

An aerial photograph of a wind farm situated on rolling green hills. Several white wind turbines are visible, with one prominently in the foreground. The landscape is lush green with some patches of brown, possibly from dry grass or erosion. In the background, there are more hills and a cloudy sky. The text is overlaid in red on the top half of the image.

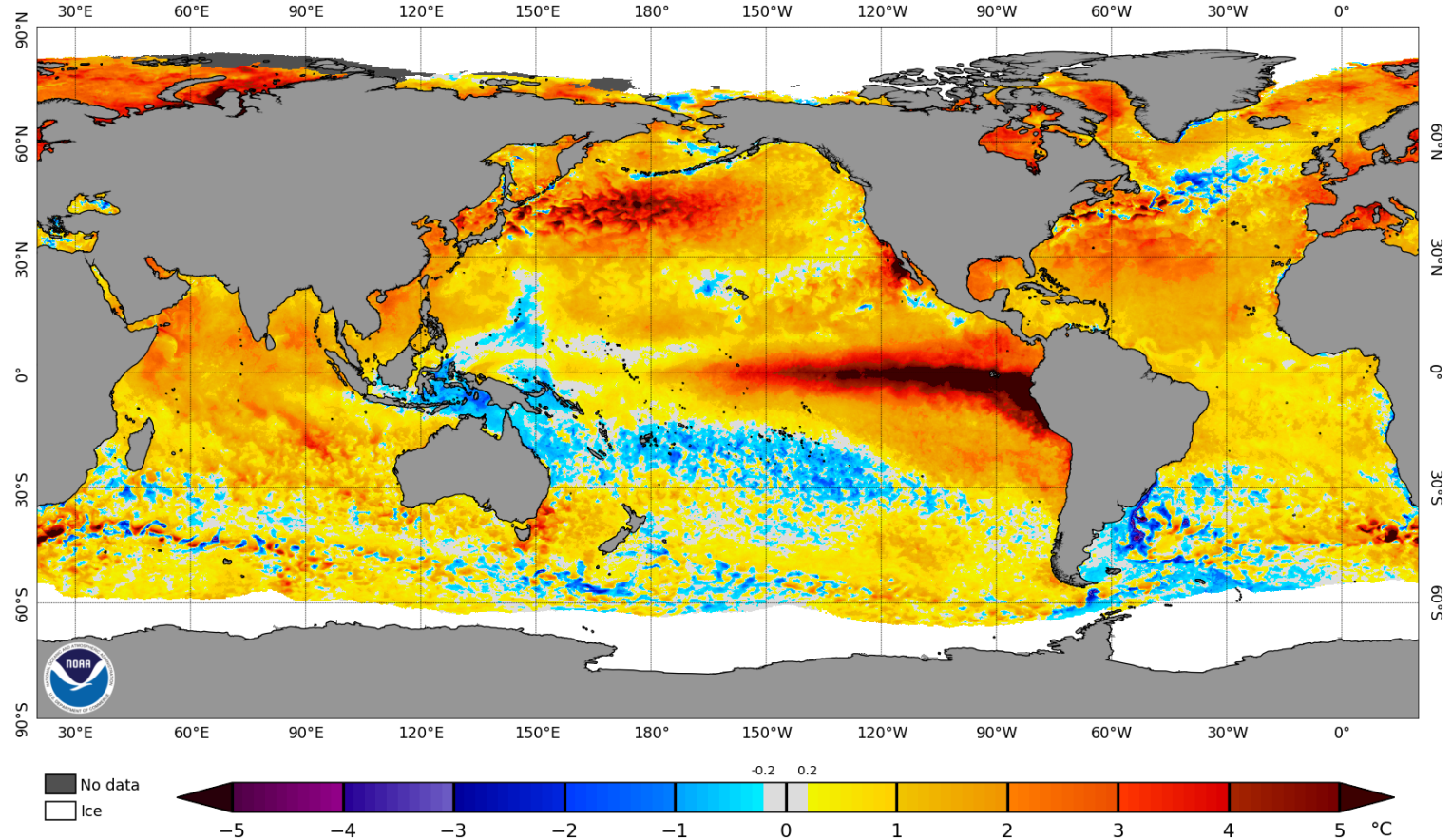
How Changes in El Nino and Extreme Weather May Affect California's Push for 100% Clean, Renewable Energy

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Stanford University

California Carbon Forum
Napa, California
October 5, 2026

Difference in Sea-Surface Temperature Oct. 4 v 1991-2020

NOAA Coral Reef Watch Daily 5km SST Anomalies (v3.1) 4 Oct 2026



Atlantic Hurricanes This Year Versus Average

Average (June 1-Nov 1)

Tropical storms plus hurricanes: 14

Hurricanes: 7

Severe hurricanes (cat 3, 4, 5): 3

Originally expected this season

Tropical storms plus hurricanes: 7-13 (8 as of Oct 4)

Hurricanes: 2-6 (0 as of Oct 4)

Severe hurricanes (cat 3, 4, 5): 0-2 (0 as of Oct 4)

Expected Impacts of El Nino on California

Higher temperatures → higher electricity demand

More severe winter storms → more heavy precipitation → more hydro output

Higher sea levels along coast → coastal flooding during storms

Stronger westerly winds and winds from storms → more wind output

More clouds from storms → less solar output

What are the Problems? Why act Quickly?

Fossil-fuel and bioenergy emissions cause ~7.4 million air pollution deaths/yr worldwide, costing ~\$30 trillion/year

Global warming will cost ~\$30 trillion/year by 2050.

Fossil fuels will become scarce, increasing energy prices and economic, political, and social instability

Drastic problems require immediate solutions

Wind, Water, Solar (WWS) Solution

Electrify or Provide Direct Heat For All Sectors and Provide the Electricity and Heat with 100% WWS

ELECTRICITY/HEAT TRANSPORTATION

BUILDINGS

INDUSTRY

Wind	Battery-electric	Heat pumps	Arc furnaces
Solar PV/CSP	H ₂ -fuel-cell elec.	Induction cooktops	Induction furnaces
Geothermal		LED lights	Resistance furnaces
Hydro		Insulation	Dielectric heaters
Tidal/Wave			Electron beam heaters
Solar/Geo Heat			Heat pumps

Types of Storage for a 100% WWS System

ELECTRICITY STORAGE

CSP with storage
Pumped hydro storage
Existing hydroelectric
Batteries
Flywheels
Compressed air
Gravitational Storage
Grid hydrogen/fuel cells

HOT/COLD STORAGE

Water tank
Ice
Underground
Borehole
Water Pit
Aquifer
Building materials
Firebricks

HYDROGEN STORAGE

Non-grid hydrogen

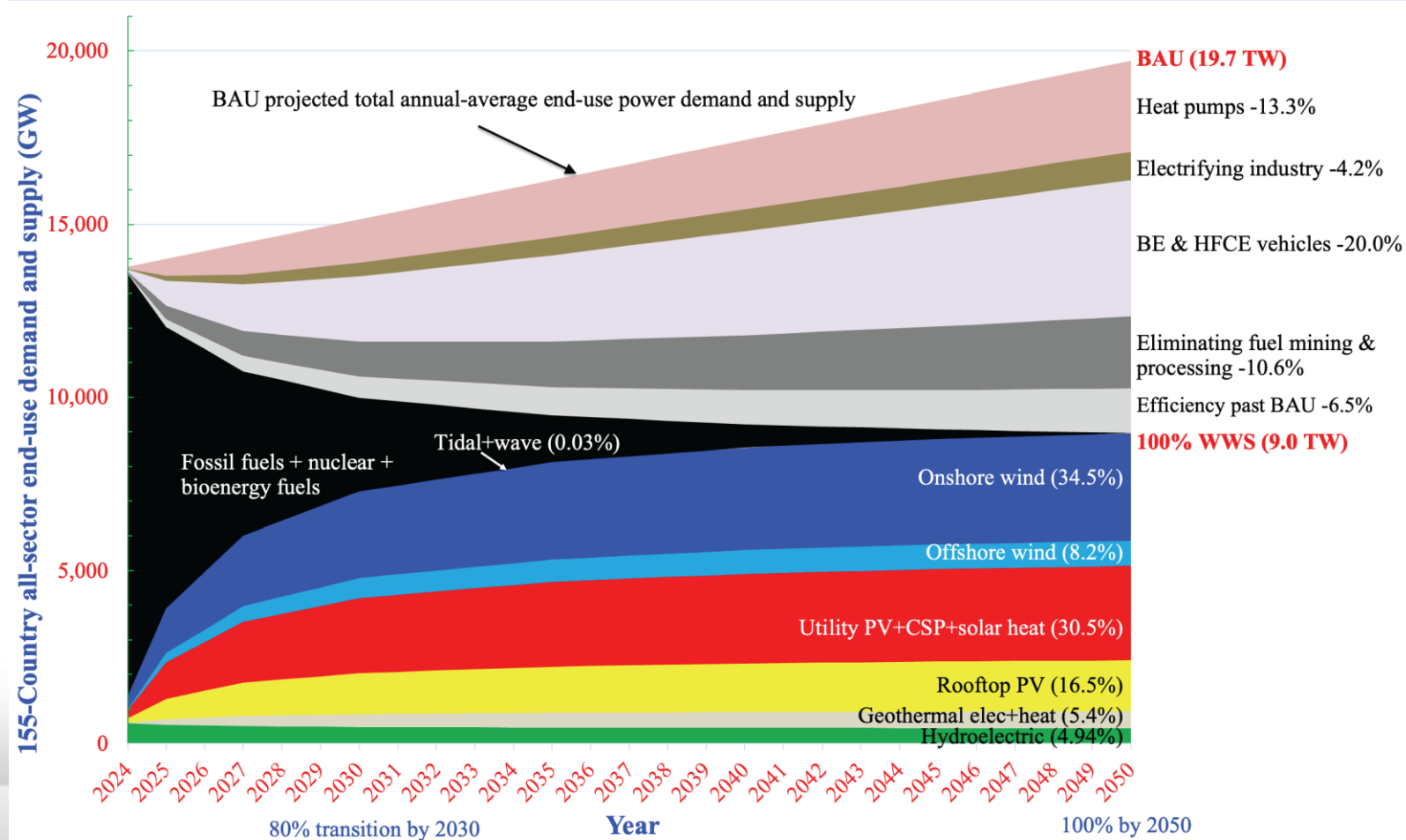
Can the World Transition to 100%, Clean, Renewable Energy for all Purposes?

