Evidence from California on Challenges Facing Electricity Supply Industries with a Significant Share of Intermittent Renewables

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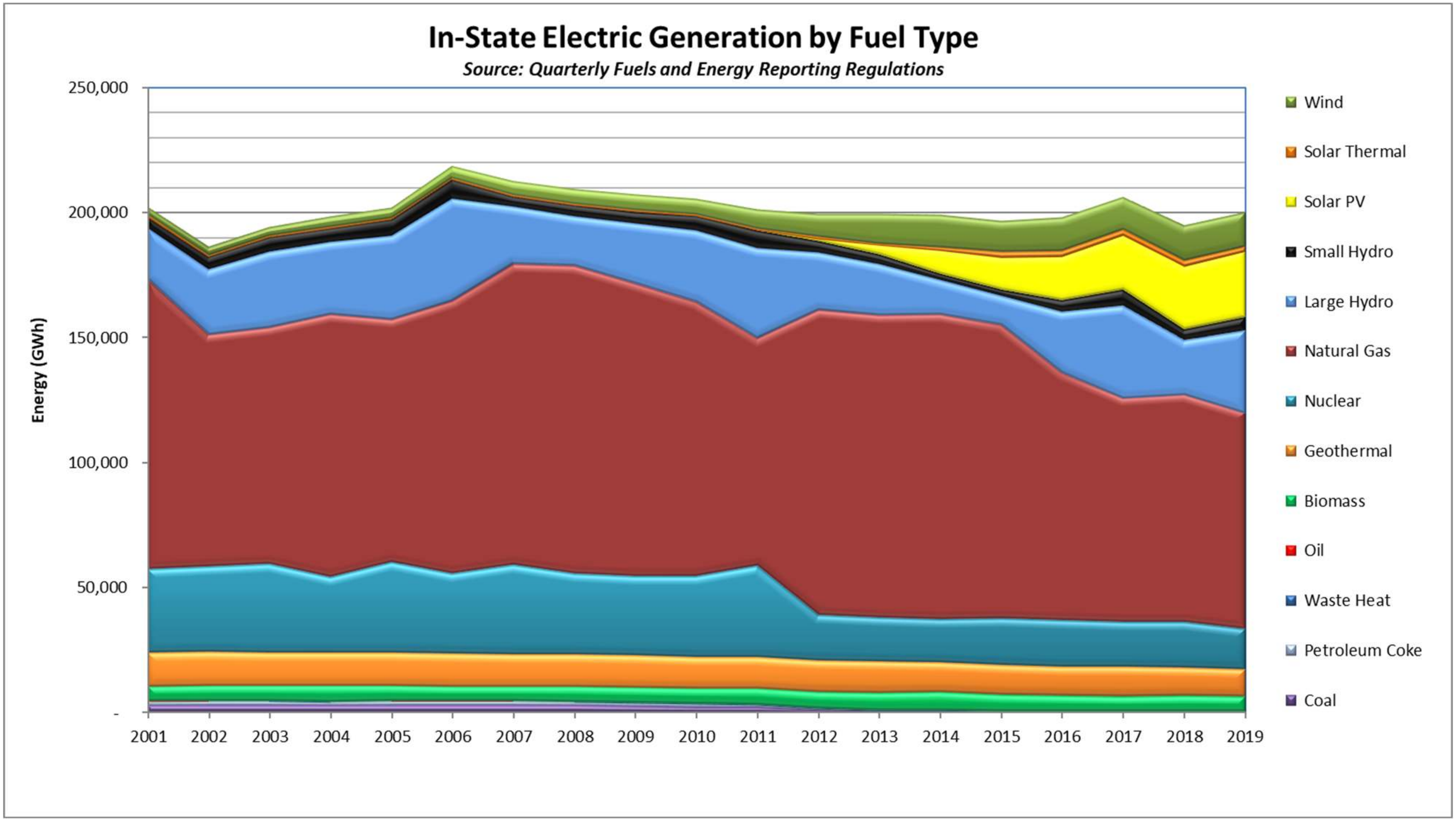
CA’s Renewable Energy Goals

- California has almost 8,000 MW of distributed solar installed
  - Most has been installed since 2007 under California Solar Initiative (CSI)
  - CSI provided $2.167 billion to support distributed solar installations
    - CSI funded by electric ratepayers through higher retail prices which has likely led to more distributed solar adoptions (and higher retail prices…)
      - Wolak (2018) “Evidence from California on the Economic Impact of Inefficient Distribution Network Pricing,” on web-site
- California has 33% Renewables Portfolio Standard (RPS) by 2020 and 60% RPS by 2030
  - 100% clean energy by 2045
  - Currently California has more than 18 GW of grid scale wind and solar resources

CA’s Renewable Energy Goals

- Between 2013, first of year of the 33% RPS compliance period, and 2019 California reduced
  - Natural gas fired-generation capacity by 8,500 MW
  - Nuclear generation capacity by 2,250 MW—San Onofre Nuclear Generation Station (SONGS) was retired
  - Total reduction of 10,750 MW in dispatchable capacity
- Dispatchable generation replaced with
  - 8,200 MW of solar photovoltaic generation capacity
  - 324 MW solar thermal generation capacity
  - 188 MW wind generation capacity
  - Total increase of 8,712 MW in intermittent capacity
- Nuclear capacity produced with ~90 percent capacity factor and natural gas capacity could produce with least at 75 percent capacity factor
- Grid scale solar and wind resources produce at ~25 percent capacity factors

CA’s Generation Mix



CA’s Energy Supply

- California is relies on imports for 25 to 33 percent of consumption annually
  - Pacific Northwest supplies hydroelectric energy in early summer
  - Desert Southwest supplies coal and natural gas-fired generation
- California has a capacity-based long-term resource adequacy mechanism
  - Each generation resource is assigned a firm capacity value
    - Amount of energy generation unit can provide under stressed system conditions
  - All load-serving entities much purchase sufficient firm capacity to cover their peak demand plus a reserve requirement
- Firm capacity (FC) of natural gas or nuclear generation unit relatively straightforward to compute
  - FC = Annual Availability Factor x Nameplate Capacity of Unit

Firm Capacity of Intermittent Resources

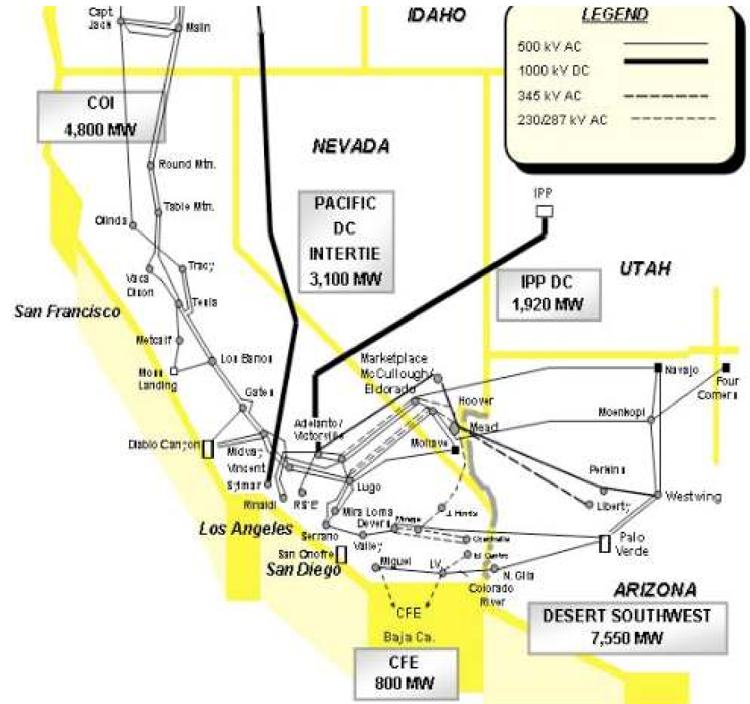
- Firm capacity of hydroelectric resource typically based on historically lowest level of annual energy output
  - Past performance no guarantee of future performance
    - For the case of hydro-dominated Colombian market, see "Market Power and Incentive-Based Capacity Payment Mechanisms," on web-site
- Firm capacity of solar or wind resource extremely challenging to compute
  - If stressed system conditions occur when it is dark, firm capacity of solar generation unit should be zero
  - If stressed system conditions occur when wind is not blowing, firm capacity of wind generation unit should be zero
- High levels of contemporaneous correlation in wind and solar output across locations in California
  - "Level versus Variability Trade-offs in Wind and Solar Energy Investments: The Case of California" on web-site
  - Similar results for wind and solar output levels for National Electricity Market (NEM) in Australia

