Utility-Scale Solar

Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States

2019 Edition – Southeastern Focus

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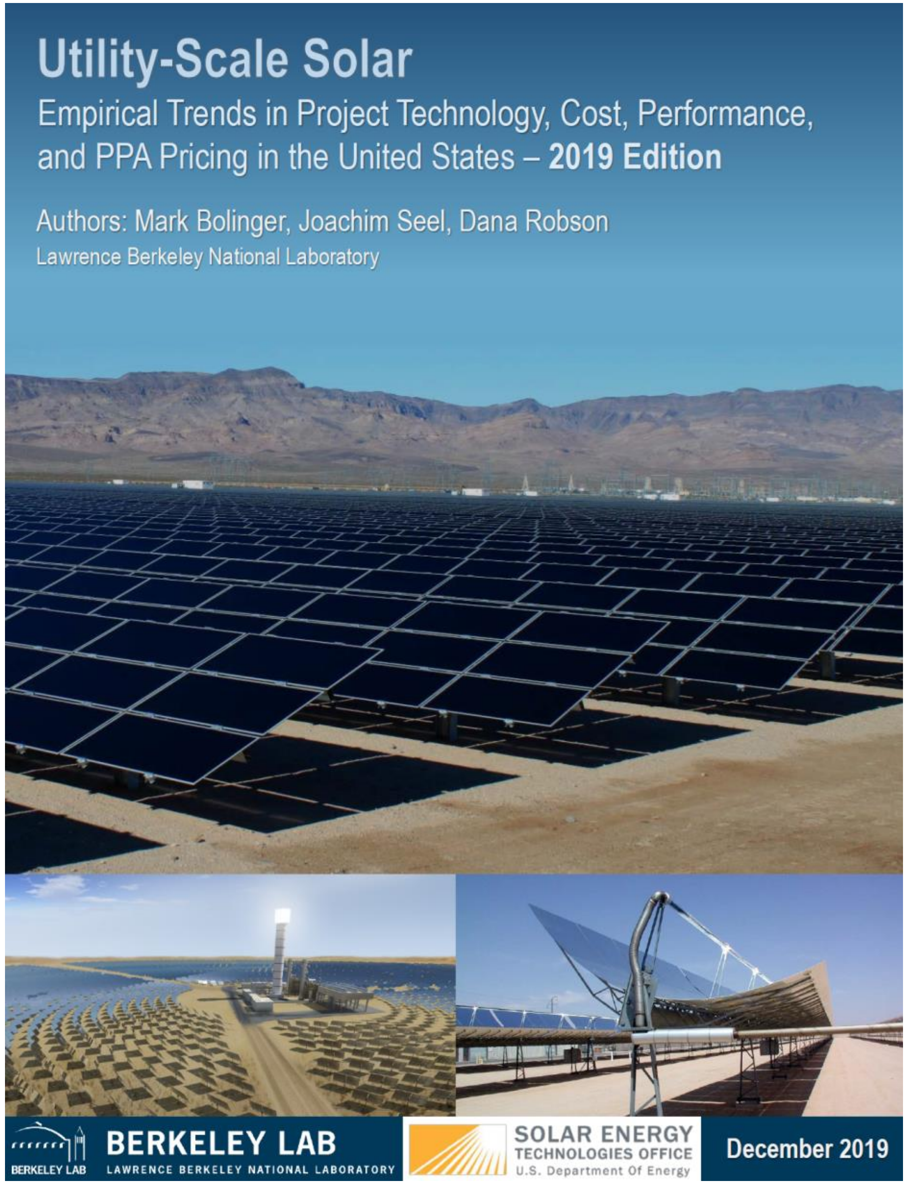
FAASSTeR presentation

April 2020

This research was supported by funding from the

U.S. Department of Energy Solar Energy Technologies Office



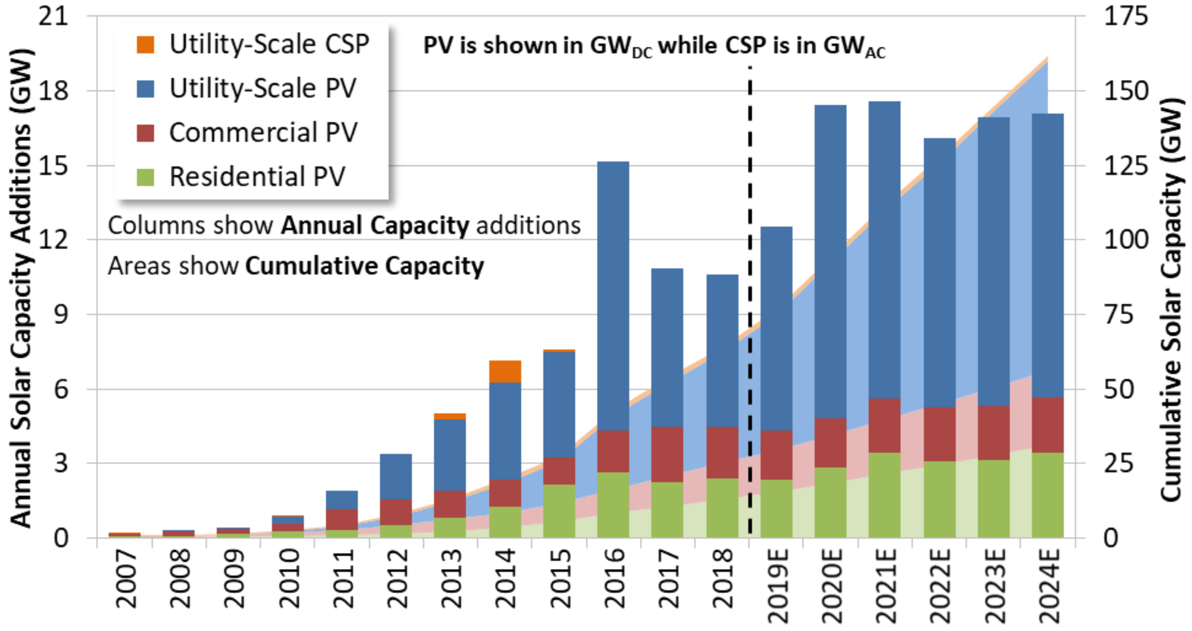
Presentation Outline

Strong growth of the utility-scale solar market provides increasing amounts of empirical project-level data that are ripe for analysis

1. Solar deployment trends (and utility-scale's relative contribution)
2. Project design, technology, and location
3. Installed project prices
4. Performance (capacity factors)
5. Power purchase agreement ("PPA") prices and levelized cost of energy ("LCOE")
6. PV+Storage
7. Future outlook

Utility-scale projects have the greatest capacity share in the U. S. solar market

The entire US

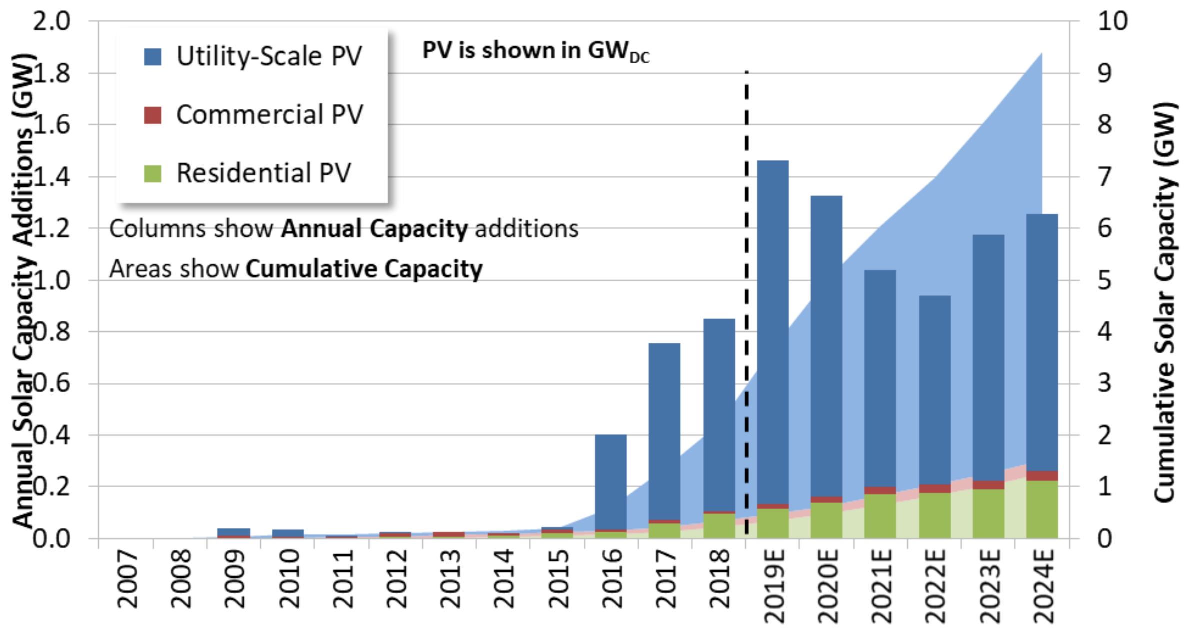


The utility-scale sector accounted for 6.2 GW_{DC} or **58% of all new** solar capacity added in 2018 and **60% of cumulative** solar capacity at the end of 2018.

Capacity additions declined slightly as a number of projects were pushed from end of 2018 to 2019.

Sources: *GTM/SEIA Solar Market Insight Reports, Berkeley Lab*

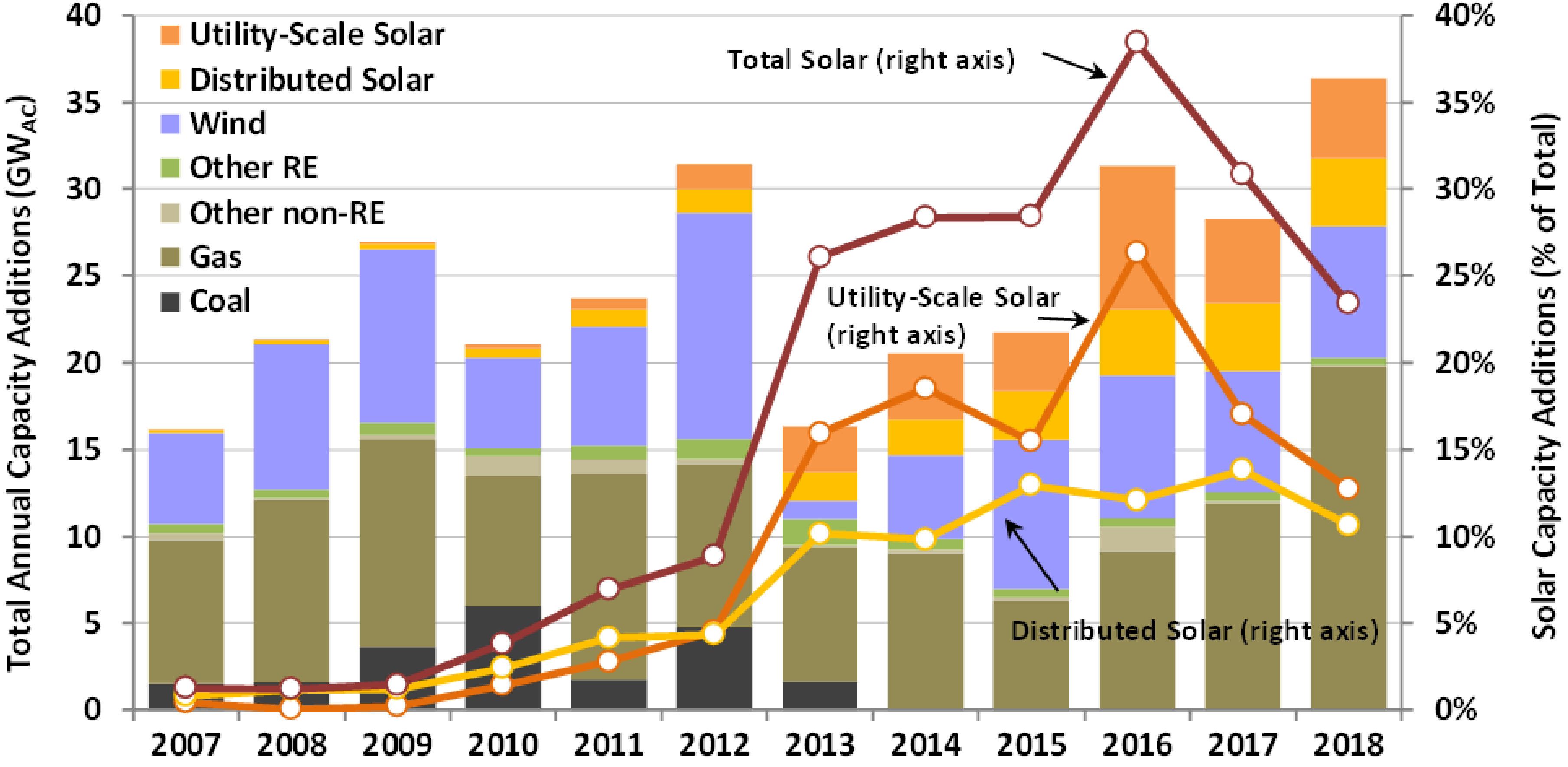
Florida only



In Florida the USS dominance is even more pronounced: 744MW_{DC} additions accounted for **87% of all new** solar capacity in 2018 and **85% of cumulative** solar capacity at the end of 2018.