Roadmaps for 155 Countries

All-Sector End-Use Power Demand BAU v WWS

Year and Fuel Type	155 Countries
2023 End-use demand	13.5 TW
2050 Demand with current fuels (BAU)	19.7 TW
2050 Demand with WWS	8.96 TW
2050 Demand reduction with WWS 20.0% efficiency of BE, HFC v. ICE 4.2% efficiency of electric industry 13.3% efficiency of heat pumps 10.6% eliminating fuel mining 6.5% efficiency beyond BAU	54.6%

Timeline for Transitioning 155 Countries 80% by 2030; 100% by 2050



Capital Costs Resulting in a Stable Electric Grids Upon Electrification of all Energy With 100% WWS

World (155 Countries): \$56.1 trillion

U.S.: \$5.9 trillion

China: \$14.4 trillion

Europe: \$4.4 trillion

2050 155-Country BAU vs WWS Annual Energy Cost

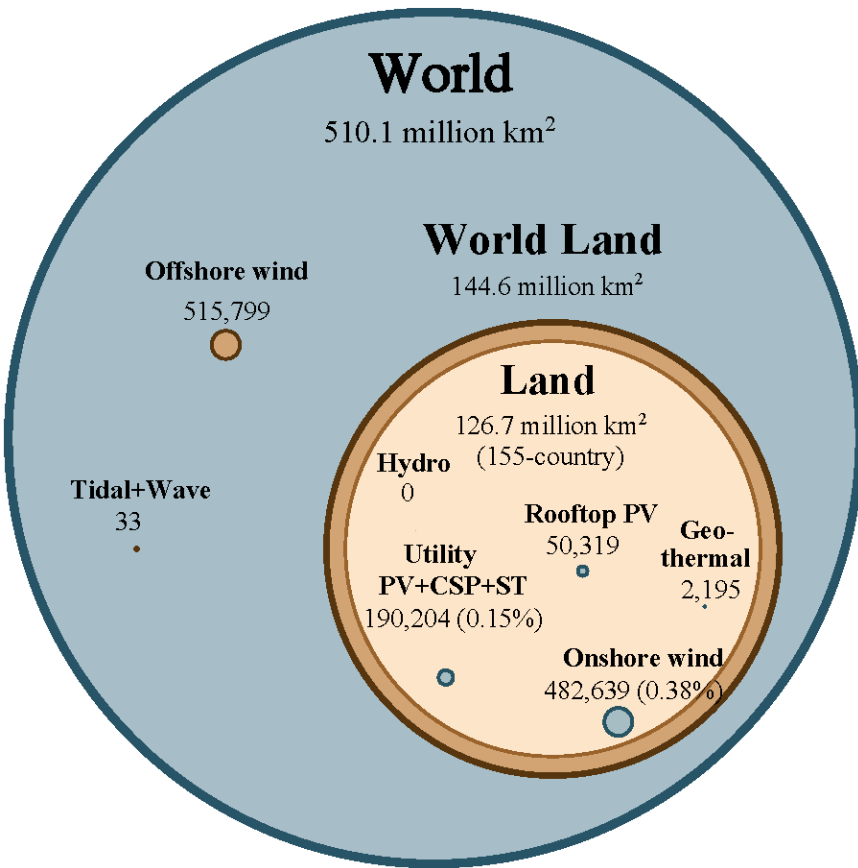
BAU fuel energy cost	\$17.7 trillion/yr
BAU fuel health cost	\$43.4 trillion/yr
<u>BAU fuel climate cost</u>	<u>\$33.0 trillion/yr</u>
BAU total social cost	\$94.1 trillion/yr

WWS total social cost	\$6.1 trillion/yr
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WWS reduces energy cost 66% and economic (social) cost 94%

→ Energy-cost-savings payback time = 5 yr; social cost payback <1 yr

Percent of Land Beyond 2023 Installations to Power 155 Countries for all Purposes With 100% WWS in 2050



Onshore wind: 0.38%
Utility PV+CSP: 0.16%
Total 155 Countries: 0.54%

Onshore wind: 0.24%
Utility PV+CSP: 0.87%
Total U.S.: 1.11%

vs. 1.24% of U.S. land for corn ethanol and 1.16% of U.S. land for the fossil industry

15 Countries 95-100% of Electricity Generation From WWS 2025

Albania 100% (H,S)

Bhutan 100% (H)

Nepal 100% (H,S,W)

Iceland 100% (H,G,W,S)

Lesotho 100% (H,S)

Ethiopia 100% (H,W,S,G)

Congo, D.R. 99.9% (H,S)

Paraguay 99.5% (H)

Costa Rica 99.5% (H,G,W,S)

Norway 98.9% (H,W,S)

S. Georgia/SW 98.7% (H,W)

Namibia 97.6% (H,S,W)

Central African Rep. 97.4% (H,S)

Sierra Leone 95.2% (H,S)

Tajikistan 94.2% (H)

China 35.0% (H,S,W)

U.S. 24.6% (W,S,H,G)

India 23.0% (S,H,W)

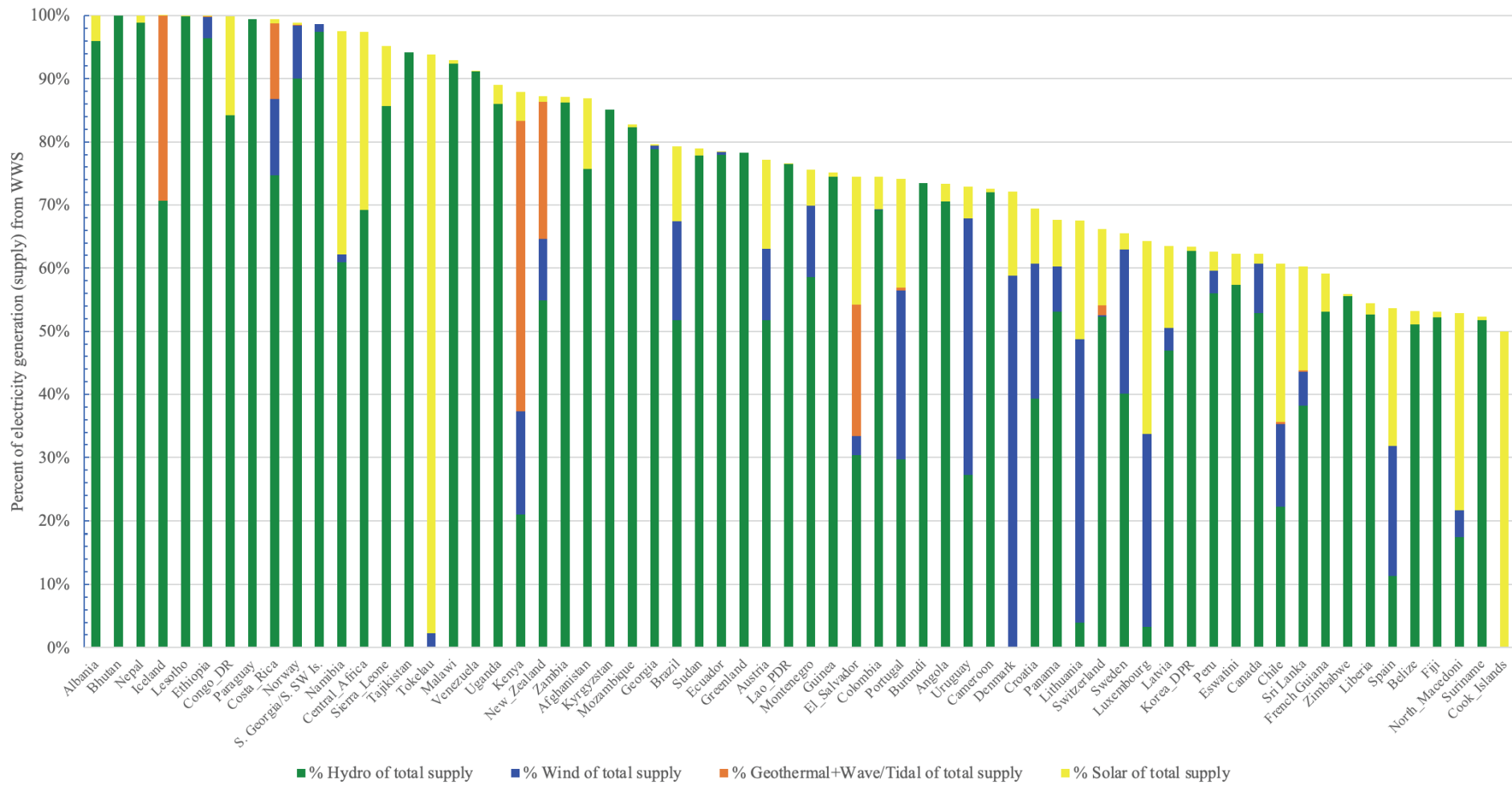
W = wind;

