Land-Based Wind Market Report: 2021 Edition

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Land-Based Wind Market Report: 2021 Edition

Purpose and Scope:

– Summarize data on key trends in the 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
  • Note that the Installation Trends, Industry Trends, and Future Outlook sections include data on both land-based and offshore wind; other chapters focus solely on land-based
– Focus on historical data, with some emphasis on the previous year

Funding:

– U.S. Department of Energy’s Wind Energy Technologies Office

Products and Availability:

– This briefing is complemented with underlying report, data file, and visualizations
– All products available at: windreport.lbl.gov
Presentation Contents

- Installation trends
- Industry trends
- Technology trends
- Performance trends
- Cost trends
- Power sales price and levelized cost trends
- Cost and value comparisons
- Future outlook
Regional boundaries applied in this analysis include the seven independent system operators (ISO) and two non-ISO regions.

Sources: AWS Truepower, NREL
Installation Trends
Wind power capacity was added at a record pace in 2020, with 16,836 MW of new capacity added and $24.6 billion invested.

- >70% of new capacity in ERCOT, MISO, SPP
- Partial repowering: 3,087 MW of turbines retrofitted in 2020

Source: ACP

Interactive data visualization: [https://emp.lbl.gov/wind-energy-growth](https://emp.lbl.gov/wind-energy-growth)
Wind power represented the largest source of U.S. electric-generating capacity additions in 2020.

Over the last decade, wind has comprised 29% of total capacity additions, and a much higher proportion in SPP, ERCOT, and MISO.

Sources: ABB, ACP, Wood Mackenzie, Berkeley Lab
Globally, the United States ranked 2\textsuperscript{nd} in annual and cumulative wind power capacity additions in 2020.

| Source: GWEC, ACP |
|-------------------|------------------|
| **Annual Capacity (2020, MW)** | **Cumulative Capacity (end of 2020, MW)** |
| China | 52,000 | China | 288,320 |
| United States | 16,836 | United States | 121,985 |
| Brazil | 2,297 | Germany | 62,850 |
| Netherlands | 1,979 | India | 38,625 |
| Germany | 1,668 | Spain | 27,250 |
| Norway | 1,532 | United Kingdom | 23,937 |
| Spain | 1,400 | France | 17,948 |
| France | 1,318 | Brazil | 17,750 |
| Turkey | 1,224 | Canada | 13,578 |
| India | 1,119 | Italy | 10,543 |
| Rest of World | 11,538 | Rest of World | 119,572 |
| **TOTAL** | 92,910 | **TOTAL** | 742,357 |

- Global wind additions hit a new record in 2020, with nearly 93 GW of newly added capacity.
- U.S. remains a distant second to China in annual and cumulative capacity.
The United States ranks lower than many other countries in terms of wind energy as a share of total generation.

Wind as Percentage of Total Generation in 2020

Source: ACP
Note: Figure includes a subset of the top global wind markets
The geographic spread of wind power projects across the United States is broad, with the exception of the Southeast.

Note: Numbers within states represent megawatts of cumulative installed wind capacity and, in brackets, annual additions in 2020.

Source: ACP, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-energy-growth
Texas installed the most wind power capacity in 2020; 16 States exceeded 10% wind as a fraction of in-state generation

