

# Utility-Scale Wind and Solar in the U.S.

## Comparative Trends in Deployment, Cost, Performance, Pricing, and Market Value

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Wind Energy Technologies Office (WETO) and Solar Energy Technologies Office (SETO)

# Much of the data and analysis presented in these slides comes from LBNL's annual utility-scale wind and solar data and tracking reports

## *Wind Technologies Market Report:*

- Now in its 14<sup>th</sup> year
- **106 GW** of wind in 2019 versus **11.5 GW** in 2006

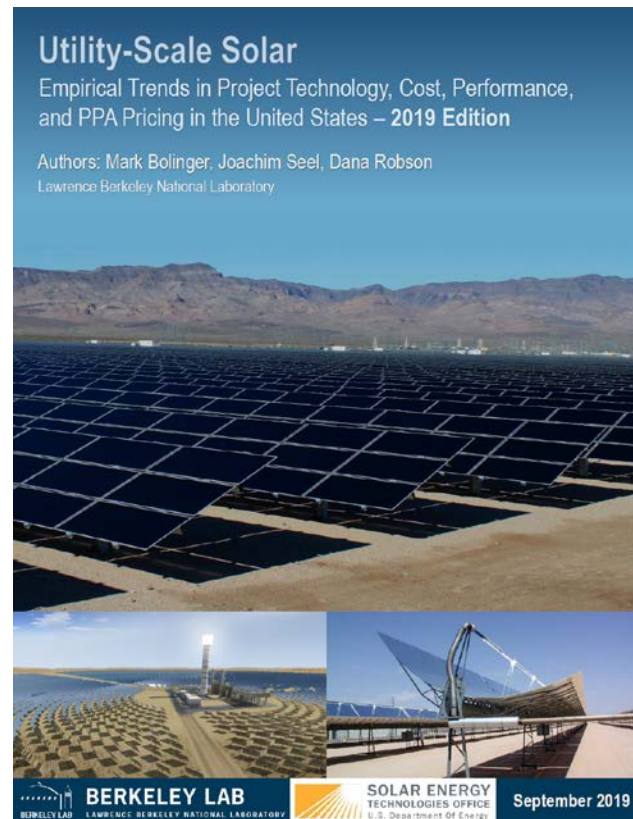
## *Utility-Scale Solar:*

- Now in its 8<sup>th</sup> year
- **29 GW** of utility-scale (>5 MW<sub>AC</sub>) PV in 2019 versus **1.7 GW** in 2012

*Both are shifting towards “data products” rather than narrative reports*



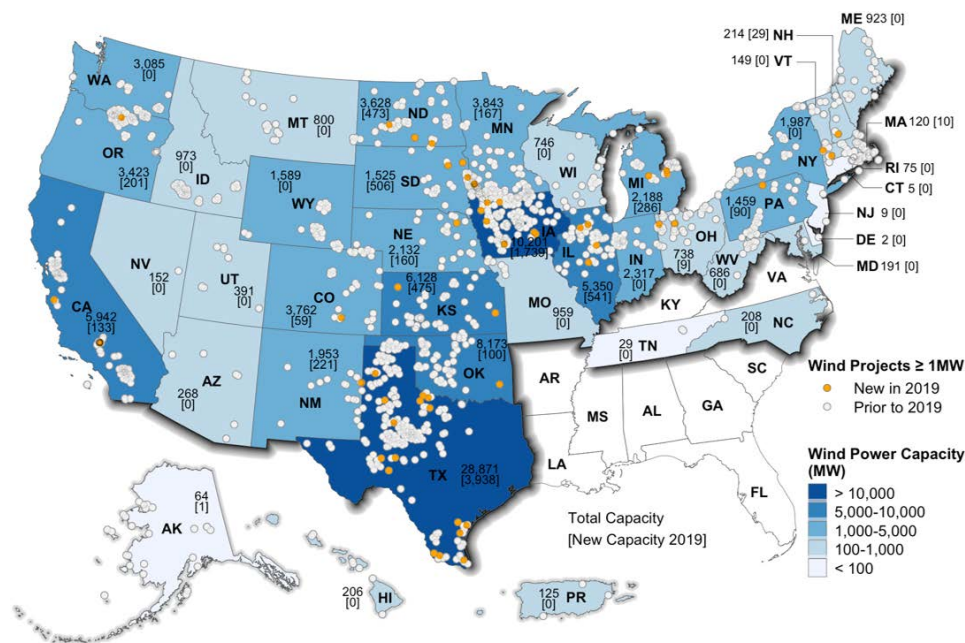
[windreport.lbl.gov](http://windreport.lbl.gov)



[utilitiescalesolar.lbl.gov](http://utilitiescalesolar.lbl.gov)

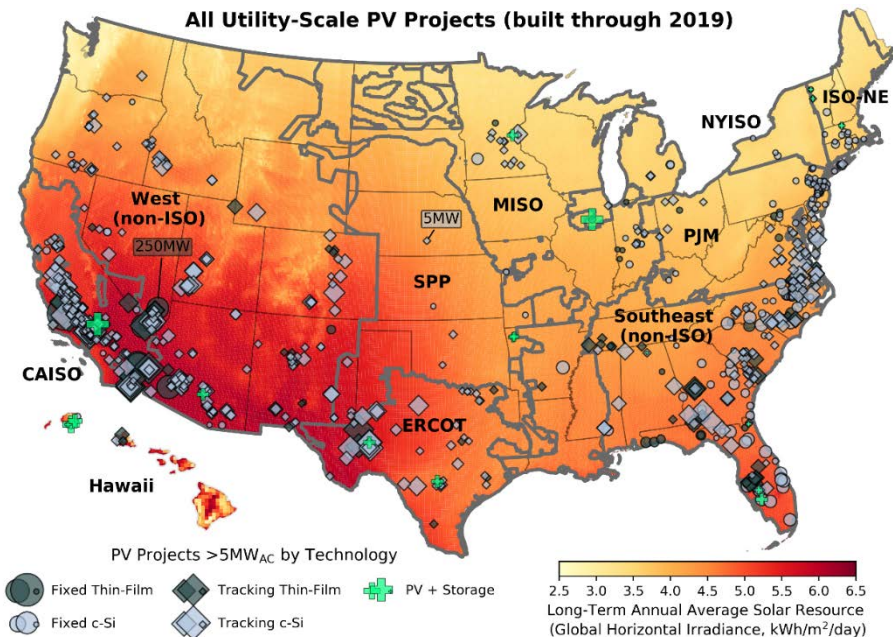
# Wind deployment is concentrated in US interior; utility-scale solar historically in California and Southwest, but spreading

Wind: 106 GW at end of 2019



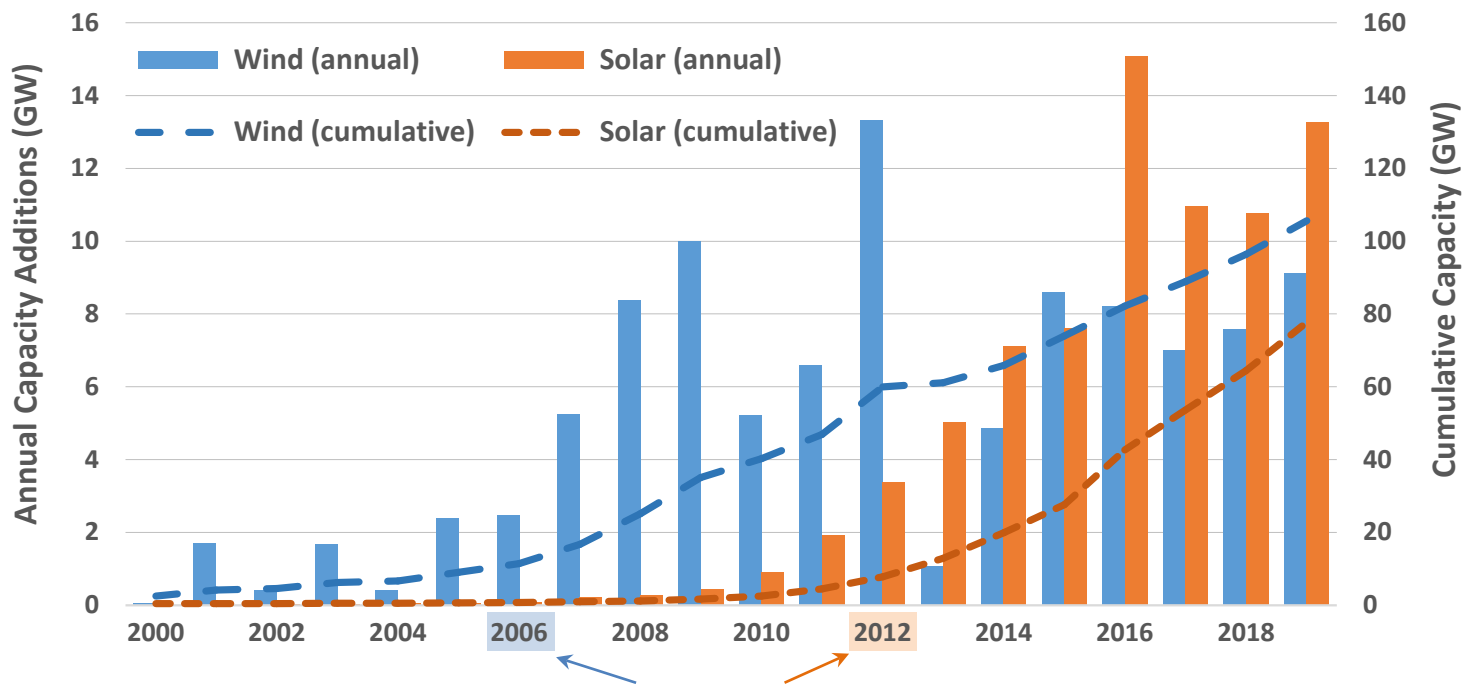
Wind map includes only projects that use wind turbines >100 kW

Solar: 29 GW<sub>AC</sub> at end of 2019



Solar map includes only “utility-scale” PV projects, which we define as ground-mounted projects > 5 MW<sub>AC</sub>

# Annual and cumulative deployment history suggests that solar is 4-5 years behind wind (but not for long?)



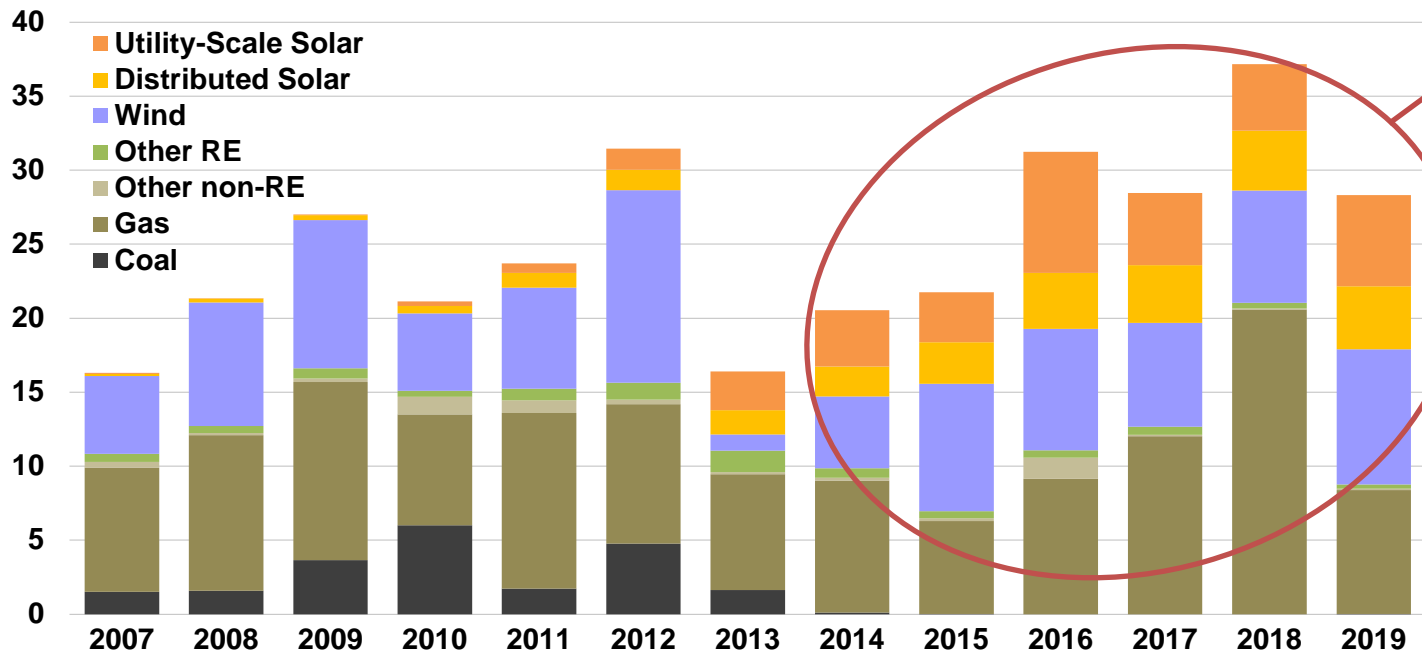
LBNL's market tracking reports for utility-scale **wind** and **solar** began in 2006 and 2012, respectively

- Both technologies have been around since the 1980s, but only started to take off in the 2000s
- Deployment spikes in 2012 (wind) and 2016 (solar) were driven by impending Production Tax Credit (PTC) and Investment Tax Credit (ITC) expirations
  - Both credits were eventually extended

*Note: The solar numbers in the graph include all sectors: residential, commercial, and utility-scale.*