Firm Capacity of Intermittent Resources

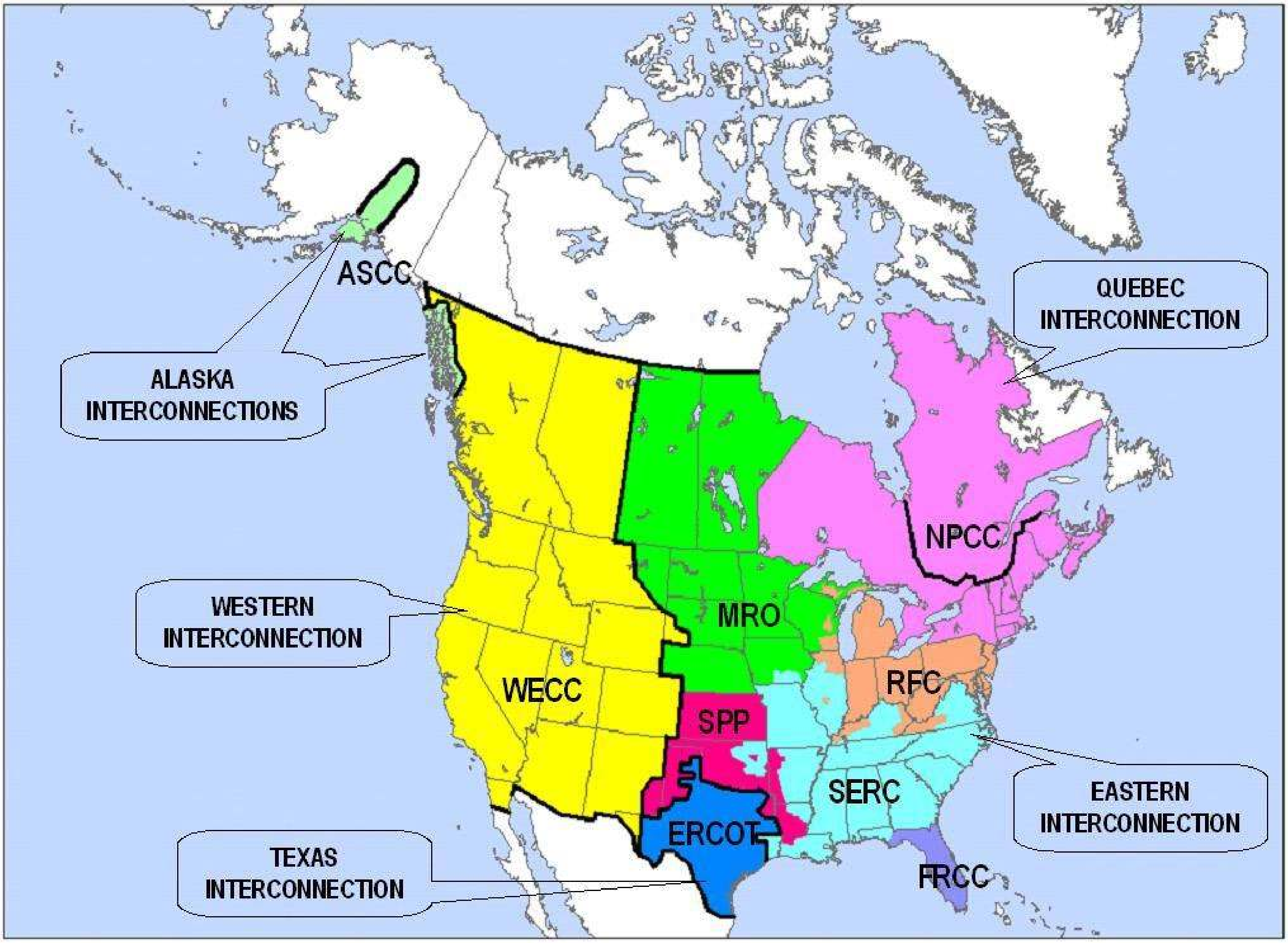
- Assignment of firm capacity to intermittent renewable resources has a significant political component
  - Firm capacity values for August 2020 for wind and solar resources were over ~20 percent nameplate capacity
  - Recent study by three CA investor-owned utilities estimated effective load carrying capability (ELCC) of solar PV at ~5 percent of nameplate capacity
    - 2020 Joint IOU ELCC Study, prepared by Astrape Consulting
- Conclusion: Firm capacity approach to long-term resource adequacy poorly suited to regions with high shares of intermittent renewable energy

California’s Import Dependence

- More than 18,000 MW of transfer capacity between California and neighboring states
    - Significant import potential
- Neighboring states have priority access to electricity produced by generation units owned by utilities in their states
    - Implication: When temperatures in the western US are uniformly high, California may not receive sufficient imports without advance purchases of energy
- California is part of Western Electricity Coordinating Council (WECC) that comprises all states and Canadian provinces west of Continental Divide
- California’s import dependence poorly suited to firm capacity-based long-term resource adequacy mechanism
    - What is firm capacity of an electricity import?



North America's Interconnections



California's Retail Market Policies

- All customers of three large investor-owned utilities—Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electricity—have interval meters
  - Meter records customer's consumption on a 15-minute basis
- No dynamic retail pricing plans offered for residential customers
  - Dynamic prices vary with real-time system conditions in wholesale market
  - Time-of-use prices are NOT dynamic prices because customer is charged same price during *peak* and *off-peak* periods of day, regardless of real-time price of wholesale electricity
- In regions with increasing share of intermittent renewables, demand must shift across of the day maintain real-time supply and demand balance
  - Andersen, Hansen, Jensen, and Wolak (2019) "Can Incentives to Increase Electricity Use Reduce the Cost of Integrating Renewable Resources?" (on web-site)

CA’s Renewables Production

Table 1: Annual Moments of Hourly Wind, Solar, and Wind and Solar Output (MWh)

	2013	2014	2015	2016	2017	2018	2019
	Hourly Wind Output (MWh)						
Mean	1033.54	1131.32	999.26	1204.73	1235.28	1597.35	1581.63
Median	973.79	1035.19	860.06	1092.49	1074.29	1496.55	1439.55
Standard Deviation	843.79	881.27	822.59	918.41	957.56	1161.22	1148.88
Coefficient of Variation	0.82	0.78	0.82	0.76	0.78	0.73	0.73
Standard Skewness	0.39	0.49	0.53	0.41	0.47	0.34	0.42
Standard Kurtosis	2.03	2.29	2.18	2.05	2.08	1.92	2.07
	Hourly Solar (MWh)						
Mean	315.39	1000.38	1510.80	1910.23	2633.99	2923.06	3035.64
Median	11.98	55.50	90.08	101.91	150.53	174.16	209.95
Standard Deviation	435.64	1290.47	1906.14	2391.94	3257.65	3587.68	3761.14
Coefficient of Variation	1.38	1.29	1.26	1.25	1.24	1.23	1.24
Standard Skewness	1.22	0.84	0.83	0.73	0.69	0.67	0.72
Standard Kurtosis	3.50	2.14	2.63	1.86	1.78	1.75	1.85
	Hourly Combined Wind and Solar Output (MWh)						
Mean	1348.93	2131.57	2510.06	3114.96	3869.27	4520.41	4617.28
Median	1364.04	1971.03	2030.58	2385.57	2595.63	3255.97	3150.32
Standard Deviation	883.40	1461.08	1983.06	2426.76	3258.25	3606.08	3818.19
Coefficient of Variation	0.65	0.69	0.79	0.78	0.84	0.80	0.83
Standard Skewness	0.19	0.45	0.63	0.55	0.60	0.55	0.62
Standard Kurtosis	2.32	2.50	2.95	2.07	1.97	1.96	2.03

Data Source: California ISO Oasis Web-Site.

