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RENEWABLE ENERGY

Distributed Wind Market Report: 2022 Edition

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List of Acronyms

ACP	American Clean Power Association
AWEA	American Wind Energy Association
CIP	Competitiveness Improvement Project
DOE	U.S. Department of Energy
DWEA	Distributed Wind Energy Association
EIA	Energy Information Administration
FIT	feed-in tariff
GE	General Electric
GW	gigawatt(s)
ICC–SWCC	International Code Council-Small Wind Certification Council
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRS	U.S. Internal Revenue Service
ITC	investment tax credit
kWh	kilowatt-hour(s)
kW	kilowatt
LCOE	levelized cost of energy
MW	megawatt(s)
NPS	Northern Power Systems
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O&M	operations and maintenance
PNNL	Pacific Northwest National Laboratory
PTC	production tax credit
PV	solar photovoltaic
REAP	Rural Energy for America Program
SGIP	Self-Generation Incentive Program
USDA	U.S. Department of Agriculture
VAWT	vertical-axis wind turbine

Executive Summary

The annual Distributed Wind Market Report provides stakeholders with market statistics and analysis along with insights into market trends and characteristics for wind technologies used as distributed energy resources. Key findings for this year's report include the following:

Installed Capacity

Cumulative U.S. distributed wind capacity installed from 2003 through 2021 now stands at 1,075 megawatts (MW) from over 89,000 wind turbines across all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and Guam. Distributed wind turbines are connected at the distribution level of an electricity system, or in off-grid applications, to serve specific or local loads.

In 2021, 15 states added a total of 11.7 MW of new distributed wind capacity from 1,751 turbine units representing a $41 million investment. The deployed capacity is down from 21.9 MW ($44 million, 11 states) in 2020 and 20.4 MW ($59 million, 22 states) in 2019. The 2020 distributed wind capacity amount is higher than initially reported because it now captures some projects that had late 2020 operational dates.

Of the 11.7 MW installed in 2021, 8.7 MW came from distributed wind projects using large-scale turbines (greater than 1 MW in size), 1.2 MW came from projects using mid-size turbines (101 kilowatts [kW] to 1 MW in size), and 1.8 MW came from projects using small wind turbines (up through 100 kW in size).

The 8.7 MW from projects using turbines greater than 1 MW is down from the 20 MW documented for 2020 and the 18.2 MW documented for 2019. Large-scale wind turbines continue to account for most of the distributed wind capacity additions; however, the total annual deployed capacity using large-scale turbines continues to jump around year to year as these projects have longer project-development cycles than smaller distributed wind energy projects.

Projects using mid-size turbines continue to represent a small part of the distributed wind market as there are a limited number of mid-size turbines commercially available and larger turbines can be more cost effective. However, the 1.2 MW of mid-size capacity from three projects deployed in 2021 was an increase from 0.28 MW from two projects in 2020 and 0.9 MW from one project in 2019.

A total of 1.8 MW of small wind was deployed in the United States in 2021 from 1,742 turbine units representing a $9.2 million investment. Small wind deployment has been fairly flat for the past few years, but the 2021 capacity deployment is an increase from 2020. There was 1.6 MW of small wind deployment documented for 2020 and 1.3 MW in 2019. The increase can be attributed to a slight increase in domestic sales from both U.S.-based and foreign small wind turbine manufacturers, the inclusion of two turbine manufacturers that PNNL had not previously tracked, and sales of early designs from additional turbine manufacturers.

Rhode Island, Kansas, and Minnesota led the United States in new distributed wind capacity additions as a result of one project in each state, which combined, represent 75% of the annual distributed wind capacity installed in 2021. The Rhode Island and Minnesota projects serve utility customers, and the Kansas project directly serves an industrial customer, an ethanol plant.

Minnesota led the United States in 2021 small wind capacity additions with 305 kilowatts. This can be attributed to Eocycle's push to sell its EOX-S16 turbine model to farmers in Minnesota and the decline of installations in New York with the discontinuation of its state incentive program. New York had led the United States in annual small wind capacity additions since 2017. Eocycle has focused on the agricultural market segment, with a start in Minnesota, because the company believes that many farms are in wind-rich areas, wind has a smaller land footprint than solar photovoltaics, winter wind energy production can match farm energy consumption trends, and wind turbines can provide a decarbonization solution for the emissions-heavy agriculture industry.

Deployment Trends

General Electric (GE) Renewable Energy has been the only consistent U.S.-based manufacturer of large-scale turbines used in distributed wind projects from 2012 through 2021. The other large-scale turbine models deployed in distributed wind projects in 2021 were from Goldwind (China) and Vensys (Germany).

Refurbished turbines continue to account for most of the mid-size market. Of the six projects using mid-size turbines in 2019, 2020, and 2021, at least four are refurbished models. Demand from customers for whom mid-size turbines are a good fit for their energy needs and the limited availability of newly manufactured turbine models explain the use of refurbished turbines in this size sector and Siva Wind's return to the U.S. market in 2021 with its 250-kW turbine model.

Small wind retrofits continue to account for a significant portion of new small wind capacity deployment. Retrofits are new turbines installed on existing towers and foundations to replace nonfunctioning turbines or to upgrade the technology. In 2021, small wind retrofits represented 42% of total installed small wind capacity, compared to 68% in 2020 and 27% in 2019.

Small wind turbine manufacturers and installers report an increased interest in microgrids and hybrid systems from potential customers. Microgrids are becoming more common, but not many are being installed with wind. There is also an interest in larger hybrid power plants. For example, the Red Lake Falls Community Hybrid project installed in 2020 includes 4.6 MW of distributed wind and 1 MW of solar photovoltaics interconnected to serve a utility's distribution system in Minnesota.

From 2012 through 2021, 90% of all documented distributed wind projects, on average, were interconnected for on-site use with the remaining 10% deployed to serve local loads on distribution systems. While the majority of distributed wind projects are interconnected for on-site use, they represent less of the deployed capacity. The percent of total installed project capacity documented as local use from 2012 through 2021 was 55% with the remaining 45% for on-site use.

Customer Types

In 2021, agricultural customers accounted for 55% of the number of all projects installed, followed by residential customers who represented 16% of installed projects. However, agricultural and residential end-use customers accounted for only a combined 12% of the documented capacity installed in 2021, compared to 3% in both 2020 and 2019. The increase in percentage of project capacity for these two customer types can be attributed to the use of mid-size turbines for agricultural customers in 2021.

Utility customers represented the largest share of total distributed wind project capacity, 56%, installed in 2021, compared to 60% in 2020 and 42% in 2019. Industrial customers represent the second largest percentage of distributed wind capacity installed in 2021, accounting for roughly 25% of capacity installed, compared to 36% in 2020 and 54% in 2019.

Distributed wind provides energy for a diverse group of customers. For example, documented government projects include wind turbines for military operations, municipal water systems, prisons, parks, and tribal governments. Most institutional customers are schools, including colleges and universities, but wind turbines have also been deployed at local unions and religious establishments. Documented commercial projects include wind turbines for warehouses, a taxidermist, hotels, and a radio station.

Incentives and Policies

The combined value of U.S. Department of Agriculture Rural Energy for America Program (USDA REAP) grants, state rebates, and state production tax credits given to distributed wind projects in 2021 was $5.2 million in eight states. This is up slightly from $4.8 million in six states in 2020 and down from $7 million in 2019 in seven states. Incentive awards from the New York State Energy and Research Development

Agency's Small Wind Incentive Program were down in 2021 because of the discontinuation of that program, but distributed wind grants from USDA REAP were slightly up and awarded in more states in 2021.

While at least 24 different small wind turbine models have been certified to the American Wind Energy Association (AWEA) 9.1-2009 standard or International Electrotechnical Commission (IEC) 61400 standards since 2011, a total of seven small wind turbine models have current certifications as of July 2022. Small wind turbines must meet either of these standards to be eligible to receive the federal Business Energy Investment Tax Credit per the U.S. Internal Revenue Service (IRS). Small wind turbine manufacturers must renew certifications annually. Manufacturers may opt not to renew if they no longer want to participate in the U.S. market or if the company has discontinued all operations.

The American Clean Power Association (ACP), the successor to AWEA, has developed a new American National Standards Institute consensus standard, ACP 101-1. The Distributed Wind Energy Association and the U.S. Department of Energy have recommended that the IRS recognize certification to either AWEA 9.1-2009 or ACP 101-1 going forward for tax credit eligibility.

Installed Costs and Performance

The average capacity-weighted installed cost for new small wind projects in 2021 was $5,120/kW, based on 16 projects (each having one turbine) in three states for a combined rated capacity of 396 kW. The overall annual average capacity-weighted installed cost for new projects in PNNL's dataset had been relatively flat through 2019 at approximately $9,970/kW, so the 2021 average is a notable decrease from past years' averages. This decrease may be attributable to the sample of projects with reported costs for 2021 only including turbines in the size segment of 11–100 kW, which tend to have a lower cost per kW than turbines in the size segment of 1–10 kW, although there was also an increase in sales in the size segment of 11–100 kW in 2021.

The average capacity-weighted installed cost for small wind retrofit projects in 2021 was approximately $3,400/kW, based on 17 projects (each having one turbine) in eight states for a total rated capacity of 494 kW. This is down from an average of $3,900/kW in 2020 (13 projects, 371 kW, 6 states) and $5,300/kW in 2019 (10 projects, 89 kW, 2 states) for small wind retrofits. Some retrofit projects use refurbished turbine units, and refurbished turbines represent the low end of the retrofit installed cost range. In 2021, six of the retrofit projects with reported costs used refurbished turbines, compared to three in 2020 and none reported in 2019, largely driving the drops in the annual average capacity-weighted installed costs over those years.

The average capacity-weighted installed cost for projects using turbines greater than 100 kW in 2021 was approximately $2,900/kW, based on just three projects using five turbines for a combined capacity of 6,250 kW. This is down from an average of $3,100/kW documented in 2019 (5 projects, 14.6 MW, 5 states), and $4,300/kW documented in 2018 (14 projects, 32.9 MW, 6 states). However, the small sample sizes and range of project sizes represented must be considered when reviewing these averages.

The overall average capacity factor in 2021 for a sample of small wind projects was 13%. The sample includes 105 turbines totaling 1.1 MW in rated capacity ranging from 2.1 kW to 56 kW in size installed from 2009 through the beginning of 2021. Observed capacity factors ranged from 1% to 33%.

Small wind projects with reported performance data for 2021 produced lower generation amounts in 2021 than the generation amounts that were initially estimated for the projects. Historical data indicates that 2021 was generally a below average wind resource year and that is one contributing factor to the low turbine performance recorded in 2021 relative to expectations.

The overall average capacity factor in 2021 for a sample of distributed wind projects using turbines greater than 100 kW was 22%. The sample includes 25 distributed wind energy projects installed from 2005 to 2018 in 14 states totaling a combined 44 MW in capacity with turbine capacities ranging from 600 kW to 3 MW. Observed capacity factors ranged from 6% to 43%.

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1 Introduction

The U.S. Department of Energy's (DOE's) annual Distributed Wind Market Report provides stakeholders with market statistics and analysis along with insights into market trends and characteristics.

Distributed wind turbines are distributed energy resources connected at the distribution level of an electricity system, or in off-grid applications, to serve specific or local loads. Distributed wind installations can range from a less-than-1-kW[1] off-grid wind turbine at a remote cabin or oil and gas platform, to a 15-kW wind turbine at a home or farm, to several multimegawatt wind turbines at a university campus, at a manufacturing facility, or connected to the distribution system of a local utility.

Individuals, businesses, and communities install distributed wind to offset retail power costs or secure long-term power cost certainty, support grid operations and local loads, help meet decarbonization goals, and electrify remote locations and assets not connected to a centralized grid. Depending on its application, distributed wind can either provide grid independence or potentially improve system resilience, power quality, reliability, and flexibility.

