Renewables in Recent and Future Heat Waves

Nir Y. Krakauer

Department of Civil Engineering, The City College of New York

Earth and Environmental Sciences, City University of New York Graduate Center, New York, NY

nkrakauer@ccny.cuny.edu

https://doi.org/10.52202/077496-0011

Abstract

Summer temperature extremes, particularly when accompanied by high humidity, drive peaks in power demand that can strain or even lead to failure of power grids. Here, I use meteorological reanalysis products to show regions where solar and wind availability were positively correlated with heat during summer 2023 to identify the potential of renewable energy to meet demand peaks and support energy resilience during heat waves.

Keywords: heat waves, solar energy, wind energy, grid resilience, global warming

Introduction

Resilience of the electric grid during climate extremes is of increasing concern. Intermittent renewable sources, mainly solar and wind, are an increasing contributor to our electricity supply, so their reliability under extreme conditions is critical. Xu et al. (2024) provide a recent overview of the potential of distributed renewables for climate resilience, particularly as related to power outages associated with tropical cyclones, and highlight the need to study the interdependent "risks from escalating climate extremes and large-scale renewable integration."

Heat waves rank as a leading climate disaster category, and one which is steadily worsening due to global warming. In 2023, the USA recorded its largest-ever number of billion-dollar weather and climate disasters (as compiled by the NOAA National Centers for Environmental Information). Of these, the costliest and most deadly was the Southern/ Midwestern summer drought and heat wave. Texas, along with the world, recorded its hottest year on record, and also set a new record for deaths attributable to heat.

The Electric Reliability Council of Texas (ERCOT), which manages electricity supply for most of the state, recorded by far its highest electricity demand on record that summer. This demand was met without major power outages with the help of rapidly rising solar-generating capacity, which generally provided 10-16% of peak-hour demand, along with surging battery capacity. As of 2023, Texas had the most wind generation capacity of any state, and the second-highest solar generation and battery storage capacities, behind California. Nevertheless, many brief price spikes occurred in the ERCOT real-time electricity market, suggesting the need for additional clean power along with better grid management to improve summer grid reliability and reduce customer costs.

To better understand the availability of solar and wind resources during heat waves at different locations, I extracted hourly weather data for June–September 2023 from the fifth-generation European atmospheric reanalysis (ERA5), a global product informed by

 https://doi.org/10.52202/077496-0011

extensive station and satellite data along with a state-of-the-art weather-forecast model (Hersbach et al., 2018; ERA, 2024).

Temperature-Solar Correlation

First, I examined the correlation between the daily mean surface (2m height) temperature and the daily mean surface downward short-wave radiation flux (Figure 1a). A positive correlation would mean that hot summer days tend to also be more sunny, providing an ample solar resource that can be tapped to meet peak power demands. These correlations were, in fact, strongly positive for most land areas, including the southern, western, and central U.S. generally.

Correlations were more weakly positive for much of the Northeast and upper Mississippi Basin and were negative for many ocean areas. Inspection of daily power demand and solar energy output by state from the U.S. Energy Information Administration's Hourly Grid Electric Monitor for the same period showed patterns consistent with these ERA5 results, with strongly positive correlations between power demand and solar production in California and Texas, but only weakly positive ones in New York.

Temperature-Wind Correlation

I also computed correlations between daily mean temperature and 100-m height wind speed (the wind speed was averaged from hourly values as $\left(\overline{v^3}\right)^{1/3}$ to better represent the proportionality of wind power to windspeed cubed) (Figure 1b). This correlation was near zero over many land and ocean areas, but was strongly positive for a large region that included the Great Plains, Texas, and eastern Mexico, for which hot days also tended to be windy. Indeed, in Texas, wind power made important contributions to evening power generation on many of the hottest days of summer 2023.

Correlations with Humid Heat

Peak power demand depends not only on temperatures but also on humidity levels, with air at higher wet bulb temperature (WBT) requiring more energy to cool (Guan et al., 2017). Therefore, I computed hourly WBT from ERA5 2-m temperature, 2-m dew point, and surface pressure fields, using formulas from Sadeghi et al. (2013). Correlations of daily mean WBT with solar and wind resources, shown in Figure 2, tended to be less positive than those for temperature, but were still positive in Texas.

Discussion

While preliminary (and needing to be confirmed by looking at more years and station data), these findings support the potential of solar and wind deployment, along with storage, to mitigate the impact of demand peaks during heat waves on grid reliability. This positive impact on resilience could be quantified for individual power grids, such as ERCOT, in more detailed follow-up modeling studies.

https://doi.org/10.52202/077496-0011

To comprehensively assess challenges to energy resilience during heat waves, a variety of other challenges and opportunities for grid resilience also need to be considered. Heavy air pollution, much of which is due to burning fossil fuels, reduces the solar resource substantially (Yang et al., 2022). Further, smoke from massive wildfires, which covered large parts of eastern North America for much of summer 2023, reduces solar generation, although also likely reducing the intensity of heatwaves in affected areas (Gilletly et al., 2023).