California has more 18,000 MW of Wind and Solar Generation Capacity

Intermittency of CA's Renewables

Table 4: Combined Wind and Solar Output Shortfall Durations (Hours)

	2013	2014	2015	2016	2017	2018	2019
Threshold Value				1000			
Number of durations	231	263	256	228	247	171	183
Mean	13.54	8.46	9.54	8.73	7.96	9.39	9.07
Standard Deviation	27.43	6.08	5.70	5.79	5.49	5.65	5.33
Maximum	288	20	18	21	16	17	17
Threshold Value				2000			
Number of durations	260	388	395	378	368	296	312
Mean	25.55	11.44	10.94	9.75	9.48	9.02	9.16
Standard Deviation	53.44	9.04	5.92	6.50	5.56	6.06	6.10
Maximum	637	82	44	66	18	41	41
Threshold Value				3000			
Number of durations	53	298	356	364	388	380	396
Mean	160.47	21.42	15.85	14.29	12.51	10.72	10.55
Standard Deviation	238.97	42.27	8.57	8.42	5.01	5.94	6.01
Maximum	1283	684	140	141	65	44	44
Threshold Value				4000			
Number of durations	4	191	312	344	360	367	367
Mean	2188	40.06	20.54	16.94	14.91	14.01	13.81
Standard Deviation	1653.46	84.36	30.16	11.69	4.62	5.10	5.82
Maximum	4022	922	501	178	66	65	67

Data Source: California ISO Oasis Web-Site.

California has more 18,000 MW of Wind and Solar Generation Capacity

Intermittency of CA's Renewables

Table 5: Combined Wind and Solar Output Shortfall Durations (Hours), Continue

	2013	2014	2015	2016	2017	2018	2019
Threshold Value				5000			
Number of durations	1	71	226	321	349	356	353
Mean	8758	119.20	32.84	19.84	16.31	15.33	15.50
Standard Deviation		260.95	65.10	21.56	8.19	6.32	7.21
Maximum	8758	1809	875	299	92	90	68
Threshold Value				6000			
Number of durations	1	15	96	258	333	343	339
Mean	8758	581.13	86.90	27.84	18.33	16.81	17.04
Standard Deviation		929.90	172.79	54.09	13.86	9.99	12.14
Maximum	8758	2938	1379	753	140	115	116
Threshold Value				7000			
Number of durations	1	1	19	131	284	318	318
Mean	8758	8759	457	61.89	23.36	19.38	19.16
Standard Deviation			800.28	155.67	36.90	22.03	20.62
Maximum	8758	8759	3177	1363	478	226	239
Threshold Value				8000			
Number of durations	1	1	3	45	227	280	283
Mean	8758	8759	2918	191.07	31.92	23.60	23.06
Standard Deviation			2794.44	437.76	71.69	46.05	43.96
Maximum	8758	8759	5583	2485	634	527	475

Data Source: California ISO Oasis Web-Site.

California has more 18,000 MW of Wind and Solar Generation Capacity

CA's Renewables Production

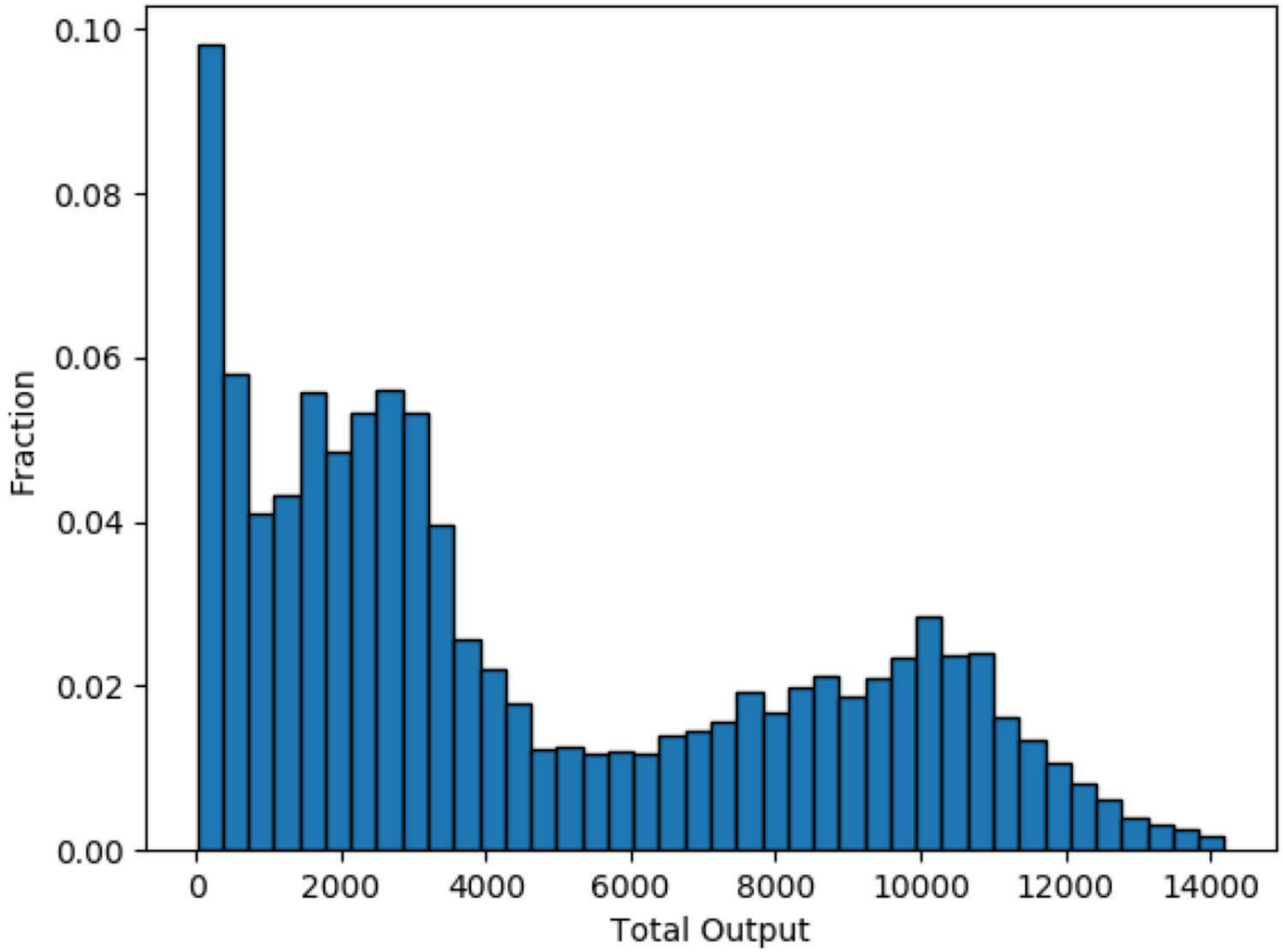
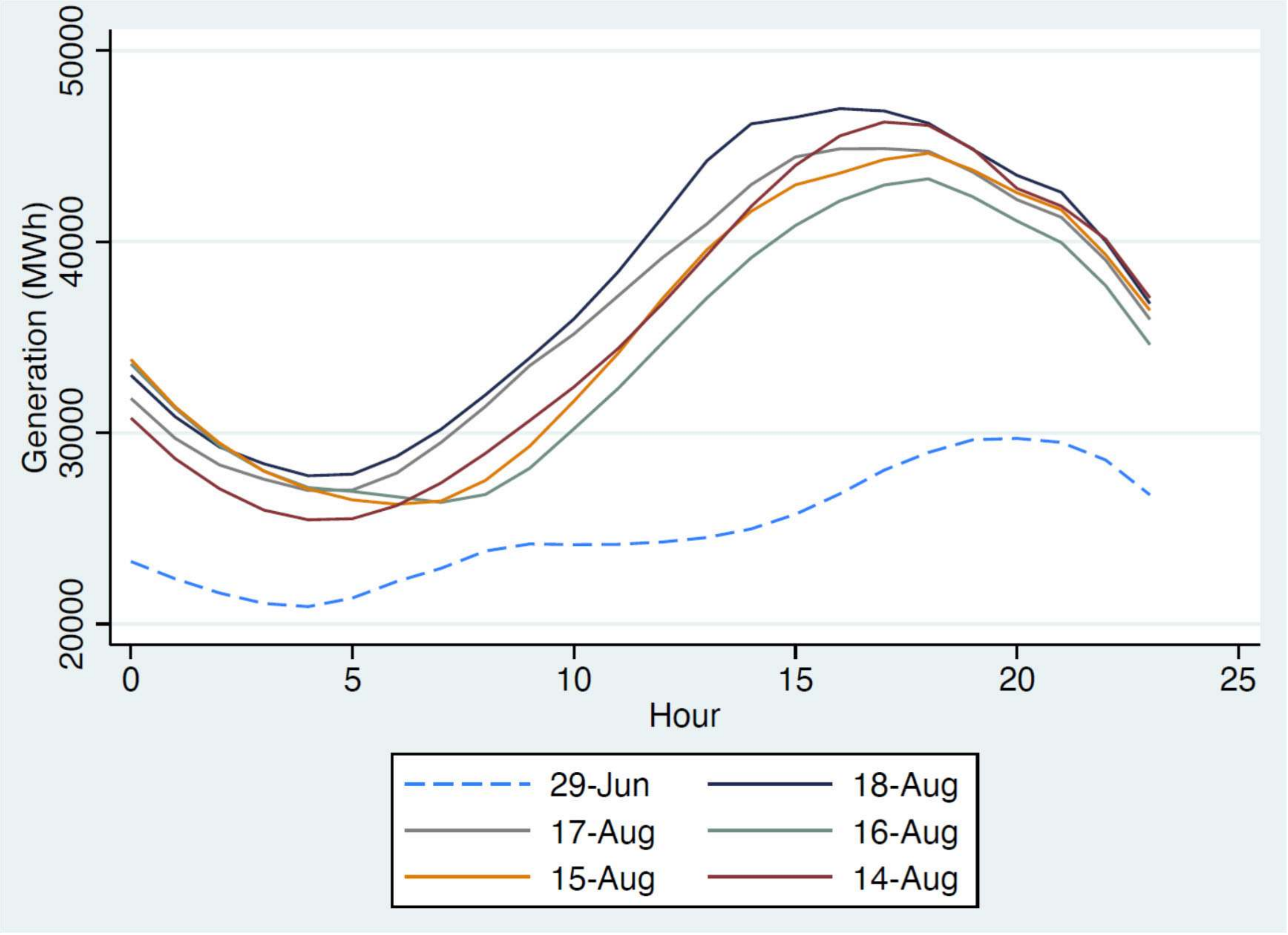


