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Exploring small-scale solar's potential to improve grid resilience during a deep freeze event

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Cover image: Austin, Texas, after Winter Storm Uri in February 2021. Credit: Roschetzky Photography via Shutterstock, https://www.shutterstock.com/image-photo/snow-covered-landscape-above-austin-texas-1920444362.

Solar energy is a remarkable resource. It is abundant – the U.S. has the technical potential to meet its 2020 electricity needs 78 times over with solar power alone.[1] As a clean and renewable energy source that can help reduce reliance on dirty fossil fuels, it helps reduce pollution and protect the environment. Rooftop solar is particularly environmentally friendly, since it takes advantage of already-developed rooftops and leaves open spaces undisturbed. One additional benefit that small-scale, distributed solar offers to communities is helping to relieve strain on the power grid during times of stress. This paper explores how maximizing rooftop solar potential could magnify that particular benefit, using the 2021 Texas power crisis as a case study.

How Texas lost power in February, 2021

In February 2021, an Arctic cold front brought extreme temperatures, snow, sleet, and freezing rain to large parts of Texas and the southern U.S.[2] The deep freeze led to widespread power outages, and more than 4.5 million Texans ultimately lost power for up to four days.[3]

Power outages began as generating units throughout Texas failed due to extreme temperatures.[4] System operators implemented rotating blackouts in order to avoid total grid failure. At the same time, methane gas supply fell short of demand, as vulnerable production, processing and transportation infrastructure was disrupted by the freeze at the same time that demand spiked.[5] In part, demand competition for gas for heating and for generating electricity led to fuel shortages in both systems.[6]

While gas- and coal-fired power plants, wind turbines, solar facilities and nuclear power stations all contributed to reduced power generation during the freeze, gas failures led to the largest gaps in power supply. Gas-fired generating units made up 55% of all unplanned outages and derates by capacity.[7]

The impacts of these power losses were nothing short of catastrophic. The outages were linked to the majority of more than 200 deaths that occurred during the storm.[8] Estimated damages totaled as much as $195 billion.[9]

The 2021 power crisis was the fourth cold-weather event to disrupt U.S. power grids in just ten years,[10] including a 2011 deep freeze that similarly led to rolling blackouts in Texas.[11] And, as climate change accelerates, extreme weather events will become increasingly common and difficult to predict.[12] Preventing devastation on the scale of that seen in the 2021 Texas power crisis during future cold snaps is of the utmost importance. One potential solution worth exploring is increasing the capacity of distributed energy resources such as rooftop solar and storage.

Solar's role in limiting the fallout

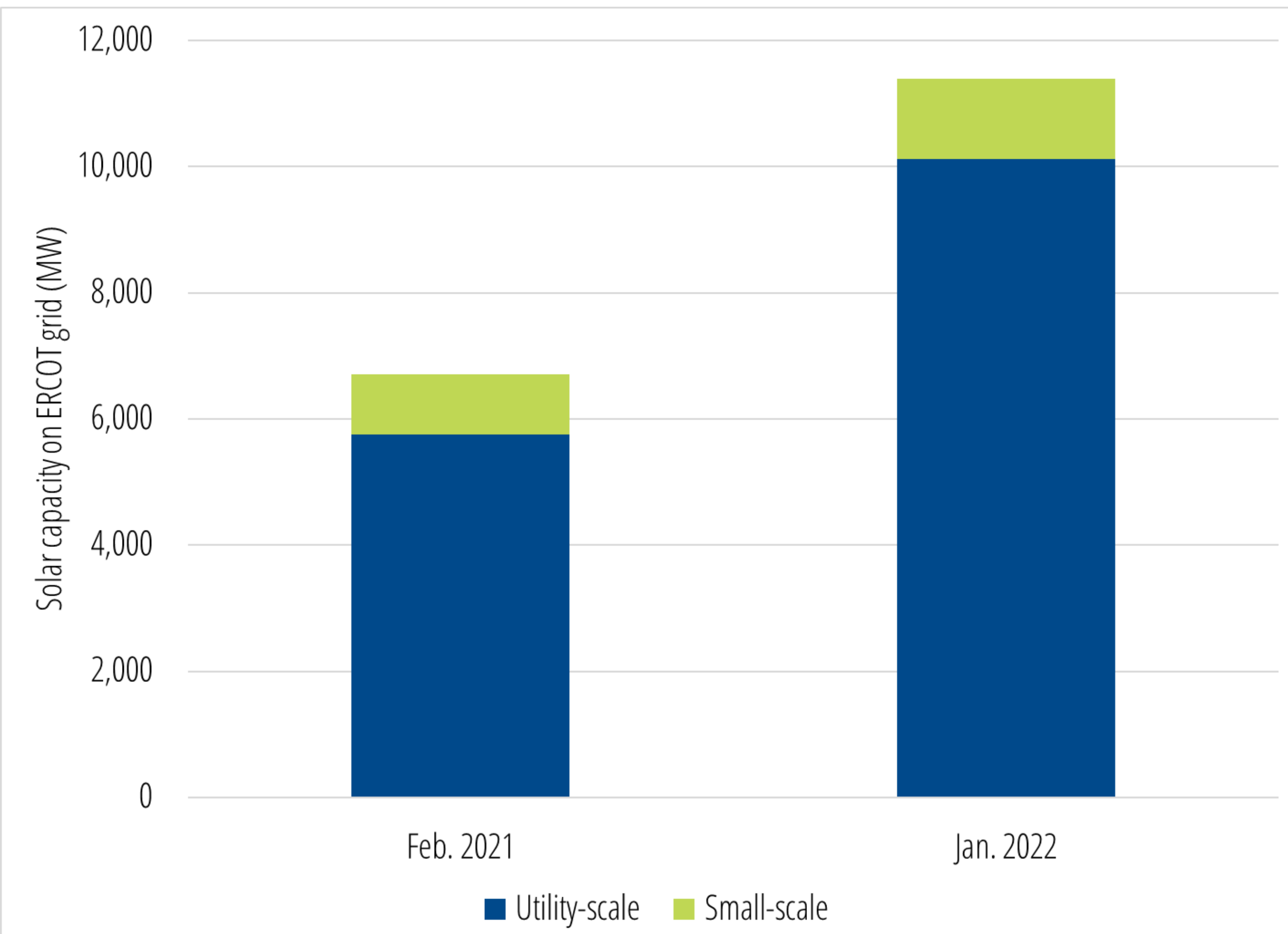
At the time of the February 2021 winter storm, a total of 6,349 MW of solar capacity was installed on Texas rooftops or in utility-scale installations across Texas.[13] Actual solar power generation, including both utility-scale and small-scale, totaled approximately 780,000 MWh for the month of February 2021,[14] or enough to power 873,120 average American homes.[15]

