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Wind Energy Technology Data Update: 2020 Edition

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Photo source: National Renewable Energy Laboratory

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Wind Energy Technology Data Update: 2020 Edition

Purpose and Scope:

- Summarize publicly available data on key trends in U.S. wind power sector
- Focus on land-based wind turbines over 100 kW in size
  - Separate DOE-funded data collection efforts on distributed and offshore wind
- Focus on historical data, with some emphasis on the previous year

Data and Methods:

- See summary at end of PowerPoint deck

Funding:

- U.S. Department of Energy's Wind Energy Technologies Office

Products and Availability:

- This briefing deck is complemented with data file and visualizations
- All products available at: windreport.lbl.gov

Presentation Contents

What's New this Year in the Online Data Set?

Consistent use of new regional boundaries in presentation

Additional data for online and planned hybrid projects

Inclusion of Level10 Energy wind power sales price data

Further presentation of trends in levelized energy costs

Refinements and additions to market value assessment

Reorganization and refinement of content and figures

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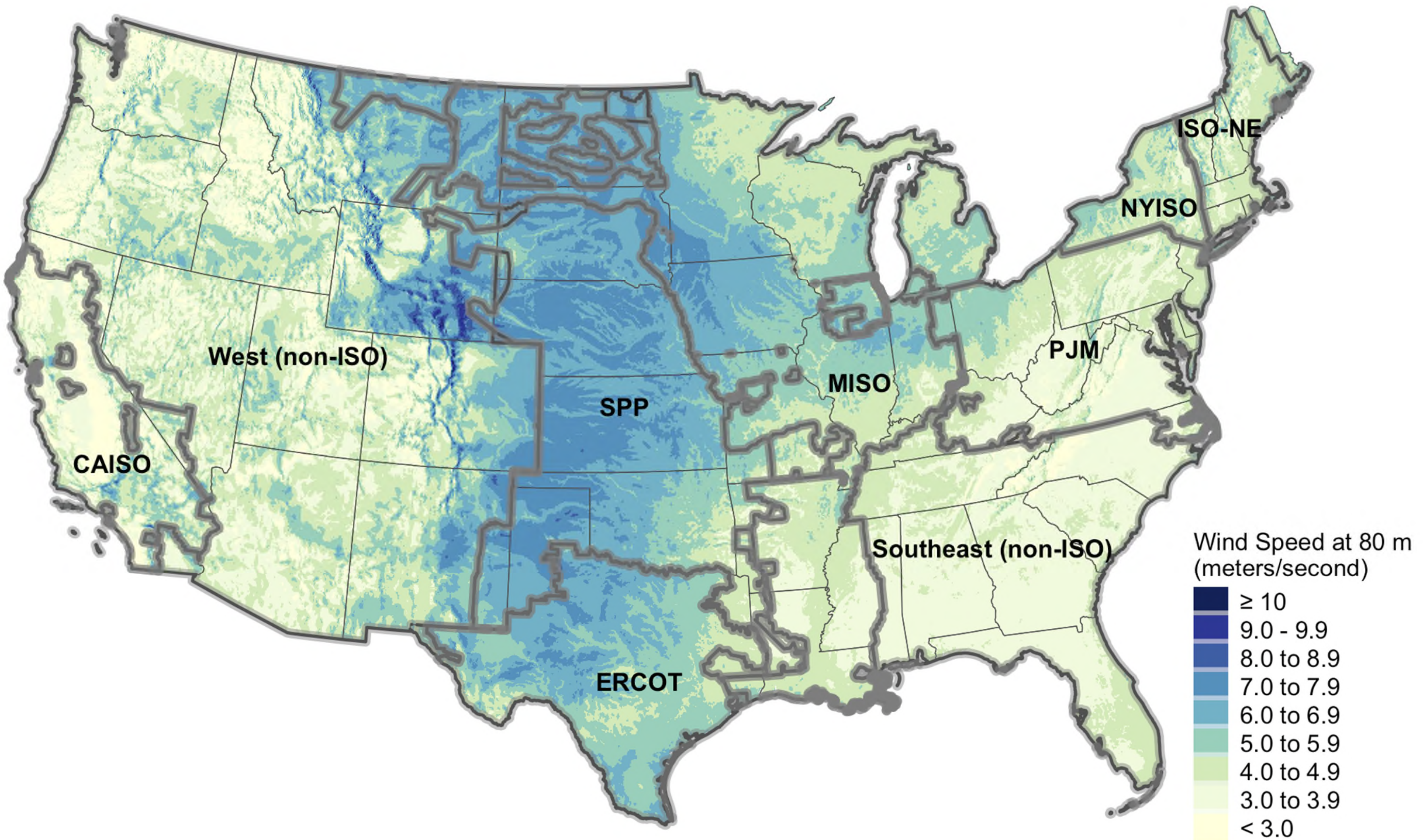
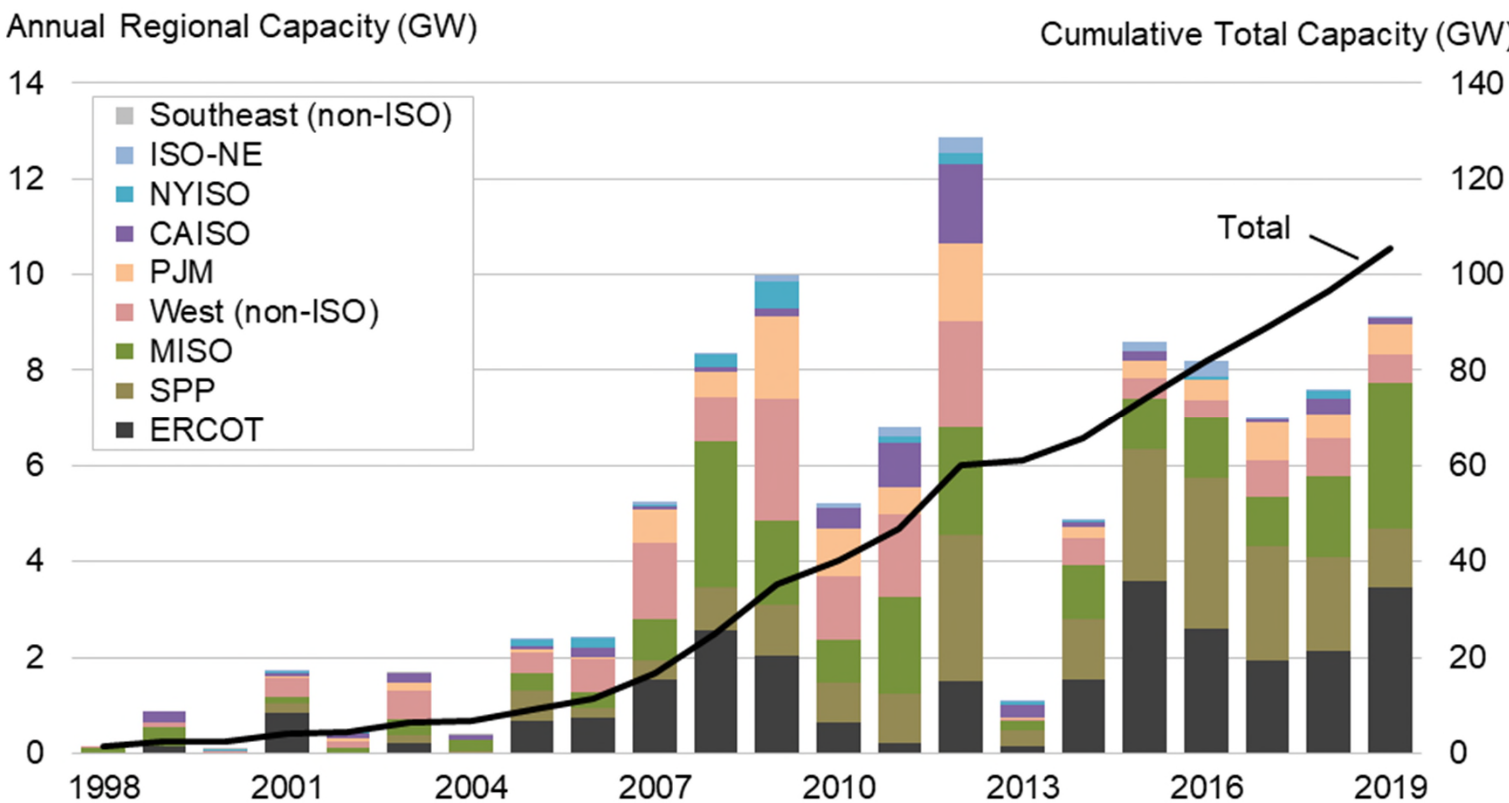
Regional boundaries applied in this analysis include the seven independent system operators (ISO) and two non-ISO regions



Sources: AWS Truepower, NREL [For more information on data sources, see pages 85-86]

Installation Data and Trends

Annual and cumulative growth in U.S. wind power capacity



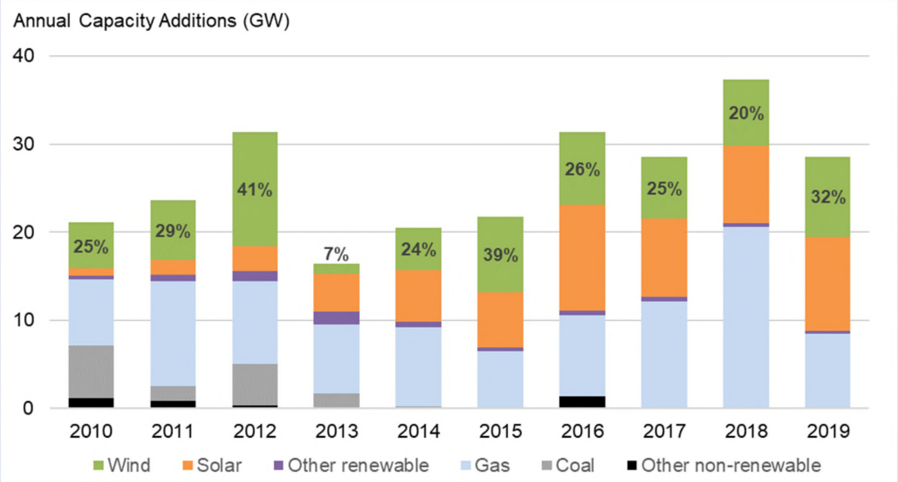
Source: AWEA WindIQ

- $13 billion invested in wind power project additions in 2019
- Most new 2019 capacity located in interior of country: ERCOT, MISO, SPP
- Partial repowering: 2,864 MW of turbines retrofitted in 2019

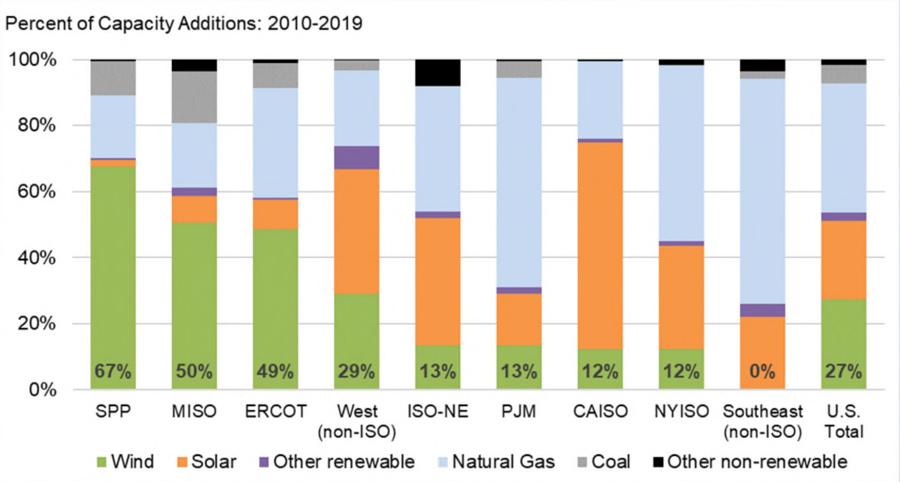
Interactive data visualization: https://emp.lbl.gov/wind-energy-growth

Relative contribution of generation types in capacity additions

Relative contribution of generation types in annual capacity additions



Generation capacity additions by region: 2010-2019



Sources: ABB, AWEA WindIQ, Wood Mackenzie, Berkeley Lab

Over the last decade, wind has comprised 27% of total capacity additions, and a higher proportion in SPP, MISO, ERCOT, and non-ISO West

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International comparisons of wind power capacity: land-based and offshore

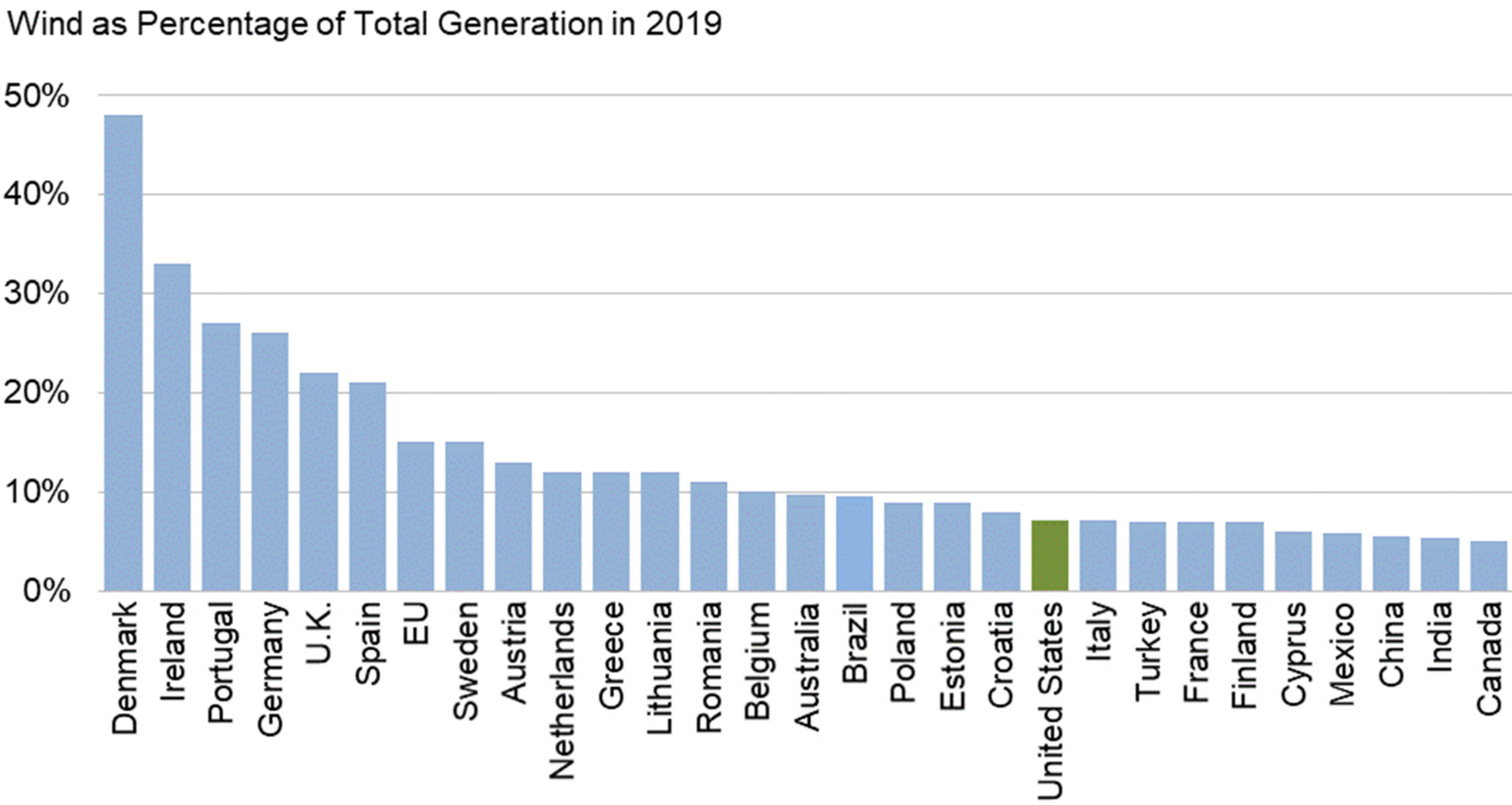
Annual Capacity (2019, MW)	
China	26,155
United States	**9,137**
United Kingdom	2,393
India	2,377
Spain	2,319
Germany	2,189
Sweden	1,588
France	1,336
Mexico	1,281
Argentina	931
Rest of World	10,639
TOTAL	**60,345**

Cumulative Capacity (end of 2019, MW)	
China	236,402
United States	**105,591**
Germany	61,406
India	37,506
Spain	25,850
United Kingdom	23,340
France	16,645
Brazil	15,452
Canada	13,413
Italy	10,406
Rest of World	104,671
TOTAL	**650,682**

Sources: GWEC, AWEA WindIQ

- U.S. remains second to China in annual and cumulative capacity
- Global wind additions in 2019 exceeded the 50,000 MW added in 2018, but were below the record level of 63,800 MW added in 2015

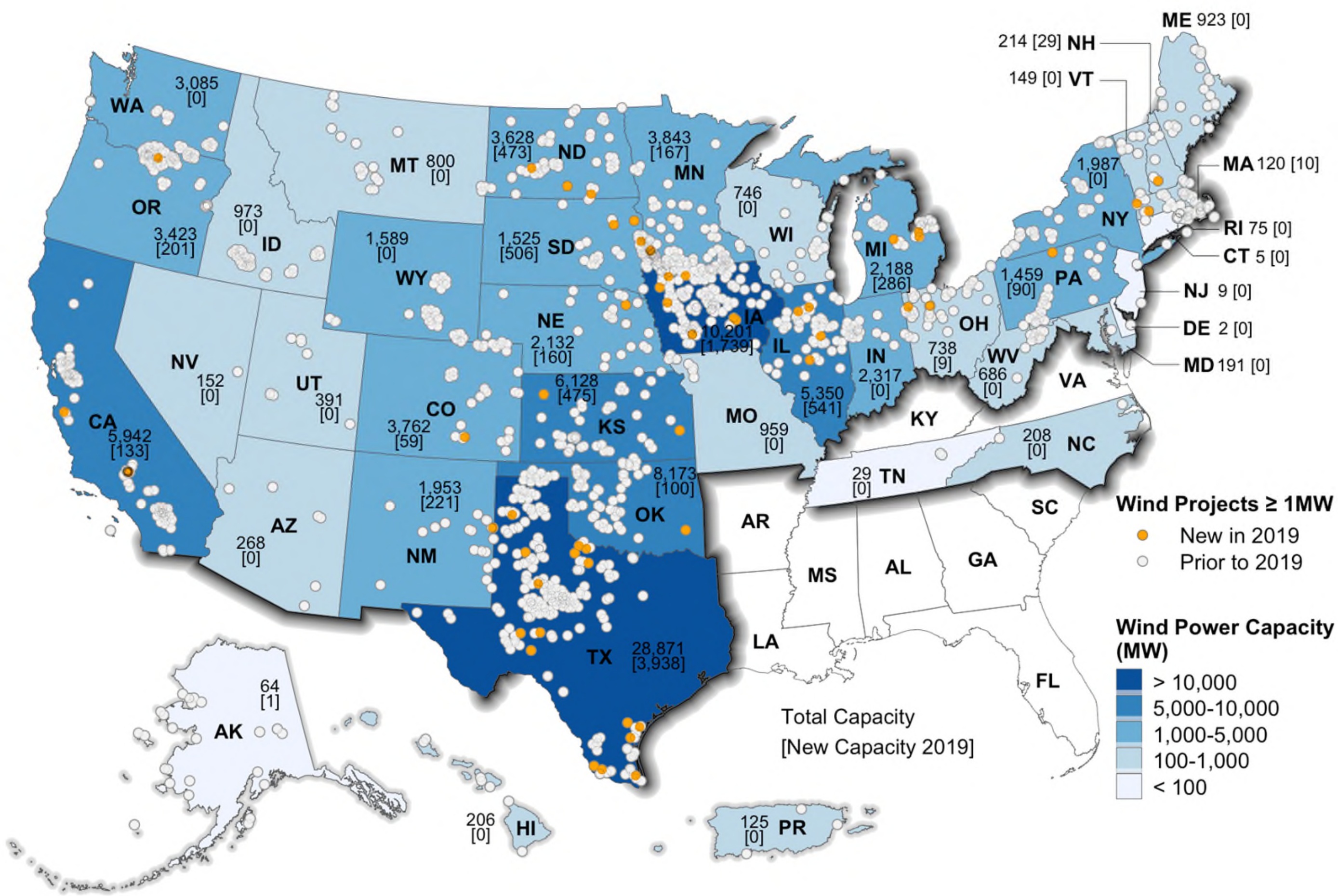
Wind energy penetration in subset of top global wind markets



Source: AWEA

Note: Figure includes a subset of the top global wind markets

U.S. wind power installations, end of 2019



Note: Numbers within states represent MegaWatts of cumulative installed wind capacity and, in brackets, annual additions in 2019.

Source: AWEA WindIQ, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-energy-growth

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U.S. wind power by state and independent system operator

Installed Capacity (MW)				2019 Wind Generation as a Percentage of:			
Annual (2019)		Cumulative (end of 2019)		In-State Generation		In-State Sales	
Texas	3,938	Texas	28,871	Iowa	41.9%	Kansas	53.5%
Iowa	1,739	Iowa	10,201	Kansas	41.4%	Iowa	53.1%
Illinois	541	Oklahoma	8,173	Oklahoma	34.6%	North Dakota	51.1%
South Dakota	506	Kansas	6,128	North Dakota	26.8%	Oklahoma	45.3%
Kansas	475	California	5,942	South Dakota	23.9%	New Mexico	27.4%
North Dakota	473	Illinois	5,350	Maine	23.6%	Nebraska	24.7%
Michigan	286	Minnesota	3,843	Nebraska	19.9%	Wyoming	24.1%
New Mexico	221	Colorado	3,762	New Mexico	19.4%	South Dakota	23.8%
Oregon	201	North Dakota	3,628	Colorado	19.2%	Texas	20.6%
Minnesota	167	Oregon	3,423	Minnesota	19.0%	Maine	20.4%
Nebraska	160	Washington	3,085	Texas	17.5%	Colorado	19.4%
California	133	Indiana	2,317	Vermont	16.4%	Minnesota	17.0%
Oklahoma	100	Michigan	2,188	Idaho	16.1%	Montana	15.4%
Pennsylvania	90	Nebraska	2,132	Oregon	11.5%	Oregon	15.0%
Colorado	59	New York	1,987	Wyoming	9.8%	Idaho	11.2%
New Hampshire	29	New Mexico	1,953	Montana	8.5%	Illinois	10.1%
Massachusetts	10	Wyoming	1,589	Illinois	7.6%	Washington	8.6%
Ohio	9	South Dakota	1,525	Washington	7.3%	Vermont	7.1%
Alaska	1	Pennsylvania	1,459	California	6.8%	Indiana	6.4%
		Idaho	973	Indiana	6.0%	Hawaii	6.3%
Rest of U.S.	*0*	*Rest of U.S.*	*7,062*	*Rest of U.S.*	*1.1%*	*Rest of U.S.*	*1.6%*
Total	**9,137**	**Total**	**105,591**	**Total**	**7.2%**	**Total**	**8.0%**

Source: AWEA WindIQ, EIA

2019 Wind Penetration by ISO/RTO: SPP: 27.5%; ERCOT: 19.9%; MISO: 8.5%; CAISO: 6.9%; PJM: 3.0%; ISO-NE: 2.9%; NYISO: 2.8%

Interactive data visualization: https://emp.lbl.gov/wind-energy-growth

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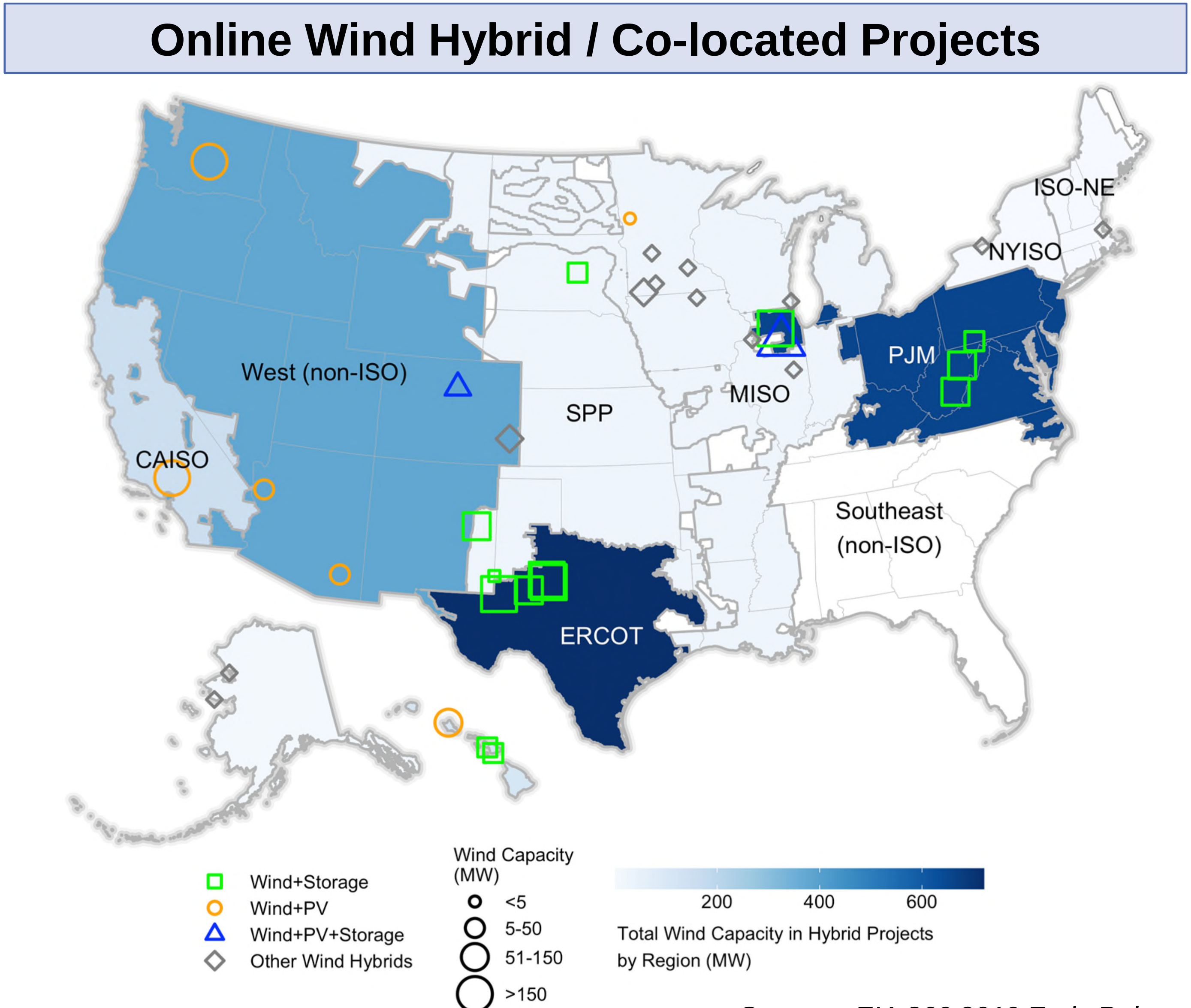
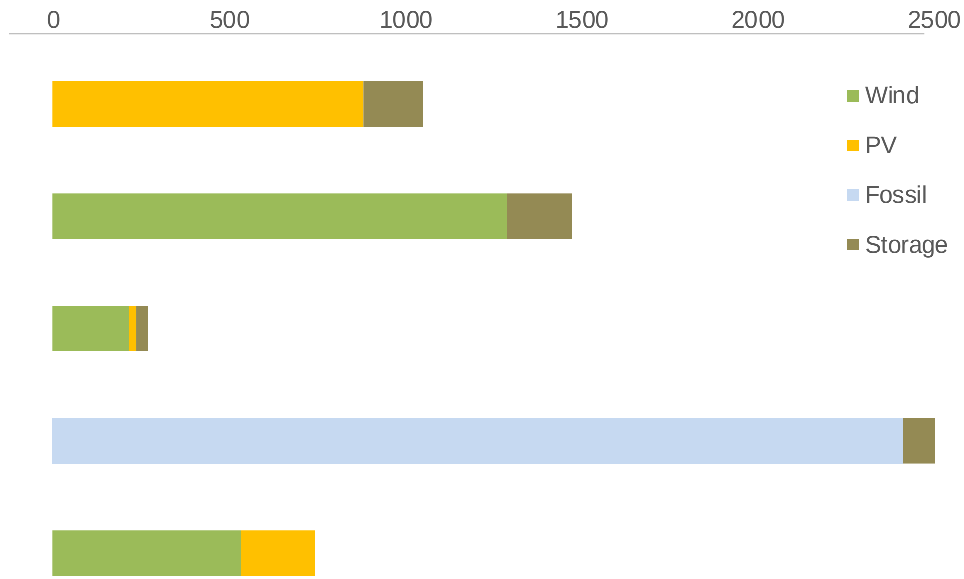
Online wind hybrid / co-located projects of various configurations



Sources: EIA 860 2019 Early Release, Berkeley Lab

Data on subset of the hybrid / co-located project configurations: end of 2019



	# projects	Storage ratio	Duration (hrs)
PV+Storage	40	19%	2.6
Wind+Storage	13	14%	0.6
Wind+PV+Storage	2	15%	0.4
Fossil+Storage	10	4%	0.9
Wind+PV	6	n/a	n/a

Note: Not included in figure are 54 other hybrid / co-located projects with other configurations; details on those projects are provided in the underlying data file. ***Storage ratio*** *defined as total storage capacity divided by total generation capacity within a type.* ***Duration*** *defined as total MWh of storage divided by total MW of storage within a type.*

Sources: EIA 860 2019 Early Release, Berkeley Lab

- Most wind hybrid / co-located projects are Wind+Storage (located in PJM and ERCOT), with storage having limited duration to serve ancillary services markets
- There are far fewer other wind hybrid / co-located configurations of significant size

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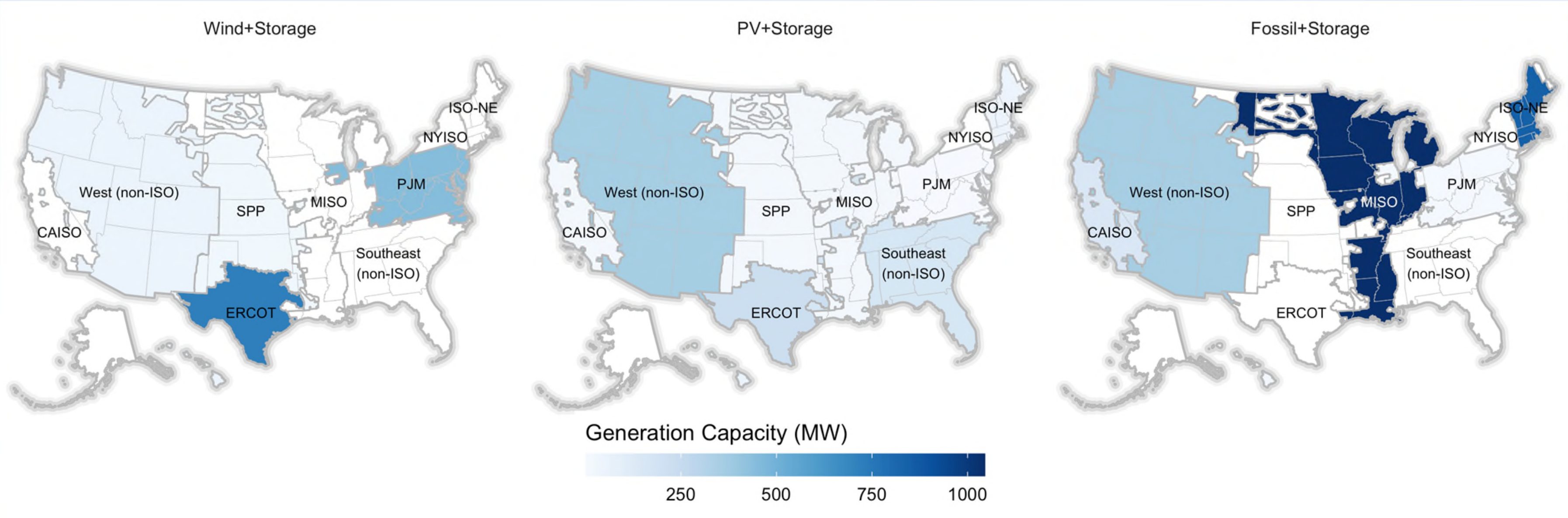
Interactive data visualization: https://emp.lbl.gov/online-hybrid-and-energy-storage-projects

