Utility-Scale Solar, 2021 Edition

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

Dr. Joachim Seel[1]

Mark Bolinger[1], Cody Warner, and Dana Robson

Lawrence Berkeley National Laboratory
[1]Corresponding authors

North America Smart Energy Week
Solar Power + Energy Storage International

September 2021

BERKELEY LAB

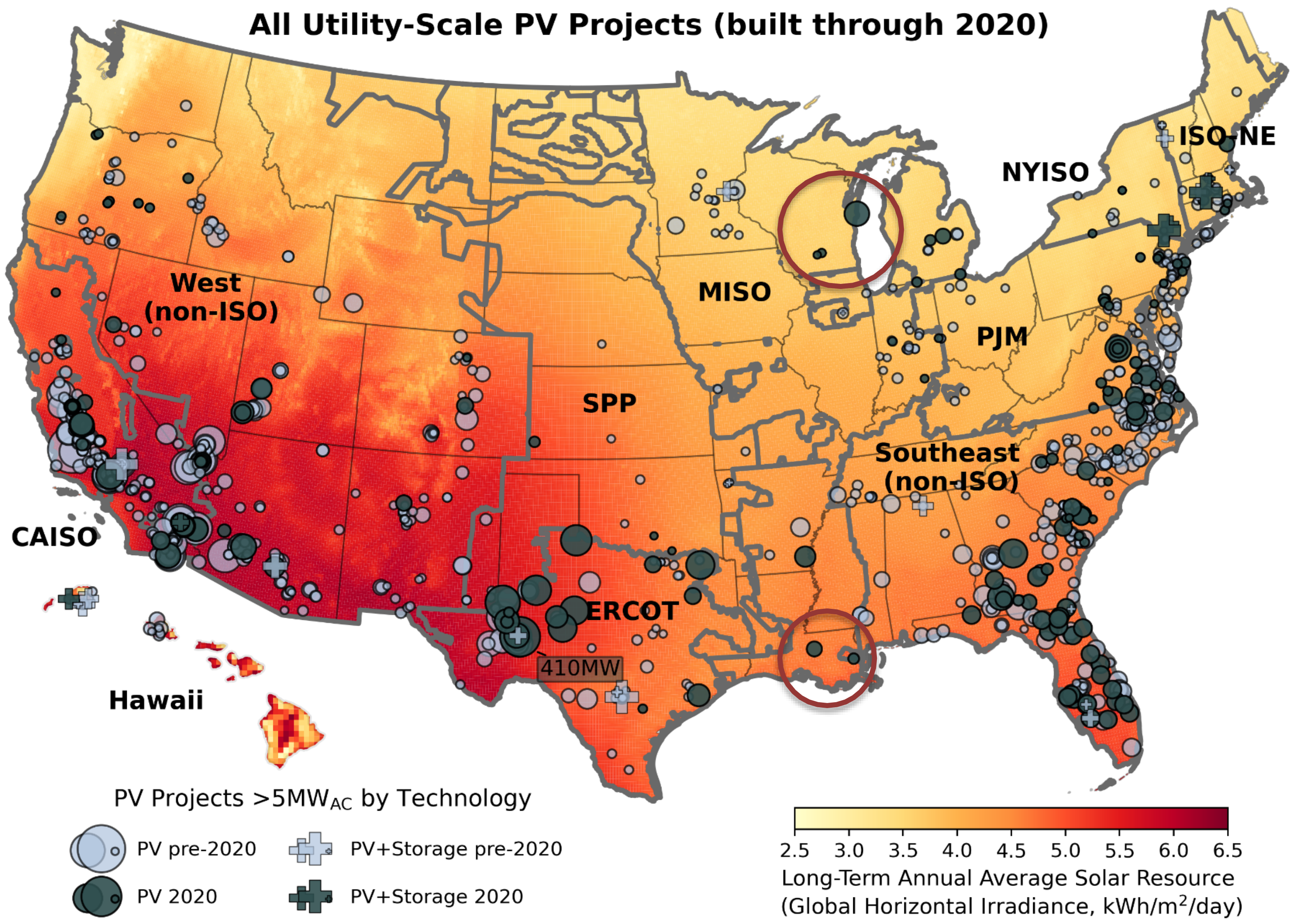
This research was supported by funding from the

U.S. Department of Energy Solar Energy Technologies Office

All underlying data is publically available at https://utilityscalesolar.lbl.gov

Photo: *Enel Green Power*

Utility-scale solar has become a growing source of electricity in all regions of the United States



Utility-scale PV is well-represented throughout the nation, with the exception of upper-Midwestern states in the "wind belt".

Texas completed some of the largest projects we have seen in the US (up to 410 MW_{AC}) and led the nation with the most solar deployment.

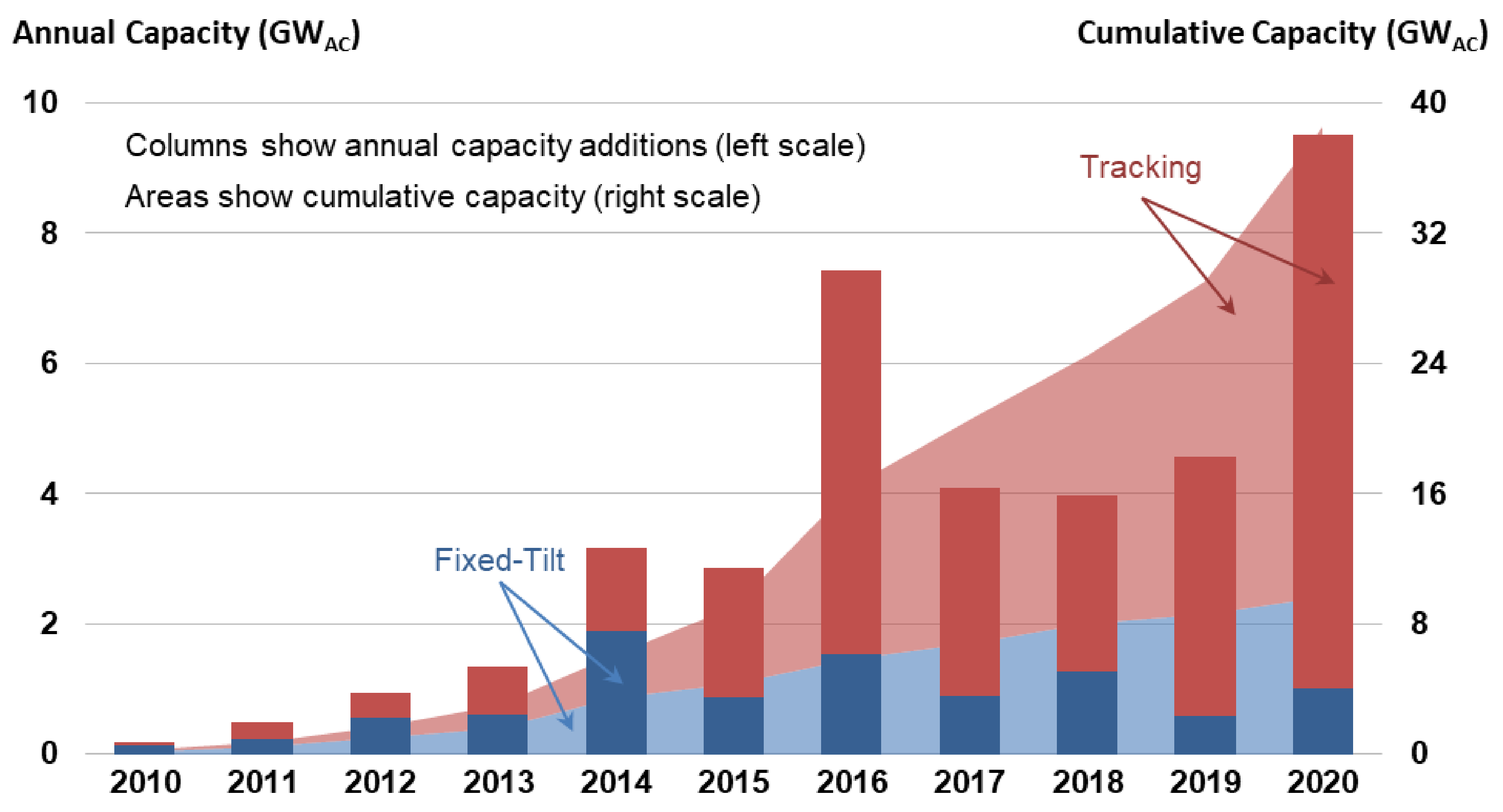
In 2020, storage (✚) was added to already existing (1) and new (5) PV projects. 4 of these were built in the northeast, while high penetration regions in HI and CA added one each.

2 new states added their first utility-scale PV projects: **Wisconsin** and **Louisiana.**