While solar only supplied a small portion of Texas's power grid during the storm and its output fluctuated along with that of other power sources, the gap between supply and demand would have been even greater without the energy that solar provided.

The recent rapid growth in solar energy means that Texas entered the winter of 2022 with significantly greater solar capacity to meet this winter's challenges. The amount of installed utility-scale generating capacity in the Electric Reliability Council of Texas (ERCOT) region – which covers about 90% of the state's grid by electric load[16] – was 76% higher at the end of January 2022 than it was at the beginning of January 2021.[17] And the amount of small-scale solar capacity was 31% higher at the end of 2021 than it was at the end of 2021's first quarter.[18]

As a result, Texas would now produce approximately 70% more solar electricity than it did a year ago under the same conditions as the February 2021 freeze event - increasing the benefit solar delivers to the environment and the grid.

Figure 1. Growth in solar generation capacity, ERCOT (small-scale based on end of Q4 2021)[19]

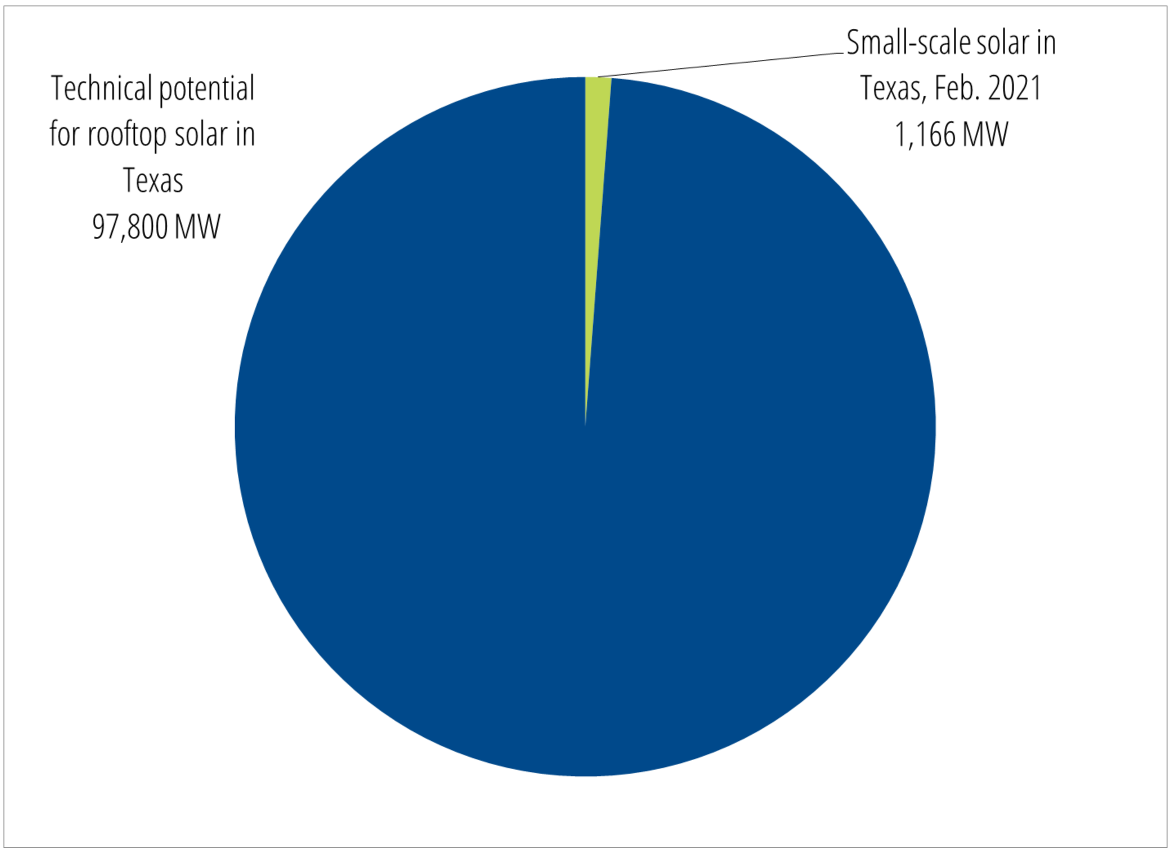


Rooftop solar's potential to limit future blackouts

While solar power has grown 123-fold in Texas over the last decade,[20] the state's vast solar potential remains largely untapped. In addition to the state's massive potential for utility-scale solar power, there are also millions of Texas rooftops that are suitable for solar power.