<table>
<thead>
<tr>
<th>State</th>
<th>Installed Capacity (MW)</th>
<th>Annual (2020)</th>
<th>Cumulative (end of 2020)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas</td>
<td>4,137</td>
<td>32,686</td>
<td></td>
</tr>
<tr>
<td>Iowa</td>
<td>1,215</td>
<td>11,377</td>
<td></td>
</tr>
<tr>
<td>Oklahoma</td>
<td>1,162</td>
<td>9,344</td>
<td></td>
</tr>
<tr>
<td>Wyoming</td>
<td>1,072</td>
<td>7,028</td>
<td></td>
</tr>
<tr>
<td>Illinois</td>
<td>1,059</td>
<td>6,409</td>
<td></td>
</tr>
<tr>
<td>Missouri</td>
<td>1,028</td>
<td>5,922</td>
<td></td>
</tr>
<tr>
<td>Colorado</td>
<td>967</td>
<td>4,692</td>
<td></td>
</tr>
<tr>
<td>Kansas</td>
<td>896</td>
<td>4,291</td>
<td></td>
</tr>
<tr>
<td>South Dakota</td>
<td>774</td>
<td>3,989</td>
<td></td>
</tr>
<tr>
<td>New Mexico</td>
<td>770</td>
<td>3,737</td>
<td></td>
</tr>
<tr>
<td>Indiana</td>
<td>651</td>
<td>3,395</td>
<td></td>
</tr>
<tr>
<td>Michigan</td>
<td>493</td>
<td>2,968</td>
<td></td>
</tr>
<tr>
<td>Minnesota</td>
<td>455</td>
<td>2,723</td>
<td></td>
</tr>
<tr>
<td>Nebraska</td>
<td>393</td>
<td>2,687</td>
<td></td>
</tr>
<tr>
<td>Arizona</td>
<td>350</td>
<td>2,681</td>
<td></td>
</tr>
<tr>
<td>North Dakota</td>
<td>343</td>
<td>2,531</td>
<td></td>
</tr>
<tr>
<td>Oregon</td>
<td>310</td>
<td>2,305</td>
<td></td>
</tr>
<tr>
<td>Washington</td>
<td>287</td>
<td>1,987</td>
<td></td>
</tr>
<tr>
<td>Ohio</td>
<td>126</td>
<td>1,987</td>
<td></td>
</tr>
<tr>
<td>California</td>
<td>111</td>
<td>1,459</td>
<td></td>
</tr>
<tr>
<td>Rest of U.S.</td>
<td>238</td>
<td>7,786</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16,836</strong></td>
<td><strong>121,985</strong></td>
<td><strong>8.3%</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>State</th>
<th>2020 Wind Generation as a Percentage of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-State Generation</td>
</tr>
<tr>
<td>Iowa</td>
<td>57.3%</td>
</tr>
<tr>
<td>Kansas</td>
<td>43.2%</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>35.4%</td>
</tr>
<tr>
<td>South Dakota</td>
<td>32.9%</td>
</tr>
<tr>
<td>North Dakota</td>
<td>30.8%</td>
</tr>
<tr>
<td>Maine</td>
<td>23.8%</td>
</tr>
<tr>
<td>Nebraska</td>
<td>23.6%</td>
</tr>
<tr>
<td>Colorado</td>
<td>23.2%</td>
</tr>
<tr>
<td>Minnesota</td>
<td>21.6%</td>
</tr>
<tr>
<td>New Mexico</td>
<td>20.7%</td>
</tr>
<tr>
<td>Texas</td>
<td>19.5%</td>
</tr>
<tr>
<td>Vermont</td>
<td>15.1%</td>
</tr>
<tr>
<td>Idaho</td>
<td>14.1%</td>
</tr>
<tr>
<td>Oregon</td>
<td>13.1%</td>
</tr>
<tr>
<td>Montana</td>
<td>12.6%</td>
</tr>
<tr>
<td>Wyoming</td>
<td>12.3%</td>
</tr>
<tr>
<td>Illinois</td>
<td>9.8%</td>
</tr>
<tr>
<td>Washington</td>
<td>7.3%</td>
</tr>
<tr>
<td>Indiana</td>
<td>7.3%</td>
</tr>
<tr>
<td>California</td>
<td>6.4%</td>
</tr>
<tr>
<td>Rest of U.S.</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

2020 Wind Penetration by ISO/RTO:
- SPP: 31.3%
- ERCOT: 22.7%
- MISO: 11.0%
- CAISO: 6.6%
- PJM: 3.4%
- ISO-NE: 3.0%
- NYISO: 2.9%

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

Source: ACP, EIA
A small but growing number of hybrid plants that pair wind with storage and other resources are operating in the United States