In contrast to the national trend, FL USS additions increased year-over-year in 2018 and are expected to range between 700-1400MW per year for the next 5 years.

Solar power was the second largest source of U.S. electricity-generating capacity additions in 2018



Led by the utility-scale sector, solar power has comprised >20% of all generating capacity additions in the United States in each of the past six years.

In 2018, solar made up 23% of all U.S. capacity additions (with utility-scale accounting for 13%), behind natural gas (55%) but ahead of wind (21%).

Sources: *ABB, AWEA, GTM/SEIA Solar Market Insight Reports, Berkeley Lab*

Note: This graph follows GTM/SEIA's split between distributed and utility-scale solar, rather than our 5 MW_{AC} threshold

Solar penetration rates top 15% in California and exceed 10% in several other states

State	Solar generation as a % of in-state generation		Solar generation as a % of in-state load	
	All Solar	Utility-Scale Solar Only	All Solar	Utility-Scale Solar Only
California	19.0%	12.8%	15.8%	10.7%
Nevada	12.7%	11.5%	13.7%	12.4%
Hawaii	11.2%	1.9%	13.3%	2.3%
Vermont	11.0%	5.7%	4.9%	2.6%
Massachusetts	10.7%	4.3%	6.1%	2.5%
Arizona	6.5%	4.5%	9.6%	6.6%
Utah	6.4%	5.4%	8.4%	7.1%
North Carolina	5.4%	5.2%	5.2%	5.1%
New Mexico	4.7%	3.9%	6.4%	5.4%
New Jersey	4.2%	1.7%	4.3%	1.7%
Rest of U.S.	*0.7%*	*0.5%*	*0.8%*	*0.5%*
TOTAL U.S.	**2.3%**	**1.6%**	**2.5%**	**1.8%**

Source: EIA's Electric Power Monthly (February 2019)

State	PV generation as a % of in-state generation		PV generation as a % of in-state load	
	All PV	USS PV	All PV	USS PV
Florida	1.16%	0.99%	1.21%	1.03%

Solar penetration rate varies considerably depending on whether it is calculated as a percentage of generation or load (e.g., see Vermont).

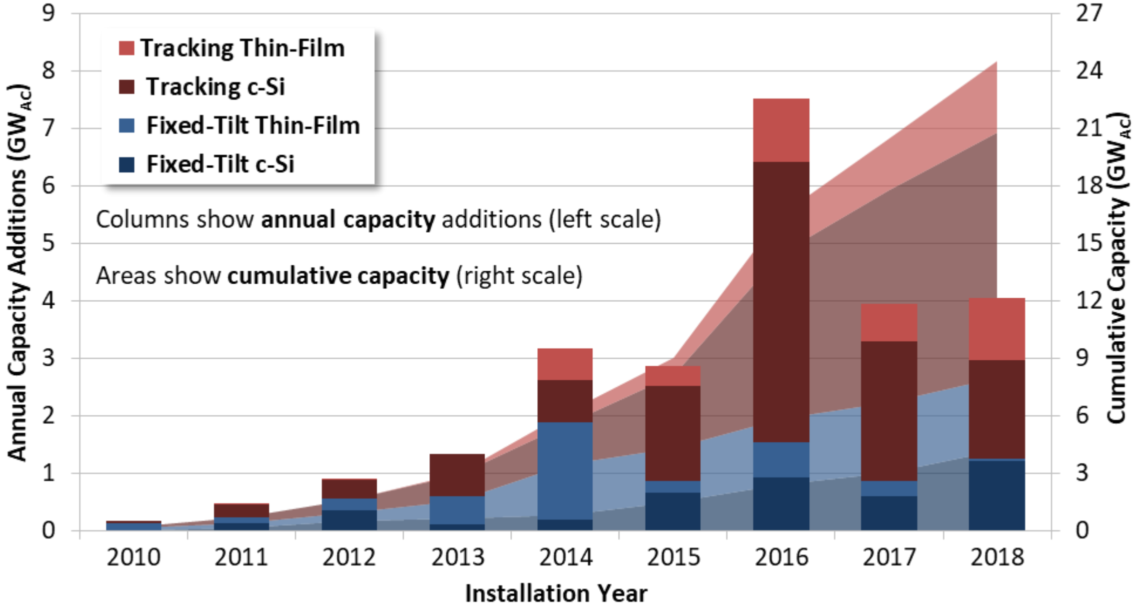
In 2018, five states achieved solar penetration levels >10% based on generation share. Three states had >10% based on load share.

Contribution of utility-scale also varies (a minority in Northeast states and Hawaii, a majority in Southwest states and overall).

Note: In this table, "utility-scale" refers to projects ≥ 1 MW_{AC}, rather than our typical 5 MW_{AC} threshold.

Projects with tracking technology dominated 2018 additions; c-Si modules led thin-film

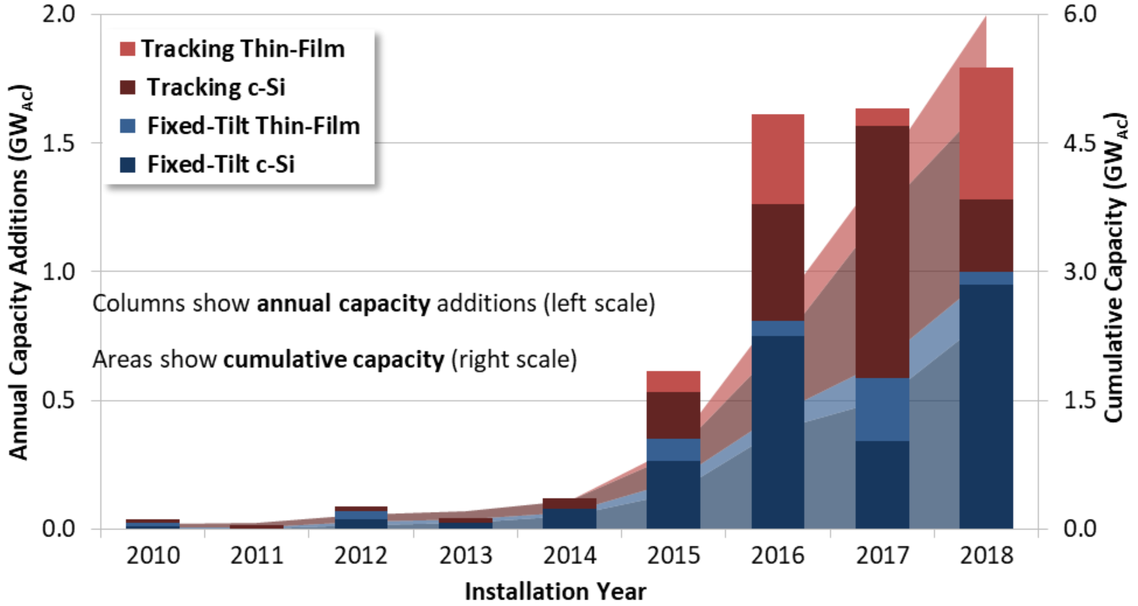
PV project population: 690 projects totaling 24,586 MW_{AC}



Continued dominance of **tracking** projects (69% of newly installed capacity) relative to **fixed-tilt** projects (31%). Thin-film projects are nearly exclusively using tracking now.

c-Si modules continue their clear lead (72% of newly installed capacity) relative to **thin-film** modules (28%).

Southeast PV project population: 188 projects totaling 5,989 MW_{AC}

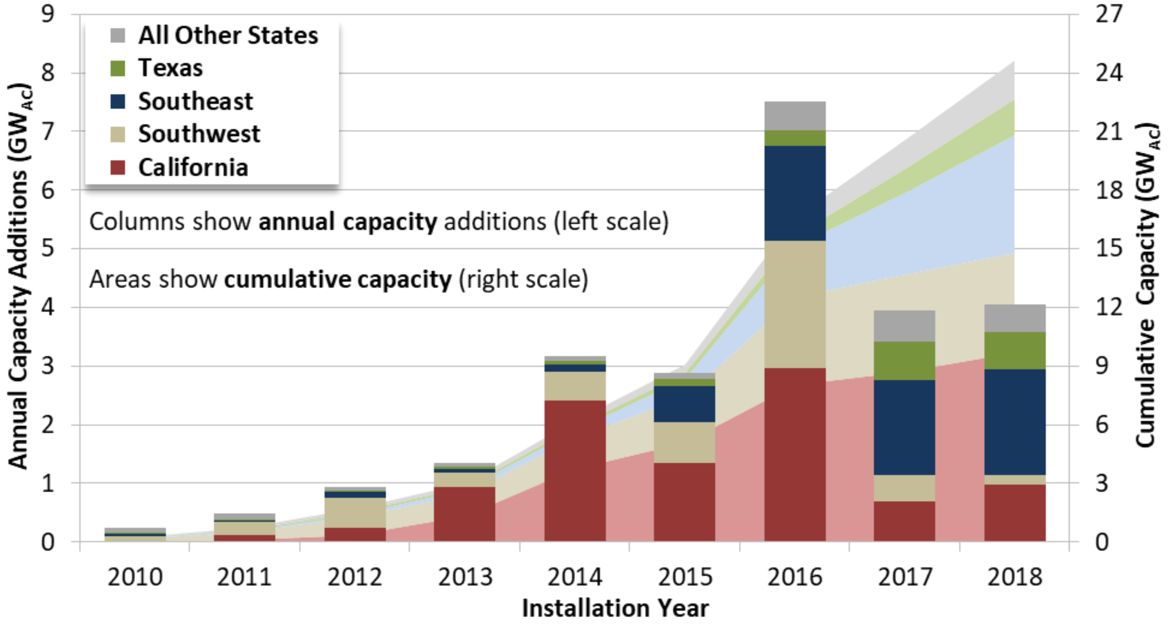


Much lower share of **tracking** projects in the southeast compared to the rest of the nation (44% of newly installed capacity and newly built projects) relative to **fixed-tilt** projects (56%). Most c-Si projects still built as fixed-tilt installations

c-Si modules also dominant in the southeast both in terms of newly installed capacity (69%) and newly installed projects (66%) relative to **thin-film** modules (31% or 34%).

Florida is the new national leader in utility-scale solar growth

Total US PV project population: 690 projects totaling 24,586 MWAC

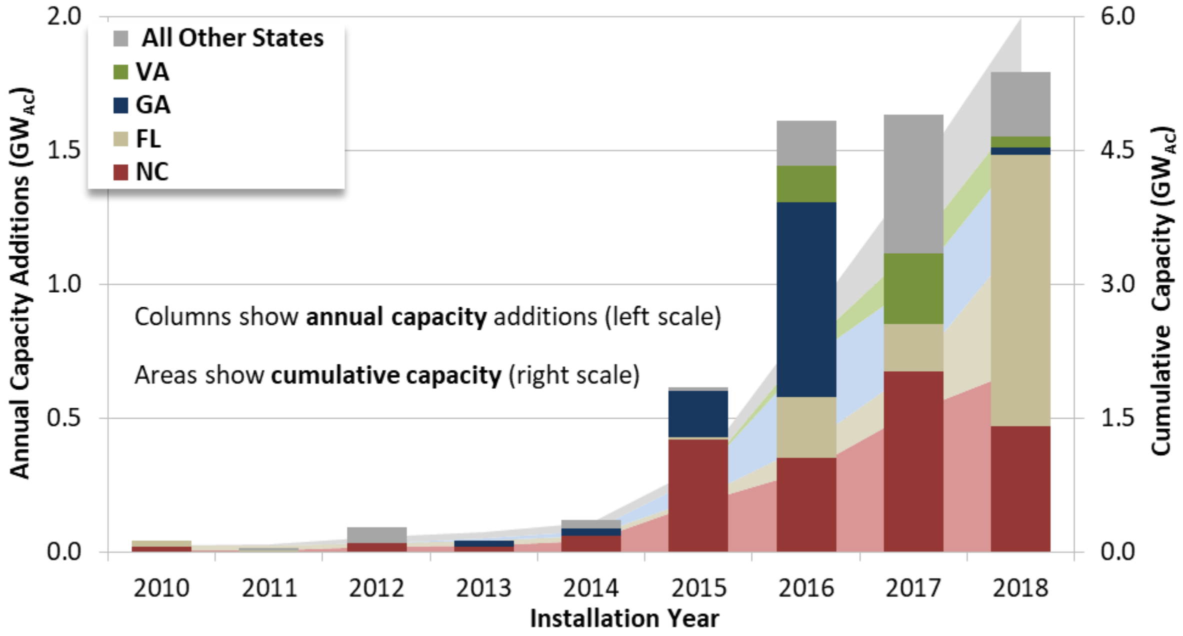


For the first time since 2011, **California** is not the state with the most capacity growth (981 MW$_{AC}$). But it still accounts for 40% of the cumulative installed capacity of the country.

Texas continues its solar growth with another year of ~650 MW$_{AC}$ and is the state with the third-most additions in 2018.

