Predicting renewable energy droughts and surplus by modeling tropical Pacific climate

El Niño and La Niña are the leading causes of year-over-year changes in global weather. Keeping a watch on the tropical Pacific can help you predict high or low renewable power generation months in advance.

Renewable energy from wind, water or solar power is intrinsically variable. In the absence of significantly oversized production or the widespread deployment of high-capacity storage devices, these sources will continue to be vulnerable to disruption caused by weak winds, dry spells and cloudy skies. How can renewable energy stakeholders use modeling insight on El Niño and La Niña to get ahead of potential supply challenges and use these perspectives to inform greater resilience?

Below, we examine the characteristics and implications of El Niño and La Niña for renewable energy providers and customers and how being forewarned of weather systems can have wide-ranging implications for renewable energy.

What are El Niño and La Niña and how do they impact renewable energy production?

Most of the time, the trade winds over the Pacific blow west across the equator, pushing warm water away from South U.S. and toward Indonesia and Papua New Guinea. Those waters — the hottest parts of the global oceans — function as an enormous engine, pumping heat and moisture into the atmosphere over the western tropical Pacific and giving rise to exceptional thunderstorms more than 15 km tall.

But every few years, the normal interplay between the ocean and atmosphere over the tropical Pacific either speeds up or breaks down. These changes have major repercussions for weather and climate across the globe and, in certain places, can significantly affect the natural resources we depend upon to produce renewable energy. Understanding what lies ahead for the tropical Pacific could help anticipate renewable energy droughts or oversupply a season or two ahead.

Normally, the atmosphere above the Pacific forms a single loop, where air rises in the west, tracks eastward at higher altitudes, sinks back down off the coast of South U.S., and then rejoins the trade winds. When this interaction of air and ocean currents intensifies, with energized winds and even hotter water in the west, we describe this supercharged state as La Niña[1].

[1] National Oceanographic and Atmospheric Administration (2023), What are El Niño and La Niña? https://oceanservice.noaa.gov/facts/ninonina.html

Alternatively, when that normal configuration breaks down, we declare an El Niño. Under El Niño, trade winds slacken and the massive pool of warm water in the west slouches eastward, taking up a position in the central Pacific. The grand column of convection rises from the middle of the Pacific, rather than its western arm, pushing air both east and west from that central location.[2]

These rearrangements and reversals toss the tropical Pacific's weather upside down. El Niño brings drought and wildfire to Indonesia, delivering surprise rainstorms and floods into the normally dry areas of Ecuador and Peru, prompting the marine food web surrounding the Galapagos Islands to collapse.[3]

The local impacts of La Niña are often more subtle, but typically include heavy rainfall and flooding in the Insular Region of Southeast Asia, and wet spring and summer weather in Australia. But because the tropical Pacific Ocean is so enormous and holds so much heat, El Niño and La Niña both reach far beyond the confines of the basin itself. As climate scientist and oceanographer at NASA's Jet Propulsion Laboratory Josh Willis once said, "When the Pacific speaks, the whole world listens."[4]

The implications of El Niño and La Niña for water hazards and supplies

The ocean's surface is by far the largest supplier of water to our atmosphere. So when warm and cold waters are rearranged over an area as large as the tropical Pacific, there are major consequences for water hazards and water supplies across the world. For El Niño, usually the most spectacular changes in the hydrological cycle happen along the western coast of the South U.S.

Centuries ago, Peruvian fishers noticed warm water from the tropics would sometimes arrive in December or February to drive the fish away. Scientists from Peru were the first to use the term 'El Niño' in print and in 1895, Federico Pezet[5] linked this *contracorriente El Niño* (or countercurrent El Niño) to torrential rains in the northwestern department of Piura. This was the first report of a 'teleconnection' between the tropical Pacific and weather inland.