1.1 Purpose of Report

The annual Distributed Wind Market Report is part of DOE's Wind Energy Technologies Office distributed wind research program, which aims to enable wind technologies as distributed energy resources to contribute maximum economic and energy system benefits now and in the future.

To that end, the Distributed Wind Market Report analyzes distributed wind projects of all sizes. By providing a comprehensive overview of the distributed wind market, this report can help guide future investments and decisions by industry, utilities, federal and state agencies, and other interested parties. This report provides key information to help stakeholders understand and access market opportunities and inform distributed wind industry research and development needs.

1.2 Distributed Wind Applications

Distributed wind can be classified by where the turbine is installed relative to the local distribution grid. Grid-connected turbines are typically either behind-the-meter or front-of-meter installations.[2] A behind-the-meter wind turbine is one that is always connected to the local distribution grid behind a customer's utility meter—typically to offset all or some of the on-site energy needs. Behind-the-meter wind turbines displace retail electricity demand and can be net metered to credit excess output flowing back onto the grid. A wind turbine connected to a distribution grid as a generation resource is considered a front-of-meter installation. Front-of-meter wind projects provide energy and grid support to the distribution system and help serve the interconnected local loads on the same distribution system.

A wind turbine can be off grid in a remote location as a distributed energy source for on-site energy needs. An off-grid distributed wind turbine can be deployed with a battery or other form of energy storage because the wind turbine is not connected to a local distribution grid that could provide backup energy or accept excess energy. An off-grid wind turbine typically serves a single load such as a remote telecommunications site or a cathodic protection system for an oil pipeline pumping station.

[1] 1 gigawatt (GW) = 1,000 megawatts (MW); 1 MW = 1,000 kilowatts (kW); 1 kW = 1,000 watts (W)

[2] Grid-connected distributed wind turbines can be physically or virtually connected to the distribution grid or on the customer side of the meter. Virtual (or remote) net metering allows a member to receive net-metering credit from a remote renewable energy project as if it were located behind the customer's own meter.

Distributed wind can be part of a microgrid or isolated grid, located either behind the meter or front of the meter. A microgrid is a group of interconnected loads and distributed energy resources within defined electrical boundaries that can operate in either a connected or disconnected (islanded) mode from the local distribution grid (Ton and Smith 2012).[3] An isolated electrical grid system powers many loads and typically serves a whole community, such as a remote village, and is not connected to a larger grid system.

1.3 Wind Turbine Size Classifications

The distributed wind market includes wind turbines and projects of many sizes. When appropriate, this report breaks the market into the following three wind turbine size classifications:

- Small wind turbines are up through 100 kW (in nominal, or nameplate, capacity)[4]
- Mid-size wind turbines are 101 kW to 1 MW
- Large-scale wind turbines are greater than 1 MW.

For projects using turbines greater than 100 kW, the project's total nominal power capacity is used in this report's cost-per-kW analysis and related analyses. For small wind, this report uses the total rated power capacity of the project in the cost-per-kW analysis and related analyses, rather than nameplate capacity.[5] A certified small wind turbine's rated capacity is its power output at 11 meters per second (m/s) per the American Wind Energy Association (AWEA) 9.1-2009 standard. For small wind turbines that are not certified, the power output at 11 m/s is assigned as the turbine's rated, or referenced, capacity.

The turbine manufacturers and models used in 2021 distributed wind projects are listed in Appendix A. Rated capacities for the small wind turbine models included in this report are listed in Appendix B.

1.4 Data-Collection, Categorization, and Analysis Methodologies

To collect data on distributed wind installations, sales, and related activities that occurred in calendar year 2021, the Pacific Northwest National Laboratory (PNNL) team issued data requests to small wind turbine manufacturers, suppliers,[6] developers, installers, and operations and maintenance (O&M) providers; state and federal agencies; utilities; trade associations; and other stakeholders. The PNNL team also reviews data from other sources for distributed wind projects using turbines greater than 100 kW. This report includes data from past data requests and presents the distributed wind market from 2003 through 2021. In some cases, because of data availability and quality, analyses use different time periods within the time range of 2003 to 2021.

The PNNL team created a project dataset to capture all projects installed in 2021 identified through the data-request and data-review process. That dataset has been consolidated with those created for past years to create a master project dataset that is available (with a free registration) on PNNL's website.

The PNNL team regularly updates the master project dataset when new information becomes available. In 2021, the PNNL team reviewed the customer types assigned to projects. Some projects were recategorized, which shifted some capacity among the customer types from what was previously reported. In addition, when the PNNL team identifies projects that were installed in past years but were not previously recorded, the team adds those projects to the master project dataset. Further, the PNNL team marks turbines confirmed to be

[3] Off-grid distributed wind can also be categorized as a type of microgrid. As interest in microgrids grows (see Section 8.2), PNNL may adjust how off-grid and microgrid distributed wind installations are categorized in future reports.

[4] The U.S. Internal Revenue Service (IRS) also defines small wind as up through 100 kW for the purpose of federal investment tax credit (ITC) eligibility (see Section 4.1.2).

[5] The nominal, or nameplate, capacity of a wind turbine is what manufacturers use to describe, or name, their wind turbine models. In the case of small wind, the nameplate capacity can be significantly different from a turbine's rated capacity. As a result, rated capacities for small wind turbines are used in this report's per-kW analyses to provide a consistent baseline. For turbines greater than 100 kW, the turbine's nameplate capacity matches the turbine's pitch-regulated maximum power output, allowing the nameplate capacity to be the consistent baseline.

[6] In relation to manufacturers, suppliers provide refurbished turbines.

decommissioned in the dataset as such, but does not actively track decommissioning. Consequently, the cumulative capacity amount presented in this report, and capacity allocations by state and by year, may differ slightly from report to report.

Many small wind turbine units sold are not tracked at the project level, such as off-grid turbine units sold by the manufacturer to distributors for resale to end users, so the PNNL team is unable to include them in the master project dataset. The master project dataset is used to make year-to-year comparisons; allocate capacity amounts across states; analyze installed costs; identify incentive funding levels; and characterize distributed wind customers, types of turbines and towers, and project applications.

The PNNL team also created a separate small wind sales dataset based on the sales reports provided by the manufacturers and suppliers listed in Appendix A.[7] The reported total number of small wind turbine units and capacity deployed, domestically and abroad, come from this small wind sales dataset. For small wind, this report details capacity figures for the same calendar year as sales reported by the manufacturers and suppliers to tally annual deployed capacity.

Appendix B provides more details for the data-collection, categorization, and analysis methodologies.

[7] Most manufacturers report precise turbine units sold, but at least one manufacturer provides estimated turbine units sold because the company's less-than-1-kW size turbine units are shipped in bulk to distributors for resale to end users.

2 U.S. Distributed Wind Deployment

From 2003 through 2021, over 89,000 wind turbines have been deployed in distributed applications across all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and Guam, totaling 1,075 MW in cumulative capacity, as shown in Figure 1.[8] In 2021, 15 states added a total of 11.7 MW of new distributed wind capacity from 1,751 turbine units representing a $41 million investment.[9] The annual deployed capacity is down from both 2020 and 2019. In 2020, 21.9 MW were deployed in 11 states from 1,497 turbine units representing a $44 million investment.[10] In 2019, 20.4 MW were deployed in 22 states from 2,179 turbine units representing a $59 million investment.

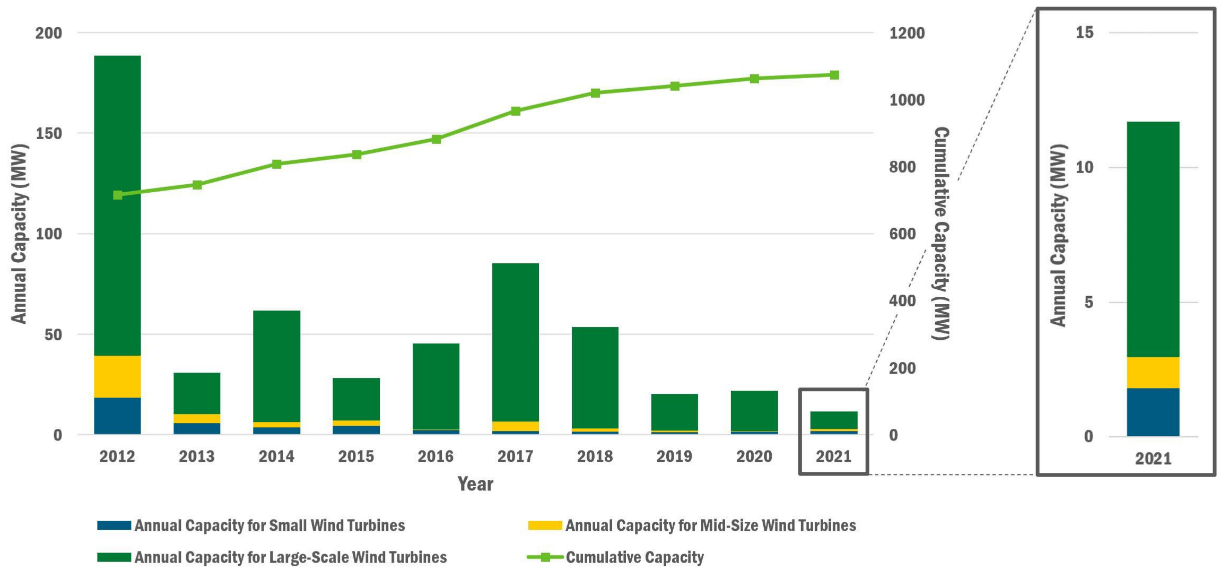

Figure 1. U.S. distributed wind capacity

2.1 Top States for Distributed Wind: Annual and Cumulative Capacity

New distributed wind projects were documented in 15 states (California, Colorado, Illinois, Iowa, Kansas, Massachusetts, Michigan, Minnesota, Nebraska, New York, Ohio, Rhode Island, Utah, Vermont, and Wisconsin) in 2021 and have been documented in all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and Guam since 2003, as shown in Figure 2.

[8] The data presented in the figures are provided in an accompanying data file available for download at https://energy.gov/windreport.
[9] All dollar values are nominal unless otherwise noted. Annual and cumulative capacity amounts are based on nameplate turbine-capacity sizes.
[10] The 2020 amounts are slightly higher than what was reported in the Distributed Wind Market Report: 2021 Edition because two additional projects installed in 2020 (Glenville and Red Lake Falls Community Hybrid) were retroactively added to the master project dataset.

