Testimony
before the
United States Senate
Committee on Energy and Natural Resources

For a hearing to examine the reliability, resiliency, and affordability of electric service in the United States amid the changing energy mix and extreme weather events

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Good morning Chairman Manchin, Ranking Member Barrasso, and members of the Committee. I am grateful to the Committee for inviting my testimony, and for your willingness to hear from someone who is neither a grid operator nor an electric industry participant, but someone whose perspective has been shaped by two decades of research, writing, and action motivated by a concern for necessary improvements in the reliability, affordability and environmental sustainability of electric service.

Congress took questions relating to the security of America's electricity supply seriously before more than a dozen states experienced energy shortages last month, but those events make this hearing all the more urgent. In 2012, 2017, and 2021 the National Academies of Science and Engineering published three separate reports on threats to the grid, resilience, and the future of electricity. [1] In its 2017 report, the Academies warned that U.S. electrical grids were increasingly "complex and vulnerable."[2]

Over the last 25 years, increasingly decentralized electricity generation in restructured electricity markets, along with growth in the number of regulatory institutions, has resulted in "divergent interests of federal, state, regional and local authorities," wrote the Academies in the 2021 report. Electricity experts are not able to clearly answer the question, "who is in charge of planning, developing and ensuring the integrity of the future power system?"[3] The Federal Energy Regulatory Commission and-the North American Electric Reliability Corporation are tasked to ensure electrical grid reliability and resilience. However, the Academies noted, "they too face short-term pressures and fiscal constraints."[4]

Meanwhile, many experts see in recent trends an inevitable transition away from coal and nuclear power plants, designed to function as baseload capacity, toward variable renewable energy sources with just-in-time natural gas back-up. The price of solar panels and wind turbines has declined 75 percent and 25 percent, respectively, since 2011.[5] The U.S. Energy Information Administration ("EIA") estimates renewables will be a larger source of electricity than natural gas in the United States by 2050. In that same time, EIA projects renewable electricity will rise from 28 percent to 50 percent of global generation.[6]

But events in mid-February throughout the center of the country, including Texas, and last summer in California, suggest that attempting to replace nuclear plants with variable renewable energy sources could make electricity grids less resilient. While energy sources across all categories failed in mid-February, they didn't all fail equally. The capacity factors for nuclear, natural gas, coal, and wind in Texas during the four days of load shedding during the cold snap were 79 percent, 55 percent, 58 percent, and 14 percent, respectively.[7]

Nuclear plants are among the most reliable components of America's power grids. Nuclear plants operate as a national fleet at 94 percent annual capacity factor, thanks to tightly choreographed refueling operations that barely interrupt eighteen-month continuous uptime at most facilities.[8] The hardening required of nuclear plants first in response to 9/11 and then in response to the loss of Fukushima Daiichi in 2011 has further ensured their contribution to reliability, resiliency, and affordability.[9]

Although Texas lost one of four of its nuclear reactors after cold water affected a sensor, automatically shutting down the reactor, it returned to service within 36 hours, and thus in time to help end the power cuts. Meanwhile, nuclear reactors in other cold snap states, Nebraska, Kansas, Arkansas, Missouri, Illinois, Minnesota, Wisconsin, Ohio, and Michigan, operated normally.[10]

Even if all Texas wind turbines had been winterized, it is unlikely that they would have contributed significantly to electricity supply because wind speeds in cold snaps are so low. It is for that reason that grid operators do not rely on wind turbines to provide more than trace amounts of power during those periods. And, indeed, while wind turbines north of Texas functioned more or less as intended, during the cold snap, they produced very little power for their grids.[11]

Part of the reason for inadequate in-state electricity supply in California last August was that state regulators had closed in-state baseload power plants. "People wonder how we made it through the heat wave of 2006," said the CEO of California's grid operator, CAISO, at the time. "The answer is that there was a lot more generating capacity in 2006 than in 2020.... We had San Onofre [nuclear plant] of 2,200 megawatts, and a number of other plants, totaling thousands of megawatts not there today."[12]