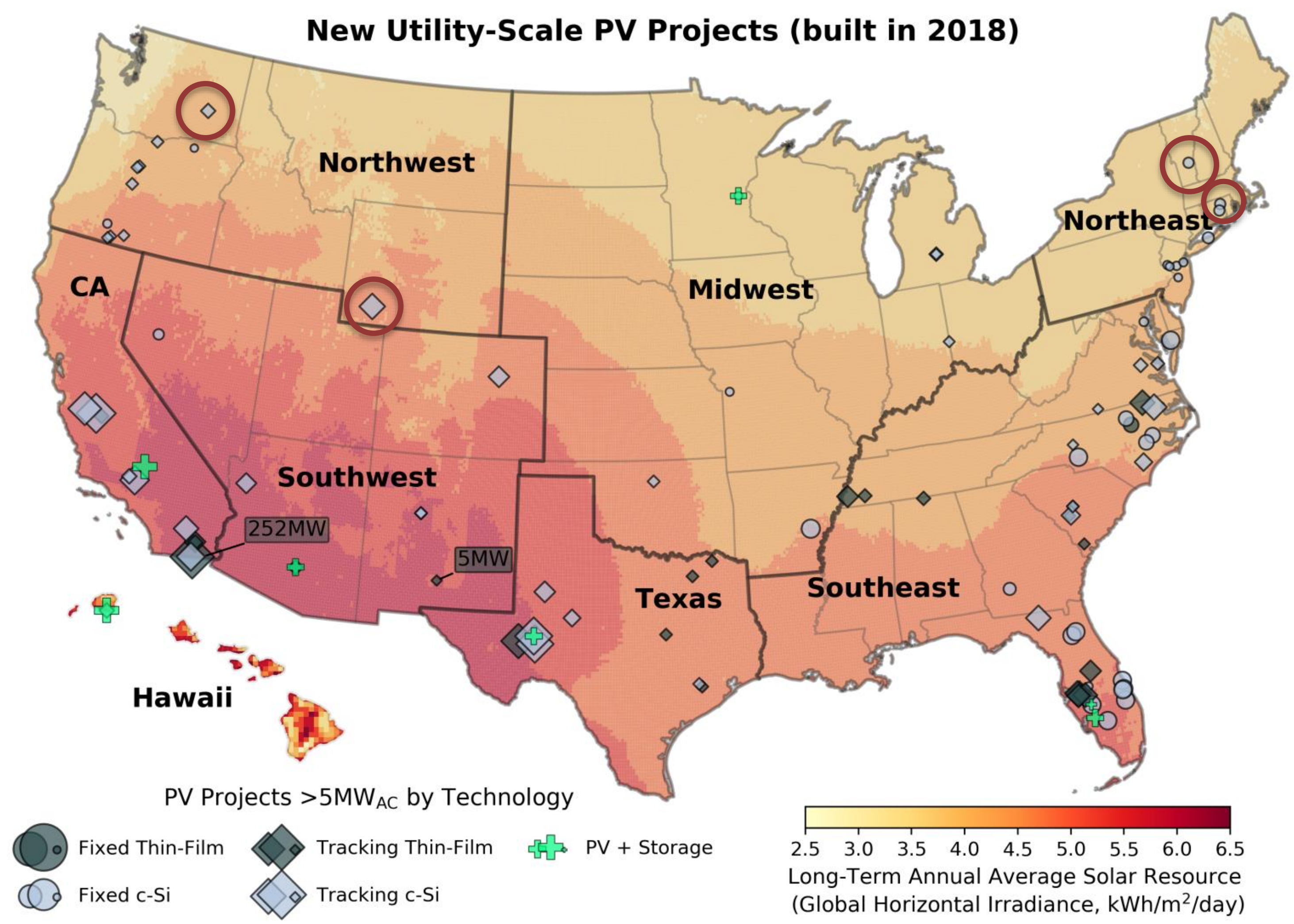
The **Southwest** only added 160 MW$_{AC}$ in 2018, and was surpassed by new installations in the **Northwest** (181 MW$_{AC}$).

Southeast PV project population: 188 projects totaling 5,989 MW$_{AC}$



The **Southeast** is the new growth engine of the US utility-scale solar market. It is led by **Florida**, now the largest annual market at 1010 MW$_{AC}$ or 25% of national additions. Established player **North Carolina** added 472 MW$_{AC}$.

Florida is the new national leader in utility-scale solar growth



Florida's growth was driven by the regulated utilities FPL and TECO, which added many fixed-tilt projects ( ).

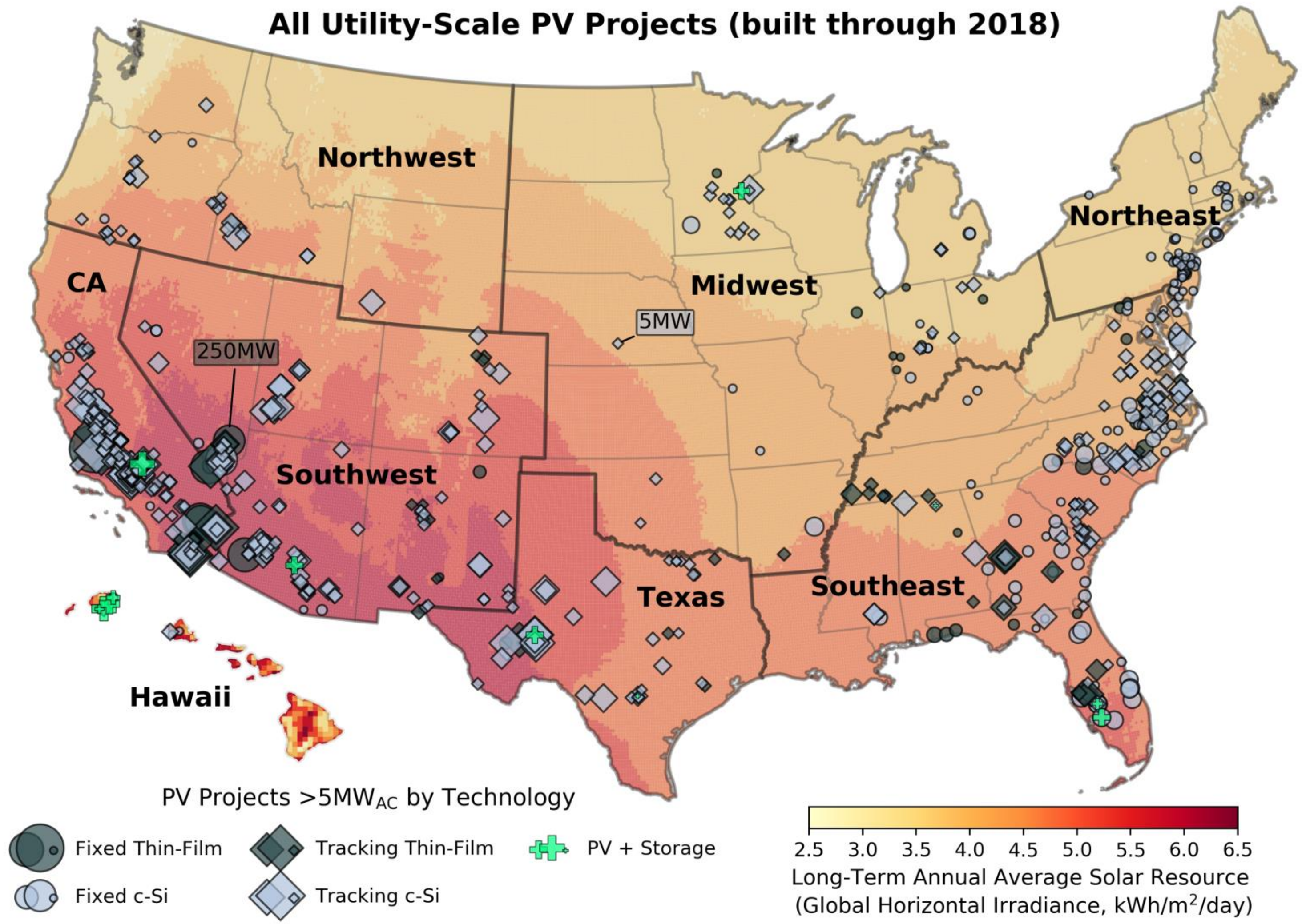
California only completed 10 projects, but these were large (up to 252 MW_{AC}) and added a respectable 981 MW.

Northwestern additions in 2018 were predominantly tracking projects ( ).

In 2018, storage ( ) was added to already existing (3) and new (4) PV projects. 6 of these were built in high penetration/transmission-constrained regions in HI, CA, AZ and TX, while the 7^{th} is in relative newcomer state MN.

4 new states added their first utility-scale PV projects: **Connecticut**, **Vermont**, **Washington** and **Wyoming.**

Utility-Scale Solar has become a growing source of electricity in all regions of the United States



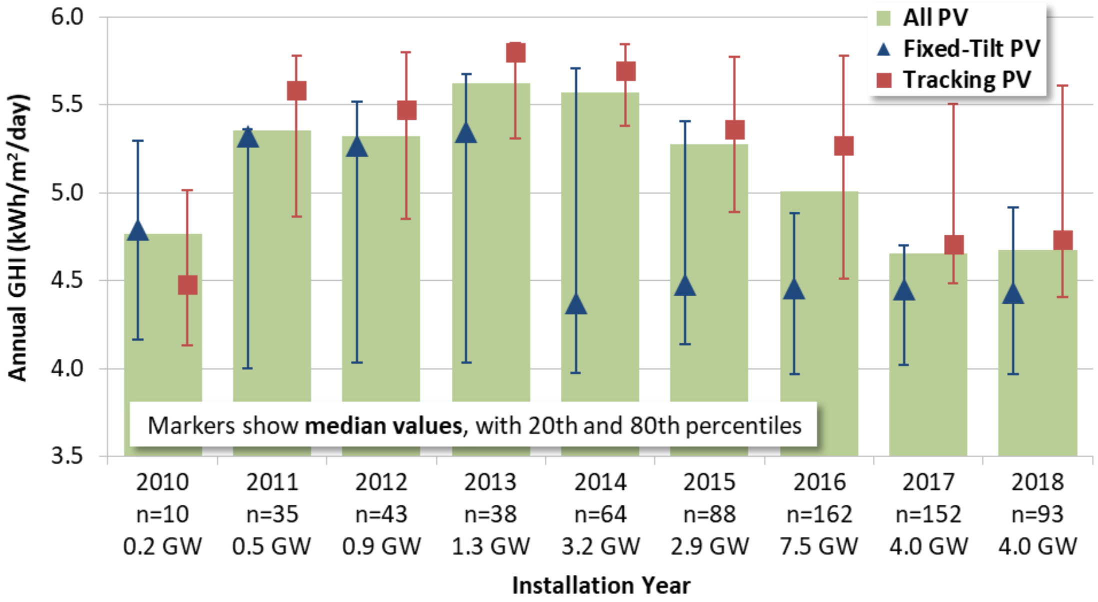
Utility-Scale PV is now well-represented throughout the nation with the exception of Midwestern states in the "wind belt."

Fixed-tilt projects (in particular c-Si ) have been built in lower-insolation regions, primarily along the east coast.

Tracking projects () started out in the Southwest but have increasingly spread throughout the country, north to Washington, Idaho, and Minnesota, and northeast to Virginia.

Utility-Scale Solar is increasingly built at lower-insolation sites

Total US PV project population: 690 projects totaling 24,586 MWAC

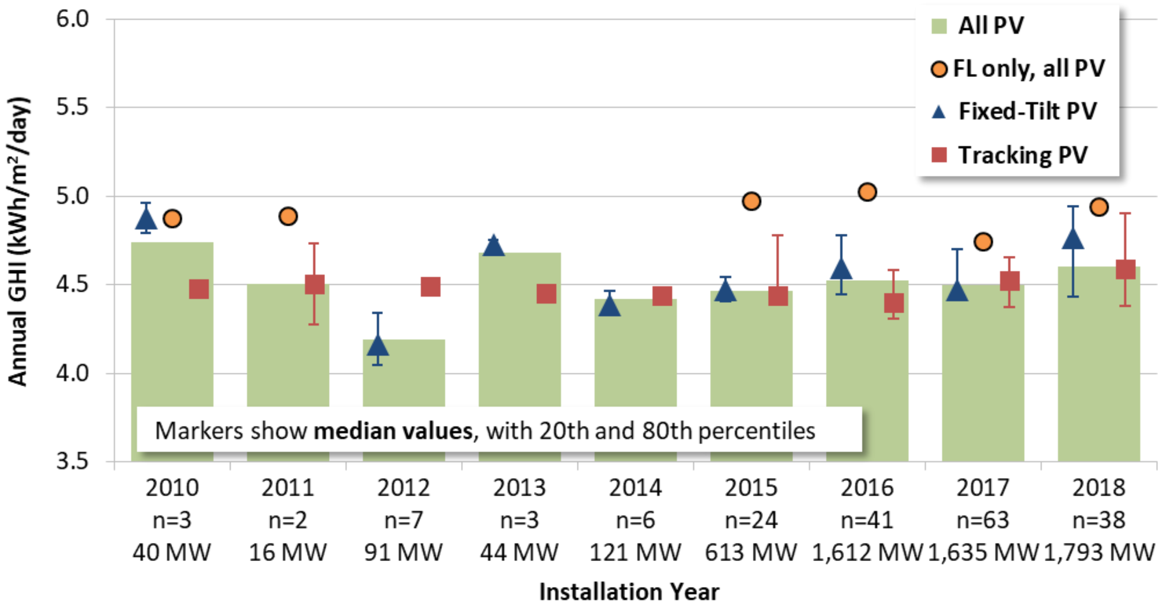


The median solar resource (measured in long-term global horizontal irradiance—**GHI**) at new project sites has decreased since 2013 as the market expands to less-sunny states but stabilized in 2018.

