Flexible loads and renewable energy work together in a highly electrified future

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Demand flexibility offers high value in supporting a highly electrified, renewables-based U.S. power system, according to the sixth and final report in the National Renewable Energy Laboratory's (NREL's) Electrification Futures Study (EFS), "Operational Analysis of U.S. Power Systems with Increased Electrification and Demand-Side Flexibility."

The EFS was launched in 2017 to explore the potential impacts of widespread electrification in all U.S. economic sectors—commercial and residential buildings, transportation, and industry.

Data, assumptions, and findings throughout the study culminated in the final phase, in which NREL analysts used first-of-a-kind national-scale simulations of U.S. power system hourly operation, operational costs, and emissions to understand the interactions between different levels of electrification, demand-side flexibility, and renewable energy deployment.

"Overall, our results show that demand-side flexibility is valuable in supporting variable renewable energy to meet new electrified demands. These flexible loads are primarily from optimized vehicle charging and flexible operations of end-use equipment in buildings and industry," said Ella Zhou, NREL analyst and lead author of the paper. "In turn, this combination of high electrification and high renewable energy can drive significant carbon emissions reductions."

How could electrification impact the grid's ability to serve load or operating reserves?

EFS researchers first examined hourly power system operation without demand-side flexibility to test whether electrification—and associated changes in annual energy demand, hourly demand, operating reserve requirements, and the capacity mix—impacts the grid's ability to serve load or operating reserves.

Simulations show the future power systems envisioned in the EFS can serve nearly 100% of the load and 100% of the operating reserves with no demand-side flexibility, including on the days with the highest net load. Without demand-side flexibility, energy storage is critical in all

scenarios to balance load and provide operating reserves. Expanded power transfer capability across regions is also needed to meet increased electrified demand.

"Our results show the importance of all sources of grid flexibility—including transmission and inter-regional power transfers, flexible generation, storage, and demand-side sources of flexibility—will likely be important for operating a power system with high electrification and high renewable energy deployment," said Trieu Mai, NREL analyst and EFS principal investigator.

Curtailed renewable energy increases in all scenarios, particularly with high electrification; however, simulations indicate that curtailment can actually provide system flexibility by supporting optimal dispatch and grid services.

How might demand-side flexibility impact system operations?

Some studies (including a previous EFS report on the potential impacts of widespread electrification) have suggested that electrification could increase demand-side participation in power system planning and operations. In the final phase of the EFS, NREL researchers put the theory to the test by examining how flexible loads change system operations with electrification.

They found demand-side flexibility can provide energy services by shifting the timing of electricity demand. Demand-side flexibility can also provide operating reserves throughout the year, reducing the need for other generators such as natural gas plants and storage to provide these important grid services.

Increasing demand-side flexibility reduces the number of low-load hours for fossil fuel generators and reduces the number of starts and shutdowns of natural gas generators—resulting in up to $10 billion in annual operating cost savings in scenarios with the greatest demand-side flexibility.

How can renewables and demand-side flexibility work together to support a highly electrified grid?

EFS researchers found that demand-side flexibility—mainly from optimized vehicle charging and flexible operations of end-use equipment in buildings and industry—can alleviate the challenges of operating a highly electrified power system with high levels of variable renewable generation.

Flexibility can balance the grid during stressful periods by shifting the load to align with wind and solar generation, also reducing the risk of unserved energy and renewable curtailment. The complementary relationship between flexible electric vehicle charging and solar generation is particularly pronounced. In the absence of demand-side flexibility, electrification can lead to increased wind and solar curtailment

Finally, coupling demand-side flexibility and variable renewables can support decarbonizing the energy sector. In modeled scenarios with high electrification and high variable renewables, demand-side flexibility can lower annual carbon emissions by 8.3% by enabling greater utilization of renewable energy and avoiding fossil fuel consumption.

"Ultimately, the analysis highlights the value of increased integration and coordination of demand- and supply-side resources in future electric system planning and operations—particularly under high electrification

futures," Zhou said.

What's next for future studies of widespread electrification?

With widespread electrification, demand sectors may become increasingly dynamic and important participants in power system operations. Additional research is needed on flexible load operation, cost, and value across a wide range of subsectors and end uses. Future studies could also assess the grid reliability of highly electrified systems (nationally and regionally) at the transmission and distribution levels.

"The EFS modeling and scenarios have helped us take a leap forward in our understanding of the interplay between future demand for and supply of electricity," Mai said. "However, there's much more research needed on grid reliability planning, consumer adoption and behavior, and, more broadly, the roles for electrification, renewable energy, and flexible loads to decarbonize the energy system."

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