Electricity lost from the closure of California's San Onofre nuclear plant undermined electricity affordability as well as reliability. It was mostly replaced by electricity from natural gas, which raised the costs of generating electricity by $350 million.[13]

California regulators in 2020 over-estimated the contribution they could reasonably expect from renewables. "The situation could have been avoided," said the CEO of CAISO. "For many years we have pointed out that there was inadequate supply after electricity from solar has left the peak. We have indicated in filing after filing after filing that procurement needed to be fixed. We have told regulators over and over that more should be contracted for. That was rebuffed. And here we are."[14]

Texas and California show that policymakers and regulators have struggled to manage the grid's high and rising level of complexity, with troubling consequences. Are we so confident that reducing energy diversity while pushing more variable energy onto electrical grids is the best path forward in terms of reliability, affordability, and sustainability?

Affordability and Sustainability: Lessons from Around the World

California offers a relevant real-world picture of the impacts of significantly expanding reliance on variable renewable energy sources while reducing reliance on nuclear energy. California significantly expanded its use of renewable energy starting in 2011. That year, California generated 13.5 percent of its in-state electricity from all non-hydroelectric renewables. In 2020, California generated 39 percent of its in-state electricity from them.[15] As a consequence of purchasing and integrating variable renewable energy onto its grid, California's electricity prices rose 39 percent in the decade from 2011 to today, despite persistently-low-priced natural gas, which made doing so easier and more affordable.[16]

California retail electricity prices rose eight times faster than the nationwide average between 2011 and 2020. Today, California households pay 55 percent more than the national average per kilowatt-hour of electricity. In 2020, California's electricity prices rose 7.5 percent, compared to just 0.25 percent in the other 49 states.[17]

The impact of variable renewable energy sources on electricity prices can be seen in the more than two-dozen states that have had in place renewable energy mandates. "Cumulatively," wrote the authors of a University of Chicago report on the impact of variable renewables on electricity prices, "consumers in the twenty-nine states studied paid $125.2 billion more for electricity than they would have in the absence of the policy." The study authors concluded that higher variability was the main driver of higher costs.[18]

With France and Germany, we can compare two major (sixth and fourth largest) economies, which are highly proximate geographically and at similarly high levels of economic development, on a decades-long time scale.[19] France spends just over half as much per kilowatt-hour for electricity that produces one-tenth of the carbon emissions of German electricity.[20] Electricity prices in Germany have risen 50 percent in the 15 years since 2007.[21] In 2019, German electricity prices were 45 percent higher than the European average.[22]

A study published in late 2019 found that Germany's nuclear phase-out is costing its citizens $12 billion per year.[23] In response to Fukushima, the Japanese government shut down its nuclear plants and the cost of electricity went up. As a result, 1,280 people died from cold from unaffordable electrical power, researchers calculate, between 2011 and 2014.[24]

Some of the cost of variable renewable energy sources comes in the form of the transmission lines they require. With funding from Bill Gates, the analytical group Breakthrough Energy Sciences last week estimated the U.S. could reduce carbon emissions 42 percent and generate 70 percent of its electricity from carbon-free sources by 2030. But Breakthrough Energy calculated that the cost of new transmission, distribution, and storage would be $1.5 trillion.[25]

And that amount does not include the costs associated with local and state political opposition. In their 2021 report, the Academies noted that while variable renewable energy sources like solar and wind appear to be popular in public opinion surveys, "political uncertainties concern the durability of policy support for renewables when deployed at large scales, especially where it is highly visible and potentially conflicts with other land uses."[26]

Local community and environmental opposition to transmission is a national and international phenomenon. A federal judge last year blocked a transmission line proposed to be built straight through whooping crane habitat in Nebraska because transmission lines are the number one cause of mortality among whooping cranes.[27] Of the 7,700 new kilometers of transmission lines Germany needed for the energy transition, only eight percent have been built. Community and conservationist resistance has been a significant factor.[28]