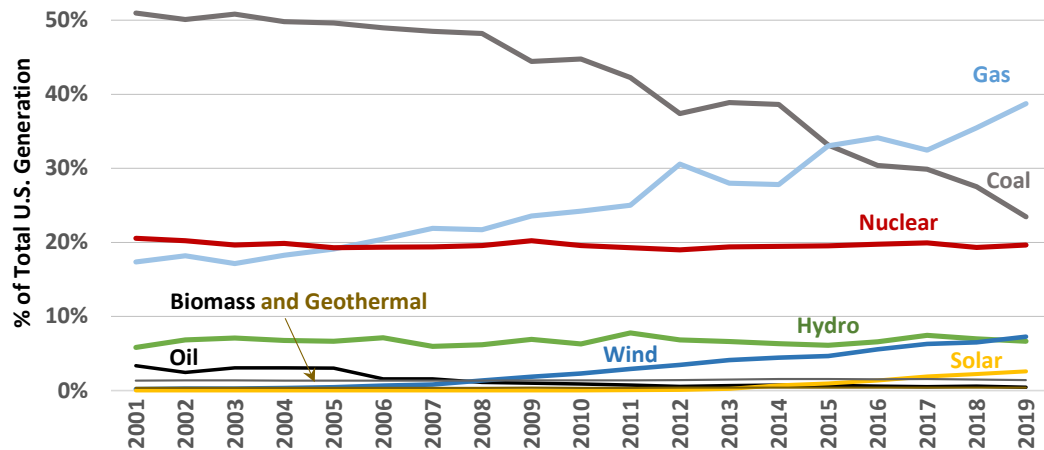
# Over the past six years, natural gas, wind, and solar have accounted for 97% of all new capacity added to the U.S. grid

Annual Capacity Additions (GW<sub>AC</sub>)



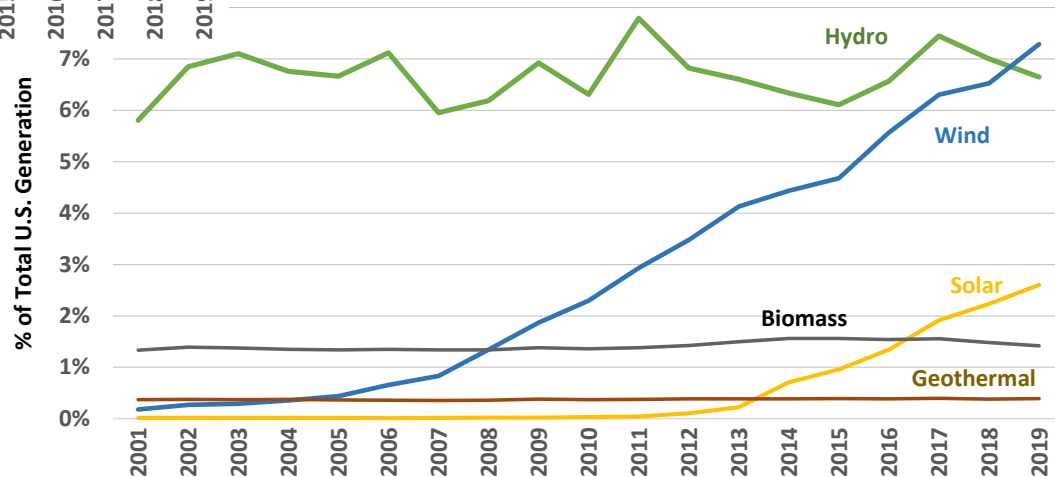
- In aggregate from 2014-2019, wind (27%) and solar (31%) contributed 58% of all new generating capacity added to the U.S. grid (with gas at 39%)
- Wind has been a consistent, significant contributor all the way back to 2007, but solar not until 2013

# Yet wind and solar combined have only ~10% market share nationally (expressed as a % of total U.S. generation)



- Top graph focuses on all resources
- Gas has surpassed coal (mirror images)
- Wind and solar's share is growing, but still small
- Everything else is stagnant or declining

- Bottom graph focuses on just the renewable sources of electricity
- Only wind and solar are growing; wind surpassed hydro in 2019
- Solar is now well ahead of biomass and geothermal



# Though some individual states are doing much better than 10%

WIND	2019 wind generation as a % of in-state:	
	Electric Sales	Generation
Kansas	53.5%	41.4%
Iowa	53.1%	41.9%
North Dakota	51.1%	26.8%
Oklahoma	45.3%	34.6%
New Mexico	27.4%	19.4%
Nebraska	24.7%	19.9%
Wyoming	24.1%	9.8%
South Dakota	23.8%	23.9%
Texas	20.6%	17.5%
Maine	20.4%	23.6%
Colorado	19.4%	19.2%
Minnesota	17.0%	19.0%
Montana	15.4%	8.5%
Oregon	15.0%	11.5%
Idaho	11.2%	16.1%
Illinois	10.1%	7.6%
Washington	8.6%	7.3%
Vermont	7.1%	16.4%
Indiana	6.4%	6.0%
Hawaii	6.3%	5.4%
TOTAL US	8.0%	7.2%

SOLAR	2019 solar generation as a % of in-state:	
	Electric Sales	Generation
California	17.7%	19.9%
Nevada	14.8%	13.7%
Hawaii	14.7%	12.6%
Arizona	9.9%	6.6%
Utah	8.5%	6.6%
Massachusetts	6.6%	13.7%
New Mexico	6.6%	4.7%
Vermont	6.1%	14.0%
North Carolina	5.6%	5.7%
New Jersey	4.7%	4.7%
Rhode Island	3.4%	3.2%
Colorado	3.3%	3.2%
Connecticut	2.8%	1.9%
Idaho	2.5%	3.6%
Minnesota	2.5%	2.8%
Maryland	2.4%	3.6%
Florida	1.9%	1.9%
Oregon	1.9%	1.5%
New York	1.7%	1.9%
Georgia	1.7%	1.9%
TOTAL US	2.9%	2.6%

Numbers include utility-scale and distributed solar

WIND & SOLAR	2019 wind & solar generation as a % of in-state:	
	Electric Sales	Generation
Kansas	53.7%	41.5%
Iowa	53.4%	42.1%
North Dakota	51.1%	26.8%
Oklahoma	45.4%	34.7%
New Mexico	34.1%	24.0%
Wyoming	25.3%	10.2%
Nebraska	24.9%	20.0%
South Dakota	23.8%	23.9%
California	23.7%	26.7%
Colorado	22.7%	22.5%
Texas	21.9%	18.6%
Maine	21.1%	24.5%
Hawaii	21.0%	18.0%
Minnesota	19.5%	21.8%
Oregon	16.9%	12.9%
Montana	15.8%	8.7%
Nevada	15.7%	14.5%
Idaho	13.7%	19.7%
Vermont	13.2%	30.5%
Utah	11.1%	8.6%
TOTAL US	10.9%	9.8%

Solar portion includes utility-scale and distributed

- “Top 20” states in terms of penetration of wind, solar, and both
- States ranked by their wind and solar generation as a % of total electric sales
- Wind tends to dominate the combined penetration, but solar tips the scales in some cases

# Diverse drivers: policy still matters, but progressively moving towards economic competitiveness

## FEDERAL TAX POLICY

Production Tax Credit  
(for wind)

Investment Tax Credit  
(for solar)

Accelerated  
Depreciation

## STATE ENERGY POLICY

Renewables Portfolio  
Standards (RPS)

State Tax Incentives

Carbon Policy

## ECONOMIC COMPETITIVENESS

Utility RFPs

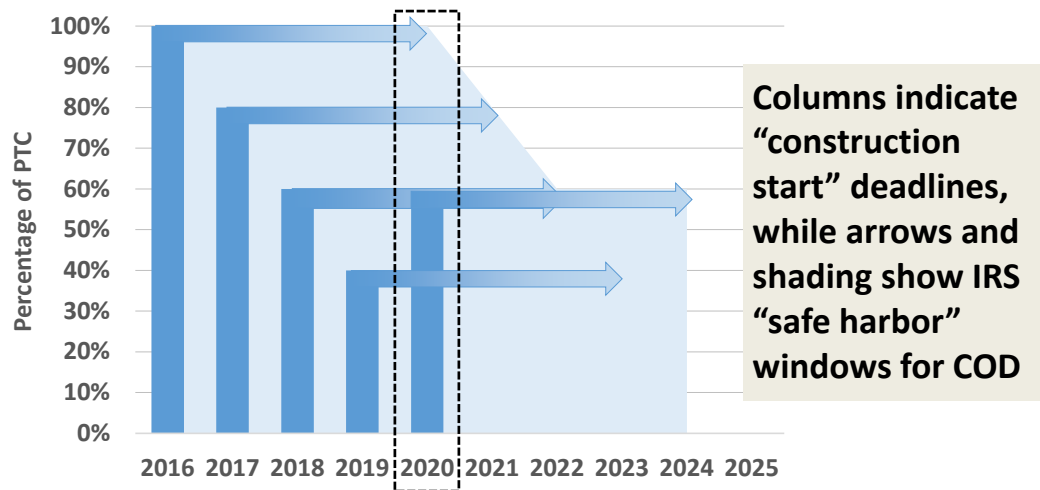
Corporate Procurement

PURPA Contracts

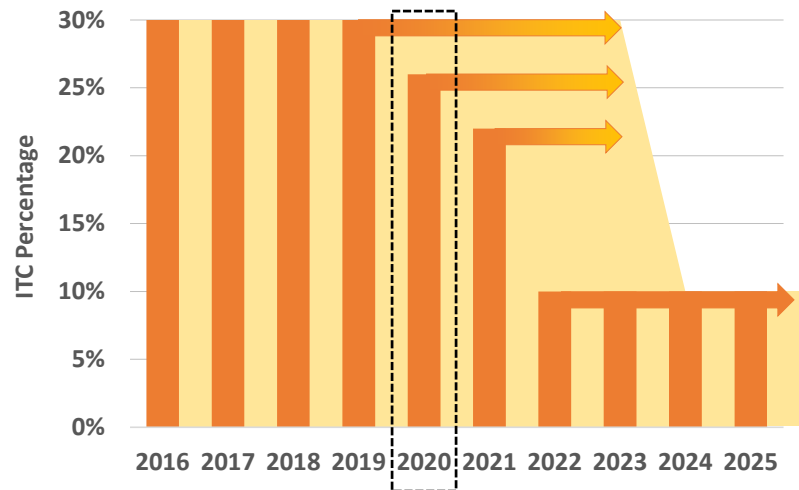
Merchant Plants

# Federal tax credits have been major drivers of wind and solar deployment— *but are being phased out (under current law)*

## Production Tax Credit (PTC)



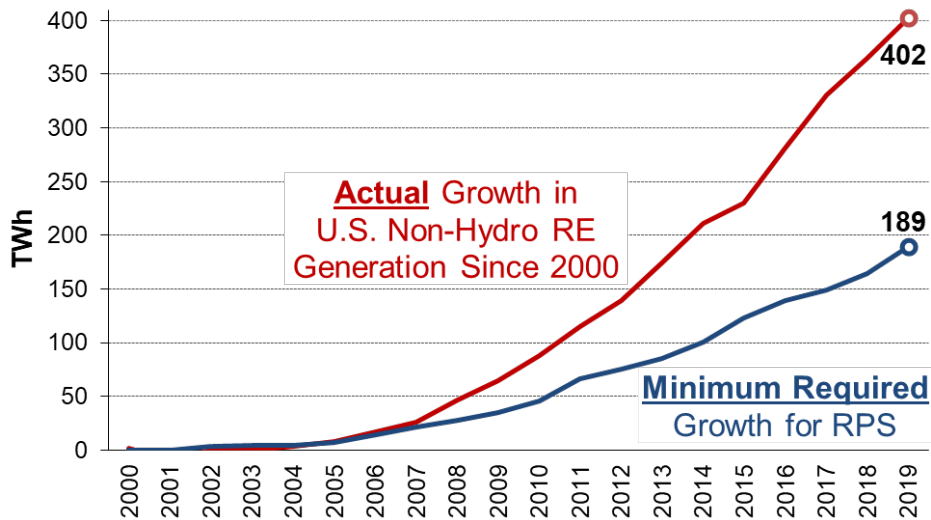
## Investment Tax Credit (ITC)



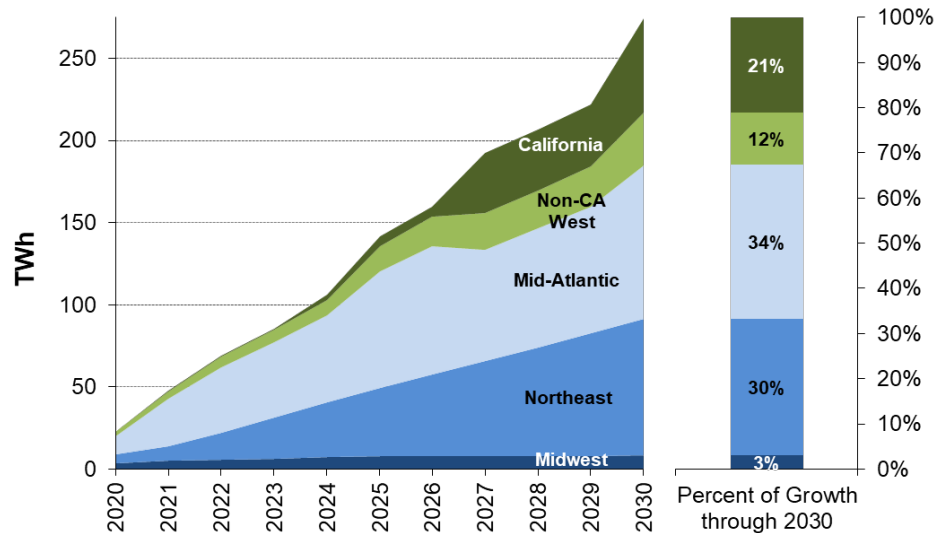
- Wind’s PTC is based on production (stands at \$25/MWh in 2020, and increases with inflation each year over a project’s first decade), while solar’s ITC is based on investment (e.g., equal to 30% of cost)
- **Different phase-down patterns:** Solar keeps its full credit longer than wind does (2023 vs. 2020), and retains the 10% ITC indefinitely (while post-2024 wind projects will not get any PTC)