S = solar

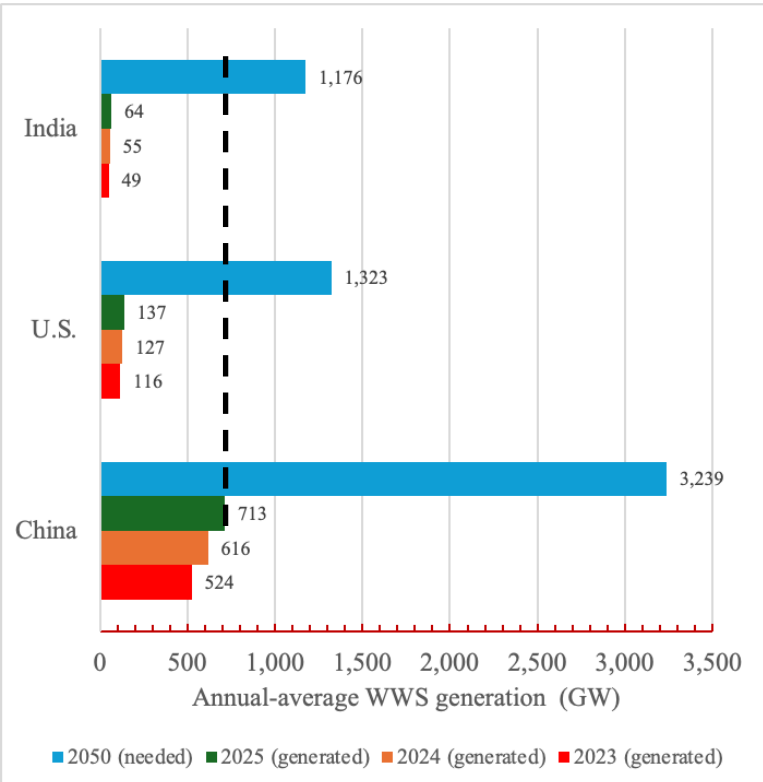
H = hydro

G = geothermal

64 Countries 50-100% of Electricity Generation From WWS 2025



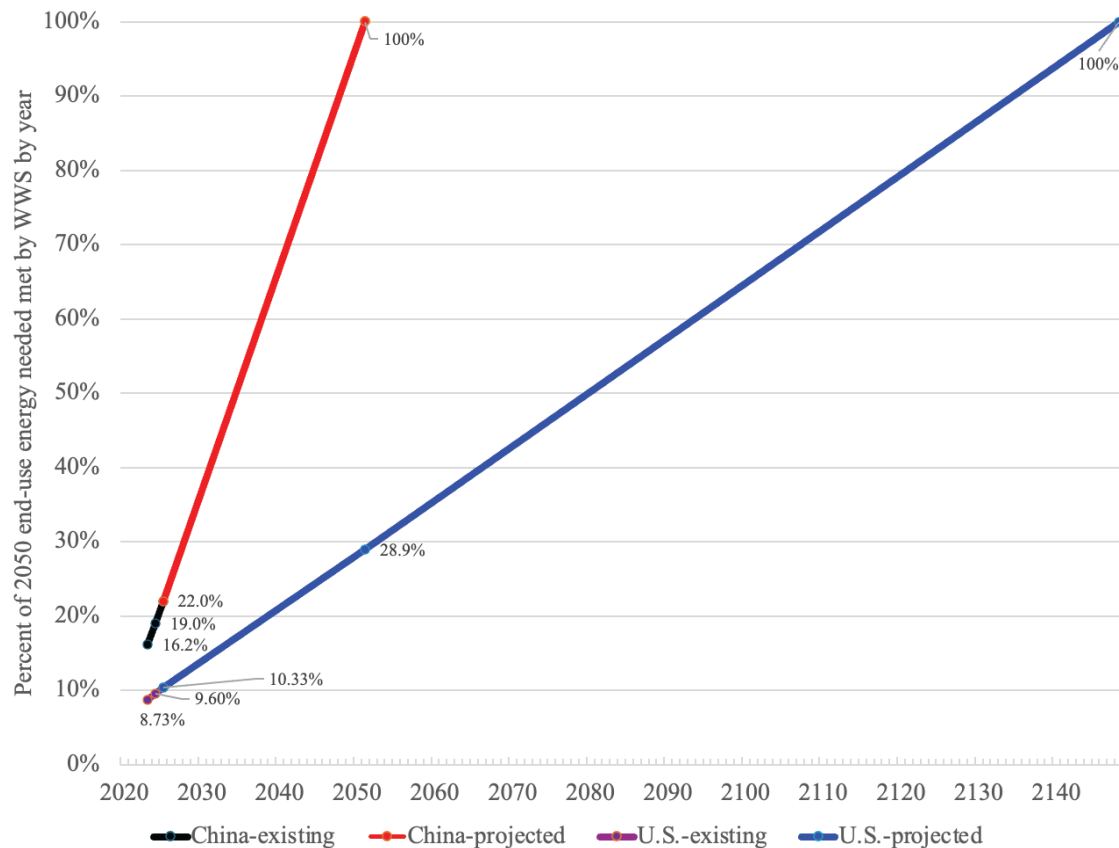
WWS Power Needed to Meet 100% of All-Sector End-Use Demand in 2050 v. WWS Generation in 2023, 2024, 2025



In 2025, China was already producing 54% of the electricity needed to power the U.S. and 61% of the electricity needed to power India for all energy purposes in 2050.

China is Projected to Reach 100% WWS by 2051, 97 Years Before the U.S. (2148)

Percent of energy needs met by WWS



14 States w/WWS Meeting 49-126% of Grid+BTM Demand Q325-Q226

S. Dakota 127% (W,H,S)

Montana 115% (H,W,S)

Washington State 90.1% (H,W,S)

Wyoming 84.7% (W,H,S)

Iowa 74.2% (W,S,H)

Kansas 72.2% (W,S,H)

Oregon 70.0% (H,W,S,G)

New Mexico 69.9% (W,S,H,G)

Maine 65.4% (S,W,H)

Idaho 58.4 (H,W,S,G)

Oklahoma 57.6% (W,H,S)

N. Dakota 57.4% (W,H)

California 51.4% (S,H,W,G)

Nevada 49.0% (S,G,H,W)

W = wind;