The land requirements of industrial renewable energy projects are two orders of magnitude larger than those of nuclear and natural gas plants. Industrial solar and wind projects require between 300 and 400 times more land than nuclear plants.[29] If the United States were to try to generate all of the energy it uses with renewables, 25 percent to 50 percent of its land would be required, according to the best-available study by a leading energy analyst and advisor to Bill Gates.[30] By contrast, today's energy system requires just 0.5 percent of land in the United States.[31]

Many energy experts are enthusiastic about solar panels, but new information has called the social and ethical value of the technology into question. The average annual pay of a power plant operator is $79,400 per year versus $46,900 for a solar installer, according to Bureau of Labor Statistics data analyzed by NBC News. [32] That appears to be in part because so much of the economic value of solar panels is at the place of manufacture, not installation.[33]

As troubling is evidence that cost declines of solar panels, most of which are made in China, appear to stem from the involuntary labor of a persecuted Muslim minority, the Uighurs. In January the U.S. State Department deemed China's treatment of the Uighurs to be genocide.[34]

Ninety-five percent of the global solar panel market contains Xinjiang silicon. While there has been talk of bringing solar manufacturing to the U.S. and Europe, doing so would significantly increase prices.[35] There is proposed Senate legislation to ban imports from Xinjiang unless they are certified, and similar legislation in introduced into the House. But given the fungible nature of silicon, some fear the Chinese government could evade such controls.[36]

And more decentralized electrical generation makes the grid more vulnerable. "We're adding a lot of stuff at the grid edge," said the lead author of the Academies' 2012, 2017, and 2021 reports, "and if I start building microgrids does that increase my potential vulnerability? The answer is, 'Yes, of course. The more complicated I make it, the more attack surfaces and, hence, the more possibilities of failure.'"[37]

The Costs of Maintaining Reliability With Variable Renewable Energies

While the switch from nickel-cadmium to lithium-ion batteries allowed for the proliferation of cell phones, laptops, and other electric appliances, it has not allowed and will not allow for the cheap storage of the grid's electricity. One of the largest lithium battery storage centers in the world is in Escondido, California. But it can only store enough power for about twenty-four thousand American homes for four hours.[38]

And storage does not easily solve the problem of long-term, seasonal variability. In January and February of this year, Germany's renewables produced just two-thirds of the electricity they produced in January and February of 2020, despite a four percent increase in solar panel and wind turbine capacity, simply because of annual variability of wind and sun.[39]

Germany has only been able to manage the seasonal fluctuations from intermittent renewables by maintaining a large and diverse fleet of coal, natural gas, and nuclear power plants. Germany added 150 percent of its total capacity in coal, natural gas, and nuclear in the form of new wind and solar capacity, which was part of why Germany's electricity prices have risen to the highest levels in Europe.[40]

One study by a group of climate and energy scientists found that when taking into account continent-wide weather and seasonal variation, for the United States to be powered by solar and wind, while using batteries to ensure reliable power, the battery storage required would raise the cost to more than $23 trillion.[41]

Most proponents of variable renewable energy thus look elsewhere for storage solutions. The most influential proposal for 100 percent renewable energy in the U.S. was created by a Stanford professor who relied on the conversion of existing hydroelectric dams into giant batteries.[42]

But in 2017, scientists writing in the *Proceedings of the National Academies of Science* observed that the 100 percent renewable proposal rested upon the assumption that we can increase the amount of power from U.S. hydroelectric dams ten-fold when, according to the Department of Energy, the real potential is just one percent of that. Without all that additional hydropower, the 100 percent renewables proposal does not work on its own terms.[43]

California is a world leader when it comes to renewables and has a major network of dams but hasn't converted them into batteries because you need the right kind of dams and reservoirs, and even then, it's an expensive retrofit. In addition, there are many other uses for the water that accumulates behind dams, namely irrigation and water supply for cities. Without large-scale ways to back up solar energy, California has had to block electricity coming from solar farms when it's extremely sunny, and pay neighboring states to take it, in order to avoid adding much energy on the grid during hours of peak solar production.[44]