In total, Texas's technical potential for rooftop solar generation alone is 97,800 MW[21] – more than 15 times the total installed capacity at the time of the 2021 power crisis.[22] **This amount of rooftop solar could produce the equivalent of about one third of the state's total electricity use in 2020.[23]** As grid operators and policymakers consider measures to help prevent future blackouts, it's worth asking: How much of a role could solar play if we took advantage of every suitable rooftop?

Figure 2. Rooftop solar capacity in Texas, Feb. 2021, versus rooftop solar technical potential[24]



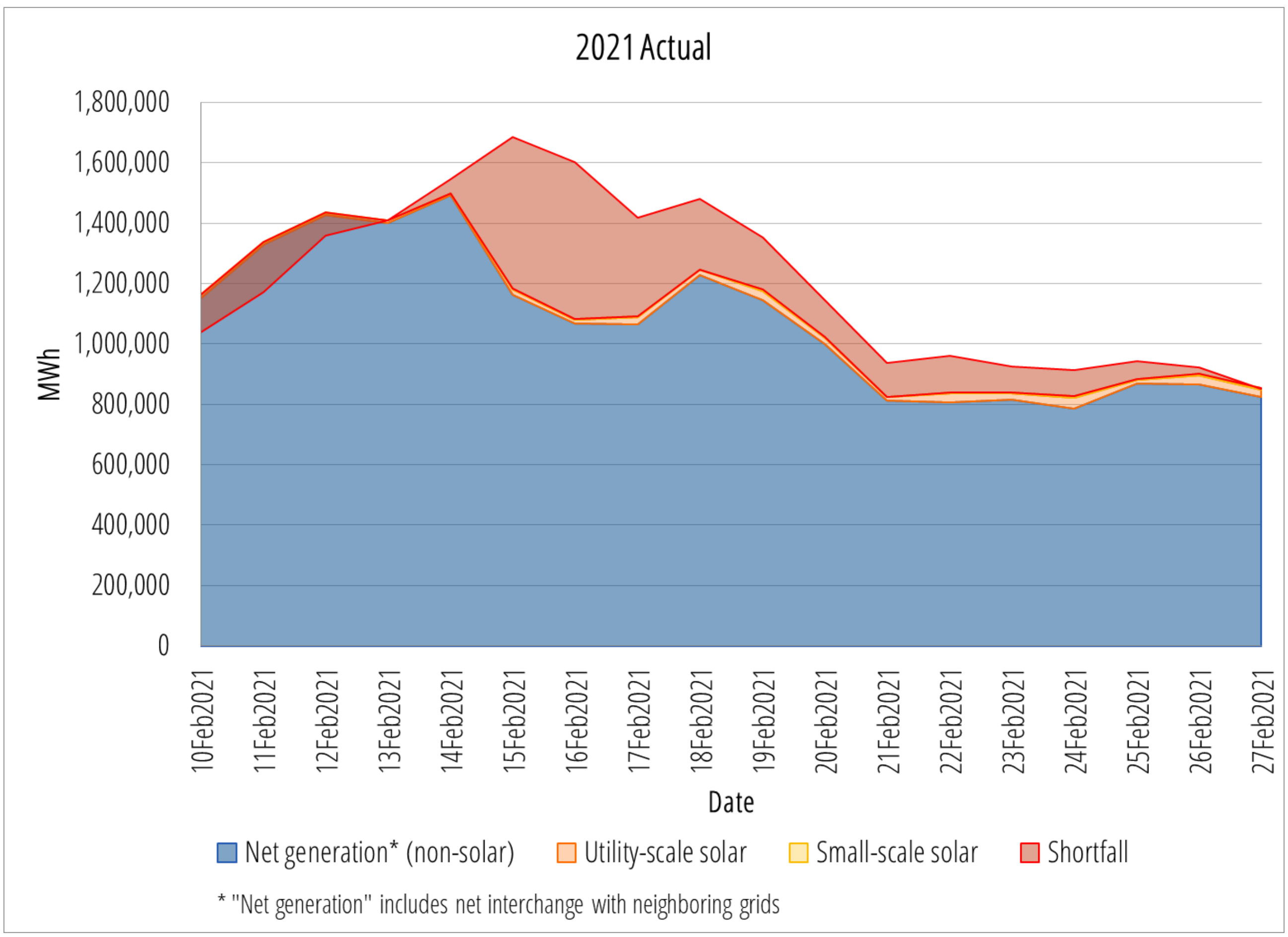
During February 2021, small-scale solar resources in the state of Texas produced 17% of their maximum capacity– what they could generate if they had full, direct sunlight 24/7– on average.[25] Utility-scale resources produced an average of 18.6% of their capacity.[26] While these capacity factors sound low, they're not unexpectedly low for a winter month such as February, as solar panels would be expected to produce less than half the time due to the shorter length of day and less intense sunlight.