Generator + storage hybrid / co-located projects at end of 2019: wind+storage, PV+storage, fossil+storage



Sources: EIA 860 2019 Early Release, Berkeley Lab

- Wind+storage plants located primarily in ERCOT and PJM
- PV+storage plants located primarily in non-ISO West, ERCOT, and Southeast
- Fossil+storage plants located primarily in MISO and ISO-NE

Interactive data visualization: https://emp.lbl.gov/online-hybrid-and-energy-storage-projects

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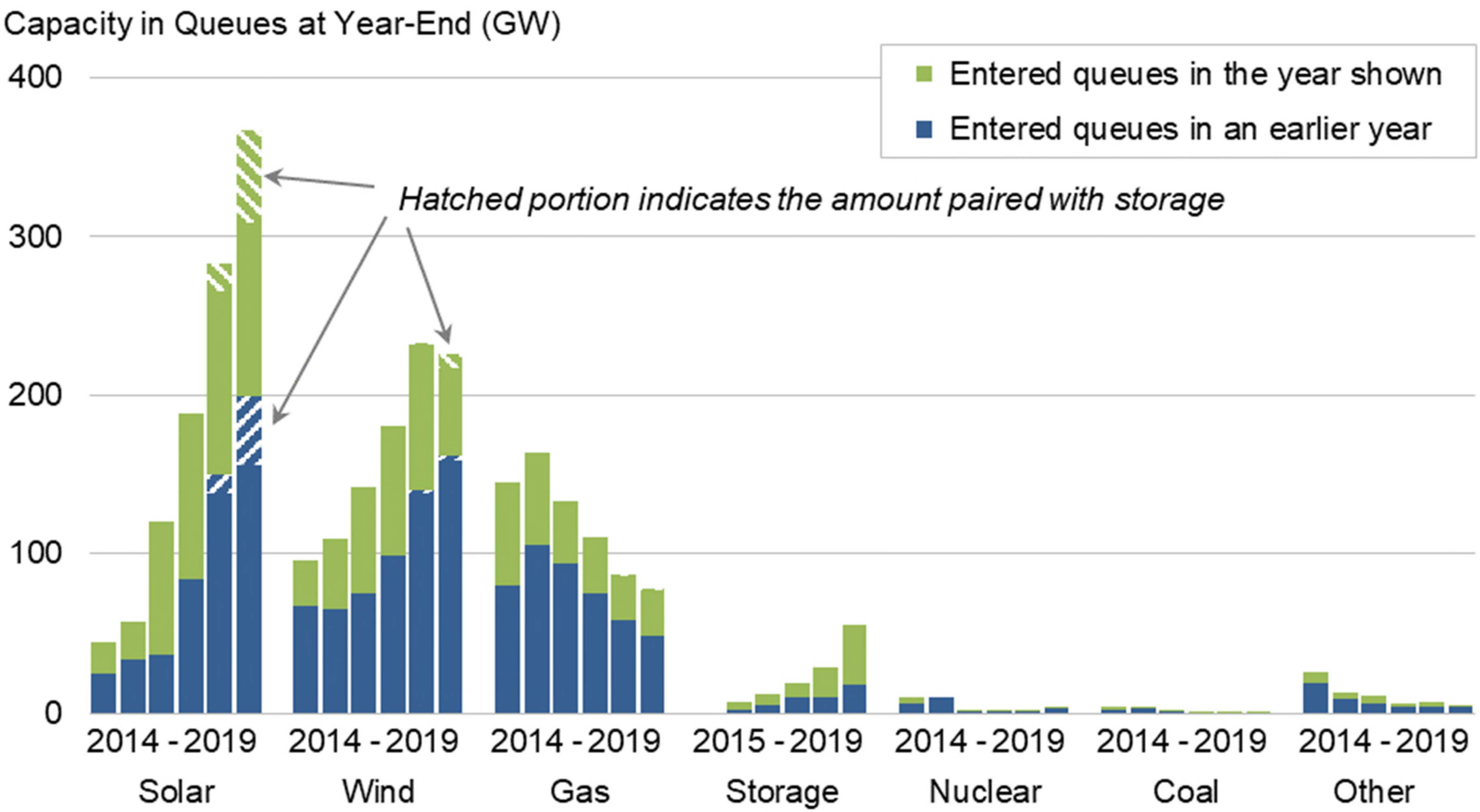
Scope of transmission interconnection queue data

- Data compiled from **interconnection queues** for 7 ISOs and 30 utilities, representing ~80% of all U.S. electricity load
  - Projects that connect to the bulk power system
  - Includes all projects in queues through the end of 2019
  - Filtered to include only “active” projects: removed those listed as “online,” “withdrawn,” or “suspended”
- Hybrid / co-located projects identified via either of these two methods:
  - “Generator Type” field includes **multiple types for a single queue entry** (row)
  - Two or more queue entries (of different gen. types) that share the **same point of interconnection** and sponsor, queue date, ID number, and/or COD
    - Emphasis was placed on identification of wind+storage and solar+storage
    - Other hybrid configurations are likely undercounted
- **Note that being in an interconnection queue does not guarantee ultimate construction: majority of plants are not subsequently built**

Generation capacity in 37 selected interconnection queues from 2014 to 2019, by resource type

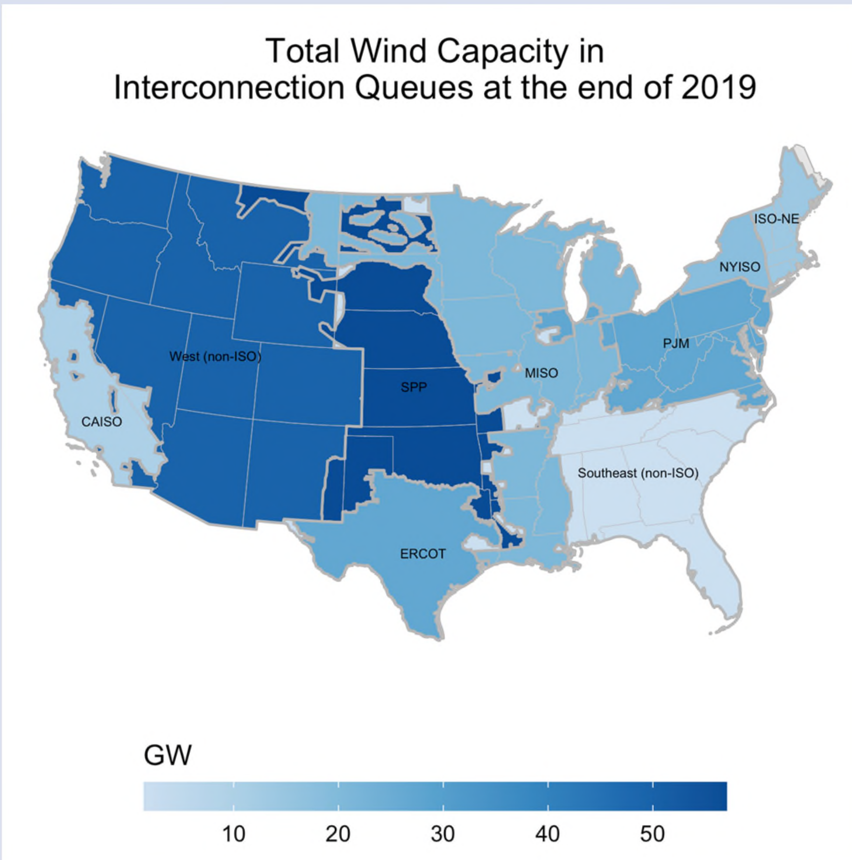


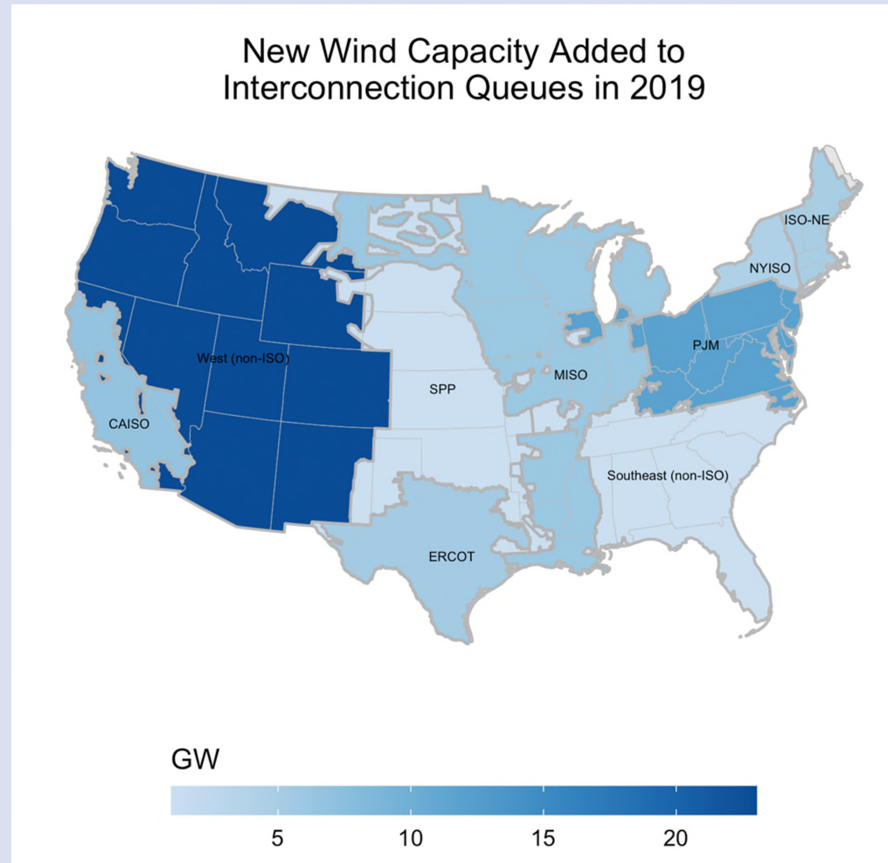
Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Wind power capacity within selected interconnection queues by region: cumulative total and 2019 additions



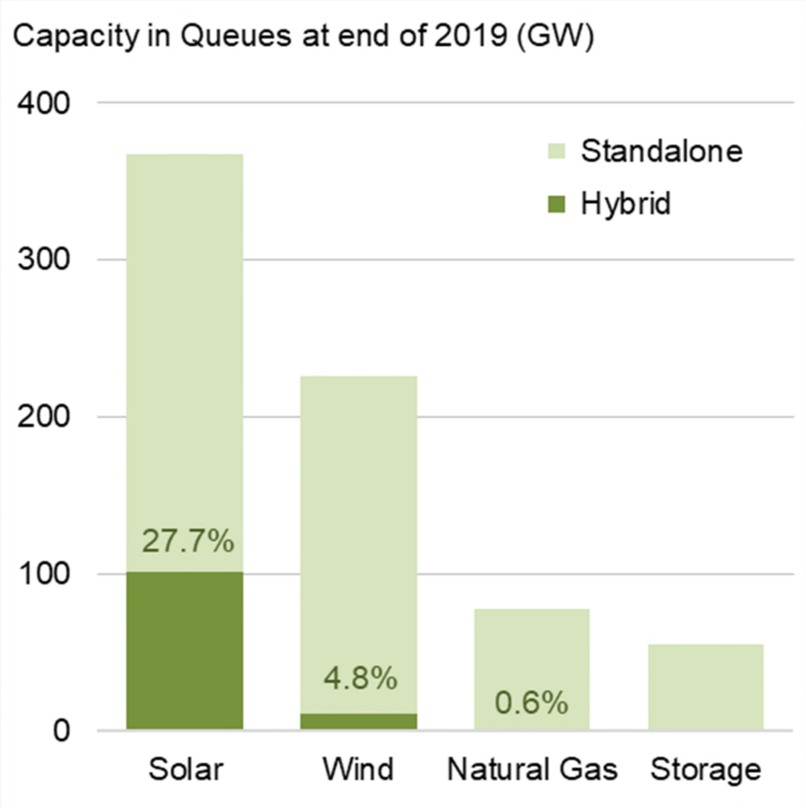


Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

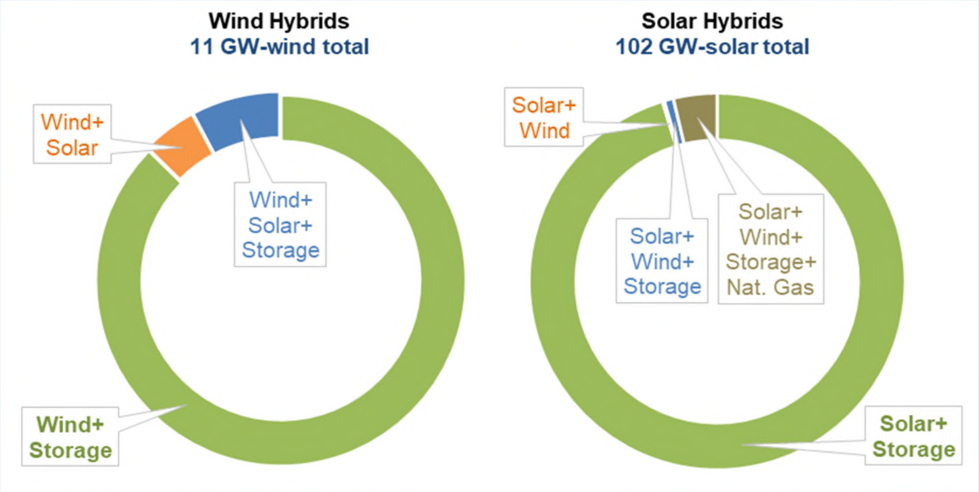
Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Hybrid / co-located capacity within interconnection queues at end of 2019: 11 GW of wind proposed as hybrids, 102 GW of solar



Source: Berkeley Lab review of interconnection queues

Wind+Storage and Solar+Storage configurations are more common than other hybrid types[1]

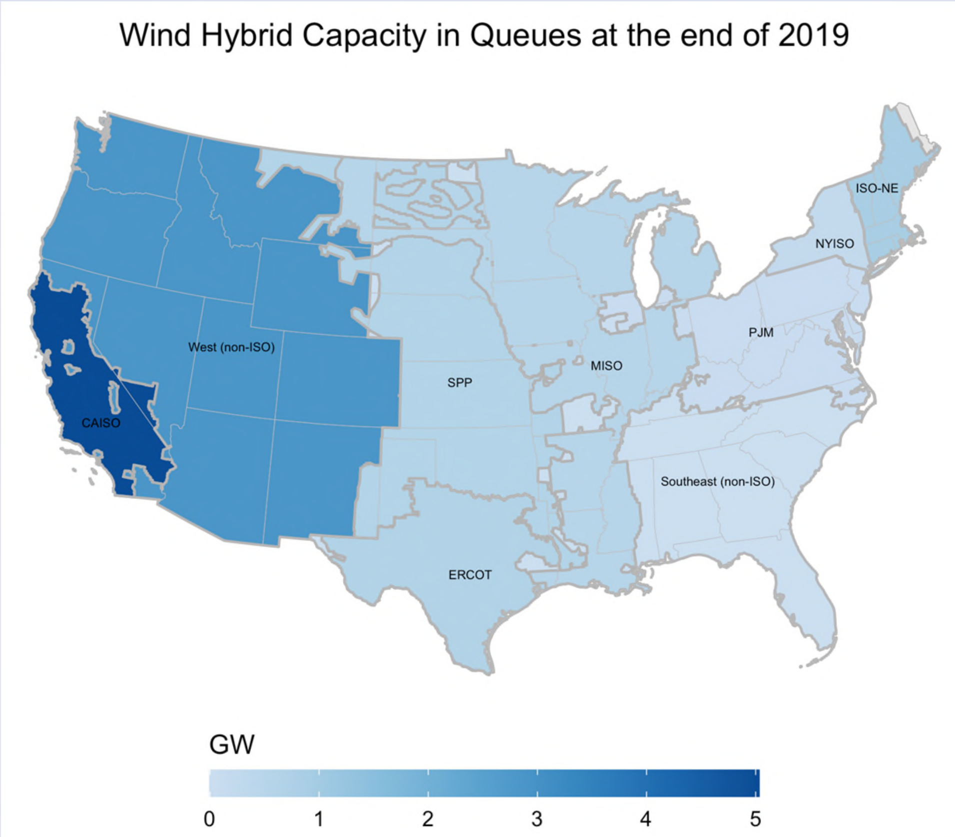


[1] Emphasis was placed on identification of wind+storage and solar+storage: other hybrid configurations are likely undercounted.

Notes: (1) Not all of this capacity will be built; (2) Hybrid plants involving multiple generator types (e.g., wind+PV+ storage, wind+PV) show up in all generator categories, presuming the capacity is known for each type.

Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Location of hybrid / co-located capacity within interconnection queues at end of 2019



As a proportion of proposed wind, solar, and natural gas in regional queues, proposed wind hybrids are more prevalent in CAISO; solar somewhat more evenly distributed

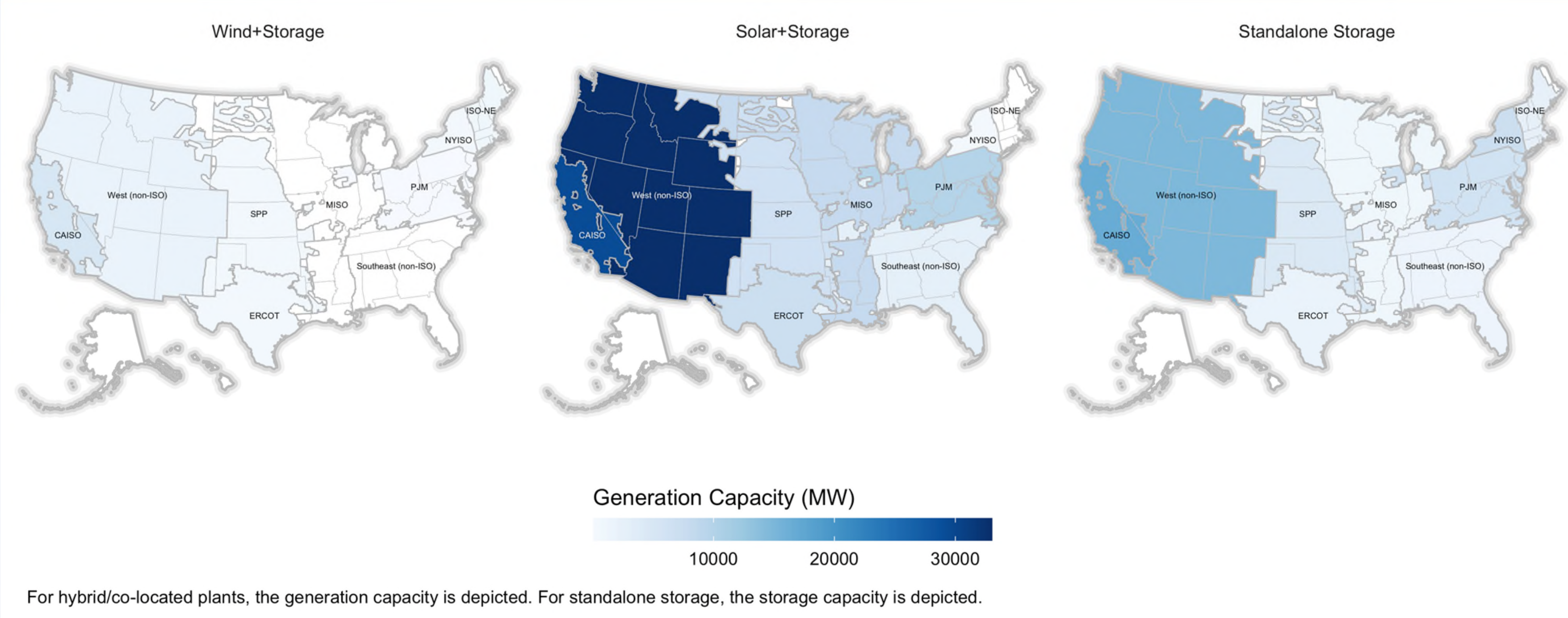
Region	Percentage of Proposed Generators Hybridizing in Each Region		
	Wind	Solar	Nat. Gas
CAISO	50%	67%	0%
ERCOT	3%	13%	0%
SPP	1%	22%	0%
MISO	2%	17%	0%
PJM	0%	17%	1%
NYISO	1%	5%	4%
ISO-NE	6%	0%	0%
West (non-ISO)	6%	50%	0%
Southeast (non-ISO)	0%	6%	0%
TOTAL	**4.8%**	**27.7%**	**0.6%**

Source: Berkeley Lab review of interconnection queues

Notes: (1) Not all of this capacity will be built; (2) Hybrid plants involving multiple generator types (e.g., wind+PV+ storage, wind+PV) show up in all generator categories, presuming the capacity is known for each type; (3) Emphasis was placed on identification of wind+storage and solar+storage in queues: other hybrid / co-located projects are likely undercounted.

Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity

Generator+storage hybrid / co-located projects and standalone storage in interconnection queues



Average storage:generation capacity ratio for solar+storage (66%) is higher than for wind+storage (27%), in subset of ISO queues shown here: solar hybrids likely to install more storage capacity relative to generation capacity than wind hybrids

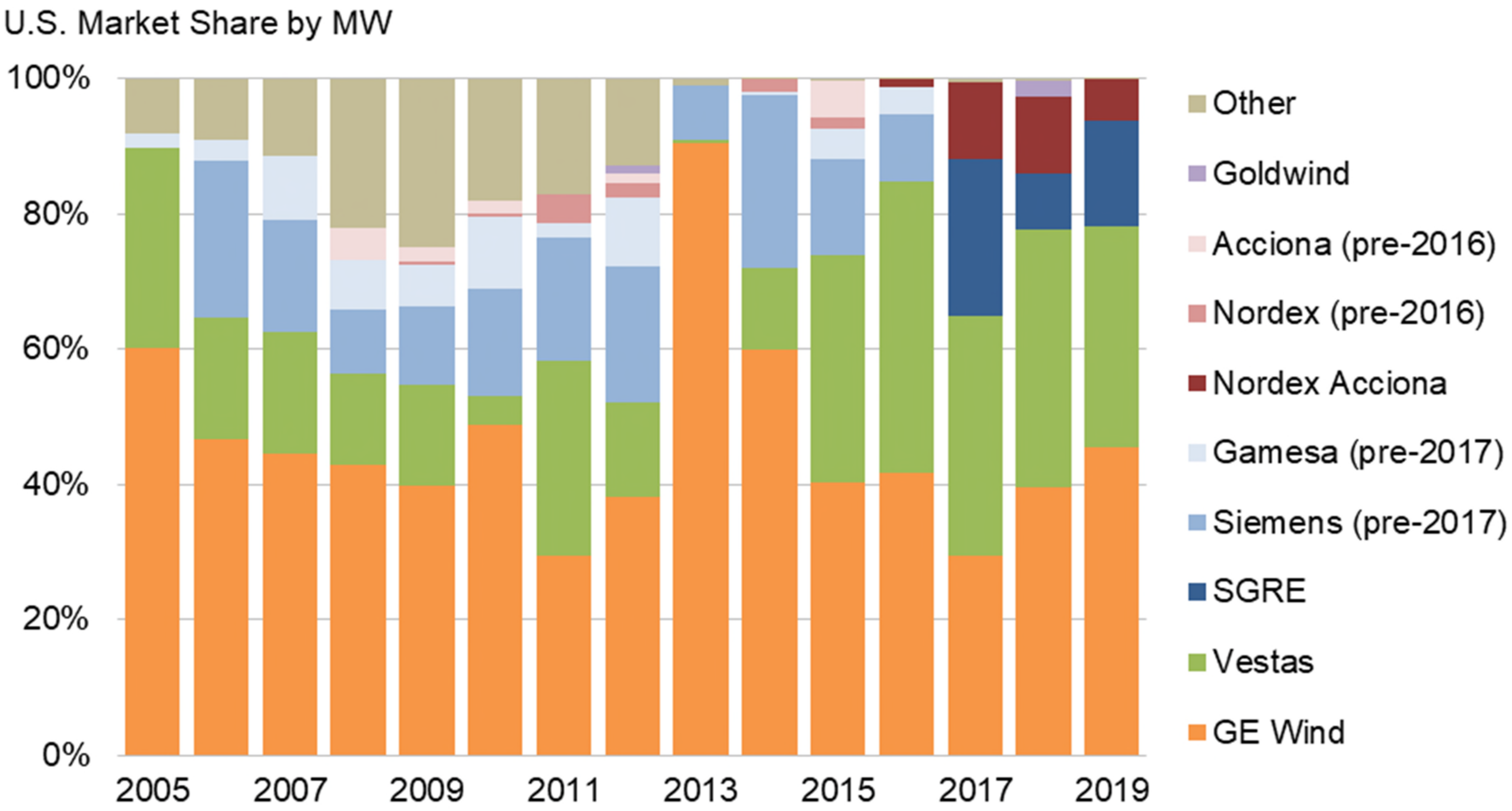
	Storage:Generation Capacity Ratio	
Region	**Wind+Storage**	**Solar+Storage**
CAISO	25%	78%
ERCOT	54%	38%
SPP	23%	38%
NYISO	7%	49%
Combined	**27%**	**66%**

Source: Berkeley Lab review of interconnection queues

Note: Not all of this capacity will be built

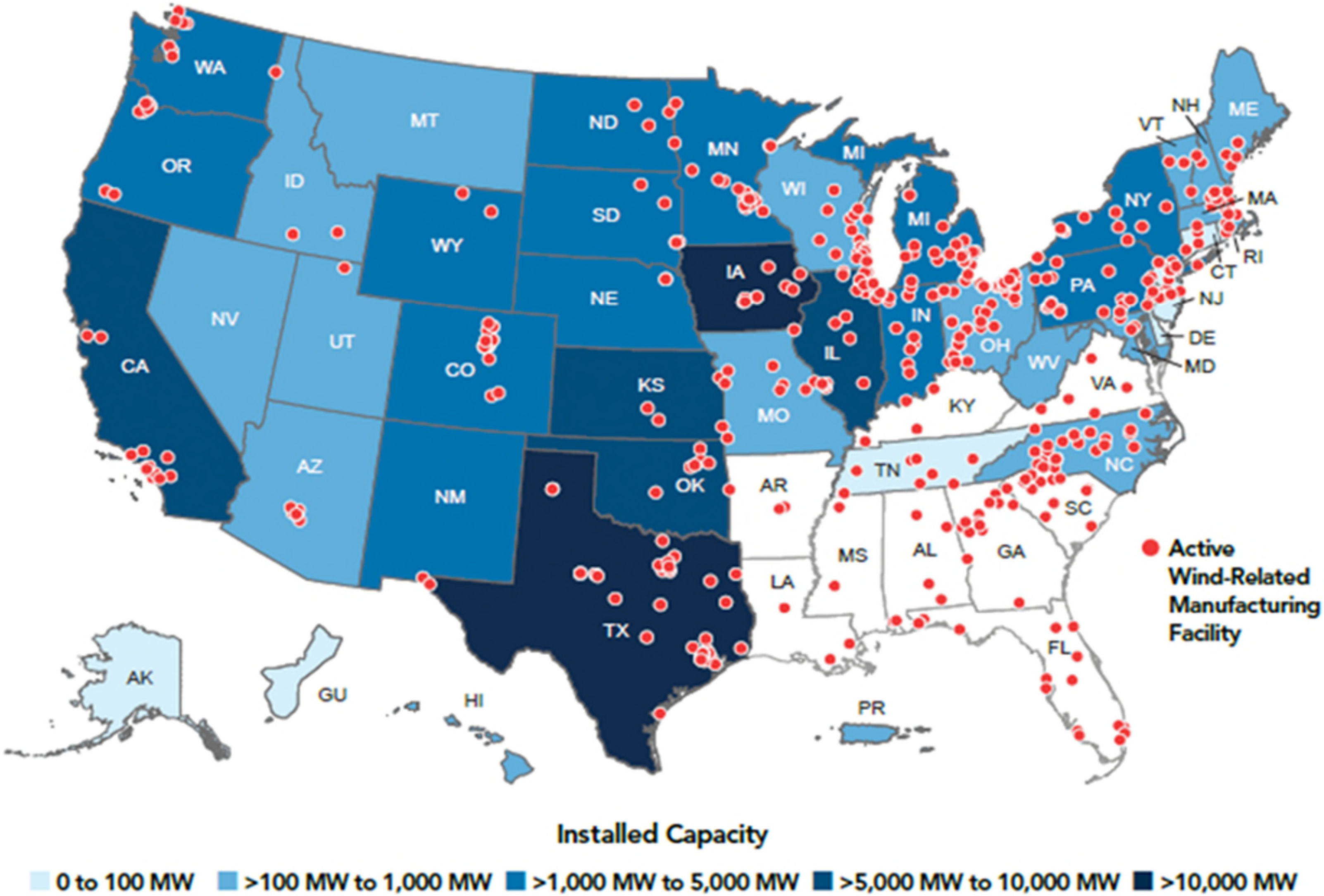
Industry Data and Trends

Annual U.S. market share of wind turbine manufacturers



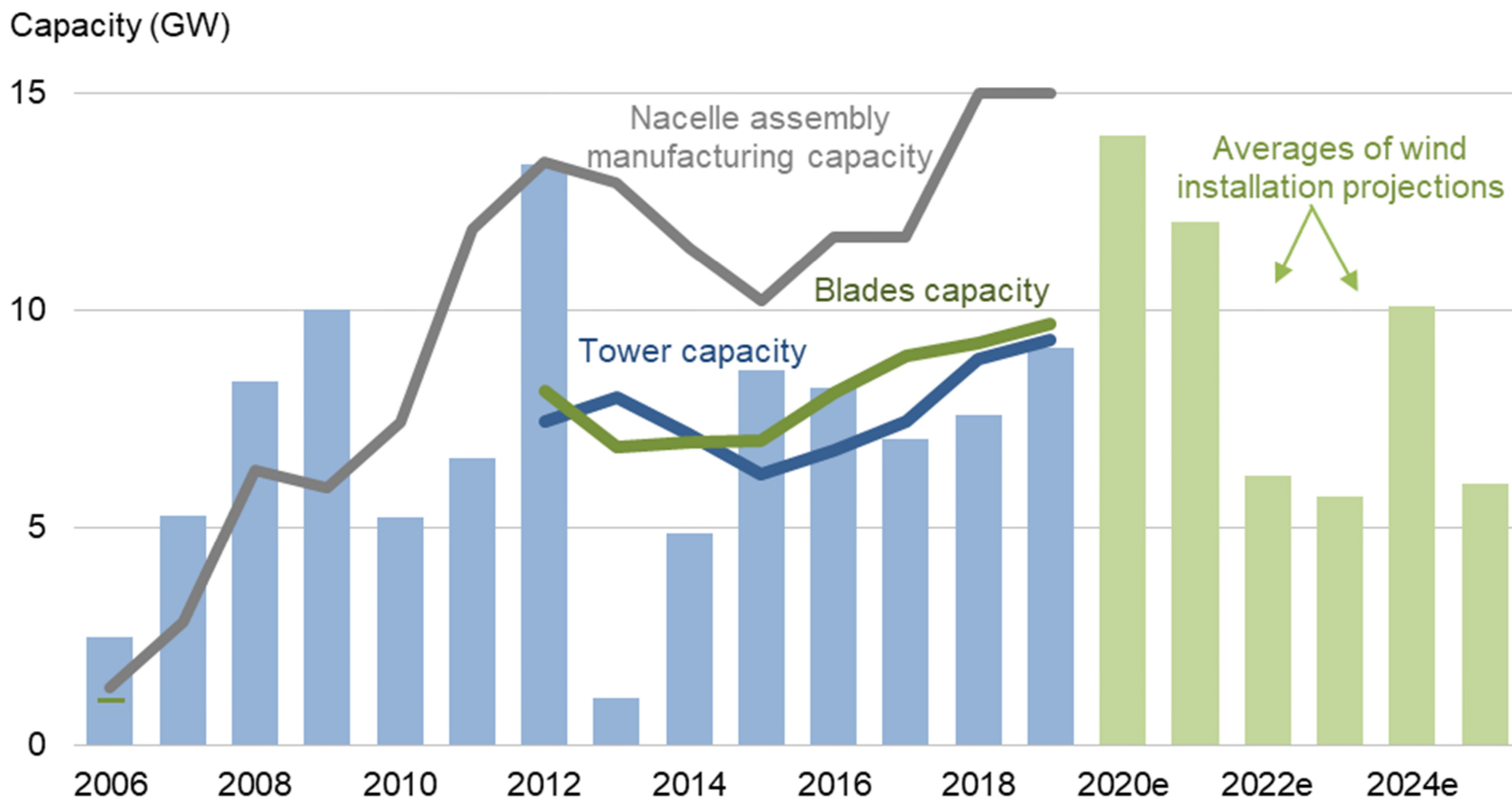
Source: AWEA WindIQ

Location of wind turbine and component manufacturing facilities, end of 2019



Source: AWEA

Domestic wind manufacturing capability vs. U.S. wind power capacity installations

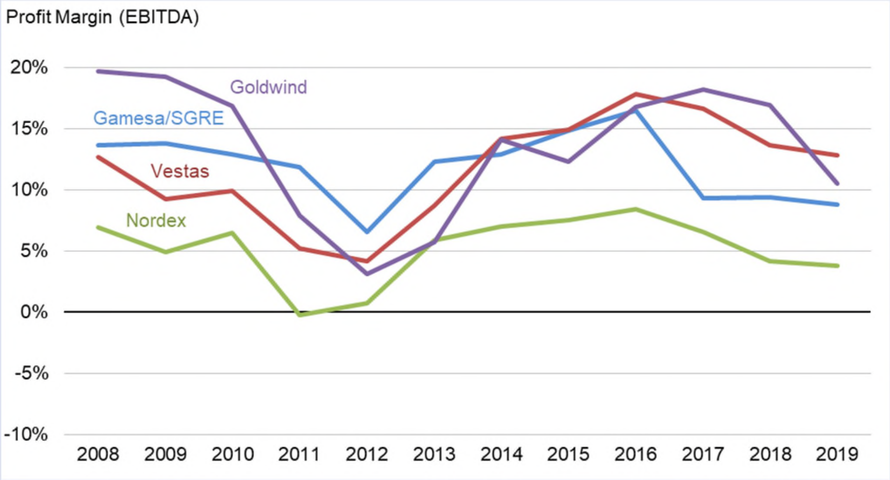


Sources: AWEA Wind IQ, independent analyst projections, Berkeley Lab

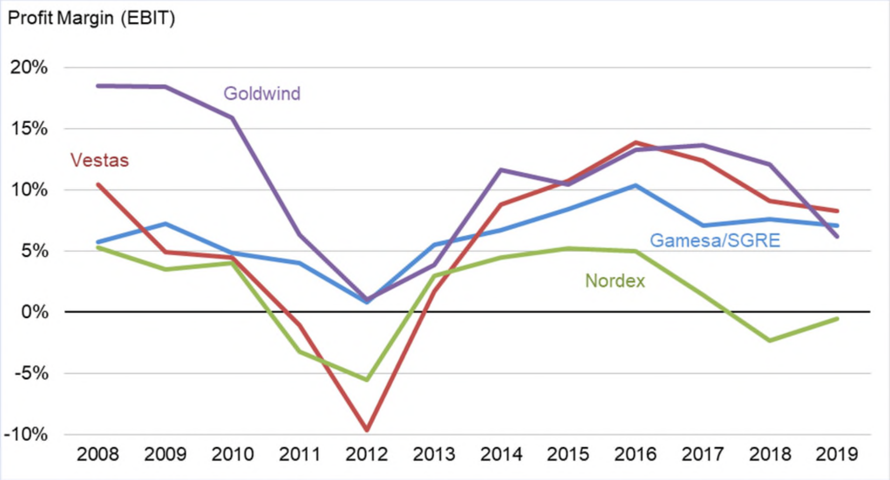
Note: Actual nacelle assembly, tower production, and blades production would be expected to be below maximum production capacity.