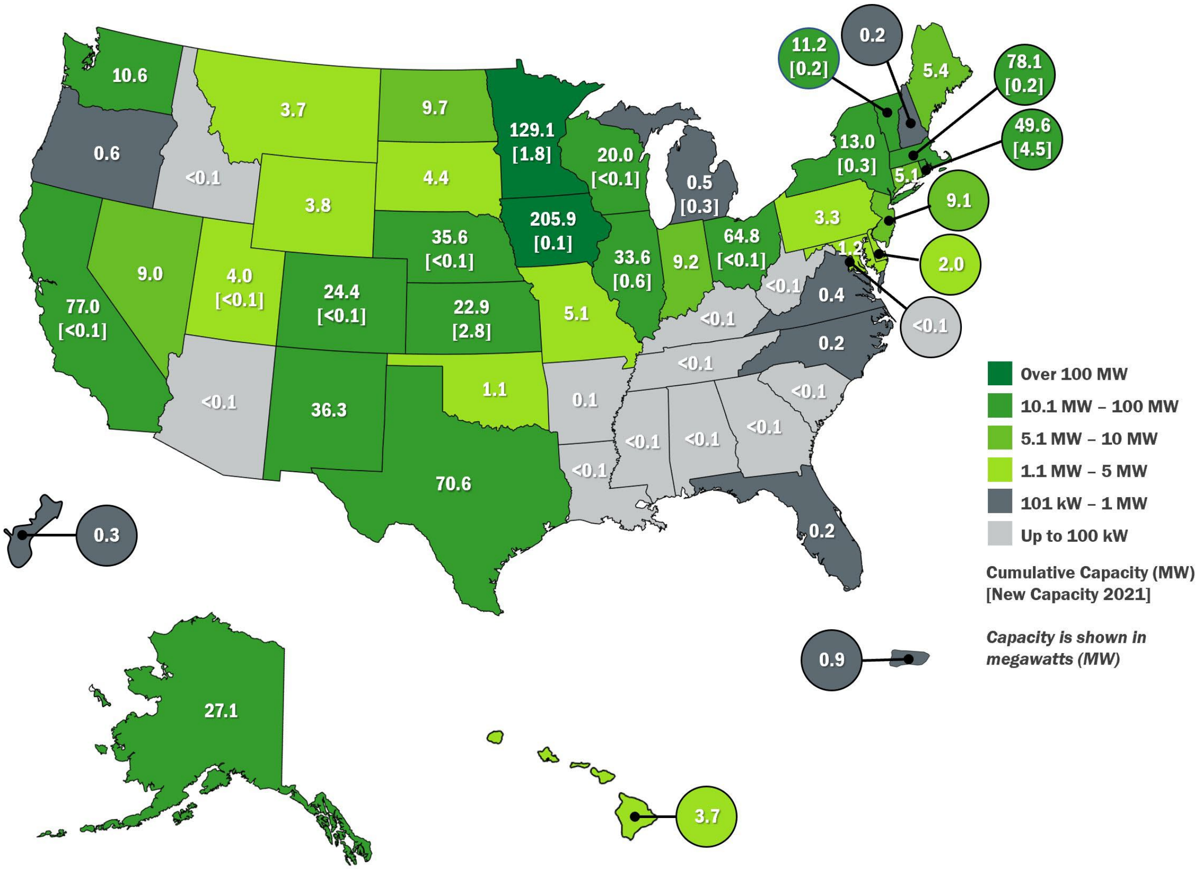

Figure 2. U.S. cumulative (2003–2021) capacity and 2021 capacity additions for distributed wind by state

Rhode Island, Kansas, and Minnesota led the United States in new distributed wind power capacity in 2021. This is a result of the front-of-meter 4.5-MW Providence Waterfront project in Rhode Island installed by Green Development, the behind-the-meter 2.72-MW Western Plains/Smokey Hills project in Kansas serving an ethanol plant installed by Juhl Energy,[11] and the 1.5-MW Altura Wind project in Minnesota for utility customers installed by WES Engineering, Inc. These three projects combined represent 75% of the distributed wind capacity installed in 2021.

The concentration of a few projects using large-scale turbines in a few states can be attributed to the project-development cycles of a handful of developers. And because each company works almost exclusively in a single state rather than nationally, annual distributed wind capacity additions can be concentrated in a few states. Project developers, namely Juhl Energy in Minnesota; One Energy Enterprises LLC (One Energy) in Ohio; Green Development, LLC in Rhode Island; Foundation Windpower in California; Optimum Renewables in Iowa; and Bluestem Energy Solutions in Nebraska, may not install new projects every year, as shown in Figure 3, because each project can take two to four years to develop (ACP 2022). These six developers have accounted for at least 40% of the distributed wind capacity from projects using turbines greater than 100 kW since 2015. The "other" category in Figure 3 primarily includes project owners (e.g., universities and municipalities), other third-party developers with a less consistent presence, and unknown developers.

[11] Juhl Energy, Inc. operates multiple subsidiaries, so Juhl Energy is used comprehensively in this report.

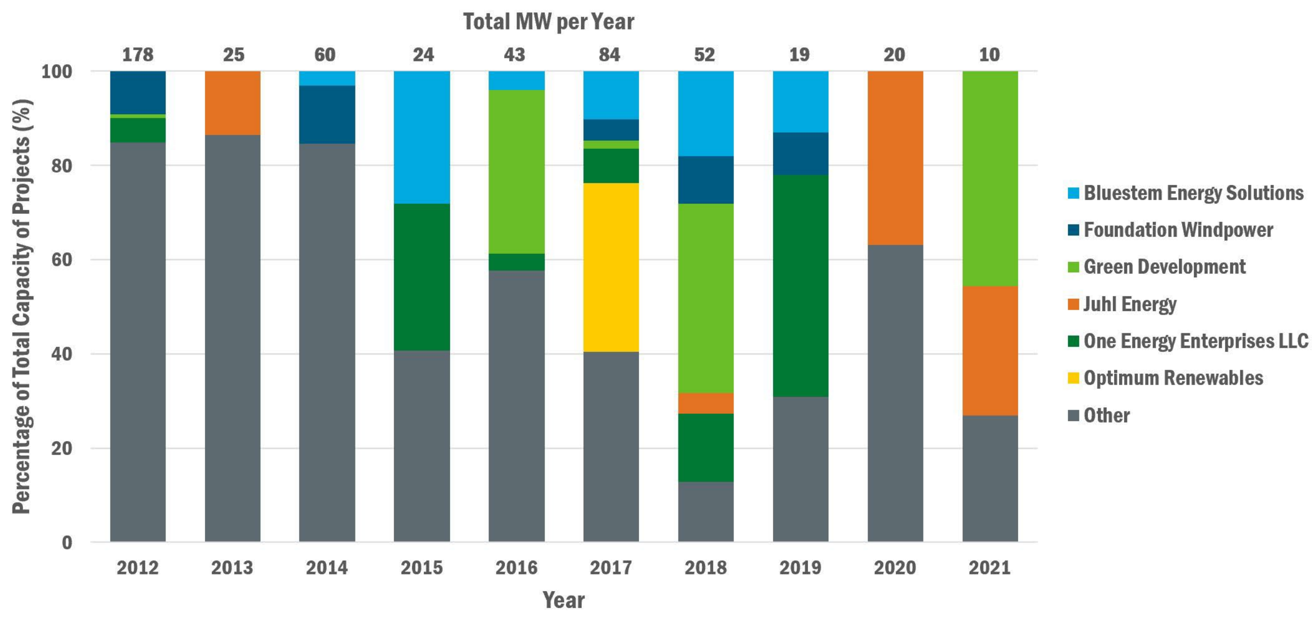

Figure 3. Project developers using turbines greater than 100 kW, 2012–2021

Annual installations vary across the states, as illustrated in Figure 4 and Figure 5. Figure 4 shows states with cumulative distributed wind capacities greater than 20 MW. Figure 5 shows states with small wind cumulative capacities greater than 2 MW.

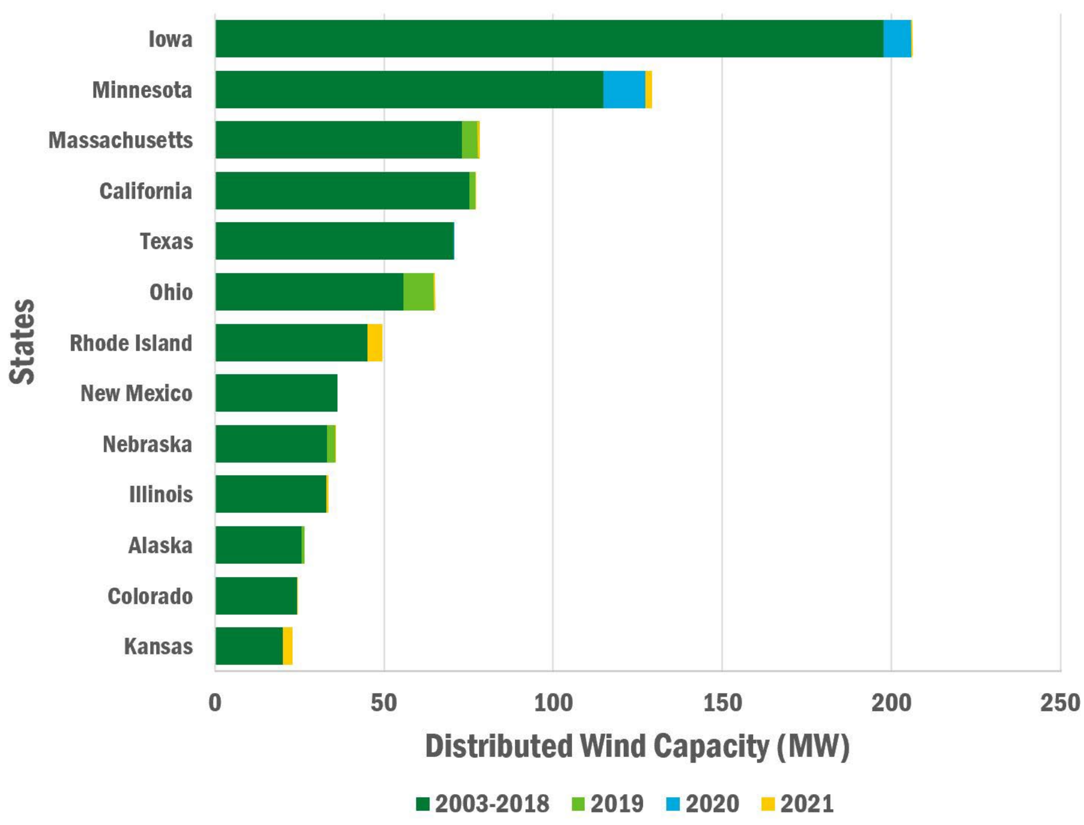

Figure 4. States with distributed wind capacity greater than 20 MW, 2003–2021

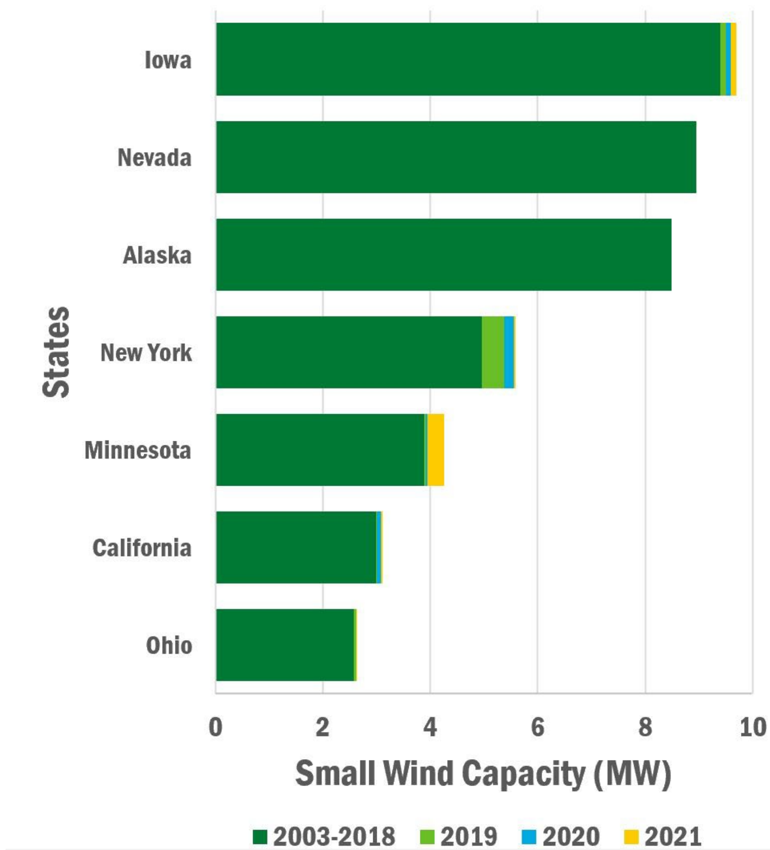

Figure 5. States with small wind capacity greater than 2 MW, 2003–2021

Iowa and Minnesota lead all the states in cumulative capacity from 2003 through 2021, with both states exceeding 100 MW, as shown in Figure 4. Both states have strong wind resources and active project developers. Both states have also received the largest share of U.S. Department of Agriculture (USDA) Rural Energy for America Program (REAP) funding for wind projects since 2003 (see Section 4.1.3).