You can explore this data interactively at https://emp.lbl.gov/technology-trends

Projects with tracking technology dominated 2020 additions

PV project population: 969 projects totaling 38,745 MW_{AC}

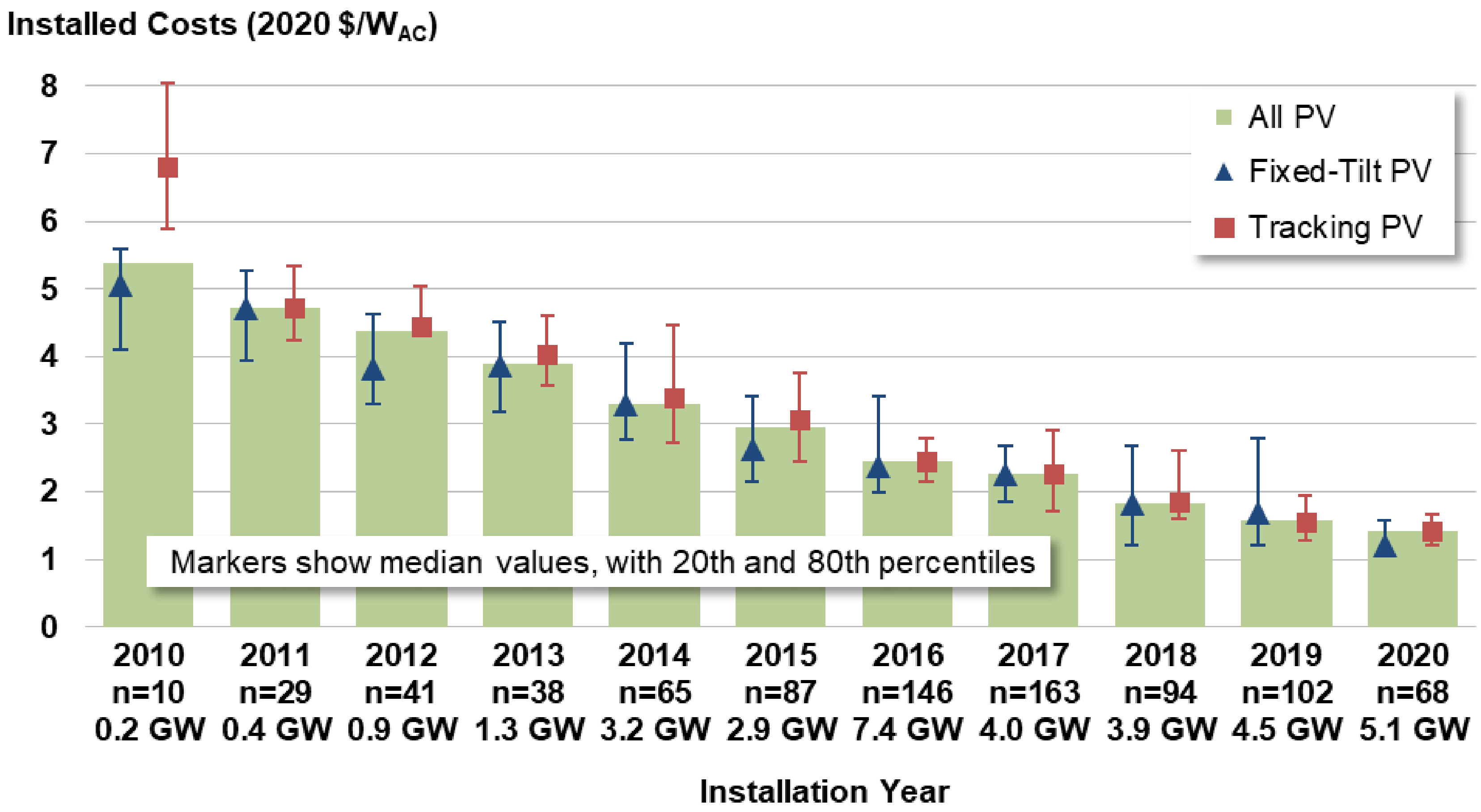


Projects using single-axis **tracking** have consistently exceeded **fixed-tilt** installations since 2015, but achieved a new level of dominance in 2020, with 89% of all new capacity using tracking.

Upfront cost premiums for trackers have fallen over the years, resulting in favorable economics in most of the United States thanks to increased generation.

Median installed costs of PV have fallen by 74% since 2010 and 12% annually to $1.42/W_{AC}$ ($1.05/W_{DC}$) in 2020

Sample: 848 projects totaling 34,020 MW_{AC}



The lowest 20th percentile of project costs fell from $1.3/W_{AC}$ ($1.0/W_{DC}$) in 2019 to $1.1/W_{AC}$ ($0.9/W_{DC}$) in 2020.

The lowest-cost project among the 68 data points in 2020 was $0.9/W_{AC}$ ($0.7/W_{DC}$).

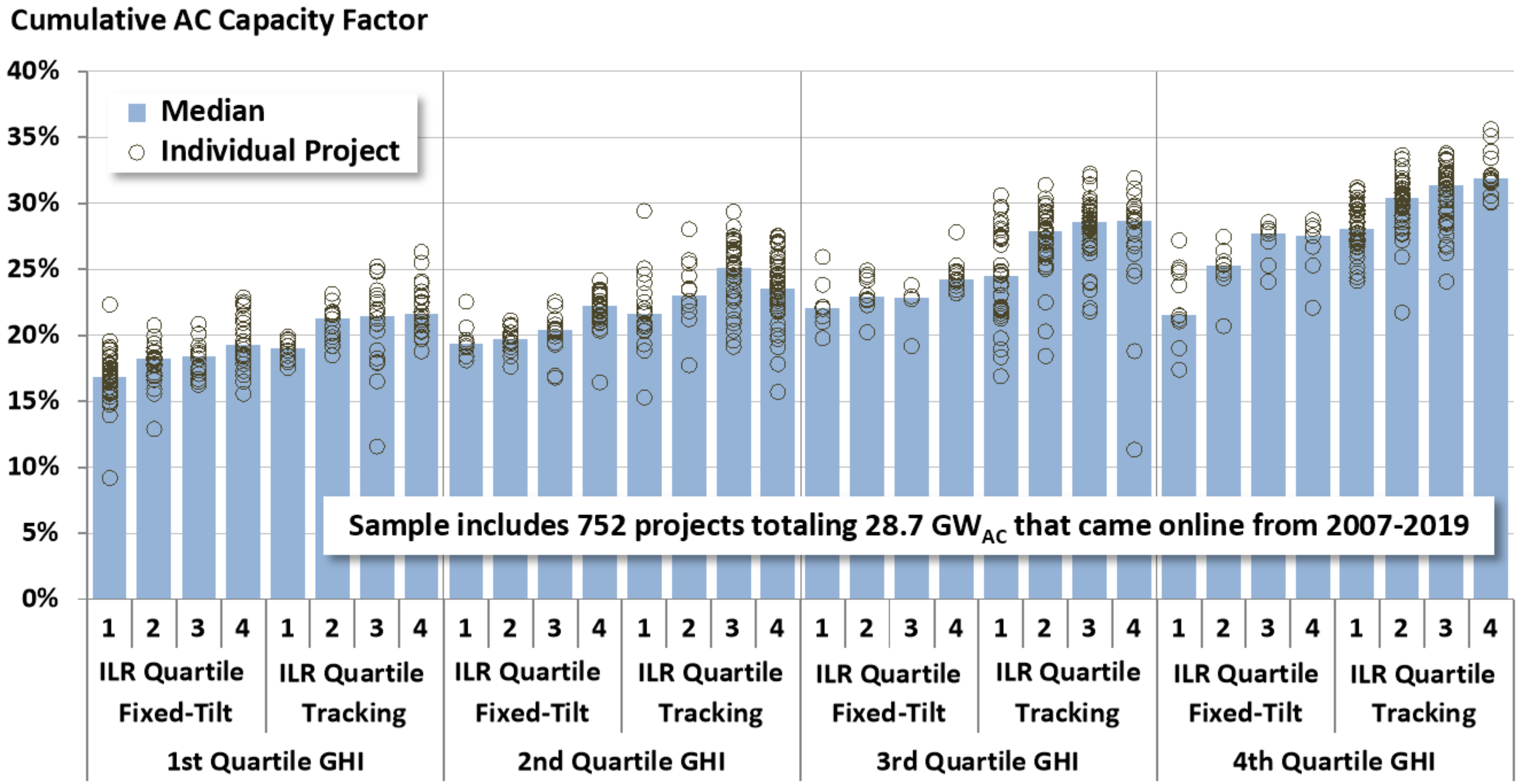
Historical sample is robust (covering 99% of installed capacity through 2019). 2020 data covers 41% of new projects or 63% of new capacity.

This sample is backward-looking and does not reflect the costs of projects built in 2021/2022.

In our 2020 sample, trackers ($1.4/W_{AC}$ or $1.1/W_{DC}$) exhibit a premium over fixed-tilt plants ($1.2/W_{AC}$ or $0.9/W_{DC}$). Trackers can sustain some amount of higher upfront costs because they deliver more kWh per kW.

24% median PV net capacity factor (cumulative, sample-wide), but with large project-level range from 9%-36%