Earnings of global wind turbine manufacturers over time

Earnings before interest, taxes, depreciation, amortization (EBITDA)

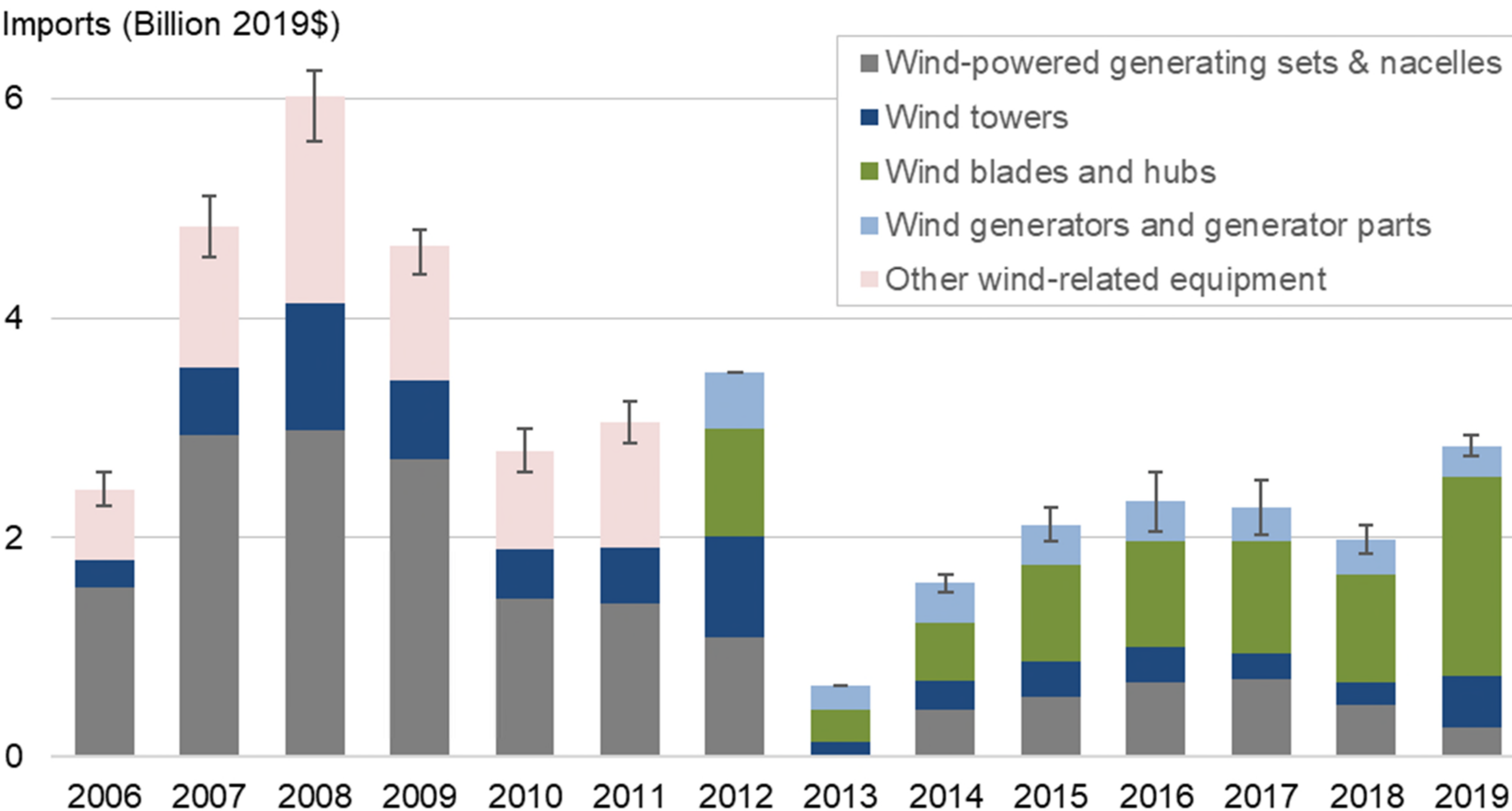


Earnings before interest and taxes (EBIT)



Sources: OEM annual reports and financial statements

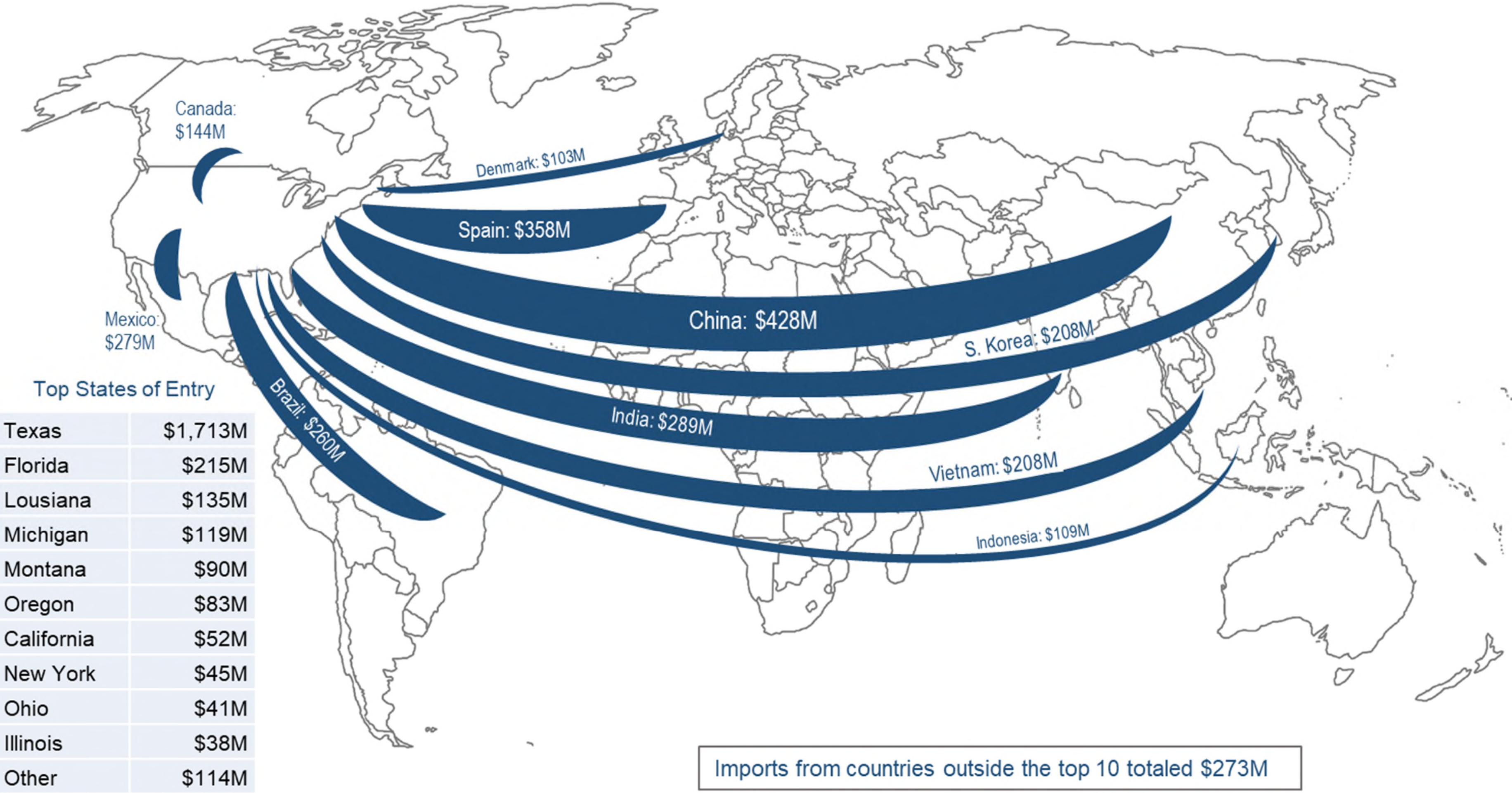
Estimated imports of wind-powered generating sets, nacelles, towers, generators and generator parts, and blades and hubs



Source: Berkeley Lab analysis of data from USITC DataWeb: http://dataweb.usitc.gov

Notes: Figure only includes tracked trade categories, misses other wind-related imports; see full report for the assumptions used to generate the figure.

Tracked wind equipment imports into the United States in 2019, by region



Top States of Entry

Texas	$1,713M
Florida	$215M
Lousiana	$135M
Michigan	$119M
Montana	$90M
Oregon	$83M
California	$52M
New York	$45M
Ohio	$41M
Illinois	$38M
Other	$114M

Source: Berkeley Lab analysis of data from USITC DataWeb: http://dataweb.usitc.gov

Note: Tracked wind-specific equipment includes: wind-powered generating sets, towers, hubs and blades, wind generators and parts

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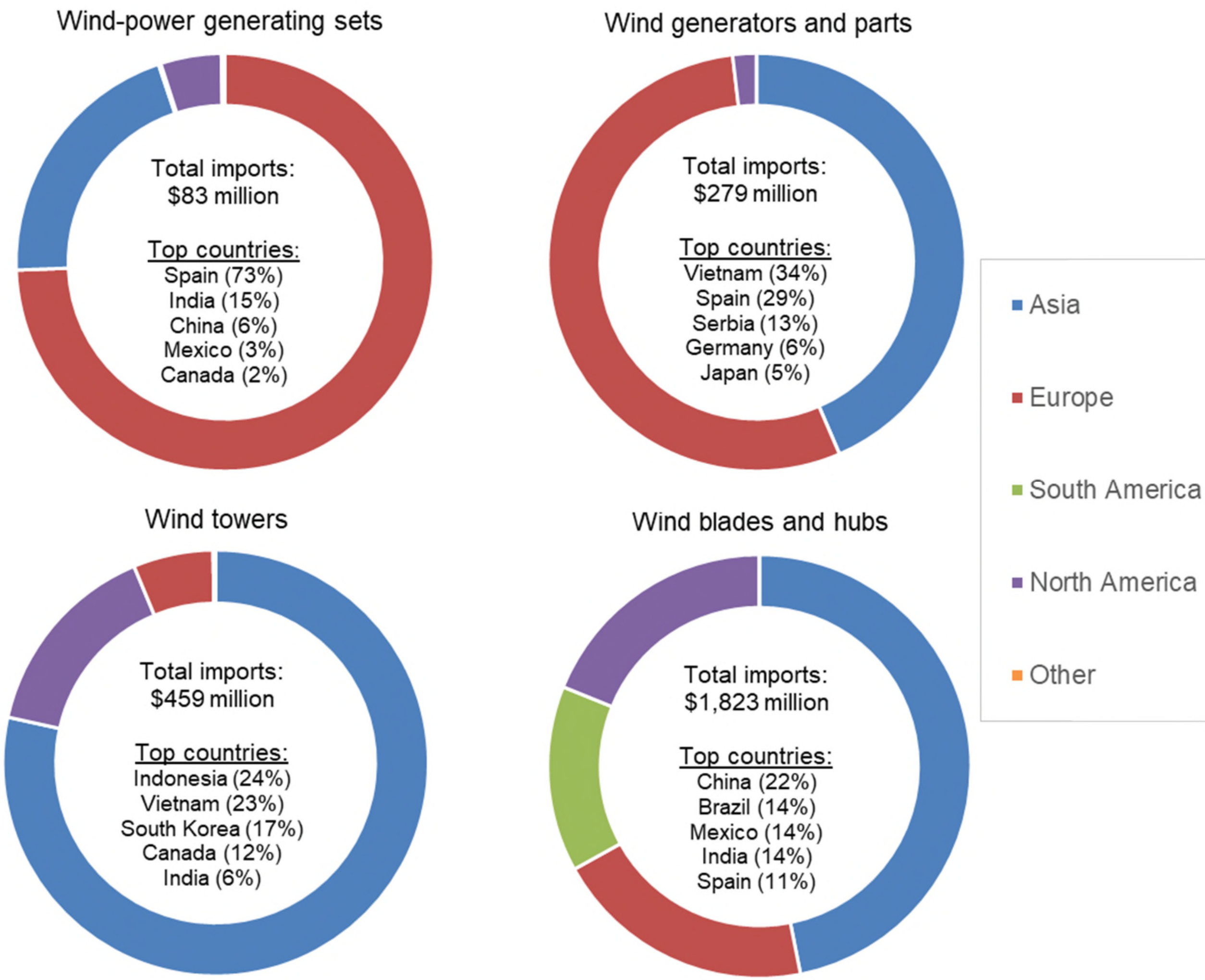
Origins of U.S. imports of selected wind turbine equipment in 2019

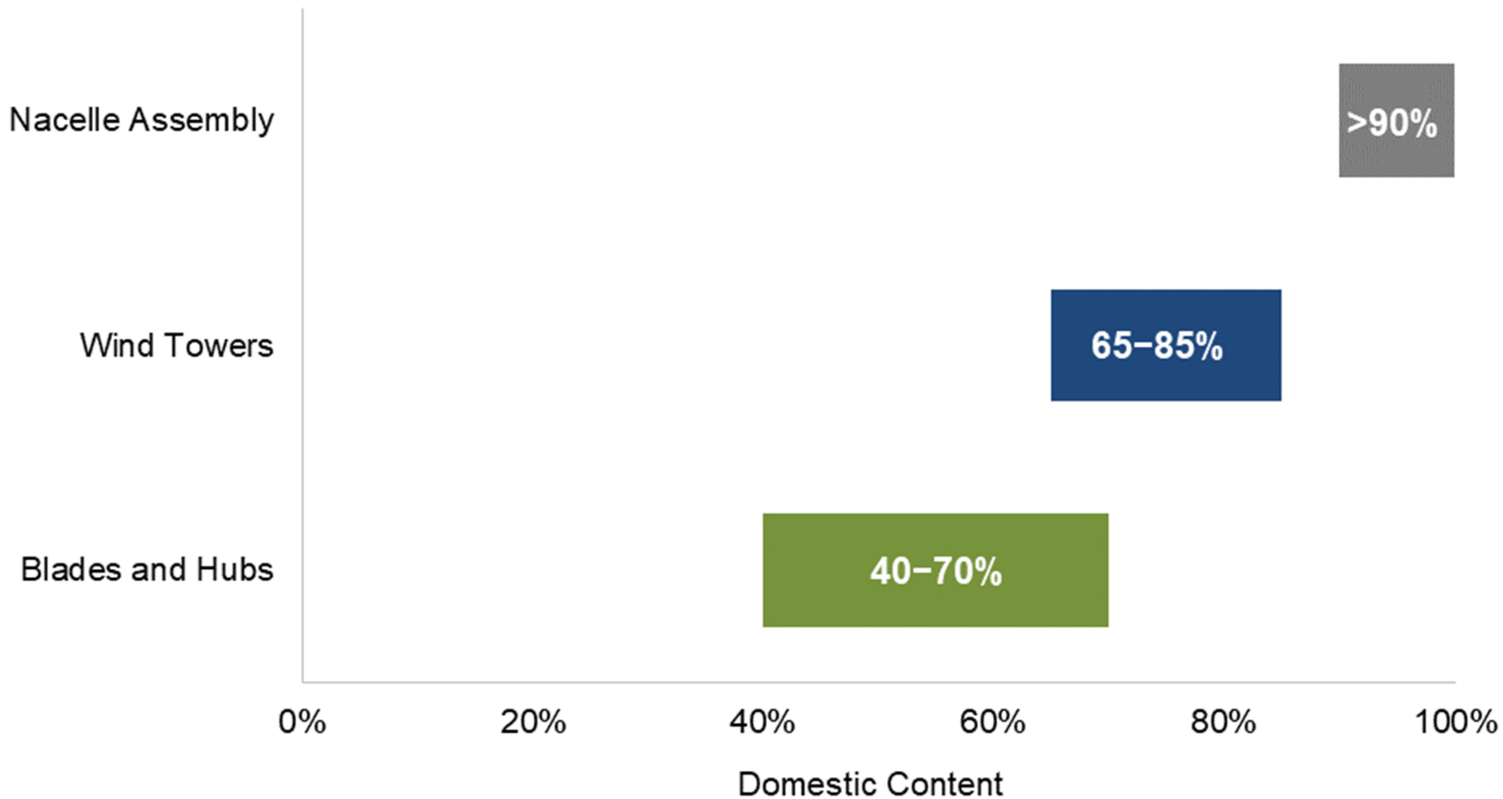


- Majority of imports of wind-powered generating sets come from Spain
- Generators and parts come from Europe and Asia
- Towers largely come from Asia, but also Canada
- Blades and hubs come from all four world regions

Source: Berkeley Lab analysis of data from USITC DataWeb: http://dataweb.usitc.gov

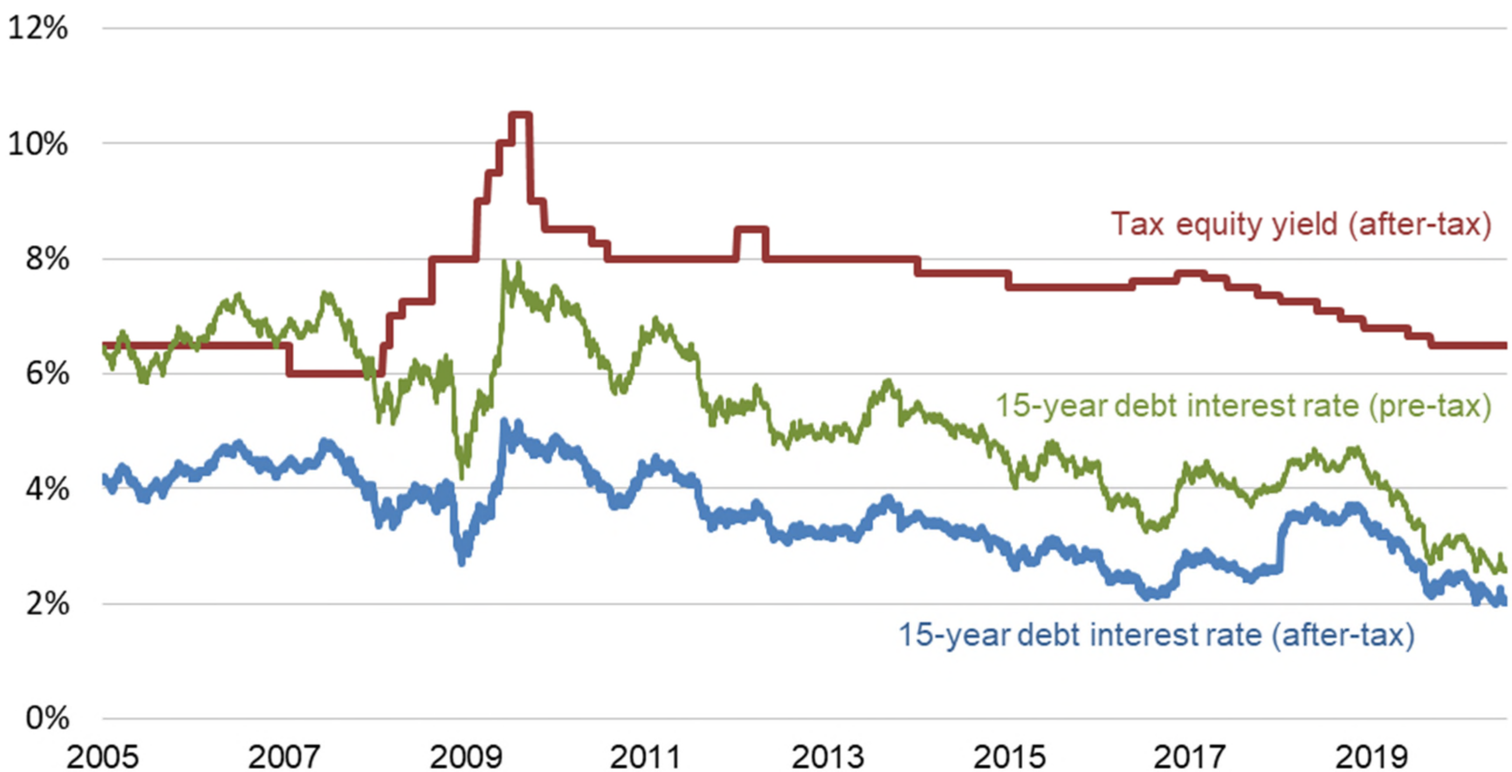
Approximate domestic content of major components in 2019

- Figure reflects percentage of blades, towers, and nacelles that were installed in the U.S. in 2019 that were also manufactured / assembled domestically
- Imports occur in untracked trade categories not included below, including many nacelle internals; nacelle internals generally have lower domestic content of < 20%



Source: Berkeley Lab

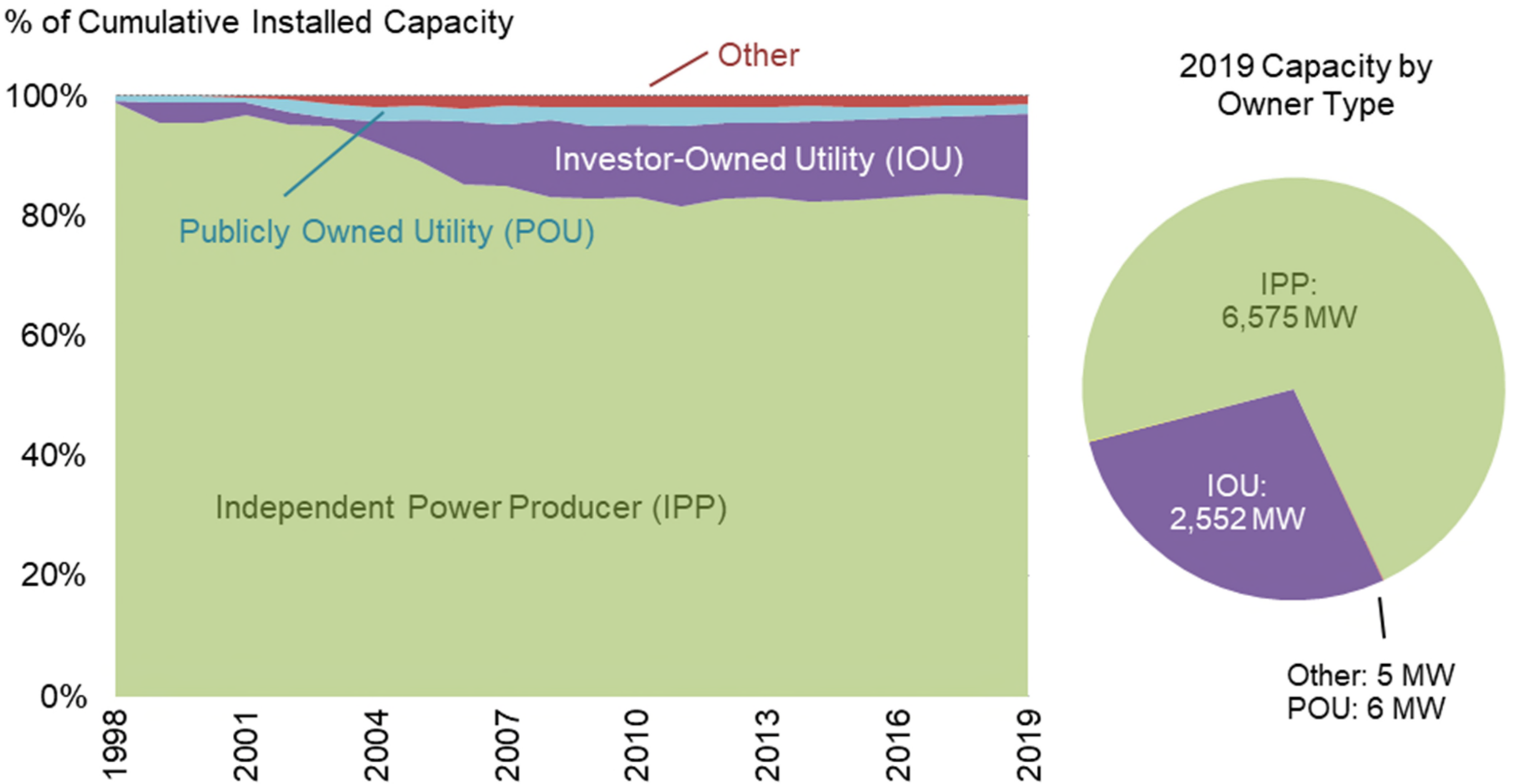
Cost of 15-year debt and tax equity for utility-scale wind projects over time



Sources: Intercontinental Exchange Benchmark Administration, BNEF, Norton Rose Fulbright, Berkeley Lab

- Both the base rate (3-mo LIBOR) and 15-yr swap rate declined by ~100 basis points in 2019, and by even more than that through the first half of 2020
- A portion of these reductions have been offset by an increase in the margins that banks charge (in response to uncertainty surrounding COVID-19)
- Even so, cost of capital (debt & tax equity) remains at or near historical lows

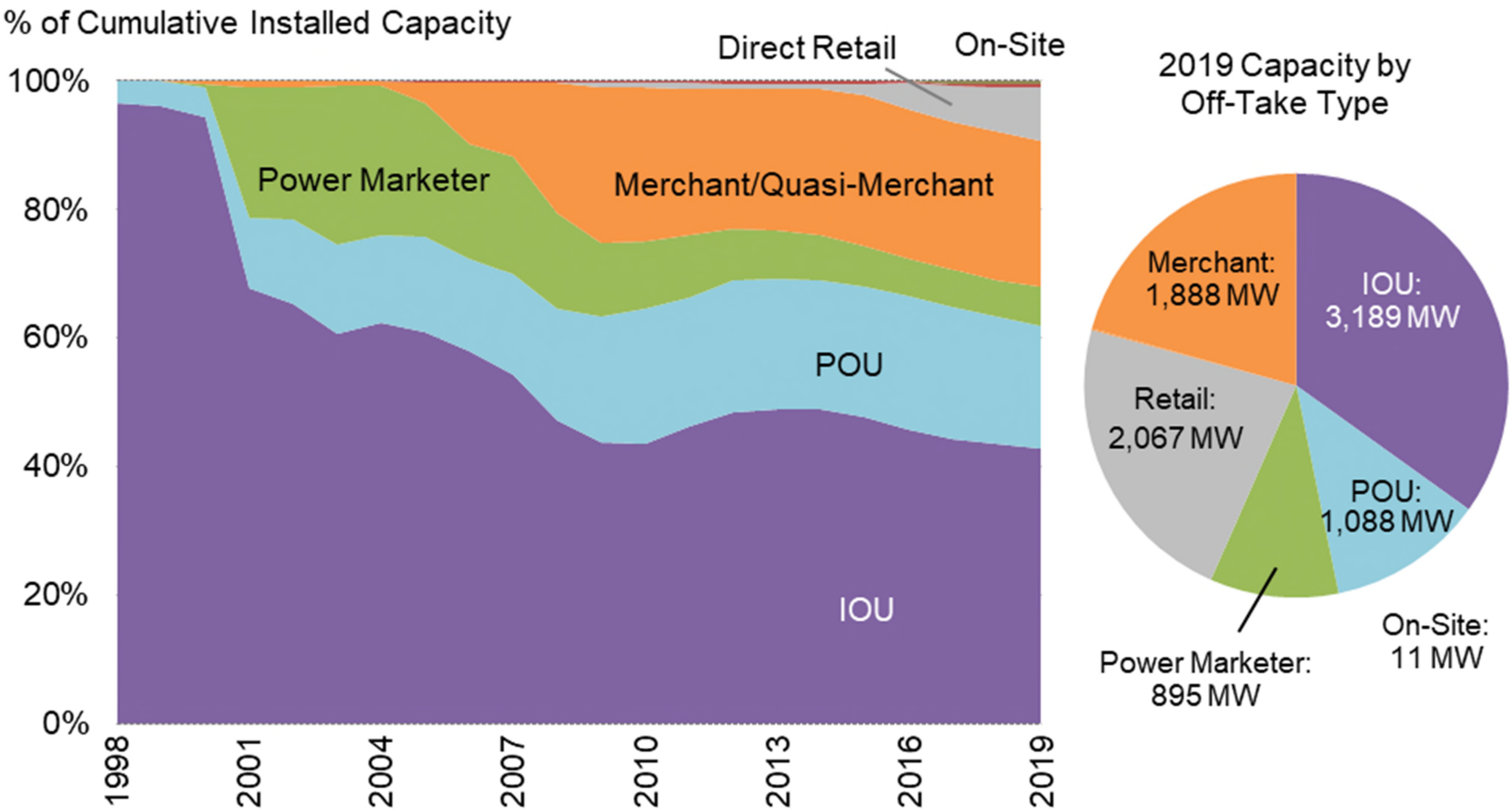
Cumulative and 2019 wind power capacity categorized by owner type



Source: Berkeley Lab estimates based on AWEA WindIQ

Note: Graphic on left shows distribution among the growing cumulative fleet of wind projects installed in the U.S. Pie chart shows distribution only among those new projects built in 2019.