Iowa, Nevada, and Alaska are the top three states for cumulative small wind capacity, as shown in Figure 5, although there were no new small wind installations recorded for Nevada and Alaska in 2021. New York led the United States in annual small wind capacity additions from 2017 through 2020 but installations declined following the discontinuation of the New York State Energy and Research Development Agency (NYSERDA) Small Wind Turbine Incentive Program.

Minnesota added the most reported small wind capacity in 2021 with 305 kW, primarily as a result of Eocycle's push to sell its EOX-S16 turbine model to farmers in Minnesota (Eocycle 2021). Eocycle has focused on the agricultural market segment, with a start in Minnesota, because the company believes that many farms are in wind-rich areas, wind has a smaller land footprint than solar photovoltaics (PV), winter wind energy production can match farm energy consumption trends, and wind turbines can provide a decarbonization solution for the emissions-heavy agriculture industry (Mogensen 2022).

3 U.S. Distributed Wind Projects, Sales, and Exports

As shown in Figure 1, of the 11.7 MW of distributed wind added in 2021, 8.7 MW came from projects using turbines greater than 1 MW (75%), 1.2 MW came from mid-size turbines (10%), and 1.8 MW came from small wind (15%).

3.1 Mid-Size and Large-Scale Turbines

A total of 8.7 MW of the distributed wind capacity added in 2021 came from projects using turbines greater than 1 MW and 1.2 MW came from mid-size turbines. The total of 9.9 MW from turbines greater than 100 kW represents $32 million in investment.[12]

The 8.7 MW from projects using turbines greater than 1 MW is down from the 20 MW documented in 2020 and the 18.2 MW documented in 2019. Two projects, the 2.5-MW Glenville project and the 4.6 MW of wind at the Red Lake Falls Community Hybrid project, both in Minnesota, came online at the end of 2020. These two projects were not originally captured in the 2020 capacity values presented in *Distributed Wind Market Report: 2021 Edition*.

Projects using mid-size turbines continue to represent a small part of the distributed wind market as there are a limited number of mid-size turbines available and larger turbines can be more cost effective (although refurbished[13] mid-size turbines can have lower capital costs than newly manufactured mid-size turbines). Added capacity from mid-size turbines has been under 5 MW annually since 2013 and has consisted of predominantly single-turbine projects. However, the 1.2 MW of mid-size capacity from three projects deployed in 2021 was an increase from 0.28 MW from two projects in 2020 and 0.9 MW from one project in 2019.

Only a limited number of newly manufactured mid-size turbines are commercially available. As turbine technology improved, turbine sizes could increase. Larger turbines (but also refurbished mid-size turbines) typically have lower capital costs on a per-kW basis making them a more cost-effective option for many applications. Turbines with nameplate capacities in the hundreds of kilowatts can be considered stepping stones to the multimegawatt turbines available today. For example, the first two phases of the Stateline Wind Farm (not considered distributed wind) along the Oregon and Washington state border were commissioned in 2001 and 2002 and deployed 660-kW wind turbines. That was once the largest wind farm in the United States. The project developers commissioned a third phase in 2009, just seven years later, but installed 2.3-MW wind turbines for that phase.

However, there is still demand from customers for whom mid-size turbines are a good fit for their energy needs. That demand and the limited availability of newly manufactured turbine models explain the use of refurbished turbines in this size sector and the re-entrance of one turbine manufacturer to the U.S. market. Of the six projects using mid-size turbines in 2019, 2020, and 2021, at least four are refurbished models. Prior to its 250-kW turbine being using in one 2021 project, Siva Wind's last U.S. installation was in 2012. The other two mid-size turbine projects in 2021 used refurbished turbine models.

The return of India-based Siva Wind to the U.S. market also helps illustrate that manufacturer representation in U.S. distributed wind projects changes from year to year and the mid-size and large-scale turbine markets often rely on imports. However, some manufacturers are consistently represented in distributed wind projects and manufacturer representation is tied to the project development cycle of the developers featured in Figure 3.

[12] This investment value reflects the estimated installed cost of the deployed capacity, not just the turbine hardware costs. The same is true for the small wind investment value presented in Section 3.2.

[13] A refurbished turbine may be one that only had a few new parts added to it or simply had a change of hydraulic or transmission fluids before being resold. Alternatively, a refurbished turbine could have undergone an extensive remanufacturing process in which all of its parts were fully rebuilt.

General Electric (GE) Renewable Energy has been the only consistent U.S.-based[14] manufacturer of large-scale turbines used in distributed wind projects over the past ten years and is the sole turbine provider for Foundation Windpower and the turbine provider for Juhl Energy and Bluestem Energy Solutions' most recent projects. China-based turbine manufacturer Goldwind is the sole turbine supplier for One Energy Enterprises LLC, and Green Development uses turbine models from the Germany-based manufacturer Vensys. Reported U.S. distributed wind projects using turbines greater than 100 kW in 2021 deployed newly manufactured turbine models from GE Renewable Energy (for Juhl Energy), Vensys (for Green Development), Goldwind, Siva Wind, and refurbished turbines from Bonus and Nordtank.

The number of mid-size and large-scale turbine manufacturers and suppliers with installations in the United States has generally declined since 2012. However, manufacturer representation in 2021 was more diverse than in 2019 and 2020, as shown in Figure 6. Manufacturers with turbines deployed in three or more years are shown separately in Figure 6. Manufacturers with turbine deployed in just one or two years in the 10-year period shown in Figure 6 are grouped in the "Other" category. For turbines greater than 100 kW, 17 manufacturers are represented in the "Other" category in Figure 6 in 2012 and three in 2021. A total of 25 manufacturers and suppliers provided turbines for distributed wind projects in 2012 compared to six in 2021, two in 2020, and three in 2019.

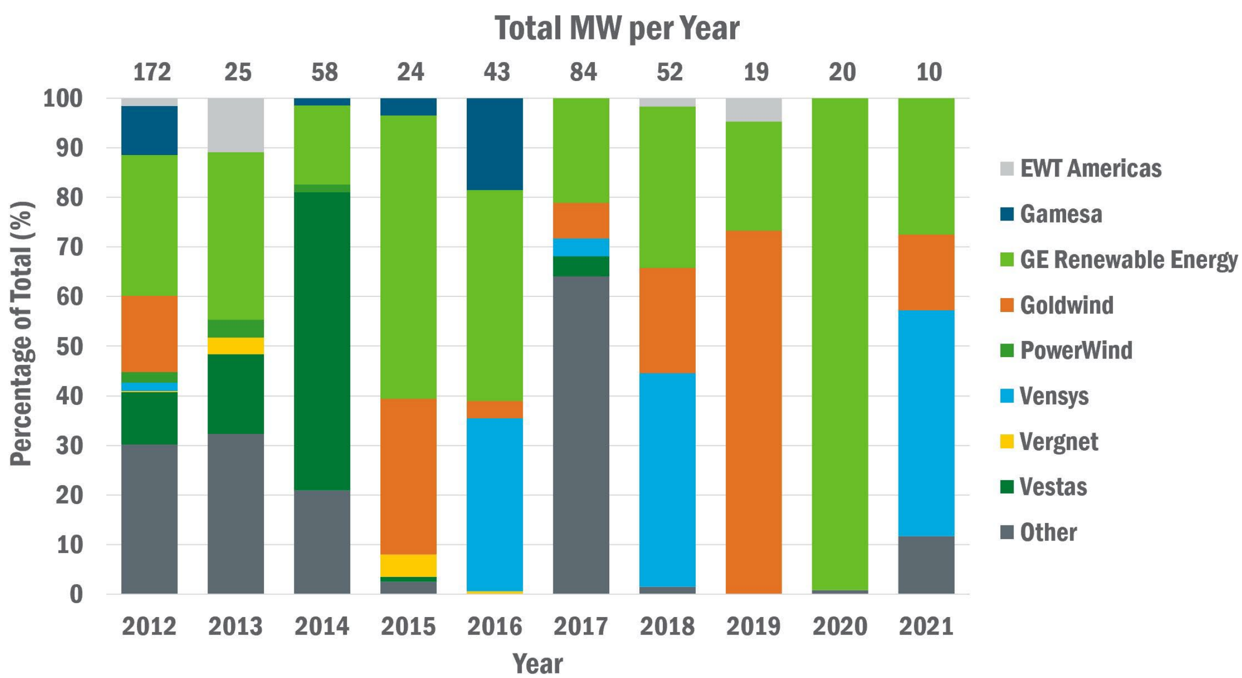

Figure 6. Wind turbine manufacturers of turbines greater than 100 kW with a U.S. sales presence, 2012–2021

3.2 Small Wind

In 2021, 1.8 MW of small wind was deployed in the United States from 1,742 turbine units representing a $9.2 million investment. The capacity and investment amounts are slightly up from 1.6 MW, 1,487 turbine units, and $7.2 million of investment in 2020 and 1.3 MW, 2,168 turbine units, and $7.6 million in 2019. This increase in deployed capacity in 2021 can be partially attributed to the inclusion of sales from two turbine manufacturers that PNNL had not previously tracked and early designs from additional turbine manufacturers.

[14] U.S.-based means the manufacturer or supplier is headquartered in the United States.

Since 2012, the number of small wind turbine manufacturers both operating and participating in the U.S. market has generally been on the decline. The 13 small wind turbine manufacturers or suppliers with a 2021 U.S. sales presence accounted for in this report (listed in Appendix A) consist of nine domestic manufacturers headquartered in eight states (Arizona, Colorado, Minnesota, New York, Oklahoma, Texas, Vermont, and Wisconsin) and four foreign manufacturers. This total is up from 2020, in which eight small wind turbine manufacturers or suppliers had sales in the United States, with six being domestic and two being foreign. However, this increase in 2021 was still down from the peak of 31 small wind turbine manufacturers with reported U.S. sales in 2012.

Based on 2021 global sales in terms of capacity (megawatts of domestic sales and exports), the top three U.S. small wind turbine manufacturers and suppliers were Primus Wind Power of Colorado, Bergey WindPower of Oklahoma, and All Energy Management of Wisconsin (supplying refurbished Endurance E-3120 turbine models).

While some small wind turbine manufacturers and installers reported that the COVID-19 pandemic affected their business in 2020, many more reported negative effects from the pandemic in 2021. The issues they reported include not having available employees to fully operate, customers needing to delay project installations, and the increased costs for raw materials and shipping. With global supply chain disruptions, the cost increases for raw materials and, in particular, shipping, were noted by many small wind industry stakeholders. Some small wind turbine manufacturers reported that they have consequently increased the prices of their turbine models.

Sales from U.S.-based manufacturers increased 7% in 2021 from 2020. However, newly manufactured small wind turbines by U.S.-based manufacturers represent a smaller percentage of overall sales in 2021 because of an increase in small wind imports from non-U.S. turbine suppliers. Four foreign small wind manufacturers reported sales in the United States in 2021 compared to two in 2020. New small wind turbines from U.S.-based manufacturers accounted for 65% of the domestic small wind sales capacity in 2021, as shown in Figure 7, compared to 71% in 2020 and 84% in 2019.