Contrarily, the recent implementation of low-sulfur fuel standards for global shipping has presumably increased solar resource availability, particularly close to shipping lanes, even while contributing to the acceleration of global warming (Ji et al., 2020). The ability of reanalysis products such as ERA5 to fully capture air pollution and smoke distribution as they impact solar resources needs to be validated. There are also other natural hazards whose co-occurrence with heatwaves should be prepared for.

Tropical cyclones can cause widespread destruction of power generation and transmission facilities, leaving people vulnerable to subsequent heatwaves (Matthews et al, 2019; Feng et al., 2020). Hailstorms, floods, and droughts are also increasingly likely to co-occur with heat waves and stress power grids by damaging generation and transmission facilities (Su et al., 2020; Stone et al., 2021; Yin et al., 2022; Gu et al., 2022). Resilient design of energy systems could include a diversity of sources and storage mediums as well as an emphasis on distributed generation (such as household-scale solar generation and neighborhood microgrids) and capacity for grid-independent operation during emergencies (Abdin et al., 2019; Bracken et al., 2023; Remund et al., 2023).

Conclusion

In summary, recent operator experiences and meteorological data support the potential of renewable energy sources to provide power generation during heat waves. Additional work is needed to integrate renewables with power storage and transmission infrastructure for resilience during increasingly frequent and intense climate extremes.

Conflict of Interest

The author declares that he has no conflicts of interest.