**Online Wind Hybrid / Co-located Projects**

- 38 hybrid wind power plants in operation at the end of 2020
- Represent 2.3 GW of wind power and 0.9 GW of co-located resources
- Most common wind hybrid project combines wind+storage; other combinations include wind+PV; wind+PV+storage; wind+fossil
- ERCOT, PJM, non-ISO West host largest amount of wind hybrid capacity

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

Sources: EIA-860 2020 Early Release, Berkeley Lab
Comparing the frequency and design of a subset of the hybrid/co-located project configurations: end of 2020

<table>
<thead>
<tr>
<th></th>
<th># projects</th>
<th>Total capacity (MW)</th>
<th>Storage ratio</th>
<th>Duration (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>PV+Storage</td>
<td>73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td></td>
<td>Wind</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>PV</td>
<td></td>
<td>PV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind+Storage</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil</td>
<td></td>
<td>Fossil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td></td>
<td>Storage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind+PV+Storage</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind+PV</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fossil+Storage</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind+PV</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: Not included in the figure are 111 other hybrid/co-located projects with other configurations. Storage ratio is defined as storage capacity divided by total generator capacity.
Sources: EIA 860 2020 Early Release, Berkeley Lab

Most wind hybrids are Wind+Storage, with limited storage duration to serve ancillary services markets.

Interactive data visualization: https://emp.lbl.gov/online-hybrid-and-energy-storage-projects
Generator + storage hybrid / co-located projects at end of 2020: wind+storage, PV+storage, fossil+storage

- Wind+storage plants located primarily in ERCOT and PJM so far
- 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
Despite a slight contraction since 2018, 209 GW of wind power capacity exists in transmission interconnection queues.

Not all of this capacity will be built: ~25% completion rate.

Hatched portion indicates the amount paired with storage.

For storage, hatched portion indicates the amount paired with generation.

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

Note: Storage capacity in hybrids was not estimated for years prior to 2020.

Source: Berkeley Lab review of interconnection queues.
Larger amounts of wind capacity in SPP, NYISO, non-ISO West, and PJM queues; 29% (61 GW) of wind capacity in queues is offshore

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
Interest in hybrid plants has increased: 6% of wind proposed as hybrids (13 GW); 34% of solar proposed as hybrids (159 GW)

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.

Interactive data visualization: https://emp.lbl.gov/generation-storage-and-hybrid-capacity
Proposed wind hybrids are primarily located in California and the non-ISO Western regions

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.

Source: Berkeley Lab review of interconnection queues

Interactive data visualization: [https://emp.lbl.gov/generation-storage-and-hybrid-capacity](https://emp.lbl.gov/generation-storage-and-hybrid-capacity)
Industry Trends
GE and Vestas accounted for 87% of the U.S. wind market in 2020

Source: ACP
The domestic supply chain for wind equipment is diverse, with manufacturing facilities located in all regions of the country.

- Despite COVID-19, with record growth in wind installations, wind-related job totals in the United States increased by 1.8% in 2020, to 116,800 full-time workers.
- These jobs include, among others, those in construction (42,300) and manufacturing (23,900).

Source: ACP
Domestic manufacturing capability for nacelle assembly, towers, and blades has been reasonably well balanced against historical demand.

Sources: ACP, independent analyst projections, Berkeley Lab

Note: Actual nacelle assembly, tower production, and blades production would be expected to be below maximum production capacity.
The profitability of global wind turbine manufacturers has generally declined over the last several years.

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

Earnings before interest and taxes (EBIT)

Sources: OEM annual reports and financial statements
Imports of wind equipment into the United States are sizable

Source: Berkeley Lab analysis of data from USA Trade Online, https://usatrade.census.gov

Notes: Figure only includes tracked trade categories, misses other wind-related imports; wind-related trade codes and definitions are not consistent over the full time period; see full report for the assumptions used to generate the figure.
Tracked wind equipment imports into the United States in 2020 came from multiple regions of the world.