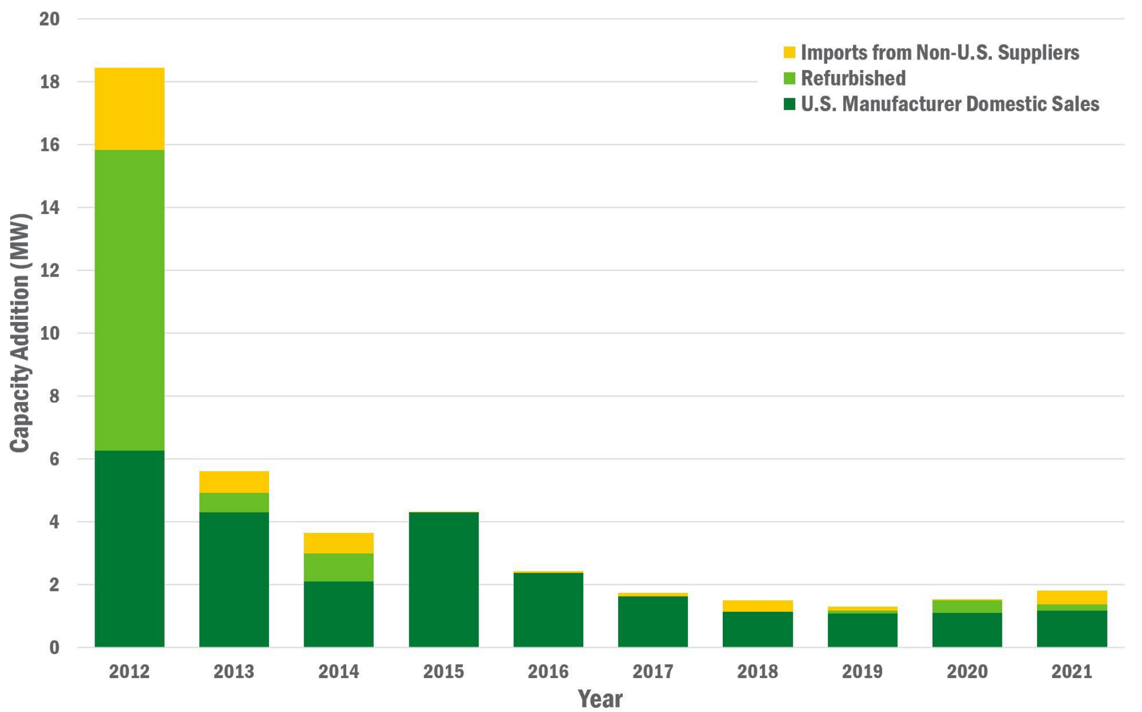

Figure 7. U.S. small wind turbine sales, 2012–2021

Although PNNL did not document any refurbished[15] small wind turbine sales from 2015 through 2018, their market presence has increased in recent years, although not with a consistent trend. Refurbished turbines accounted for 11% of U.S. small wind sales in 2021, 26% in 2020, and 8% in 2019. Given the inconsistent presence of foreign manufacturers and refurbished turbines in the U.S. small wind market, these market-share divisions are expected to keep shifting.

3.3 Small Wind Exports

U.S. small wind turbine manufacturers also export to international markets. Since 2014, more than 50 MW of U.S. small wind turbines have been exported globally, but these exports have declined significantly from a peak of 21.5 MW valued at $122 million from six U.S.-based manufacturers in 2015 to just 134 kW valued at $700,000 from three manufacturers in 2021. In 2020, exports were nearly 200 kW valued at $1.1 million from three manufacturers and in 2019, exports were 500 kW valued at $3 million from three manufacturers.

Italy, the United Kingdom, and Japan had been key export markets for U.S. small wind turbine manufacturers due to those countries' feed-in tariff (FIT) programs. In the peak year for exports, 2015, 99% of U.S. small wind turbine manufacturers' exports went to these three countries. The FIT programs in Italy, the United Kingdom, and Japan have since been discontinued or drastically reduced, thus reducing the attractiveness of these markets for U.S. small wind turbine manufacturers.

The FIT rate in Italy ranged between €0.11 and €0.25 ($0.13 to $0.29)[16] per kilowatt-hour (kWh) from 2015 to 2016 before expiring in 2017. It was replaced by the FER1 Decree, which provided rates of €0.15 ($0.18) per kWh for small wind (0–100 kW) projects until it expired at the end of 2021 (Dentons 2019; Dentons 2020). The United Kingdom closed its FIT program to new applicants on April 1, 2019 and has introduced the Smart Export Guarantee program. Under the Smart Export Guarantee program, applicants now receive a tariff determined by the buyer, rather than a fixed price determined by the government (Ofgem 2021). Japan's FIT rates have steadily declined since 2015, with a peak of ¥55 ($0.50) per kWh that subsequently fell to ¥19 ($0.17) per kWh as of 2019 for turbines less than 20 kW. FIT rates for turbines 20 kW and greater reduced from ¥21–¥22 ($0.19–$0.20) in 2015 to ¥19 ($0.17) as of 2019. For 2022, the rate has been set even lower, to just ¥16 ($0.14) (Enerdata 2022). The government is in the process of designing new market-based feed-in premiums to support integration of renewables into the power market (IEA 2021).

3.4 Global Small Wind Market

An examination of the global small wind market provides additional context for small wind market trends and a point of comparison for the U.S. small wind market. For 2021, PNNL documented 40 MW of new small wind capacity from six countries, including the United States, as shown in Table 1. This is an increase from the 31 MW of international small wind PNNL documented for 2020. However, PNNL depends on agencies in other countries to report their statistics, so that dependency results in an incomplete picture of the global market. Other countries, not included in Table 1, may have different market situations.

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[15] Most of the refurbished turbines deployed in the United States were originally manufactured by a non-U.S.-based manufacturer and then refurbished by a U.S.-based supplier. As a result, refurbished turbines are shown separately in Figure 7.

[16] All currency conversions are based on the exchange rates per U.S. Department of Treasury Reporting Rates as of May 13, 2022, found in https://fiscaldata.treasury.gov/datasets/treasury-reporting-rates-exchange/treasury-reporting-rates-of-exchange for reference.

Table 1. Global Small Wind Capacity Reports

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	Cumulative	Cumulative Years
	(MW)										
Australia[a]	*	0.02	0.03	*	0.02	*	0.01	0.00	0.00	1.47	2001–2021
Brazil[b]	0.03	0.02	0.11	0.04	0.11	0.29	0.44	0.07	0.11	1.11	2013–2021
Canada[c]	*	*	*	*	*	*	*	*	*	13.47	As of 2018
China[d,e]	72.25	69.68	48.60	45.00	27.70	30.76	21.40	25.65	33.38	610.61	2007–2021
Denmark[f,g]	11.04	7.50	24.78	14.61	2.58	0.40	0.18	0.05	0.01	610.88	1977–2021
Germany[h]	0.02	0.24	0.44	2.25	2.25	1.00	2.50	2.50	2.50	35.75	As of 2021
Italy[i,j]	7.00	16.27	9.81	57.90	77.46	0.47	0.12	1.10	2.39	192.92	As of 2021
Japan[k]	*	*	*	*	*	*	*	*	*	12.88	As of 2019
New Zealand[l]	*	*	*	*	*	*	*	*	*	0.19	As of 2015
South Korea[m]	0.01	0.06	0.09	0.79	0.08	0.06	0.00	*	*	4.08	As of 2019
United Kingdom[n]	14.71	28.53	11.72	7.73	0.39	0.42	0.43	*	*	141.51	As of 2019
United States	5.70	3.67	4.32	2.43	1.74	1.51	1.30	1.55	1.82	154.47	2013–2021
Global	110.75	126.01	99.90	130.75	112.32	34.90	26.37	30.91	40.22	1,815.34	

* Data not available
a www.cleanenergyregulator.gov.au
b www.aneel.gov.br
c The Atlas of Canada – Clean Energy Resources and Projects
d China Wind Energy Equipment Association
e Chinese Wind Energy Association
f www.energinet.dk
g Danish Energy Agency, Master Data Register of Turbines
h Bundesnetzagentur; Bundesverband Kleinwindkraftanlagen; 0–50-kW capacity (estimate)
i www.assieme.ed; 0–250-kW capacity
j Gestore dei Servizi Energetici
k Japan Small Wind Turbine Association
l Sustainable Electricity Association of New Zealand
m Korea Energy Association
n www.gov.uk, Monthly feed-in tariff commissioned installations

The 33 MW of small wind installed in China in 2021 accounts for 83% of the documented capacity added globally in 2021, based on the reports made available to PNNL. China experienced a 30% increase in small wind installations from 2020 to 2021. Italy submitted reports showing significant wind capacity additions through 2017, but did not send reports to PNNL for 2018 and 2019 when initially requested. Table 1 reflects the updated annual additions of less than 1 MW for both 2018 and 2019 provided to PNNL during this report's data-collection process, and the higher capacity amounts of 1.1 MW and 2.4 MW for 2020 and 2021, respectively. Although less generous than past FIT schemes, this uptick coincides with Italy's FER1 Decree on July 4, 2019 (Gestore dei Servizi Energetici 2020). The FER1 Decree applies to new renewable energy projects not already incentivized under previous FIT schemes (Dentons 2020). The United Kingdom had significant small wind capacity additions through 2016 followed by a dramatic decline in the years 2017 through 2019. With the closing of their FIT program in 2019, the United Kingdom no longer tracks and reports on small wind capacity additions (Gov.UK 2019). Japan's FIT program continues, however PNNL was unable to obtain the country's current small wind data report.

Total global installed cumulative small wind capacity is estimated to be just over 1.8 gigawatts (GW) as of 2021 as shown in Table 1. Small wind is generally defined as turbines up through 100 kW, but deviations from this definition are noted in the table footnotes.

4 Policies, Incentives, and Market Insights

A number of factors affect the U.S. distributed wind market, including the availability of, and changes to, federal and state policies and incentives.

4.1 Policies and Incentives

Federal, state, and utility incentives and policies (e.g., rebates, tax credits, grants, net metering, production-based incentives, and loans) are important to the development of distributed wind and other distributed energy resource projects.

Figure 8 shows the value of incentives given to distributed wind projects from 2013 to 2021.[17] The combined value of USDA REAP grants, state rebates, and state production tax credits in 2021 was $5.2 million across eight states (Iowa, Kansas, Michigan, Minnesota, Nebraska, New Mexico, New York, and Vermont). This is up slightly from $4.8 million in six states in 2020, down from $7 million in 2019 in seven states, and down significantly from a peak of $100 million worth of incentives dispersed across 22 states in 2012.