PV performance sample: 752 projects totaling 28,652 MW_{AC}

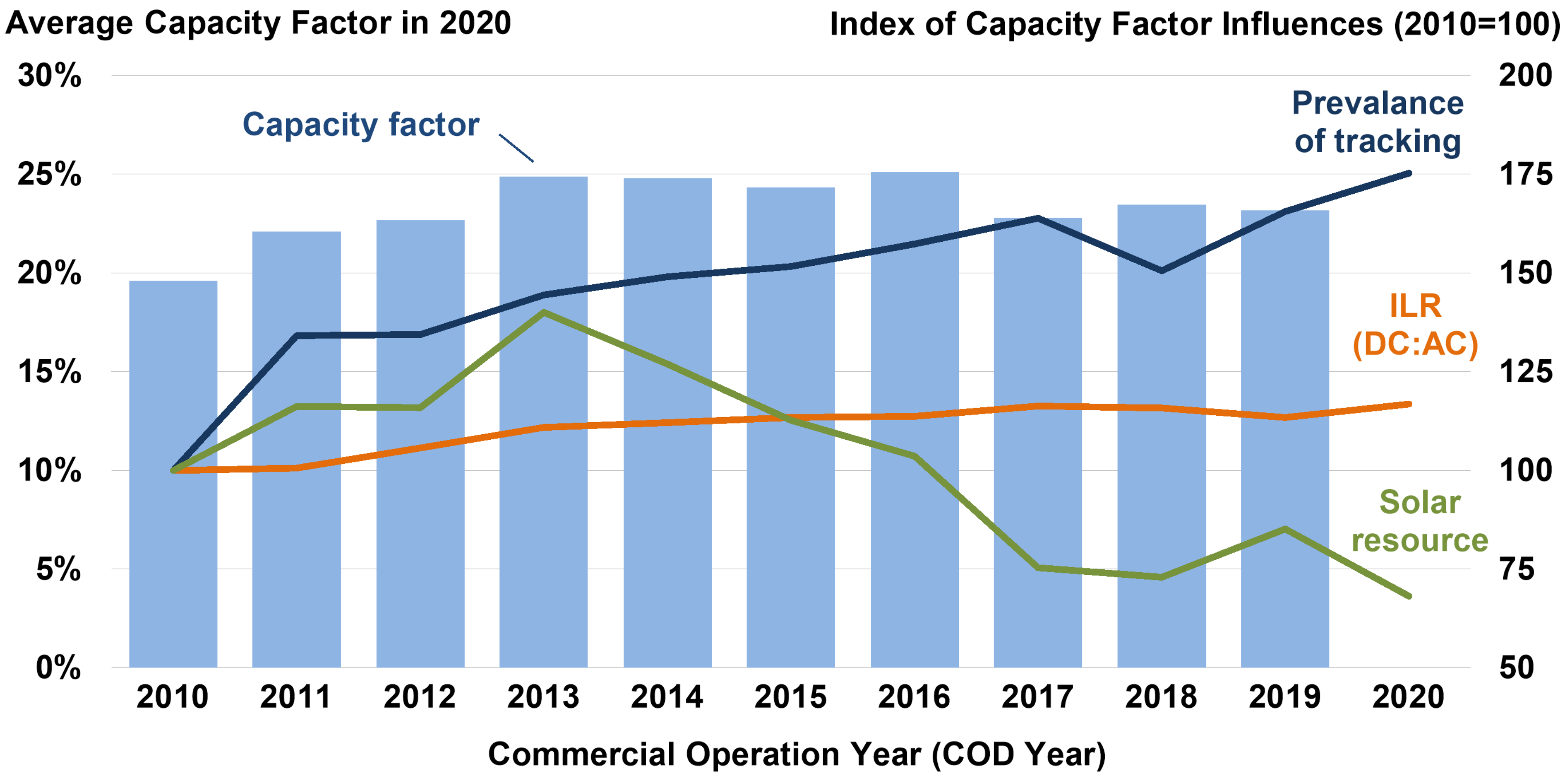


Project-level variation in PV capacity factor driven by:

- **Solar Resource (GHI)**: Strongest solar resource quartile has a ~8 percentage point higher capacity factor than lowest resource quartile
- **Tracking**: Adds ~4 percentage points to capacity factor on average, depending on solar resource quartile
- **Inverter Loading Ratio (ILR)**: Highest ILR quartiles have on average ~3 percentage point higher capacity factors than lowest ILR quartiles

You can explore this data interactively at https://emp.lbl.gov/pv-capacity-factors

Since 2013, competing drivers have caused average capacity factors by project vintage to stagnate



The columns represent the capacity factor (left axis), the lines show changes in major drivers (right axis)

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 59% of projects)
- average site-level GHI (from 4.97 to 5.37 kWh/m^2/day)

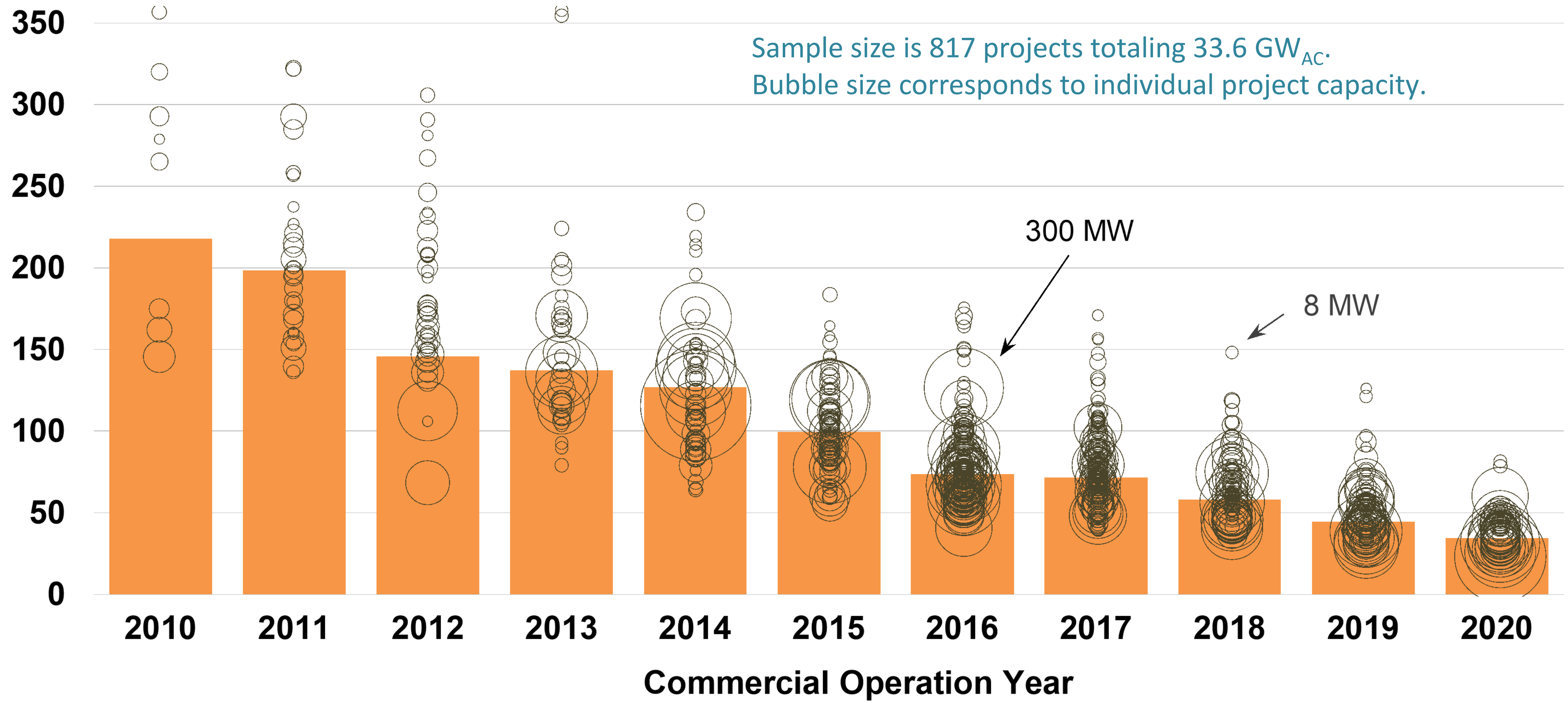
Since 2013, however, ILRs have moved only slightly higher (to 1.31 in 2019), while tracking (80% in 2019) and GHI (4.82 kWh/m2/day) have moved in opposite directions, resulting in capacity factor stagnation (on average)

Recent flat-to-declining trend is not necessarily negative, but rather a sign of a market that is expanding geographically into less-sunny regions

You can explore this data interactively at https://emp.lbl.gov/pv-capacity-factors

LCOE has fallen by 85% since 2010, to $34/MWh (without the ITC)

Generation-Weighted Average and Project-Level LCOE (2020 $/MWh)



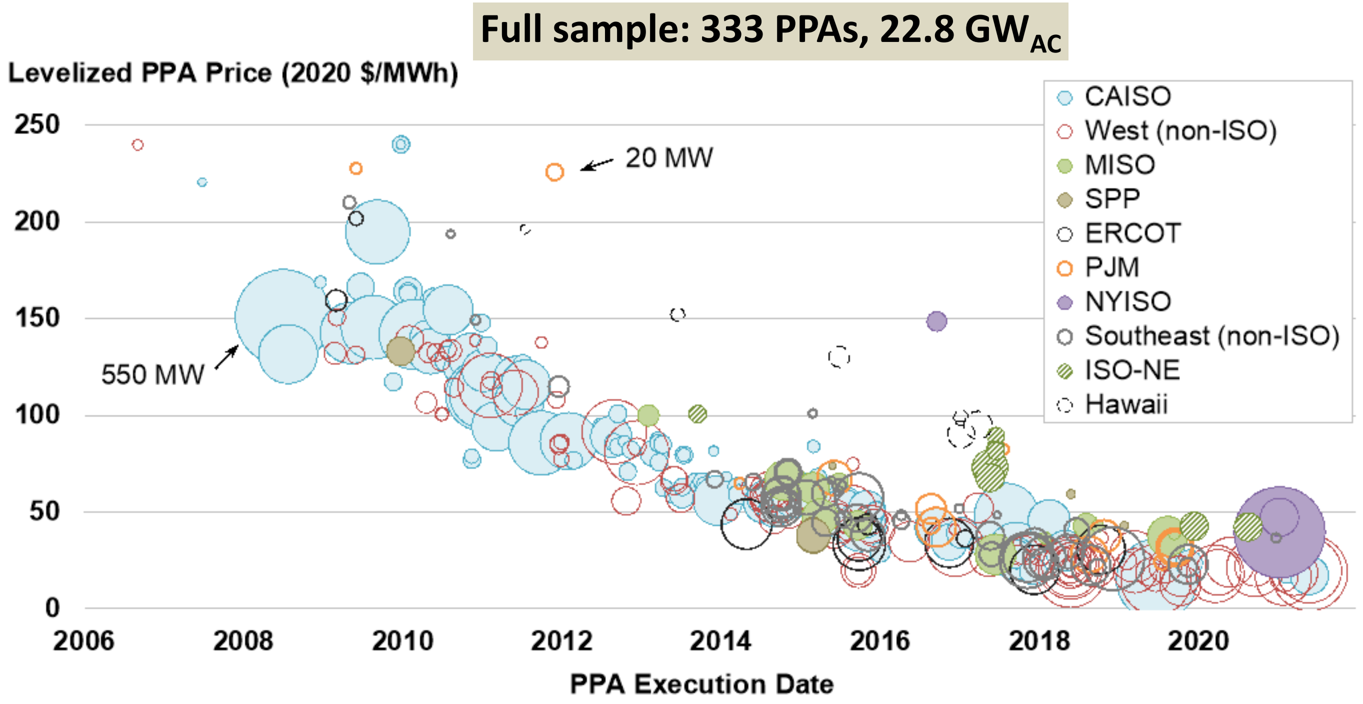
Driven by lower capital costs costs and, at least through 2013, higher capacity factors (as well as lower operating expenses, longer design life, and improved financing terms), utility-scale PV's average LCOE has fallen by about 85% since 2010, to $34/MWh in 2020 (not including the ITC).