S = solar

H = hydro

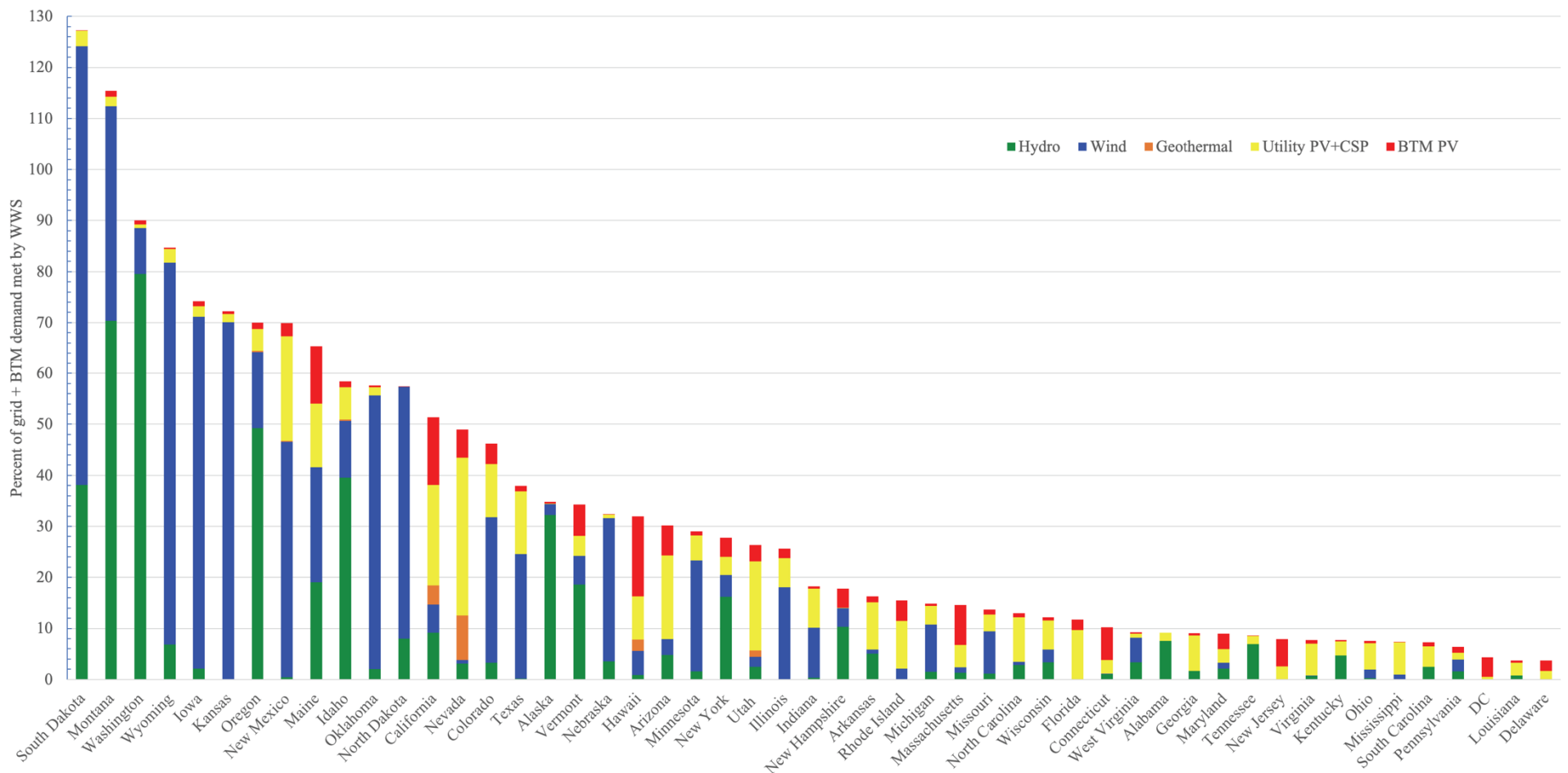
G = geothermal

Wind: Largest WWS source in 7 states

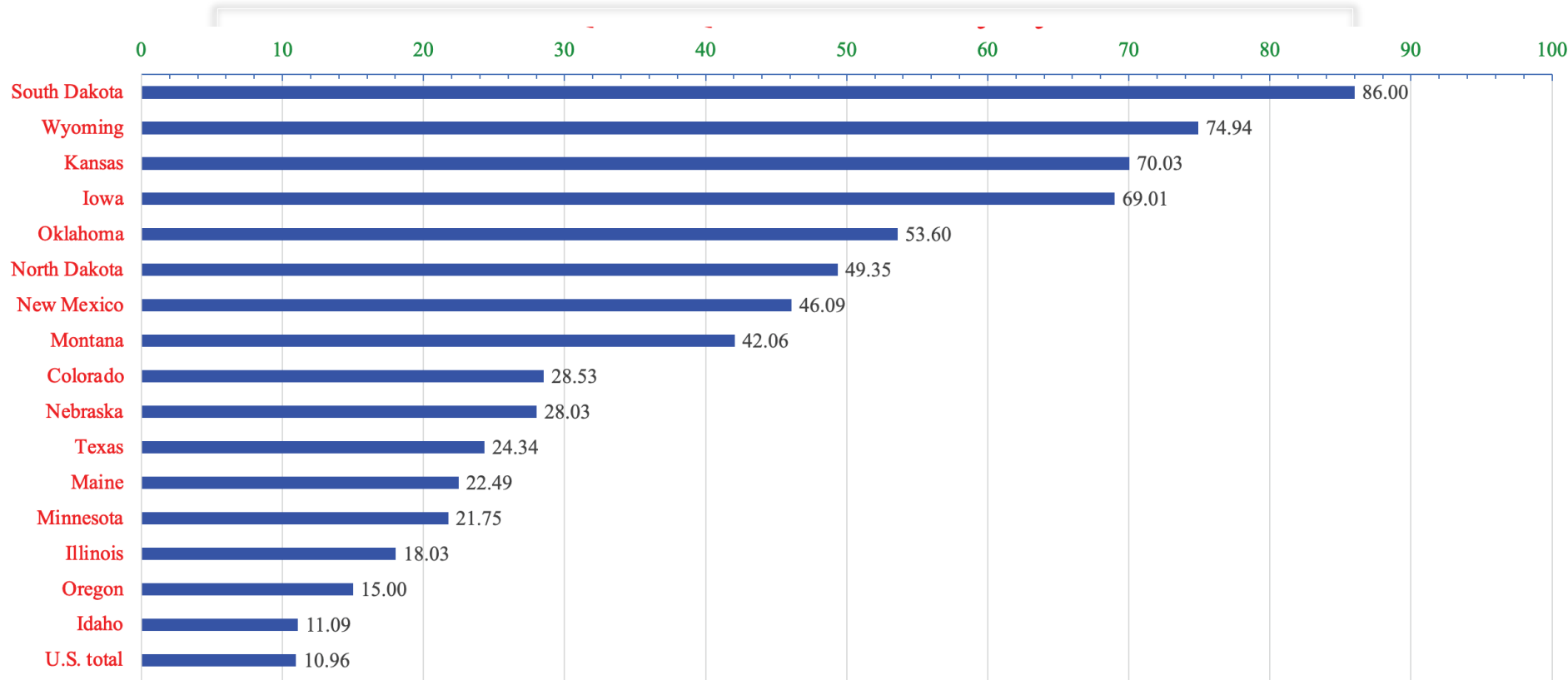
Water: Largest WWS source in 4 states

Solar: largest WWS source in 3 states

13 States w/WWS Meeting 51-127% of Grid+BTM Demand Q325-Q226

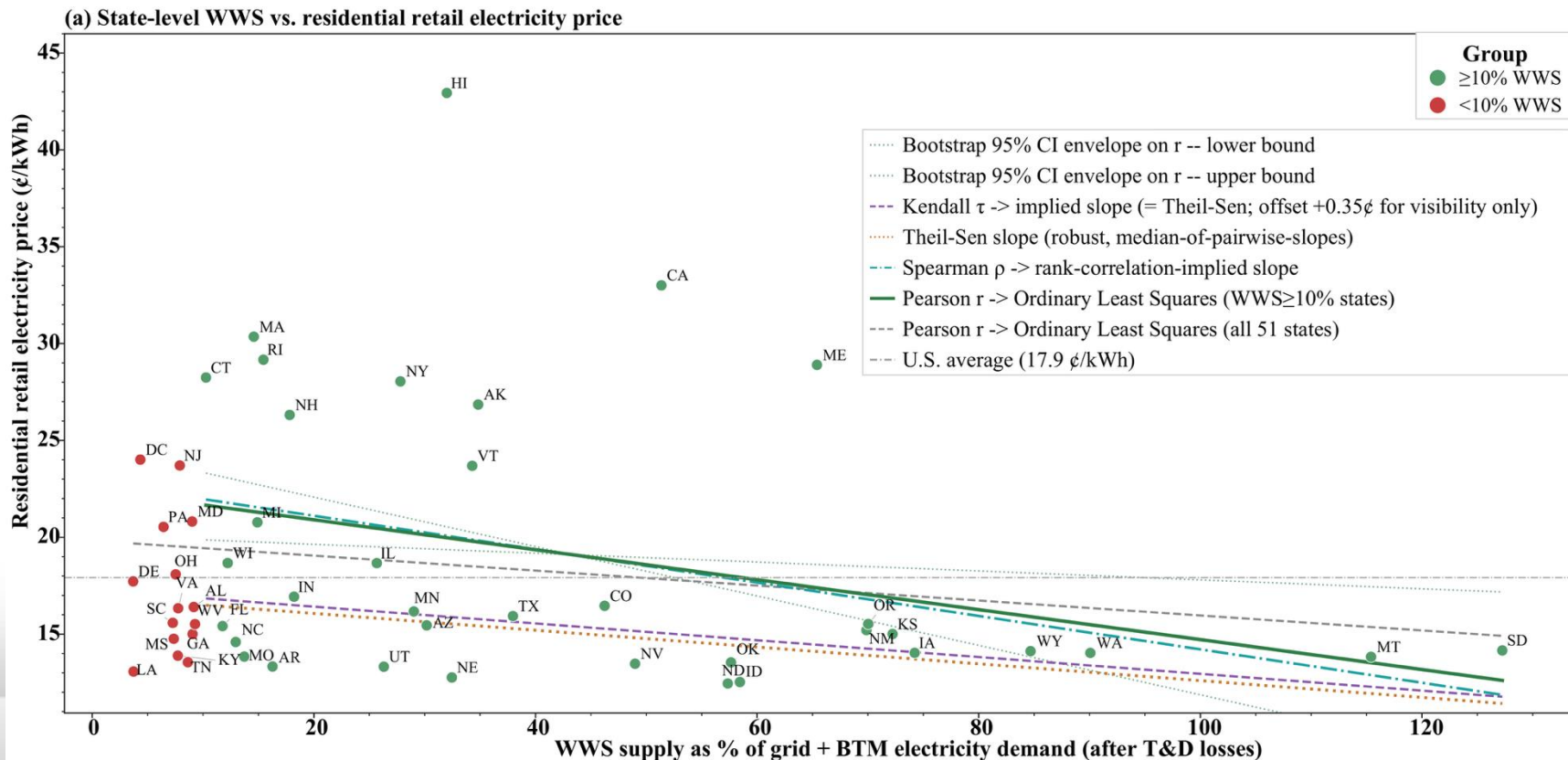


Jul 1, '25 to Jun 30, '26 Percentage of U.S. State Grid Plus Behind-the-Meter Electricity Demand Met Solely by Wind