More than a century later, that relationship still holds firm: flood damages for coastal Peru are 25-50% higher in El Niño years.[6]

Over southern Africa, El Niño and La Niña are the main influences on the region's climate between December and March, the middle of the local rainy season. During El Niño events, we see major reductions in both total rainfall and the number of rain days over a wide east-west band spanning central and southern Mozambique, Zimbabwe, Botswana, southwestern Zambia, southeastern Angola, and northeastern Namibia.[7]

When forecasts declare El Niño, these countries may be challenged by less-than-expected water supplies for rain-fed agriculture and hydroelectric power.

The regional response to La Niña is not equal nor opposite to that of El Niño, but generally includes more rainy days and heavy rainstorms, especially over Zimbabwe and southern Mozambique.

[2] Di Liberto (2014), The Walker Circulation: ENSO's atmospheric buddy. https://www.climate.gov/news-features/blogs/enso/walker-circulation-ensos-atmospheric-buddy
[3] Karnauskas (2015), El Niño and the Galápagos. https://www.climate.gov/news-features/blogs/enso/el-niño-and-galápagos
[4] NASA Earth Observatory (2022), La Niña times three, https://earthobservatory.nasa.gov/images/150691/la-nina-times-three
[5] Pezet (1896), La Contracorriente 'El Niño' en la costa norte del Perú, Boletín de la Sociedad Geográfica de Lima, 5.
[6] Ward et al. (2014), Strong influence of El Niño Southern Oscillation on flood risk around the world. Proceedings of the National Academy of Sciences 111 (44) 15659-15664. https://doi.org/10.1073/pnas.1409822111
[7] Hoell et al. (2023), The modulation of daily southern Africa precipitation by El Niño–Southern Oscillation across the summertime wet season. Journal of Climate 34, 1115-1134. https://doi.org/10.1175/JCLI-D-20-0379.1

Understanding the impact of future weather events on renewable energy

Renewables now provide 5.5% of global energy supply. If we hope to achieve net-zero carbon emissions by 2050, global production needs to ramp up by roughly 13% per year over the next three decades.[8]

Although more solar, wind, hydro, geothermal and ocean energy are critical to delay or halt climate change, these renewable energy sources are strongly dependent on prevailing weather. As energy systems become increasingly reliant on renewables, we will face greater risks around inclement conditions that could reduce total power supply and create renewable energy 'droughts'.[9]

Because El Niño and La Niña have had an appreciable impact on both renewable resources and production in the past, renewable energy sector stakeholders should pay attention to the potential of future events to function as either a benefit or challenge to specific situations. For example:

- More than a decade ago, a colleague and I showed prolonged episodes of low winds on the southern Canadian Prairies, sometimes lasting for several months, nearly always happened during an El Niño.[10] A few months later, underperforming wind power production at several important regions in Canada and the U.S. was attributed to the 2009/10 El Niño.[11] Subsequent research showed El Niño is associated with slack winds across most of the western Great Plains, including Texas, and the lower Mississippi River Valley.[12] However, the opposite does not hold: La Niña conditions do not lead to noticeably stronger winds or higher production for wind energy facilities.
- Solar energy can also be influenced by the tropical Pacific, even in places of solar abundance. During the austral winter, La Niña usually brings rainy weather with heavy clouds to the eastern northeastern part of Australia, which serves to decrease solar radiation.[13] On the other hand, El Niño should be good news for energy production because it raises solar exposure across much of Queensland, New South Wales, and the Northern Territory. But because El Niño usually makes summer in Australia hotter and drier, the solar industry could still face undesirable consequences should heatwaves increase demand for electricity or lead to facilities producing power less efficiently.[14]
- For hybrid renewable systems, the particular effects of El Niño can be quite different, depending on both geography and energy source. A recent study[15] led by Dr Hannah Bloomfield tested the influence of the tropical Pacific on wind and solar power generation in sub-Saharan Africa. The research team found in Kenya, El Niño causes wintertime wind power to drop by 15% and prompts similar but more modest downturns in solar energy production. By contrast, renewable energy production in Senegal appears to be resilient with respect to El Niño, with solar power generation increasing slightly by 1% during El Niño-like summers.