# Deployment has been outpacing state renewable portfolio standard (RPS) goals, but a number of states have recently increased their targets

## Past Renewable Energy Growth



## Future RPS Demand Relative to Supply



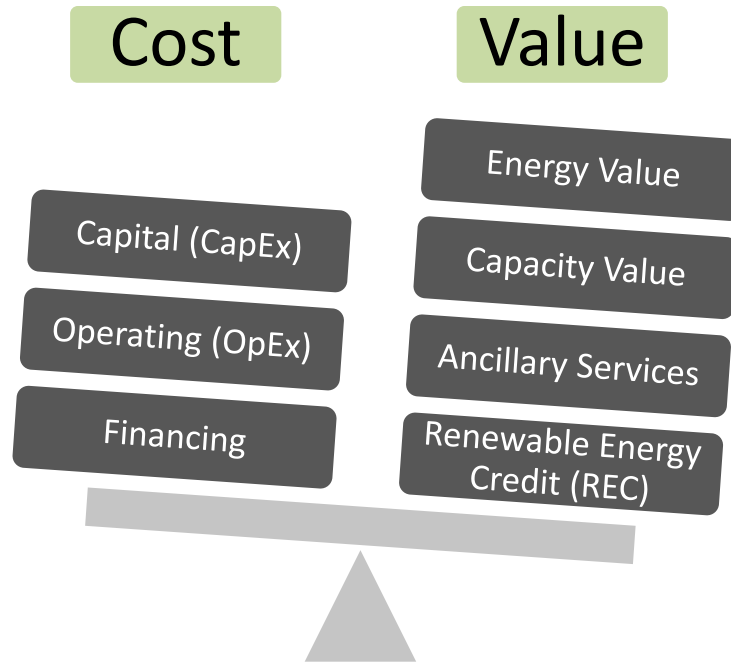
States that have significantly increased RPS (or CES) policies in 2019-2020:

DC, MD, ME, NM, NV, VA, WA

# Economic competitiveness: weighing cost and value

All three **costs** shown in the figure (CapEx, OpEx, and financing), along with capacity factor and useful life, factor into LCOE and PPA prices

- I'll cover all of these, for both **wind** and **solar**



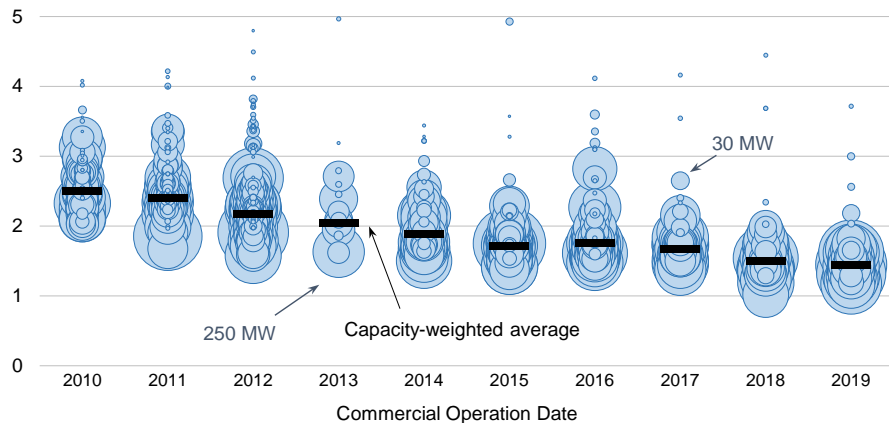
**Value** includes energy and capacity value in wholesale markets, as well as any additional value derived from selling ancillary services and/or renewable energy credits (RECs)

- I'll cover energy and capacity value for both **wind** and **solar**...but will ignore ancillary services (which provide minimal value) and RECs (which are state- or policy-specific)

Since 2010, average installed costs have fallen by 40% (wind) and 70% (solar)

## Wind Installed Costs

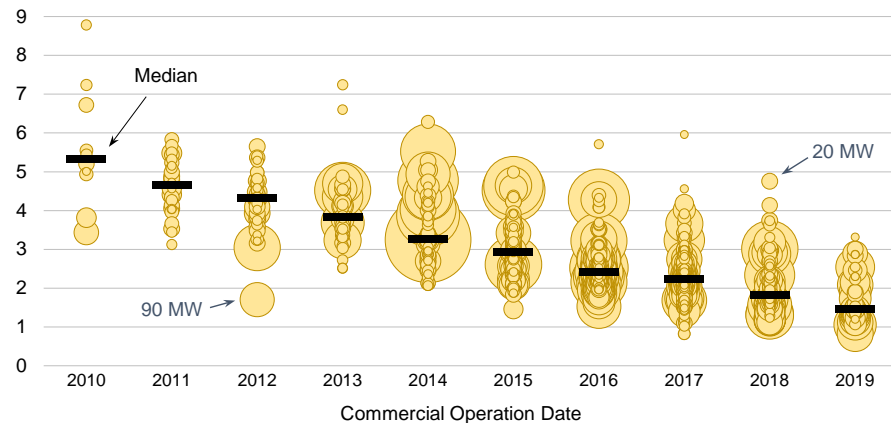
Installed Project Cost (2019  $\$/W_{AC}$ )



Wind's per-unit ( $\$/W$ ) costs have declined despite significant turbine scaling aimed at improving performance (i.e., larger rotors and taller towers to boost energy capture and capacity factor)

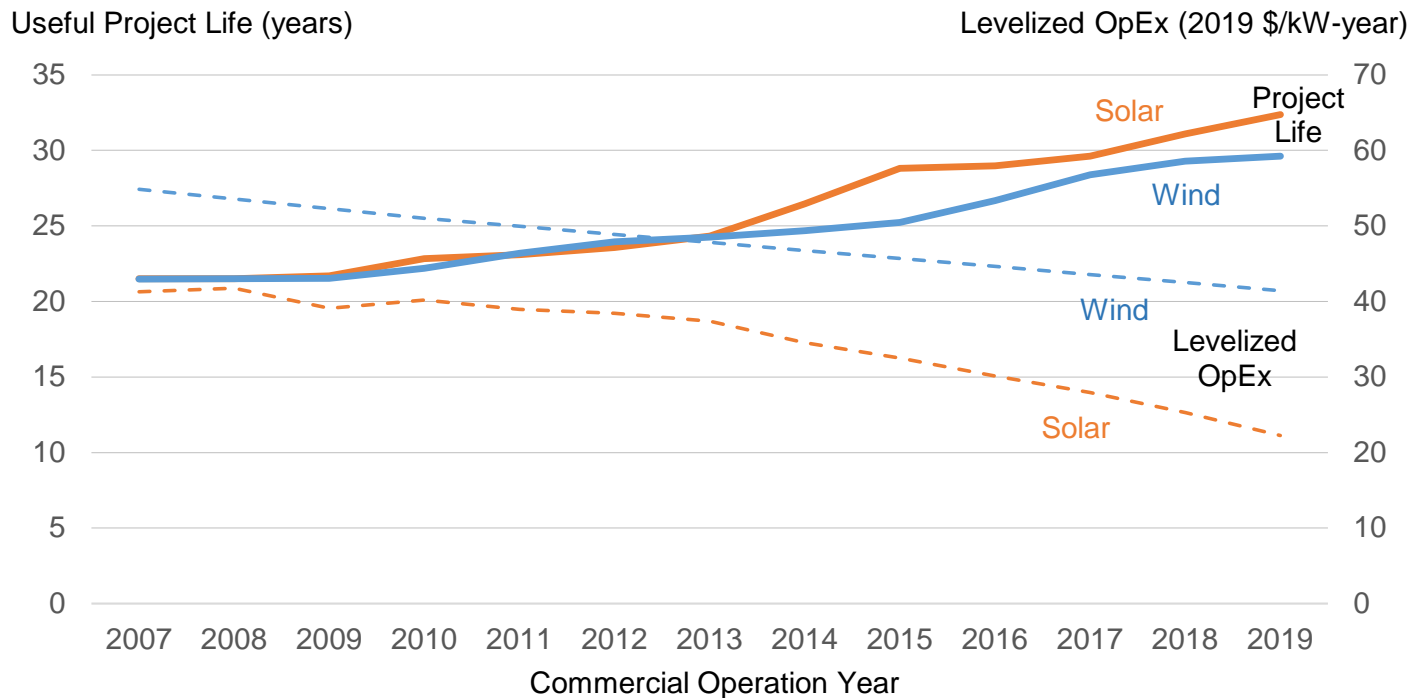
## Utility-Scale PV Installed Costs

Installed Project Cost (2019  $\$/W_{AC}$ )



PV plants do not have this same performance-related scaling linkage—instead, efficiency improvements over time manifest almost exclusively in lower installed costs

# “Survey says...” that operating expenses (OpEx) have steadily declined while assumed useful project life has lengthened

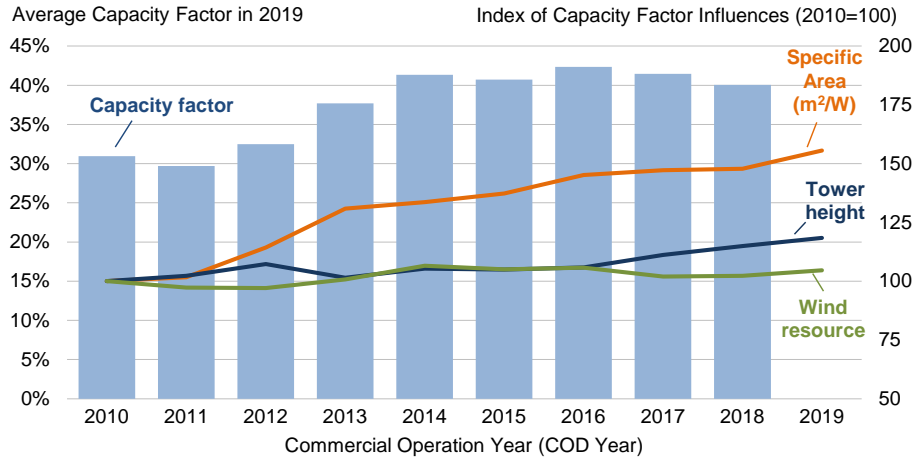


- A ~30-year life assumption is now common for both wind and solar
- Longer life and lower OpEx both reduce LCOE

Because useful life and levelized OpEx are largely projections, we surveyed wind and solar developers, project owners, financiers, etc. for their views—the graph represents the average values from the survey

# Newer wind and solar projects have performed better (as measured by capacity factor)

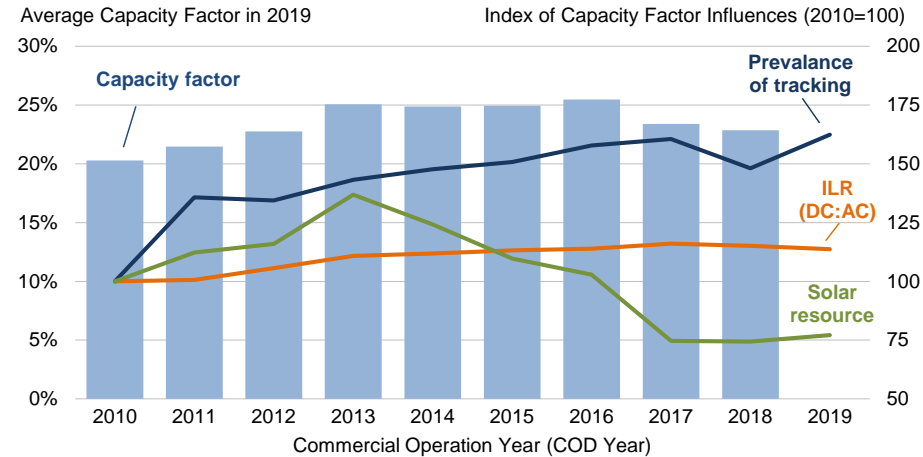
## Wind Capacity Factor



### Wind:

- Average capacity factor rose from ~30% to >40%, driven by an increase in the swept area of the rotor (m²) relative to rated capacity (W)
- Tower height has increased only slightly—but that will change in the next few years with larger turbines

## Solar Capacity Factor



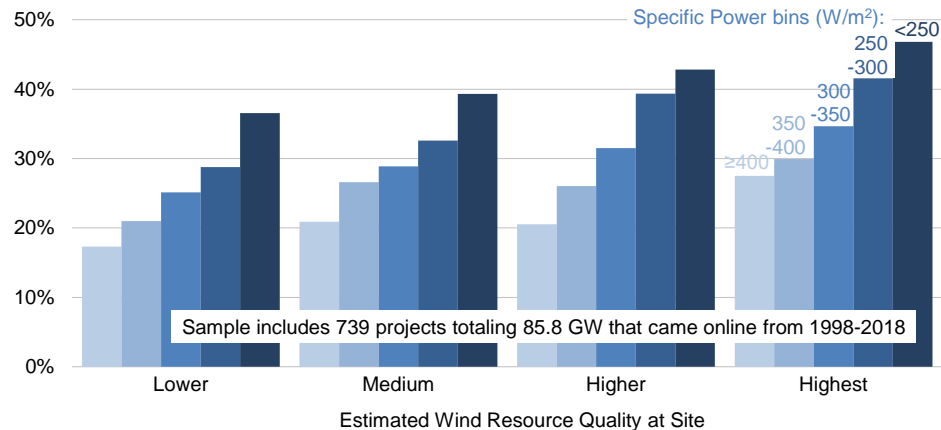
### Solar:

- 2010-2013: Average capacity factor rose from 20% to 25%, driven by higher inverter loading ratios (ILR), greater use of single-axis tracking, and buildout of sunnier sites
- Since 2013: Stagnant, as market expansion to less-sunny regions has offset the other two drivers

# Capacity factor depends on resource quality—but also technology

## Wind Capacity Factor

Average Capacity Factor in 2019

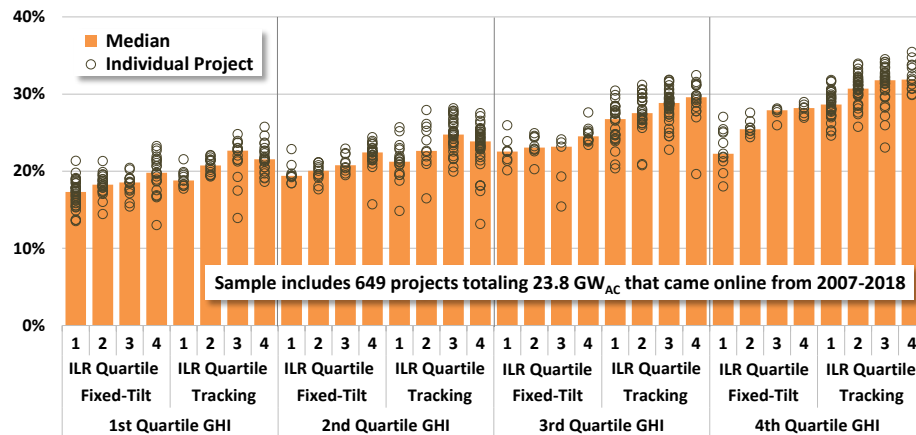


## Wind:

- As the swept area of a wind turbine's rotor ( $m^2$ ) increases relative to its generator capacity (W), the "specific power" ( $W/m^2$ ) of the turbine declines
- Reducing specific power boosts capacity factor as much as, or more than, moving to a better wind resource site

## Solar Capacity Factor

Cumulative AC Capacity Factor

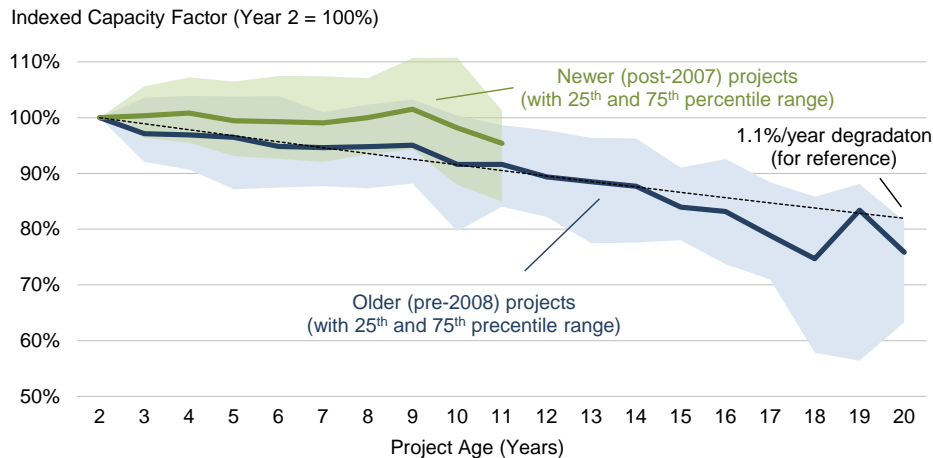


## Solar:

- Within each solar resource quartile (denoted by global horizontal irradiance or GHI), projects using single-axis tracking outperform fixed-tilt projects...
- ...and projects with higher inverter loading ratios (ILR or DC:AC ratio) outperform projects with lower ILRs

# The performance of both wind and solar declines as projects age (both graphs control for inter-annual variation in the wind and solar resource)

## Wind Performance Degradation

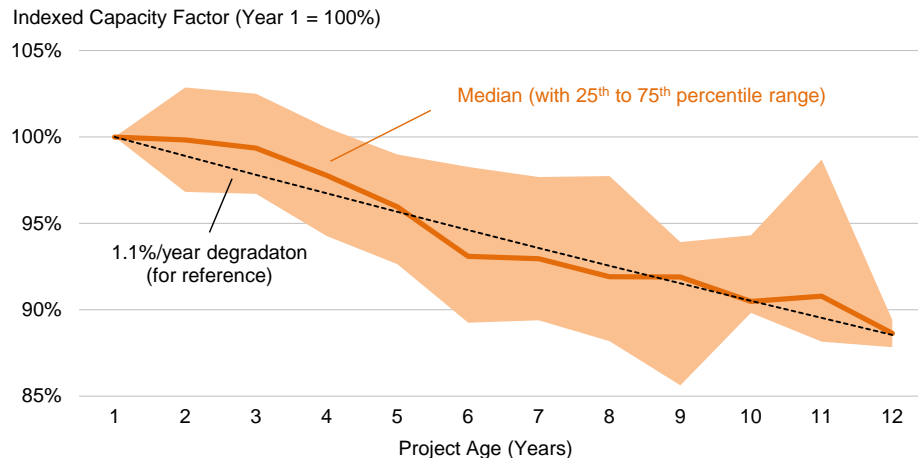


Wind project performance seems to decline more significantly after the first decade

- 10-year PTC term, 10-year O&M contracts

Newer projects seem to be degrading less

## Solar Performance Degradation

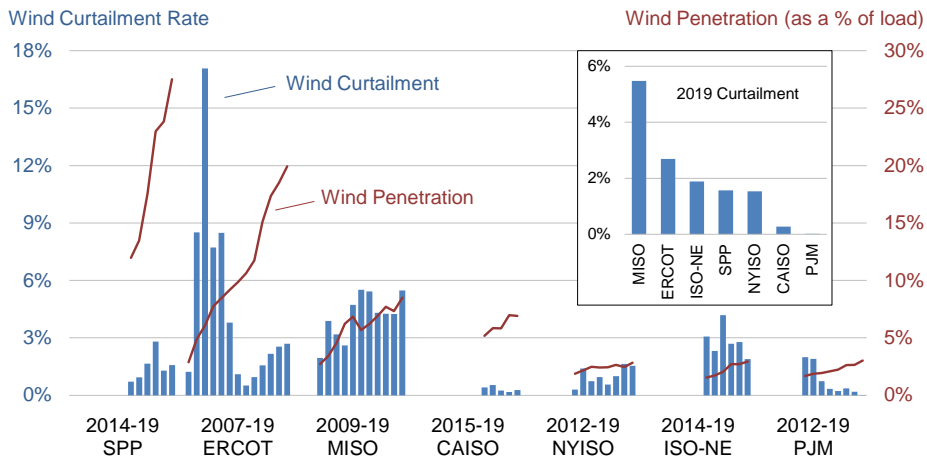


1.1%/year decline in project performance is worse than is commonly assumed

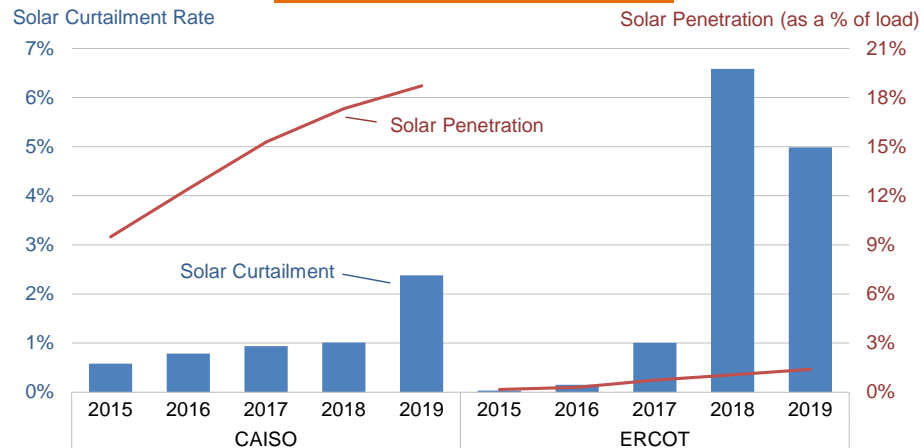
- **Note:** Neither the wind nor solar degradation graphs control for curtailment, which could be driving some of the trend

# Wind and solar curtailment versus market penetration

## Wind Curtailment



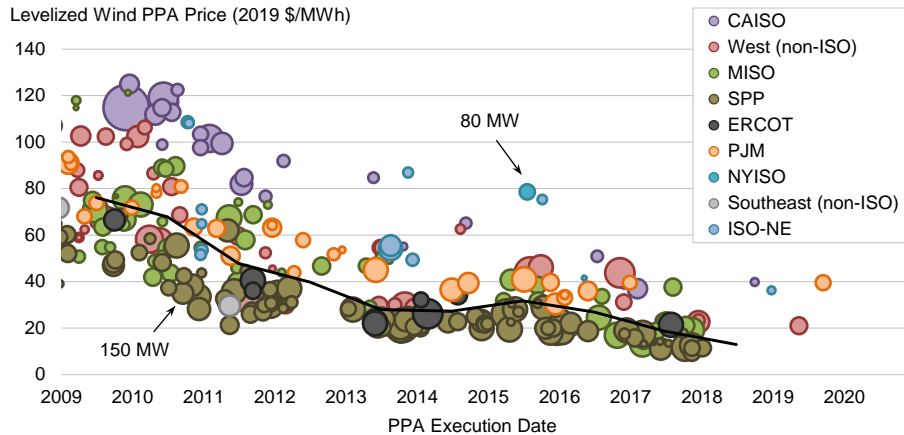
## Solar Curtailment



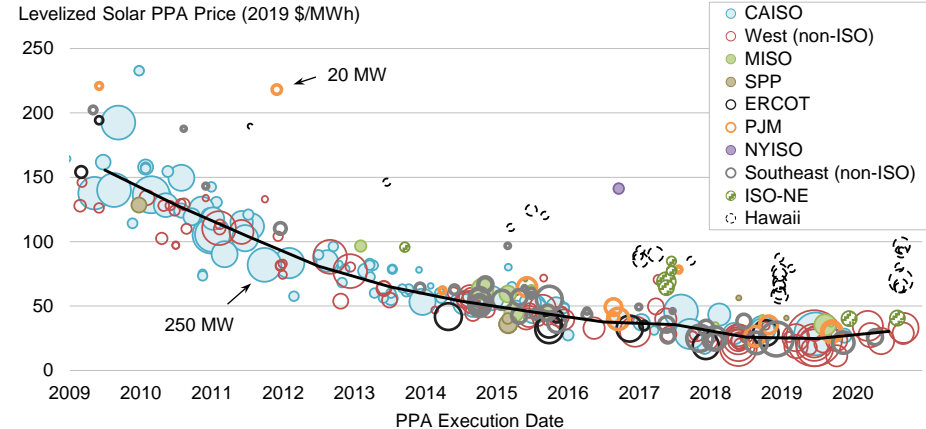
- All seven ISOs report wind curtailment, but only CAISO and ERCOT report solar curtailment (so far)
- Though curtailment can increase with market penetration, local congestion is a bigger factor:
  - **Wind:** Contrast ERCOT in 2009 (6% penetration and 17% curtailment) and 2015 (12% penetration and 1% curtailment)
  - **Solar:** ERCOT has much higher curtailment than CAISO in 2018 & 2019, but much lower penetration

# The combo of lower CapEx/OpEx/finance costs and higher capacity factors and longer lives has driven power purchase agreement (PPA) prices to all-time lows