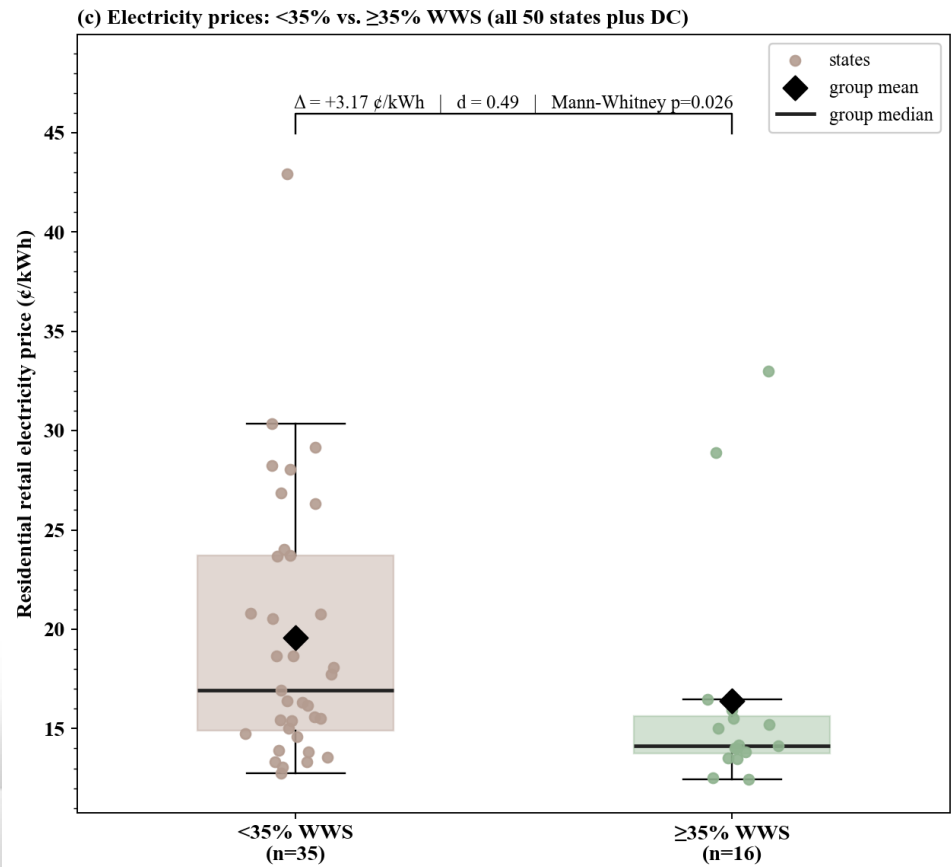
Jul 1, '25-Jun 30, '26 U.S. State Residential Retail Electricity Price vs WWS Supply as a % of Grid Plus Behind-The-Meter Demand

Multiple Fits With WWS>10% are Statistically Significant



July 1, 2025-June 30, 2026, U.S. State Residential Retail Electricity Price for States With <35% vs ≥35% WWS Supply as % of Grid Plus Behind-The-Meter Demand

Mean Difference in Price: 3.2 cents/kWh (Statistically Significant)



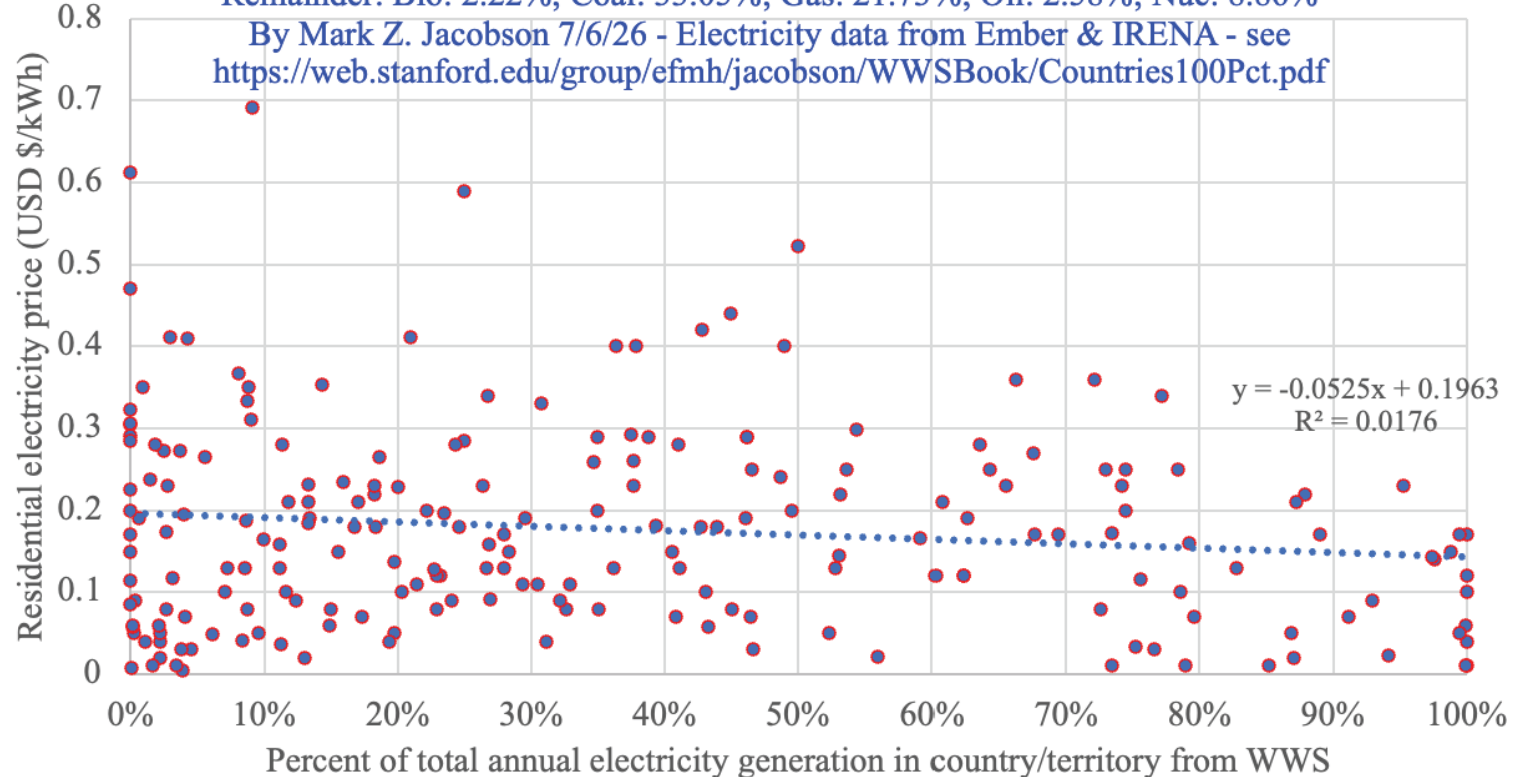
2025 Electricity Price vs. Percent of Total Electricity Production From Wind-Water-Solar in 208 Countries & Territories

WWS met 31.55% of world supply

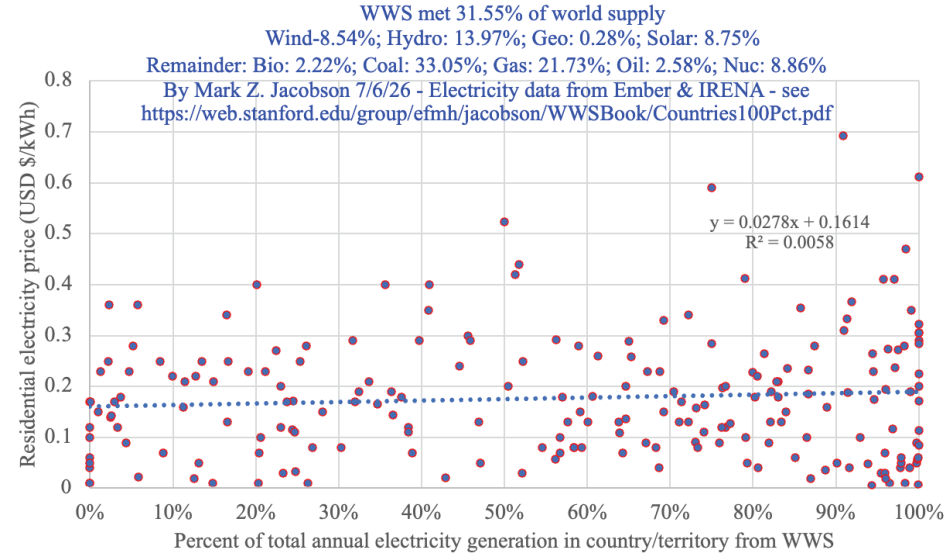
Wind-8.54%; Hydro: 13.97%; Geo: 0.28%; Solar: 8.75%