Figure 7: Histogram of Hourly Combined Wind and Solar Output in California ISO Control Area in 2019 (MWh).

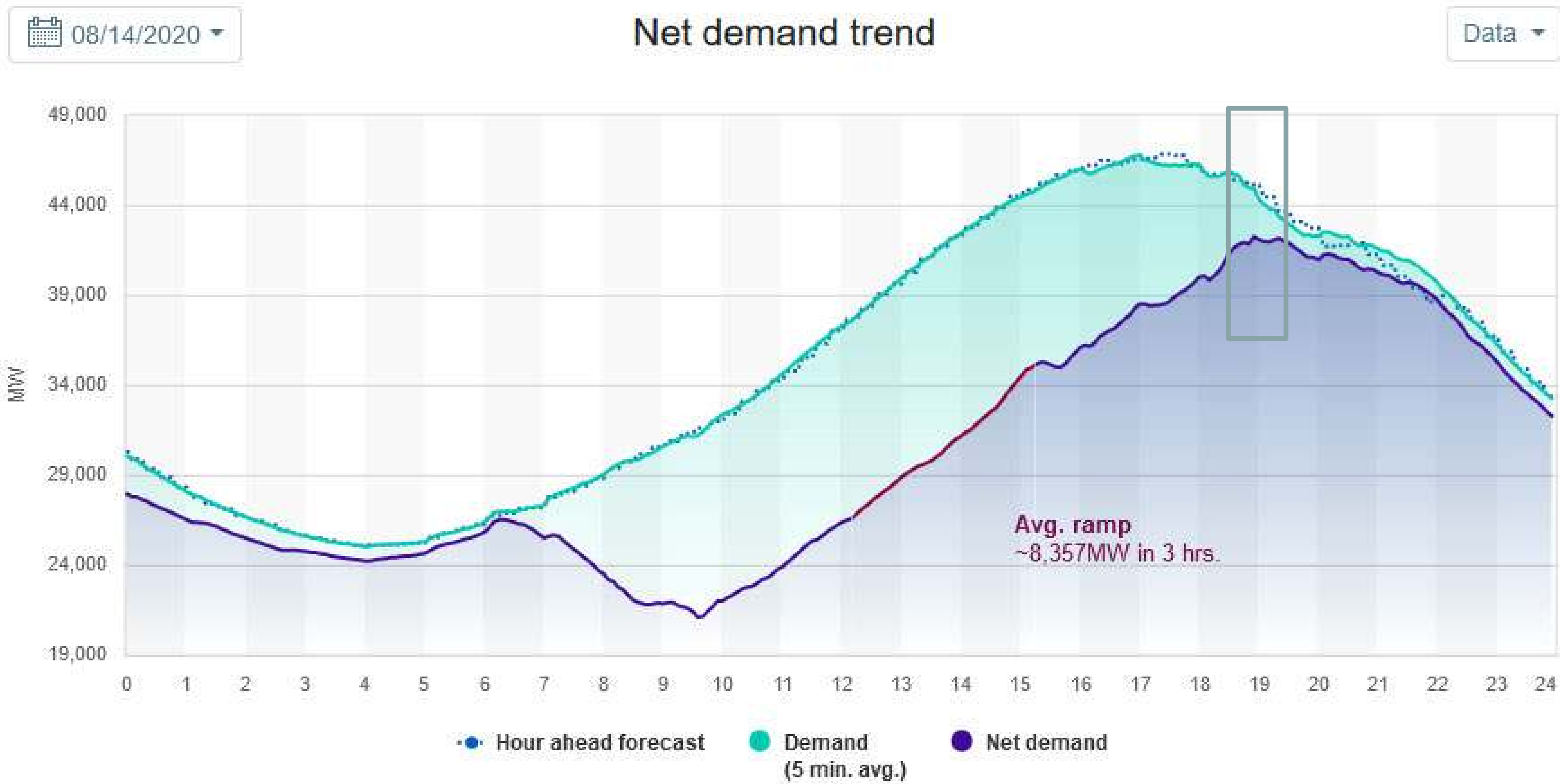
California has more 18,000 MW of Wind and Solar Generation Capacity