## Wind PPA Prices

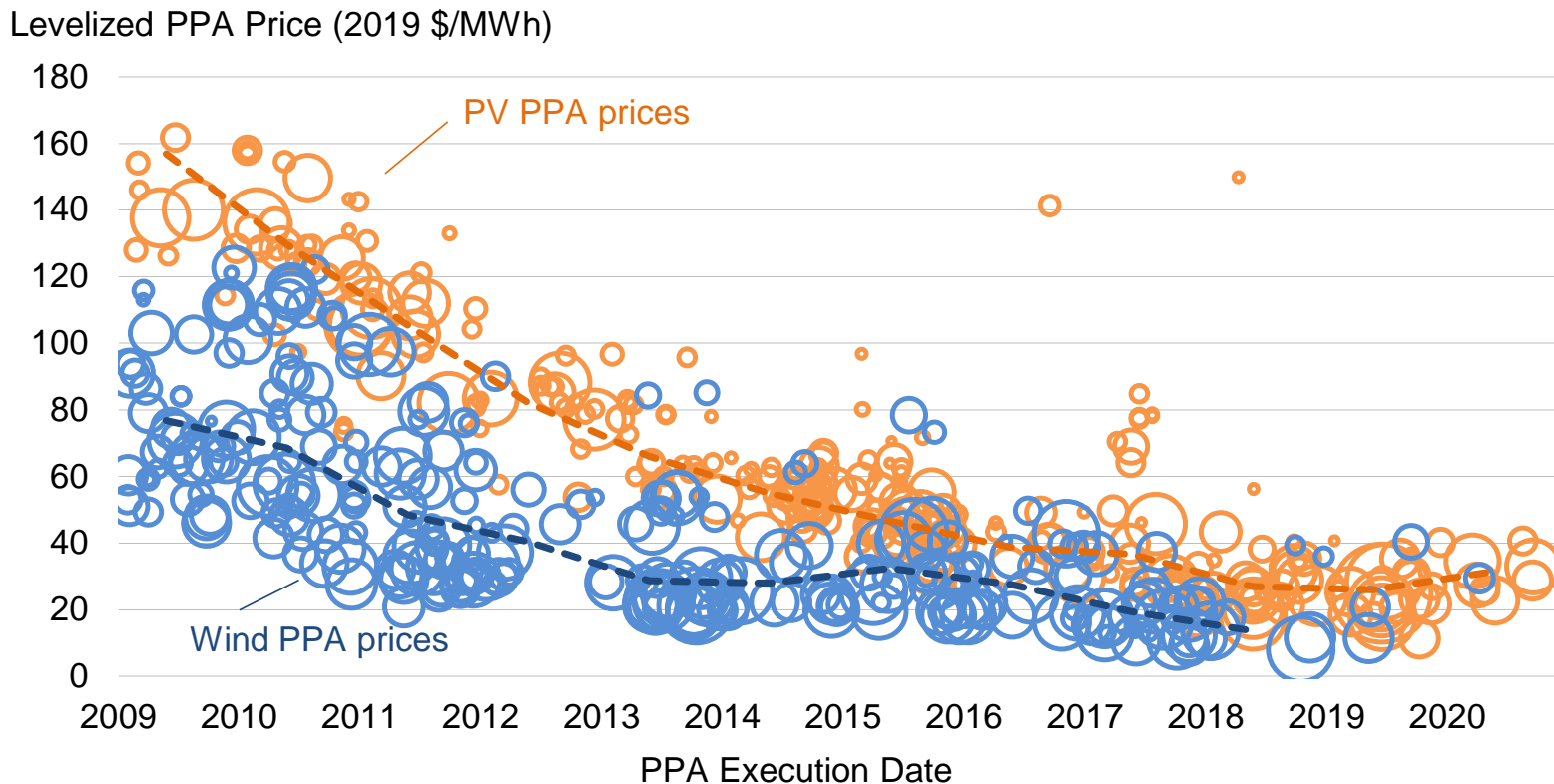


## Utility-Scale PV PPA Prices



- Bubbles show levelized PPA prices by contract execution date (bubble size denotes PPA capacity)
- The black lines through the bubbles show generation-weighted average trend lines by calendar year
- Since 2009, average PPA prices have declined by ~80% for both wind and solar

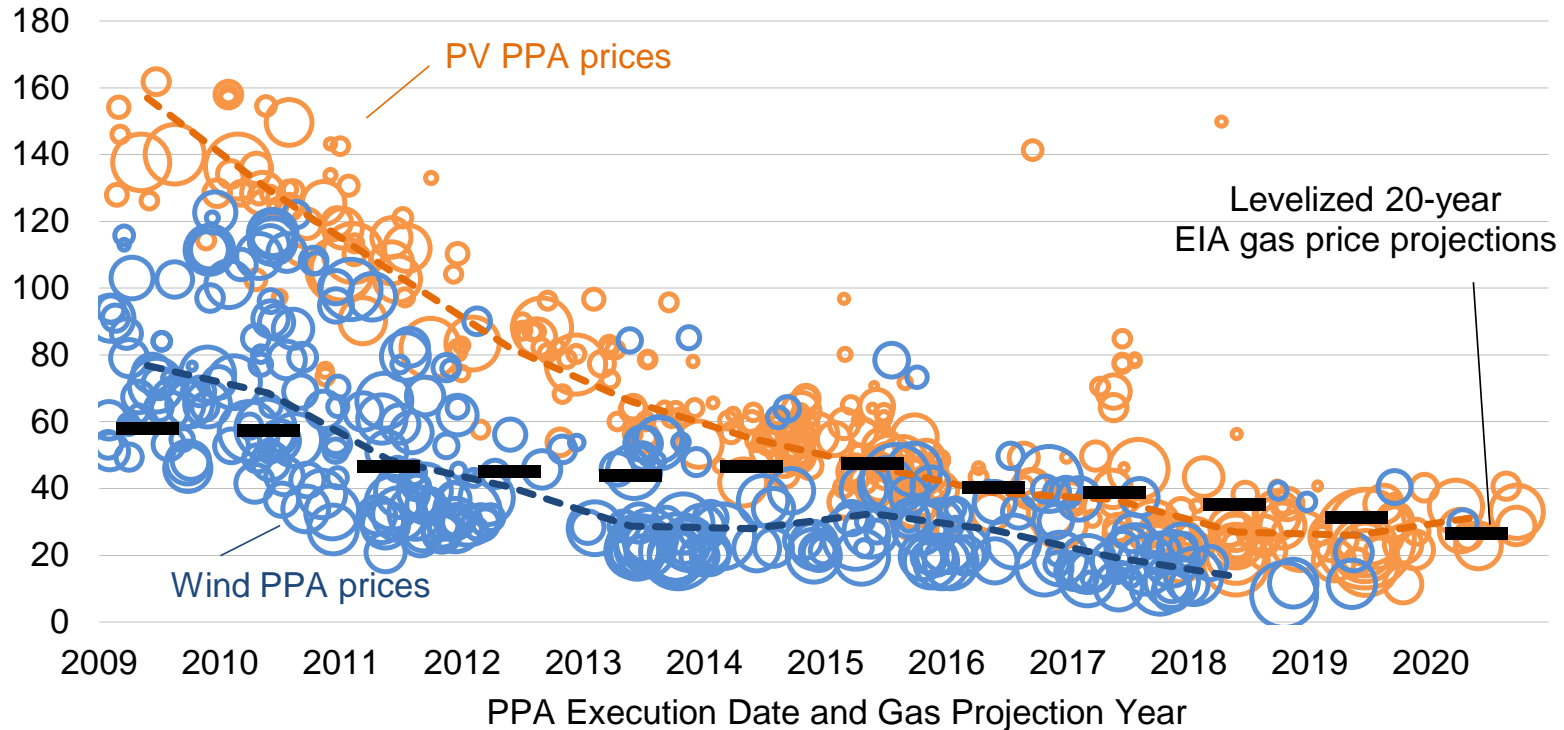
# Solar and wind PPA prices have converged over time, but solar is still more costly on average



The blue and orange dashed lines represent the generation-weighted average PPA price across years

# Wind and solar PPA prices are increasingly competitive with the cost of burning gas in an existing combined-cycle gas turbine

Levelized PPA and Gas Price (2019 \$/MWh)

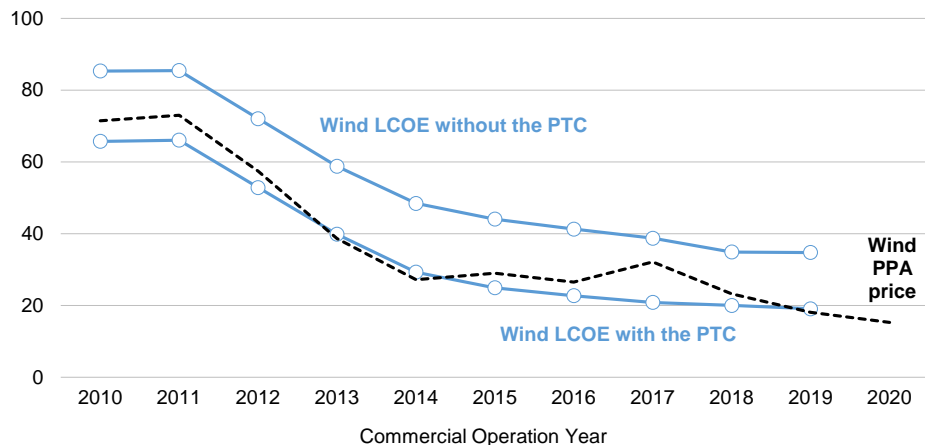


Black dashes represent the EIA's then-current delivered natural gas price projections over the coming 20 years, converted to \$/MWh terms using a heat rate of 7.5 MMBtu/MWh and levelized at a real discount rate of 4%

# LCOE estimates confirm PPA price trends and wind/solar convergence— implying a relatively efficient and cost-based PPA market

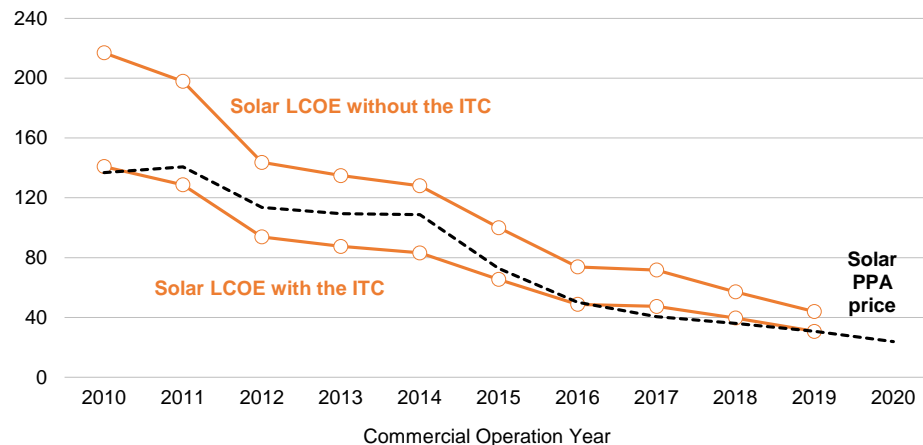
## Wind LCOE and PPA Price

National Average LCOE and Levelized PPA Price (2019 \$/MWh)



## Solar LCOE and PPA Price

National Average LCOE and Levelized PPA Price (2019 \$/MWh)



- LCOE typically does NOT reflect the receipt of tax credits—but credits can be factored in (though imperfectly—it's hard to capture financing effects)
- The relatively close agreement between LCOE with tax credits and PPA prices suggests full pass-through of the credits and an efficient, cost-based, competitive market for PPAs

## But cost is only half the story...also need to consider “market value”

**Market value** can be thought of as the revenue that a merchant wind or solar plant would earn by selling all of its generation into real-time wholesale markets.

Or, for plants with long-term, fixed-price PPAs, market value equals the buyer’s avoided cost (i.e., what the buyer would have otherwise paid for the same quantity and timing of MWh in real-time markets).

**We analyze the two main sources of wholesale market value:**

Energy value =  $\Sigma$  (hourly energy price \* hourly generation)

Capacity value =  $\Sigma$  (capacity credit \* capacity price) / MWh

➤ Capacity credit is based on wind or solar’s contribution to meeting resource adequacy requirements

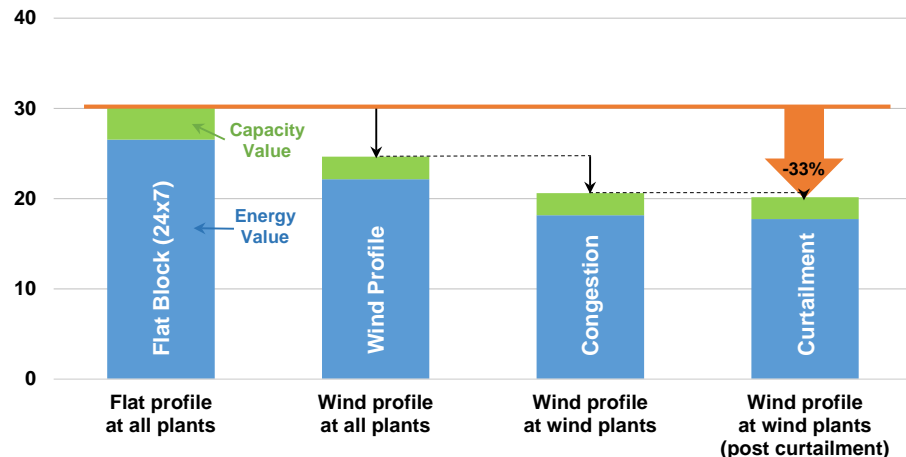
Wholesale market value depends on:

- 1) Hourly **generation profiles** of wind and solar, and how they align with hourly **price profiles**
- 2) Energy and capacity prices at the **location** of wind and solar plants, considering **congestion**
- 3) The extent to which wind and solar experience **curtailment**

# Solar's market value exceeds wind's (on a nationwide, annual average basis)

## Wind Market Value

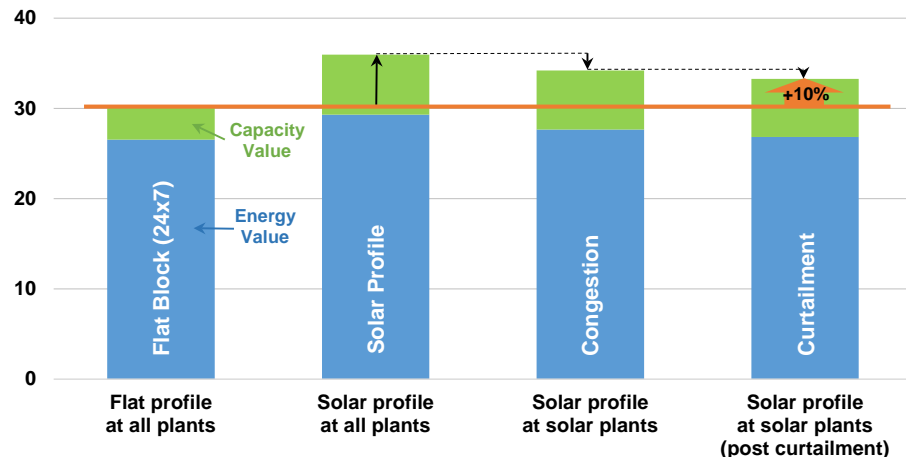
Wind Market Value in 2019 (2019 \$/MWh)