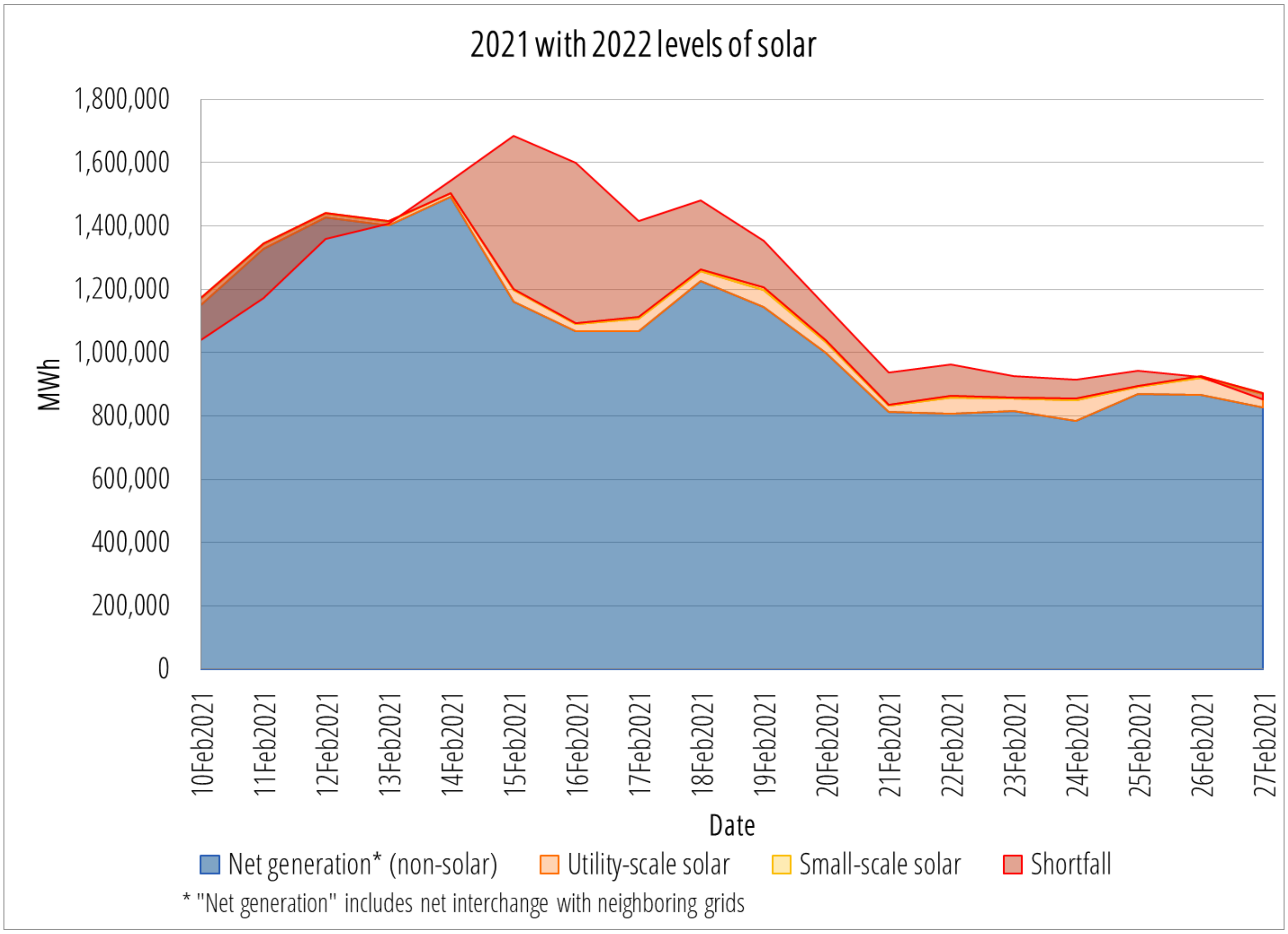
On the worst days of the freeze for solar generation, however, the daily capacity factor for the state's utility-scale power plants dipped even further, to 5% of maximum capacity.[27]

