Team expands power grid planning to improve system resilience

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In September 2017, Hurricane Maria wrecked Puerto Rico's electric power grid, leaving almost all of the island's 3.3 million people without electricity. Credit: The (Puerto Rico) National Guard, CC BY 2.0, via Wikimedia Commons.

In most animal species, if a major artery is cut off from the heart, the animal will struggle to survive. The same can be said for many of our critical infrastructure systems, such as electric power, water and communications. They are networked systems with vulnerable connections.

This vulnerability was on display in September 2017 when Hurricane Maria wrecked Puerto Rico's electric power grid, leaving almost all of the island's 3.3 million people without electricity. The months-long blackout that followed was the worst in U.S. history.

Claire Trevisan, then a civil and environmental engineering undergraduate student in the Department of Engineering Systems and Environment at the University of Virginia, took note of Puerto Rico's plight. She asked her fourth-year capstone advisor, professor and associate director of the UVA Environmental Resilience Institute Andres Clarens, if they could use her project to study the problem.

Trevisan's capstone became the impetus behind a critical improvement to the energy system optimization models engineers use to plan infrastructure: Integrating impacts of future hurricanes into decisions about how grids are designed. An interdisciplinary team led by UVA Ph.D. student Jeffrey Bennett and including collaborators from North Carolina State University and the University of Puerto Rico at Mayagüez just published the research in the journal *Nature Energy*.

Their research demonstrates that modernizing power grids by using more renewable energy sources distributed across the landscape will cost less than repairing hurricane damage to a centralized grid.

Optimization models analyze data to find the cheapest way to deliver power under a set of constraints. Established models already account for costs related to construction, fuels, emissions and resilience—meaning the system's ability to recover if something disrupts operation—but the costs of predictable damage from events such as hurricanes, wildfires and floods are not built into existing models.

"In the past, people didn't know how often hurricanes would hit and what kind of damage they would do," Clarens said. "Now we do know those things, and we have the computing power to actually run simulations to say, 'Okay, if we build it this way, how much more is it going to cost your electricity customers?'"

How the grid is configured, or its topology, is integral to the team's research. When the United States was electrified a century ago, the most efficient way to deliver power to customers involved centralized generation plants feeding electricity over a huge network. That was true even with the risk of widespread outages when a main power station or transmission artery was disrupted.

The researchers wanted to examine what happens as grids are gradually redesigned to support more renewable energy sources, which is already underway in much of the country with solar and wind generation. The model can identify the combinations of generation sources that make the most economical sense when you anticipate the cost of hurricane repairs.

"The ability to do this is important because the frequency and severity of storms are increasing as a result of climate change," Clarens said.

Puerto Rico is a good case study to apply the model. The island has been in the path of 13 named storms over the past 25 years. The existing grid architecture remains outdated today, and the system relies on imported fossil fuels, making power expensive. On the other hand, Puerto Rico has abundant solar and wind resources.

One problem in planning, Bennett said, is that government policies such as emissions controls and market conditions—including decreasing costs of wind and solar energy production and storage—can create "stranded assets," expensive, built-to-last power plants that end up being retired early because they're no longer economical to run.

Given the large number of policy- and weather-related combinations that could happen in the future, the team needed to run the model on UVA's supercomputer, Rivanna.

"In our study, we simulate the likelihood and intensity of a storm hitting the grid in each five-year time step. The hurricane intensity is used to predict the wind speed and project damage to the electric grid infrastructure," Bennett said.

"The system then builds new infrastructure to be able to meet electricity demand. By considering combinations of hurricane intensities and probabilities, we are then able to project average electricity costs and examine how infrastructure investments vary. Our results show that hurricanes increase electricity costs by 32% based on historical hurricane trends, and more if you consider that storms are increasing in frequency and severity as a result of climate change. Transitioning to renewables and natural gas reduces costs and emissions regardless of hurricane frequency."

Although the research addresses wind damage to the electric power grid brought on by hurricanes, the team's approach can be applied to other weather- and climate-related disasters, Clarens said.

"With this approach to grid decision-making, you can also look at cases like wildfires in the American West and floods in the Midwest," he said. "There are changes to the climate that are impacting our engineered systems. We're trying to develop new tools and new insights that can help us to say, 'Look, the past is not a good model for the future anymore. We need new ways to simulate the future so that we can make the best decisions possible.'"

More information: Jeffrey A. Bennett et al, Extending energy system modelling to include extreme weather risks and application to hurricane events in Puerto Rico, *Nature Energy* (2021). DOI: 10.1038/s41560-020-00758-6

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