Source: Berkeley Lab analysis of data from USA Trade Online, https://usatrade.census.gov

Notes: Line widths are proportional to amount of imports, by country. Figure does not intend to depict the destination of these imports, by state. Tracked wind-specific equipment includes: wind-powered generating sets and parts, towers, generators and generator parts, blades and hubs, and nacelles.
Source markets for 2020 wind equipment imports vary by type of wind equipment

- India, followed by Denmark, Germany, Brazil, and Spain, were the primary source markets for wind-powered generating sets and nacelles in 2020.
- Tower imports came from a mix of countries near and far—Canada, India, Malaysia, Spain, and Indonesia.
- With regard to blades and hubs, China, Mexico, India, Spain and Brazil topped the charts in 2020.
- Wind-related generators and generator parts primarily came from Spain, Vietnam, Germany and Serbia.

Source: Berkeley Lab analysis of data from USA Trade Online, https://usatrade.census.gov
Domestic manufacturing content in 2020 was relatively strong for nacelle assembly, towers, and blades.

Imports occur in untracked trade categories not included above, including many nacelle internals. Blade domestic content has declined in recent years. BloombergNEF (2021) has recently estimated that a typical onshore wind project in the U.S. sources 57% of its components (by dollar value) domestically.

Source: Berkeley Lab
Project finance was volatile in 2020

Sources: Intercontinental Exchange Benchmark Administration, BNEF, Norton Rose Fulbright
Independent Power Producers own the majority of wind assets built in 2020, but Investor-Owned Utilities own a sizable share.

Source: Berkeley Lab estimates based on ACP

Note: Graphic on left shows distribution among growing cumulative fleet of projects installed. Pie chart shows distribution only among those projects built in 2020.
Utilities remained the most common offtaker (through ownership and purchases), but retail sales and merchant were also very significant.

Source: Berkeley Lab estimates based on ACP

Note: Graphic on left shows distribution among growing cumulative fleet of projects installed. Pie chart shows distribution only among those projects built in 2020.
Technology Trends
Turbine capacity, rotor diameter, and hub height have all increased significantly over the long term.

Sources: ACP, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-power-technology-trends
Turbine size maintains upward trajectory; turbines originally designed for lower wind speeds dominate the market.

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

2020 average = 223 W/m²

Sources: ACP, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/specific-power
Wind turbines were deployed in somewhat lower wind speed sites in 2020 than in the previous seven years.

Wind resource quality (index, 80m)

Wind speed (m/s, 80m)

Sources: ACP, Berkeley Lab, AWS Truepower, FAA files

Note: 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.
Low specific power turbines are deployed on widespread basis; taller towers are seeing increased use in wider variety of sites.

Sources: ACP, U.S. Wind Turbine Database, AWS Truepower, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-power-technology-trends
Wind projects planned for the near future are poised to continue the trend of ever-taller turbines

Proposed turbines show significant growth in total turbine height, compared to 2020 projects

% of turbines

<table>
<thead>
<tr>
<th></th>
<th>2020 projects</th>
<th>Under const.</th>
<th>Adv. dev.</th>
<th>Pending</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>0%</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Average Total height (feet)

- 750–650 ft
- 650–750 ft
- 550–650 ft
- 450–550 ft
- <450 ft

Average: right axis

Sources: ACP, FAA files, AWS Truepower, Berkeley Lab

FAA = Federal Aviation Administration
In 2020, 33 wind projects were partially repowered, most of which now feature significantly larger rotors and lower specific power ratings.

The mean age of turbines retrofitted in 2020 was just 12 years.
Performance Trends
The average capacity factor in 2020 exceeded 40% among wind projects built in recent years, and reached 36% on a fleet-wide basis.

Source: EIA, FERC, Berkeley Lab

Interactive data visualization: https://emp.lbl.gov/wind-power-performance
The central part of the country features the highest capacity factors, in part reflecting the strength of the wind resource.

Newer projects (right figure) have considerably higher capacity factors than the full sample of 1998–2019 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
Turbine design and site characteristics influence performance, with declining specific power leading to sizable increases in capacity factor.