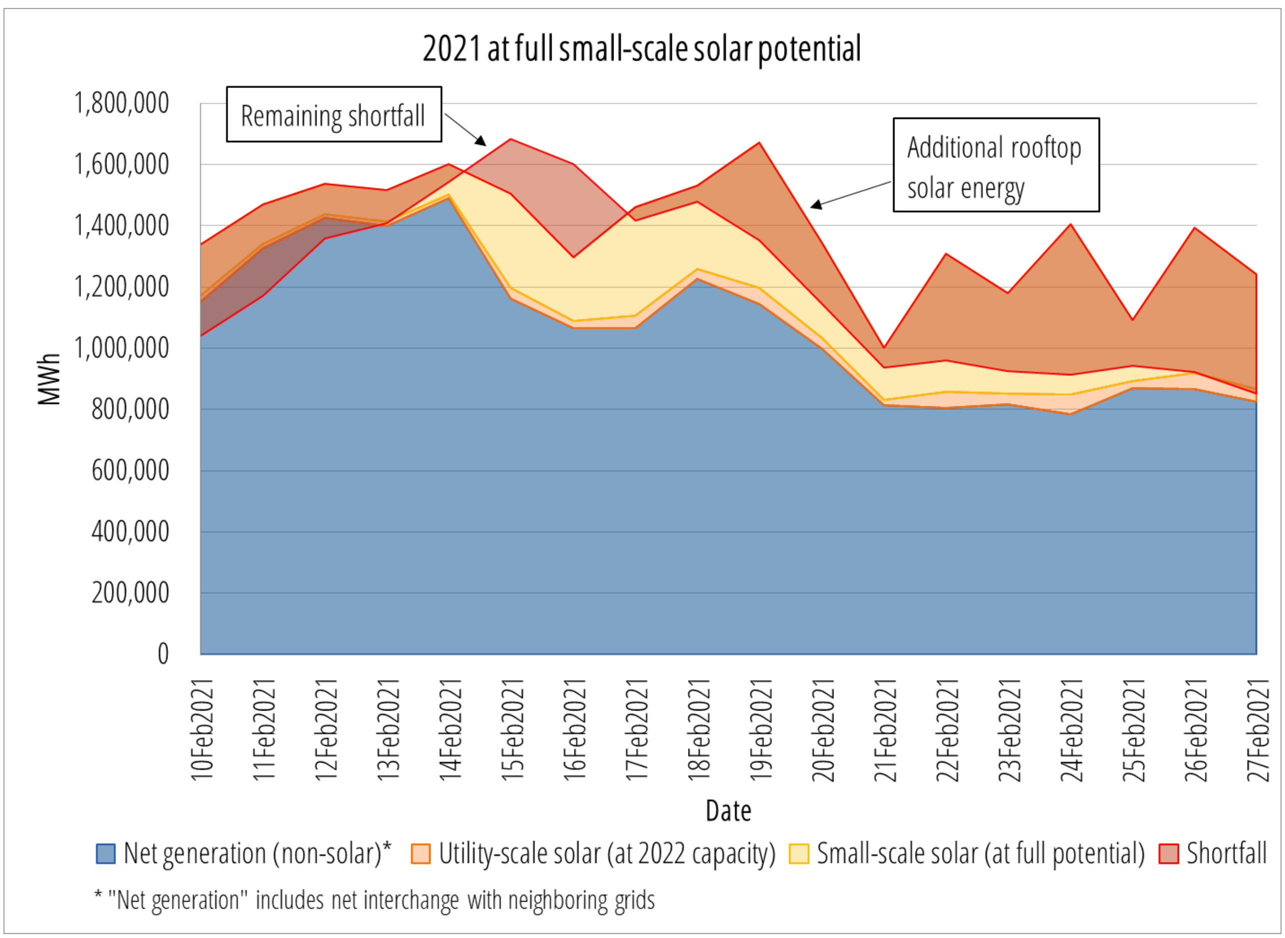
Even assuming similar capacity factor constraints during a future deep freeze event, tapping Texas's full rooftop solar potential would have made a world of difference. **There were 13 days during mid- to late February during which power production fell short of forecasted demand; On 11 of those days, rooftop solar could have supplied more than enough power to meet the daily shortfall in power demand, on aggregate.**[28] And, during the two days when the gap between supply and demand was greatest (Feb 15-16, 2021), rooftop solar could still have made up between 40%- 60% of the gap.[29]

The charts below show the actual daily power balance on the ERCOT grid during February 2021 and the estimated power balance under two scenarios of increased solar deployment. The first chart shows actual conditions during February 2021. The second shows the amount of solar power that would have been available in February 2021 had February 2022 levels of solar been present. The third chart shows the amount of solar power that would have been available had Texas tapped its full technical potential for rooftop solar.

Figure 3. Grid conditions during February 2021: actual, at 2022 levels of solar, and at full rooftop solar potential




2021 with 2022 levels of solar
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
MWh
10Feb2021
11Feb2021
12Feb2021
13Feb2021
14Feb2021
15Feb2021
16Feb2021
17Feb2021
18Feb2021
19Feb2021
20Feb2021
21Feb2021
22Feb2021
23Feb2021
24Feb2021
25Feb2021
26Feb2021
27Feb2021
Date
Net generation* (non-solar)
Utility-scale solar
Small-scale solar
Shortfall
* "Net generation" includes net interchange with neighboring grids


2021 at full small-scale solar potential
Remaining shortfall
Additional rooftop solar energy
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
MWh
10Feb2021
11Feb2021
12Feb2021
13Feb2021
14Feb2021
15Feb2021
16Feb2021
17Feb2021
18Feb2021
19Feb2021
20Feb2021
21Feb2021
22Feb2021
23Feb2021
24Feb2021
25Feb2021
26Feb2021
27Feb2021
Date
Net generation (non-solar)*
Utility-scale solar (at 2022 capacity)
Small-scale solar (at full potential)
Shortfall
* "Net generation" includes net interchange with neighboring grids

The red area at the top of each chart indicates the shortfall between the forecast power consumption and the amount of electricity actually available to the Texas grid (net generation plus limited imports from neighboring grids) during February 2021. In the first chart, solar power (the yellow and orange areas) makes a small but noticeable contribution to addressing the demand shortfall. In the second chart, solar makes a larger contribution, indicating that if last year's freeze conditions had occurred today, the recent addition of small-scale and utility-scale solar power in Texas would help to meet the challenge. The third chart shows that by taking advantage of Texas' full potential for rooftop solar, the state could have further reduced the dangers posed by the freeze, while generating additional electricity that could be used to reduce demand from fossil fuel-fired power plants and reduce emissions of greenhouse gasses and pollutants that harm human health.