Cumulative and 2019 wind power capacity categorized by power off-take arrangement



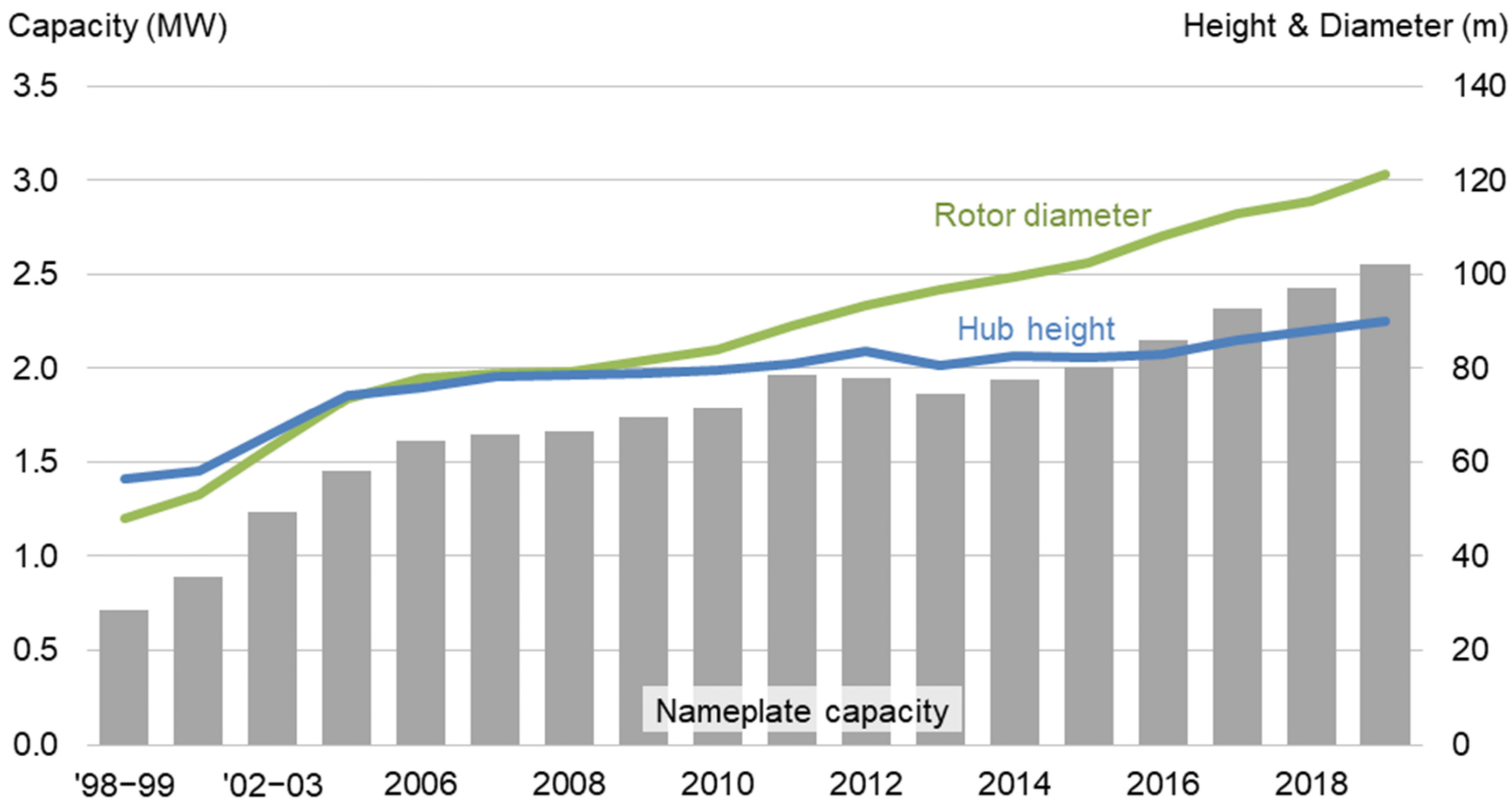
Source: Berkeley Lab estimates based on AWEA WindIQ

Notes: Graphic on left shows distribution among the growing cumulative fleet of wind projects installed in the U.S. Pie chart shows distribution only among those new projects built in 2019. Merchant/quasi-merchant plants often execute electricity or natural gas hedges to reduce merchant risk exposure.

Technology Data and Trends

Average turbine nameplate capacity, hub height, and rotor diameter for land-based wind over time

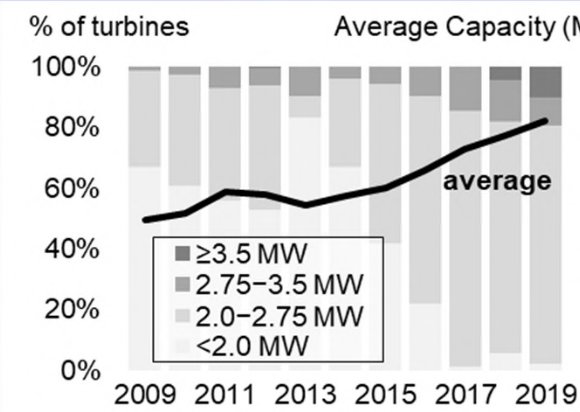
Growth in rotor diameter and nameplate capacity have outpaced growth in hub height over the last two decades; 2019 averages = 2.55 MW capacity, 121 m rotor diameter, 90 m hub height

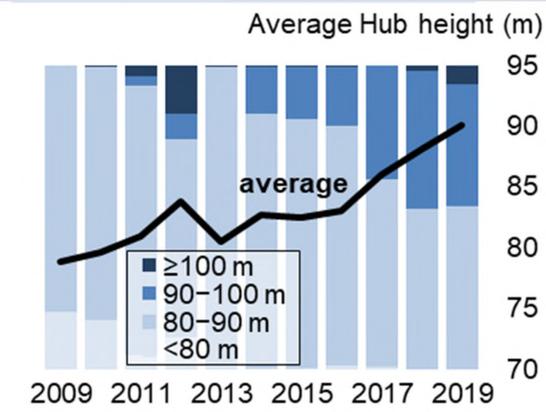


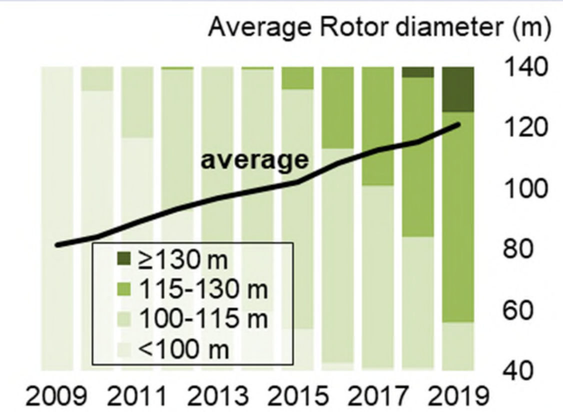
Sources: AWEA Wind IQ, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-power-technology-trends

Trends in turbine nameplate capacity, hub height, rotor diameter, and specific power

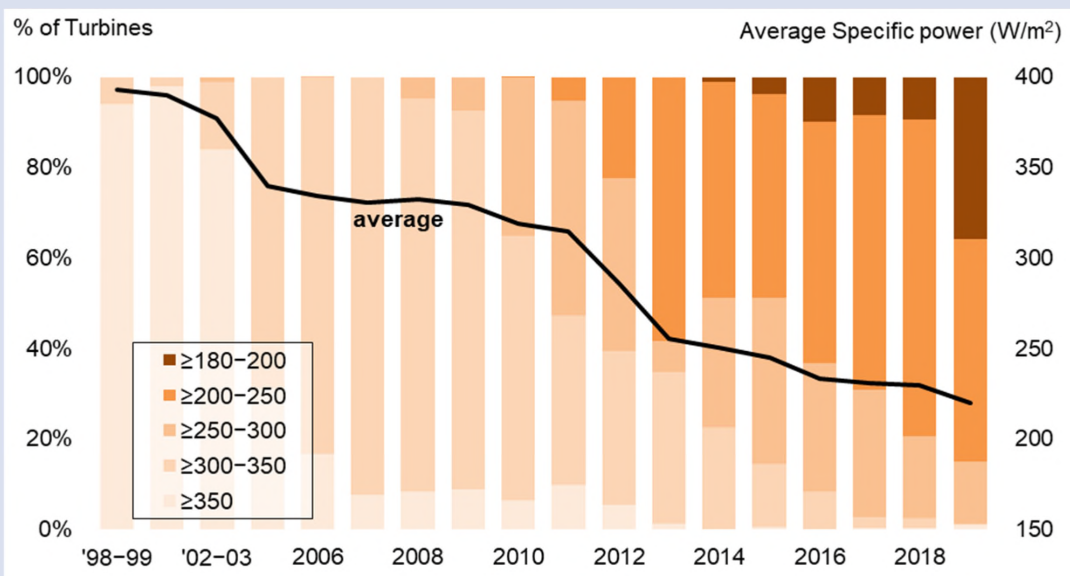






Specific power: turbine capacity divided by swept rotor area; lower specific power leads to higher capacity factors, as shown later

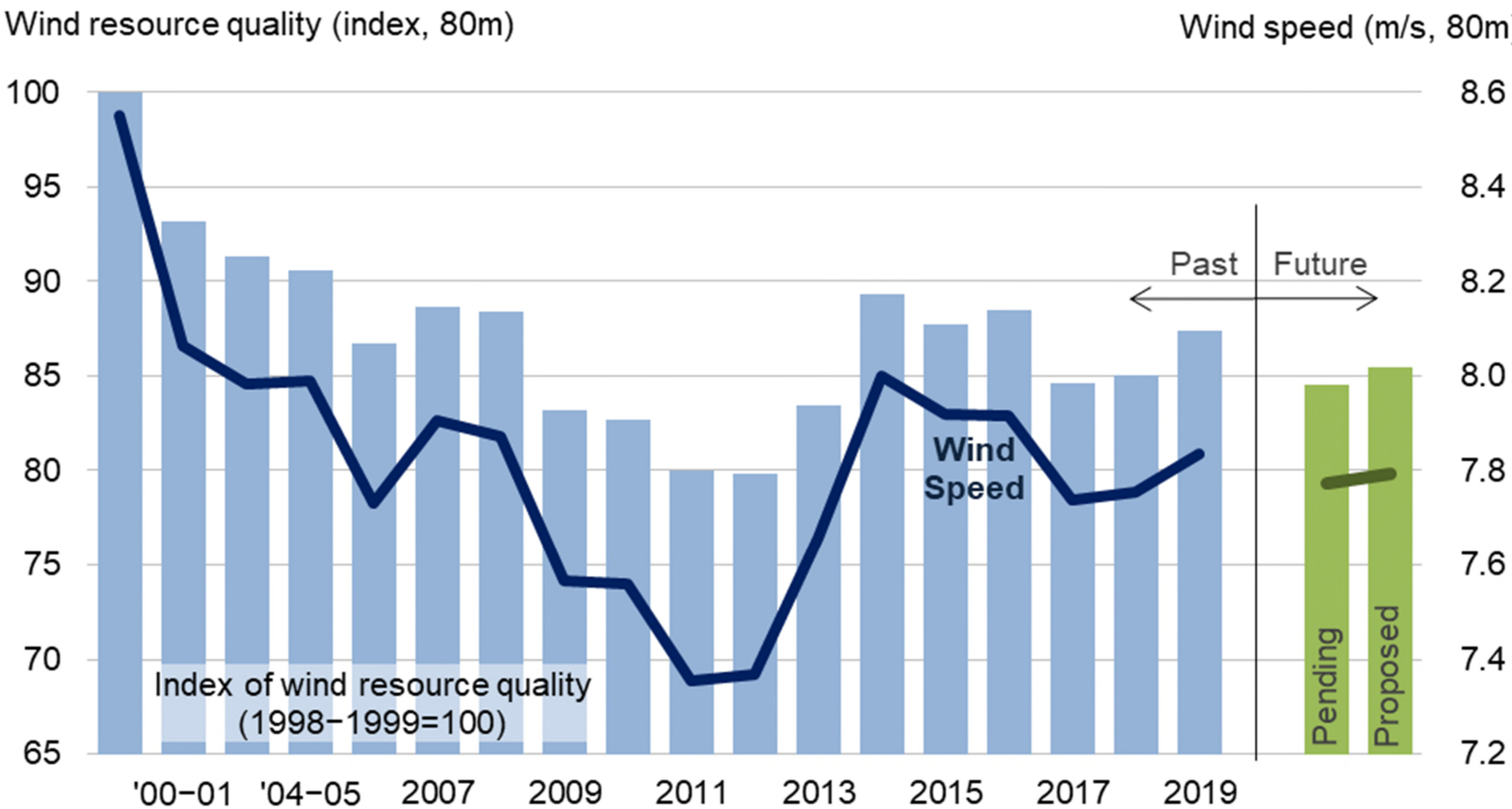
2019 average = 220 W/m^2



Interactive data visualization: https://emp.lbl.gov/specific-power

Sources: AWEA Wind IQ, Berkeley Lab

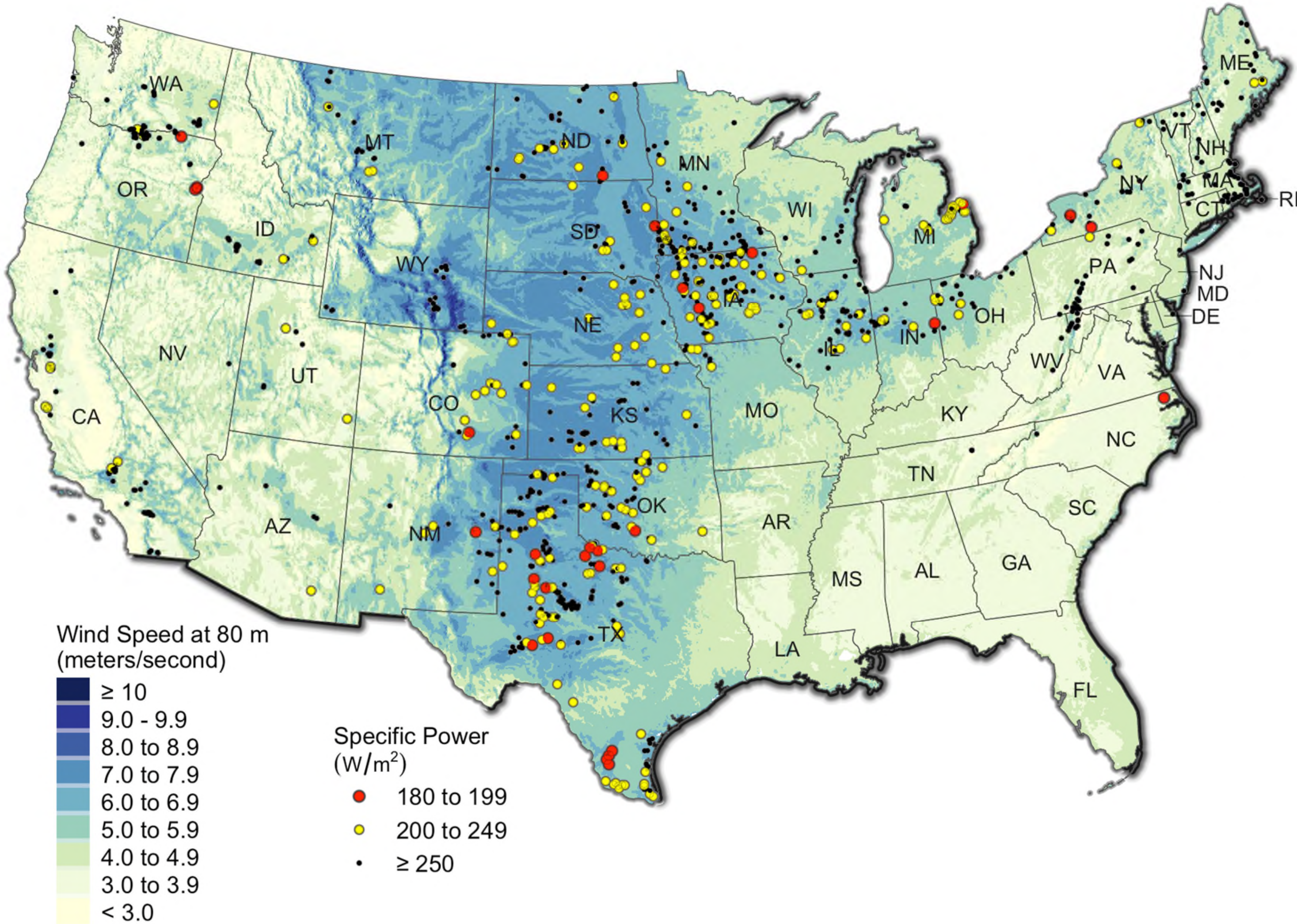
Wind resource quality by year of installation



Sources: AWEA Wind IQ, Berkeley Lab, AWS Truepower, FAA OE/AAA files

Note: The wind resource quality index is based on site estimates of gross capacity factor at 80 meters by AWS Truepower. A single, common wind-turbine power curve is used across all sites and timeframes, and no losses are assumed. Values are indexed to those projects built in 1998—1999.

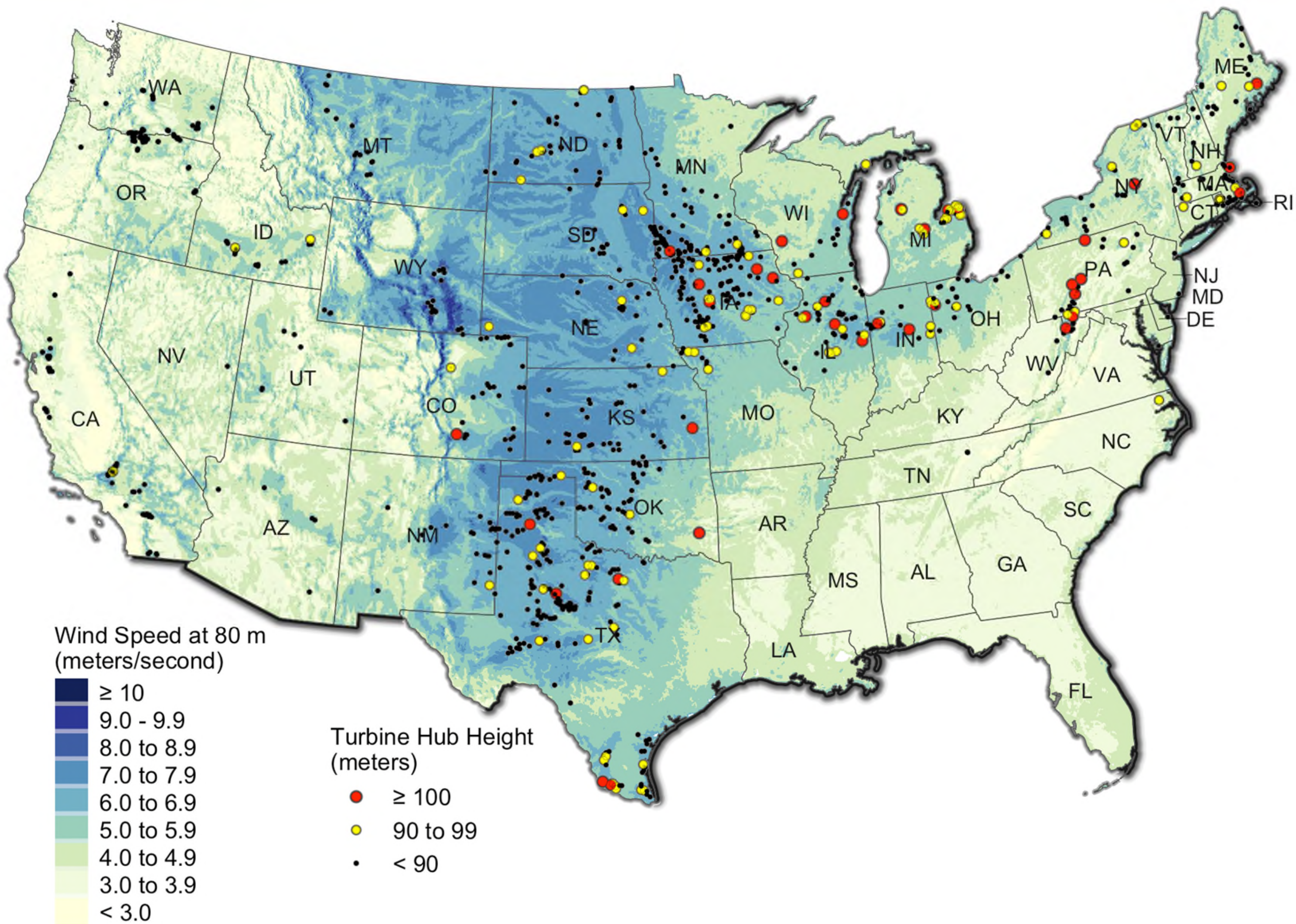
Locations low specific power installations at end of 2019



Sources: AWEA WindIQ, USWTDB, AWS Truepower, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-power-technology-trends

Locations tall tower installations at end of 2019

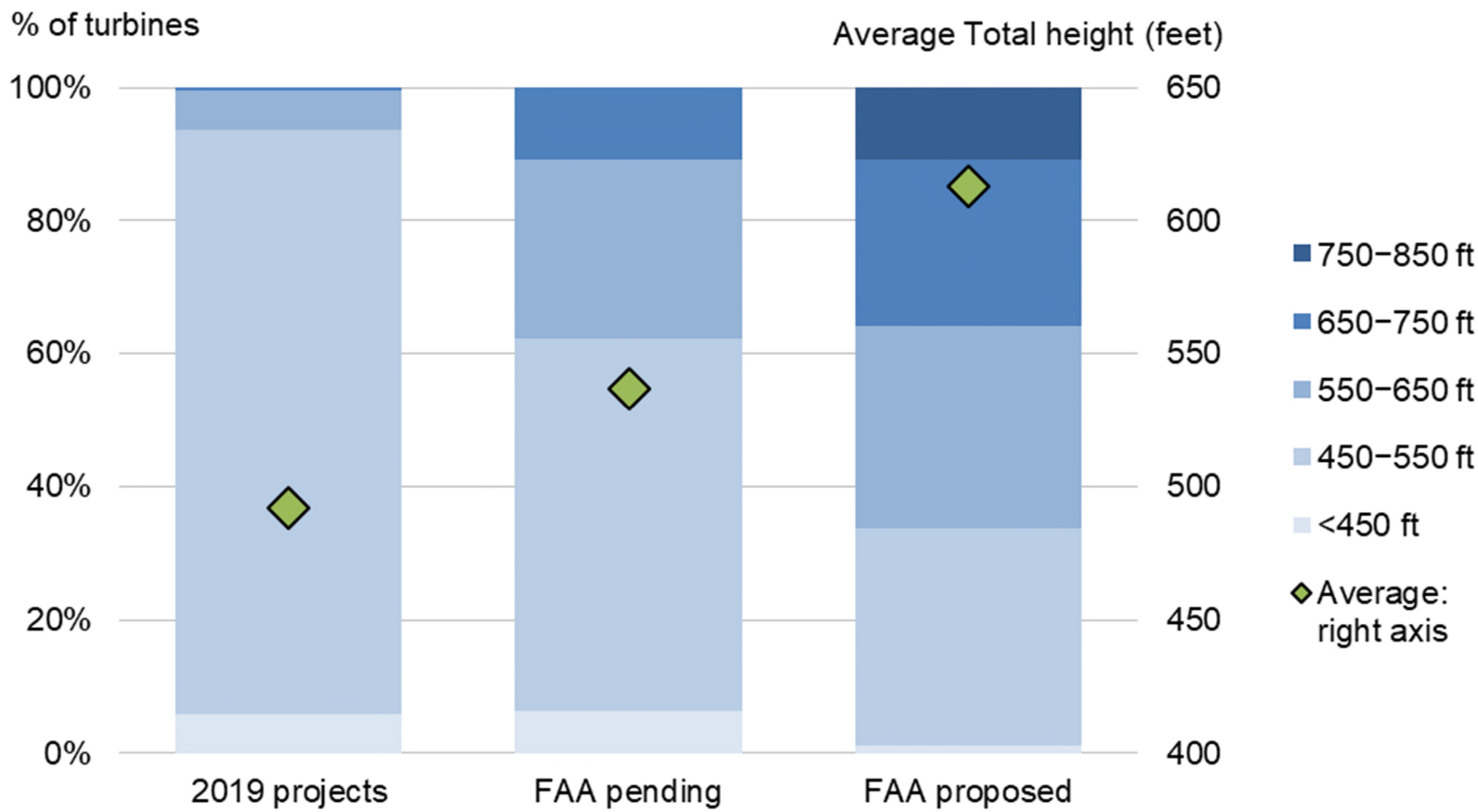


Sources: AWEA WindIQ, USWTDB, AWS Truepower, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-power-technology-trends

Distribution of total turbine height based on proposed projects via FAA applications, and compared to 2019 installations

FAA pending and proposed turbines show significant growth in total turbine height, compared to 2019 wind projects

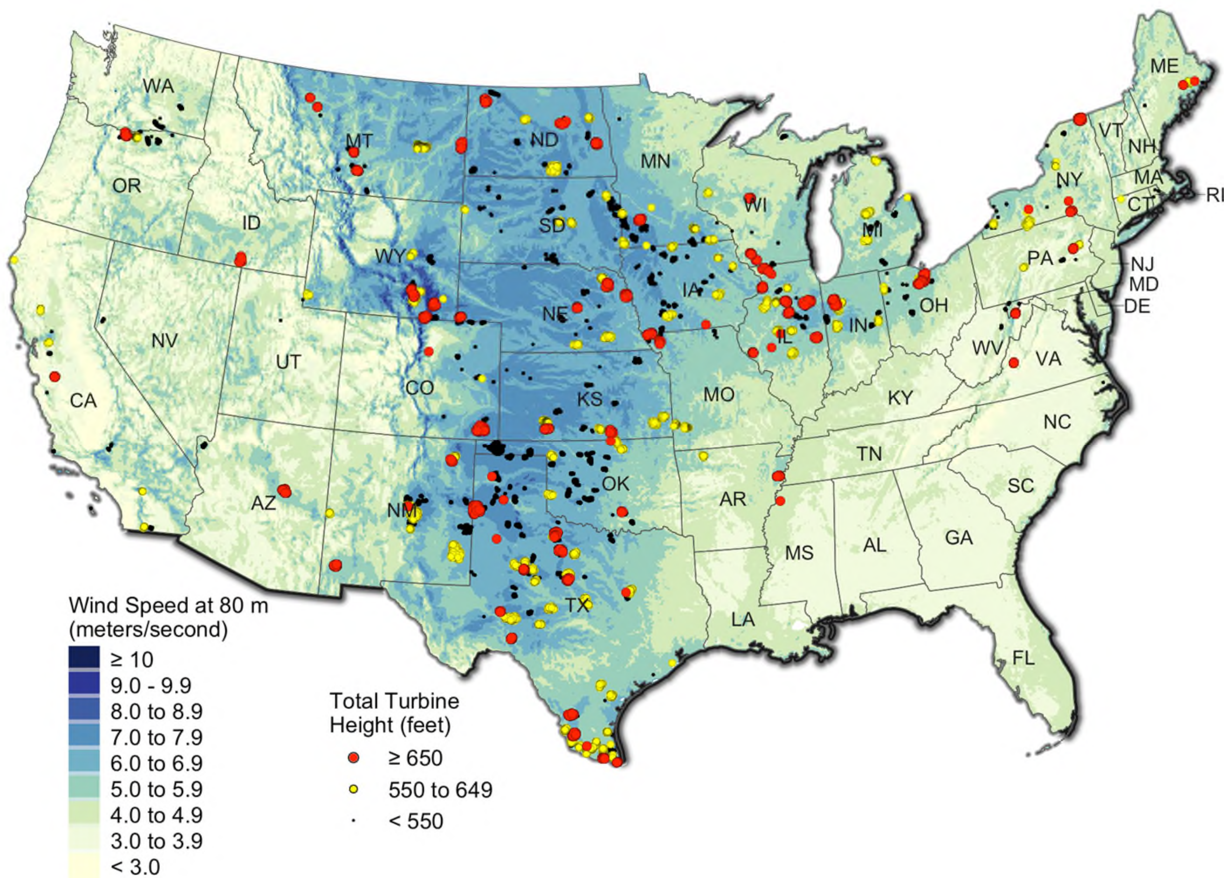


FAA = Federal Aviation Administration

Sources: AWEA Wind IQ, FAA OE/AAA files, AWS Truepower, Berkeley Lab

Geographic distribution of total turbine height based on proposed projects via FAA applications

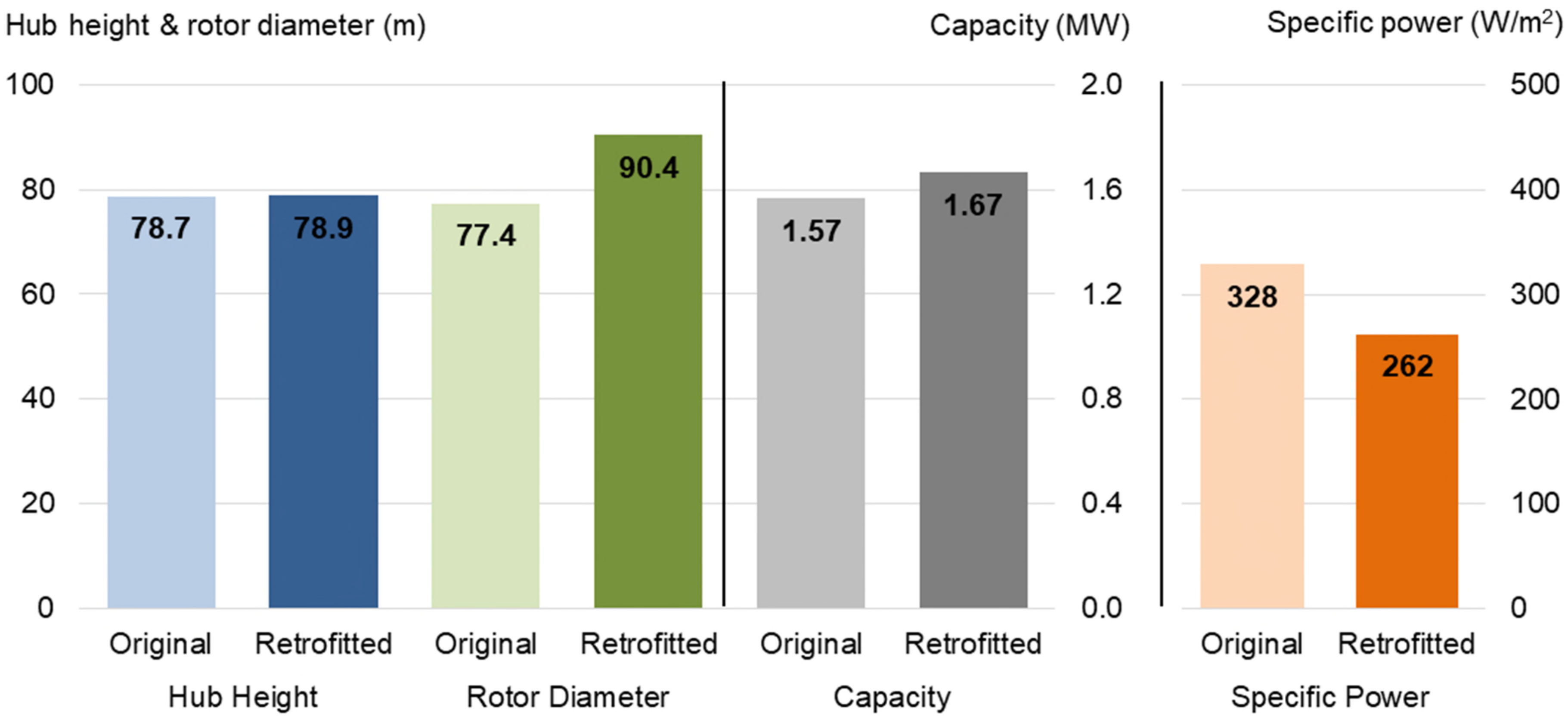
Tall turbines (via FAA pending and proposed) have been proposed in all regions and wind resource regimes, to varying degrees



FAA = Federal Aviation Administration

Sources: AWEA Wind IQ, FAA OE/AAA files, AWS Truepower, Berkeley Lab

Retrofitted turbines in 2019: changes in average hub height, rotor diameter, capacity, and specific power