Fixed-tilt PV is increasingly relegated to lower-insolation sites (note the decline in its **80th percentile**), while tracking PV is pushing into those same areas (note the decline in its **20th percentile**).

All else equal, the buildout of lower-GHI sites will dampen sample-wide capacity factors (reported later).

Southeast PV project population: 188 projects totaling 5,989 MW_{AC}



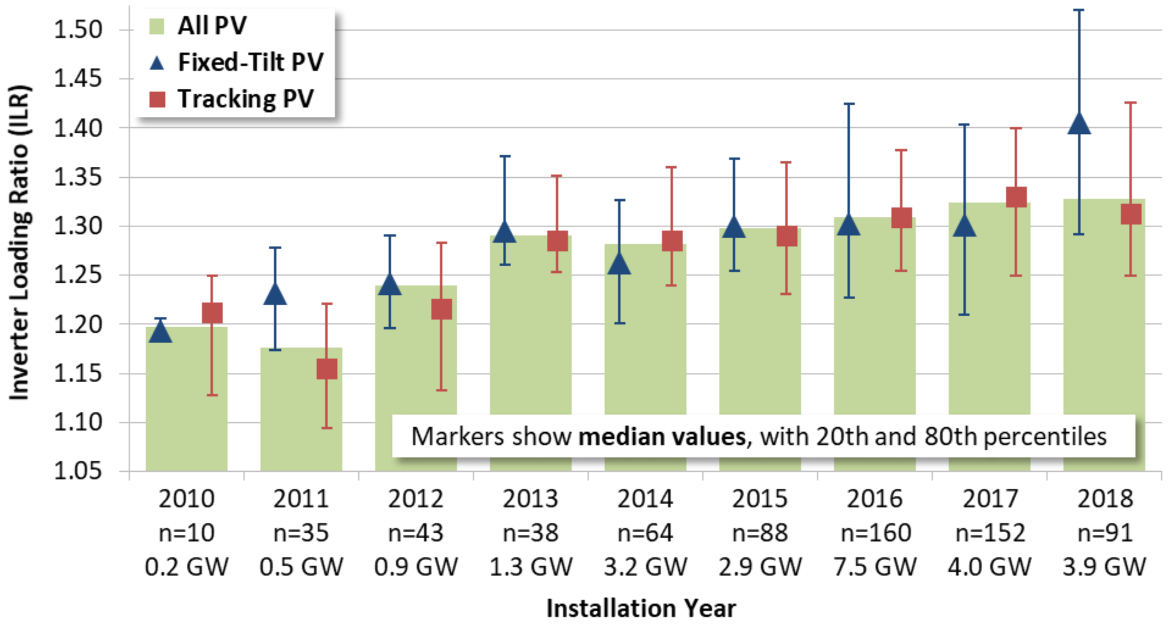
Florida has better solar resources than the rest of the Southeast.

Within the Southeast the trend of installing fixed-tilt installations only in less sunny areas is not as pronounced as in the rest of the country.

High coastal wind loads and potential salt corrosion may be a contributing factor to installing fixed-tilt projects even in otherwise very sunny areas.

The median inverter loading ratio (ILR) continued to climb, especially for fixed-tilt projects

Total US PV project population: 690 projects totaling 24,586 MWAC

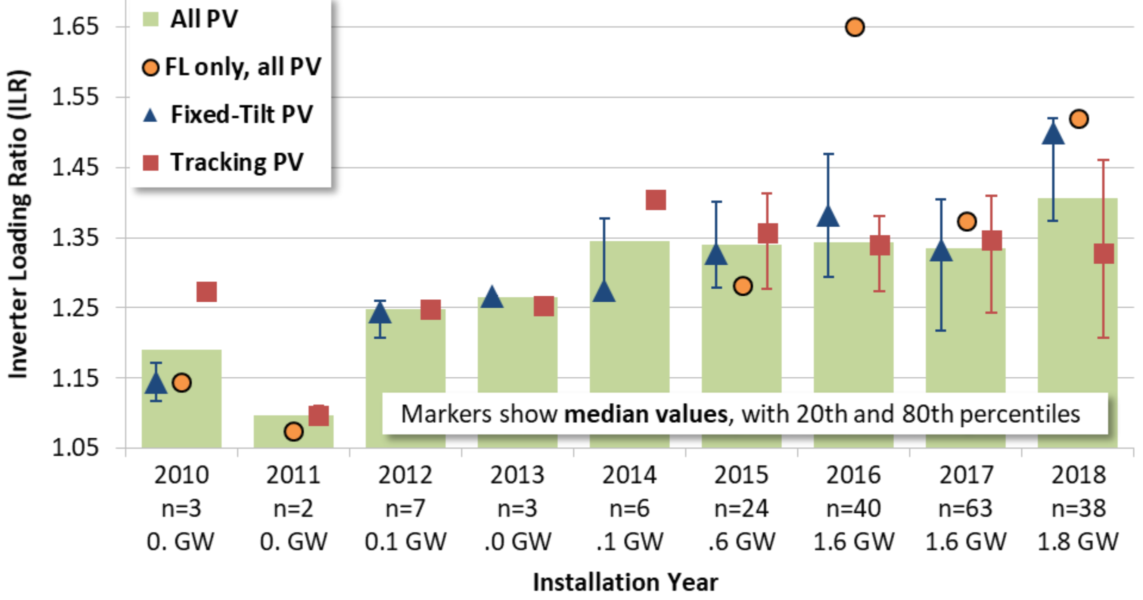


As module prices have fallen (faster than inverter prices), developers have oversized the DC array capacity relative to the AC inverter capacity to enhance revenue and reduce output variability.

The median inverter loading ratio (**ILR** or DC:AC ratio) increased to 1.33 in 2018, though considerable variation remains (ranging from 1.14 to 1.59).

Fixed-tilt PV has more to gain from a higher ILR than does tracking PV, and 2018 showed a new record lead for fixed-tilt installations (1.41 vs. 1.31 - driven by high ILR projects in Florida, CT, and MD).

Southeast PV project population: 188 projects totaling 5,989 MW_{AC}



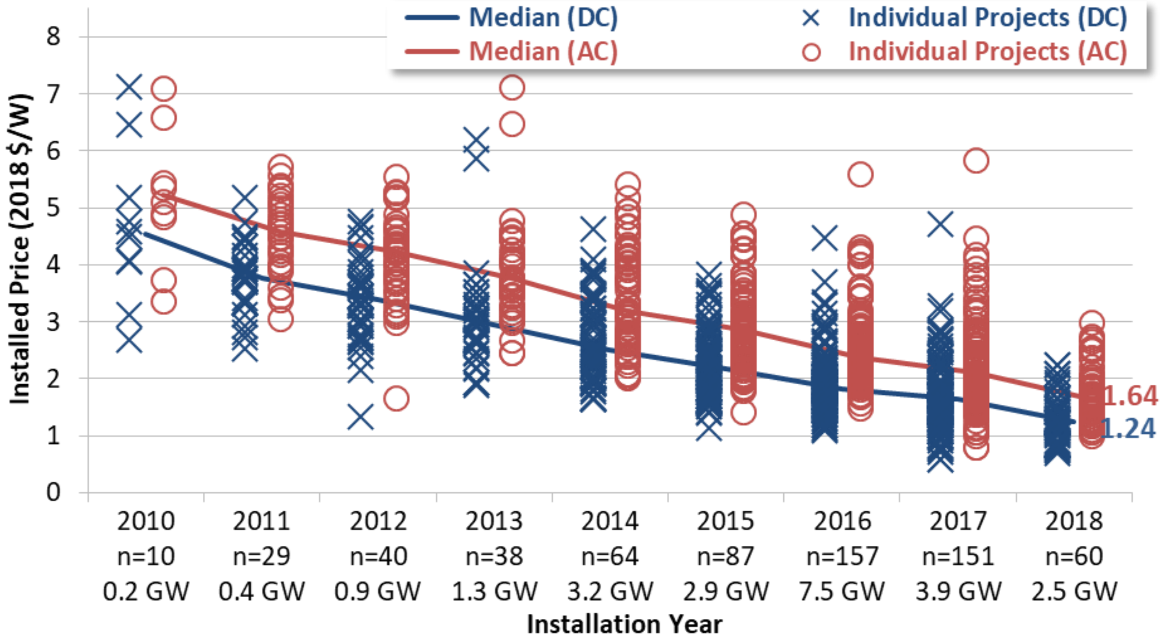
The Southeast tended to have higher median ILR ~1.4 than the rest of the nation.

Several FPL installations have among the highest ILRs we have in the entire national sample (one of these projects has been retrofitted with a DC-coupled battery to capture clipped energy).

No consistent difference in ILR between fixed and tracking installations in the Southeast.

Median installed price of PV has fallen by nearly 70% since 2010, to \$1.6/W_{AC} (\$1.2/W_{DC}) in 2018

Total US PV price sample: 641 projects totaling 22,886 MW_{AC}

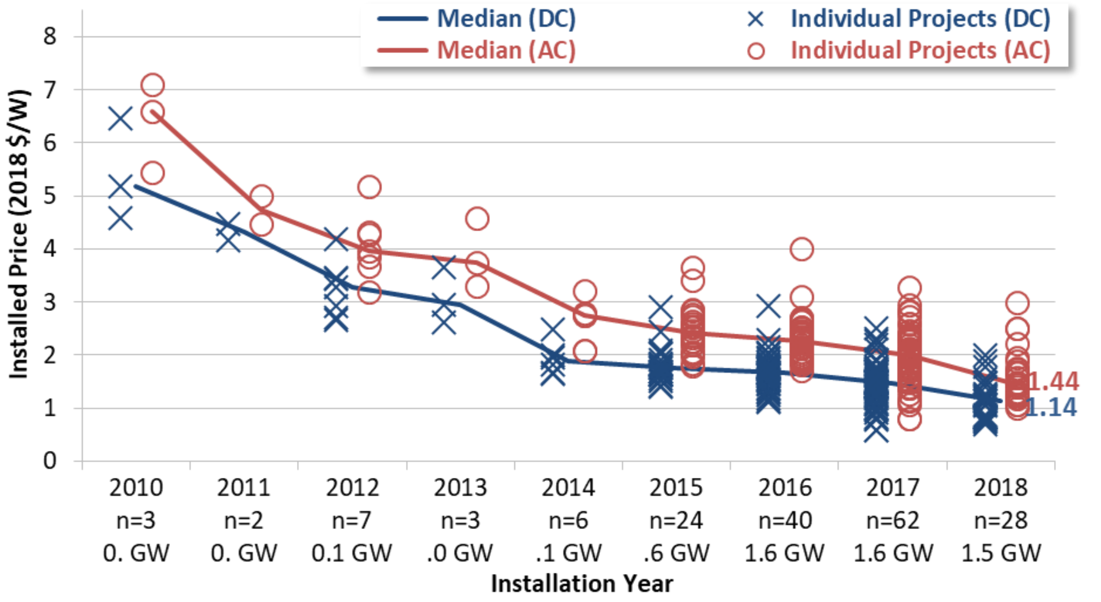


The lowest 20th percentile of project prices fell from \$1.7/W_{AC} (\$1.3/W_{DC}) in 2017 to \$1.3/W_{AC} (\$0.9/W_{DC}) in 2018.

The lowest projects among the 60 data points in 2018 was \$1.0/W_{AC} (\$0.7/W_{DC}).

Historical pricing sample is robust (99% of installed capacity through 2017). 2018 data covers 64% of new projects or 62% of new capacity.

Southeast PV project population: 176 projects totaling 5,660 MW_{AC}



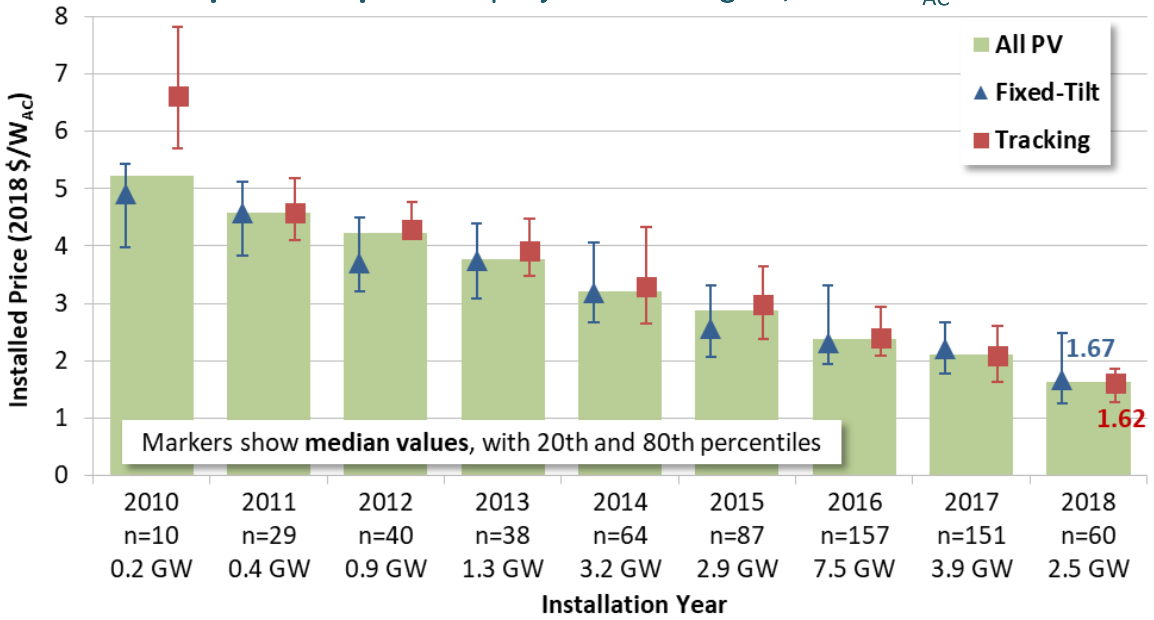
Southeast similar to national sample – earlier price reductions before market started growing in 2015. Since then price declines have been more modest.