These figures are based on daily electricity production and consumption. Texas' electricity grid must remain in balance on an hour-by-hour and minute-by-minute basis. Because solar panels do not generate power at night, solar power (without associated energy storage) would not have been able to meet all of Texas' energy needs during last year's freeze. However, solar power did contribute to meeting power demand on 13 of the 20 peak load hours during the February 2021 Texas freeze.[30]

Increasing the amount of solar energy that can be stored for later use - including through the use of utility-scale and distributed battery storage (as well as, potentially, the use of vehicle-to-building and vehicle-to-grid capabilities with electric vehicles[31]) - could allow solar power to play a role in addressing grid challenges even during times when the sun isn't shining.

Building a better grid

While Texas may never realize 100% of its rooftop solar potential, even taking advantage of just half of suitable roofs would provide a tremendous amount of beneficial clean energy.

Rooftop solar provides unique benefits to the electric grid that can be especially helpful in the face of extreme weather events. By generating electricity right where it's needed, small-scale solar reduces demand for electricity from the power grid, thereby reducing the need for centralized power plants and transmission.[32] Those benefits help reduce the costs and improve the reliability of our power system all year, but are especially helpful for resilience during times of high grid stress.

As a clean and renewable resource, solar energy reduces global warming pollution, and also reduces emissions of dangerous air pollutants such as nitrogen oxides, mercury and particulate matter.[33] **Given these benefits and the enormous amount of available solar potential, rooftop solar has an important role to play in addressing energy challenges like those experienced in Texas in 2021.**

Solar is, however, far from the only tool that can and should be deployed to help build a better, more resilient grid in Texas and beyond. Distributed energy storage, in the form of batteries, will be necessary to maximize the resilience benefits of rooftop solar and enable them to supply power even when the sun isn't shining. Even solar plus storage won't be enough to ensure that intermittent resources like sunshine can supply energy around the clock – a balanced, resilient grid will need to incorporate multiple, complementary resources, including wind. Studies have also shown that expanding the geographic breadth of the grid by increasing transmission capacity and connecting regional grids can also improve efficiency and reliability.[34] Finally, reducing and managing energy demand will be important strategies for improving stability, especially during extreme weather events.[35]

Conclusions

The power crisis that took place in Texas in 2021 offered a reminder of the fragility of the energy systems that most Americans depend on. During extreme weather events, the network of power plants, transmission lines and fuel pipelines that power our lives can fail, and the consequences can be dire. Fortunately, we have the tools to greatly reduce those risks and build a truly resilient energy system.

Rooftop solar is one of those tools. Taking advantage of the nation's vast rooftop solar potential would not only help build a more reliable grid, but also reduce other environmental and public health impacts of our current energy system. **Rooftop solar is a key building block of a cleaner, greener, more resilient energy future – in Texas and across the U.S.**

Appendix

Methodology

Day-ahead forecast demand, actual demand, net generation, electricity interchange and net generation from utility-scale solar in the ERCOT balancing area by day were obtained from the U.S. Energy Information Administration's *Hourly Electric Grid Monitor* on 25 January 2022.[36] The "shortfall" in electricity production in ERCOT during the freeze was calculated by subtracting the sum of net generation in the region and net interchange from day-ahead forecast demand.

Utility-scale solar capacity of 5,747 MW in the ERCOT region for February 2021 is based on installed capacity as of 1 February 2021 from ERCOT, *PVGR Integration Report, 2/1/2021*, accessed at https://www.ercot.com/misapp/GetReports.do?reportTypeId=19325&reportTitle=PVGR%20Integration%20Report%20&showHTMLView=&mimicKey/.

Small-scale solar capacity of 965 MW based on capacity of "unregistered" distributed solar from ERCOT, *Unregistered DG Installed Capacity Quarterly Report, Q1 2021*, downloaded from https://www.ercot.com/misapp/GetReports.do?reportTypeId=13544&reportTitle=Unregistered%20DG%20Installed%20Capacity%20Quarterly%20Report&showHTMLView=&mimicKey, 31 January 2022.

The data above were used to calculate the capacity factor of utility-scale solar in the ERCOT region for each day during the February 2021 freeze event.