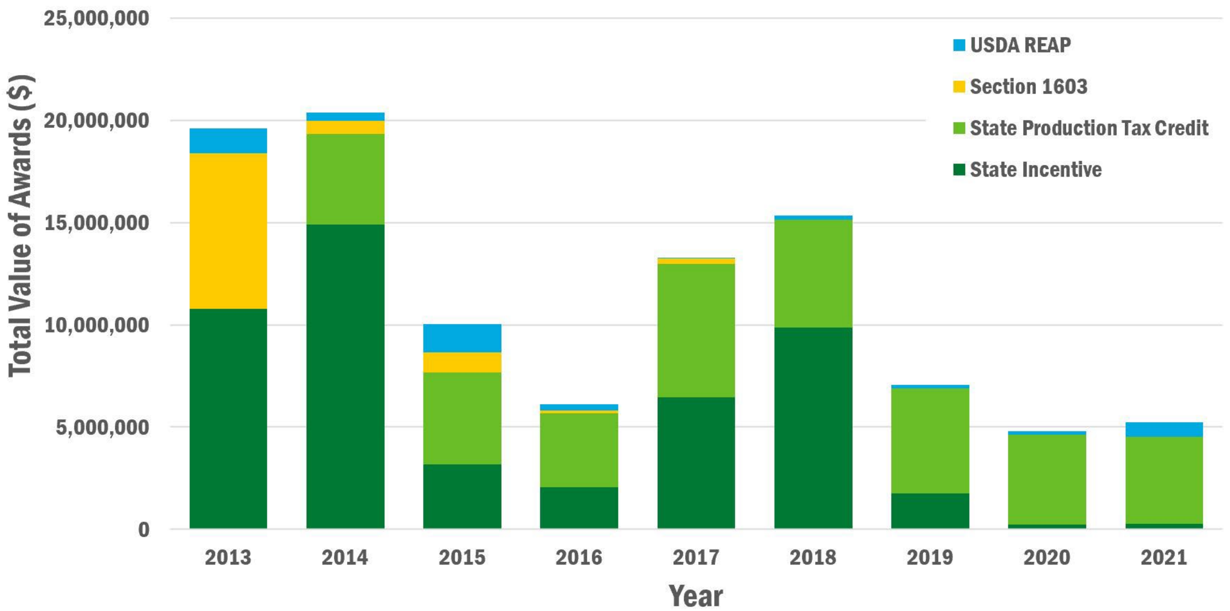

Figure 8. U.S. distributed wind incentive awards, 2013–2021

The incentives included in Figure 8 are state rebates, grants, and production-based incentives; USDA REAP grants; New Mexico and Iowa state production tax credits; and U.S. Treasury cash grants (otherwise known as Section 1603 payments). PNNL started tracking the New Mexico and Iowa state production tax credits in 2014, when the New Mexico credit was first initiated. Figure 8 excludes repaid loans, the federal Business Energy investment tax credit (ITC), the federal Residential Energy Tax Credit, federal depreciation, and USDA High Energy Cost Grants. The federal tax credits are excluded because information on how many wind projects have claimed the federal Business Energy ITC and the Residential Energy Tax Credit is not public

[17] Distributed wind projects often receive incentive funding at a different time than when they are commissioned. For example, although USDA REAP grants are recorded for this report in the year they are awarded, they are paid after the project is commissioned and this can be up to two years after the award. In addition, this report reflects that some historical California state incentives were corrected because of a past PNNL misunderstanding of when incentives were applied for compared to when they were paid out.

record. High Energy Cost Grants are excluded because they typically cover full systems with multiple technologies (e.g., new wind turbines, boilers, and electric thermal storage devices) and the value of the grant for the wind portion cannot be distinguished. New Mexico and Iowa state production tax credit values are estimated based on available project energy production reports.

Awards from all of these incentive programs have been decreasing over the past years. Iowa production tax credit payments are decreasing as some projects have completed their 10-year eligibility period. The last Section 1603 payments were made in 2017 (Treasury 2018).[18] The decline in state incentives is explored in Section 4.1.1. Federal tax-based incentives are discussed in Section 4.1.2. USDA REAP wind applications and grants are discussed in Section 4.1.3.

4.1.1 State Policy and Incentive Highlights

State renewable portfolio standard requirements, net-metering policies, interconnection standards and guidelines, FITs, utility programs, and the availability of grants, rebates, performance incentives, and state tax credits can affect the cost effectiveness and deployment of distributed wind in a state. In 2012, 12 state programs reported incentive payments for distributed wind projects. In contrast, three state programs reported incentive payments for distributed wind projects in 2021 while four reported payments in 2020, 2019, and 2018. The three programs are the Iowa and New Mexico state production tax credits and the NYSERDA Small Wind Turbine Incentive Program. The fourth program with payments in 2020, 2019, and 2018, the California Self-Generation Incentive Program (SGIP), did not make any awards to distributed wind projects in 2021, but projects are in the application queue for potential future awards. With the expiration of the NYSERDA incentive, the California SGIP is the last state rebate program PNNL is aware of that consistently provides funding to distributed wind projects.

4.1.2 Federal Tax-Based Incentives

The federal Business Energy ITC (26 U.S.C. § 48) and the Residential Renewable Energy Tax Credit (26 U.S.C. § 25D) are federal policy mechanisms that offset some of the capital costs of qualified renewable energy projects. Under the Consolidated Appropriations Act of 2021 (enacted as Public Law 116-260 on December 27, 2020), small wind turbines' eligibility for the Business Energy ITC at 26% of qualified expenditures was extended through 2022, with a scheduled phasedown to 22% for properties that begin construction by the end of 2023, after which the credit expires. Similarly, the Residential Renewable Energy Tax Credit will remain at the current 26% rate through 2022 and reduce to 22% for properties placed in service through 2023, after which the credit ends.

The federal production tax credit (PTC) for onshore wind was extended through December 31, 2021, under the Consolidated Appropriations Act 2021. Projects that began construction by the end of 2021 were eligible for a PTC at 60% of the full rate over 10 years. Alternatively, projects that began construction by the end of 2021 could have opted instead for a Business Energy ITC of 18% of the total project cost.

4.1.3 USDA REAP

The USDA provides agricultural producers and rural small businesses grant funding and loan financing to purchase or install renewable energy systems or make energy-efficiency improvements. Through REAP, the USDA issues loan guarantees for renewable energy projects for up to 75% of the project's cost or a maximum of $25 million. The USDA also issues REAP grants for up to 25% of the project's cost, or a maximum of

[18] The federal ITC was temporarily augmented in 2009 to allow for cash payments from the federal government in lieu of the tax credit, otherwise known as the U.S. Treasury cash grants or Section 1603 payments. To qualify for Section 1603 payments, wind power projects must have applied for a grant before October 1, 2012, and be placed in service by 2011, or began construction in 2009, 2010, or 2011 and placed in service by December 31, 2016. Because payments were made after the project was placed in service, not prior to or during construction, payments continued through 2017.

$500,000 for renewable energy projects. A combination of REAP loans and grants can cover up to 75% of total eligible project costs.

In 2021, USDA REAP awarded $696,964 in grants to 22 wind projects from 34 applications. The 22 projects represent a total of 604 kW of capacity from 23 turbines in five states. The projects are expected to generate a combined 2.5 GWh of energy annually. USDA REAP did not provide any loan guarantees to wind projects in 2021. The 2021 funding amount was greater than the $155,025 in wind grants awarded in 2020 in three states, when three projects out of four applications received awards.

Renewable energy and energy-efficiency applications for REAP funding must first go through a technical merit review, with different criteria depending on the project's total cost. For example, technical information evaluated may include the project description, resource assessment, project economic assessment, project construction and equipment, and qualifications of key service providers as provided by the applicant (7 CFR 4280.116). If the application is determined to have adequate technical merit, then it is eligible for further consideration for funding. Eligible applications are scored on eight criteria, one of which is the project's simple payback (7 CFR 4280.121).

The uptick in wind awards and applications in 2021 can be partially attributed to the USDA's use of priority points, or discretionary points, in scoring underrepresented technologies such as distributed wind projects. Priority points help advance USDA Rural Development priorities[19] by raising certain projects' scores, which in turn improves the chances of those projects being scored high enough to warrant awards (USDA 2022). Wind grant applications must compete against other renewable energy and energy-efficiency grant applications.

REAP grant applicants and USDA REAP staff have indicated to PNNL that small wind's high capital cost results in lower scores than solar PV or energy-efficiency projects. The USDA's simple payback calculation excludes grants and state and federal incentives; it is based exclusively on the installed cost and value of the electricity generated. If a project's simple payback period is longer than 25 years, it receives zero points for this criterion, lowering its overall score and, thus, its likelihood of receiving an award.

In addition, REAP applications must go through an environmental review process under the National Environmental Policy Act. Projects cannot be awarded funding until the environmental review process has been completed with no adverse findings. Because a wind turbine installation includes groundbreaking for the foundation, it may have a more complicated environmental review than a rooftop solar PV installation, resulting in project delays.

Although there was an increase in wind applications and awards in 2021, USDA REAP grant and loan amounts for wind projects have decreased significantly since 2012, as shown in Figure 9 and Figure 10, respectively. In addition, drastically fewer grants are awarded for wind projects than for solar PV projects.

In 2021, wind projects represented 1.7% of all REAP grant awards and 1.5% of all REAP grant funding, while energy-efficiency projects represented 27% of grant awards and 21% of grant funding; and solar PV projects represented 67% of grant awards and 63% of grant funding. Other renewable energy awards include biogas, biomass, geothermal, and hydroelectric projects. In 2020, wind projects represented 0.19% of all REAP grant awards and 0.31% of REAP grant funding. With respect to loans over the period of 2012 to 2021, there was only one loan guarantee for a distributed wind project in 2018 and six loans guaranteed in 2012. This is in contrast to the record number of 76 loans guaranteed to solar PV projects in 2021(up from 60 in 2020 and 52 in 2019).

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[19] USDA Rural Development's three key priorities are 1) assist rural communities recover economically from the impacts of the COVID-19 pandemic, particularly disadvantaged communities, 2) ensure all rural residents have equitable access to Rural Development programs and benefits from Rural Development-funded projects, and 3) reduce climate pollution and increasing resilience to the impacts of climate change through economic support to rural communities (USDA 2022). State Director and Administrator priorities are also used in the scoring process (7 CFR 4280.121).

Since 2003, the USDA has awarded over $73 million in REAP wind grants. States receiving the largest share of this funding are Iowa with $23.3 million, Minnesota with $21.7 million, Illinois with $4.1 million, Ohio with $2.9 million, and Oregon with $2.8 million. The top five states in terms of number of wind projects awarded are Iowa with 265 projects, Minnesota with 186, New York with 50, Wisconsin with 45, and Alaska with 30.

