of inefficient wholesale and retail electricity pricing will be much greater in the future than at present.

To explore the key features of efficient electricity pricing in future deeply decarbonized power systems, we used the open-source GenX capacity expansion model (CEM) to simulate efficient, deeply decarbonized electricity systems in three US regions in 2050 under a number of carbon emissions and technological scenarios. GenX includes representation of various supply and demand-side resources, including energy storage with independent discharging and charging power capacities and energy storage capacity, demand flexibility, demand response, and use of hydrogen for non-electric end uses. We imposed system-wide constraints on carbon emissions, which is equivalent to imposing a carbon tax or, under certainty, a competitive cap-and-trade system, and we focus on deep decarbonization scenarios that get close to zero carbon emissions.

Our analysis includes a number of advances compared to the existing literature evaluating wholesale electricity price outcomes for VRE-dominant electricity system. First, we evaluate the impact of various technology options that have previously received only limited attention, including several different energy storage technologies, flexible demand, and the effects of sector-coupling between electricity and other end-use sectors (e.g. industrial process heat). Second, for all technology and emissions scenarios, we discuss the implications for hourly distribution of wholesale electricity prices as well as revenues earned by different technologies if they are paid exclusively through the wholesale market. Third, we elaborate on the implications of the hourly price distributions under carbon-constrained scenarios on economy-wide decarbonization via electrification and retail electricity price reform.

In our analysis, we compare dispatchable thermal power plants to VRE generators. Dispatchable thermal power plants, which dominate the generation portfolio in most power systems today, have positive marginal costs. VRE generators, however, use no fuel inputs and thus have near zero marginal operating costs. Thus, a shift from primary reliance on dispatchable thermal generators to primary reliance on VRE generators with a greater role for storage decouples the determination of MVE in efficient systems from marginal generating cost. This transition also seems likely to change the frequency distributions of wholesale electricity prices.

What the application of our model shows is that deeply decarbonized systems will have many more hours of very low wholesale prices – corresponding to periods of high VRE availability relative to load – and more hours of relatively high prices – approaching the value of lost load – than today. In decarbonized VRE-dominant energy-only wholesale power markets without price caps, generators and storage facilities will earn the bulk of their annual energy market revenues in relatively few hours compared to the situation today. Financial instruments to hedge price volatility will consequently be more costly. The presence of demand response, long-duration energy storage, dispatchable low-carbon generation, and flexible electricity-based hydrogen production weaken but do not reverse these results.

We respond to recent research papers that suggest that instances of very low wholesale prices could be infrequent, and prices may never approach the value of lost load, if a large fraction of future energy demand could be met either by electricity or by switching to carbon-free chemical energy carriers (referred here on as "synthetic fuels"). In deeply decarbonized energy systems, however, the availability and cost of carbon-free synthetic fuels that can substitute for electricity at scale is highly uncertain. Moreover, if electricity is consumed in producing these synthetic fuels, which is likely, then the cost and availability of synthetic fuel may vary over time, which is inconsistent with the constant cost and availability assumption made by some studies. By incorporating the investment and operation of the supply chain of synthetic fuels, including production, storage and utilization, we show a reduction in instances of low and high MVEs (by improving VRE and storage utilization) but not an elimination of them.

Our findings reveal that in decarbonized VRE-dominant energy-only wholesale power markets without price caps, in which spot prices approximate MVEs, generators and storage facilities would earn the bulk of their annual energy market revenues in relatively few hours. It is likely that many wholesale markets will cap energy prices and will employ capacity remuneration mechanisms to provide adequate investment incentives. Some current mechanisms can be adopted, with difficulty, to handle VRE generation, but storage presents new conceptual challenges, and it is critical to avoid approaches that distort spot prices for the following reason. On the retail side, to encourage economy-wide electrification, the marginal retail price of electricity should be low whenever the wholesale MVE is low. But recent grid contingency events (e.g., Texas in Feb 2021) makes clear that requiring retail customers to pay wholesale spot prices on the margin would impose intolerable risks today, and our work shows that those risks would be much higher in future decarbonized systems. With automated control of demand via demand response contracts, we argue that the risks of price volatility faced by retail customers can be mitigated with appropriate insurance contracts without sacrificing incentives for decarbonization.