Lessons from Blackouts of August 14-15, 2020

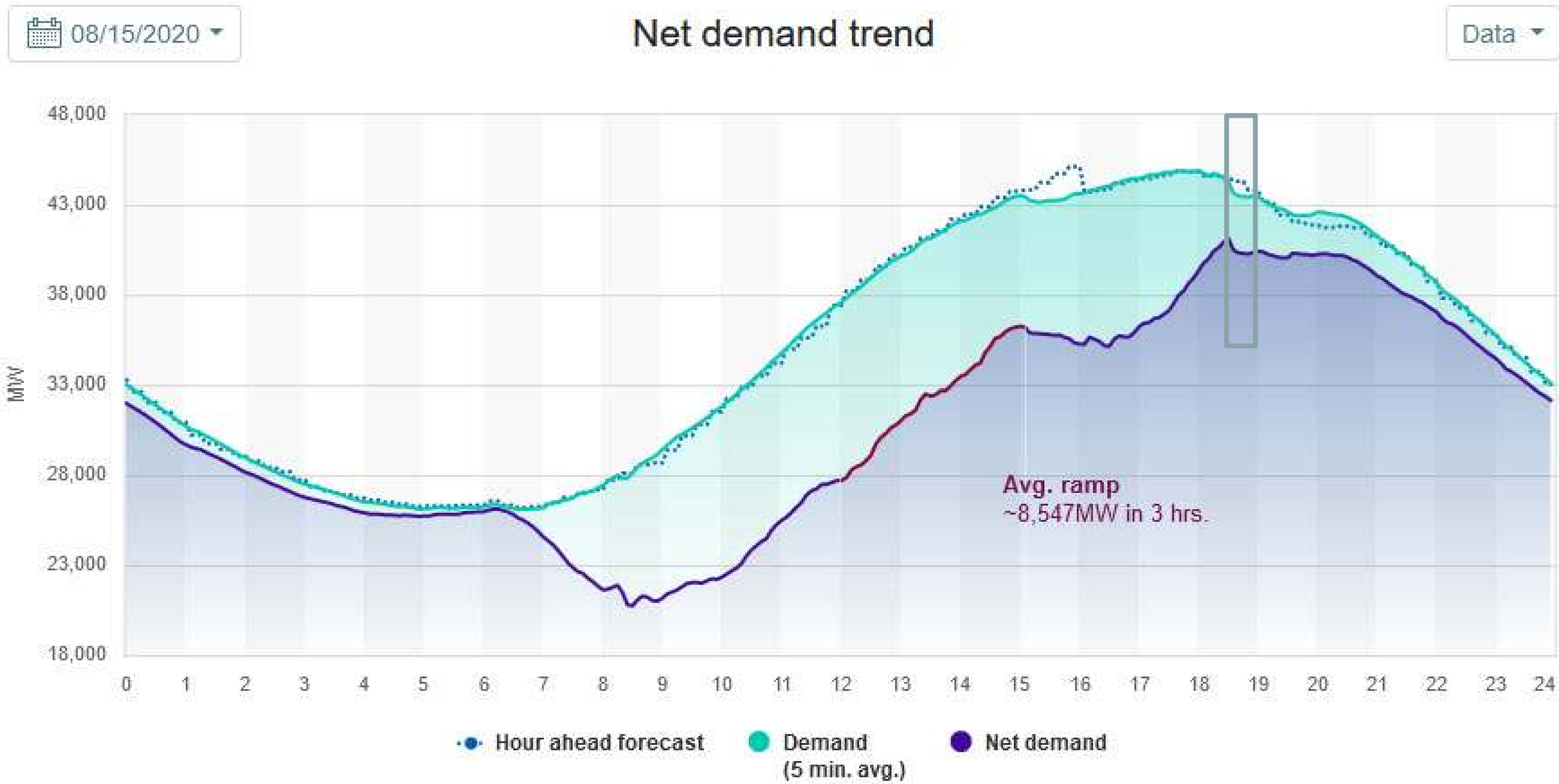
The Rolling Blackouts of 8/14/20-8/15/20 (Hourly Demand in MWh)