2018 national price sample is dominated by southeastern installations, yet the southeast beats national prices by \$0.2/W_{AC} (\$0.1/W_{DC}) .

This sample is backward-looking and does not reflect the price of projects built in 2019/2020.

Within our sample, projects with trackers now have lower average upfront costs than fixed-tilt projects

Total US PV price sample: 640 projects totaling 22,880 MW_{AC}

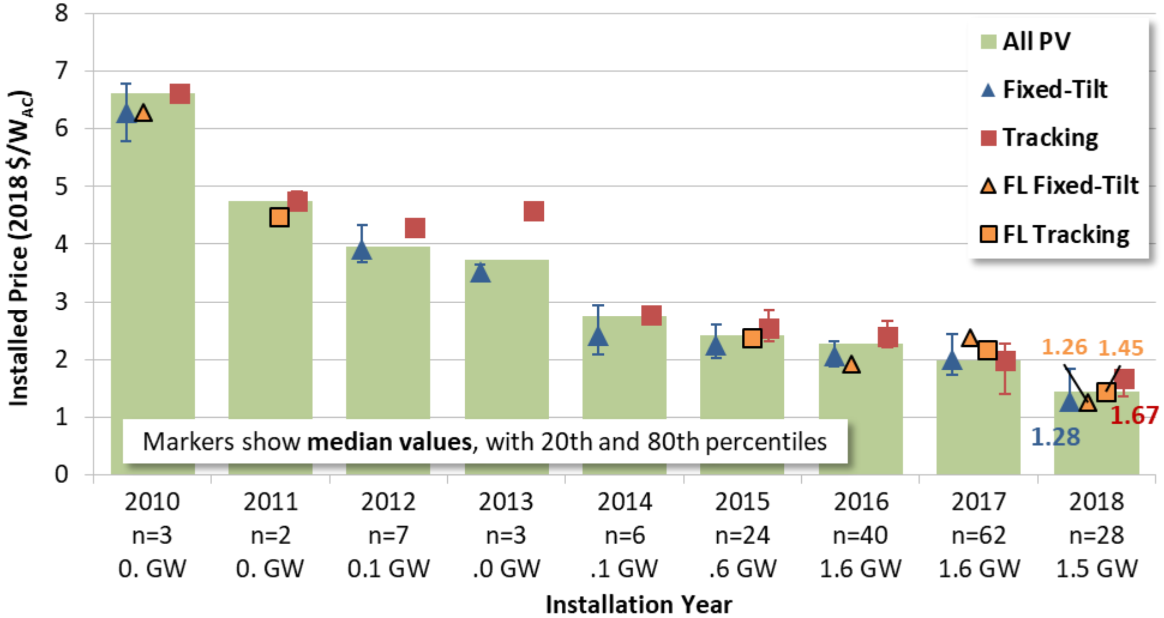


Through 2016, projects with tracking were regularly more expensive (though by varying amounts) than fixed-tilt projects in our sample on average.

But in both 2017 and 2018, this historical relationship seemingly reversed, with average pricing in 2018 at \$1.7/W_{AC} (\$1.3/W_{DC}) for fixed-tilt projects vs. \$1.6/W_{AC} (\$1.2/W_{DC}) for tracking projects.

This apparent reversal may be driven by challenging construction environments for fixed-tilt projects (e.g., high wind loads, sensitive brown-field sites) as well as sampling issues. However, for any ***individual*** project, using trackers still likely has a higher CapEx than mounting at a fixed-tilt.

Southeast PV project population: 176 projects totaling 5,660 MW_{AC}

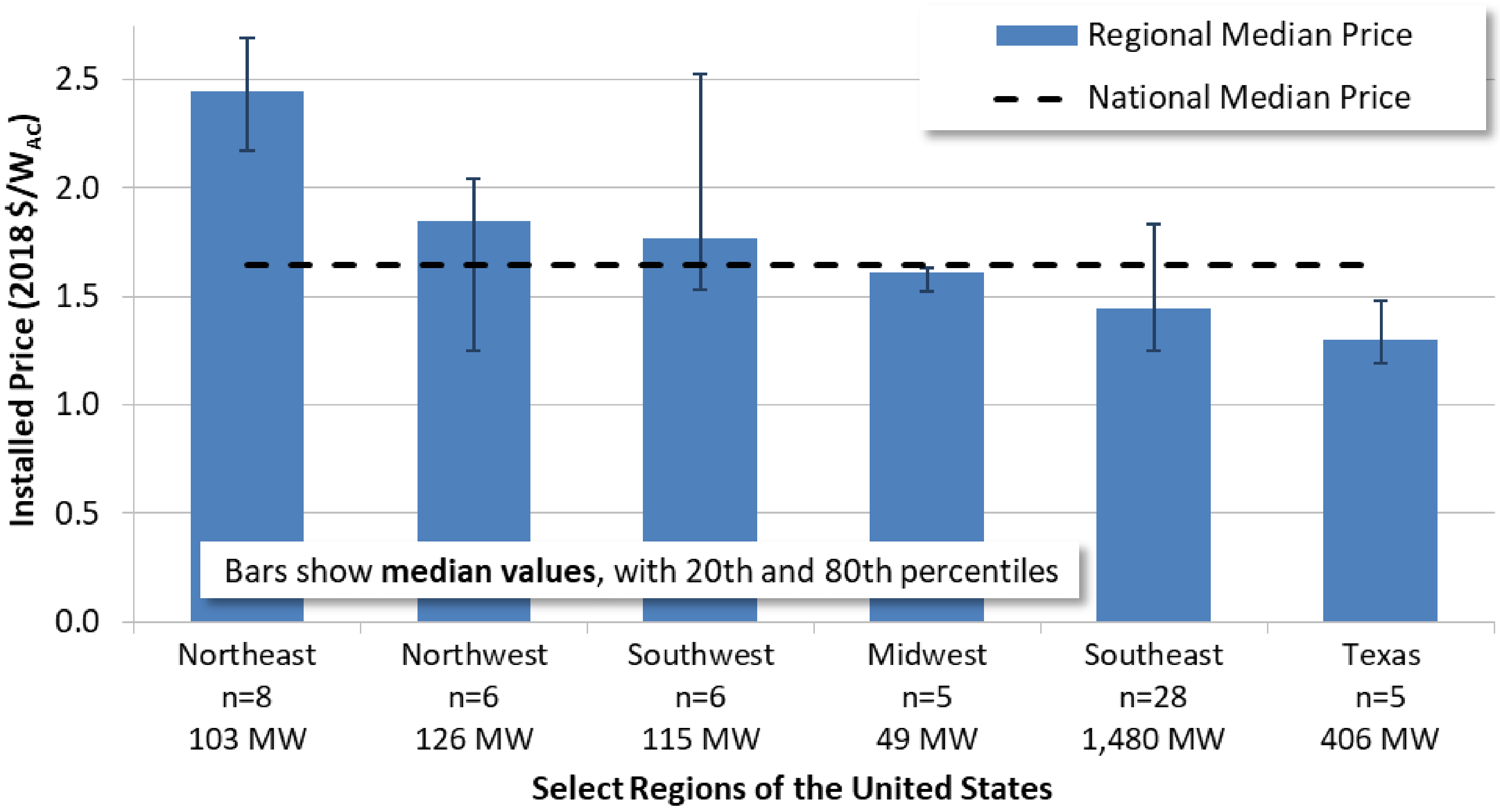


In Southeast the tracking projects appear to be still more costly than fixed-tilt installations (in contrast to the national sample).

In Florida, tracking projects continue to be slightly more expensive in 2018 at \$1.45/W_{AC} (\$1.20/W_{DC}) compared to \$1.26/W_{AC} (\$0.83/W_{DC}) for fixed tilt installations.

Project prices vary by region, newcomers have lower prices

PV price sample for 2018: 60 projects totaling 2,499 MW_{AC}



Note: The regions are defined in the earlier slides with a map of the United States

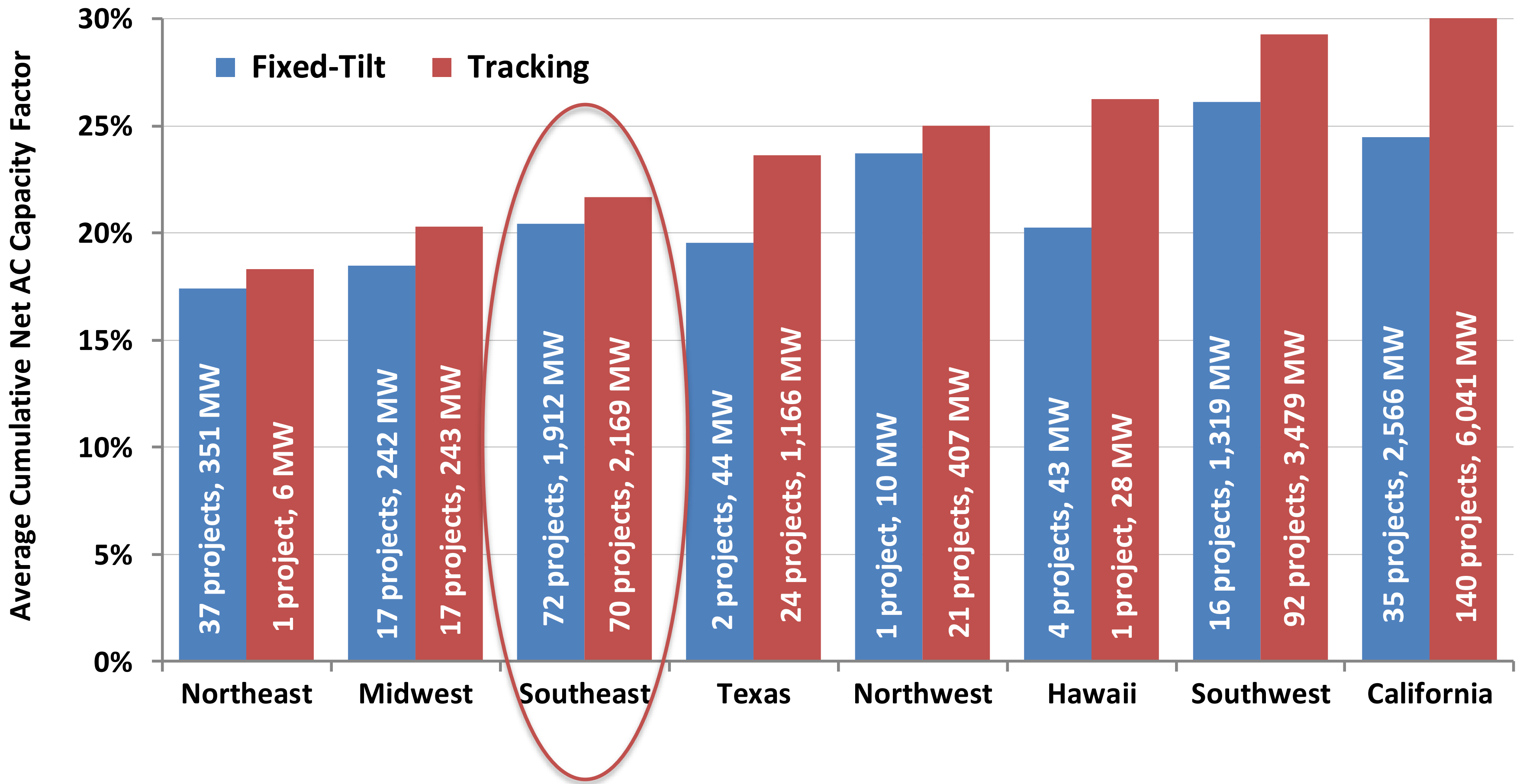
Price differences could be driven in part by technology ubiquity; other factors may include labor costs and share of union labor, land costs, terrain, soil conditions, snow and wind loads, and balance of supply and demand.

The Northeast, Northwest and Southwest seem to be priced above the national median, while the Midwest, Southeast and Texas appear to be lower priced.

Sample size outside of Southeast is very limited (Hawaii and California are excluded due to few observations), so these rankings should be viewed with some caution.