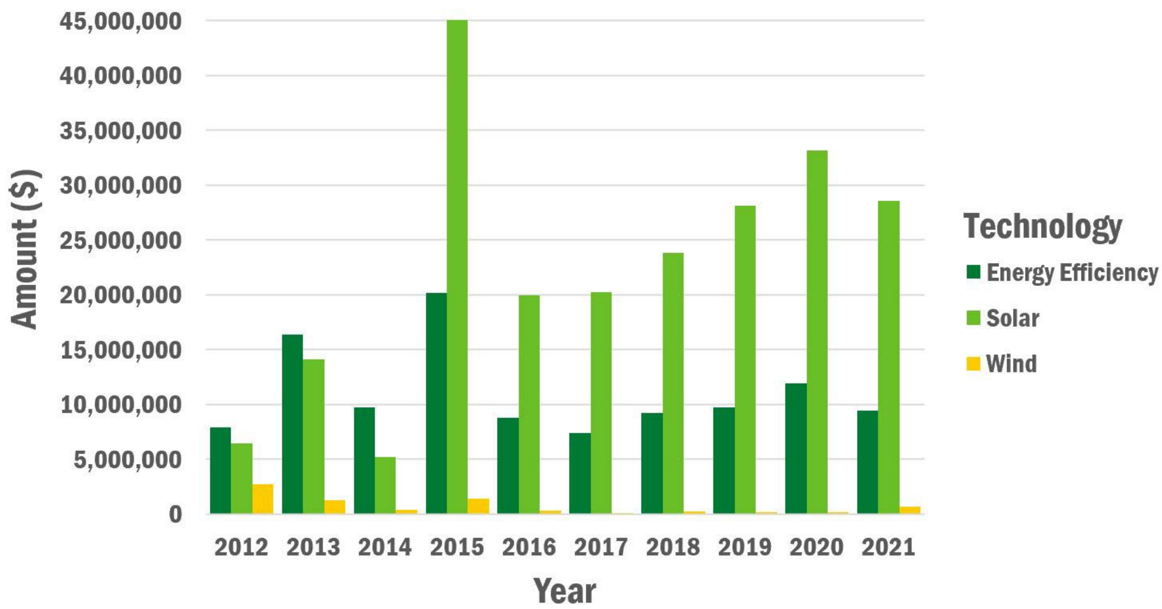

Figure 9. USDA REAP grants by technology, 2012–2021

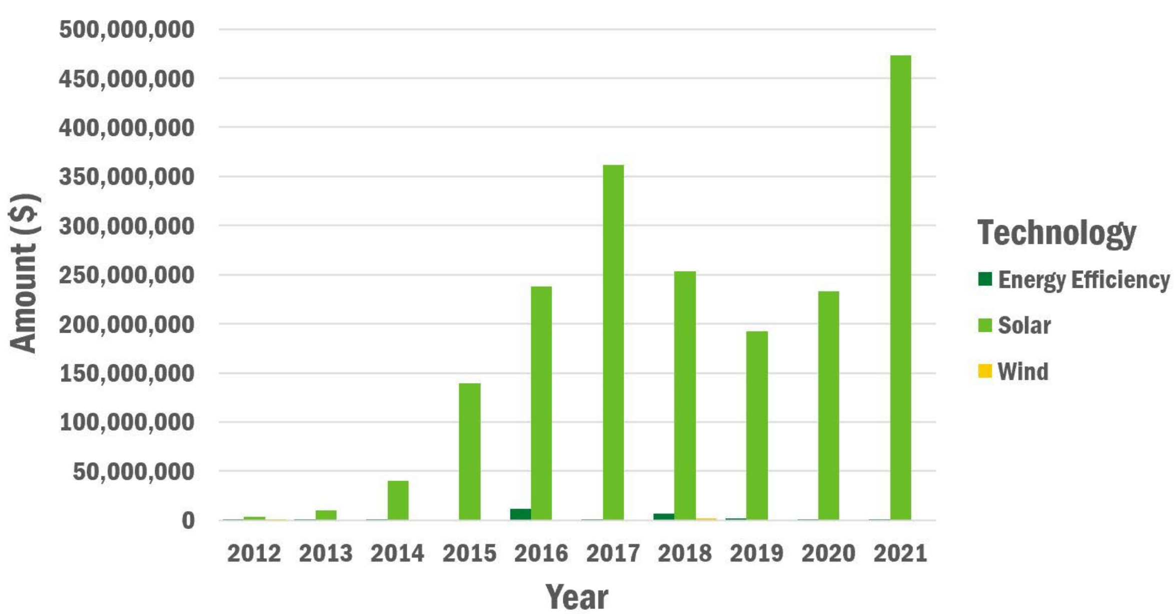

Figure 10. USDA REAP loans by technology, 2012–2021

4.2 Market Insights

Other factors beyond policy decisions and changing incentives, such as technology innovations and new market development, affect the distributed wind market. This section provides a few highlights of these types of activities.

4.2.1 Small Wind Retrofits

Small wind retrofits continue to account for a significant portion of new domestic small wind capacity deployment. In 2021, small wind retrofits represented 42% of the total installed small wind capacity, compared to 68% in 2020 and 27% in 2019. This fluctuation is likely a result of how many customers an installer can manage in a year, turbine supply availability, and each year's sample size of reported projects. The percentage values for retrofits in 2020 and 2019 presented here differ from what was presented in *Distributed Wind Market Report: 2021 Edition* because PNNL was able to add more small wind project records to its master project dataset over the past year.

Retrofits are new (either newly manufactured or refurbished) turbines installed on existing towers and foundations to replace nonfunctioning turbines or to upgrade the technology. The small wind retrofit projects in 2021 primarily used either new Bergey Excel 15 turbine units or refurbished Endurance E-3120 turbine units. Of the retrofit projects that used refurbished turbines in both 2020 and 2021, the majority of them were refurbished Endurance E-3120 turbine units to replace older, nonfunctioning Endurance E-3120 turbine units. Refurbished Endurance E-3120 turbine units have also been deployed in some new installations.

The retrofit trend is largely driven by customers' interest in reusing existing infrastructure to maintain on-site wind generation. The PNNL team expects retrofitting activities to continue as small wind turbines reach the ends of their life cycles and customers seek out improved technologies.

4.2.2 Hybrids and Co-Located Distributed Energy Resources

Co-located and co-operated energy resources with shared components and control strategies are the characteristics that most typically define a hybrid power plant or system (Murphy et al. 2021; Ahlstrom et al. 2019). Installers and small wind turbine manufacturers report increased interest from customers for hybrid systems, particularly for off-grid applications. Wind and solar generation can be complementary, and this resource diversity can allow a wind-solar hybrid to achieve a more consistent renewable generation profile throughout the year (Clark et al. 2022; Reiman et al. 2020). A homeowner with a small wind turbine and rooftop solar PV can also benefit from the complementarity, even if the two resources are not controlled together.

There is also interest in larger hybrid power plants. At the end of 2020, at least 38 wind hybrid power plants, with sizes greater than 1 MW, were operating across the United States (Wiser et al. 2020). Hybrid power plants are being installed at all scales, including at the distribution level. The Red Lake Falls Community Hybrid project, installed in 2020, includes 4.6 MW of distributed wind and 1 MW of solar PV interconnected to serve a utility's distribution system in Minnesota.

Because of this interest and growing trend, PNNL now documents in its master project dataset, to the extent possible, if the distributed wind project is part of a hybrid power plant, part of a hybrid power system, or has co-located distributed energy resources.

4.2.3 Competitiveness Improvement Project

The Competitiveness Improvement Project (CIP), which is funded by DOE and administered by the National Renewable Energy Laboratory (NREL), awards cost-shared subcontracts via a competitive process to manufacturers of small and medium wind turbines. Since 2012, NREL has awarded 52 subcontracts to 25 companies, totaling $12.4 million of DOE funding and leveraging $6.4 million in additional private-sector investment (NREL 2022a).

The CIP is aligned with the goals of the DOE Wind Energy Technologies Office's Distributed Wind Research Program. These goals are to make small and medium wind technology cost competitive with other distributed energy resources, measured through levelized cost of energy reduction, and to increase the number of small and medium wind turbine designs tested to national performance and safety standards, measured through number of tested designs.

The 2022 CIP request for proposals (which closed on April 6, 2022) included a new topic area that would support the costs associated with the commercialization process and development of partnerships with a pathway to larger-scale deployments. The 2022 request for proposals focused on projects that would develop new, innovative distributed wind energy concepts; transform and optimize existing designs for lower cost, increased energy production, or expanded capabilities; conduct wind turbine and component testing to national standards to verify performance and safety; create advanced manufacturing processes to reduce hardware costs; and accelerate pathways to commercialization (NREL 2022b).

4.2.4 Certified Small and Medium Turbines

Certifying a small or medium turbine model to consensus standards provides a method for manufacturers to demonstrate that the turbine model meets performance, durability, and quality requirements and establishes common performance metrics to enable performance comparisons. Certifications issued by independent, accredited third-party certification bodies allow wind turbine manufacturers to demonstrate compliance with regulatory and incentive program requirements. In addition, certified ratings allow purchasers to directly compare products and give funding agencies and utilities greater confidence that small and medium turbines installed with public assistance comply with applicable standards.

As of January 2015, small wind turbines must meet either the AWEA Small Wind Turbine Performance and Safety Standard 9.1-2009 or the International Electrotechnical Commission (IEC) 61400-1, 61400-12, and 61400-11 standards to be eligible to receive the Business Energy ITC (IRS 2015).[20] These standards address power performance, duration (durability), structural, safety, and acoustic sound requirements.

The American Clean Power Association (ACP), the successor to AWEA, has developed a new American National Standards Institute consensus standard, ACP 101-1, but it is not yet publicly available as of report publication. The ACP 101-1 standard defines small wind turbines as having a peak power of 150 kW or less and microturbines as having a peak power up to 1 kW. The Distributed Wind Energy Association (DWEA) and DOE have recommended that the U.S. Internal Revenue Service (IRS) recognize certification to either AWEA 9.1-2009 or ACP 101-1 going forward for tax credit eligibility. The ACP 101-1 standard has been designed to facilitate easier compliance, so the industry expects that new turbine models will be certified to this standard.

In addition, power electronics for wind turbines and other distributed energy resources are increasingly being required to meet more advanced controls and communications requirements, especially in markets with high distributed energy resource contributions. The required technical standards for these devices, such as UL Standard 1741, Edition 3 for inverters and Institute of Electrical and Electronics Engineers (IEEE) Standard 1547 for interconnection requirements, have been undergoing revision while certification and listing of devices to these standards are also evolving rapidly. The CIP is helping industry stakeholders address this emerging need as well. For example, CIP awards have been granted to companies working together to manufacture an inverter specifically designed for small- and medium-scale wind turbines that can be certified to meet UL Standard 1741 requirements (WETO 2021).

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[20] This certification requirement does not apply to wind projects that opt out of the PTC to instead receive the Business Energy ITC (26 U.S.C. § 48), nor is it codified in the Residential Renewable Energy Tax Credit (26 U.S.C. § 25D) requirements.

Table 2 lists the seven small wind turbine models currently certified to the AWEA 9.1 standard or the IEC 61400 standards as of July 2022. While at least 24 different small wind turbine models have been certified to these standards since 2011, only turbine models that have met annual renewal requirements are included in the table.[21] Manufacturers may opt not to renew if they no longer want to participate in the U.S. market or if the company has discontinued all operations.

Table 2. Certified Small Wind Turbines[22]

Applicant	Turbine Model	Date of Initial Certification	Certified Power Rating[a] @ 11 m/s (kW)	Certification Standard
Bergey WindPower	Excel 10	11/16/2011	8.9	AWEA 9.1
Bergey WindPower	Excel 15	2/5/2021	15.6	AWEA 9.1
Eveready Diversified Products (Pty) Ltd.	Kestrel e400nb	2/14/2013	2.5	AWEA 9.1
Eocycle Technologies, Inc.	EO20/E025	3/21/2017	22.5/28.9	AWEA 9.1
HI-VAWT Technology Corporation / Colite Technologies	DS3000	5/10/2019	1.4	AWEA 9.1
Primus Wind Power	AIR 30/AIR X	1/25/2019	0.16	IEC 61400
Primus Wind Power	AIR 40/Air Breeze	2/20/2018	0.16	IEC 61400

a Power output at 11 m/s (24.6 mph) at standard sea level conditions. Manufacturers may describe or name their wind turbine models using a nominal power, which may reference output at a different wind speed (e.g., 10-kW Bergey Excel 10).

[21] The certification for SD Wind Energy's SD6 turbine model expired July 1, 2022 and the company was pursuing renewal as of report publication.
[22] Other information about these certifications, such as rated sound levels and rated annual energy production amounts, are available from the certification bodies (ICC–SWCC 2022; SGS 2021; UL 2021).

5 Installed and Operations and Maintenance (O&M) Costs

Cost data in this section were derived from state and federal agencies, project owners and developers, installers, and news reports.

5.1 Small Wind Installed Costs

Figure 11 presents the average annual and project-specific small wind installed costs (in 2021 dollars) for 2012 through 2021. Figure 11 only includes projects with reported installed costs that use turbines with known rated capacities[23] and only includes an annual average for years in which there are three or more reported projects.