The Rolling Blackouts of 8/14/20-8/15/20

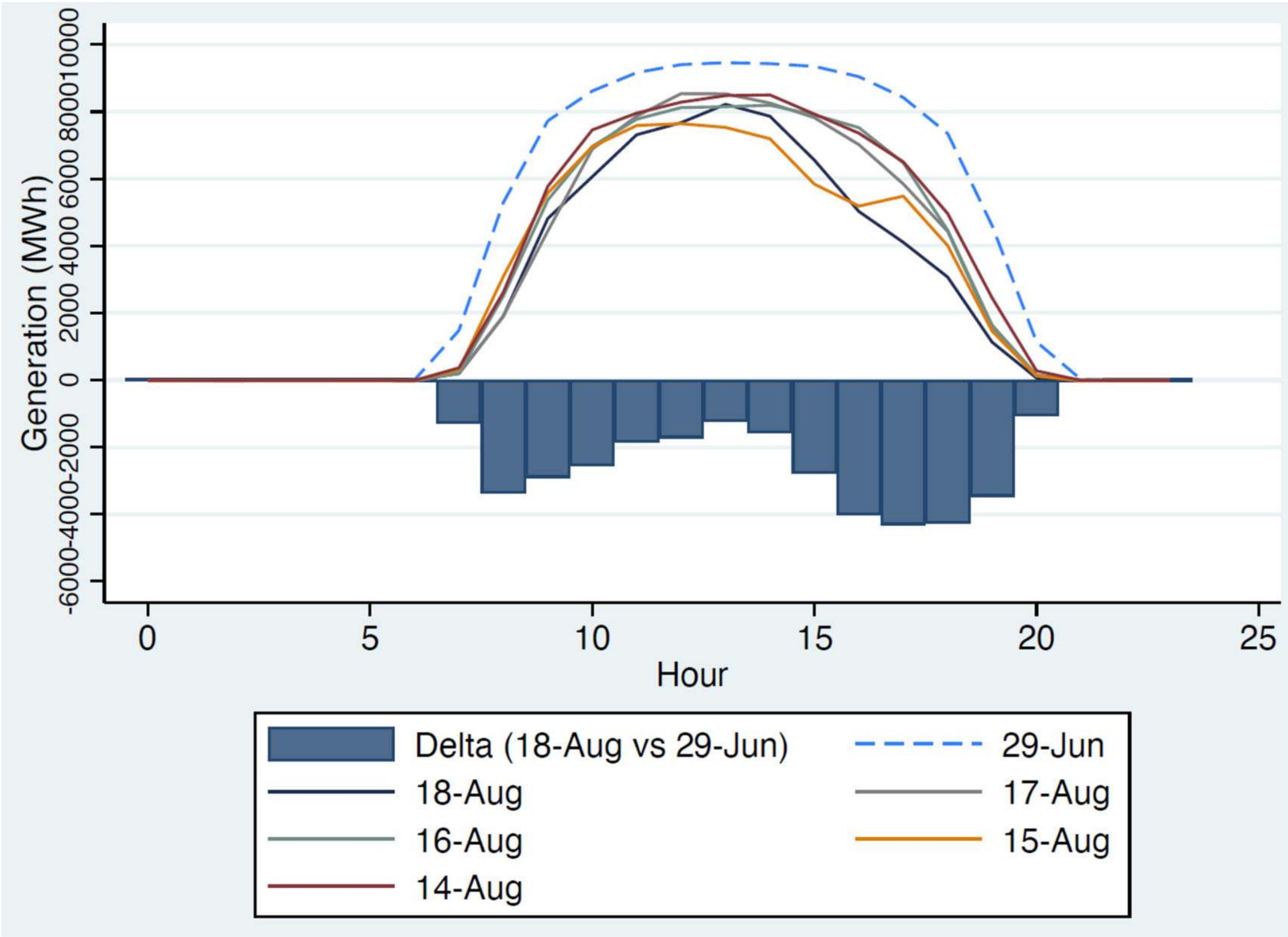


The Rolling Blackouts of 8/14/20-8/15/20



The Rolling Blackouts of 8/14/20-8/15/20

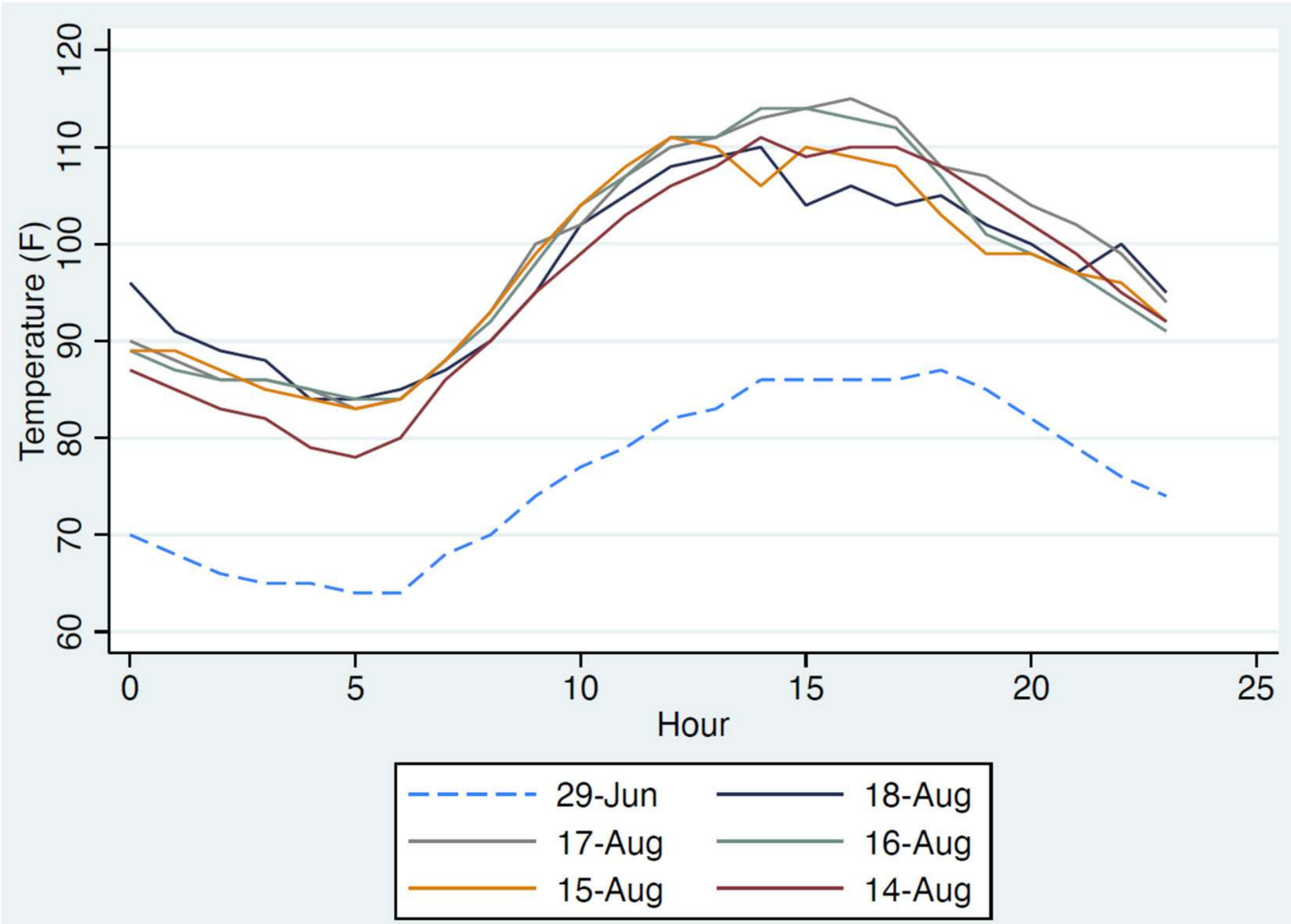
(Hourly Production of Grid-Scale Solar Energy)



Solar Production in California

- June 29, 2020 is an ideal day for solar production in California
  - Panels have maximum efficiency for converting light into electricity at a temperature of 77^{o} F
- Hot days with significant particulate matter in the air are not ideal for solar production
- What explains almost 20% reduction in solar production relative to ideal conditions on August 14 to 18, 2020?

The Rolling Blackouts of 8/14/20-8/15/20
(Hourly Temperature in Barstow, CA)