- In 2019, wind's market value (energy + capacity value) was \$20/MWh
  - 33% below that of a 24x7 "flat block" of power (\$30/MWh)
- Wind's value was hurt the most by profile and congestion, less so by curtailment

## Solar Market Value

Solar Market Value in 2019 (2019 \$/MWh)



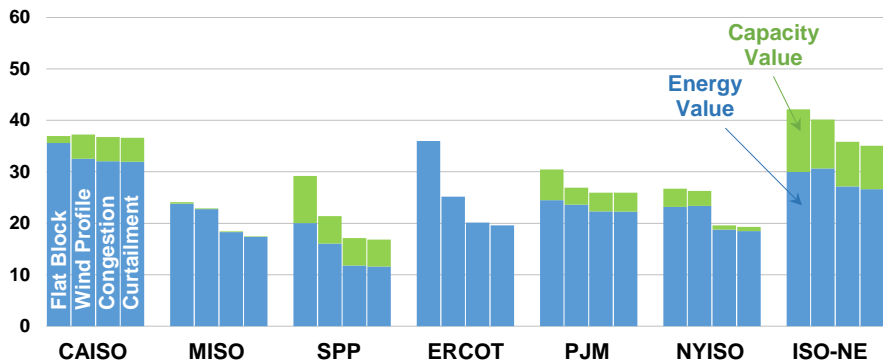
- In 2019, solar's market value (energy + capacity value) was \$33/MWh
  - 10% above that of a 24x7 "flat block" of power (\$30/MWh)
- Solar's value was *helped* by profile but hurt by congestion and curtailment

# Can make the same comparison, and examine the same drivers, by ISO:

## In 2019, the value of wind and solar varied substantially across the country

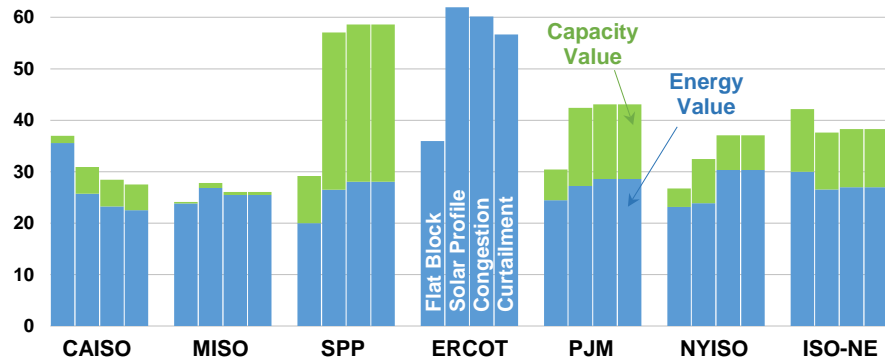
### Wind Market Value

Wind Market Value in 2019 (2019 \$/MWh)



### Solar Market Value

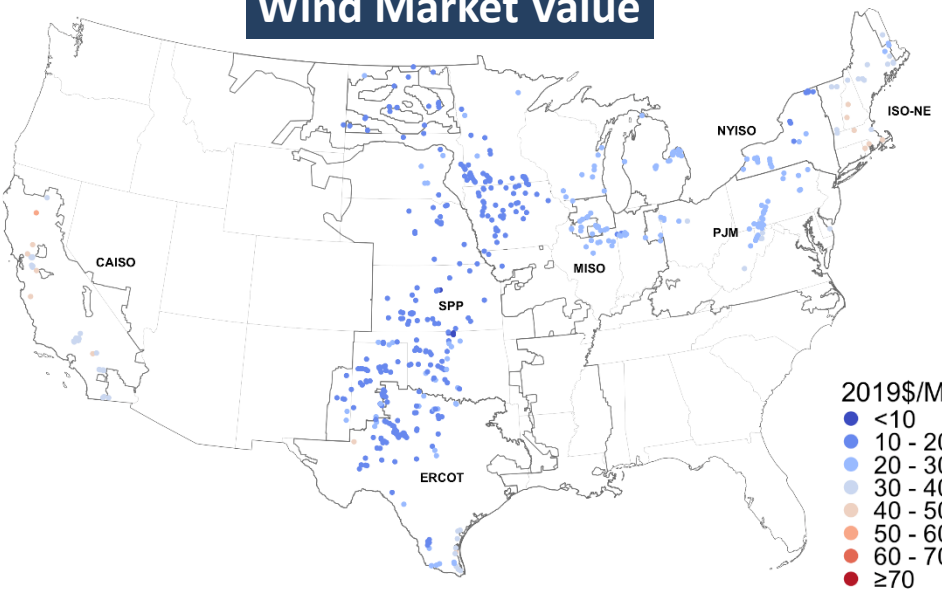
Solar Market Value in 2019 (2019 \$/MWh)



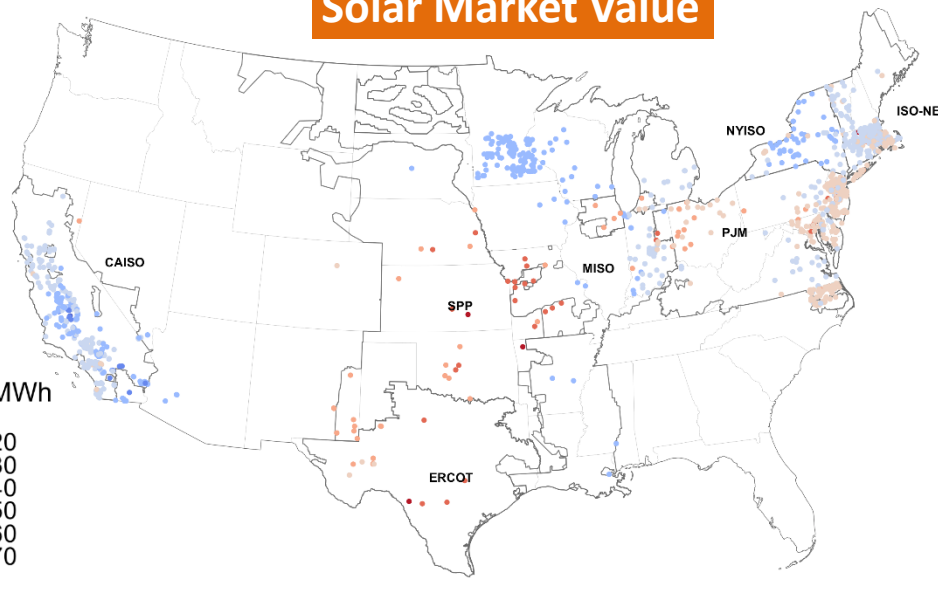
- **Wind:** Only in CAISO does wind's market value approximate a 24x7 flat block (both ~\$37/MWh)
- **Solar:** Except for CAISO and ISO-NE, solar's value exceeds a 24x7 flat block in all other ISOs
- In 2019, solar was worth more than wind in all ISOs except CAISO
- For both wind and solar, profile is generally the largest driver of value, but congestion/location is also important (and more so for wind than solar)

# Project-level data show variation in market value even *within* ISOs

## Wind Market Value

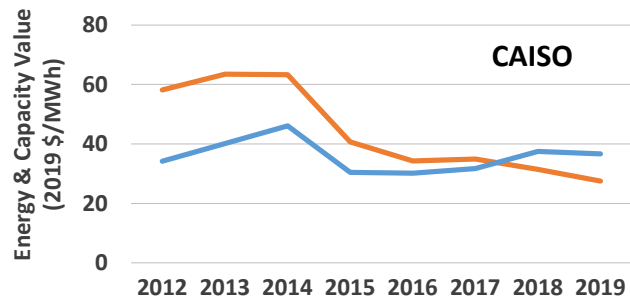


## Solar Market Value

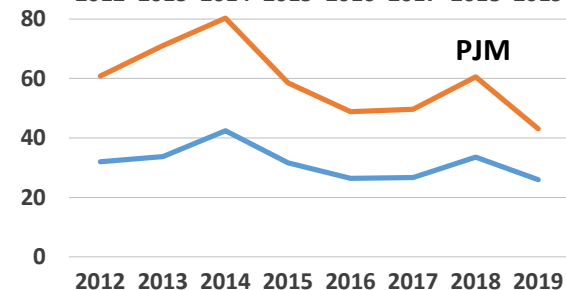
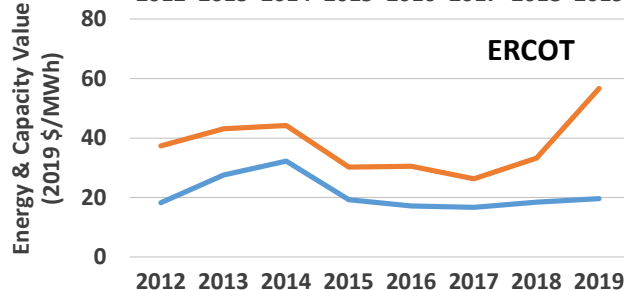
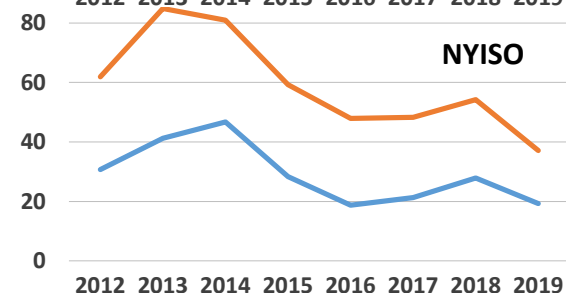
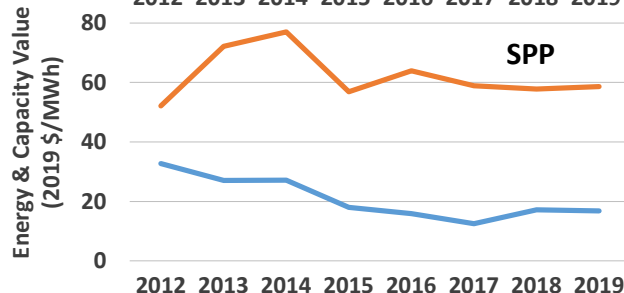
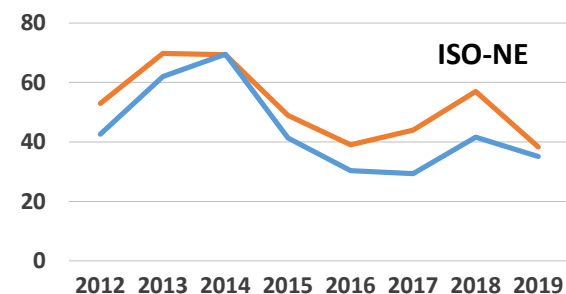
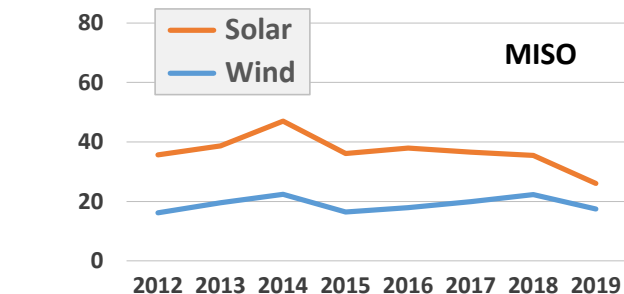


- Wholesale market value tends to be lowest where market penetration is highest
  - Interior (ERCOT, SPP, MISO) for wind
  - Southwest (CAISO) for solar
- But value can be low even in low-penetration markets, simply due to low wholesale prices
  - Solar in MISO and NYISO

# Solar's greater value has generally persisted over time (except in CAISO)

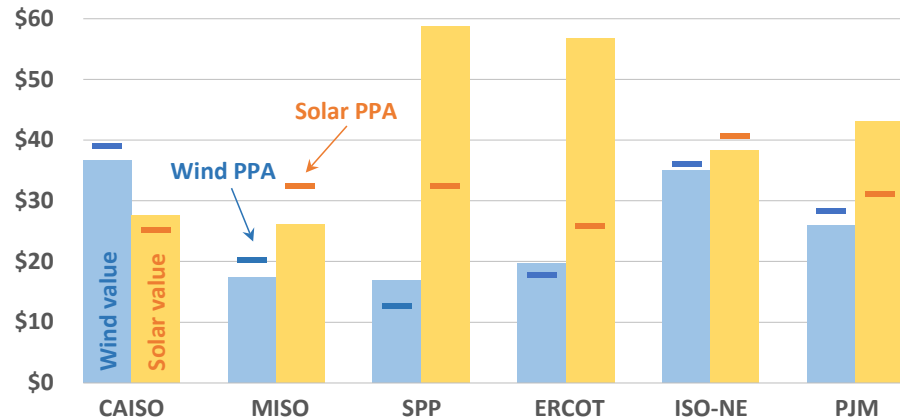


- In CAISO, increasing penetration has reduced solar's value, to the point where it's now worth less than wind
- In the other six ISOs, solar has consistently been worth more than wind back through 2012
  - Value gap is narrowest in ISO-NE, where peak pricing typically occurs during winter heating months, when solar output is low
  - ERCOT solar value in 2019 helped by ORDC and price spikes