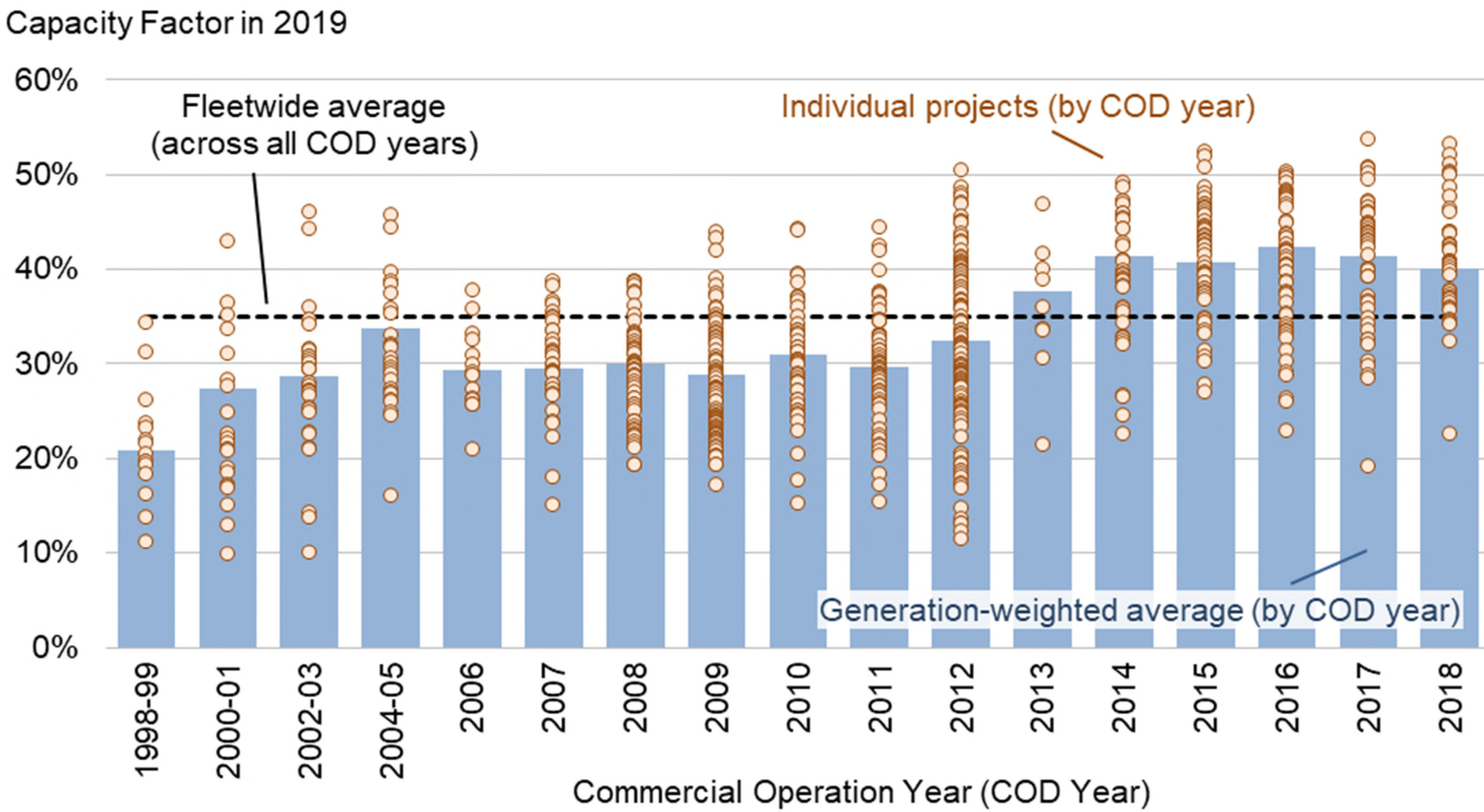


Sources: AWEA Wind IQ, Berkeley Lab, OEMs

- 1,828 turbines (2,864 MW) were retrofitted in 2019 via partial repowering
- Partial repowering most-often led to changes in rotor diameter and modest changes to nameplate capacity; tower height was rarely changed
- The mean age of turbines retrofitted in 2019 was just 11 years

Performance Data and Trends

Calendar year 2019 wind project capacity factors by commercial operation date

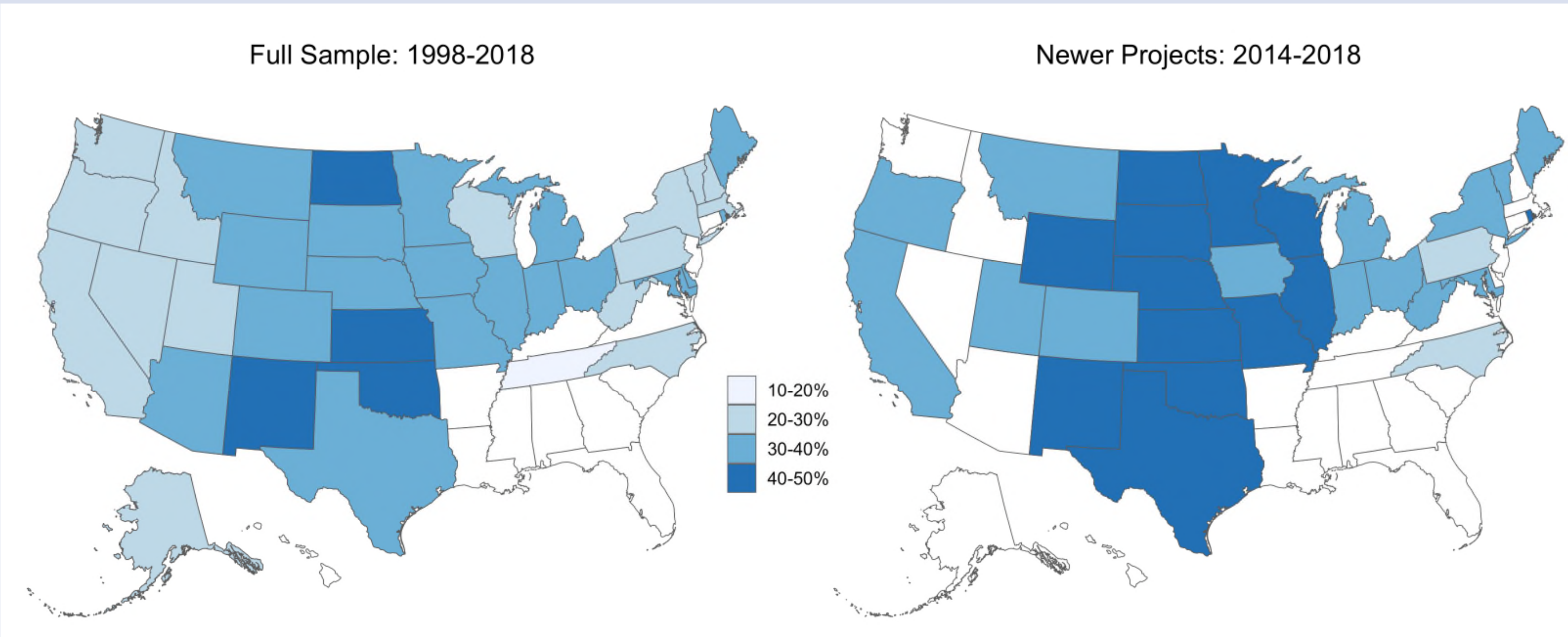


Source: EIA, FERC, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-power-performance

Average calendar year 2019 capacity factors by state: full sample of wind projects vs. more-recent projects

Newer projects (right figure) have considerably higher capacity factors than the full sample of 1998—2018 projects (left figure)

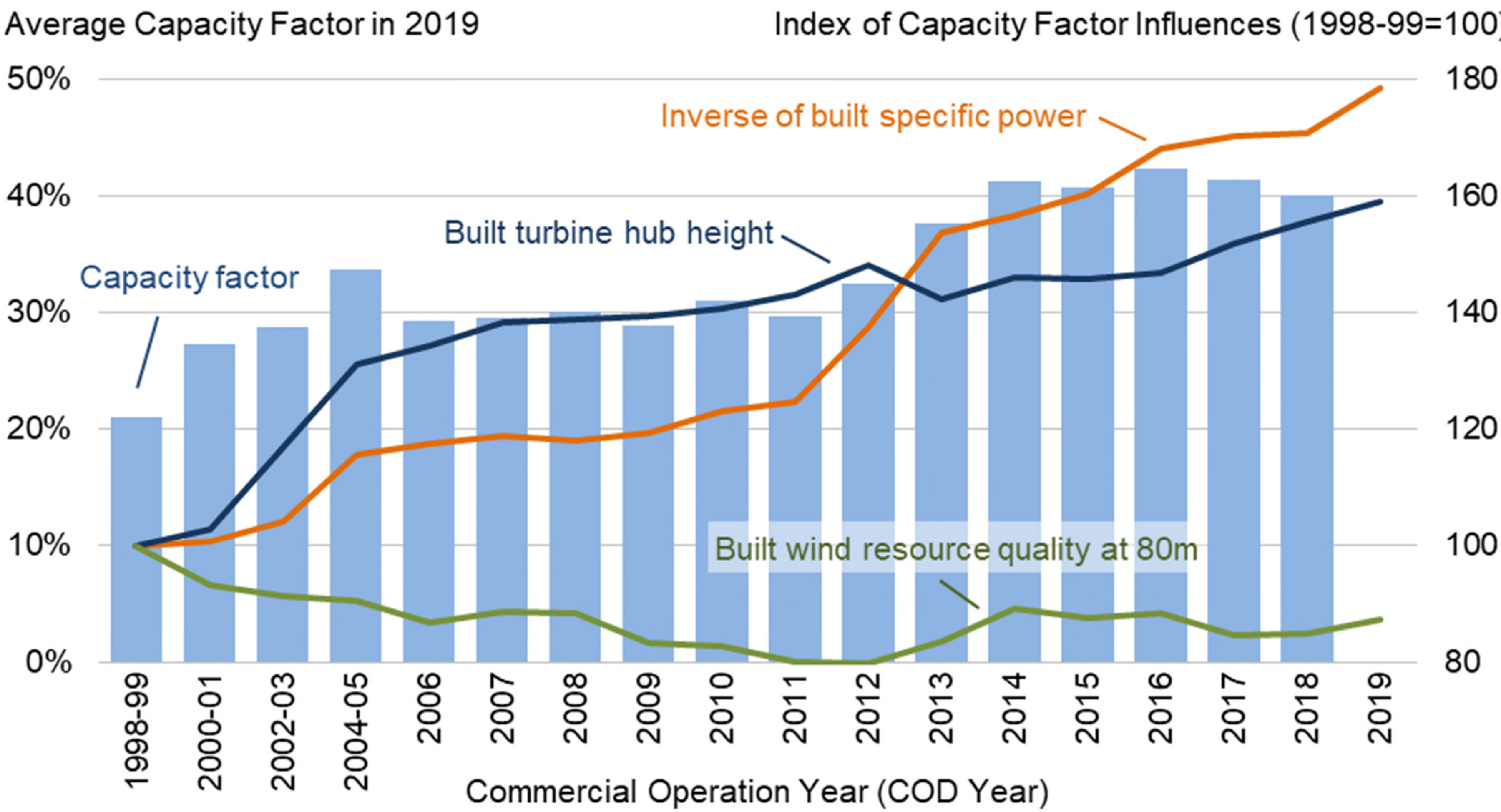


Source: EIA, FERC, Berkeley Lab

Note: States shaded in white have no projects in full sample (left) or in newer sample (right)

Interactive data visualization: https://emp.lbl.gov/wind-power-performance

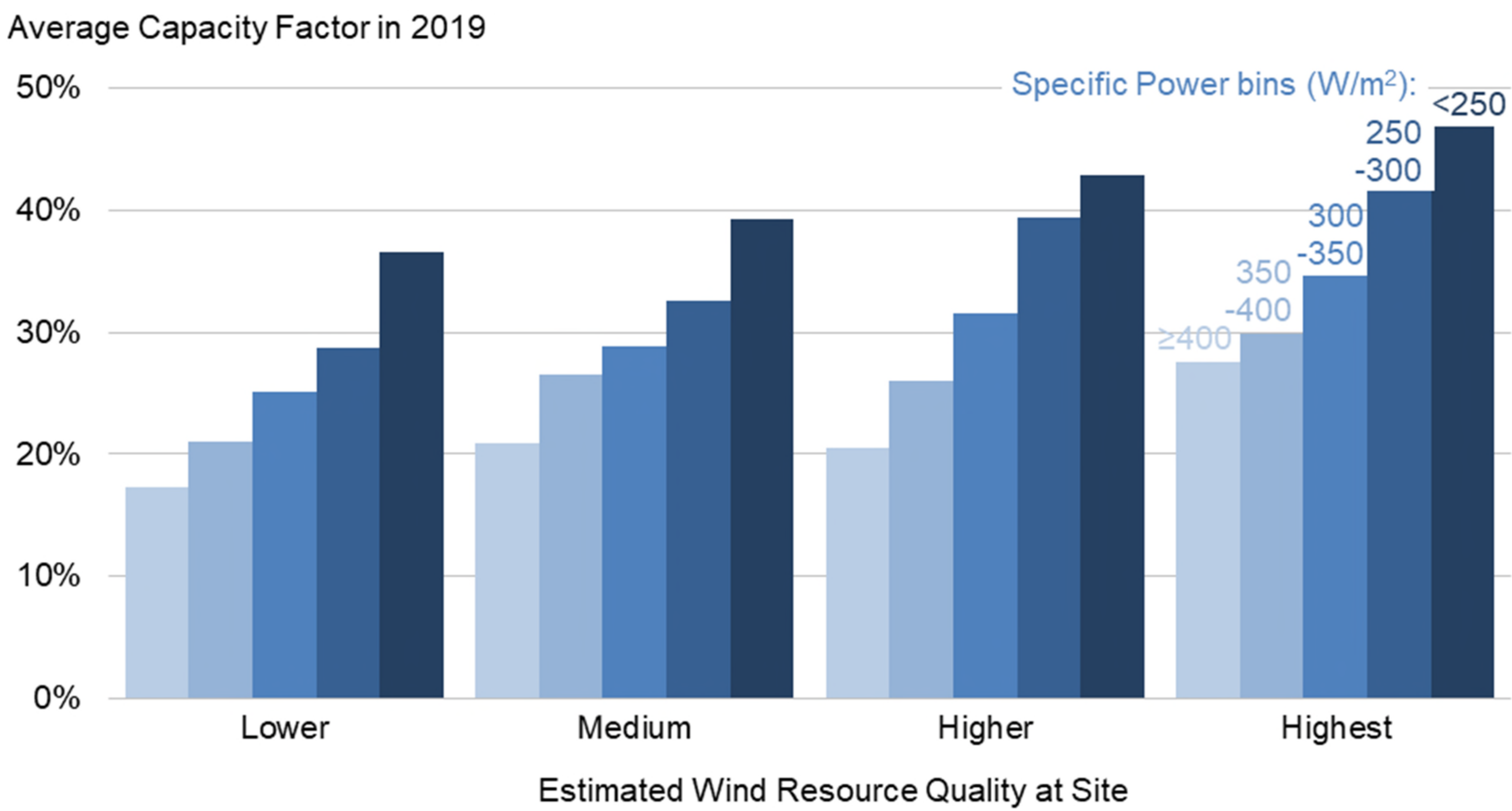
2019 capacity factors and various drivers by commercial operation date



Source: EIA, FERC, Berkeley Lab

Calendar year 2019 capacity factors by wind resource quality and specific power: 1998-2018 projects

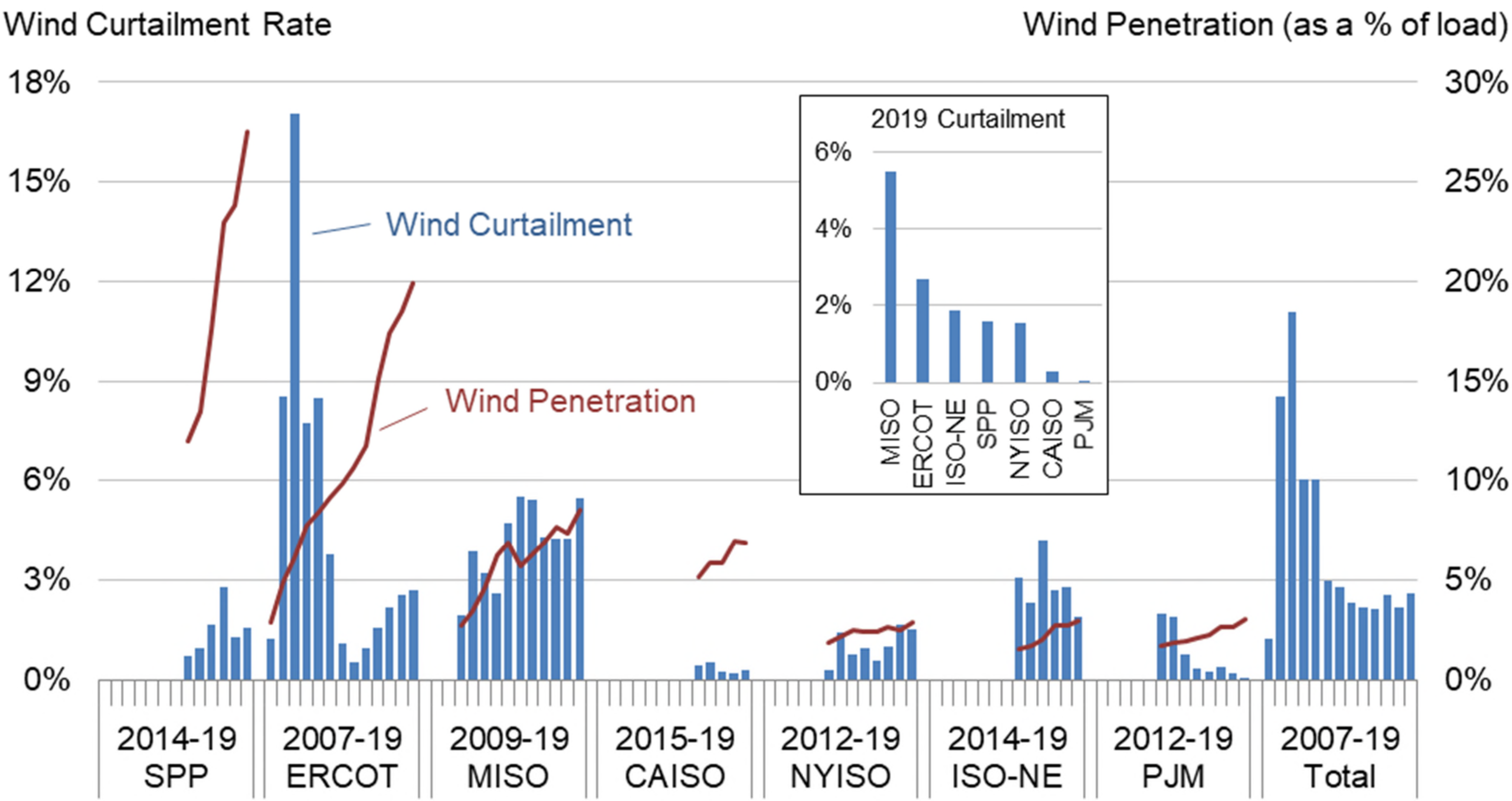
Low specific power turbines are driving capacity factors higher for projects located in given wind resource regimes



Source: EIA, FERC, Berkeley Lab

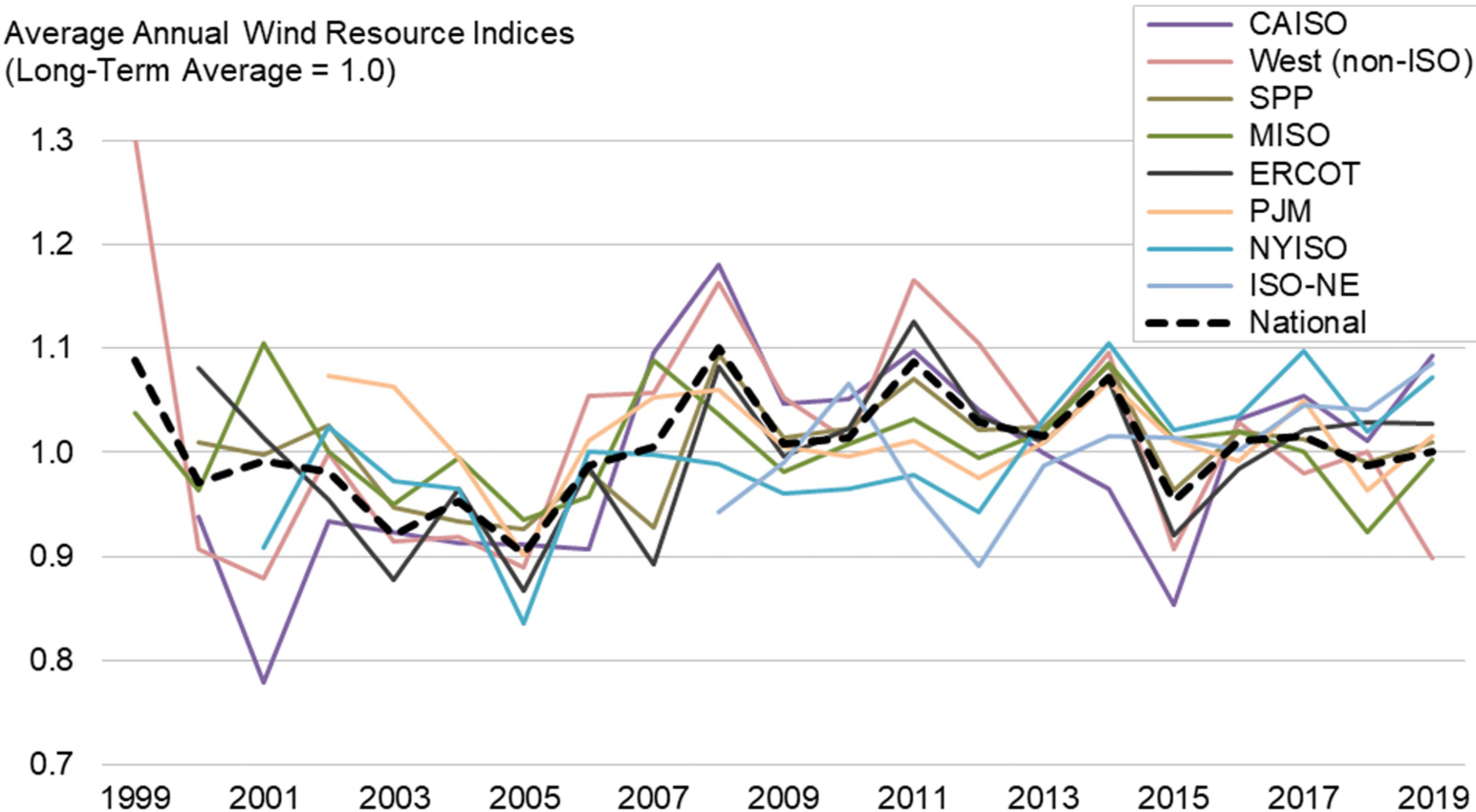
Note: Wind resource quality is based on site estimates of gross capacity factor at 80 meters by AWS Truepower, using a single, common wind-turbine power curve. The “lower” category includes all projects with an estimated gross capacity factor of less than 40%; “medium” corresponds to ≥40%–45%; “higher” ≥45%–50%; and “highest” ≥50%.

Wind curtailment and penetration rates by ISO



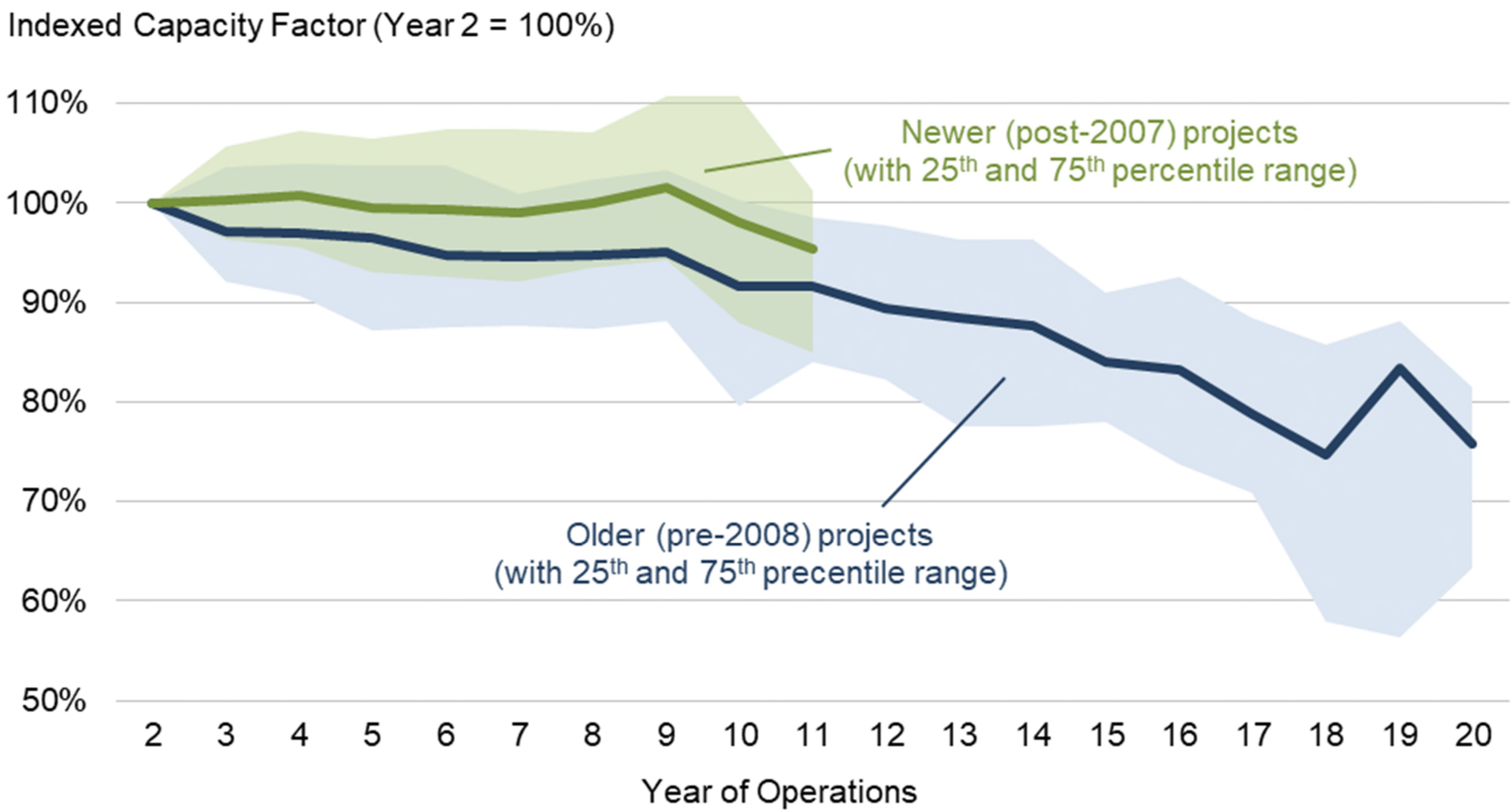
Sources: ERCOT, MISO, CAISO, NYISO, PJM, ISO-NE, SPP

Inter-annual variability in the wind resource by region and nationally



Source: ERA, Berkeley Lab; methodology behind the index of inter-annual variability is explained in report appendix

Changes in project-level capacity factors as projects age: newer projects vs. older projects

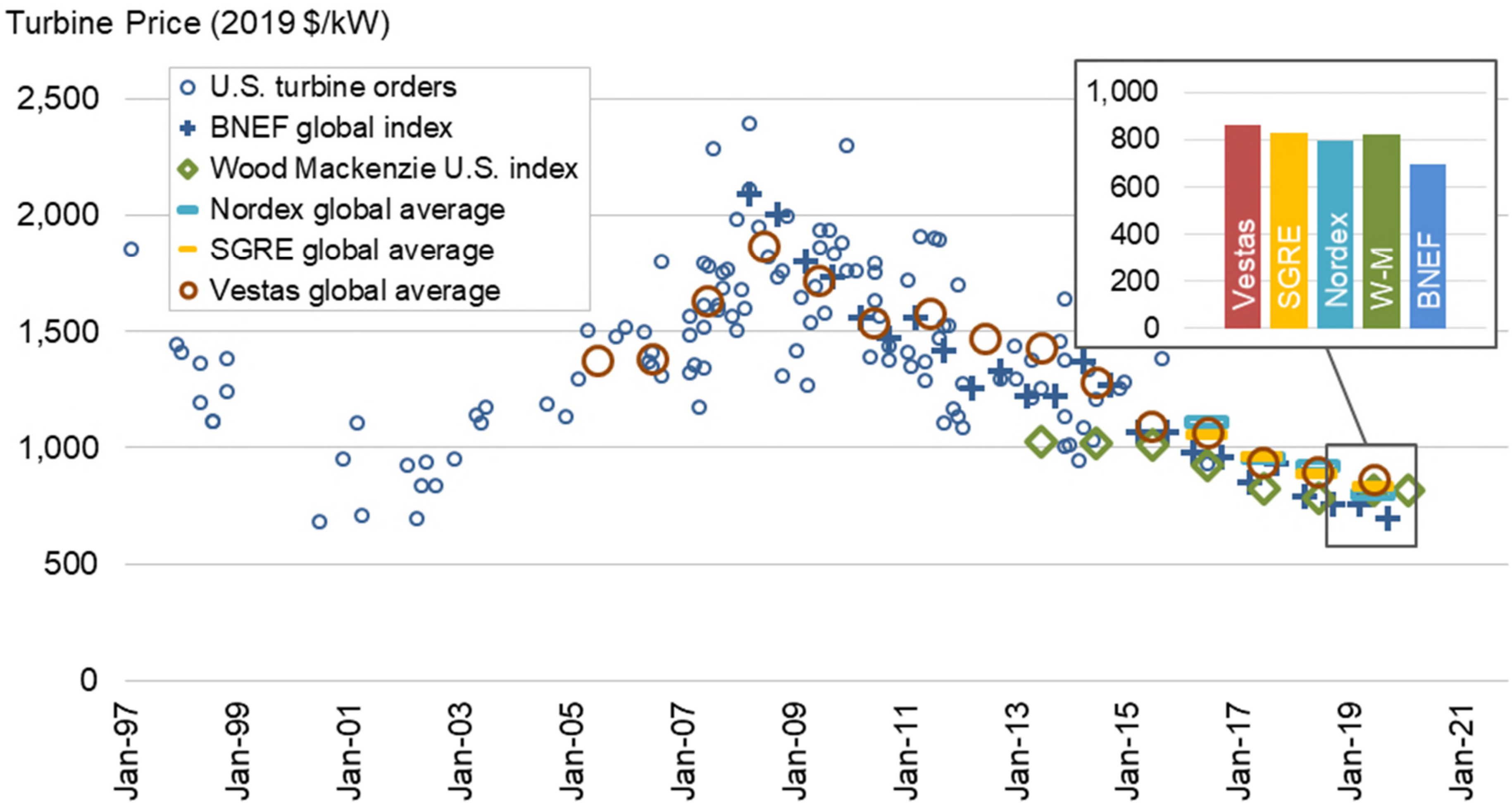


Source: EIA, FERC, Berkeley Lab

For more analysis on wind project performance with plant age, see:
https://emp.lbl.gov/publications/how-does-wind-project-performance

Cost Data and Trends

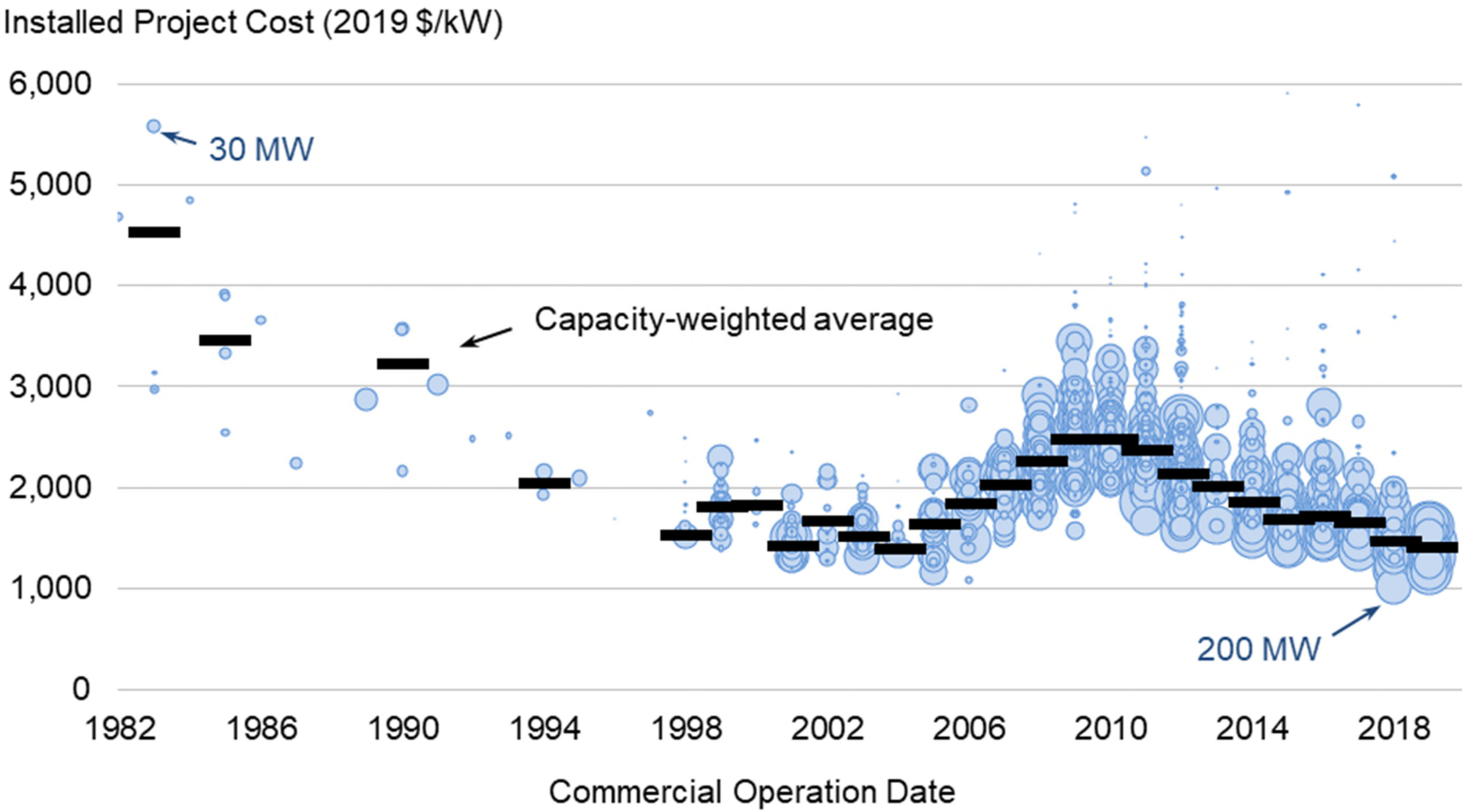
Reported wind turbine transaction prices per unit of capacity, over time