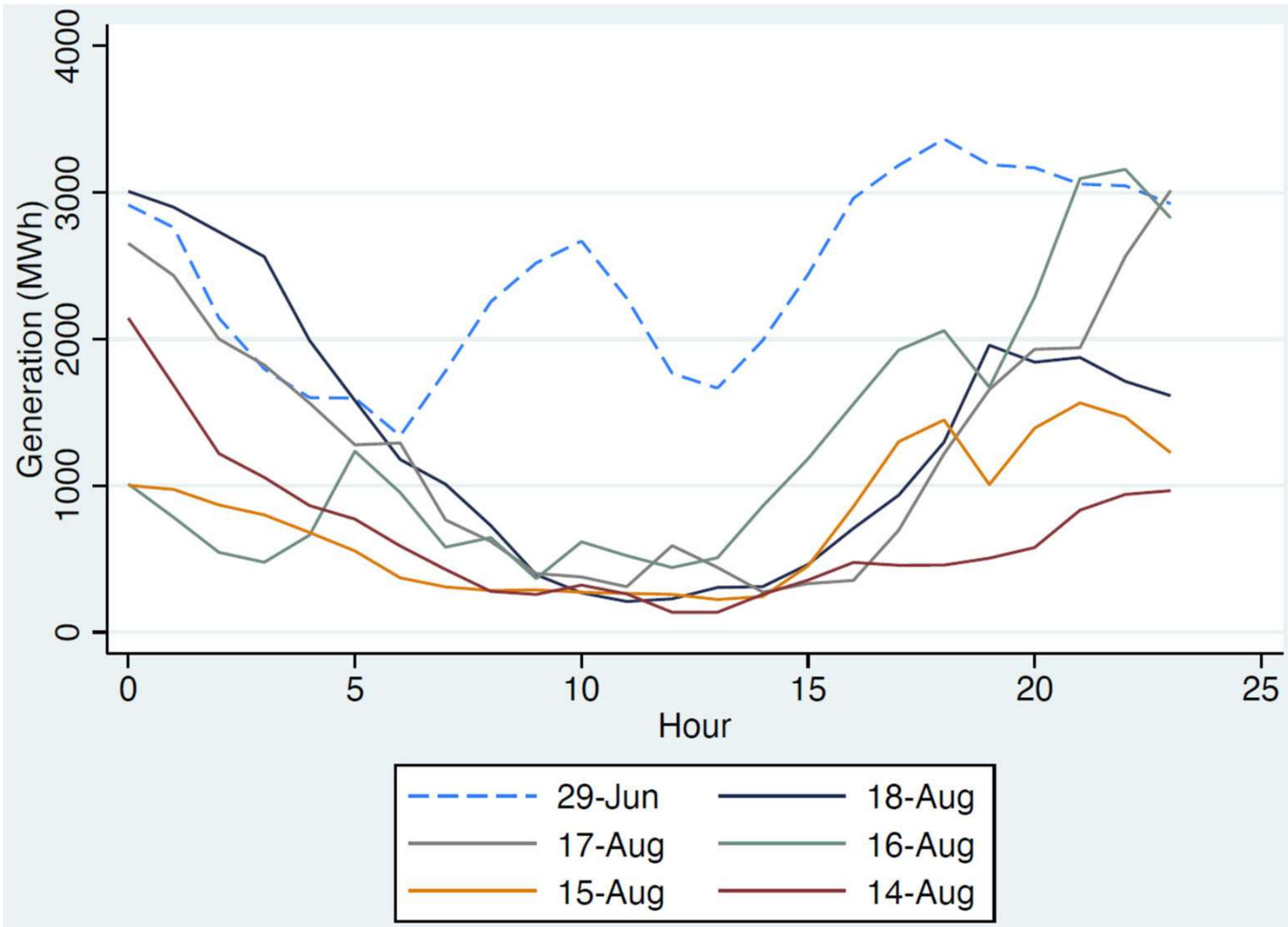
Solar Panels and Temperature

- PV panels are rated at 77^{o} F temperature
  - Convert light into electricity
- Efficiency of panels declines linearly with every degree of temperature above 77^{o} F
- On-site electricity consumption on high temperature days likely to be greater than on lower temperature days
  - Air conditioning load
- Both factors lead to lower net injections to grid from solar PV units
  - Explains less net production from solar units on August 14-18 versus June 29

Wind Production and Temperature

- Wind production on extremely hot days unlikely to be very high
  - Wind occurs because of temperature differentials between locations
  - If it is hot everywhere, there is likely to be very little wind
  - Higher wind production on lower temperature days
- Wind production likely to be greatest at beginning and end of the daylight hours

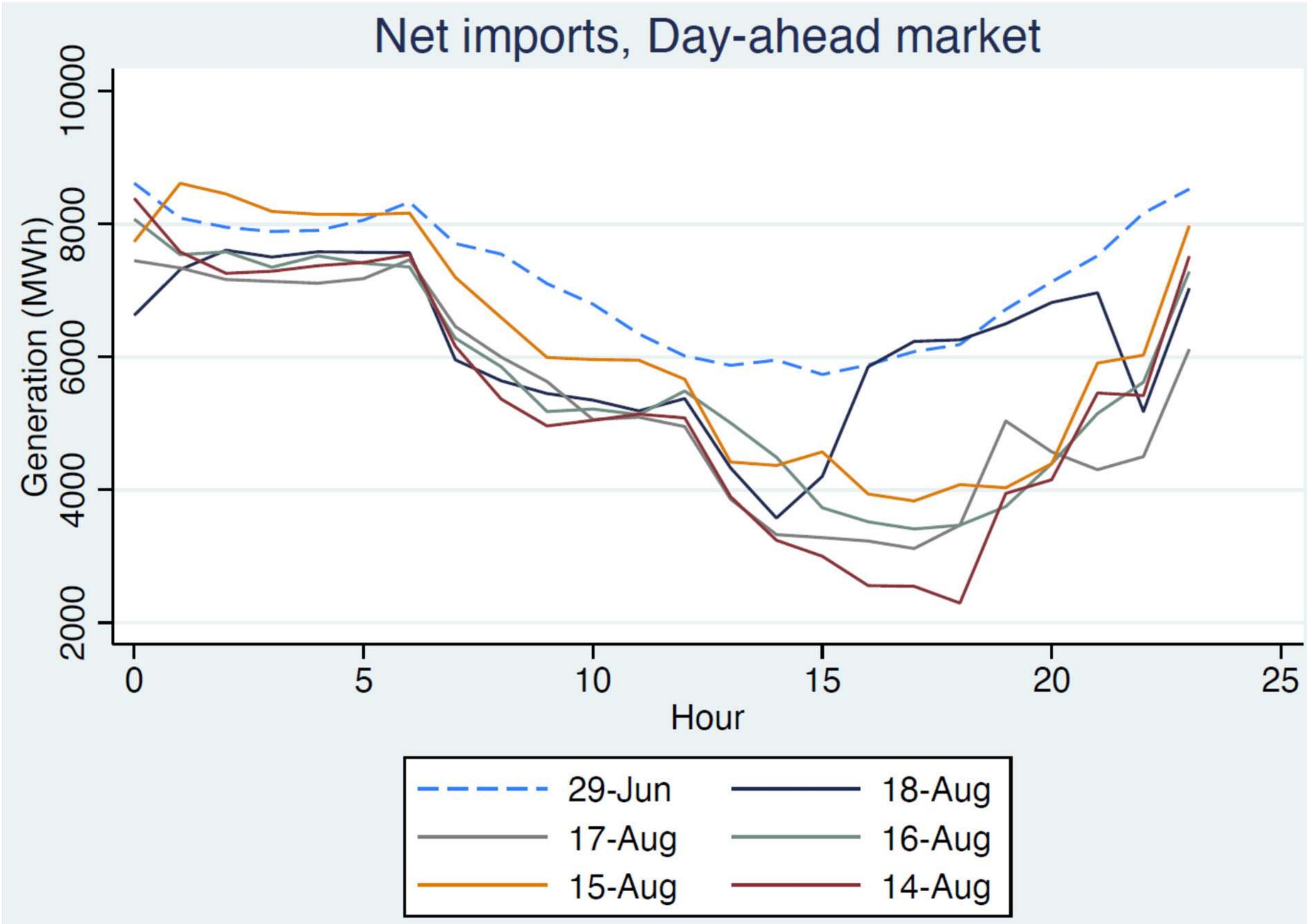
Wind Production and Temperature (Hourly Wind Output)