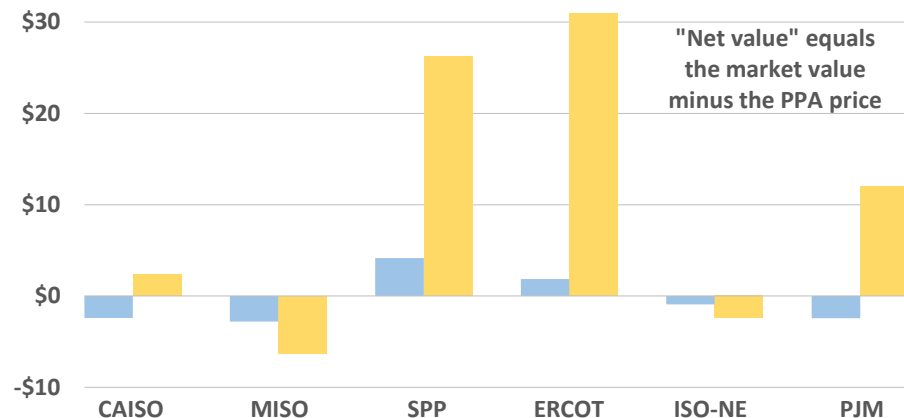
# After netting out PPA prices, solar still provides positive “net value” in many regions (and often higher net value than wind)

2019 Market Value vs. PPA Price (\$/MWh)



- The graph on the left plots average wind and solar PPA prices from a sample of recent contracts (dashes) against 2019 wind and solar market value (columns)
- Except for in CAISO, solar is more expensive than wind, BUT is also more valuable than wind

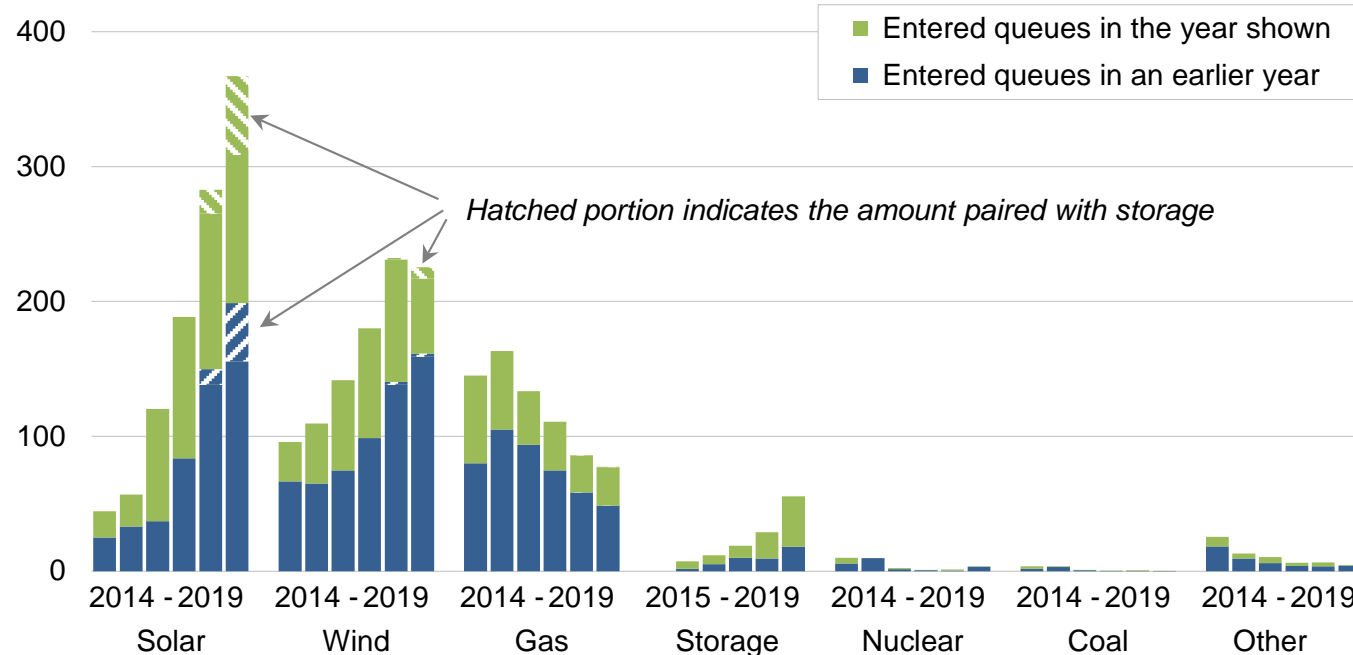
2019 Net Value (\$/MWh)



- The graph on the right subtracts the PPA prices from the 2019 market value, to show “net value” by ISO
- **Solar has positive net value, and greater net value than wind, in 4 of the 6 ISOs shown**
  - MISO and ISO-NE are the exceptions

# Which is partly why solar has rocketed to the top of grid interconnection queues across the country

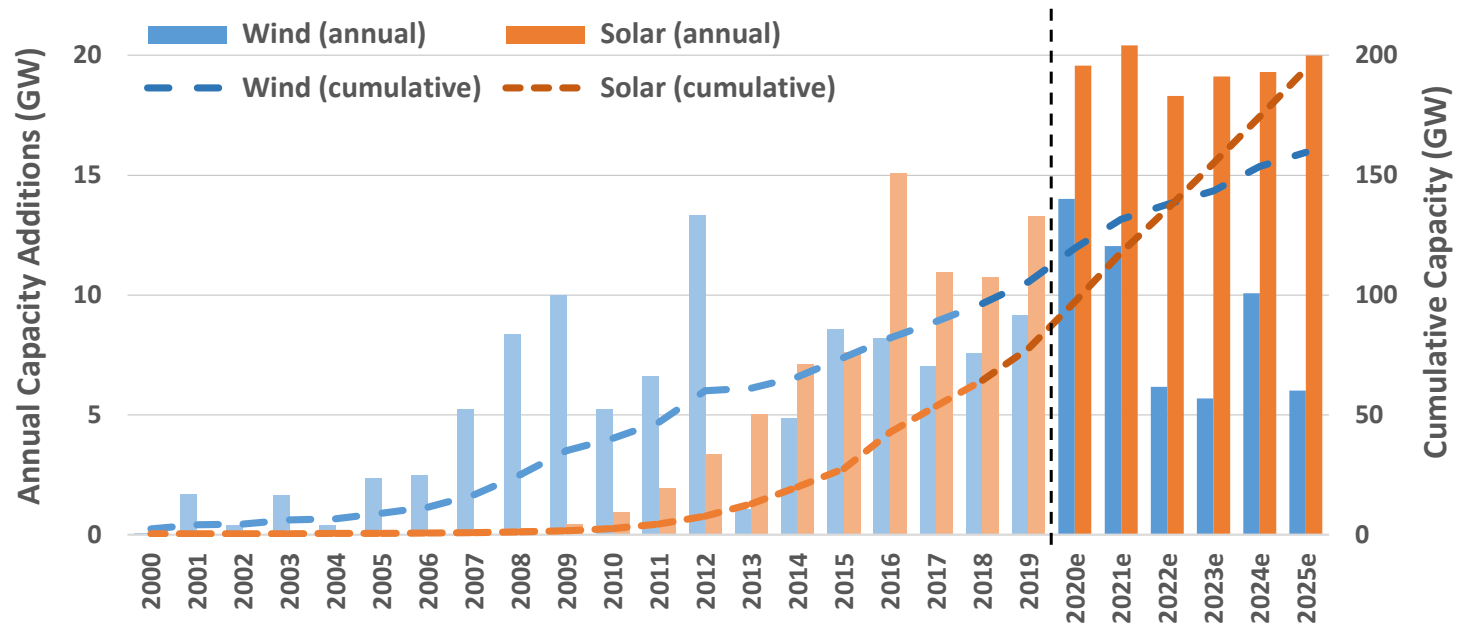
Capacity in Queues at Year-End (GW)



***Not all of this capacity will be built—much of it will languish in the queues***

- These 37 queues cover ~80% of non-coincident demand in the U.S.
- Solar, storage, and—until 2019, wind—have been growing; everything else declining
- Solar ranked 3<sup>rd</sup> in the queues as recently as 2016, but is now 1<sup>st</sup> by far
- 28% of PV capacity in the queues is paired with battery storage (compared to just 5% of wind capacity)

# And is why analysts project cumulative solar capacity to surpass wind by 2023



The projected deployment patterns are also driven in part by the phase-down of federal tax credits (e.g., wind drops off post-2020, as the PTC phases out, while solar retains the 30% ITC through 2023)

- Wind projections represent the average of 4 different analysts
- Solar projections are solely from Wood Mackenzie, and include both distributed and utility-scale solar

## But a number of headwinds could slow market growth

Phase-down of  
federal tax credits

Macroeconomic  
factors (tariffs,  
exchange rates,  
interest rates)

Low-cost natural gas  
a potent competitor

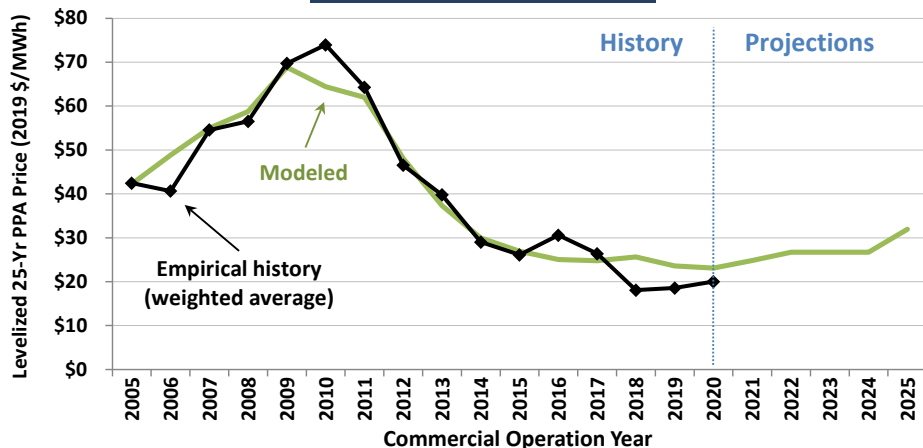
Modest electricity  
demand growth in  
most regions

Inadequate  
transmission in  
some locations

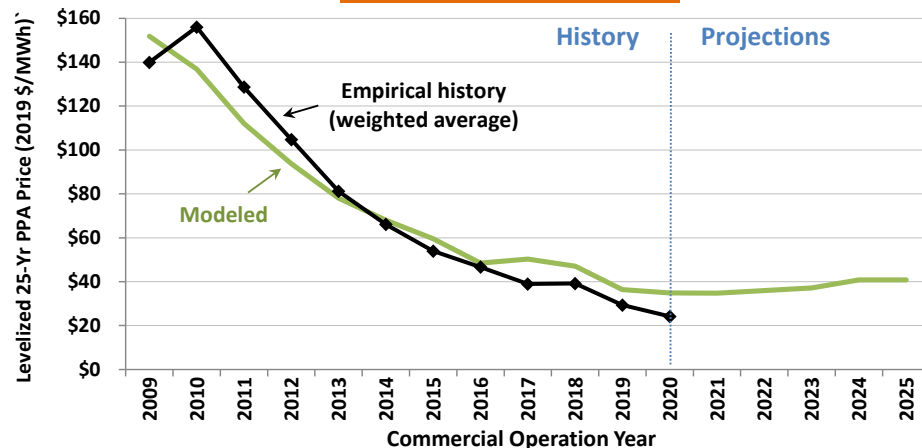
Market saturation  
(and value decline)  
absent proactive  
grid integration

# All else equal, tax credit phase-out will cause PPA prices to increase

## Wind PPA Prices



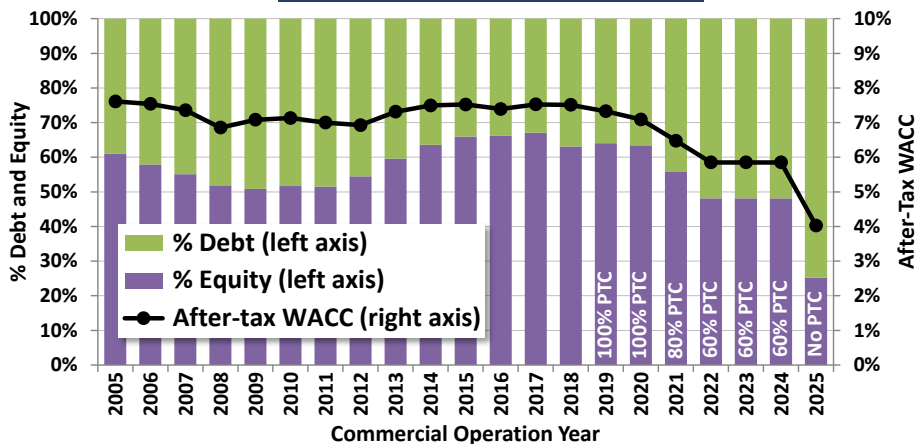
## Solar PPA Prices



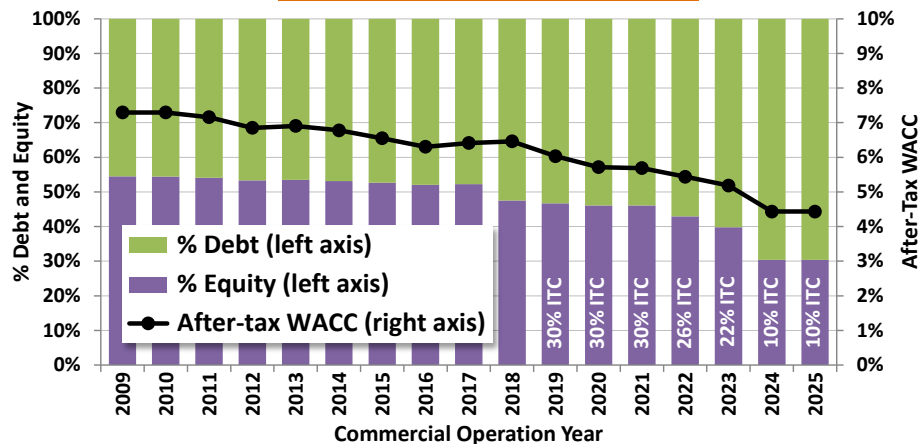
- Modeled PPA prices (based in part on the empirical CapEx and capacity factor data presented earlier) match empirical history reasonably well—which suggests we can use the model for forecasting purposes
- Holding all inputs constant going forward ***except for tax credit phase-out*** suggests that, all else equal:
  - Wind PPA prices could increase by \$9/MWh (+39%) by 2025
  - Solar PPA prices could increase by \$6/MWh (+17%) by 2025