Sources: Berkeley Lab, annual financial reports, forecast providers

Turbine price = tower, nacelle, blades, delivery to site

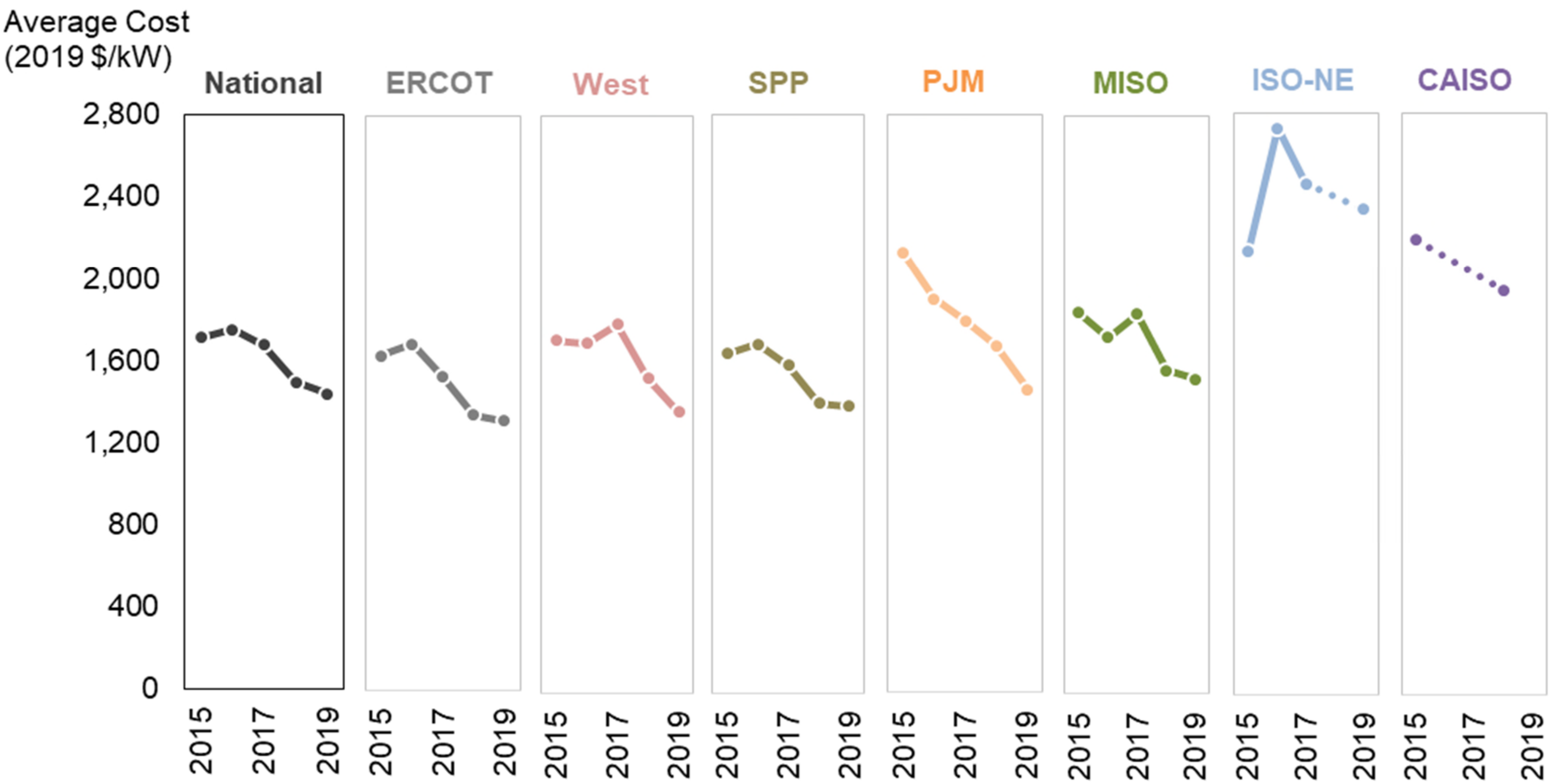
Installed wind power project costs per unit of capacity, over time



Sources: Berkeley Lab (some data points suppressed to protect confidentiality), Energy Information Administration

Interactive data visualization: https://emp.lbl.gov/wind-energy-capital-expenditures-capex

Installed wind power project costs per unit of capacity, by region and over time



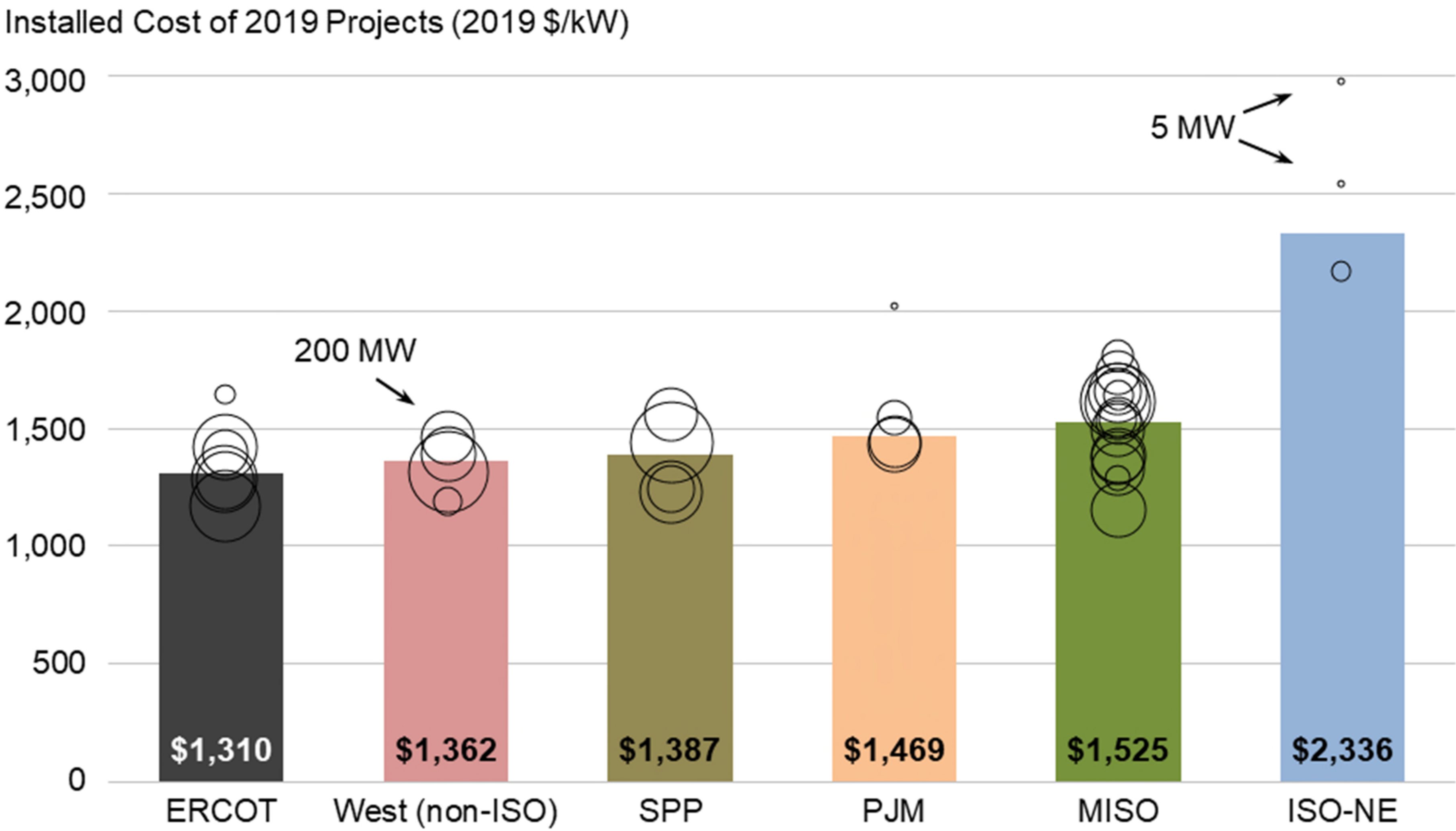
Sources: Berkeley Lab (some data points suppressed to protect confidentiality), Energy Information Administration

Note: Total sample presented here includes 34 GW of installed wind capacity, but regional sample is especially small in ISO-NE (569 MW) and CAISO (319 MW, no data in 2019).

BERKELEY LAB

Interactive data visualization: https://emp.lbl.gov/wind-energy-capital-expenditures-capex

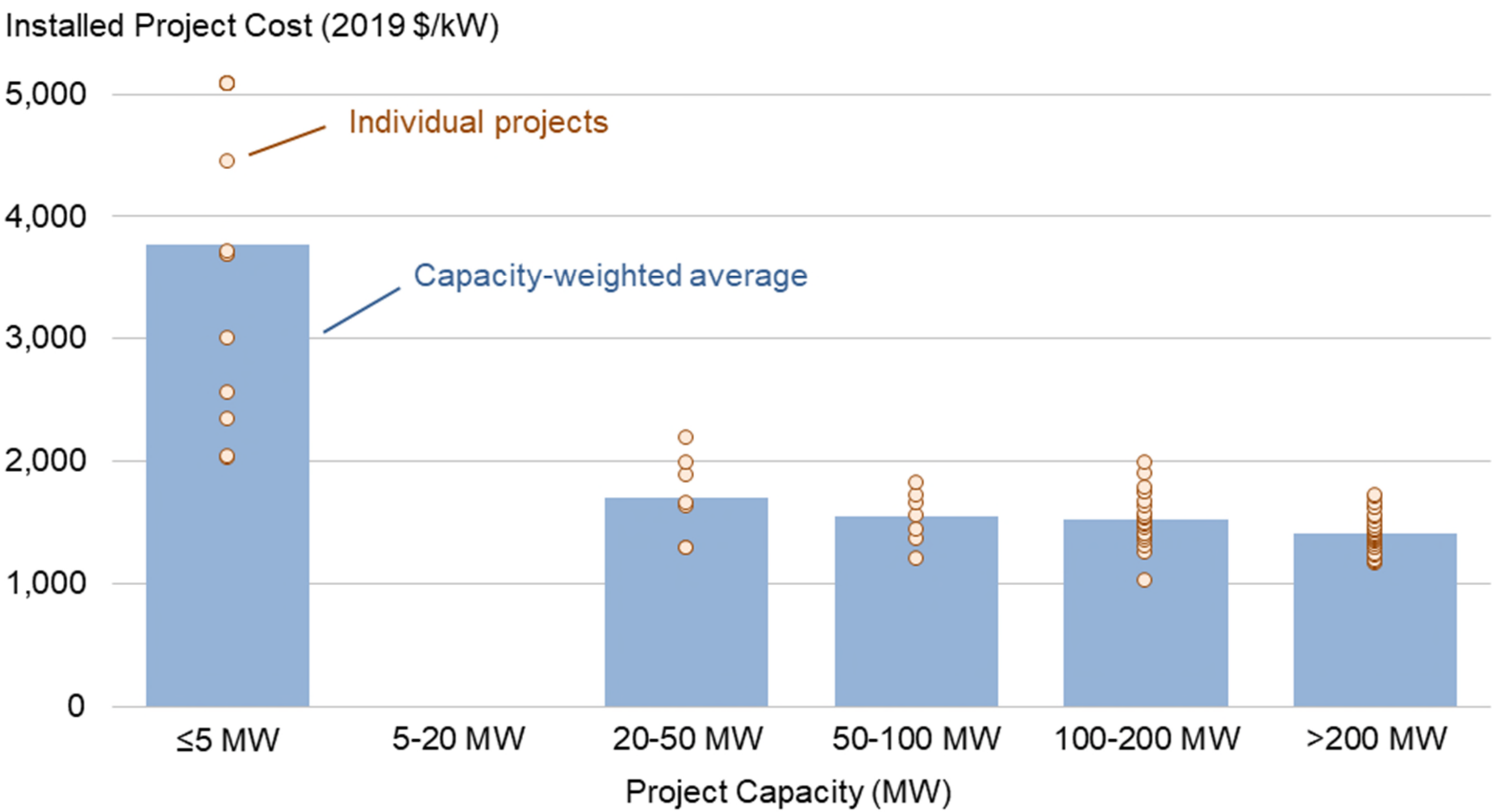
Installed wind power project costs per unit of capacity, by region in 2019



Sources: Berkeley Lab, Energy Information Administration

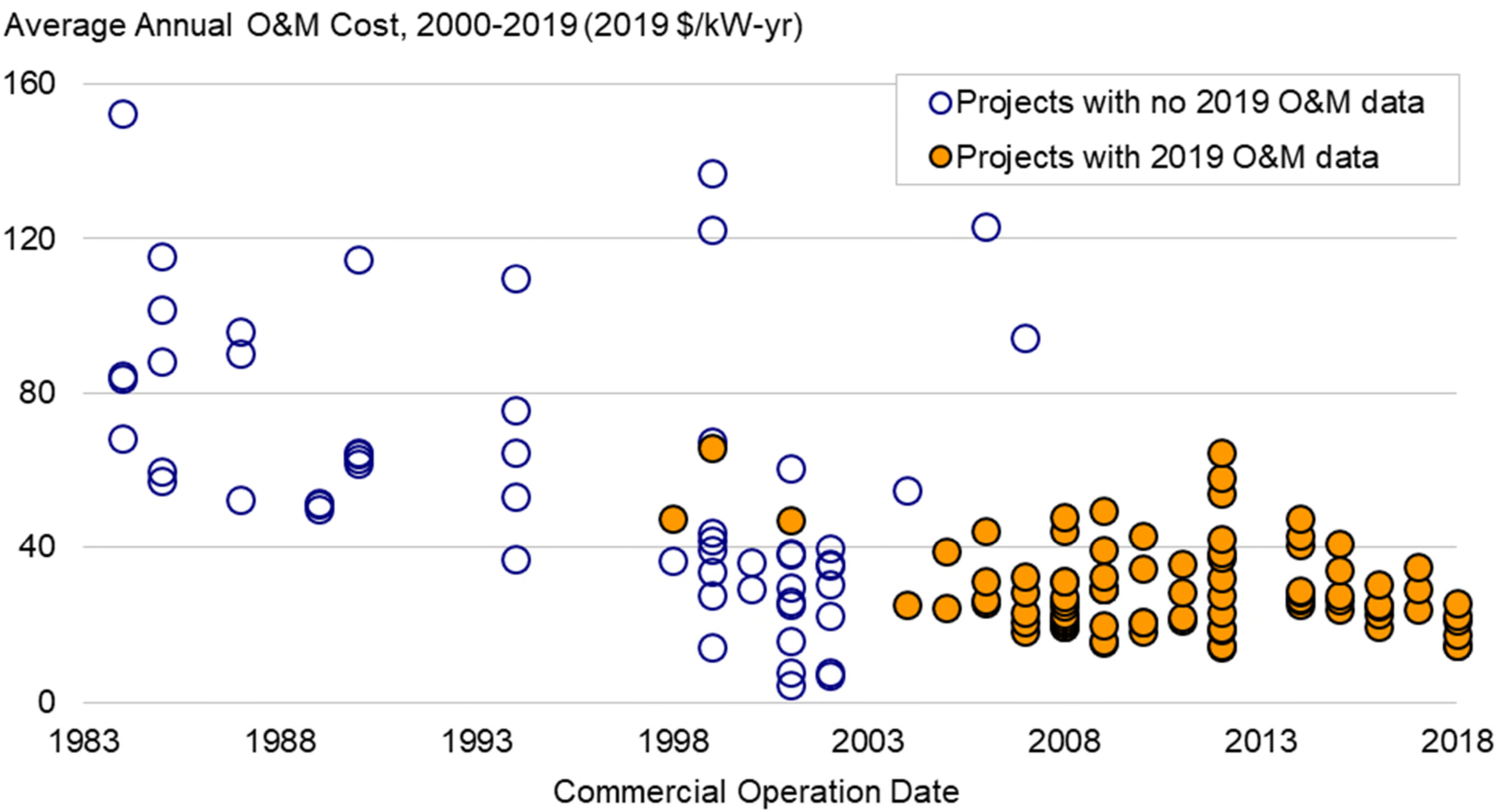
Interactive data visualization: https://emp.lbl.gov/wind-energy-capital-expenditures-capex

Installed wind power project costs by project size: 2018 and 2019 projects



Source: Berkeley Lab

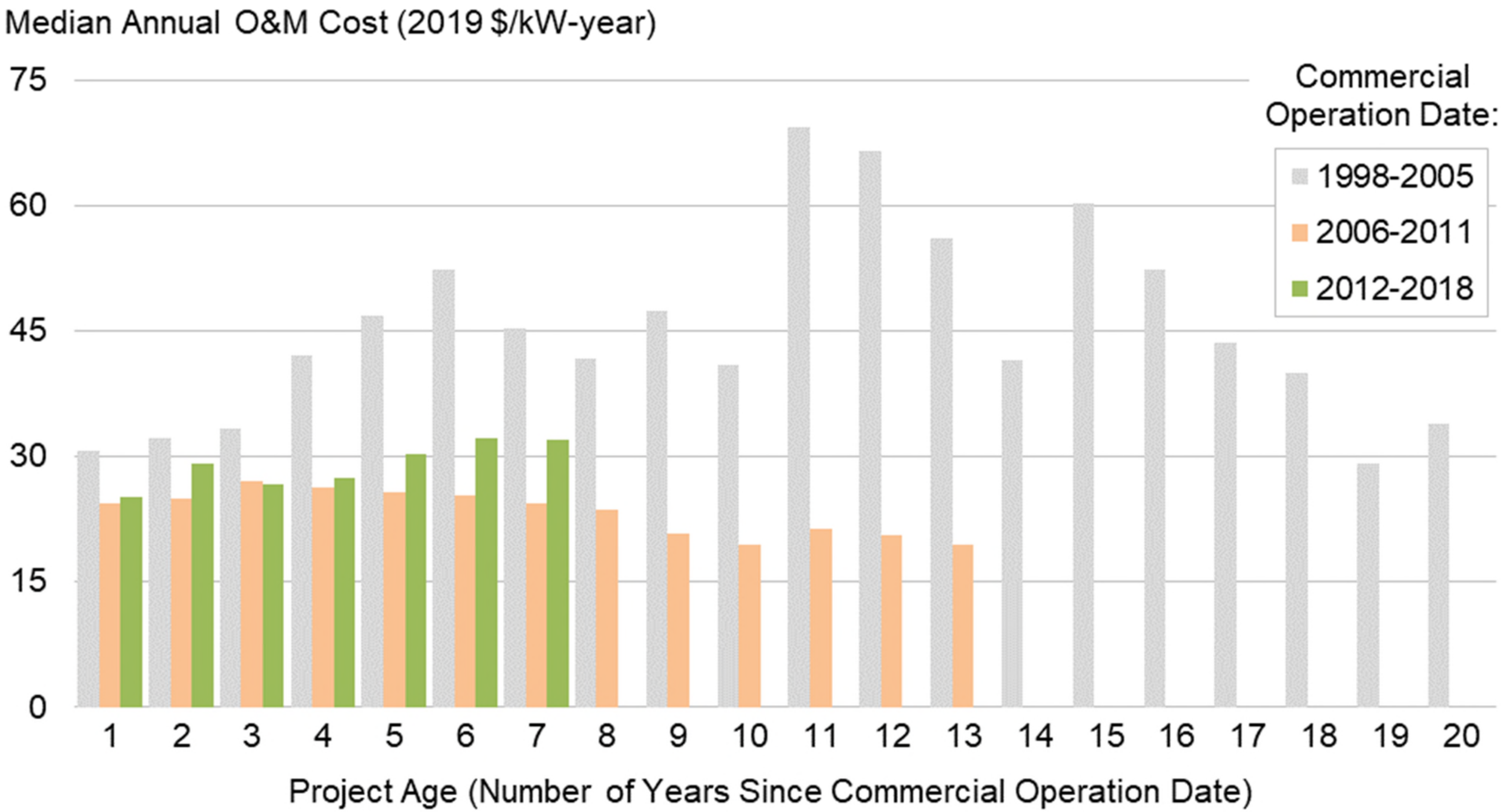
Average operations and maintenance (O&M) costs per unit of capacity, for available data years from 2000 to 2019, by COD



Source: Berkeley Lab, EIA, FERC; some data points suppressed to protect confidentiality

Note: Sample is limited; few projects in sample have complete records of O&M costs from 2000-19; O&M costs reported here do not include all operating costs.

Median annual O&M costs by project age and commercial operation date



Source: Berkeley Lab; EIA, FERC; medians shown only for groups of two or more projects, and only projects >5 MW are included.

Note: Sample size is limited, especially in years 15-20

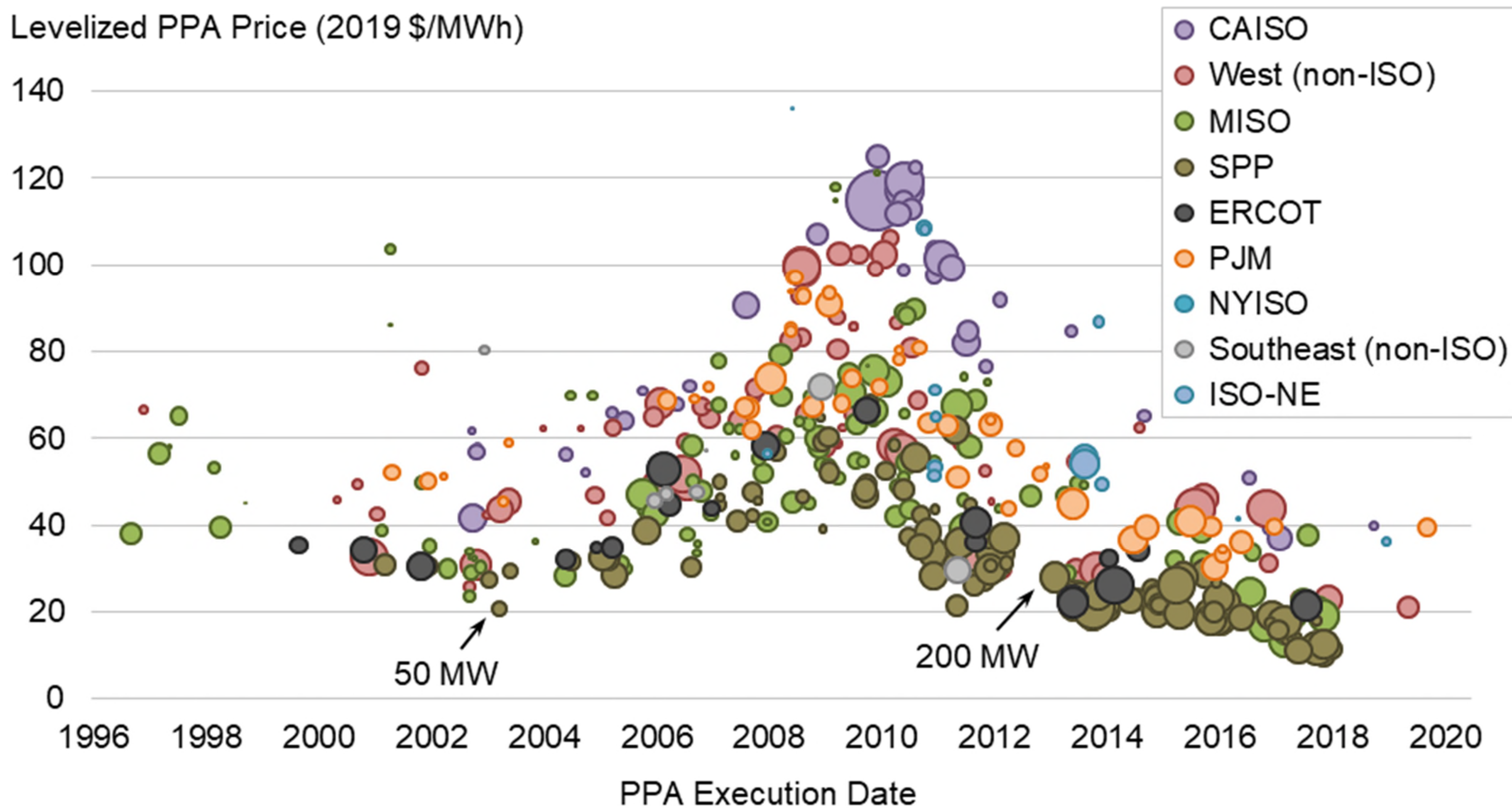
O&M reported here does not include all operating costs: all-in operating costs for the most recent wind projects average ~$43/kW-year

Power Sales Price and Levelized Cost Data and Trends

Wind power sales price and LCOE analysis: data sets and methodology

- Berkeley Lab collects data on long-term power purchase agreement (PPA) prices for wind energy
- Sample includes 465 contracts totaling 44,026 MW from projects built from 1998 to the present, or planned for future installation
- Prices reflect the bundled price of electricity and RECs as sold by the project owner under a PPA
  - Dataset excludes merchant plants, projects that sell renewable energy certificates (RECs) separately, and most direct retail sales
  - Prices reflect receipt of state and federal incentives (e.g., the PTC), and various market influences; as a result, prices do not reflect wind generation costs
- Also presented are Level10 Energy data on PPA offers; these are often for shorter contract durations, and levelization details are unclear
- Levelized cost of energy is calculated based on following assumptions
  - Project-level CapEx and capacity factor data presented elsewhere in this deck
  - Levelized OpEx declines from \$83/kW-yr in 1998 to \$43/kW-yr in 2019 (2019\$); project life increases from 20 years in 1998 to 29.6 years in 2019 (from previous LBNL research)
  - Weighted average cost of capital (WACC) based on 10% equity return over time; debt interest rate varies over time as shown earlier in deck; constant 65%/35% debt/equity ratio
  - Combined income tax of 40% pre-2018 and 27% post-2017; 5-yr MACRS; no PTC; 2% inflation

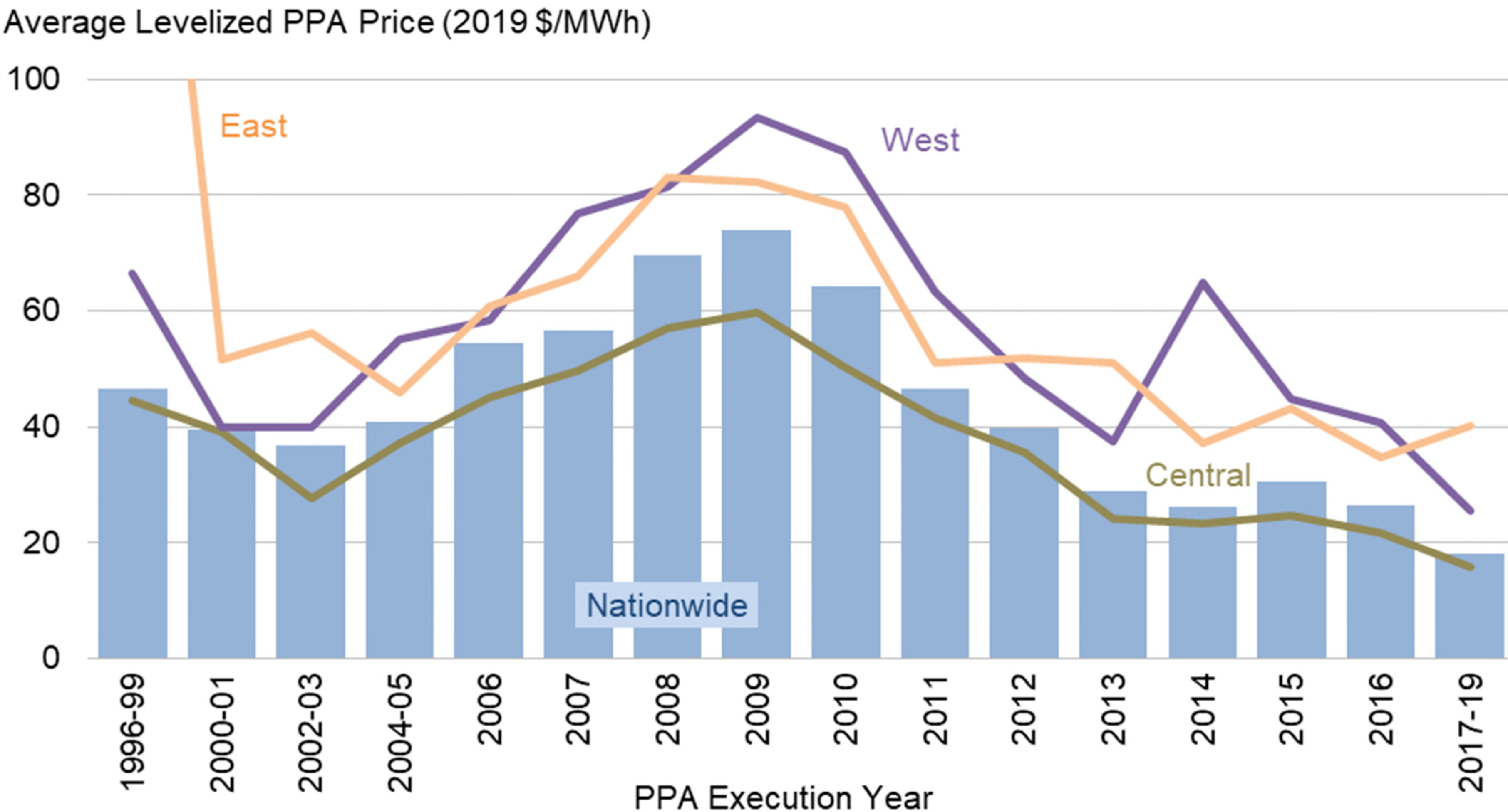
Levelized wind PPA prices by PPA execution date and region (full sample)



Source: Berkeley Lab, FERC

Interactive data visualization: https://emp.lbl.gov/wind-power-purchase-agreement-ppa-prices

Generation-weighted average levelized wind PPA prices by PPA execution date: national and region averages