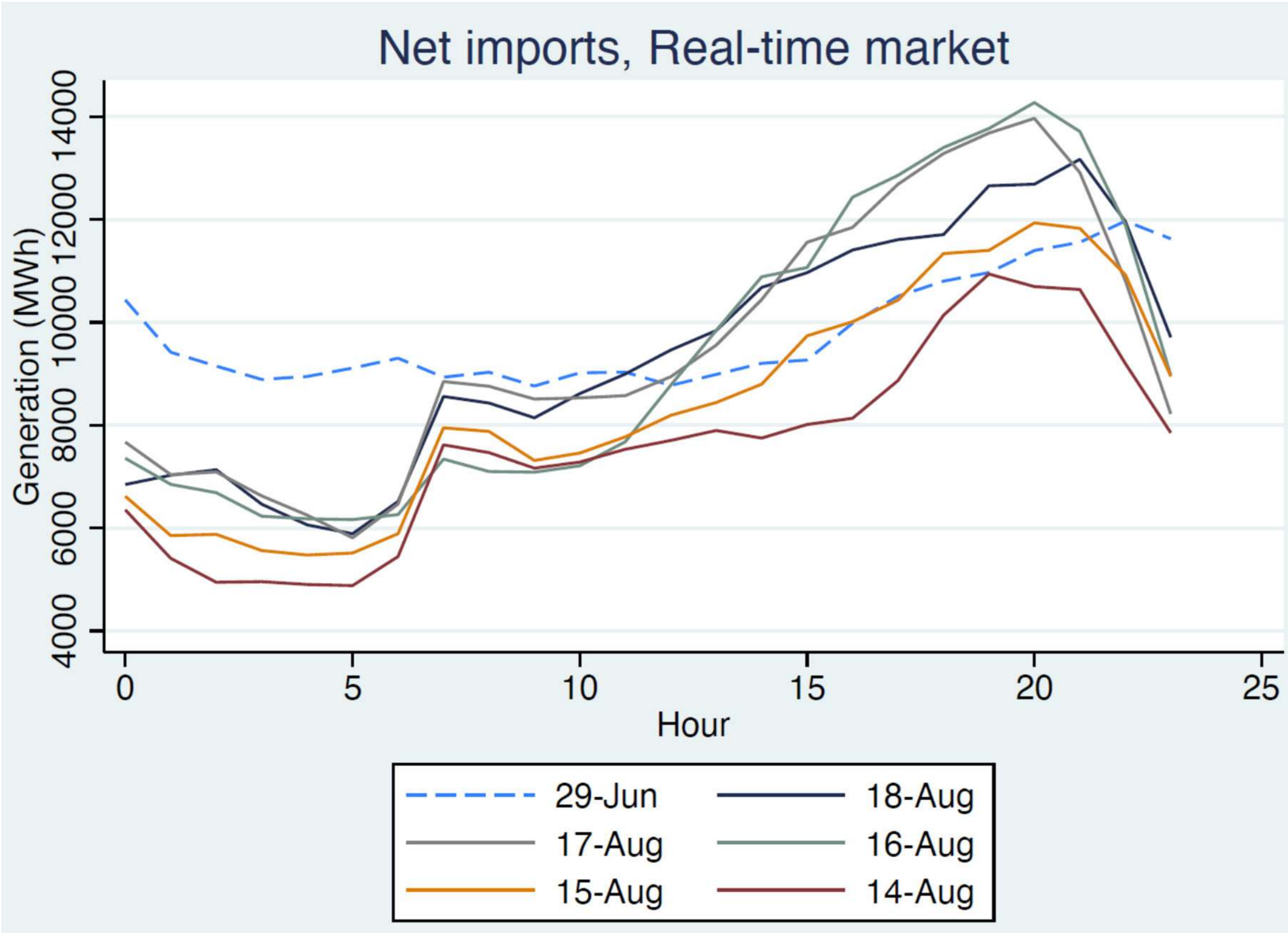
Imports and Temperature in the WECC

- Recall that neighboring control areas have priority for output of generation units in their state
- California load-serving entities can purchase this energy in advance in a fixed-price forward contract to ensure that it is supplied to California
- California can also purchase energy in real-time market
  - Only if price California is willing to pay is higher than price other control areas are willing to pay
  - Prices outside of California were higher than offer cap on California ISO's real-time market on August 14 and 15
- Important lesson—Offer caps on California market can reduce real-time supply to state during stressed system conditions

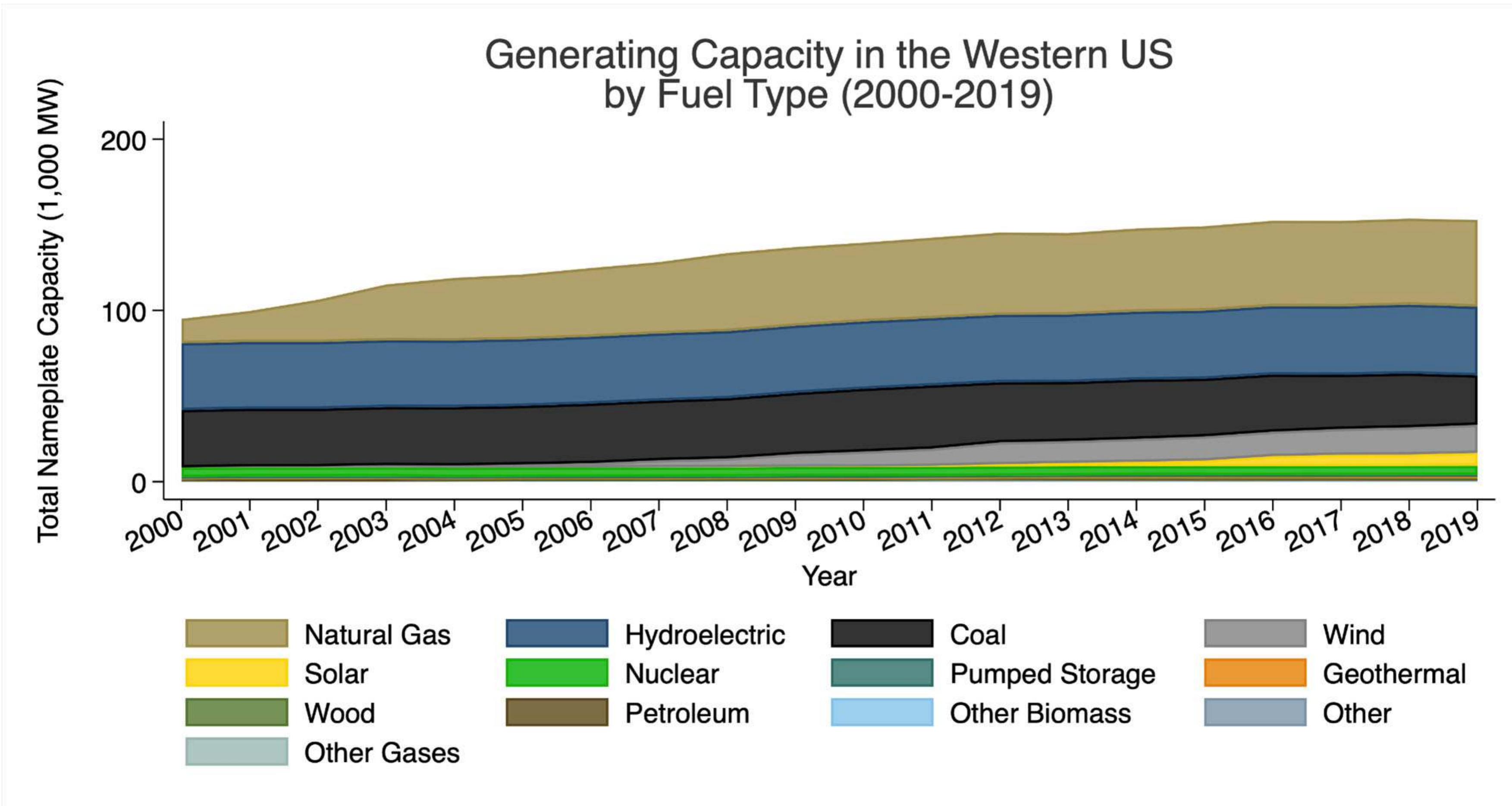
Imports and Temperature



Imports and Temperature



Fuel Mix of Imports



Imports and Temperature

- Difference between August 14 and 15 and August 16 to 18 is that California was able to obtain more imports in real-time market
- A substantial amount of generation capacity exists in the WECC
  - Owners of these units need a financial incentive to turn units on and sell energy to California
  - Events of August 14 and 15 demonstrated California was willing to pay high price for needed energy
- September 5 and 6 heat wave in WECC led to real-time prices during late evening close to $1,000/MWh
  - Annual average wholesale prices in 2019 was slightly less than $40/MWh

Imports and Carbon Emissions

- Imports are at least as carbon intensive as natural gas-fired generation in California
  - Coal or natural gas is input fuel for marginal imports
- California can continue to rely on imports when renewables inside California disappear
  - More global carbon intensive solution to meeting renewables shortfalls in California
- Policy Question: Does California want to reduce GHG emissions from energy produced in California or global GHG emissions
  - Maintaining natural gas units in California accomplishes second goal and reduces probability of events like August 14 and 15, 2020

Conclusions from Analysis

- Replacing dispatchable generation capacity with intermittent generation capacity is very risky
- California has two options to meet real-time demand with less solar and wind energy without instate natural gas units
  - Increase imports, which can be difficult if entire WECC region is hot and California has a finite offer cap on short-term market
  - Reduce real-time demand, which is difficult because of no customers pay according to dynamic prices
- California needs **energy-based** long-term resource adequacy mechanism
  - Buy necessary energy in forward market to ensure it is committed to California market
    - Buying energy on spot market on hot days is likely flying stand-by on Thanksgiving
  - Wolak (2020) “Market Design in a Zero Marginal Cost Intermittent Renewable Future,” (on web-site)

Questions/Comments

For more information

http://www.stanford.edu/~wolak