Tracking boosts net-capacity factors by up to 5% in high-insolation regions

PV Performance sample: 550 projects totaling 20,024 MW_{AC}

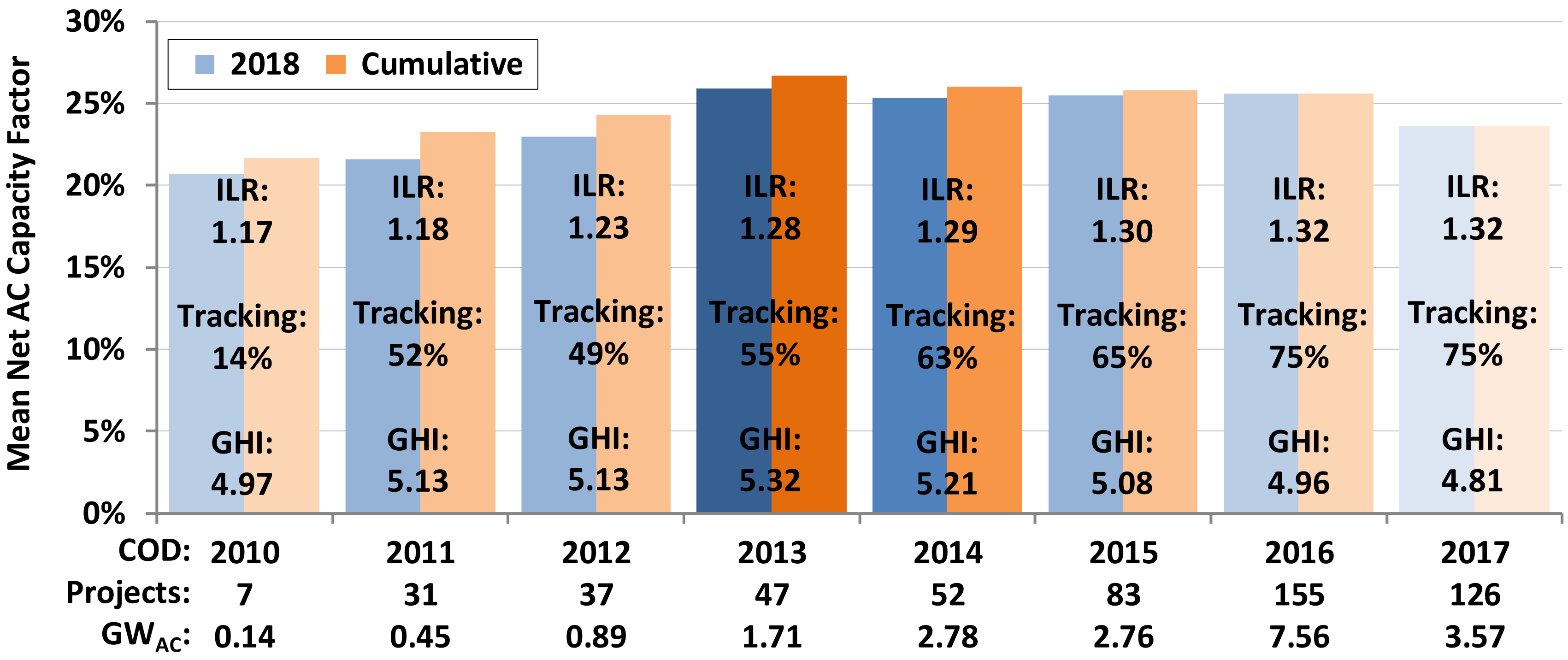


Not surprisingly, capacity factors are highest in California and the Southwest, and lowest in the Northeast and Midwest.

Although sample size is small in some regions, the greater benefit of tracking in the high-insolation regions is evident, as are the greater number of tracking projects in those regions.

Note: The regions are defined in the earlier slides with a map of the United States

Since 2013, competing drivers have gradually reduced average capacity factors by project vintage



Recent flat-to-declining trend is not necessarily negative, but rather a sign of a market that is expanding geographically into less-sunny regions (as indicated by changes to GHI, portrayed both numerically and via shading intensity)

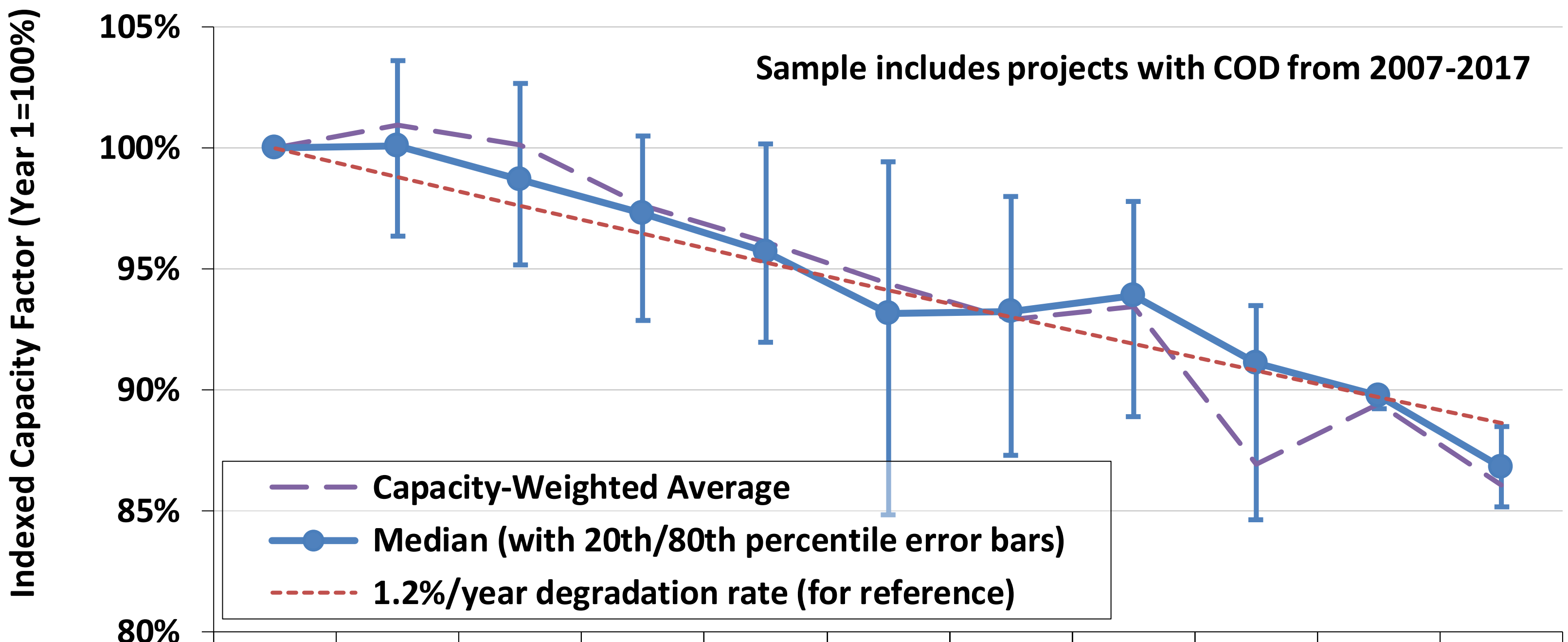
Average capacity factors increased from 2010- to 2013-vintage projects due to an increase in:

- ILR (from 1.17 to 1.28)
- tracking (from 14% to 55%)
- average site-level GHI (from 4.97 to 5.32 kWh/m^2/day)

But trends in tracking and GHI were at odds from 2013- to 2016-vintage projects, resulting in capacity factor stagnation (on average)

2017-vintage projects match 2016-vintage on both ILR and tracking, but GHI has declined further, resulting in a 2 percentage point drop in average capacity factor (from 25.6% down to 23.6%)

Performance degradation is evident, but is difficult to assess and attribute at the project level



Years post-COD:	1	2	3	4	5	6	7	8	9	10	11
Sample projects:	541	411	262	181	128	81	44	13	6	3	2
Sample MW_{AC}:	19,876	16,256	8,757	6,070	3,278	1,567	675	227	83	29	19

Graph shows indexed capacity factors in each full calendar year following COD. Capacity factors have been normalized to correct for inter-year resource variation.

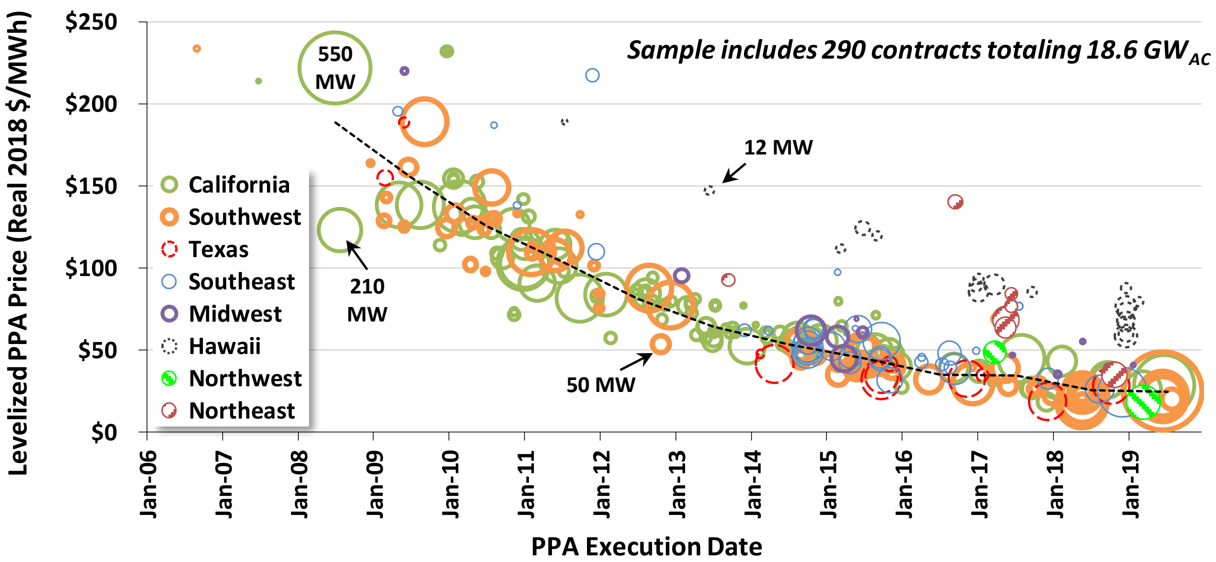
Weather-corrected fleet-wide degradation appears to be running at ~1.2%/year—i.e., higher than commonly assumed.

However, other important factors are not properly controlled for here:

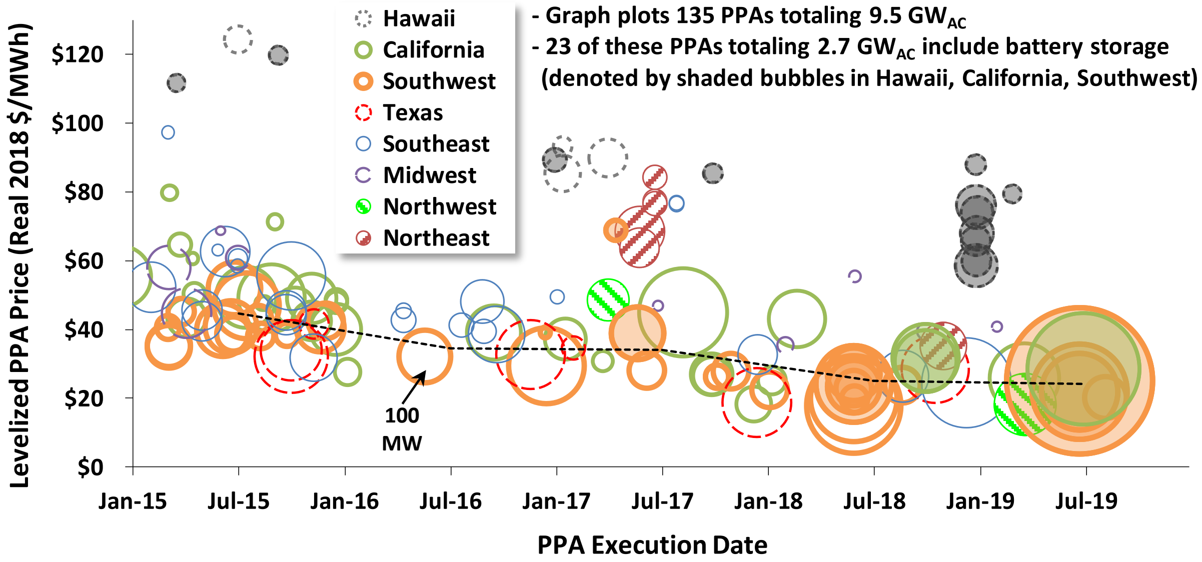
- **curtailment** (1.2% in California and 6.7% in Texas in 2018—see later slides)
- **an inconsistent sample** (which drops off quickly in each successive year)

PPA prices have fallen dramatically, in all regions of the country

Full sample:

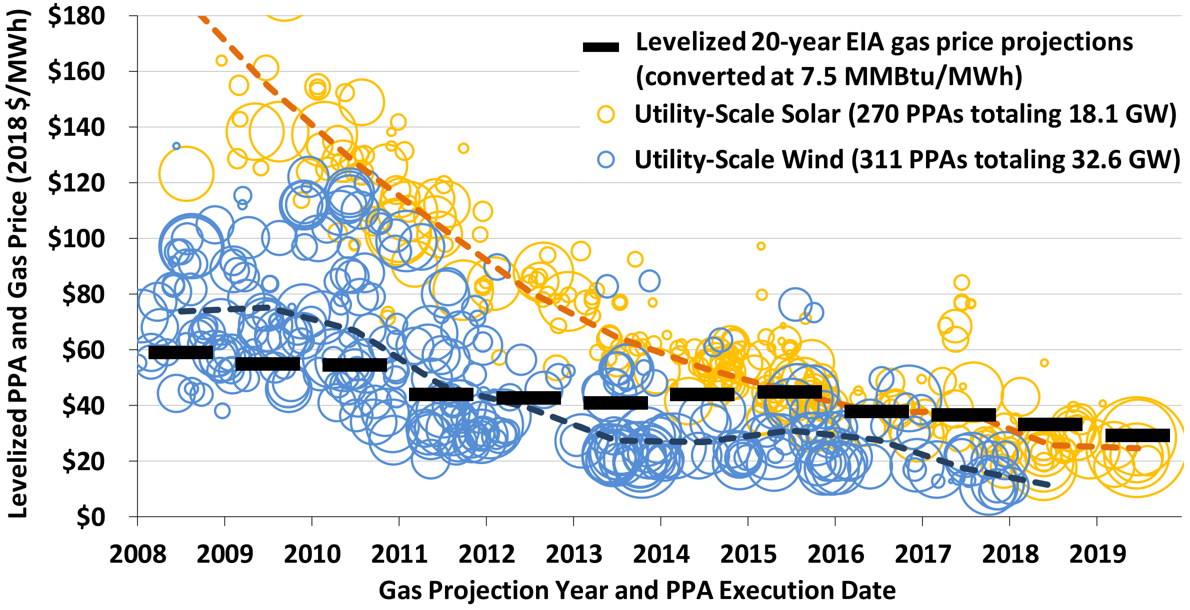


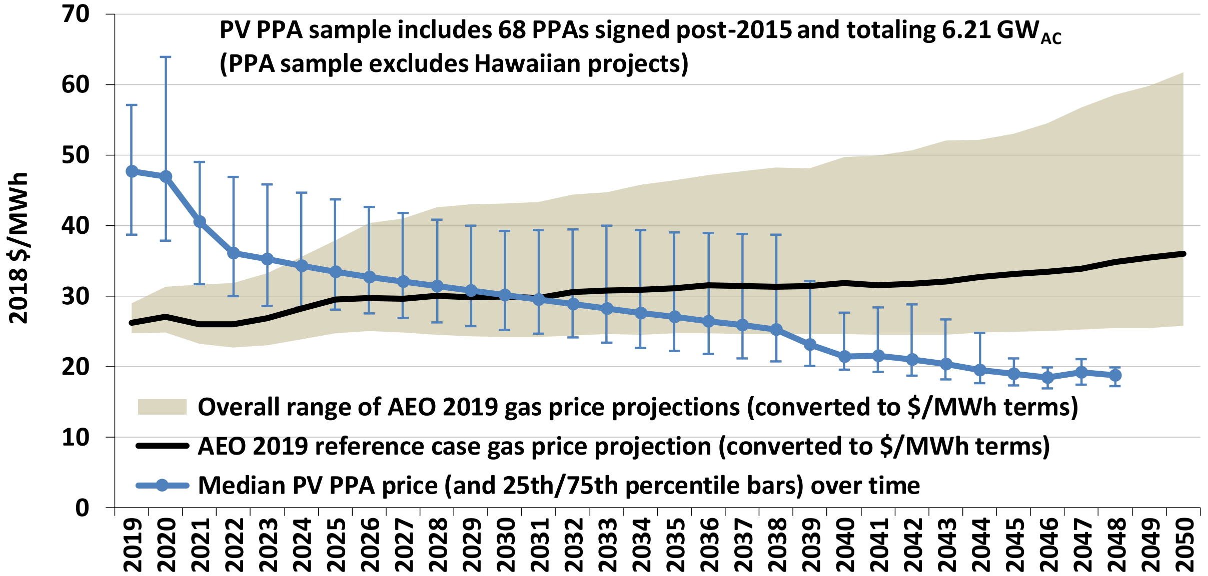
Focus on post-2014 period:



- Power Purchase Agreement (PPA) prices are **levelized** over the full term of each contract, after accounting for any escalation rates and/or time-of-delivery factors, and are shown in real 2018 dollars
- 27 of 38 post-2017 PPAs in our sample are <$40/MWh, with 21 <$30/MWh and 4 even <$20/MWh (all levelized, in 2018 dollars)
- 23 PPAs featuring PV plus medium-duration battery storage (4-5 hour, shaded in right graph) do not seem to be priced at much of premium to their PV-only counterparts
- Hawaii projects show a consistent and significant premium of ~$40/MWh over the mainland
- Smaller projects (e.g., 20-50 MW) are seemingly no less competitive
- >80% of the sample is currently operational

Despite record-low PPA prices, solar faces stiff competition from both wind and natural gas

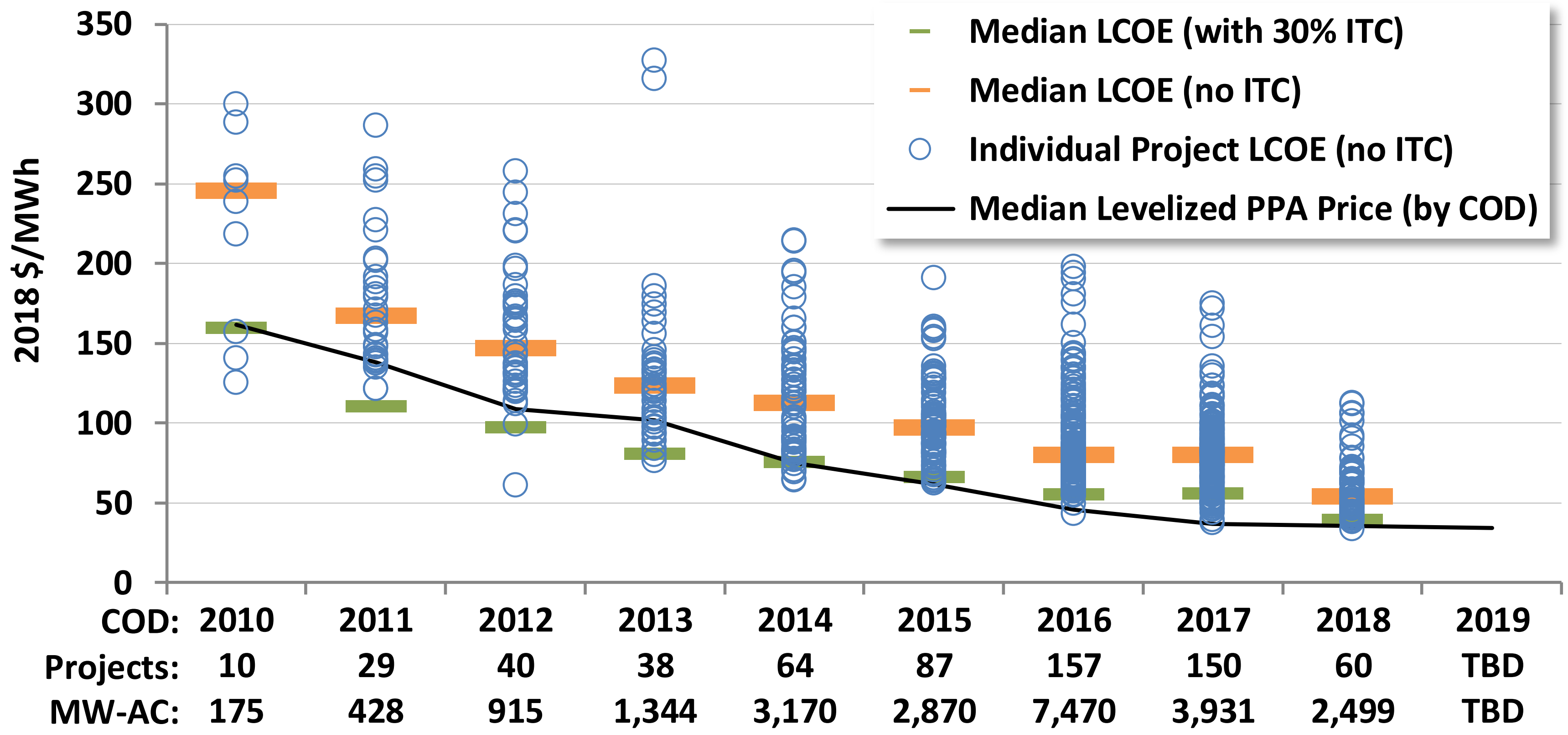




- Left graph shows that solar PPA prices have nearly closed the gap with wind, and both are competitive with levelized gas price projections
- Right graph compares recent solar PPA prices to range of gas price projections from AEO 2019. Although solar PPAs signed post-2015 are priced higher than the cost of burning fuel in an ***existing*** combined-cycle natural gas unit (NGCC), over longer terms PV is potentially more competitive (depending on what happens to the price of natural gas), and can help protect against fuel price risk.
- PV PPAs are priced to recover *both* capital *and* other ongoing operational costs (for an NGCC, this would add another ~$21-$50/MWh to fuel costs). With declining battery costs, PV+storage is becoming a serious competitor to new gas-fired peaker plants (that have higher heat rates and thus higher fuel costs than those depicted in the right graph).

Levelized PPA prices track the LCOE of utility-scale PV

LCOE sample: 640 projects totaling 22,876 MW_{AC}



Using empirical data from elsewhere in the report, along with a number of assumptions (e.g., about financing), we calculated project-level LCOEs for the entire sample of projects for which we have CapEx data.

Median estimates of LCOE track median PPA prices (shown here by COD rather than by execution date) reasonably well, suggesting a fairly competitive PPA market.

PV + battery projects have proliferated within our PPA price sample

State	Project			Actual or Expected COD	Capacity (MW-AC)			Battery Storage		Battery:PV Capacity	Levelized PPA Price
State	Name	Sponsor	Offtaker	(PV/Wind/Battery)	PV	Wind	Battery	Hours	MWh	Ratio	(2018 $/MWh)
AL	Redstone Arsenal	SunPower	Redstone Arsenal	Dec-17	10	0	1	2.0	2	10%	?
AR	Searcy	NextEra	Entergy (owner)	Dec-21	100	0	30	?	?	30%	#N/A
AZ	Pinal Central	NextEra	SRP	Apr-18	20	0	10	4.0	40	50%	68.9
AZ	Wilmot	NextEra	TEP	Dec-19	100	0	30	4.0	120	30%	40.7
AZ	Redhawk(?)	First Solar	APS	Jun-21	65	0	50	2.7	135	77%	?
CA	Desert Harvest II	EDF-RE	SCPPA	Dec-20	70	0	35	4.0	140	50%	LMP plus $15.25
CA	RE Slate 2	ReCurrent	MBCP and SVCE	Jun-21	150	0	45	4.0	180	30%	≤31.8
CA	BigBeau	EDF-RE	MBCP and SVCE	Dec-21	128	0	40	4.0	160	31%	≤30.9
CA	?	NextEra	Kaiser Permanente	Dec-20/Dec-21/Dec-21	131	50	110	?	?	84%	?
CA	Sonrisa	EDPR	SJCE & EBCE	Dec-22	200	0	40	4.0	160	20%	?
CA	Raceway	sPower	EBCE	Dec-22	125	0	80	2.0	160	64%	?
CA	Eland	8minute Solar	LADWP/Glendale	Dec-23	400	0	300	4.0	1200	75%	28.5
FL	Babcock	NextEra	FPL (owner)	Dec-16/NA/Mar-18	74.5	0	10	4.0	40	13%	#N/A
FL	Citrus	NextEra	FPL (owner)	Dec-16/NA/Mar-18	74.5	0	4	4.0	16	5%	#N/A
FL	Manatee	NextEra/FPL	FPL (owner)	Dec-16/NA/Dec-21	74.5	0	409	2.2	900	549%	#N/A
HI	Kapaia	Tesla	KIUC	Apr-17	13	0	13	4.0	52	100%	119.8
HI	Lawai	AES	KIUC	Oct-18	20	0	20	5.0	100	100%	89.4
HI	Kekaha	AES	KIUC	Sep-19	14	0	14	5.0	70	100%	85.5
HI	West Loch	HECO	HECO (owner)	Oct-19	20	0	20	4.0	80	100%	#N/A
HI	Waikoloa Solar	AES	Hawaiin Electric	Jul-21	30	0	30	4.0	120	100%	59.8
HI	Kuihelani Solar	AES	Hawaiin Electric	Jul-21	60	0	60	4.0	240	100%	58.5
HI	West Oahu	AES	Hawaiin Electric	Sep-21	12.5	0	12.5	4.0	50	100%	79.5
HI	Hoohana Solar 1	174 Power Global	Hawaiin Electric	Dec-21	52	0	52	4.0	208	100%	76.3
HI	Mililani I Solar	Clearway	Hawaiin Electric	Dec-21	39	0	39	4.0	156	100%	68.0
HI	Waiawa Solar	Clearway	Hawaiin Electric	Dec-21	36	0	36	4.0	144	100%	74.0
HI	Hale Kuawehi	Innergex	Hawaiin Electric	Jun-22	30	0	30	4.0	120	100%	65.8
HI	Paeahu	Innergex	Hawaiin Electric	Jun-22	15	0	15	4.0	60	100%	87.9
MN	Ramsey/Athens	Engie/NextEra	Connexus	Dec-18	10	0	15	2.0	30	150%	?
NV	Battle Mountain	Cypress Creek	NV Energy	Jun-21	101	0	25	4.0	100	25%	22.3
NV	Dodge Flat	NextEra	NV Energy	Dec-21	200	0	50	4.0	200	25%	23.1
NV	Fish Springs Ranch	NextEra	NV Energy	Dec-21	100	0	25	4.0	100	25%	25.9
NV	Townsite	Capital Dynamics	Munis/Co-op	Dec-21	180	0	90	4.0	360	50%	?
NV	Arrow Canyon	EDF-RE	NV Energy	Dec-22	200	0	75	5.0	375	38%	21.8
NV	Southern Bighorn	8minute Solar	NV Energy	Sep-23	300	0	135	4.0	540	45%	21.9
NV	Gemini	Quinbrook/Arevia	NV Energy	Dec-23	690	0	380	3.8	1460	55%	25.1
OK	Skeleton Creek	NextEra	WFEC	Dec-23/Dec-19/Dec-23	250	250	200	4.0	800	80%	?
OR	Wheatridge	NextEra	PGE	Dec-21/Dec-20/Dec-21	50	300	30	4.0	120	60%	?
TX	Castle Gap	Luminant	Luminant (owner)	Jun-18/NA/Dec-18	180	0	10	4.2	42	6%	#N/A