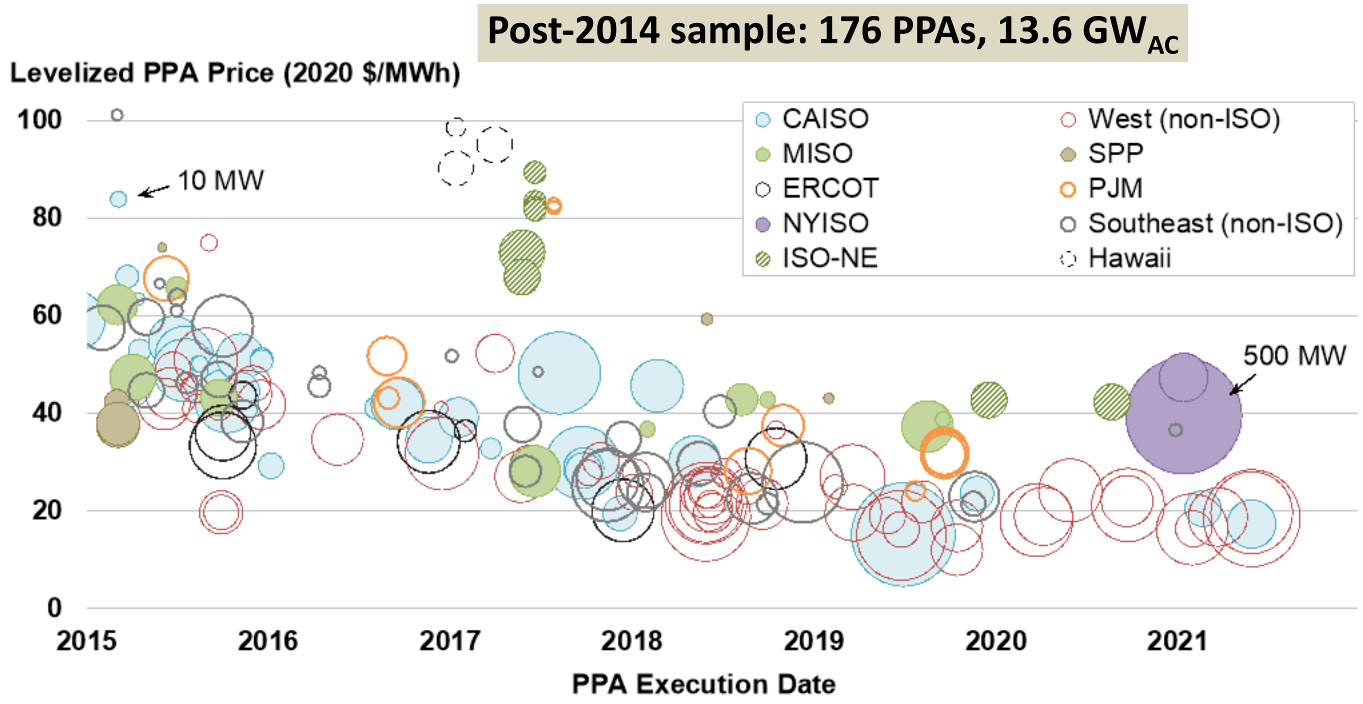
The standard deviation of project-level LCOEs has declined sharply among recent vintages (though the coefficient of variation has been more stable).

BERKELEY LAB

See interactive visualization at https://emp.lbl.gov/capex-lcoe-and-ppa-prices-region

Levelized PPA prices have followed LCOE lower in all regions



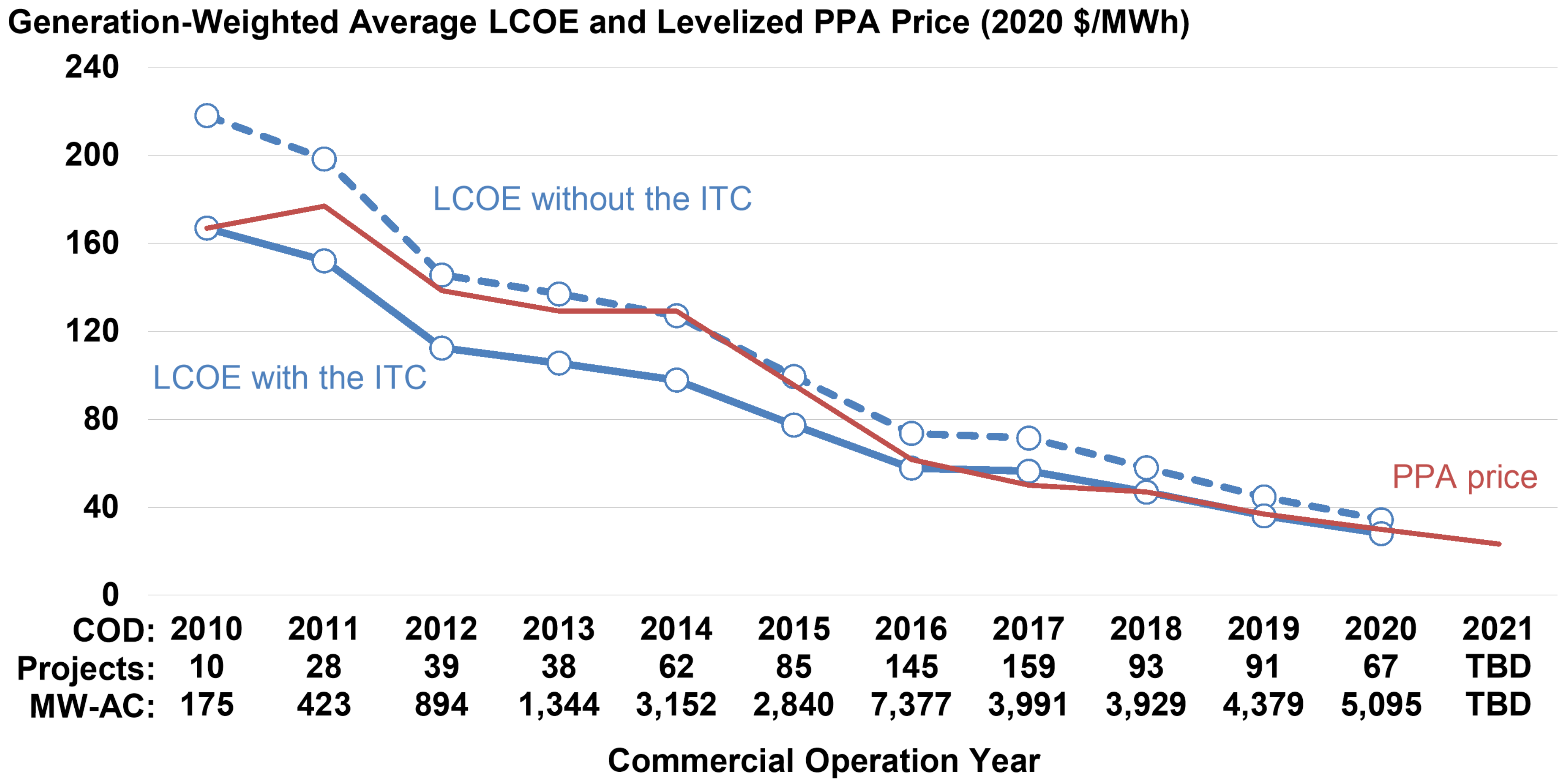


- Power Purchase Agreement (PPA) prices are levelized over the full term of each contract, after accounting for any escalation rates and/or time-of-delivery factors, and are shown in real 2020 dollars
- Aided by the 30% ITC, most recent PPAs in our sample are priced around $20/MWh for projects in CAISO and the non-ISO West, and $30-$40/MWh for projects elsewhere in the continental United States
- Hawaiian PPAs are often higher-priced (and most include battery storage, and so are not shown here—see later section)
- >95% of the sample is currently operational

You can explore this data interactively at https://emp.lbl.gov/pv-ppa-prices

Levelized PPA prices track the LCOE of utility-scale PV

Sample: 817 projects totaling 33,599 MW_{AC}

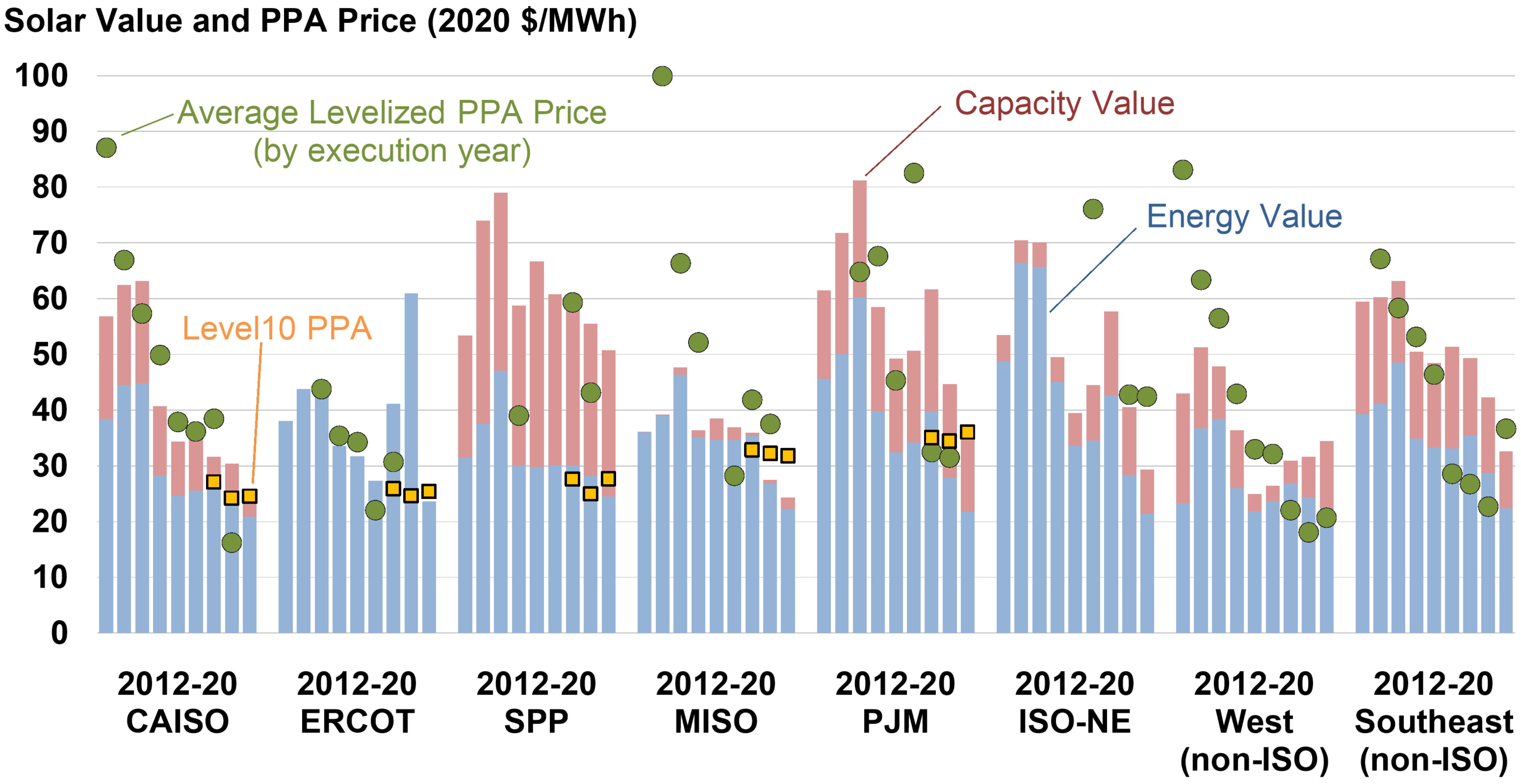


Prior LCOE graphs exclude the ITC, but here we graph LCOE both with and without the ITC, plotted against PPA prices by COD year (rather than by PPA execution date).