Germany will have spent $580 billion on renewables and related infrastructure by 2025, according to energy analysts at Bloomberg[45] and Germany generated 37.5 percent of its electricity from wind and solar in 2020, as compared to the 70 percent France generates from nuclear.[46] Had Germany invested the $580 billion it's spending on renewables and their grid upgrades into new nuclear power plants instead, it could be generating 100 percent of its electricity from zero-emission sources and have sufficient zero-carbon electricity to power all of its cars and light trucks (if electrified) by 2025, as well.[47]

From this information we can gain a clearer picture of electric reliability, resiliency, and affordability. What tends to make electric grids more reliable, resilient, and affordable is the generation of electricity by a few large, efficient plants with the minimal amount necessary of wires and storage. What tends to makes grids less reliant, resilient, and affordable is significantly increasing the number of power plants, wires, storage mechanisms, people, and organizations required for operating them.

Loss of Nuclear Plants Threatens Reliability, Affordability, and Sustainability

The U.S. reduced its greenhouse gas emissions between 2000 and 2020 more than any other nation in history in absolute terms, according to preliminary analysis by the Rhodium Energy Group. U.S. greenhouse gas emissions in 2020 were 21 percent below 2005 levels, which is nearly a one-quarter larger reduction than that promised by the United States under the Copenhagen Accord target of a 17 percent reduction. Even without the pandemic, emissions would have declined 3 percent in 2021, Rhodium estimates.[48]

The premature closure of nuclear plants threatens reliability, resiliency, affordability, as well as America's reductions in greenhouse gases. Without state or federal action, the US will close twelve nuclear reactors by 2025, which constitute 10.5 gigawatts of highly-reliable, low-cost, and low-carbon power.[49] Despite ratcheting regulations, the cost of operating America's nuclear plants fell from $44.57 per megawatt-hour on average in 2012 to $30.42 in 2019.[50]

But restructured wholesale electricity markets, low-priced natural gas, and subsidized variable renewable energy have undermined the economics of nuclear power plants, including those that prevented wider power outages during the recent cold snap. Those plants are Byron and Dresden in Illinois, Palisades in Michigan, Davis-Besse and Perry in Ohio, and

Beaver Valley in Pennsylvania. If those nuclear plants are lost, grids may suffer from energy shortages during future heat waves or cold snaps.

The U.S. might achieve higher levels of electricity resiliency, reliability, affordability, and sustainability by reconsidering whether nuclear power plants are really so unattractive, and wholesale markets really so efficient.

In restructured markets, as more renewables are integrated into the system, the costs to keep reliable baseload power plants in service keep rising. In Texas, there was no mechanism to ensure that baseload plants were ready for the weather. As a result, many were in seasonal shutdown for repairs, or had not been winterized. In Germany, the government has had to resort to various mechanisms to prevent utilities from going bankrupt.[51]

Restructured electricity markets did not result in the oft-promised lower prices in California, Texas, or the U.S. as a whole.[52] And from 2010 to 2019, consumers from across the U.S. who purchased electricity from electricity retailers paid $19.2 billion more than they would have had they purchased power from legacy utilities, according to a recent *Wall Street Journal* analysis.[53]

According to the Academies, the older model of regulated and vertically integrated electric utilities were better at taking a "longer-term perspective" that can take into account "broader societal benefits" than today's tangle of federal and state agencies, electric utilities, and power companies.[54]

While a significant amount of electricity policy is determined by the states, the Senate can play a constructive role in maintaining the reliability, resiliency, affordability, as well as the diversity and sustainability, of our grid by taking policy action now to keep operating the nuclear plants that have been critical to preventing power outages in recent years.

Thank you again for the opportunity to testify and I look forward to your questions.

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