Remainder: Bio: 2.22%; Coal: 33.05%; Gas: 21.73%; Oil: 2.58%; Nuc: 8.86%

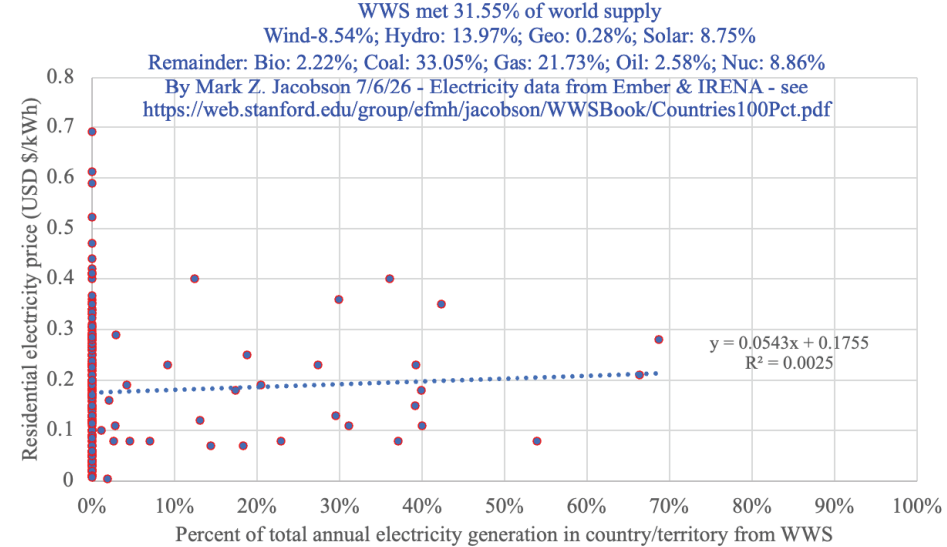
By Mark Z. Jacobson 7/6/26 - Electricity data from Ember & IRENA - see
<https://web.stanford.edu/group/efmh/jacobson/WWSBook/Countries100Pct.pdf>



2025 Electricity Price vs. Percent of Total Electricity Production From Fossil Fuels in 208 Countries & Territories



2025 Electricity Price vs. Percent of Total Electricity Production From Nuclear in 208 Countries & Territories



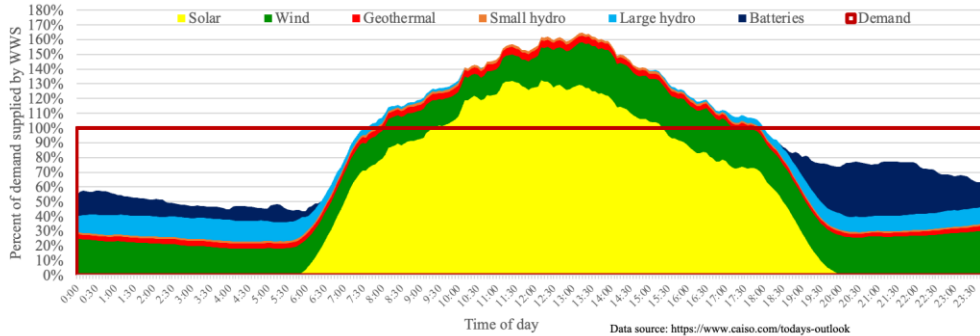
Progress in California Toward 100% WWS in the Electric Power Sector

Examples With the CAISO Grid

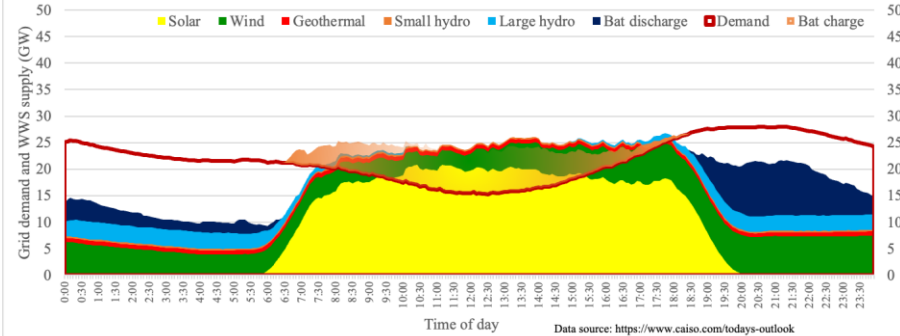
Saturday, June 20, 2026

Record WWS as a Percent of Demand (164.6%)

Percent of California Main Grid Electricity Demand Supplied by Wind-Water-Solar (WWS)
Sat. June 20, 2026



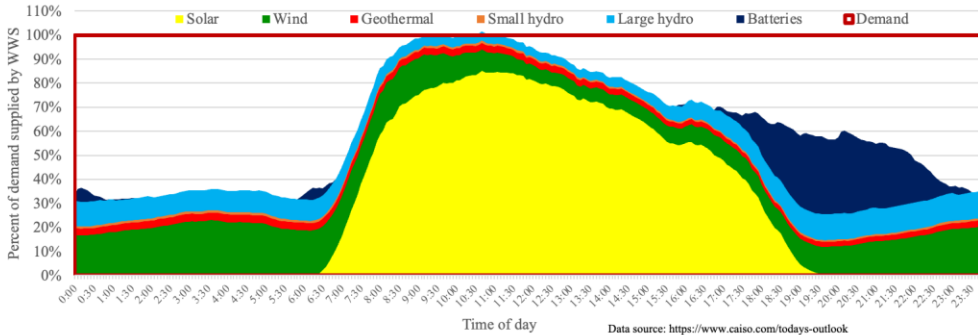
California Main Grid Electricity Demand and Wind-Water-Solar (WWS) Supply (GW)
Sat. June 20, 2026



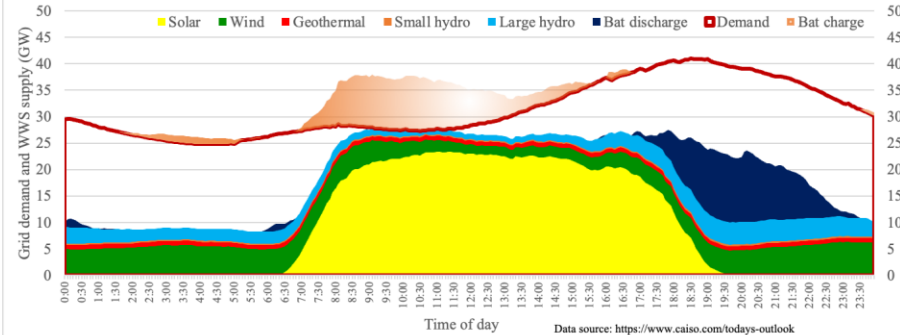
Tuesday, August 18, 2026

Record battery discharge rate: 13.44 GW

Percent of California Main Grid Electricity Demand Supplied by Wind-Water-Solar (WWS)
Tue. August 18, 2026