Levelized PPA prices fall within the range of the two LCOE curves over time, and since 2016 have closely tracked LCOE with the ITC, suggesting full pass-through of the credit and a competitive PPA market.

Also notable is the declining value of the ITC in $/MWh terms: while the credit has remained constant over time in percentage terms (at 30%), it has shrunk in $/MWh terms along with the CapEx to which it is applied.

In a subset of regions for which we have sufficient data, falling PPA prices have largely kept pace with declining solar value



The green dots show the average levelized solar PPA price within each region among new contracts signed in each year as reported by Berkeley Lab, the yellow squares represent PPA price estimates by LevelTen.

While solar's market value within several of these regions has declined over time, falling PPA prices have largely kept pace, more or less maintaining solar's competitiveness.

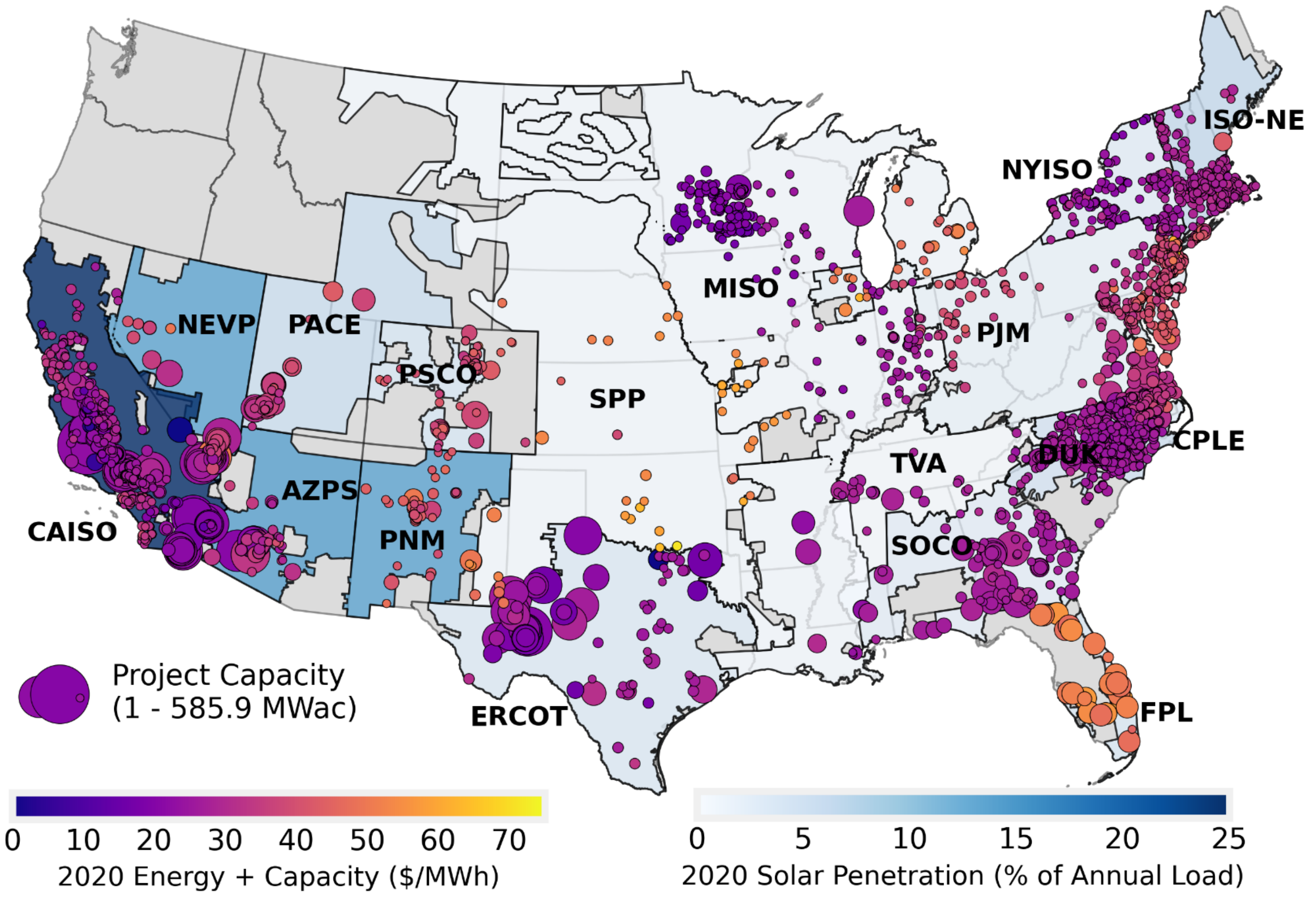
For more information please refer to Berkeley Lab's Solar-to-Grid Publication:
https://emp.lbl.gov/renewable-grid-insights

Solar's energy and capacity value varied by location

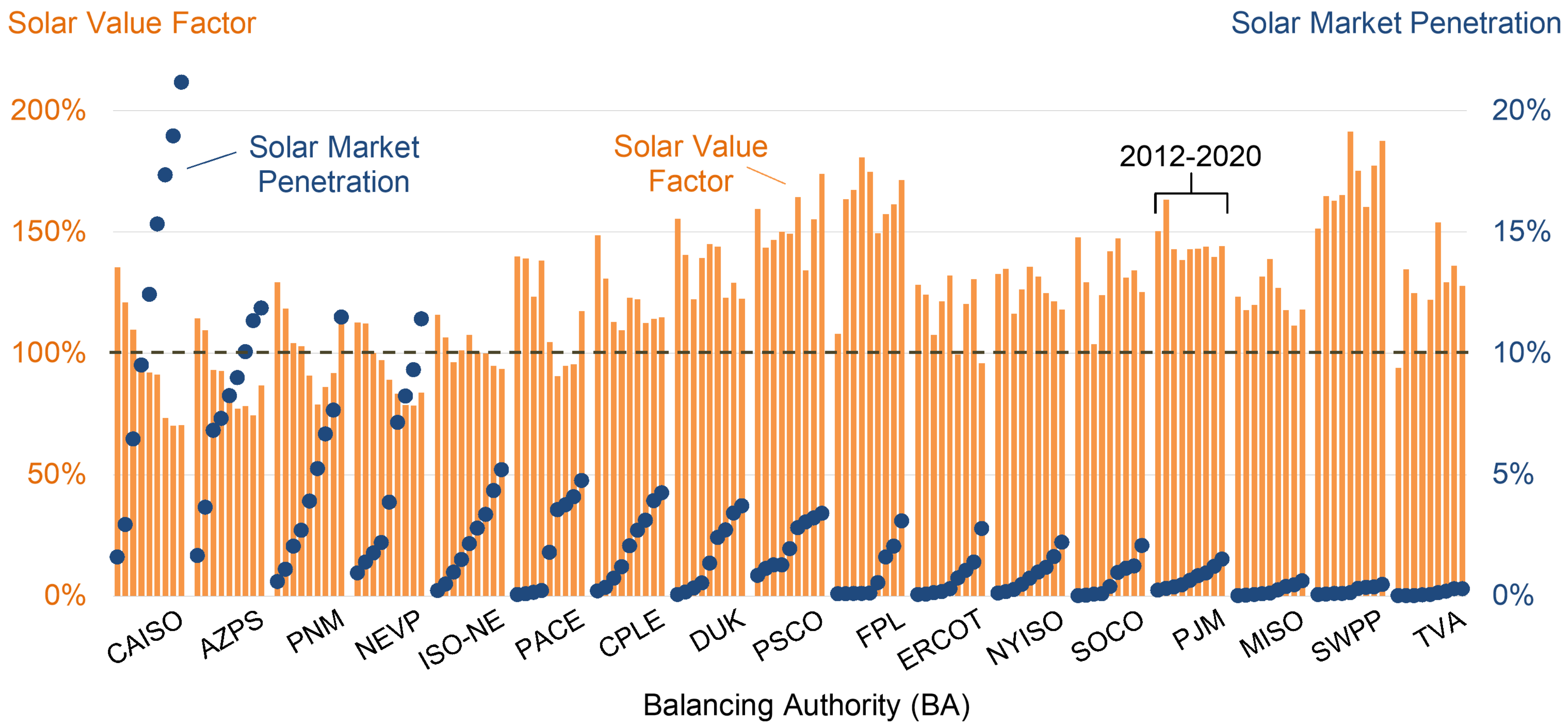
This map shows all larger-scale solar projects in our value sample (but it does not distributed solar).

Solar's value varies between regions (low in CAISO and MISO and high in SPP and FPL) and within regions (for example, western ERCOT has lower solar values than eastern ERCOT).

Some markets showed very little variation in solar value in 2020 (value across ISO-NE differed by only 7%) while others had large discrepancies (values varied by up to 50% in ERCOT and NYISO).