Table includes metadata on 38 PV hybrid projects in 11 states totaling 4.3 GW_{AC} of PV and 2.6 GW_{AC} of battery capacity (all with 2-5 hours of storage)

- <10 of these projects are currently online
- These 38 projects are just a small fraction of the >55 GW of PV hybrid projects that were in the interconnection queues at the end of 2018

Most projects in the table are greenfield projects, but there are 3 retrofits, with many more to come

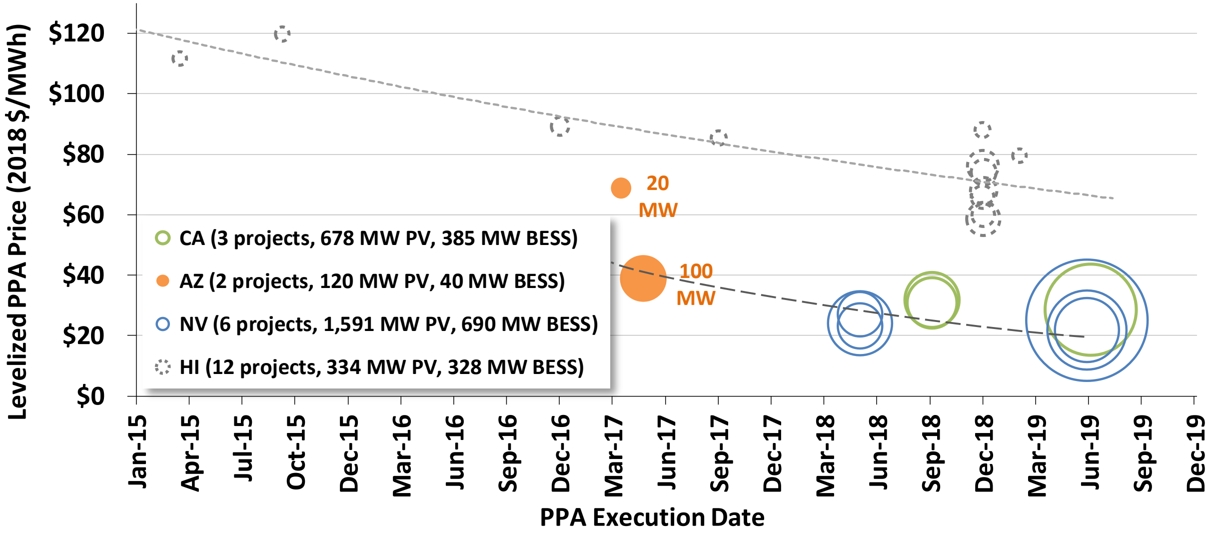
Three projects include wind power

The ratio of battery-to-PV capacity varies widely, reflecting specific circumstances of each project

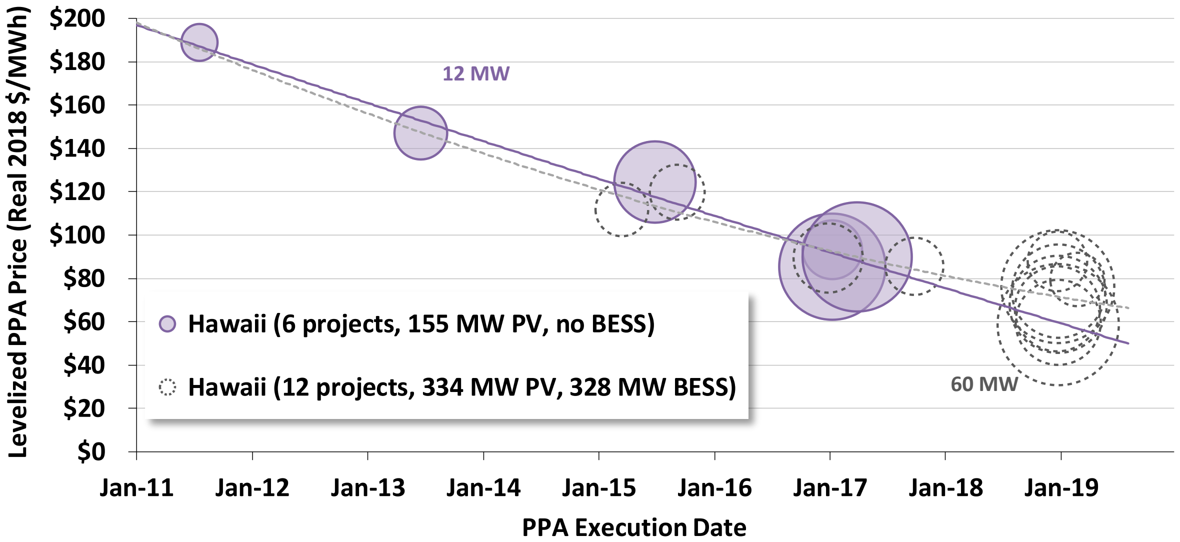
- For example, Hawaii is at 100% in all 12 cases, reflecting an isolated island grid with high solar penetration

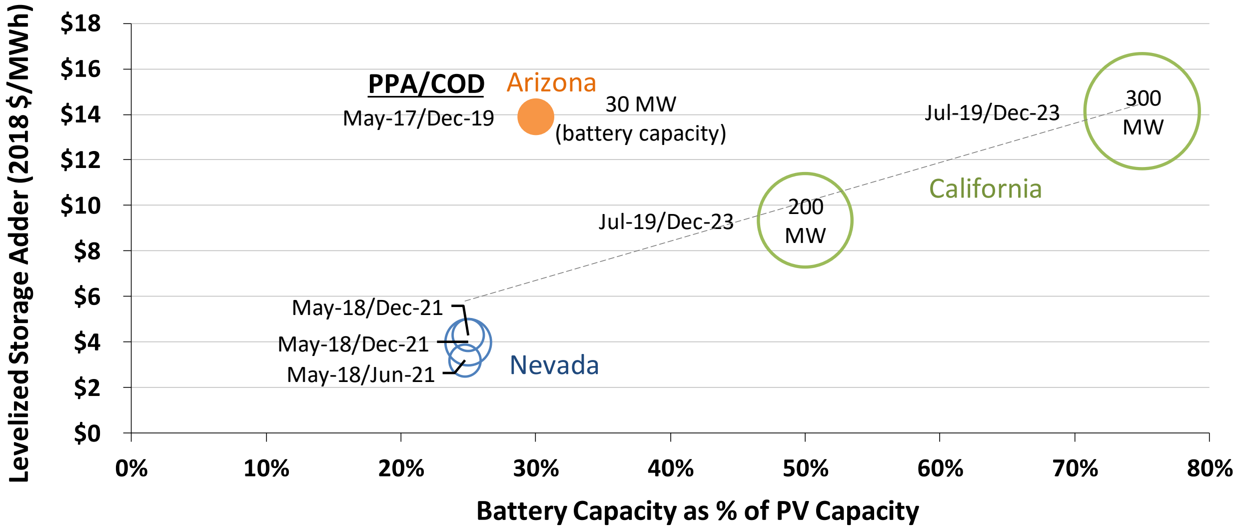
Among the sub-sample of 32 hybrid projects with PPAs, storage is compensated in several different ways (i.e., no consensus yet)

PPA price details from sample of 23 PV hybrid projects

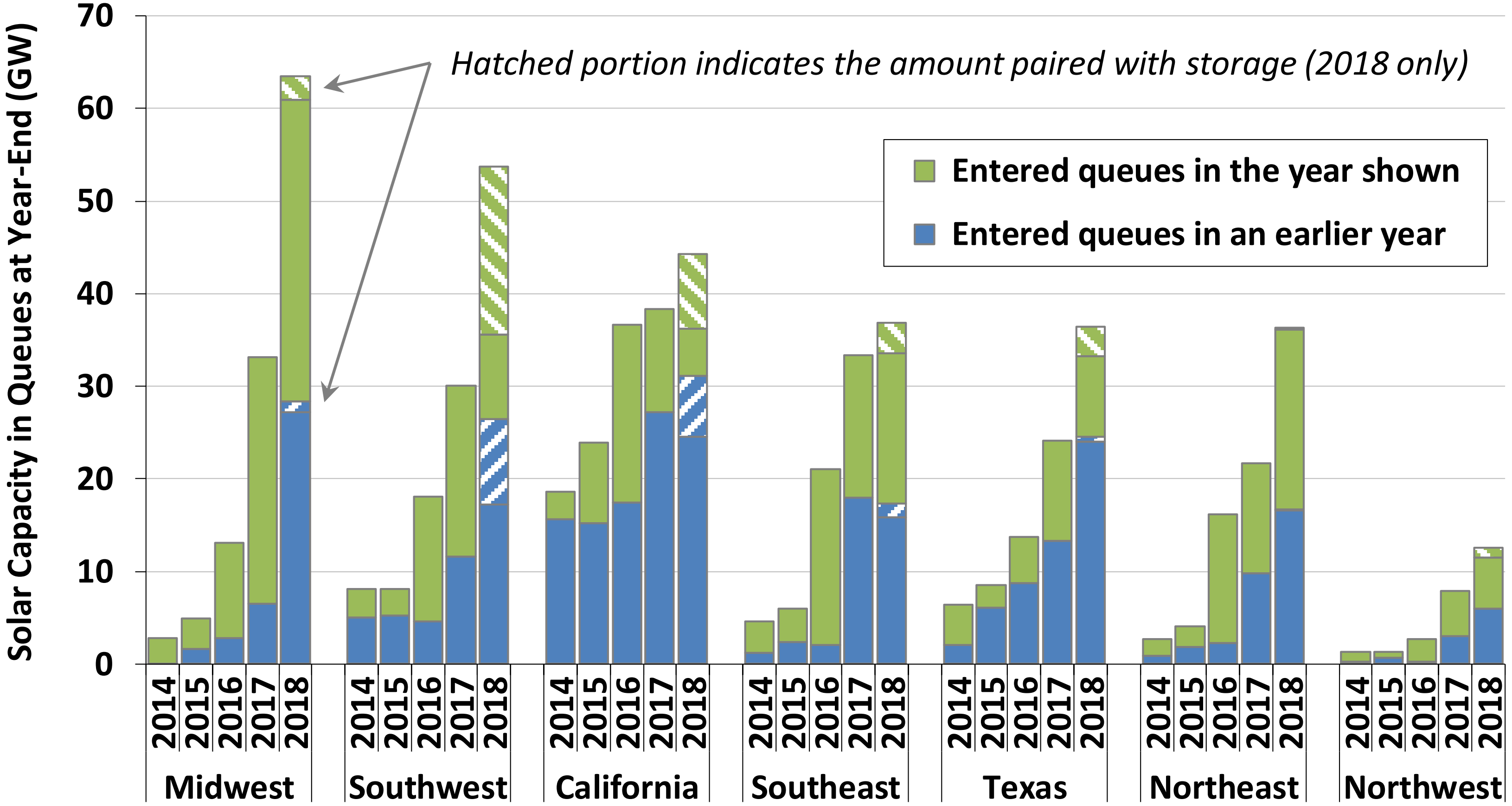


- Top left graph shows levelized PPA prices from just the 23 PV hybrid projects for which we have data
- Notable premium for Hawaii projects (top left) seems to be general rather than related to storage (bottom left)…
- …particularly given that the storage price adder (below) increases linearly with the battery-to-PV capacity ratio (which is high in Hawaii, at 100%)





Looking ahead: Significant broadening of the market



Graphs show solar capacity in 37 interconnection queues across the U.S.
Not all of these projects will ultimately be built!

Very strong solar growth in all regions, but especially in the Midwest, which ranked next-to-last in 2016, but two years later is leading the pack (having added a record 33 GW in 2018 alone)

Solar capacity in the queues is now much more evenly distributed across the country than it was just three years ago

>75% of the 55 GW of PV hybrid capacity in the queues at the end of 2018 is in the Southwest (49%) and California (26%)—two high-penetration regions that are grappling with “duck curve” issues that can be at least partly alleviated by battery storage

Questions?

Download the full report, a data file, and this slide deck at:

http://utilityscalesolar.lbl.gov

Download all of our other solar and wind work at:

http://emp.lbl.gov/reports/re

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This research was supported by funding from the

U.S. Department of Energy Solar Energy Technologies Office