https://doi.org/10.52202/077496-0011

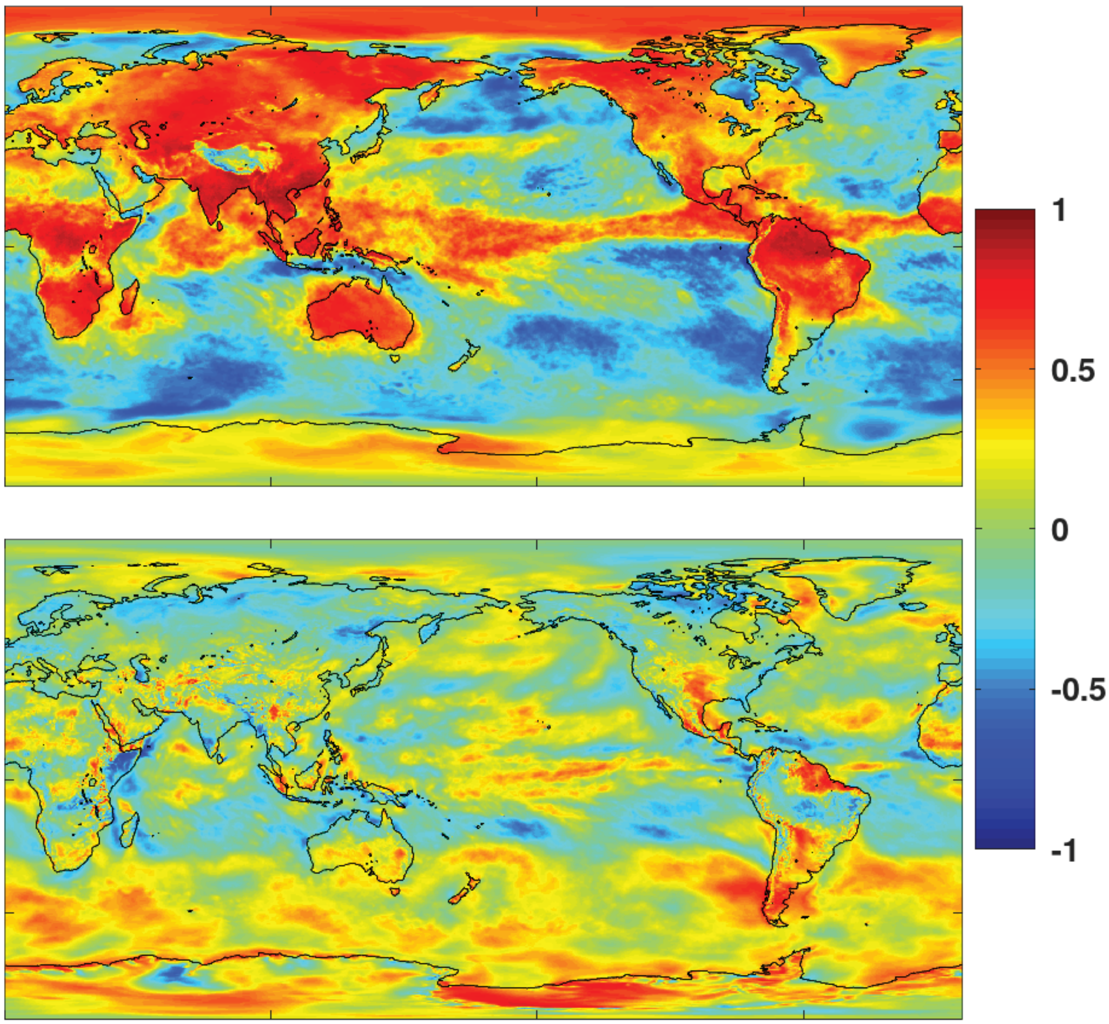

Figure 1. Correlation with daily-mean temperature for June-September 2023 of daily-mean (a [top]) solar irradiance and (b [bottom]) wind speed. Positive correlations generally indicate that hot days were likely to feature above-average solar and/or wind resources.

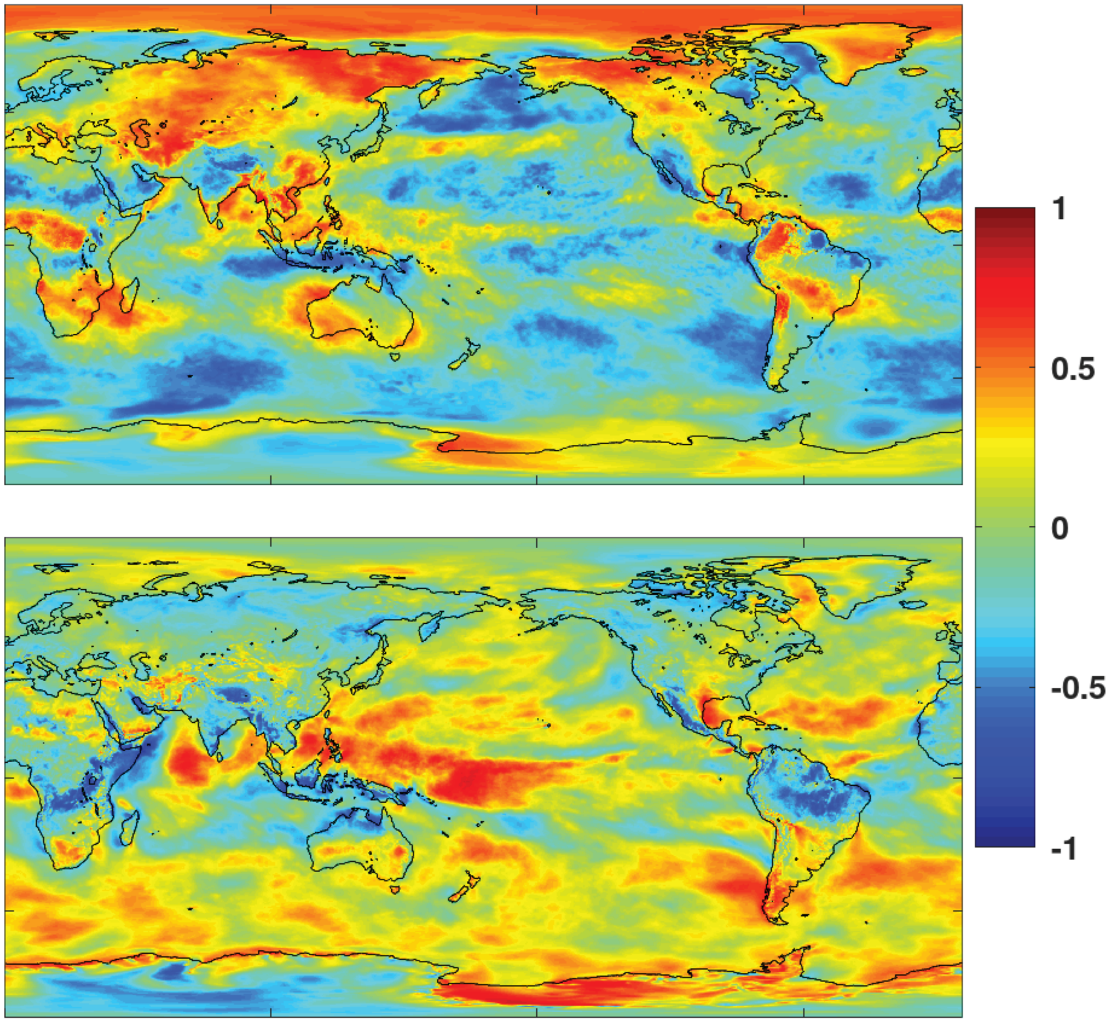

Figure 2. Same as Figure 1, but for daily-mean wet-bulb temperature instead of (dry-bulb) temperature.