# Projected wind and solar PPA price increases would be twice as large if not for a favorable shift in capital structure (i.e., debt/equity ratio)

## Wind Capital Structure



## Solar Capital Structure

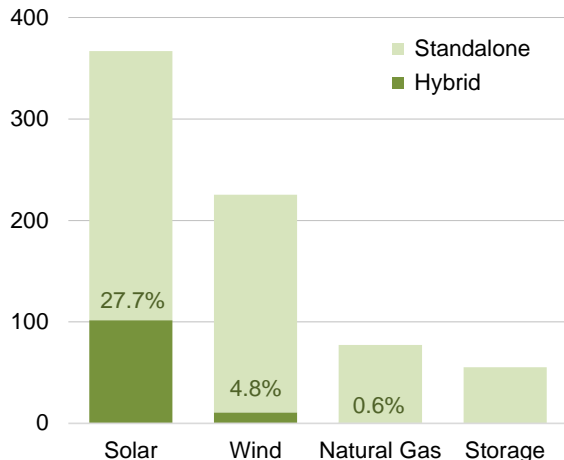


Without the tax credits, wind and solar projects can support more lower-cost debt (green bars)

- As a result, the projected 2025 weighted-average cost of capital (WACC) is **3.0 (for wind)** and **1.3 (for solar)** percentage points *lower* than it is in 2020
- If 2025 had the same capital structure as 2020, then 2025's PPA price increase would be even greater:
  - An additional \$10/MWh (+33%) for wind (for a total of +\$19/MWh, or +84%)
  - An additional \$7/MWh (+18%) for solar (for a total of +\$13/MWh, or +38%)

# Antidote for market saturation? Strong interest in adding battery storage—particularly to solar projects, and particularly in CAISO

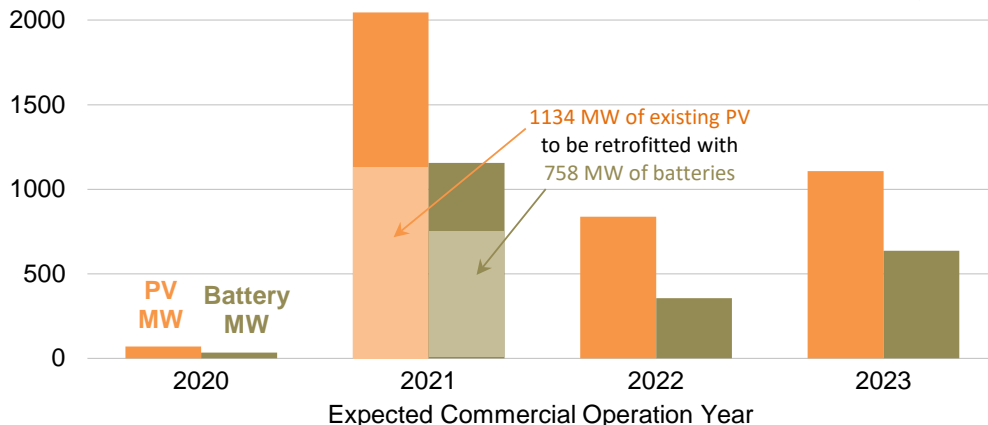
Capacity in Queues at end of 2019 (GW)



- Interconnection queue data show 28% of all PV capacity in the queues is paired with battery storage (compared to just 5% of wind capacity)—much of this hybrid capacity is in CAISO's queue
- Though queue data are highly speculative, PPA announcements are less so—and suggest that **at least 2.2 GW** of battery storage will be built in CA through 2023 as part of PV hybrid plants

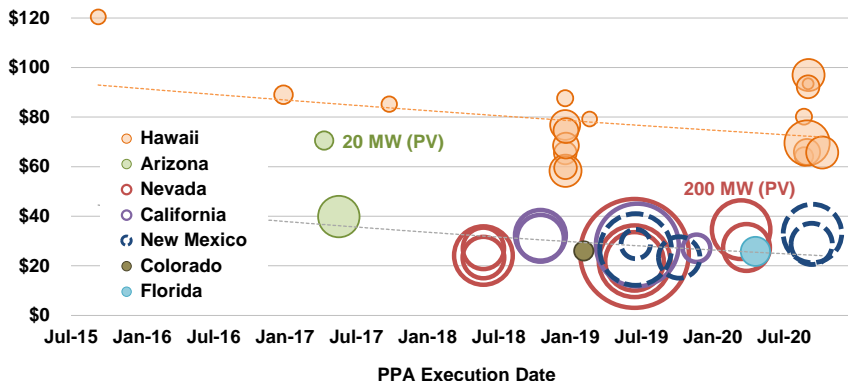
Region	Percentage of Proposed Generators Hybridizing in Each Region		
	Solar	Wind	Nat. Gas
CAISO	67%	50%	0%
ERCOT	13%	3%	0%
SPP	22%	1%	0%
MISO	17%	2%	0%
PJM	17%	0%	1%
NYISO	5%	1%	4%
ISO-NE	0%	6%	0%
West (non-ISO)	50%	6%	0%
Southeast (non-ISO)	6%	0%	0%
<b>TOTAL</b>	<b>27.7%</b>	<b>4.8%</b>	<b>0.6%</b>

Contracted PV+battery hybrid capacity (MW<sub>AC</sub>) in CA, by COD

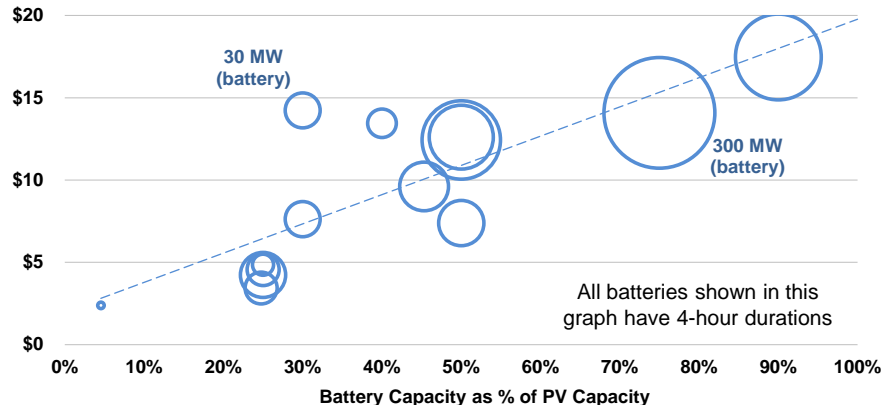


# Growing interest in hybridization stems from falling costs, modest adder...

Levelized PPA Price (2019 \$/MWh-PV)

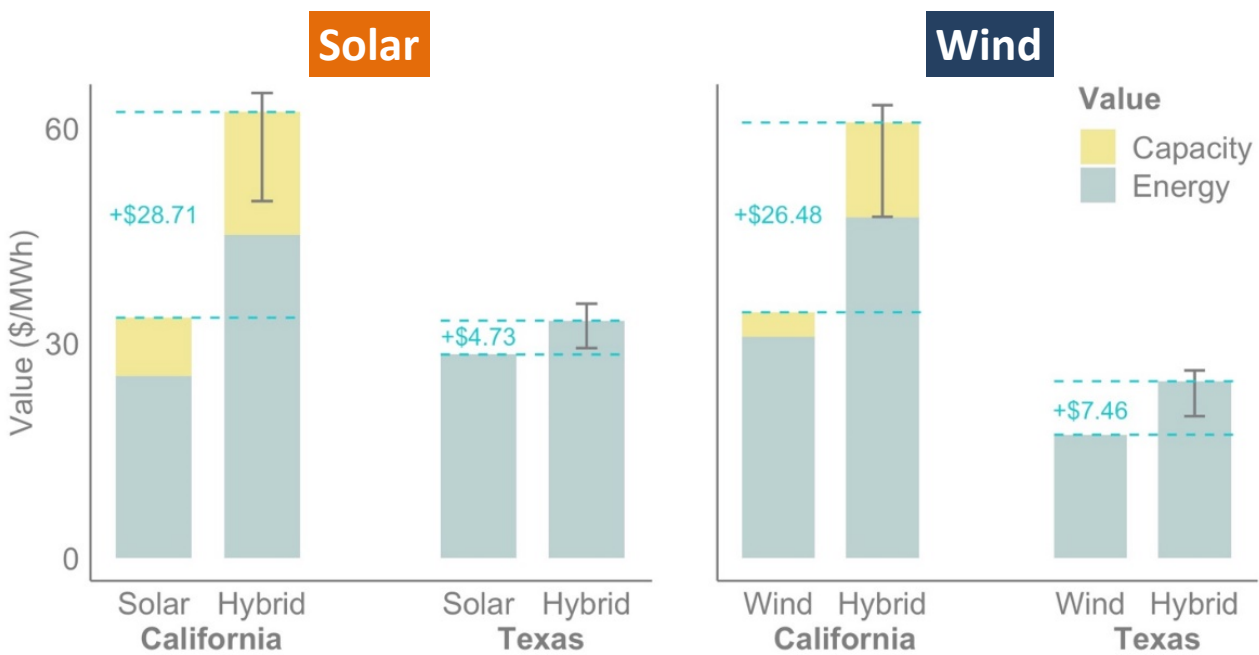


Levelized Storage Adder (2019 \$/MWh-PV)



- Top graph shows levelized PPA prices for 40 PV+battery projects in Hawaii (orange circles and trend line) and on the mainland
  - Recent mainland projects are priced around \$30/MWh (levelized in real dollar terms)
  - Wide range of configurations: batteries have 2-8 hour durations and battery:PV capacity ratio varies from 5-100%
- 14 of these 40 PPAs break out the PV and battery pricing, enabling us to calculate the incremental cost of adding batteries—i.e., the “levelized storage adder”
- Bottom graph shows that the “levelized storage adder” increases linearly with the battery:PV capacity ratio
  - ~\$5/MWh-PV at 25% battery:PV capacity, ~\$10/MWh at 50%, ~\$20/MWh at 100%
  - One project developer thinks of (and markets) this as paying an extra ~\$10/MWh for “near-firm” renewables

# ...and strong value proposition, particularly in solar-saturated grids like CAISO



- LBNL analysis of adding a 4-hour duration battery (sized to 50% of PV nameplate capacity) to a standalone PV project increased overall market value by >\$28/MWh in CAISO
  - This value boost exceeds the empirical ~\$10/MWh storage cost adder discussed on the previous slide
  - Similar value boost for wind, in CAISO

- Value of hybridization is less-evident in ERCOT (which has no capacity market, and where solar has a much lower market share)

# Summary

- A combination of lower CapEx, lower OpEx, lower finance costs, better performance, and longer economic lives have driven utility-scale wind and solar PPA prices and LCOE to all-time lows
  - Historically, solar has cost more than wind, but their PPA prices (and LCOE) have converged in recent years
  - Current wind and solar PPA prices are often competitive even with just the cost of burning fuel in an efficient natural gas combined cycle unit (i.e., a portion of NGCC operating costs)—*despite historically low gas prices*
- The wholesale market value of wind and solar tends to decline as market penetration increases
  - To date, declining PPA prices have largely kept pace with the erosion of wind and solar's market value
  - After netting out PPA prices, solar tends to offer greater “net value” than wind (except in CAISO)
- Looking ahead, the phase-down of federal tax credits will push wind and solar PPA prices higher (all else equal) as wind and solar's market value likely continue to decline with growing market share
  - A fortuitous shift in the debt/equity ratio as tax credits fade will mitigate some of this PPA price increase
  - Hybridization by adding battery storage can help boost wind and (particularly) solar's market value—*driving strong interest from the market*

# Thanks for tuning in! Questions?

## Wind Energy Technology Data Update: 2020 Edition

- Ryan Wiser (rhwiser@lbl.gov), Mark Bolinger (mabolinger@lbl.gov), Ben Hoen, Dev Millstein, Joe Rand, Galen Barbose, Naïm Darghouth, Will Gorman, Seongeun Jeong, Andrew Mills, Ben Paulos
- Excel data file with embedded graphics, slide deck briefing, and interactive data visualizations: ***windreport.lbl.gov***

## Utility-Scale Solar Data Update: 2020 Edition

- Mark Bolinger (mabolinger@lbl.gov), Joachim Seel (jseel@lbl.gov), Dana Robson, Cody Warner
- Excel data file with embedded graphics, slide deck briefing, and interactive data visualizations: ***utilityscalesolar.lbl.gov***

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