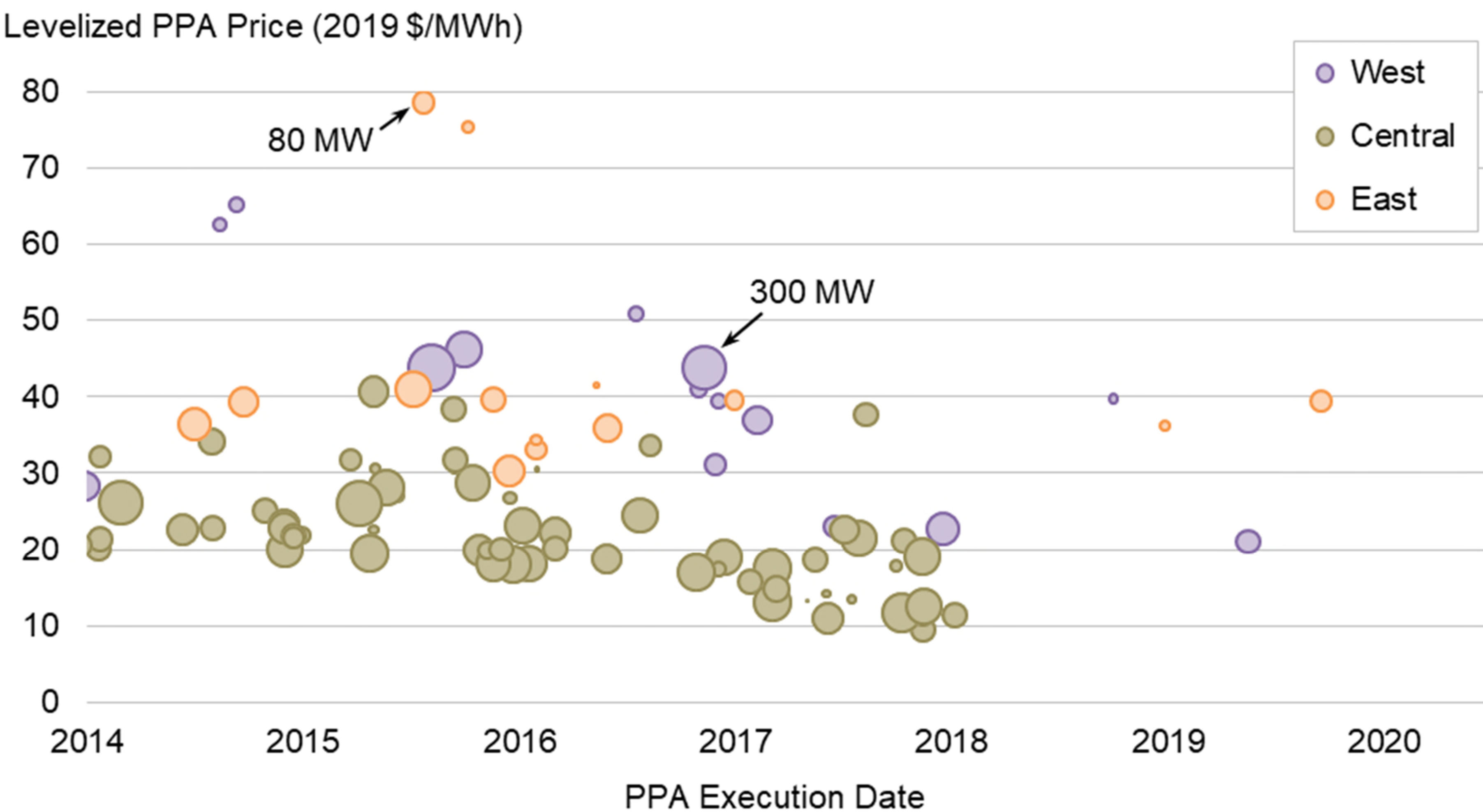


Source: Berkeley Lab, FERC

Note: West = CAISO, West (non-ISO); Central = MISO, SPP, ERCOT; East = PJM, NYISO, ISO-NE, Southeast (non-ISO)

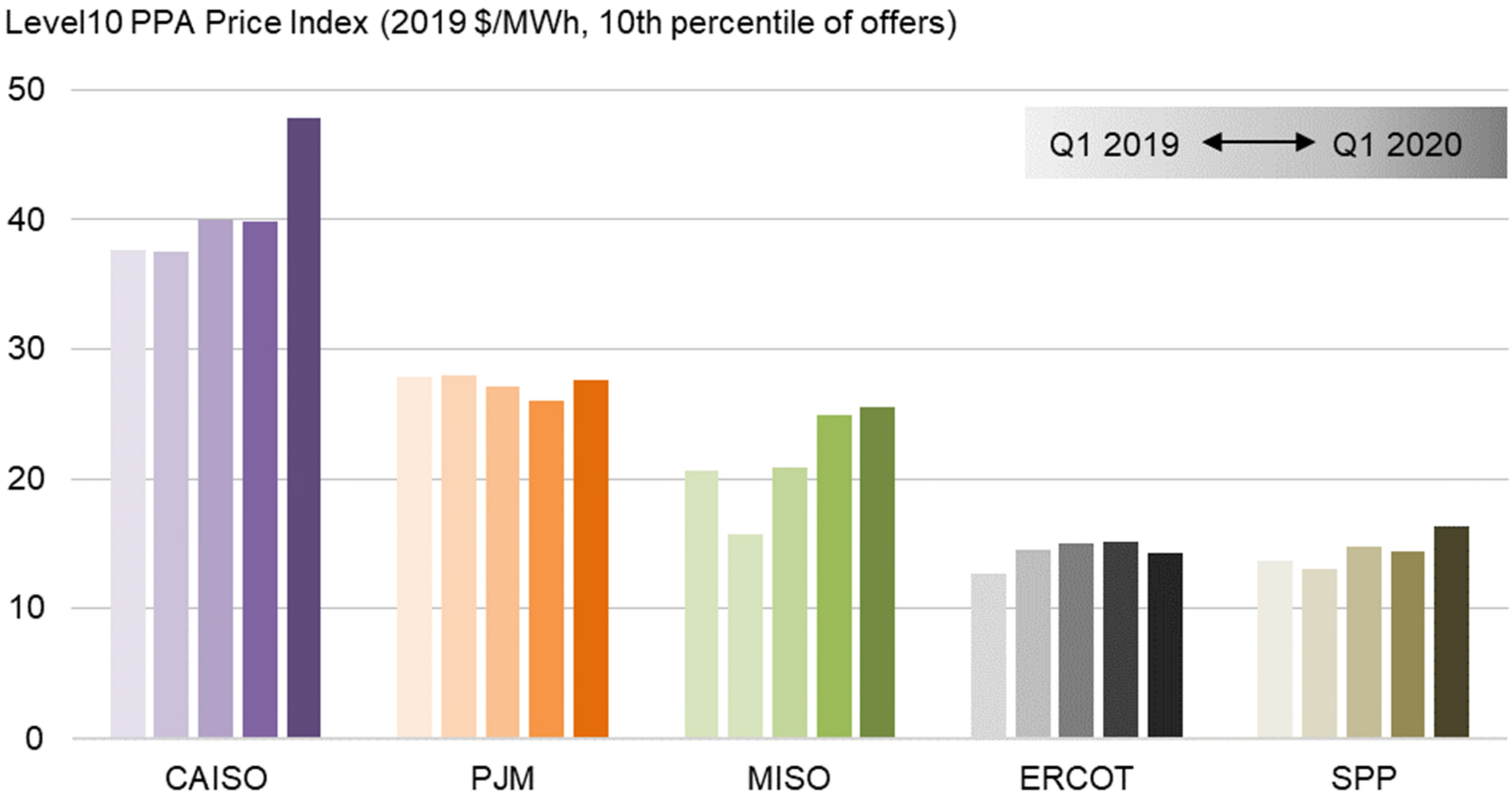
Interactive data visualization: https://emp.lbl.gov/wind-power-purchase-agreement-ppa-prices

Levelized wind PPA prices by PPA execution date and region (recent sample)



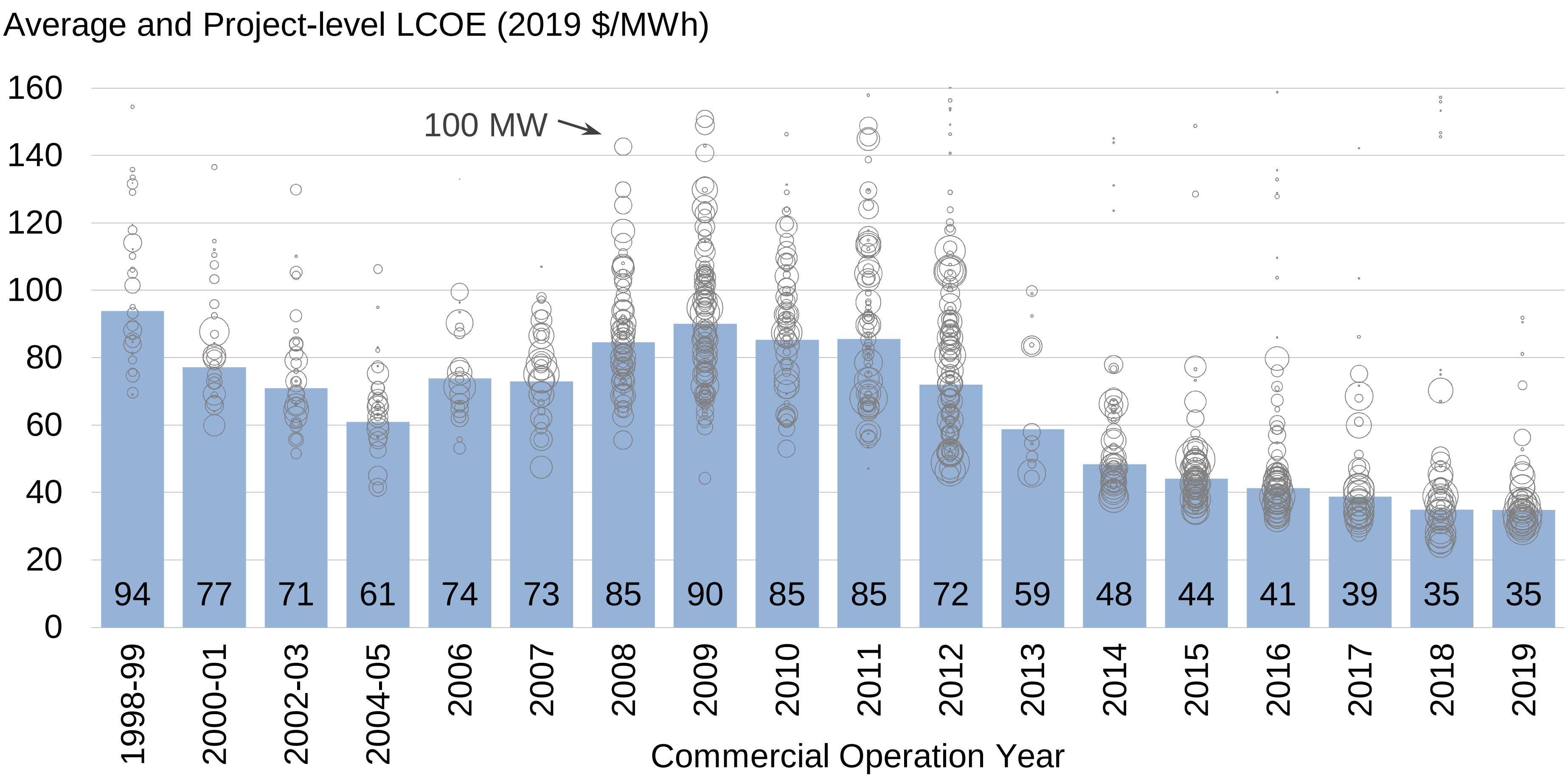
Source: Berkeley Lab, FERC

Level10 Energy wind PPA price indices



Source: Level10 Energy

Levelized cost of wind energy by commercial operation date

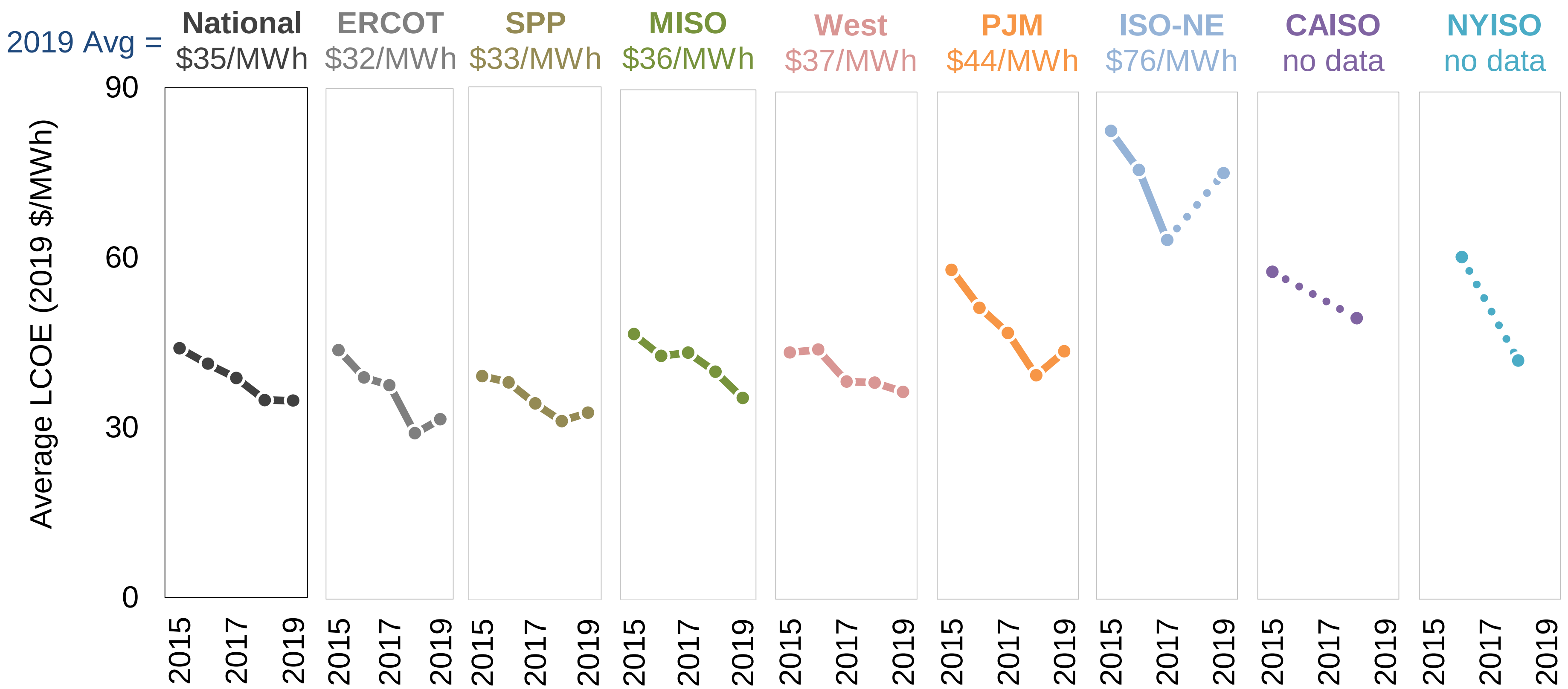


Source: Berkeley Lab

Note: Yearly estimates reflect variations in installed cost, capacity factors, operational costs, cost of financing, and project life; includes accelerated depreciation but exclude PTC. See full report for details.

Interactive data visualization: https://emp.lbl.gov/levelized-cost-wind-energy

Levelized cost of wind energy by region, over last five years

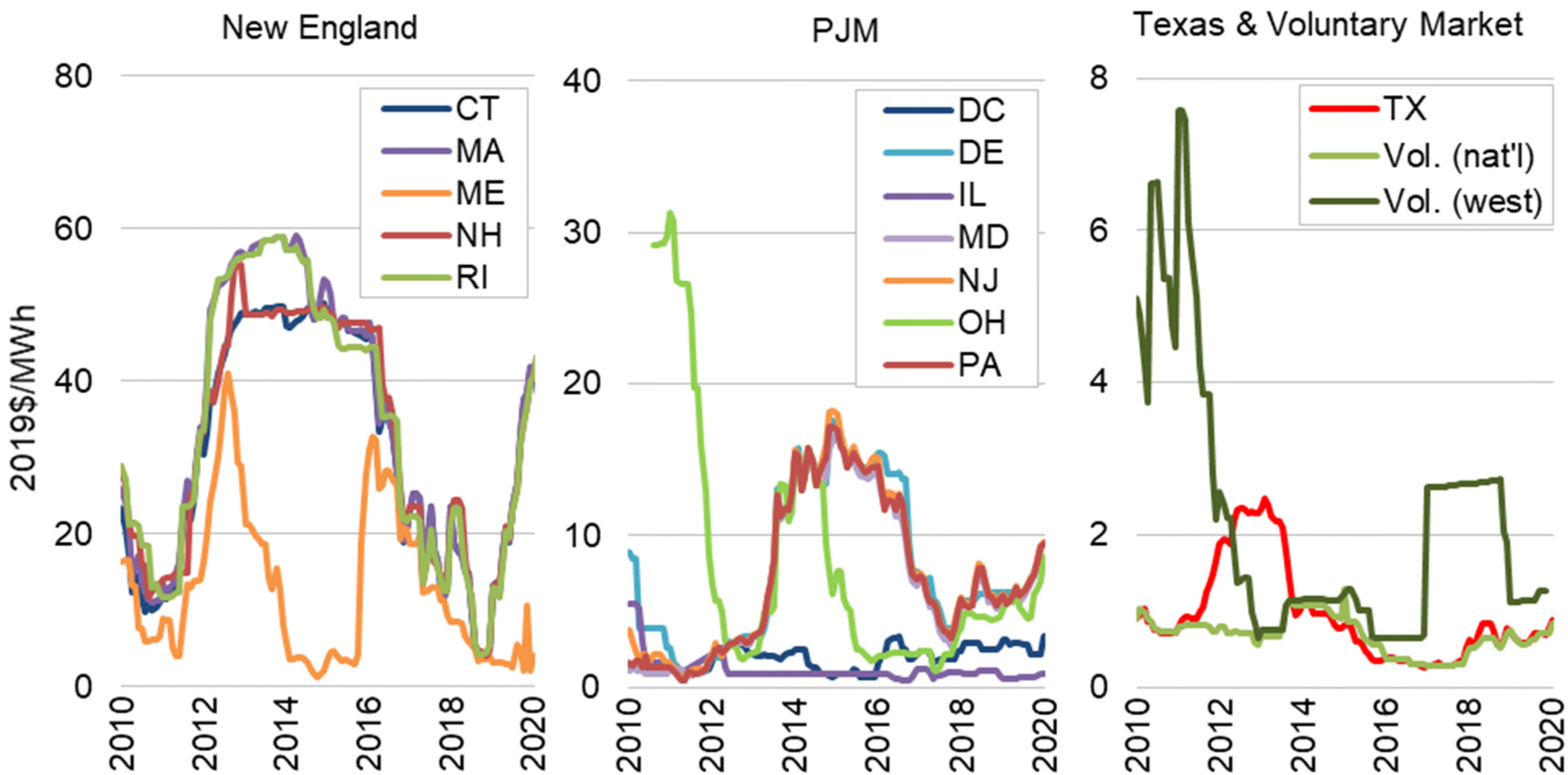


Source: Berkeley Lab

Note: Total sample presented here includes 34 GW of installed wind capacity, but regional sample is especially small in ISO-NE (569 MW), CAISO (319 MW, no data in 2019), and NYISO (156 MW, no data in 2019)

Interactive data visualization: https://emp.lbl.gov/levelized-cost-wind-energy

Historical renewable energy certificate (REC) prices

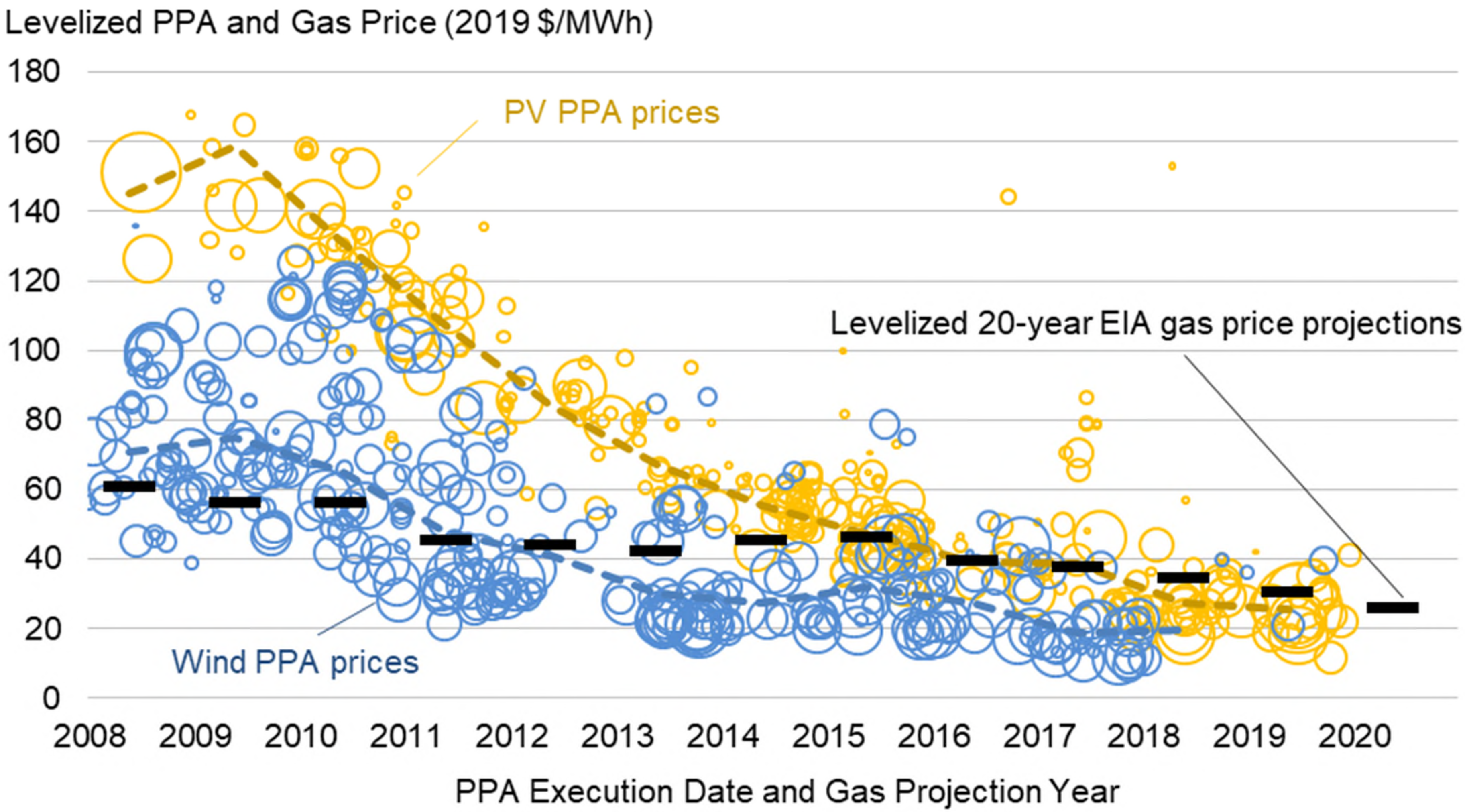


Source: Marex Spectron

REC prices vary by: market type (compliance vs. voluntary); geographic region; specific design of state RPS policies.

Price and Value Comparisons

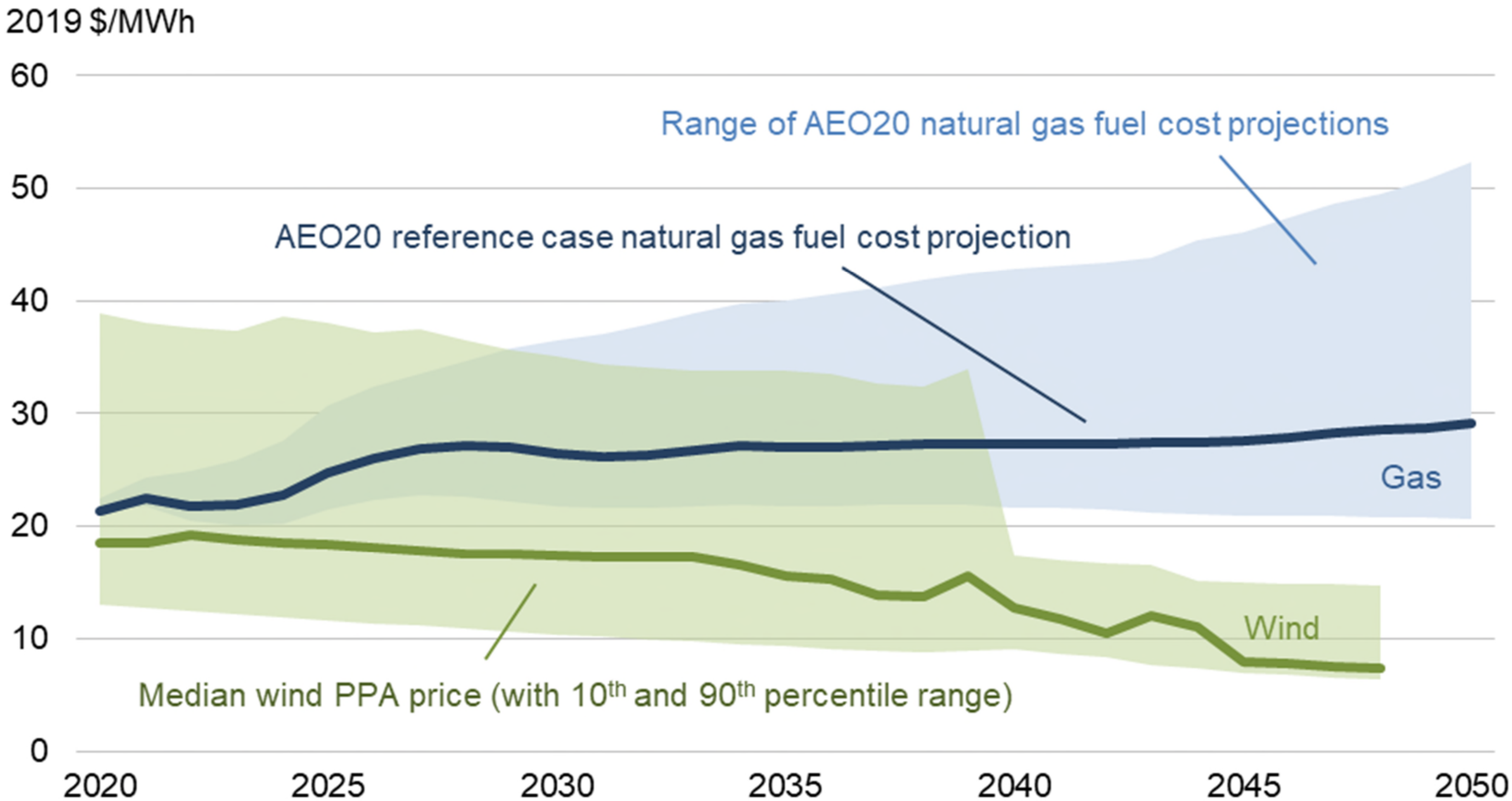
Levelized wind and solar PPA prices and levelized gas prices



Source: Berkeley Lab, FERC, Energy Information Administration

Note: Smallest bubble sizes reflect smallest-volume PPAs (<5 MW), whereas largest reflect largest-volume PPAs (>500 MW).

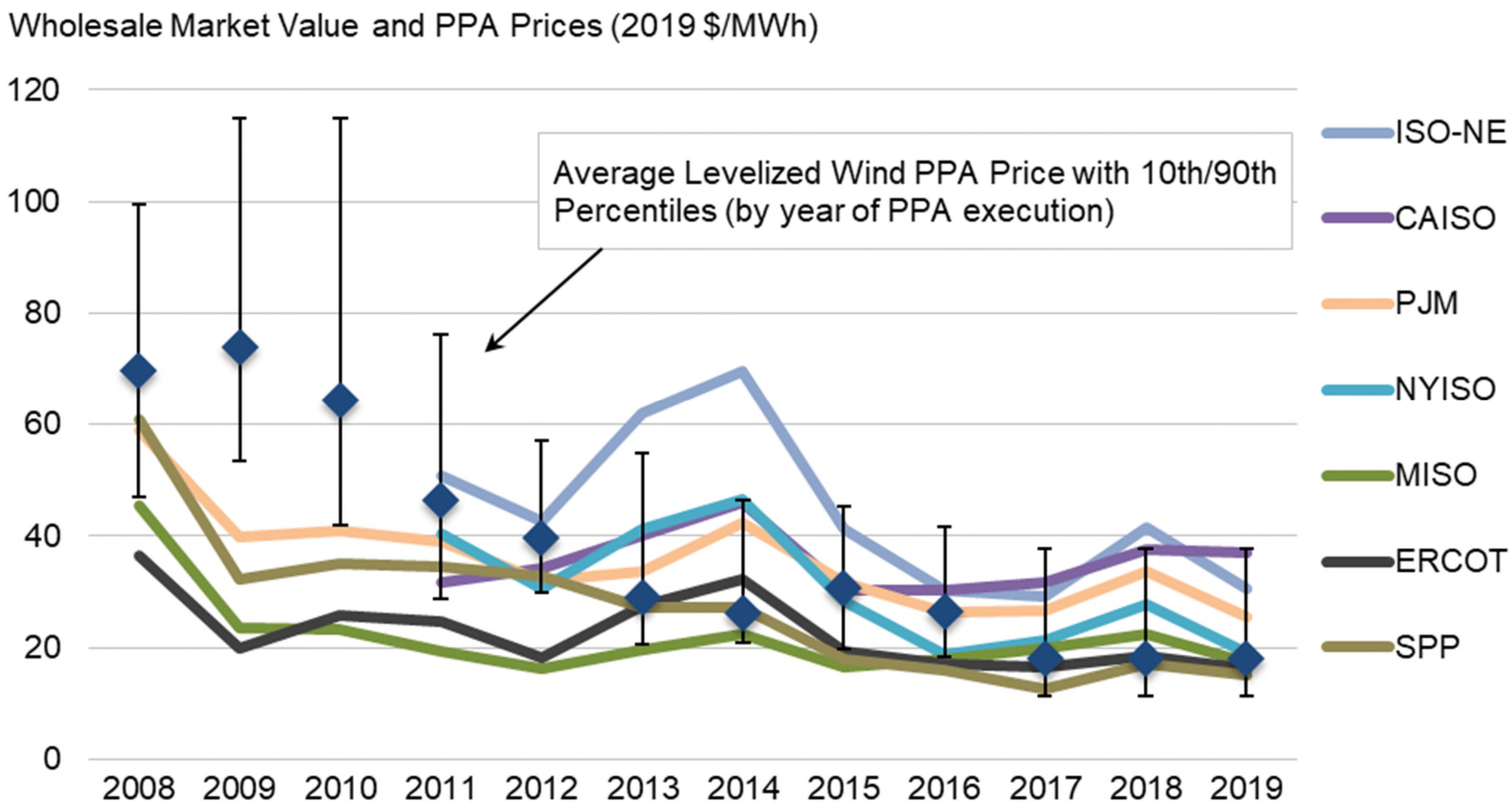
Wind PPA prices and natural gas fuel costs by calendar year over time



Source: Berkeley Lab, FERC, Energy Information Administration

Notes: Price comparisons shown are far from perfect—see earlier 2019 report for details. Large drop in upper range of wind prices in 2040 reflects a smaller sample of generally-lower-priced projects.