Average Capacity Factor in 2020

Index of Capacity Factor Influences (1998-99=100)

Inverse of built specific power

Capacity factor

Built turbine hub height

Built wind resource quality at 80m

Source: EIA, FERC, Berkeley Lab
Low specific power turbines are driving capacity factors higher for projects located in given wind resource regimes.

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%.

Source: EIA, FERC, Berkeley Lab
Wind curtailment impacts project performance; MISO and ERCOT experienced the highest levels of curtailment in 2020.

Sources: ERCOT, MISO, CAISO, NYISO, PJM, ISO-NE, SPP
Yearly variations in average wind speed impact project performance; 2020 wind speeds were slightly above the long-term average

Average Annual Wind Resource Indices (Long-Term Average = 1.0)

Source: ERA, Berkeley Lab; methodology behind the index of inter-annual variability is explained in report appendix
Wind project performance degradation with project age also explains why older projects did not perform as well in 2020.

Indexed Capacity Factor (Year 2 = 100%)

- Newer (post-2007) projects (with 25th and 75th percentile range)
- Older (pre-2008) projects (with 25th and 75th percentile range)

Performance decline after year 10 may, in part, reflect operational choices impacted by the federal PTC.

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 Trends
Wind turbine prices remained well below the levels seen a decade ago: ~$775-850/kW in 2020

Turbine Price (2020 $/kW)

Sources: Berkeley Lab, annual financial reports, forecast providers
Lower turbine prices have driven reductions in total installed project costs: ~$1,460/kW average in 2020

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

Installed Project Cost (2020 $/kW)

Commercial Operation Date

Note: Size of “bubble” reflects project capacity
Sources: Berkeley Lab, EIA (some data points suppressed to protect confidentiality)
General trend towards lower installed project costs exists across all regions of the United States

Average Cost (2020 $/kW)

Sources: Berkeley Lab, EIA

Note: NYISO data are not available over this period. For other regions, data for specific years are missing.

Interactive data visualization: https://emp.lbl.gov/wind-energy-capital-expenditures-capex
Regional differences in average wind project costs in 2020 are apparent, but sample size is limited in some regions.

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

Note: Size of “bubble” reflects project capacity
Source: Berkeley Lab
Economies of scale are evident, especially when moving from small- to medium-sized projects: 2019 and 2020 projects

Source: Berkeley Lab
Operations and maintenance (O&M) costs vary by commercial operations date and project age

Average Annual O&M Cost, 2000–2020 (2020 $/kW-yr)

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

Note: Sample is limited; few projects in sample have complete records of O&M costs from 2000-20; O&M costs reported here do not include all operating costs.
O&M costs are lower for more-recently built projects, but cost trends as projects age do not follow consistent patterns.

Median Annual O&M Cost (2020 $/kW-year)

O&M reported here does not include all operating costs: all-in operating costs for the most recent wind projects average ~$44/kW-year.

Source: Berkeley Lab; 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.
Power Sales Price and Levelized Cost Trends
Wind power purchase agreement (PPA) prices remain low

Levelized PPA Price (2020 $/MWh)

Note: Size of bubble reflects contract capacity
Source: Berkeley Lab, FERC

Interactive data visualization: https://emp.lbl.gov/wind-power-purchase-agreement-ppa-prices
Average PPA prices have steeply declined since 2009; prices below $20/MWh in central region, but have been flat or risen in recent years.

Source: Berkeley Lab, FERC

Note: West = CAISO, West (non-ISO); Central = MISO, SPP, ERCOT; East = PJM, NYISO, ISO-NE, Southeast (non-ISO)
Recent wind power purchase agreements are priced in the mid-teens in some cases.