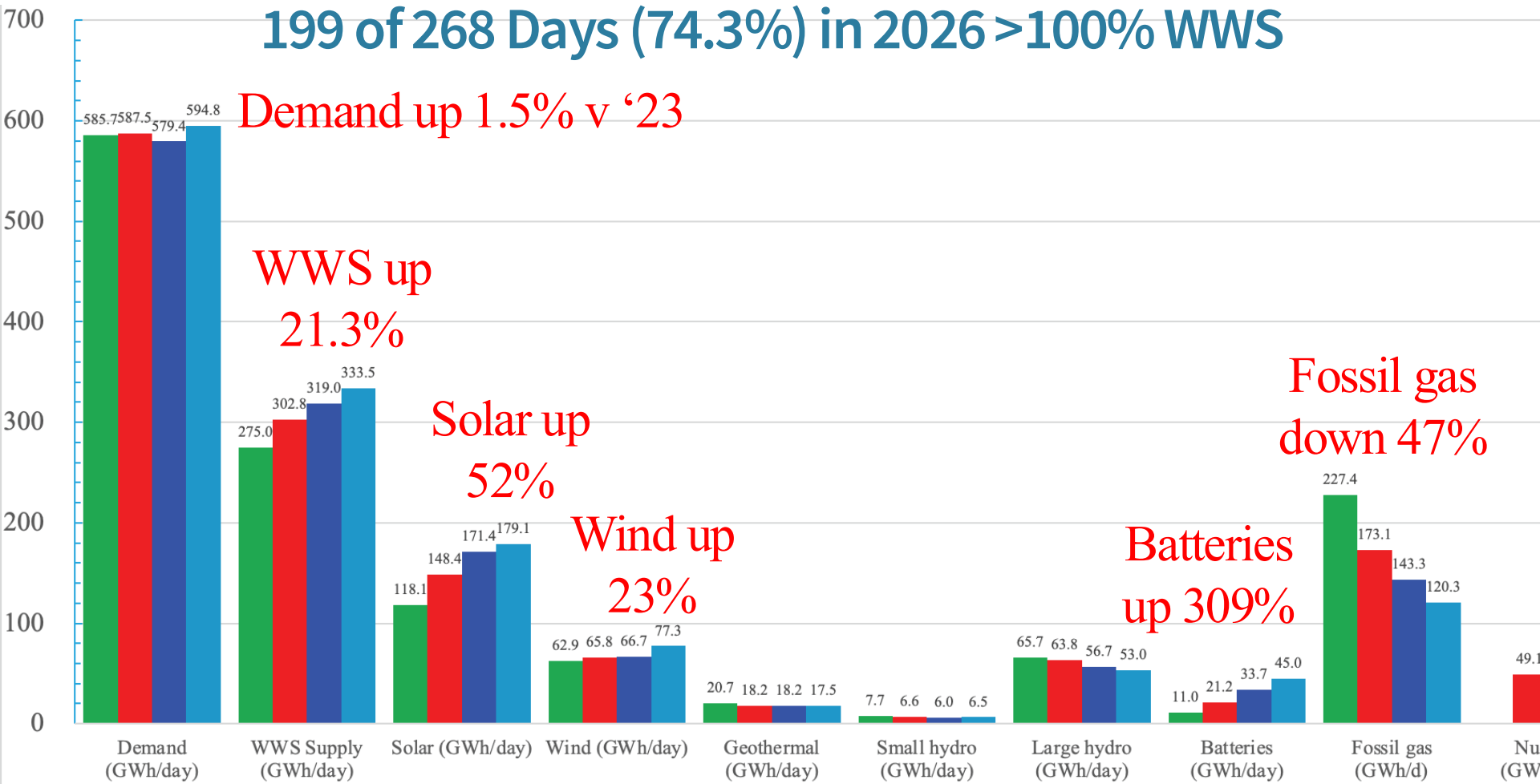


California Main Grid Electricity Demand and Wind-Water-Solar (WWS) Supply (GW)
Tue. August 18, 2026



California ISO Statistics Jan 1–Sep 25, '26 vs '25, '24, & '23

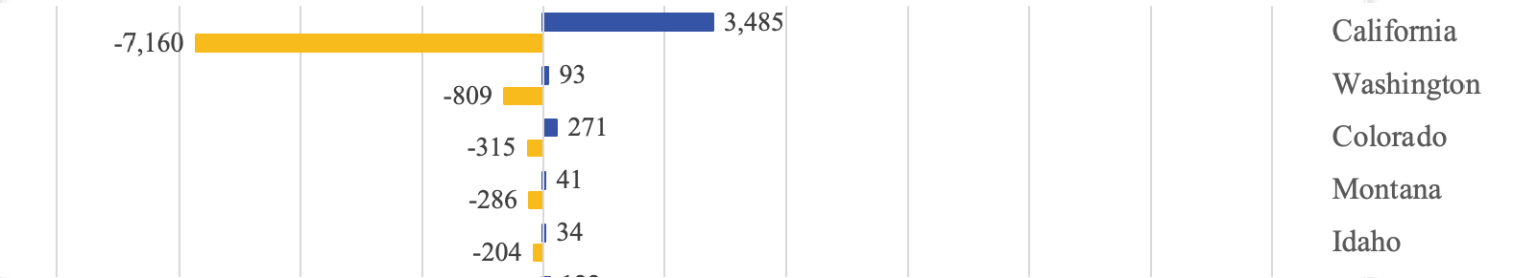
199 of 268 Days (74.3%) in 2026 >100% WWS



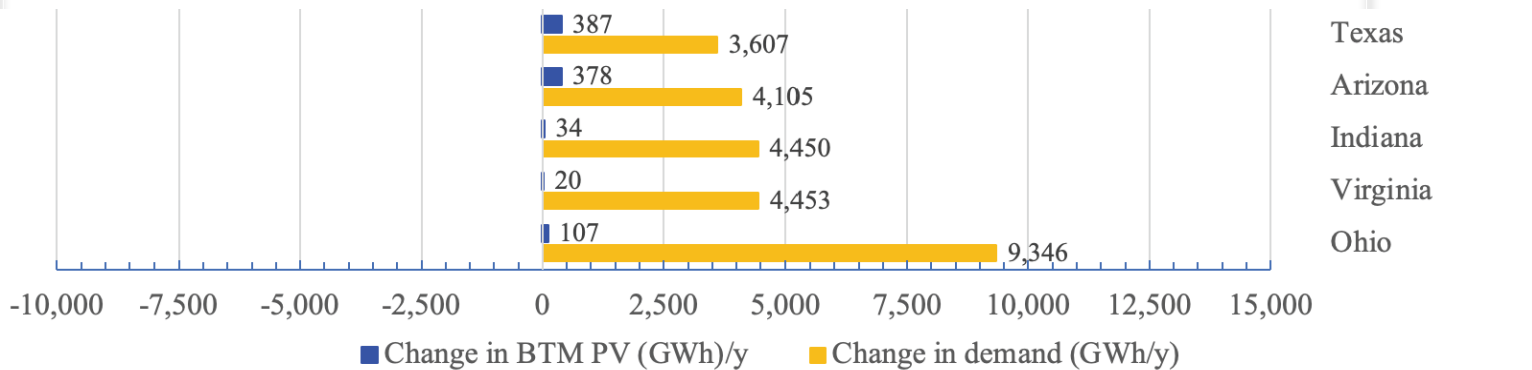
Q324-Q225 to Q325-Q226 Change in US State Behind-the-Meter (BTM) PV Output (Blue) v Change in Grid Elec. Demand (Yellow) (GWh/y)

Growth in BTM PV in California Contributed to Grid Demand Decrease

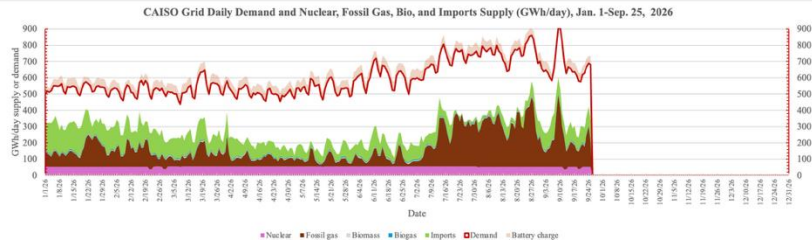
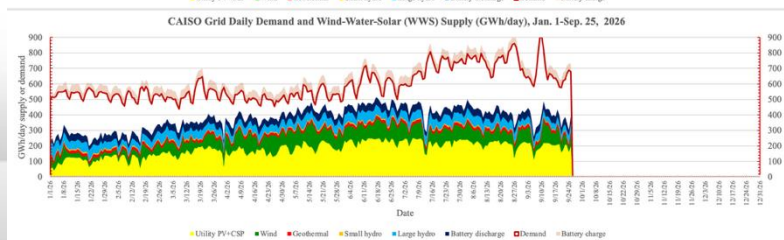
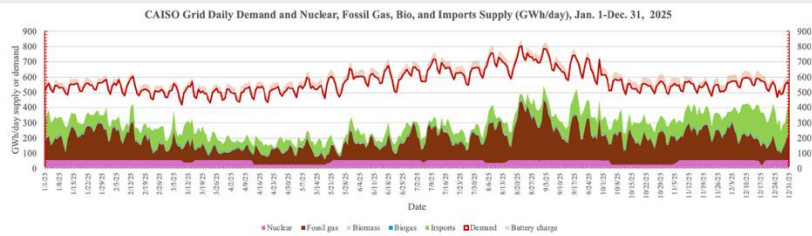
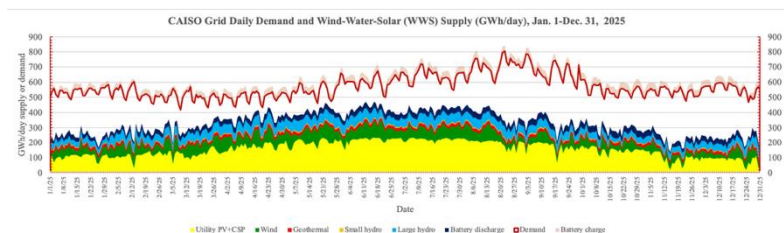
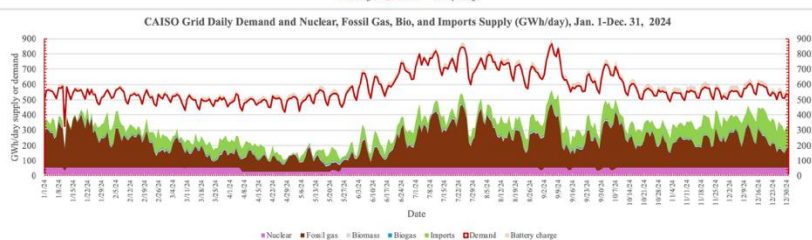
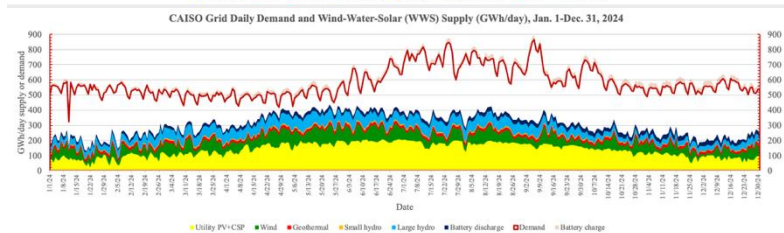
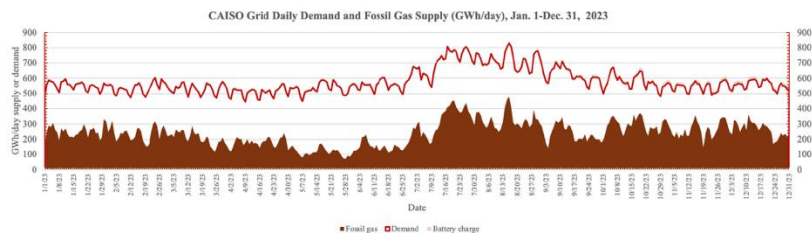
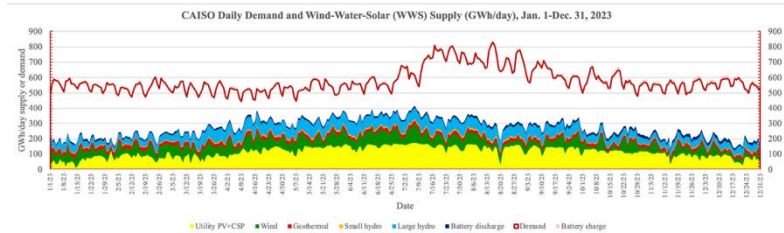
Top 5