To account for differences in the capacity factor between utility-scale and rooftop solar panels, we calculated average capacity factors for both types of solar installations in the state of Texas (note: not the ERCOT region) during February 2021, using data from the U.S. Energy Information Administration (EIA). Utility-scale solar capacity was obtained from EIA, *Preliminary Monthly Electric Generator Inventory (Form-860M data) for February 2021*, downloaded from https://www.eia.gov/electricity/data/eia860m/, 25 January 2022. Utility-scale net generation was obtained from EIA, *Electricity Data Browser*, accessed at https://www.eia.gov/electricity/data/browser/#/topic/0?agg=1,0,2&fuel=004&geo=0000000002&sec=o3g&freq=M&start=200101&end=202111&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0, 1 February 2022. Small-scale solar generation and capacity for February 2021 were obtained from EIA, *Form EIA-861M detailed data, Small-scale PV estimate for 2021*, accessed at https://www.eia.gov/electricity/data/eia861m/, 25 January 2022. The capacity factor for small-scale solar (16.9%) was 9% lower than the capacity factor for utility-scale solar plants (18.6%).

The technical potential for rooftop solar on Texas buildings was based on Pieter Gagnon, et al., National Renewable Energy Laboratory, *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*, January 2016, accessed at https://www.nrel.gov/docs/fy16osti/65298.pdf. The amount of additional solar energy that could have been produced in February 2021 by building out Texas' technical potential was calculated by multiplying the technical potential estimate in MW (minus the capacity of existing distributed solar in the ERCOT region) by the daily capacity factor for utility-scale solar estimated above, then by 91% (to account for the lower capacity factor for distributed solar), and finally by 24 hours. Note that this estimate may be conservative in that the power density of solar modules has increased significantly since publication of the NREL technical potential study in 2016.

The degree to which small-scale solar could have alleviated the shortfall in electricity generation was calculated by subtracting the estimated additional distributed solar generation from the shortfall as calculated above.

Notes

1 Gideon Weissman, Frontier Group and Emma Searson, Environment America Research & Policy Center, *We Have the Power: Realizing clean, renewable energy's potential to power America*, June 2021, p.1, accessed 2 February 2022 at https://environmentamerica.org/sites/environment/files/We_Have_The_Power_2021-Environment_America_Frontier_Group.pdf.

2 Houston/Galveston TX Weather Forecast Office, National Weather Service, "Valentine's Week Winter Outbreak 2021: Snow, Ice, & Record Cold," archived at https://web.archive.org/web/20220205173610/https://www.weather.gov/hgx/2021ValentineStorm.

3 Federal Energy Regulatory Commission, North American Electric Reliability Corporation and Regional Entities; *The February 2021 Cold Weather Outages in Texas and the South Central United States*; 16 November 2021, p. 10, accessed 2 February 2022 at https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and.

4 Ibid., p. 11.

5 Ibid., p. 14.

6 Ibid., p. 11.

7 Ibid., p. 15-16.

8 Ibid., p. 235.

9 City of Austin and Travis County, *City of Austin and Travis County Winter Storm Uri After-Action Report & Improvement Plan Technical Report*, 27 October 2021, p. 7, archived at http://web.archive.org/web/20211115053458/http://www.austintexas.gov/sites/default/files/files/HSEM/Winter-Storm-Uri-AAR-and-Improvement-Plan-Technical-Report.pdf.

10 See note 3, p. 9.

11 Tony Dutzik, Frontier Group, Blog Post: "Texas' Deep Freeze and the Nation's Energy Future," 8 February 2011, accessed 2 February 2022 at https://frontiergroup.org/blogs/blog/fg/texas%E2%80%99-deep-freeze-and-nation%E2%80%99s-energy-future.

12 Katherine Hayhoe, et al., U.S. Global Change Research Program, *Third National Climate Assessment: Extreme Weather*, 6 May 2014, accessed 2 February 2022 at https://nca2014.globalchange.gov/highlights/report-findings/extreme-weather.

13 Small-scale solar generation and capacity for February 2021 were obtained from U.S. Energy Information Administration, *Form EIA-861M detailed data, Small-scale PV estimate for 2021*, downloaded 25 January 2022 from https://www.eia.gov/electricity/data/eia861m/; Utility-scale solar capacity was obtained from U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory (Form-860M data) for February 2021*, downloaded 25 January 2022 from https://www.eia.gov/electricity/data/eia860m/.

14 Small-scale solar generation and capacity for February 2021 were obtained from U.S. Energy Information Administration, *Form EIA-861M detailed data, Small-scale PV estimate for 2021*, downloaded 25 January 2022 from https://www.eia.gov/electricity/data/eia861m/; Utility-scale net generation was obtained from U.S. Energy Information Administration, *Electricity Data Browser*, accessed 1 February 2022 at https://www.eia.gov/electricity/data/browser/#/topic/0?agg=1,0,2&fuel=004&geo=0000000002&sec=o3g&freq=M&start=200101&end=202111&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0.

15 Calculation: 779,696 MWh = 779,696,000 kWh; 779,696,000 kWh / 893 kWh per home per month = 873,120 homes for 1 month.
893 KWh per home per month from: U.S. Energy Information Administration, Frequently Asked Questions (FAQS), “How much electricity does an American home use?”, last updated 7 October 2021, accessed 2 February 2022 at https://www.eia.gov/tools/faqs/faq.php?id=97&t=3.

16 Electric Reliability Council of Texas (ERCOT), “About ERCOT,” accessed 2 February 2022 at https://www.ercot.com/about.

17 Based on ERCOT, *PVGR Integration Report: 02/01/2021*, 2 February 2021, and ERCOT, *PVGR Integration Report: 01/30/2022*, 31 January 2022, downloaded 1 February 2022 from https://www.ercot.com/misapp/GetReports.do?reportTypeId=19325&reportTitle=PVGR%20Integration%20Report%20&showHTMLView=&mimicKey.