Solar provides below-average value in regions with high solar penetration rates



The columns represent the solar value factor (left axis), the dots show growth in solar market penetration (right axis)

The "Value Factor" is defined as the ratio of solar's total market value (both energy and capacity) to the market value of a "flat block" (i.e., a 24x7 block) of power.

It indicates whether the total revenue captured by solar is higher (>100%) or lower (<100%) than the average wholesale price across all hours.

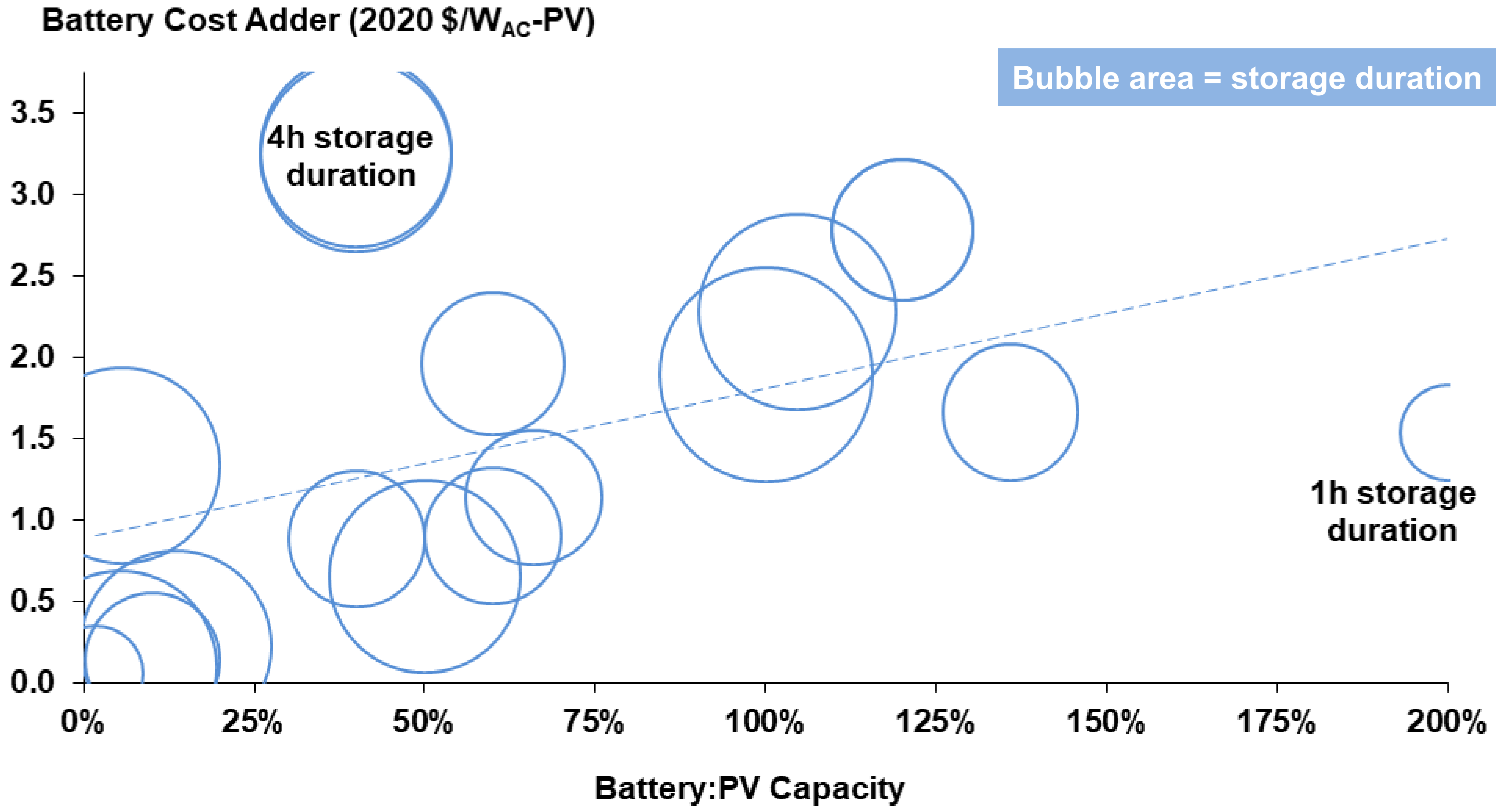
It controls for fluctuations in energy and capacity prices across years (and across ISOs), and focuses instead on the impact of solar's generation profile (and penetration) on value.

Regions with the highest solar penetration rates (CAISO, AZPS, PNM, NEVP, and ISO-NE) all show Value Factors less than 100% (except PNM).

For more information please refer to Berkeley Lab's Solar-to-Grid Publication: *https://emp.lbl.gov/renewable-grid-insights*

For PV+battery hybrid plants, the battery cost adder scales with increased storage capacity and duration

Sample: 18 projects totaling 180 MW_{AC} of PV, 116 MW_{AC} of battery capacity, and 392 MWh of battery energy, with CODs from 2017-2019

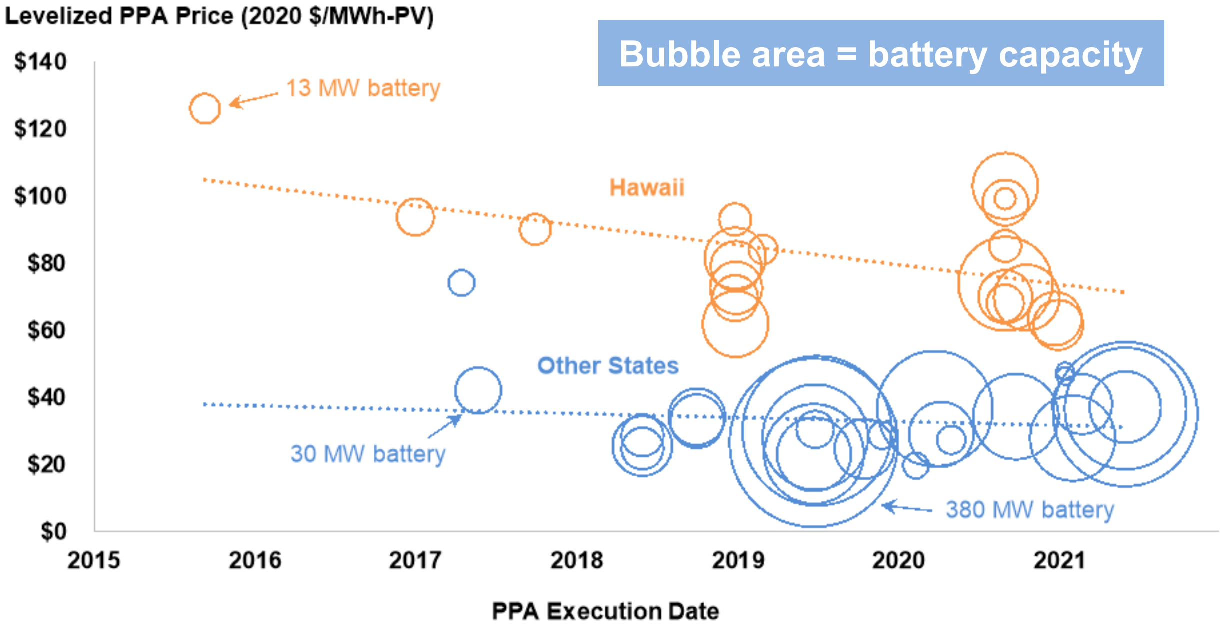


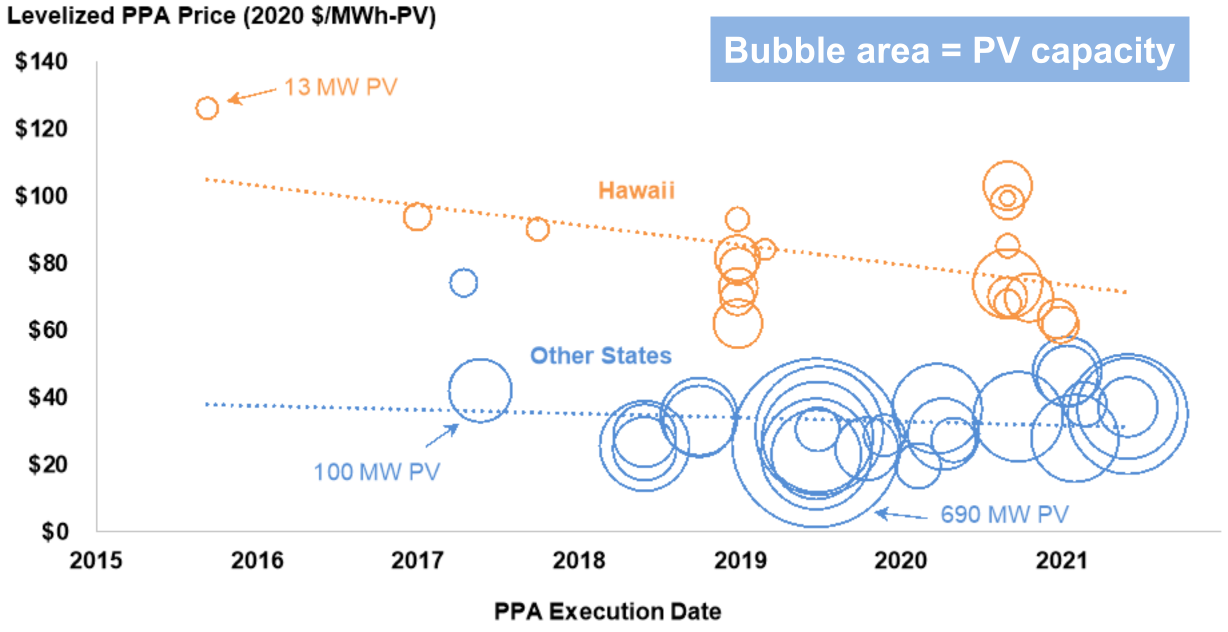
Empirical cost sample for utility-scale PV+battery hybrid projects is still very thin, and does not include 2020.

The median reported battery costs among 11 projects with a 2019 COD was $1,100/kWh, representing a median cost adder of $1.54/$W_{AC}$-PV, or 48% of overall hybrid project installed costs.

