A call for better energy system models to enable a decarbonized future

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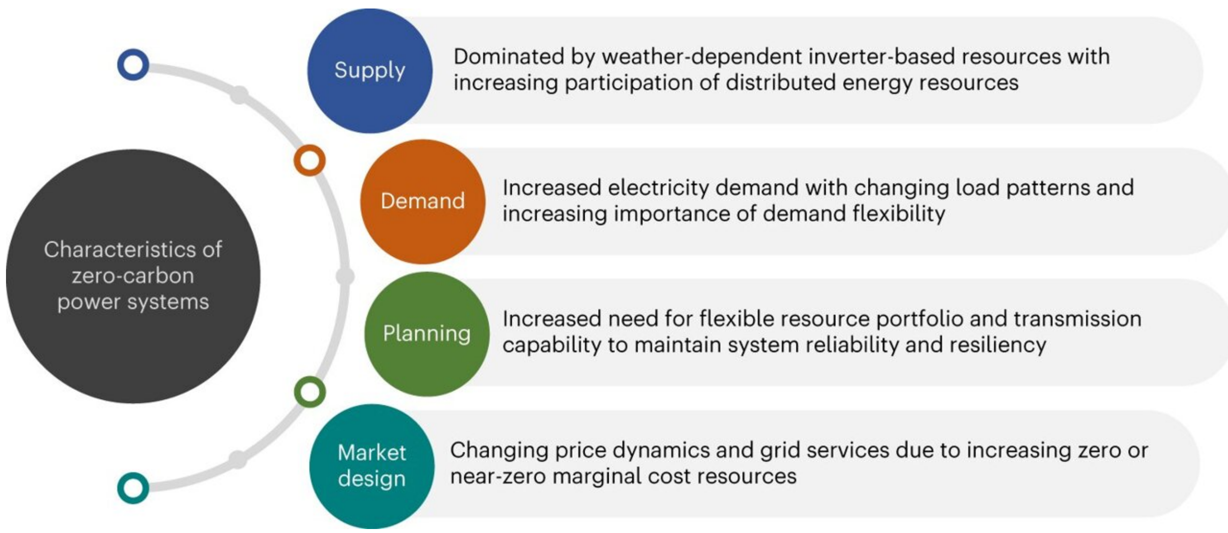

A fully decarbonized power system will exhibit several new characteristics and dynamics that must be represented accurately in CEM to capture the value of different technologies and identify socially optimal capacity expansion pathways. Credit: *Nature Energy* (2023). DOI: 10.1038/s41560-023-01340-6

Energy system models fail to accurately represent energy storage and might recommend decarbonization strategies that make electric grids less reliable.

Policy makers and utilities need robust energy system models to determine the best strategies to decarbonize the world's electric grids.

But most existing models were designed for grids operating more than a decade ago. Today's grids are much different. New technologies such as solar power and grid energy storage are being rapidly deployed. To accommodate these and other technologies, utilities must run grids in completely new ways.

Improvements are needed in energy system models so that they adequately account for these significant changes. Without these crucial updates, the models may lead to decarbonization strategies and infrastructure investments that compromise grid reliability and make power less affordable for consumers.

Leading modeling experts from the U.S. Department of Energy's (DOE) Argonne National Laboratory and several other institutions call attention to the urgent need for better energy system models in a recent *Nature Energy* paper. Their objective was to inform researchers, regulators, policymakers, industry and funding agencies about opportunities to enhance the models.

The paper focuses specifically on capacity expansion models, which are tools used to simulate future grids and identify optimal investments over multi-year periods. These models account for a complex set of factors, such as new policies, technology advances and electricity demand forecasts. Electric utilities use the models in long-term grid planning. Regulators and other governmental agencies use them to evaluate new energy and environmental policies.

Energy storage: A key enabler of grid decarbonization

To address climate change, governments and companies around the world have committed to net-zero greenhouse gas emissions by mid-century. These commitments have facilitated rapid deployment of solar and wind power.

Solar and wind generation are variable depending on when the sun shines and wind blows. That means more flexible energy resources are needed to balance energy supply and demand and maintain grid reliability.