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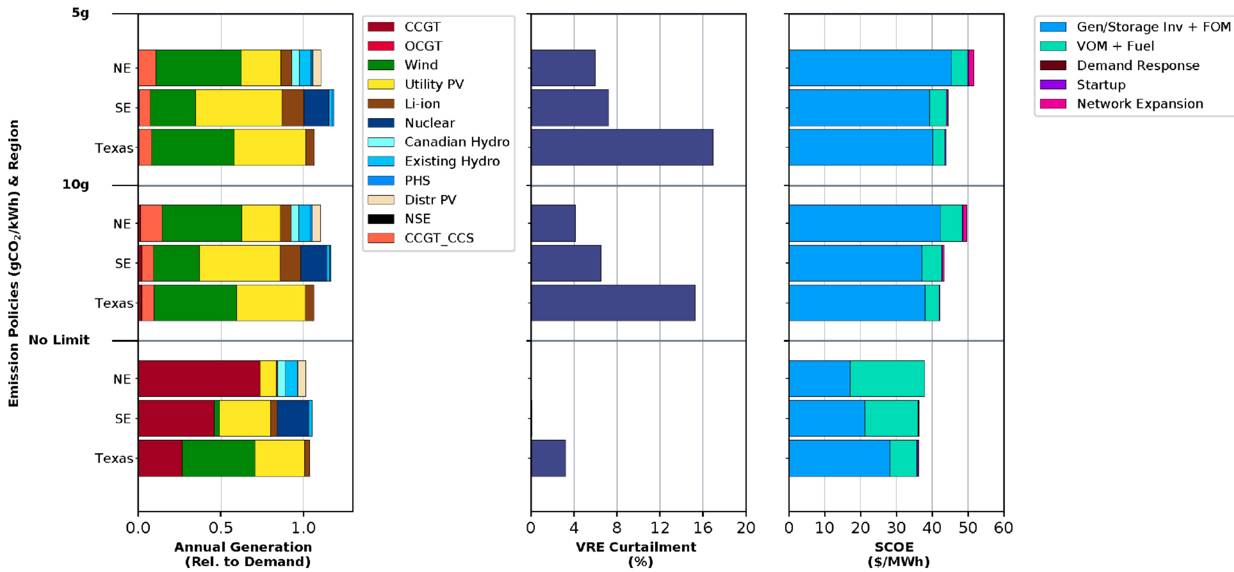

Figure 1. Annual generation, VRE curtailment, and system average costs of electricity (SCOE) in the Northeast (NE), Southeast (SE), and Texas (TX) under tightening CO_2 emmission constraints. Modeling results are shown for a scenario with no limit on emissions (bottom row) and for two alternative carbon emissions limits scenario with an emissions intensity limit of 10 (middle row) and 5 gCO_2/kWh (top row). SCOE includes total annualized investment, fixed O&M, operational costs of generation, storage, and transmission, and any non-served energy penalty. Emissions intensity under the "No Limit" policy case for each region is as follows: NE: 253 gCO_2/kWh, SE: 158 gCO_2/kWh, Texas: 92 gCO_2/kWh. For the Northeast case, "Wind" represents the sum of onshore and offshore generation.

References

Mallapragada, D., C. Junge, C. Wang, J. Pfeifenberger, P. Joskow, and R. Schmalensee (2022), "Electricity Pricing Problems in Future Renewables – Dominant Power Systems," MIT CEEPR Working Paper 2019-017R, February 2022.

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Dharik Mallapragada is a Principal Research Scientist at MIT and joined the MIT Energy Initiative in May 2018. Through his Ph.D. and nearly five years of research experience in the chemicals and energy industry, Dharik has worked on a range of sustainability-focused research topics such as designing light-weight composite materials and carbon-efficient biofuel pathways, as well as developing novel tools for energy systems analysis. His research interests include the design of novel energy conversion processes and their integration into the energy system. At MIT, Dharik is working on advancing power systems modeling tools to study questions around renewables integration and economy-wide electrification. Dharik holds a M.S. and Ph.D. in Chemical Engineering from Purdue University. He received a B.Sc. in Chemical Engineering from the Indian Institute of Technology, Madras.

Cristian Junge is a graduate research assistant at the MIT Energy Initiative. As part of the Future of Storage Economics Team, his research focuses on understanding the role of energy storage technologies in deeply decarbonized power systems.

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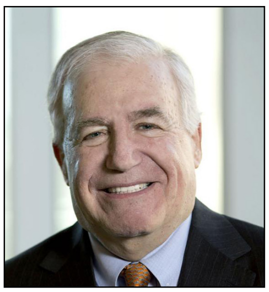
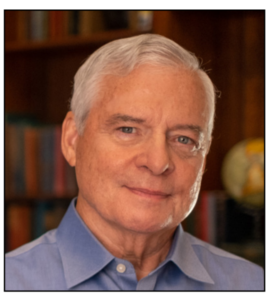


Paul Joskow is the Elizabeth and James Killian Professor of Economics at the Massachusetts Institute of Technology (MIT) and President emeritus of the Alfred P. Sloan Foundation. Joskow has been on the MIT faculty since 1972, where he was the head of the MIT Department of Economics from 1994 to 1998 and director of the MIT Center for Energy and Environmental Policy Research from 1999 to 2007. Joskow became president of the Sloan Foundation in 2008 and returned to MIT in 2018. At MIT his teaching and research areas include industrial organization, energy and environmental economics, competition policy, and government regulation of industry. He has served on the boards of the New England Electric System, National Grid PLC, TC Energy, State Farm Indemnity, Exelon Corporation (current), Putnam Mutual Funds (current), and the Whitehead Institute for Biomedical Research.



Richard Schmalensee served as the John C Head III Dean of the MIT Sloan School of Management from 1998 through 2007. He was a member of the President's Council of Economic Advisers from 1989 through 1991 and served for 12 years as Director of the MIT Center for Energy and Environmental Policy Research. Professor Schmalensee is the author or coauthor of 11 books and more than 120 published articles, and he is co-editor of volumes 1 and 2 of the Handbook of Industrial Organization. His research has centered on industrial organization economics and its application to managerial and public policy issues, with particular emphasis on antitrust, regulatory, energy, and environmental policies. He has served as a consultant to the U.S. Federal Trade Commission, the U.S. Department of Justice, and numerous private corporations.

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