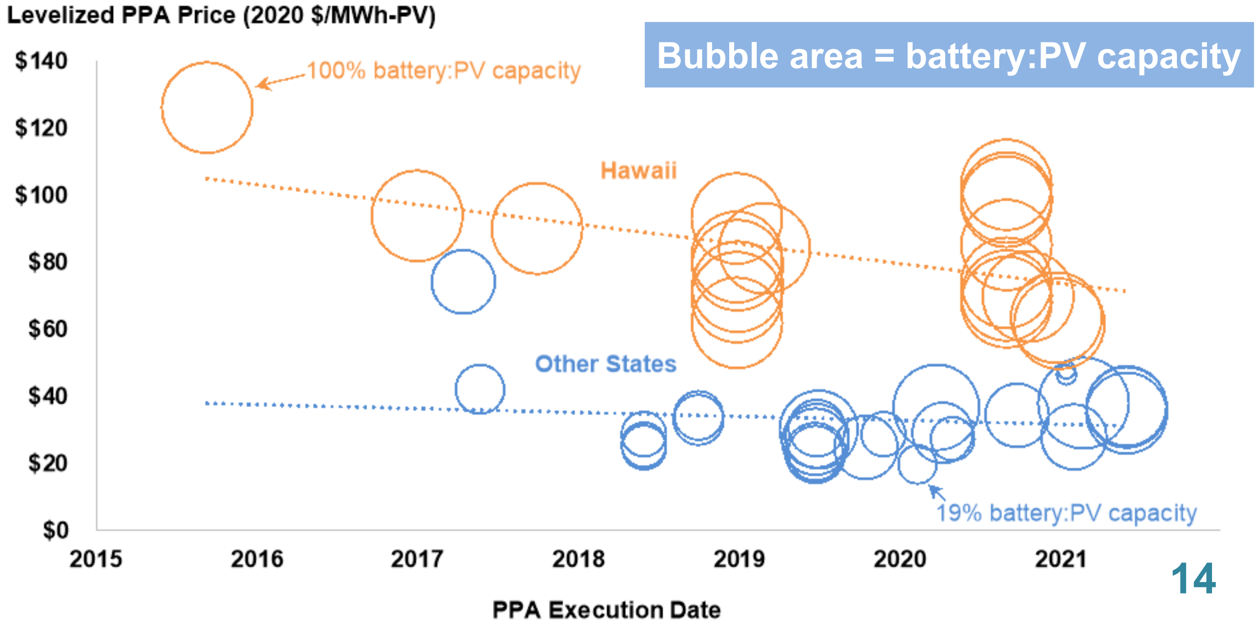
Within this 2019 COD sample, the median battery capacity is 60% of the PV capacity and can release energy at rated power for a little more than 2 hours.

PPA prices for PV+battery hybrids have declined over time; Hawaii priced at a premium

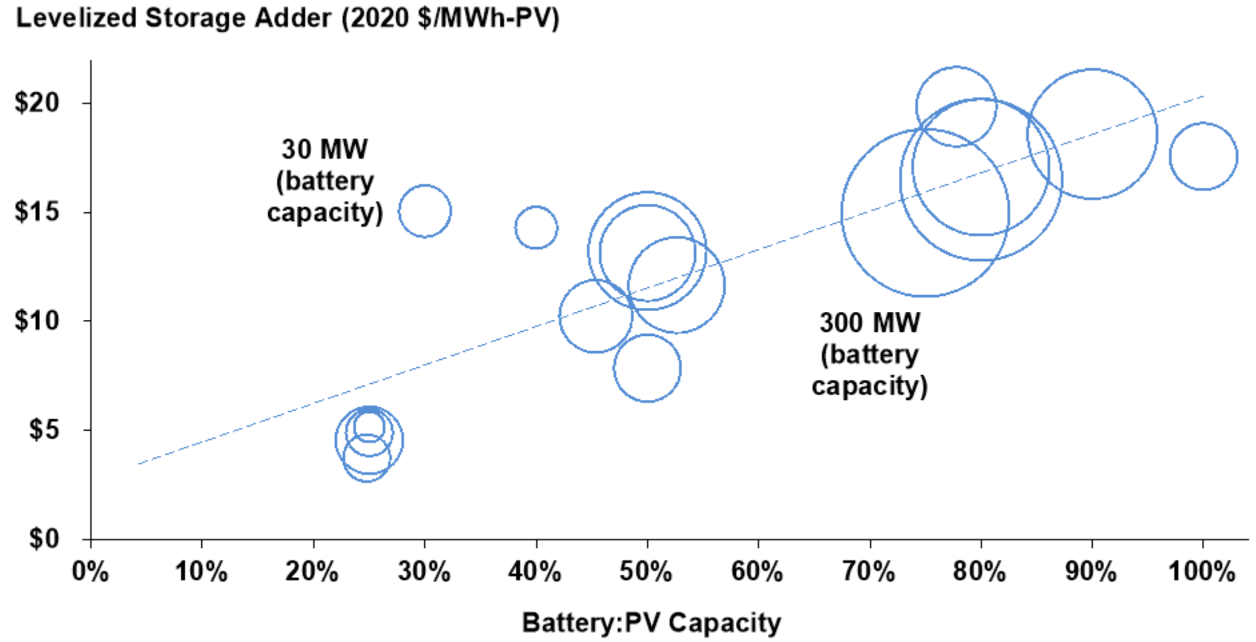


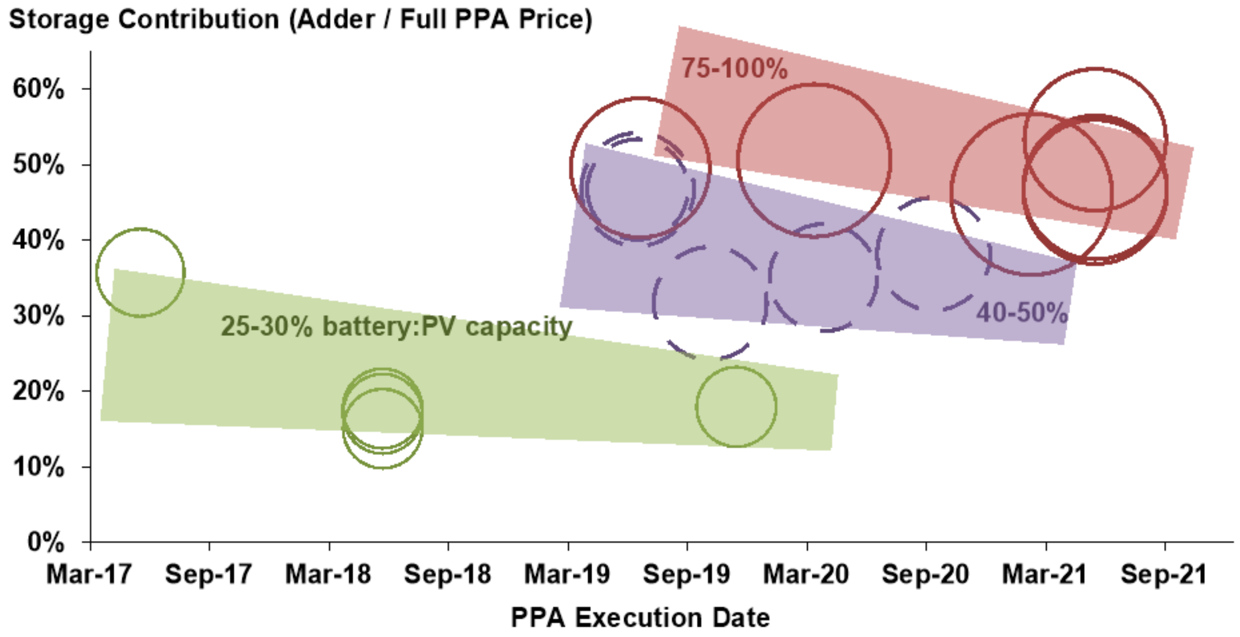


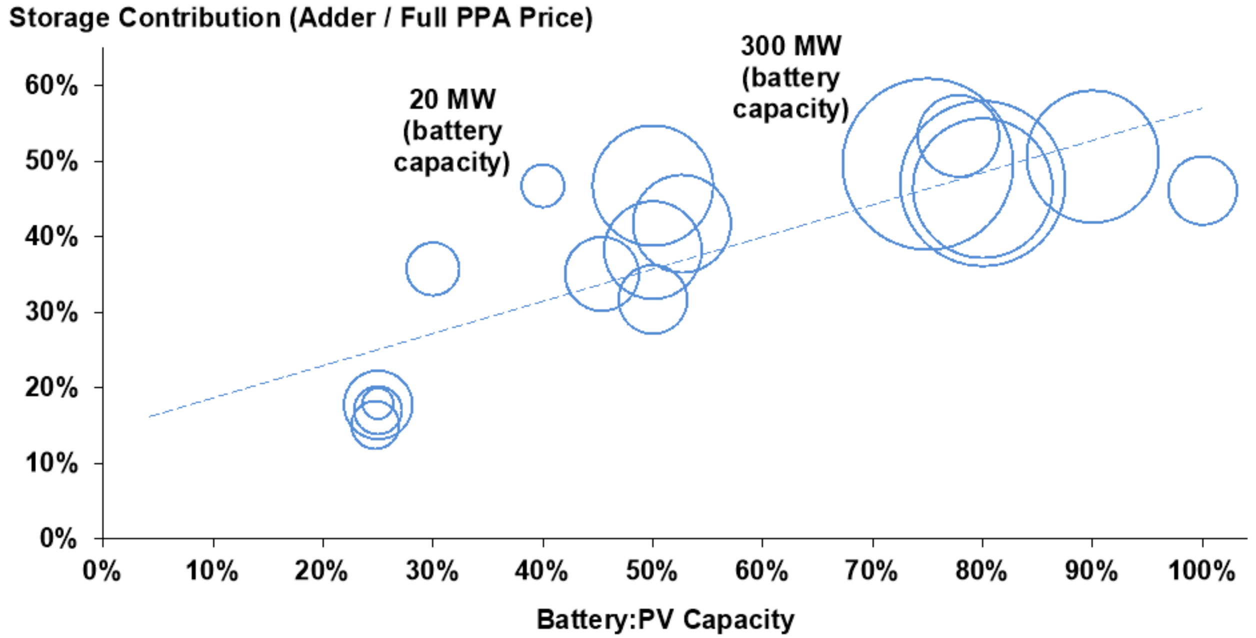
- All three graphs show the same data from a sample of 47 PPAs (totaling 5.4 GW_{AC} of PV and 3.1 GW_{AC} of battery); the only difference is what the bubble size represents
- Downward trend over time, particularly in HI, but refinement is complicated by multi-dimensionality of these plants; "Other States" (in blue) are more heterogeneous than HI in terms of solar resource
- Battery:PV capacity ratio always at 100% in HI; lower on the mainland
- Battery duration ranges from 2-8 hours; 44 of the 47 plants shown have durations ≥4 hours (other three are 3.8, 2, and 2 hours)