Source: Berkeley Lab, FERC
Interactive data visualization: https://emp.lbl.gov/wind-power-purchase-agreement-ppa-prices
LevelTen Energy price indices confirm low but rising PPA prices, and regional variations in wind energy prices

Source: LevelTen Energy
Levelized cost of wind energy (LCOE) has generally declined: nationwide average of $33/MWh for projects installed in 2020

Average and Project-level LCOE (2020 $/MWh)

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 costs vary by region, with the lowest costs in ERCOT, SPP, and the non-ISO West

Source: Berkeley Lab
Note: Regional sample is limited in some regions and years

Interactive data visualization: https://emp.lbl.gov/levelized-cost-wind-energy
Renewable Energy Certificate (REC) prices continue to vary substantially across markets and time.

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

Source: Marex Spectron
Cost and Value Comparisons
Despite recent low wind PPA prices, wind faces competition from solar and natural gas.

Levelized PPA and Gas Price (2020 $/MWh)

- PV PPA prices
- Levelized 20-year EIA gas price projections
- Wind PPA prices

Source: Berkeley Lab, FERC, EIA

Note: Smallest bubble sizes reflect smallest-volume PPAs (<5 MW), whereas largest reflect largest-volume PPAs (>500 MW).
Recent wind prices are competitive with the expected future cost of burning fuel in natural gas plants.

Source: Berkeley Lab, FERC, EIA

Notes: Price comparisons shown are far from perfect—see full report for details.
Wind PPA prices have been broadly attractive compared to wind’s grid-system value in wholesale power markets

Wholesale Market Value and PPA Prices (2020 $/MWh)

Average Levelized Wind PPA Price with 10th/90th Percentiles (by year of PPA execution)

Wholesale market value considers hourly local wholesale energy price and hourly wind output, along with capacity value where available.

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

Sources: Berkeley Lab, ABB, ISOs
The wholesale market value of wind energy in 2020 varied by region: lowest in ERCOT, MISO, NYISO, SPP; highest in CAISO.

Wholesale Market Value in 2020 (2020 $/MWh)

*Interactive data visualization: [https://emp.lbl.gov/wind-energy-market-value](https://emp.lbl.gov/wind-energy-market-value)*

Sources: Berkeley Lab, ABB, ISOs
The grid-system market value of wind varies by project location

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

Sources: Berkeley Lab, ABB, ISOs
Average “value factor” of wind (value relative to flat block) is highly variable across regions, tends to decline with penetration.

**Wind Value Factor**

- ISO-NE
- CAISO
- PJM
- NYISO
- MISO
- ERCOT
- SPP

**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.
Grid-system market value of wind tends to decline with penetration, impacted by output profile, transmission congestion, and curtailment.

Average market value de-rate of wind in 2020 relative to a flat block varied by region: dominated by wind’s output profile in some regions (SPP, PJM, CAISO), and congestion in others (MISO, NYISO).

**Value of flat block**
- ERCOT: $21/MWh
- MISO: $21/MWh
- SPP: $26/MWh
- NYISO: $23/MWh
- ISO-NE: $31/MWh
- PJM: $24/MWh
- CAISO: $35/MWh

**Wind market value**
- ERCOT: $11/MWh
- MISO: $11/MWh
- SPP: $14/MWh
- NYISO: $13/MWh

**Sources:** Berkeley Lab, ABB, ISOs
As a weather-driven resource, wind power impacts grid-system operations

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

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, as those earlier estimates focus on hourly trends in wind output whereas balancing costs often address forecast effort and sub-hourly output variations.

Sources: see data file for details
As a location-dependent resource, wind power often requires or benefits from new transmission

New transmission build has been relatively modest in recent years

Completed Transmission (miles/year)

Source: FERC
The health and climate benefits of wind dwarf its grid-system value, and the combination of all three far exceeds the levelized cost of wind.

Health and Climate Benefits of Wind in 2020 Vary Regionally, Average $76/MWh Nationally

Grid, Health, and Climate Benefits of New Wind Plants in 2020 Exceed LCOE

Note: Estimates not provided for Southeast due to small number of wind plants in that region.

Sources: Berkeley Lab, EIA Form 930, Fell and Johnson (2021)
Future Outlook

Annual Capacity (GW)

Sources: ACP, independent analyst projections
The underlying report, an accessible data file, and multiple visualizations can be found at:

• windreport.lbl.gov

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