Bottom 5

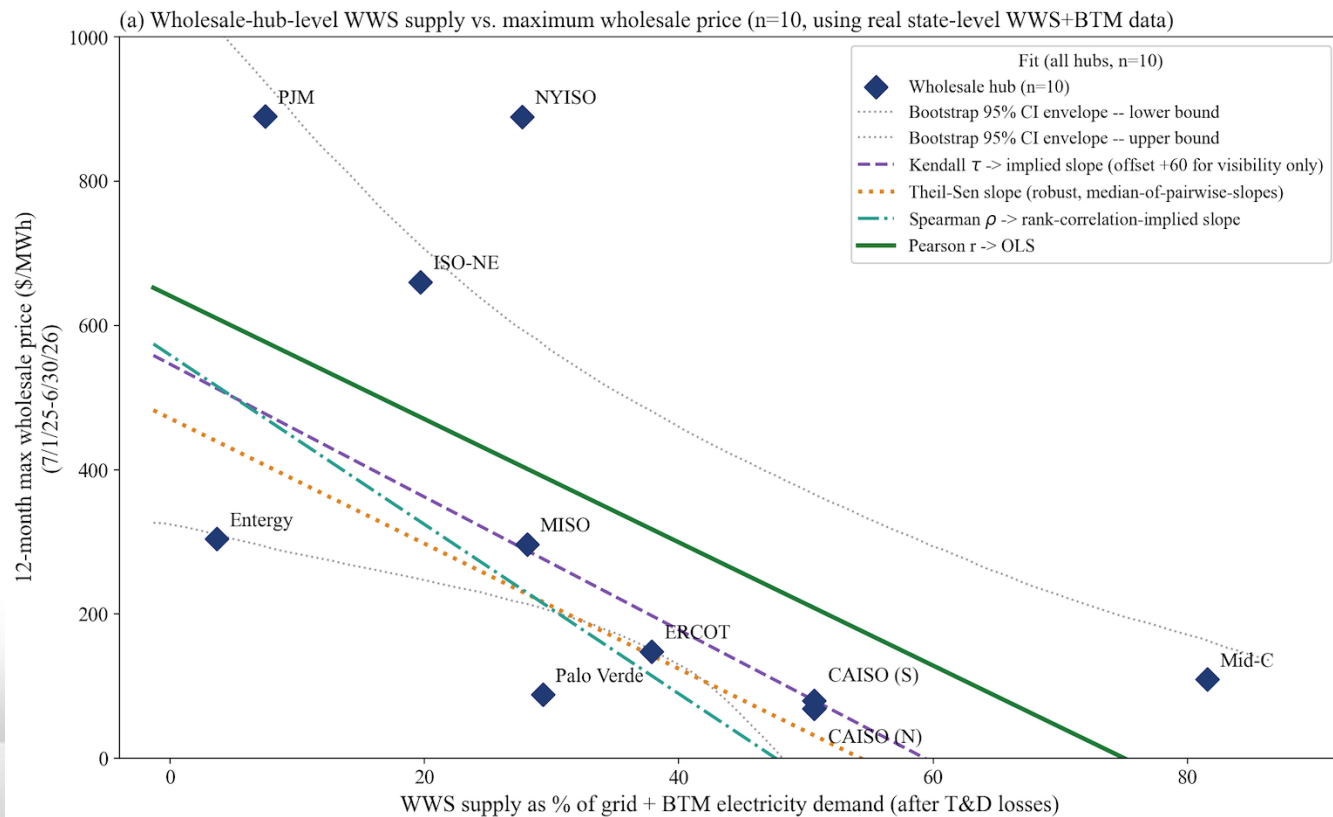


2023-2026 WWS (Left) and Nuc/Gas/Imports (Right) Vs. CAISO Demand



Jul 1, '25-Jun 30, '26 U.S. Maximum Wholesale Electricity Price vs WWS Supply as a % of Grid Plus Behind-The-Meter Demand

Correlations Statistically Significant; CAISO has Most Stable Grid



What Can be Done to Obtain 100% WWS Every Hour?

More utility PV+batteries

More rooftop PV+batteries, heat pumps, & energy-efficient buildings

Offshore wind

Enhanced geothermal

Shift more hydro to night

Use demand response more effectively

California ISO Transmission Connection Requests

Currently on grid (as of Aug. 5, 2026):

23.9 GW PV

12.3 GW Wind

17.13 GW Batteries

Queue requests:

17 GW PV

0.8 GW Wind

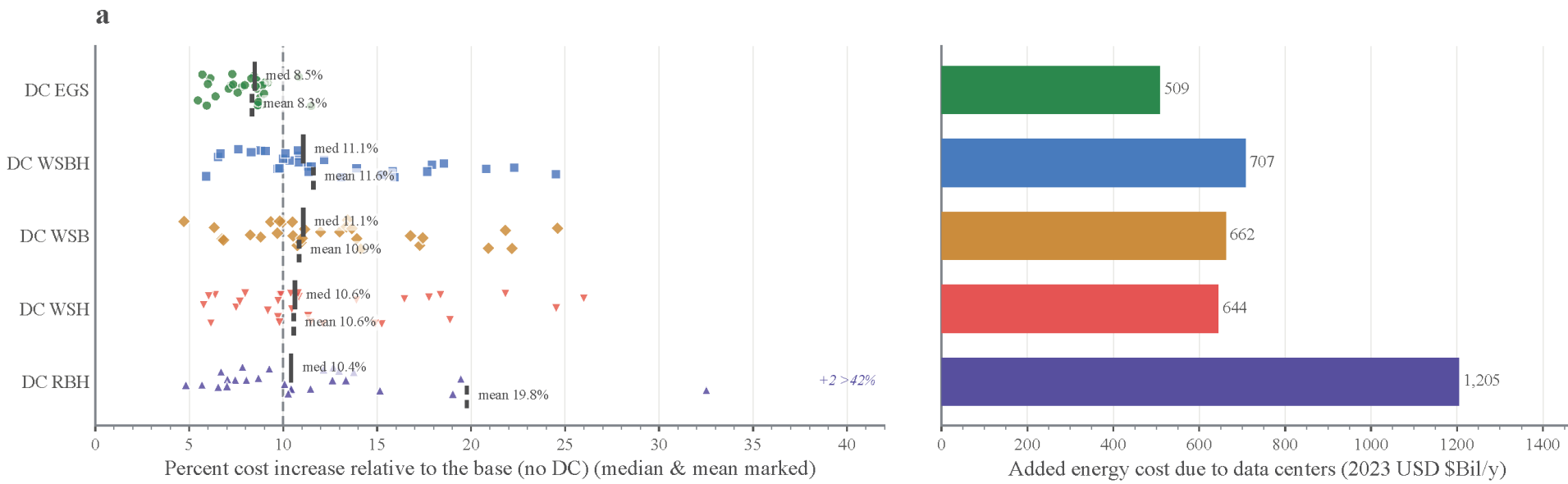
10.9 GW Storage (95% batteries)

0 GW gas, biomass, or nuclear

Powering Data Centers in 155 countries/30 regions in 5 WWS Ways

EGS, WSBH, WSB, WSH, RBH

EGS lowest-cost in 19 regions; RBH in 5; WSH in 4; WSB in 2



Summary

Transitioning the world to 100% clean, renewable energy for all energy purposes...

Avoids over 7 million air pollution deaths per year worldwide

Slows then reverses global warming

Reduces energy needs by 55%

Reduces annual energy costs by 66%

Reduces annual energy plus health plus climate costs by 94%

Creates 23 million more jobs than lost

Requires less land than the current energy infrastructure

Keeps grids stable worldwide

New book on transitioning the world to WWS →

WWS Plans for Countries, States, Cities

[web.stanford.edu/group/efmh/jacobson/Articles
/I/WWS-50-USState-plans.html](http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html)