Regional wholesale market value of wind and average levelized long-term wind PPA prices over time



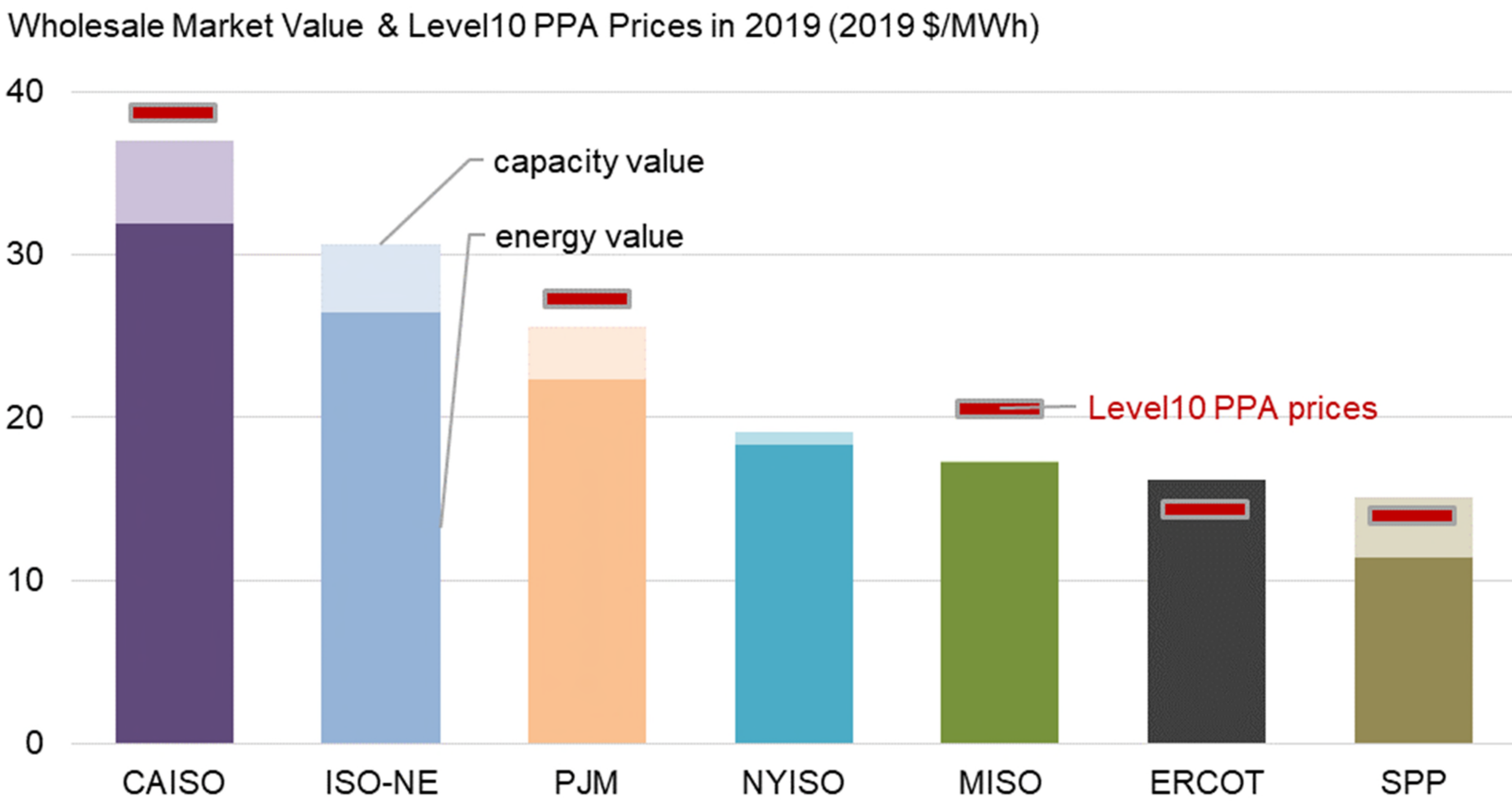
Sources: Berkeley Lab, ABB, ISOs

- Wholesale market value considers hourly local wholesale energy price and hourly wind output, along with capacity value where available
- Wholesale market value has declined over last decade, but recent wind PPAs are comparable to grid-system market value

Interactive data visualization: https://emp.lbl.gov/wind-energy-market-value

Wholesale market value of wind in 2019 by region, and compared to Level10 wind PPA prices

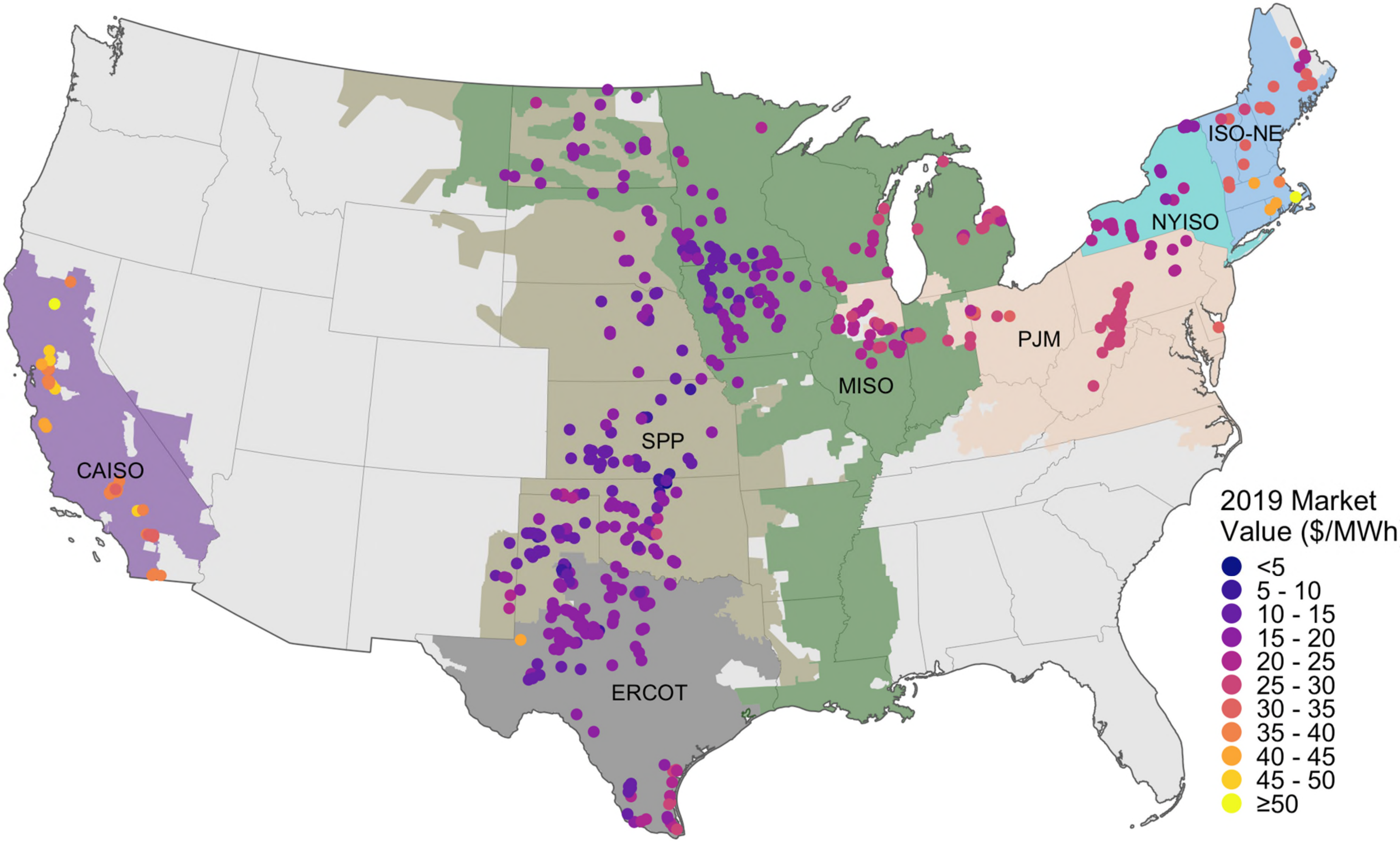
Recent wind PPA prices are comparable to 2019 grid-system market value in many regions: sometimes slightly higher, sometimes lower



Sources: Berkeley Lab, ABB, ISOs

Interactive data visualization: https://emp.lbl.gov/wind-energy-market-value

Wholesale market value of wind in 2019, by plant

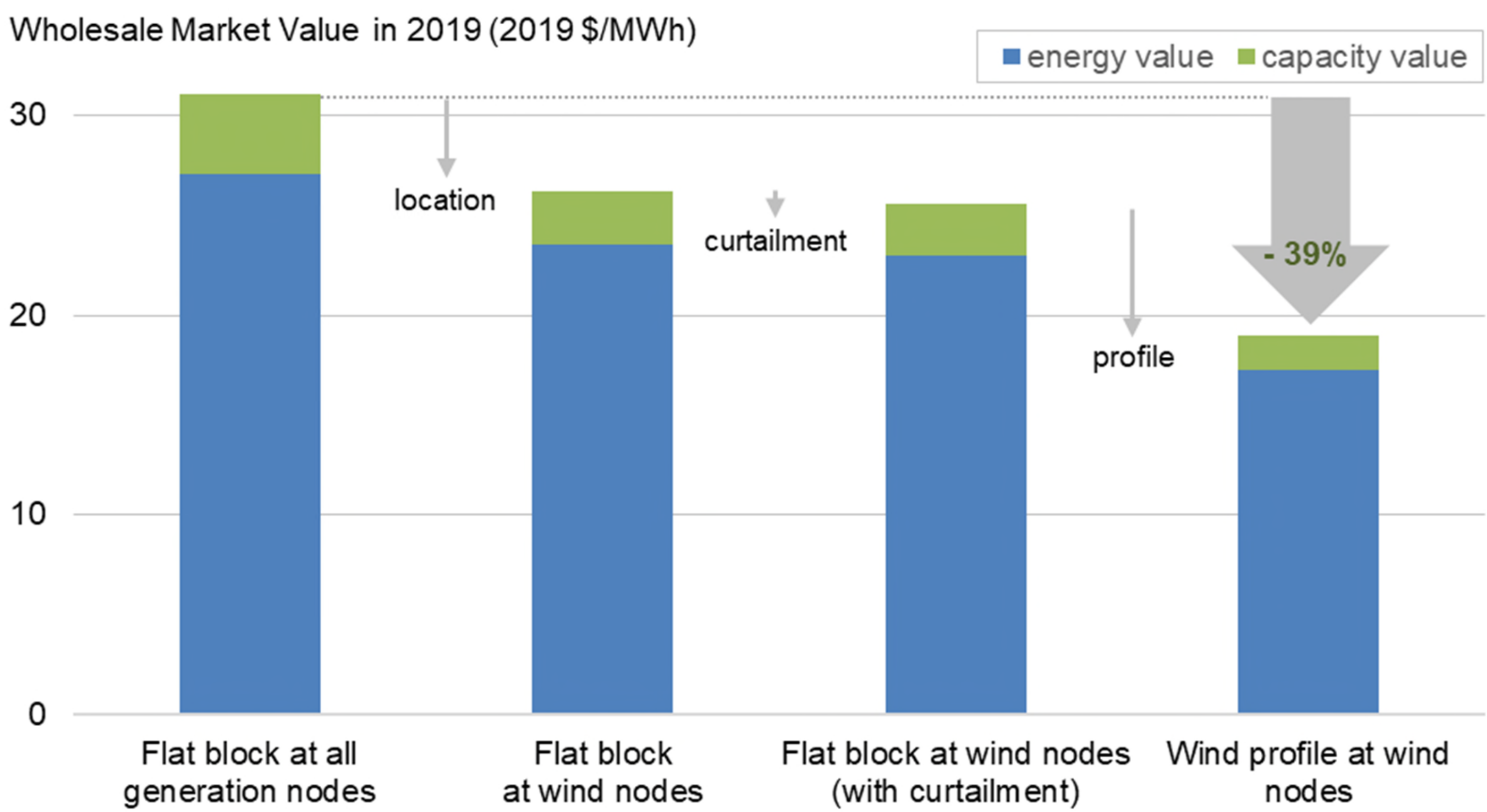


Sources: Berkeley Lab, ABB, ISOs

Interactive data visualization: https://emp.lbl.gov/wind-energy-market-value

Market value of wind relative to a ‘flat block’ of power (i.e., average price across all pricing nodes)

National average wholesale market value of wind in 2019 was 39% less than that of a generalized flat block of power—driven down by wind’s location (transmission congestion) and temporal output profile, with curtailment generally being a comparatively minor influence



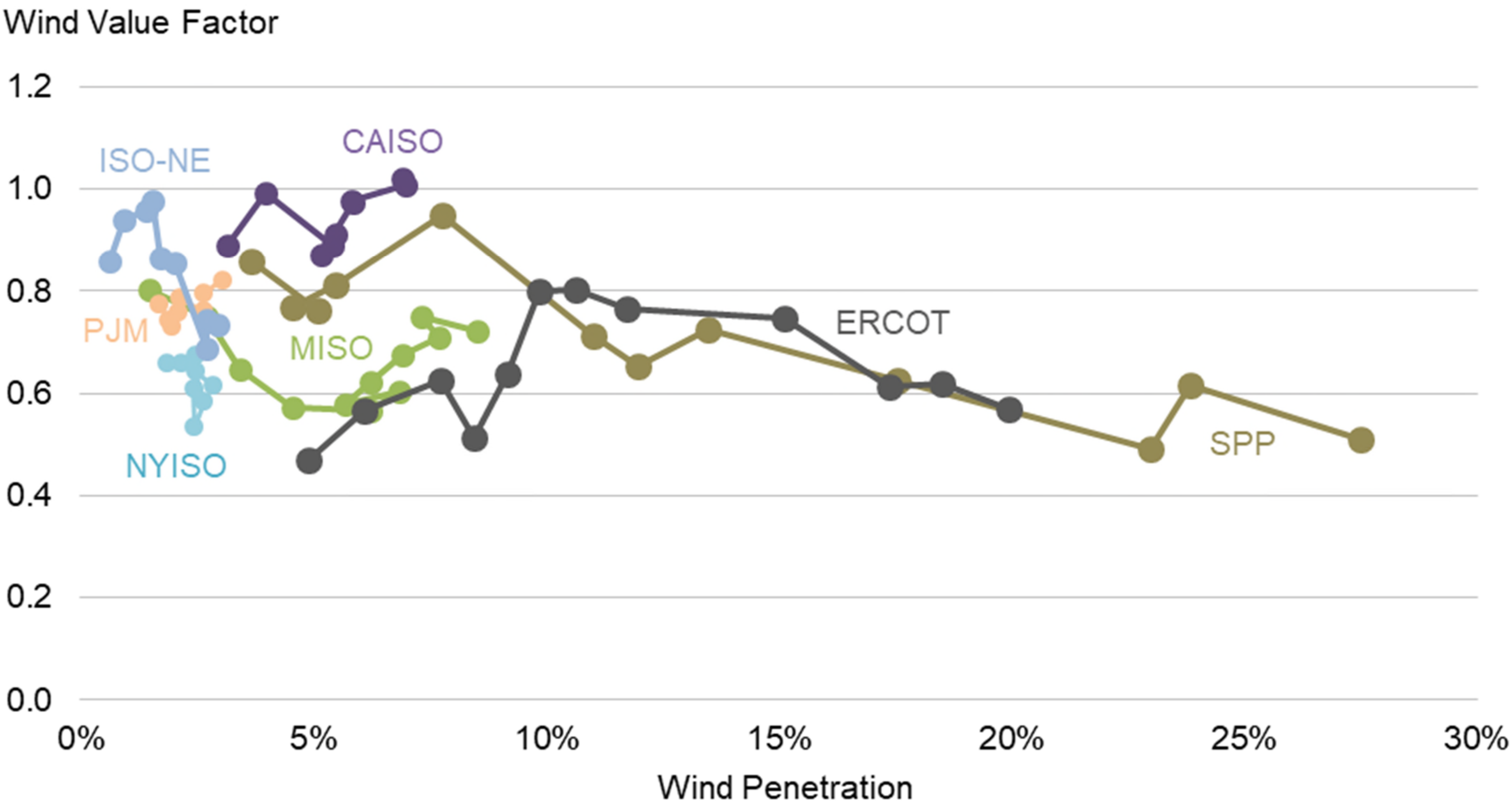
Sources: Berkeley Lab, ABB, ISOs

Market value of wind relative to a 'flat block' of power, by region

Average market value de-rate of wind in 2019 relative to a flat block varied by region: dominated by wind's output profile in some regions (SPP, ERCOT, ISO-NE, PJM), and location in others (NYISO)

Sources: Berkeley Lab, ABB, ISOs

Average “value factor” of wind (value relative to flat block) by region and with wind penetration

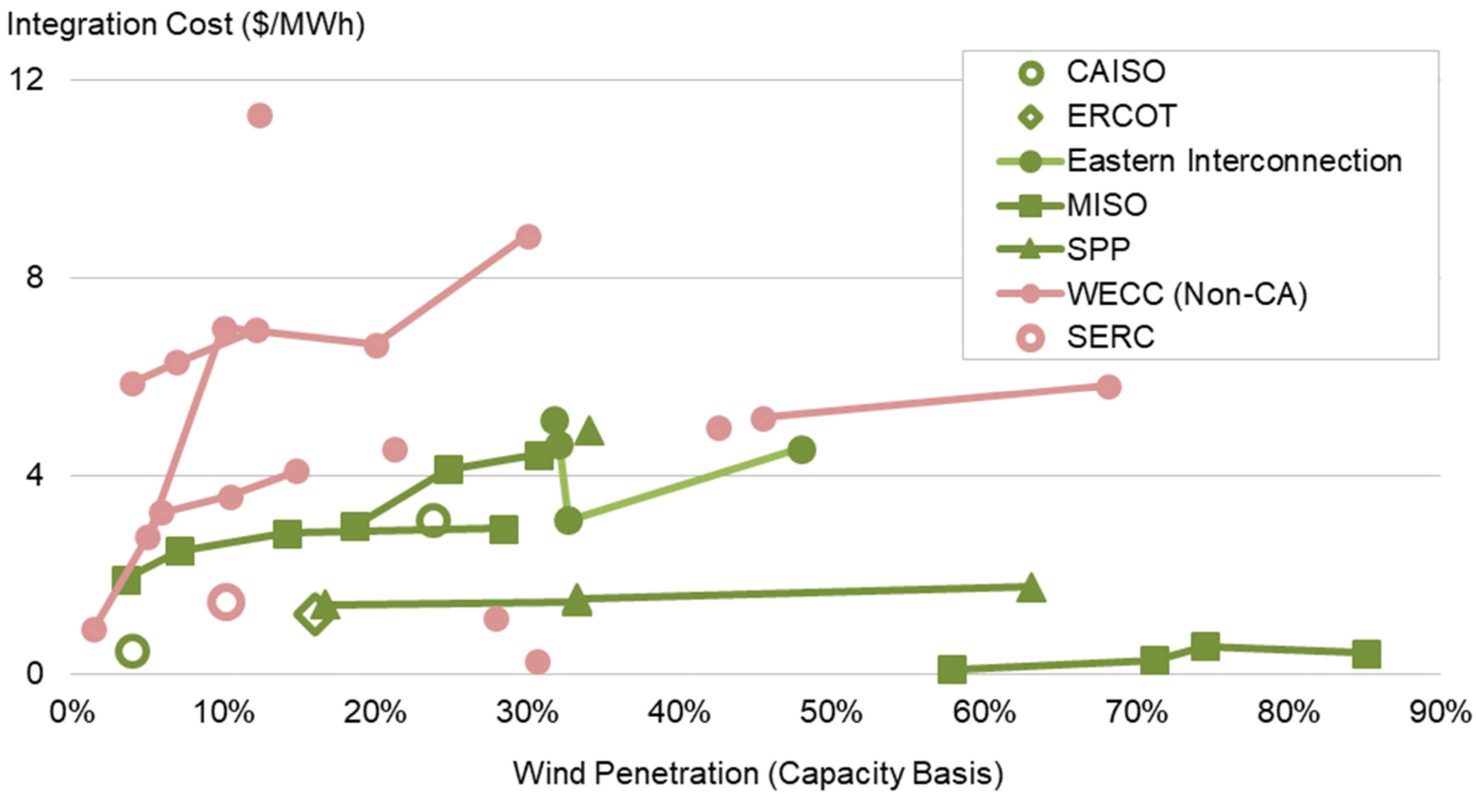


Sources: Berkeley Lab, ABB, ISOs

Value factor = wholesale market value of wind relative to generalized flat block of power in region; generalized flat block is 24x7 average price across all pricing nodes in region

Estimates of wind power integration costs, by region and wind penetration level

Integrating wind energy into power systems is manageable, but not free of additional costs

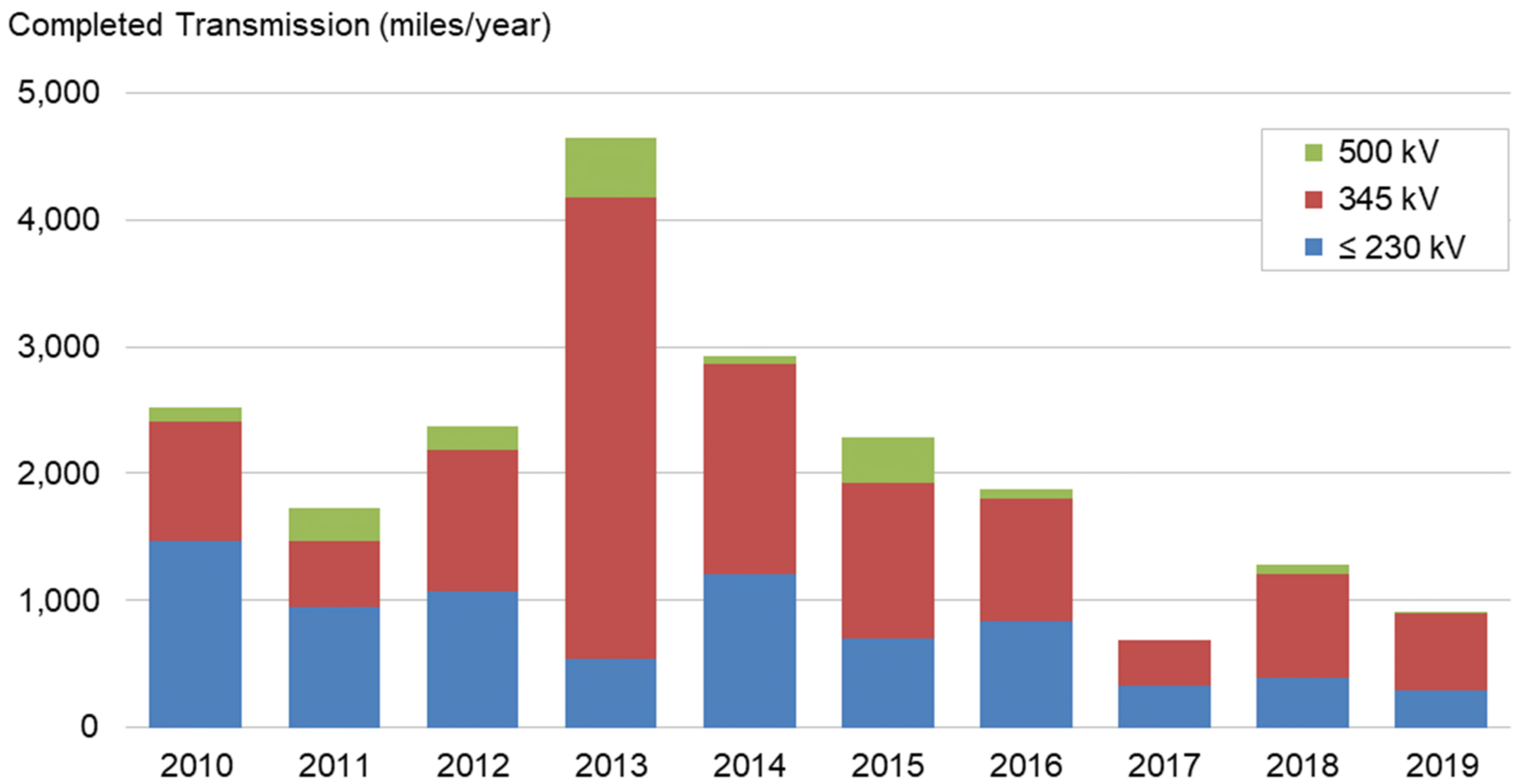


Sources: see data file for details

Note: Because methods vary and a consistent set of operational impacts has not been included in each study, results from the different analyses presented here are not fully comparable. Nonetheless, in general, the balancing costs included in the above graphic are often additional to the market value and value factor results presented in previous slides.

Miles of transmission projects completed, by year and voltage

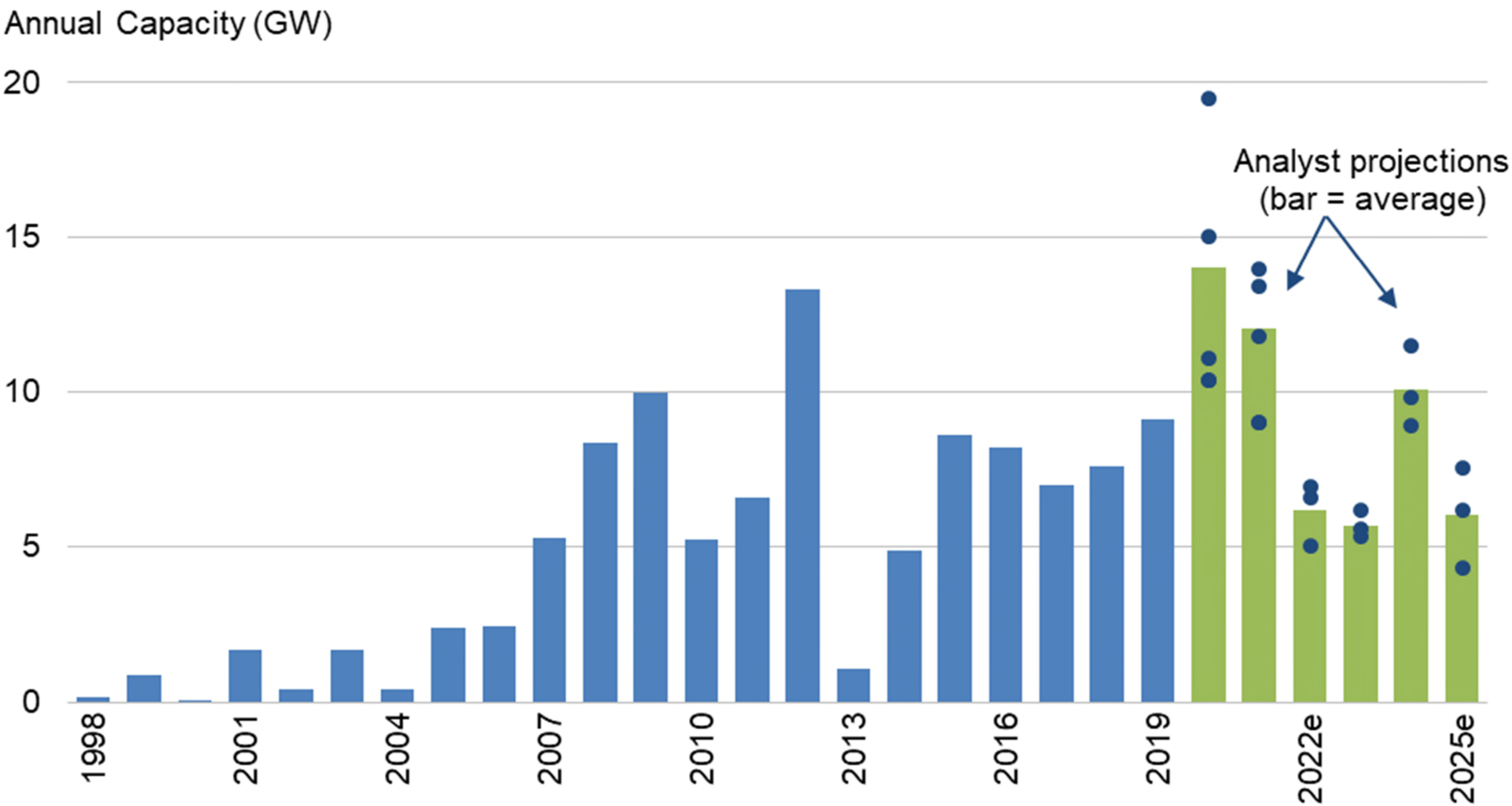
New transmission build has been relatively modest in recent years



Source: FERC

Summary of Data

Wind power capacity additions: historical installations and projected growth by various independent analysts



Sources: AWEA Wind IQ, independent analyst projections

Factors potentially affecting wind power outlook

- Degree of continued wind technology cost reductions
- Demand by corporate and other retail customers
- Phase-out of federal tax incentives
- Natural gas and wholesale electricity prices
- Cost of solar energy
- Potential decline in market value if wind penetration increases
- Electricity demand growth
- Demand from state RPS/CES policies
- Transmission infrastructure build-out

Data Summary

- Wind additions continued in 2019, with most analysts anticipating significant new builds in the near-term, due in part to continued incentives provided by the Production Tax Credit
- Wind energy has proven to be a significant source of new electric generation, and exceeded 7% of U.S. power production in 2019, with double-digit shares in many States
- The wind energy supply chain is geographically dispersed across the U.S., with strong shares of domestic content for towers, blades, and assembly of nacelles
- Turbine generator size, rotor swept area and tower heights have all increased, boosting wind project performance and lowering installed costs
- Wind power sales prices and the levelized cost of energy continued to decline, enabling wind energy to compete economically (with the PTC) with low natural gas power prices
- The outlook for land-based wind energy, beyond the PTC, remains uncertain, with influencing factors that include electricity demand, competing technologies, uncertain state and national policy environments, and the anticipated continued advancement of wind energy technology

Data and Methods

Summary of Data and Methods

Installation Trends

Data on U.S. wind installations and wind as a percentage of load and generation come from the Energy Information Administration (https://www.eia.gov/electricity/), AWEA Annual Report (https://www.awea.org/resources/publications-and-reports/market-reports), AWEA WindIQ Database (https://windiq.awea.org/), and USGS U.S. Wind Turbine Database (https://eerscmap.usgs.gov/uswtdb/). Data related to other generation additions come from ABB's Velocity database and Wood Mackenzie. Wind power capacity globally comes from GWEC (https://gwec.net/global-wind-report-2019/), and data on wind as a percentage of total generation by country is compiled in the AWEA Annual Report. Data on existing hybrid plants largely come from EIA Form 860 (https://www.eia.gov/electricity/data/eia860/), with some data cleaning by Berkeley Lab. Data from interconnection queues is collected and synthesized by Berkeley Lab.

Industry Trends

Data on manufacturer market share, facilities, and manufacturing capability, as well as wind plant ownership and offtake, come from the AWEA WindIQ Database and Annual Report. Data on turbine manufacturer profitability is collected from corporate annual financial reports. Data on imports of wind equipment and estimated domestic content come from Berkeley Lab analysis of the USITC's DataWeb (http://dataweb.usitc.gov). The cost of debt and tax equity are compiled from the Intercontinental Exchange Benchmark Administration, Bloomberg New Energy Finance, and Norton Rose Fulbright.

Technology Trends

Data on turbine nameplate capacity, hub height, and rotor diameter come largely from the AWEA WindIQ database and USGS U.S. Wind Turbine Database. The location and characteristics of possible future plants come from Federal Aviation Aadministration data files (https://oeaaa.faa.gov/oeaaa/external/portal.jsp). Wind resource quality is assessed based on site estimates of gross capacity factor at 80 meters by AWS Truepower (under license to NREL).

Performance Trends

Data on U.S. wind plant performance primarily comes from EIA Form 923 (https://www.eia.gov/electricity/data/eia923), FERC Electronic Quarterly Reports (https://www.ferc.gov/industries-data/electric/power-sales-and-markets/electric-quarterly-reports-eqr), and FERC Form 1 (https://www.ferc.gov/industries-data/electric/general-information/electric-industry-forms/form-1-electric-utility-annual). Curtailment data come from each of the seven independent system operators. Data on yearly variations in annual wind speed come from the ERA5 reanalysis data product (https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5).

Summary of Data and Methods, Continued

Cost Trends

Wind turbine transaction prices were, in part, compiled by Berkeley Lab. Additional data come from annual financial reports from Vestas, SGRE and Nordex, and from consultancies BNEF and Wood Mackenzie. Berkeley Lab uses a variety of public and some private sources of data to compile capital cost data for a large number of U.S. wind projects. For 2009–2012 projects, data from the Section 1603 Treasury Grant program were used extensively; for projects installed from 2013 through 2017, confidential EIA Form 860 data were used extensively. Wind project O&M costs come primarily from two sources: EIA Form 412 data from 2001 to 2003 for private power projects and projects owned by publicly-owned utilities, and FERC Form 1 data for investor-owned utility projects.

Power Sales Price and Levelized Cost Trends

Wind power purchase agreement (PPA) price data come from multiple sources, including prices reported in FERC's Electronic Quarterly Reports, FERC Form 1, avoided-cost data filed by utilities, pre-offering research conducted by bond rating agencies, and a Berkeley Lab collection of PPAs. Additional data come from Level10 Energy (https://leveltenenergy.com/). The levelized cost of wind energy estimated based on assumptions described on a later slide. REC prices come from Marex Spectron (https://www.marexspectron.com/).

Price and Value Comparisons

Data on solar PPA prices are based on the same sources as wind prices. Gas price projections come from EIA's Annual Energy Outlook (https://www.eia.gov/outlooks/aeo/). Details on the calculation of energy and capacity value are available in Wiser and Bolinger (2019): https://emp.lbl.gov/sites/default/files/wtmr_final_for_posting_8-9-19.pdf. In brief, estimated hourly wind generation profiles are matched to hourly nodal real-time wholesale prices from ABB's Velocity database. The capacity value of each plant is estimated based on the modeled wind profiles and ISO-specific rules for wind's capacity credit and ISO-zone-specific capacity prices. Integration cost estimates derive from a Berkeley Lab review of the available published literature: see data-file for the full list of citations. Data on completed transmission lines come from FERC Infrastructure reports (https://www.ferc.gov/industries-data/resources/staff-reports-and-papers).

Conclusions

Independent analyst projections for wind additions in 2020-2025 come from BNEF, Wood Mackenzie, IHS, and IEA.

For additional details, see appendix of Wiser and Bolinger (2019): https://emp.lbl.gov/sites/default/files/wtmr_final_for_posting_8-9-19.pdf

An accessible data file and multiple visualizations can be found at windreport.lbl.gov

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