https://doi.org/10.52202/077496-0011

References

Abdin, A. F., Fang, Y.-P., & Zio, E. (2019). A modeling and optimization framework for power systems design with operational flexibility and resilience against extreme heat waves and drought events. *Renewable and Sustainable Energy Reviews*, 112, 706–719. https://doi.org/10.1016/j.rser.2019.06.006

Bracken, C., Voisin, N., Burleyson, C. D., Campbell, A. M., Hou, Z. J., & Broman, D. (2023). Standardized benchmark of historical compound wind and solar energy droughts across the Continental United States. *Renewable Energy*, 119550. https://doi.org/10.1016/j.renene.2023.119550

Feng, K., Min, O., & Lin, N. (2020). Hurricane-blackout-heatwave compound hazard risk and resilience in a changing climate. *arXiv*, 2012. http://arxiv.org/abs/2012.04452v1

Gilletly, S. D., Jackson, N. D., & Staid, A. (2023). Evaluating the impact of wildfire smoke on solar photovoltaic production. *Applied Energy*, 348, 121303. https://doi.org/10.1016/j.apenergy.2023.121303

Gu, L., Chen, J., Yin, J., Slater, L. J., Wang, H.-M., Guo, Q., Feng, M., Qin, H., & Zhao, T. (2022). Global increases in compound flood-hot extreme hazards under climate warming. *Geophysical Research Letters*, 49(8). https://doi.org/10.1029/2022gl097726

Guan, H., Beecham, S., Xu, H., & Ingleton, G. (2017). Incorporating residual temperature and specific humidity in predicting weather-dependent warm-season electricity consumption. *Environmental Research Letters*, *12*(2), 24021. https://doi.org/10.1088/1748-9326/aa57a9

Hersbach, H., de Rosnay, P., Bell, B., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Alonso-Balmaseda, M., Balsamo, G., Bechtold, P., Berrisford, P., Bidlot, J.-R., de Boisséson, E., Bonavita, M., Browne, P., Buizza, R., Dahlgren, P., Dee, D., Dragani, R., et al. (2018). *Operational global reanalysis: progress, future directions and synergies with NWP* (No. 27). ECMWF. https://doi.org/10.21957/tkic6g3wm

Ji, J. S. (2020). The IMO 2020 sulphur cap: a step forward for planetary health? *The Lancet Planetary Health*, *4*(2), e46–e47. https://doi.org/10.1016/s2542-5196(20)30002-4

Matthews, T., Wilby, R. L., & Murphy, C. (2019). An emerging tropical cyclone–deadly heat compound hazard. *Nature Climate Change*, *9*(8), 602–606. https://doi.org/10.1038/s41558-019-0525-6

Remund, J., Perez, R., Perez, M., Pierro, M., & Yang, D. (2023). Firm photovoltaic power generation: overview and economic outlook. *Solar RRL*, *7*(23). https://doi.org/10.1002/solr.202300497

Sadeghi, S.-H., Peters, T. R., Cobos, D. R., Loescher, H. W., & Campbell, C. S. (2013). Direct calculation of thermodynamic wet-bulb temperature as a function of pressure and elevation. *Journal of Atmospheric and Oceanic Technology*, *30*(8), 1757–1765. https://doi.org/10.1175/JTECH-D-12-00191.1

 https://doi.org/10.52202/077496-0011

Stone, B., Mallen, E., Rajput, M., Gronlund, C. J., Broadbent, A. M., Krayenhoff, E. S., Augenbroe, G., O'Neill, M. S., & Georgescu, M. (2021). Compound climate and infrastructure events: how electrical grid failure alters heat wave risk. *Environmental Science & Technology*, *55*(10), 6957–6964. https://doi.org/10.1021/acs.est.1c00024

Su, Y., Kern, J. D., Reed, P. M., & Characklis, G. W. (2020). Compound hydrometeorological extremes across multiple timescales drive volatility in California electricity market prices and emissions. *Applied Energy*, 276, 115541. https://doi.org/10.1016/j.apenergy.2020.115541

Xu, L., Feng, K., Lin, N., Perera, A. T. D., Poor, H. V., Xie, L., Ji, C., Sun, X. A., Guo, Q., & O'Malley, M. (2024). Resilience of renewable power systems under climate risks. *Nature Reviews Electrical Engineering*, *1*(1), 53–66. https://doi.org/10.1038/s44287-023-00003-8

Yang, L., Gao, X., Li, Z., & Jia, D. (2022). Quantitative effects of air pollution on regional daily global and diffuse solar radiation under clear sky conditions. *Energy Reports*, 8, 1935–1948. https://doi.org/10.1016/j.egyr.2021.12.081

Yin, J., Slater, L., Gu, L., Liao, Z., Guo, S., & Gentine, P. (2022). Global increases in lethal compound heat stress: hydrological drought hazards under climate change. *Geophysical Research Letters*, *49*(18). https://doi.org/10.1029/2022gl100880