PPAs that price the PV and storage separately enable us to calculate a "levelized storage adder"—which depends on the battery:PV capacity ratio

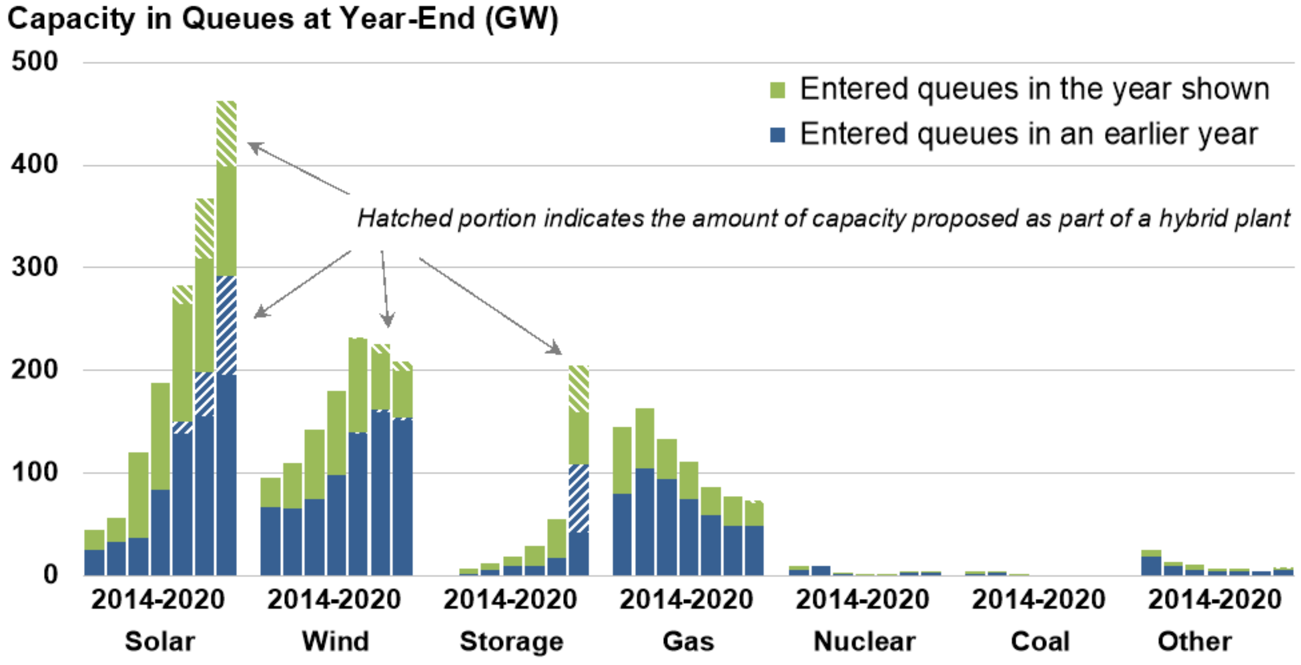






- The "levelized storage adder"—*expressed in the top-left graph in $/MWh-PV, not $/MWh-stored*—increases linearly with the battery:PV capacity ratio: ~$5/MWh-PV at 25% battery:PV capacity, ~$10/MWh at 50%, ~$20/MWh at 100%
- Bottom-left graph presents the storage adder as a percentage of the full PPA price (i.e., storage's contribution to the overall price)
- Top-right graph shows storage's contribution holding fairly steady, and a trend toward larger battery:PV capacity, over time
- All batteries depicted on this slide have a 4-hour storage duration

Looking ahead: Strong growth in the utility-scale solar pipeline

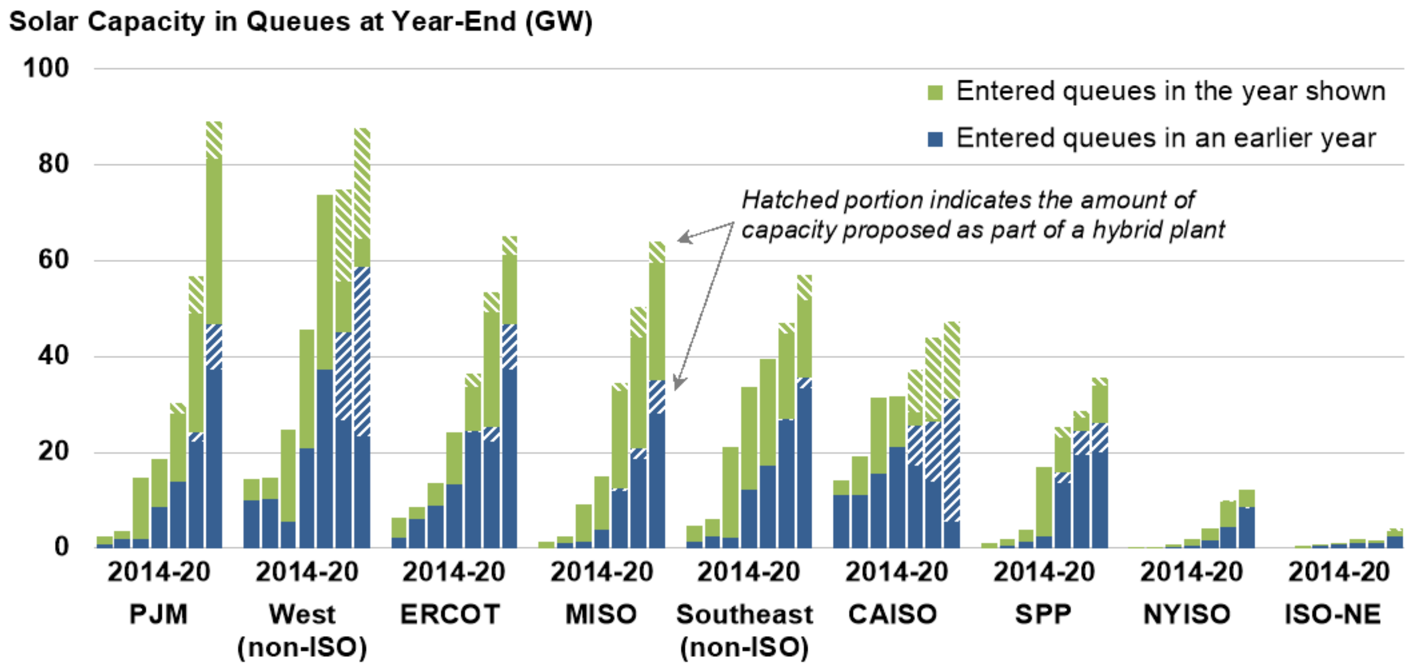


460 GW of solar was in the queues at the end of 2020—170 GW of this total entered the queues in 2020 (the remainder entered in earlier years, and remain active)

Nearly 160 GW of the 460 GW of solar in the queues (i.e., 34%) includes a battery in a PV hybrid configuration

The growth of solar within these queues is widely distributed across almost all regions of the country, with PJM and the non-ISO West leading the way with nearly 90 GW_{AC} each, followed by ERCOT, MISO, and the non-ISO Southeast, each with ~60 GW_{AC}

Nearly 90% of the solar capacity in CAISO's queue at the end of 2020 was paired with a battery; in the non-ISO West, that number is also relatively high, at 67%



Data Summary

- Utility-scale PV continued to lead solar deployment in 2020, with Texas adding the most new capacity. 81% of new projects and 89% of new capacity feature single-axis tracking.
- The median installed cost of projects that came online in 2020 fell to $1.4/W_{AC}$ ($1.1/W_{DC}$), down 10% from 2019 and 75% from 2010.
- Average capacity factors range from 19% in the least-sunny regions to 30% where it is sunniest. Single-axis tracking adds roughly five percentage points to capacity factor in the regions with the strongest solar resource. Fleet-wide performance has declined at ~1.2%/year.
- Not including the ITC, the median LCOE from utility-scale PV has declined by 85% since 2010, to $34/MWh in 2020. Levelized PPA prices have kept pace, and—with the benefit of the ITC—currently range from $20/MWh in CAISO and the non-ISO West to $30-$40/MWh elsewhere.
- In higher-penetration markets like CAISO, the market value of solar has been declining, but falling PPA prices have largely kept pace, preserving solar's net value.
- There has been much interest in hybridization (pairing PV with batteries). Our public data file includes metadata on >150 PV+battery projects that are operating or planned in 23 states. Some of these PV+battery hybrid projects have inked PPAs in the mid-$20/MWh range.
- Across all 7 ISOs and 35 additional utilities, there were 460 GW of solar in interconnection queues at the end of 2020. More than a third of this proposed solar capacity is paired with battery storage, with the highest concentration of these PV+battery hybrid plants in CAISO and non-ISO West.

For more information

Explore this briefing deck, an extensive workbook with all underlying data data, and interactive visualizations: http://utilityscalesolar.lbl.gov

Download all of our other solar and wind work at: http://emp.lbl.gov/reports/re

Join our mailing list to receive notice of future publications: https://emp.lbl.gov/mailing-list

Follow us on Twitter @BerkeleyLabEMP

Contact the corresponding authors:

Mark Bolinger (MABolinger@lbl.gov)

Joachim Seel (JSeel@lbl.gov)

Berkeley Lab's contributions to this work were funded by the Solar Energy Technologies Office, Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231. The authors are solely responsible for any omissions or errors contained herein.

Photo: *Enel Green Power*