[8] International Energy Agency (2023), Renewables. https://www.iea.org/energy-system/renewables#
[9] Allen and Otero (2023), Standardised indices to monitor energy droughts. Renewable Energy 217, 119206. https://doi.org/10.1016/j.renene.2023.119206
[10] St. George and Wolfe (2009), El Niño stills winter winds across the southern Canadian Prairies. Geophysical Research Letters 36, L23806. https://doi.org/10.1029/2009GL041282
[11] Renewable Energy Magazine (2010), El Niño causes drop in wind power production. https://www.renewableenergymagazine.com/wind/el-nino-causes-drop-in-wind-power
[12] Hamlington et al. (2014), Effects of climate oscillations on wind resource variability in the United States. Geophysical Research Letters 42, 145-152. https://doi.org/10.1002/2014GL062370
[13] Davi and Troccoli (2012), Interannual variability of solar energy generation in Australia. Solar Energy 86, 3554-3560. https://doi.org/10.1016/j.solener.2011.12.004
[14] McConnell and MacGill (2023), An El Niño looms over Australia's stressed electricity system — and we must plan for the worst. University of New South Wales — Sidney. https://newsroom.unsw.edu.au/news/science-tech/el-niño-looms-over-australia's-stressed-electricity-system-–-and-we-must-plan-
[15] Bloomfield et al. (2022), Characterizing the variability and meteorological drivers of wind power and solar power generation over Africa. Meteorological Applications 29, e2093. https://doi.org/10.1002/met.2093

Using modeling to inform energy grid design and anticipate energy drought

By reading the signs in the tropical Pacific, climate scientists are able to spot El Niño and La Niña on the horizon one or two seasons in advance.

Currently scientists make these long-term forecasts in one of three ways.[16] The first and oldest approach builds statistical models that predict an index of the El Niño/La Niña system based on other measured aspects of the tropical Pacific, such as deep ocean temperatures, air pressure patterns, or even the state of the index in previous months. The second approach — dynamic modeling — uses high-performance computers to simulate the physical behavior of the ocean and atmosphere over the coming months. The third, and newest, technique searches the huge database of climate model output to find all cases where the simulation closely resembles the current state of the Pacific Ocean.[17] Researchers can then trace how 'lookalikes' evolved over the next several months within the simulation and use this insight to forecast El Niño and La Niña in the real world.

Much of what we know about El Niño's effects on climate is based on weather observations made over the past several decades. That experience is crucial for us to understand what's possible over the months ahead. But we should also be mindful that future El Niño and La Niña events will play out across a world much warmer than those influenced by their predecessors.

Because our forecasting techniques are operating in uncharted waters, we should maintain caution on predicting the future arc of the tropical Pacific. Renewable energy from wind, water or solar power is intrinsically variable. In the absence of significantly oversized production or the widespread deployment of high-capacity storage devices, these sources will continue to be vulnerable to disruption caused by weak winds, dry spells and cloudy skies.

However, because El Niño and La Niña are predictable several months in advance, understanding their impact can both help inform the design of regional energy grids and anticipate impending energy droughts.

The tropical Pacific Ocean regularly switches between El Niño, La Nina, and neutral conditions. Understanding its current and future behavior can help anticipate generally high or low production from renewable energy sources (wind, solar and hydroelectric) several months in advance. Data are from the U.S. Climate Prediction Center (https://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt).

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[16] Barnston (2014), How good have ENSO forecasts been lately? https://www.climate.gov/news-features/blogs/enso/how-good-have-enso-forecasts-been-lately
[17] Cooperative Institute for Research in Environmental Sciences (2019), Mining climate models for seasonal forecasts. https://cires.colorado.edu/news/mining-climate-models-seasonal-forecasts