Batteries and other energy storage technologies are widely viewed as key providers of this flexibility. They can store excess energy during periods of high solar and wind generation and release energy during low generation periods. Grid operators also envision the use of storage to ensure energy availability during extreme weather.

"Energy storage is fundamentally changing how the grid is operated," said Todd Levin, Argonne's electricity markets team lead and one of the paper's authors. "Historically, grid operators have had to precisely balance generation and consumption of energy in real-time. By moving energy through time, energy storage enables a grid that doesn't need to generate electricity in the same second that it's used."

Increasingly, policymakers are applying capacity expansion models to inform decisions on decarbonization pathways and associated investments. But existing models are not designed for grids that rely on energy storage to integrate large amounts of variable renewable energy resources.

According to the paper, models don't accurately represent the technical and economic characteristics of energy storage. Additionally, they do not account for the interactions between storage and other grid components, such as wind and solar power plants. What's more, they don't properly incorporate the value of energy storage in its various grid and electricity market uses.

Argonne workshop leads to the paper

In late 2021, Argonne organized a workshop that gathered modeling experts to identify key research needs associated with applying capacity expansion models to decarbonization. The presenters agreed to write a paper to capture key insights from the event—and point to ways to enhance models.

The stakes are high. "If these models do not accurately represent energy storage, they may recommend decarbonization pathways that make grid operations more expensive or less reliable," said Audun Botterud, an Argonne senior energy systems engineer and one of the paper's authors. "If we don't maintain high reliability, public support for decarbonization efforts could be eroded."

"Figuring out how to model energy storage is no longer just an academic question," said Jesse Jenkins, another author of the paper and a Princeton University researcher focused on improving energy system models. "Batteries are already playing a critical role in keeping the lights on."

"Utilities, storage companies, policy makers and other stakeholders need state of the art tools that capture the full range of services and capabilities storage has to offer," Jenkins added. "This paper outlines the challenges and best practices. It draws on the experience of some of the world's best modelers and storage experts."

"Energy storage technologies hold great promise to cost-effectively and reliably integrate more renewable energy on the grid—as well as provide energy across variable weather patterns," said Scott Burger, one of the paper's authors and analytics director at Form Energy, a company that develops grid storage systems.

"To meet this potential, grid planners need better tools for large-scale storage investments and operations," added Burger. "This important paper highlights the frontier of energy storage modeling and provides a critical roadmap for industry to follow."

Many challenges, many research needs

One of the many challenges identified by the paper is that models do not adequately consider state of charge—the amount of energy stored in a battery at a given time. Storage systems charge and discharge to provide various services to grid. At times, they may be fully discharged. With visibility into state of charge, grid operators know if storage systems have enough power to meet demand on short notice when wind and solar generation are less than predicted. State of charge management is fundamentally new to grid operations. Models need to be enhanced so that they track changes in state of charge due to evolving grid conditions.

Today's models do not account for battery electrochemistry. Different battery chemistries may have different operating characteristics and perform differently depending on how utilities use them. Batteries tend to degrade faster than other grid components. Models need to capture these nuances because they have important implications for the grid costs and reliability.

According to the paper, most models ignore supply chain challenges associated with manufacturing energy storage technologies. Identifying the best decarbonization pathways will require consideration of global battery supply chains. A modeler may need to limit the deployment of a particular storage technology in a decarbonization analysis because of volatile supply chains.

The paper also points to a need for model enhancements to ensure that the benefits of the clean energy transition are shared across all segments of the population. Historically, disadvantaged communities have not had equal access to clean energy technologies. Energy storage can potentially promote equity by reducing energy costs in disadvantaged communities and enhancing their resilience during extreme weather.

However, these benefits may not be realized because capacity expansion models have traditionally focused on minimizing costs of grid investments. They have ignored equitable distribution of the grid's benefits and costs.

The path forward

The paper's recommendations can guide crucial research in the near term. Researchers at national laboratories and universities will develop and demonstrate ideas for model improvements. Promising concepts then lead to industry-sponsored research and adoption in commercial modeling tools. Argonne is developing advanced models and making them available as open-source software. This can speed industry adoption and ultimately the clean energy transition.

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