18 Based on ERCOT, *Unregistered DG Installed Capacity Quarterly Report, Q1 2021* and ERCOT, *Unregistered DG Installed Capacity Quarterly Report, Q4 2021*, downloaded 2 February 2022 from https://www.ercot.com/misapp/GetReports.do?reportTypeId=13544&reportTitle=Unregistered%20DG%20Installed%20Capacity%20Quarterly%20Report&showHTMLView=&mimicKey.

19 See notes 17 and 18.

20 Sarah Nick and Tony Dutzik, Frontier Group, and Emma Searson, Environment America Research & Policy Center; *Renewables on the Rise 2021: The rapid growth of renewables, electric vehicles and other building blocks of a clean energy future*, November 2021, p. 6, accessed 2 February 2022 at https://environmentamerica.org/sites/environment/files/Renewables-On-The-Rise-21.pdf?_ga=2.119527561.1234300751.1643312230-812521743.1642440068.

21 Calculation: 62.7 GW small building potential (Table 3) + 35.1 GW medium and large building potential (Table 5) = 97.8 GW = 97,800 MW. Pieter Gagnon, et al., National Renewable Energy Laboratory, *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*, January 2016, archived at http://web.archive.org/web/20220201130047/https://www.nrel.gov/docs/fy16osti/65298.pdf.

22 Calculation: 97,800 MW / 6,349 MW (from note 13) = 15.4.

23 See note 1, p. 30.

24 Small-scale solar generation and capacity for February 2021 were obtained from EIA, *Form EIA-861M detailed data, Small-scale PV estimate for 2021*, downloaded 25 January 2022 from https://www.eia.gov/electricity/data/eia861m/; Technical potential for rooftop solar on Texas buildings from Pieter Gagnon, et al., National Renewable Energy Laboratory, *Rooftop Solar Photovoltaic Technical Potential in the United States: A Detailed Assessment*, January 2016, archived at http://web.archive.org/web/20220201130047/https://www.nrel.gov/docs/fy16osti/65298.pdf.

25 Average capacity factors for both utility– and small-scale solar installations in the state of Texas (note: not the ERCOT region) during February 2021 calculated based on data from the U.S. Energy Information Administration (EIA). Small-scale solar generation and capacity for February 2021 from: U.S. Energy Information Administration, *Form EIA-861M detailed data, Small-scale PV estimate for 2021*, downloaded 25 January 2022 from https://www.eia.gov/electricity/data/eia861m/.

26 Average capacity factors for both utility– and small-scale solar installations in the state of Texas (note: not the ERCOT region) during February 2021 calculated based on data from the U.S. Energy Information Administration (EIA). Utility-scale solar capacity from: U.S. Energy Information Administration, *Preliminary Monthly Electric Generator Inventory (Form-860M data) for February 2021*, downloaded 25 January 2022 from https://www.eia.gov/electricity/data/eia860m/; utility-scale net generation from: U.S. Energy Information Administration, *Electricity Data Browser*, accessed 1 February 2022 at https://www.eia.gov/electricity/data/browser/#/topic/0?agg=1,0,2&fuel=004&geo=0000000002&sec=o3g&freq=M&start=200101&end=202111&ctype=linechart&ltype=pin&rtype=s&pin=&rse=0&maptype=0.

27 Utility-scale solar capacity for the ERCOT grid based on based on installed capacity as of 1 February 2021 from ERCOT, *PVGR Integration Report, 2/1/2021*, accessed at https://www.ercot.com/misapp/GetReports.do?reportTypeId=19325&reportTitle=PVGR%20Integration%20Report%20&showHTMLView=&mimicKey/. Net generation from utility-scale solar in ERCOT based on

daily data from the ERCOT balancing area for 10 February 2021-27 February 2021 downloaded from U.S. Energy Information Administration, *Hourly Electric Grid Monitor*, https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48 on 25 January 2022.

28 See Methodology.

29 Ibid.

30 Electric Reliability Council of Texas, *Peak Average Capacity Contribution Percentages for Wind and Solar, Winter 2020-2021*, downloaded 1 February 2022 from https://www.ercot.com/gridinfo/resource.

31 Elsa Wenzel, "Vehicle-to-grid technology is revving up," *GreenBiz*, 12 November 2019, archived at http://web.archive.org/web/20220201220640/https://www.greenbiz.com/article/vehicle-grid-technology-revving.

32 Gideon Weissman, Frontier Group, and Emma Searson and Rob Sargent, Environment America Research and Policy Center, *The True Value of Solar: Measuring the Benefits of Rooftop Solar Power*, July 19, accessed 2 February 2022 at https://environmentamerica.org/sites/environment/files/resources/AME%20Rooftop%20Solar%20Jul19%20web.pdf.

33 Ibid.

34 See note 1, p. 6 and 15.

35 Ibid, p. 21.

36 ERCOT balancing area data for 10 February 2021-27 February 2021 downloaded 25 January 2022 from: U.S. Energy Information Administration, *Hourly Electric Grid Monitor,* https://www.eia.gov/electricity/gridmonitor/dashboard/electric_overview/US48/US48.