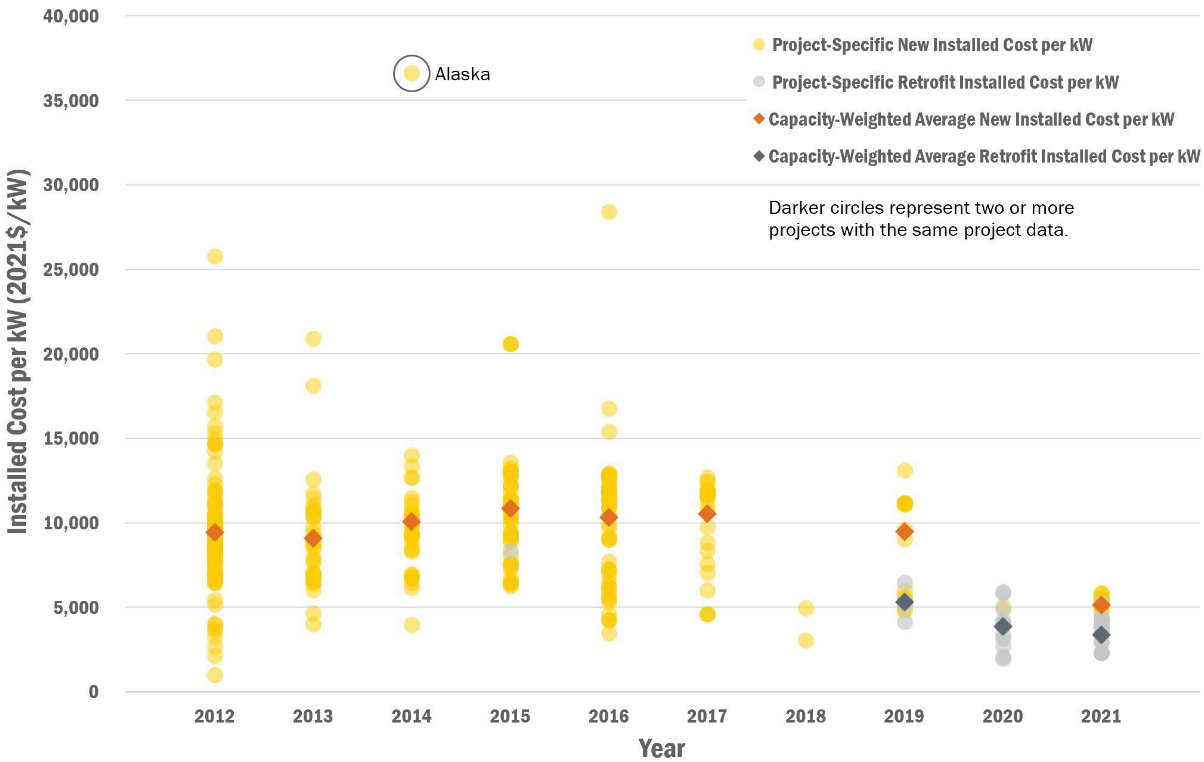

Figure 11. Average and project-specific U.S. new and retrofit small wind installed project costs, 2012–2021

The average capacity-weighted installed cost for new small wind projects in 2021 was $5,120/kW based on 16 projects (each having one turbine) in three states for a combined rated capacity of 396 kW. The annual average capacity-weighted installed cost for new projects in PNNL's dataset had been relatively flat through 2019 at around $9,970/kW, so the 2021 average is a notable decrease from past years' averages. This decrease may be attributable to the fact that the sample of projects with reported costs for 2021 only includes turbines in the size segment of 11–100 kW, which tend to have a lower cost per kW than turbines in the size segment of 1–10 kW. Although there may be bias in the sample, there was also an increase in sales in the size segment of 11–100 kW in 2021, as discussed in Section 8.3.

[23] See Table B.1 in Appendix B for the small wind turbine models included in this analysis.

The installed cost amount includes the wind turbine equipment costs, or the hardware costs, as well as the balance-of-station costs. Balance-of-station costs[24] can represent up to 60% of a new small wind project's total installed cost and therefore play a significant role in overall small wind installed costs (Orrell and Poehlman 2017). The varying sample sizes and the high variance in project-specific costs contributes to the cost ranges exhibited each year. The outlier project circled in Figure 11 is in Alaska, where transportation expenses and cold climate turbine features contributed to the higher project-specific installed cost.

Average annual (when available) and known project-specific small wind retrofit installed costs (in 2021 dollars) are also shown in Figure 11. Of the 33 small wind projects with reported costs for 2021, 17 were confirmed as retrofits. These 17 small wind retrofit projects (each having one turbine) are in eight states and represent a combined rated capacity of 494 kW. The annual average capacity-weighted installed cost for small wind retrofit projects was approximately $3,400/kW in 2021. This is down from an average of $3,900/kW in 2020 (13 projects, 371 kW, 6 states) and $5,300/kW in 2019 (10 projects, 89 kW, 2 states) for small wind retrofits.

As discussed in Section 4.2.1, some retrofit projects use refurbished turbine units. In 2021, six retrofit projects with reported costs used refurbished turbines, compared to three in 2020 and none in 2019. These refurbished turbines represent the low end of the retrofit installed cost range and largely drive the drops in the annual average capacity-weighted installed cost from 2019 to 2020 to 2021.

5.2 Installed Costs for Projects Using Wind Turbines Greater Than 100 kW

Figure 12 presents the average annual and project-specific costs (in 2021 dollars) for projects using turbines greater than 100 kW for years 2012 through 2021. Figure 12 only includes projects with reported installed costs and only includes an annual average for years in which there are three or more reported projects.

The annual average capacity-weighted installed cost for three projects in 2021 was approximately $2,900/kW. These three projects using turbines greater than 100 kW are from three states using five turbines for a combined capacity of 6,250 kW. This is down from an average of $3,100/kW documented in 2019, and $4,300/kW documented in 2018. However, the small sample sizes and range of project sizes represented must be considered when reviewing these averages.

The availability of cost information for distributed wind projects using turbines greater than 100 kW varies from year to year. As a result, the average costs reported for each year likely contain bias because of the project sample-size variation (e.g., military projects with higher costs due to specific cybersecurity requirements may dominate one year's sample while cost information for lower-cost agricultural projects in Minnesota may dominate another year's sample). The outlier project circled in Figure 12 is installed in Guam. Higher installation costs in Guam are expected because of its remoteness, but the distributed wind energy will also displace higher electricity costs (compared to the continental United States), so the project could still be cost-effective.

[24] The balance-of-station costs of a distributed wind system include customer acquisition and qualification; installation, foundation, and electrical labor, materials, and equipment; transportation; taxes; zoning, permitting, inspection, interconnection, and incentive labor and fees; engineering and design (e.g., site assessment, foundation design, and geotechnical report); financing; and overhead and profit (Forsyth et al. 2017).

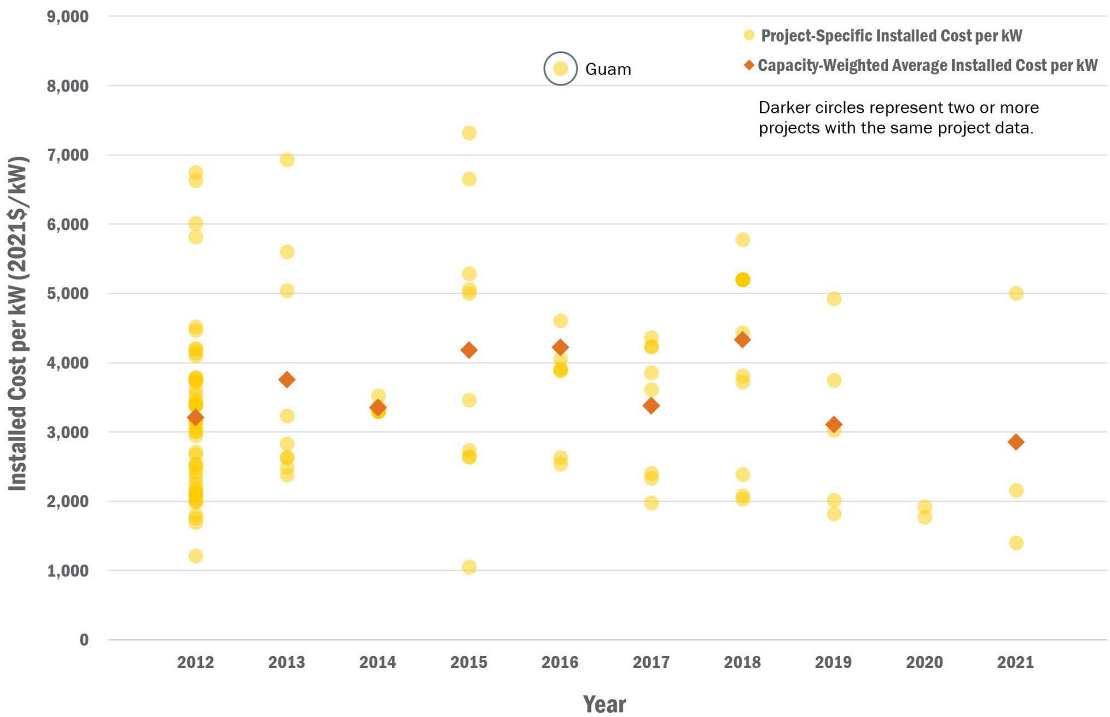

Figure 12. Average and project-specific installed costs for projects using turbines greater than 100 kW, 2012–2021

5.3 Operation and Maintenance Costs

The term "O&M costs" is common; however, operation costs differ from maintenance costs and not all distributed wind projects experience them equally. O&M activities can be performed by project owners or outsourced to third-party service providers. Operation costs for wind projects may include land lease payments, remote monitoring, various operations contracts, insurance, and property taxes. Operations are a significant expense for wind farms and large distributed wind projects, but they are not typically substantial, or even present, for small distributed wind projects, primarily because the turbine owner and the land owner are one and the same. On the other hand, all wind projects, distributed or otherwise, require maintenance.

For a large distributed wind project, O&M costs of the turbine system are part of the project's total operating expenses. The Land-Based Wind Market Report reports that operating expenses for recently installed projects are anticipated to average between $33/kW/year and $59/kW/year (Wiser and Bolinger 2022).

Maintenance costs can be categorized as scheduled or unscheduled. Scheduled maintenance activities for small wind projects can include inspecting the turbine, controller, and tower; adjusting blades; checking the production meter and communications components; and providing an overall biannual or annual scheduled maintenance visit per the manufacturer's owner's manual. Unscheduled maintenance can include activities ranging from responding to a customer's complaint of noise from the turbine to replacing the generator, electrical components, inverter, blades, anemometer, or furling cable.

For small wind, in most cases, the project installer or developer performs the maintenance for the small wind owner. Maintenance costs include labor, travel to the site, consumables, and any other related costs. Therefore, small wind maintenance costs can depend on the maintenance provider's proximity to the project site (i.e., travel costs), the availability of spare parts, and the complexity of maintenance and repairs. The average scheduled maintenance cost per visit for small wind is about $37/kW (Orrell and Poehlman 2017). This is in line with other data that suggest operation and maintenance costs for all distributed wind projects up to 10 MW are $30–$40/kW/yr (NREL 2016).

6 Performance

A wind project's capacity factor is one way to measure the project's performance. The capacity factor is a project's actual annual energy production divided by its annual potential energy production if it were possible for the wind turbine to operate continuously at its full capacity.[25] This section looks at capacity factors in various ways to evaluate the performance of distributed wind turbines.

6.1 Capacity Factors

Figure 13 presents the calculated capacity factors, arranged by geographic region, for a sample of small wind projects that produced energy in 2021. A box-and-whisker plot was selected to provide visibility into the average, median, and extreme capacity factors in each region. This approach should allow PNNL to compare these metrics across different years in future reports. The small wind annual generation data used in the capacity factor calculations are from turbine monitoring web portals and include 105 turbines totaling 1.1 MW in rated capacity ranging from 2.1 kW to 56 kW in size installed from 2009 through the beginning of 2021. Of the 105 turbines, PNNL had the metadata available to classify 71 into geographic regions; the remaining 34 are classified as having unknown exact locations.

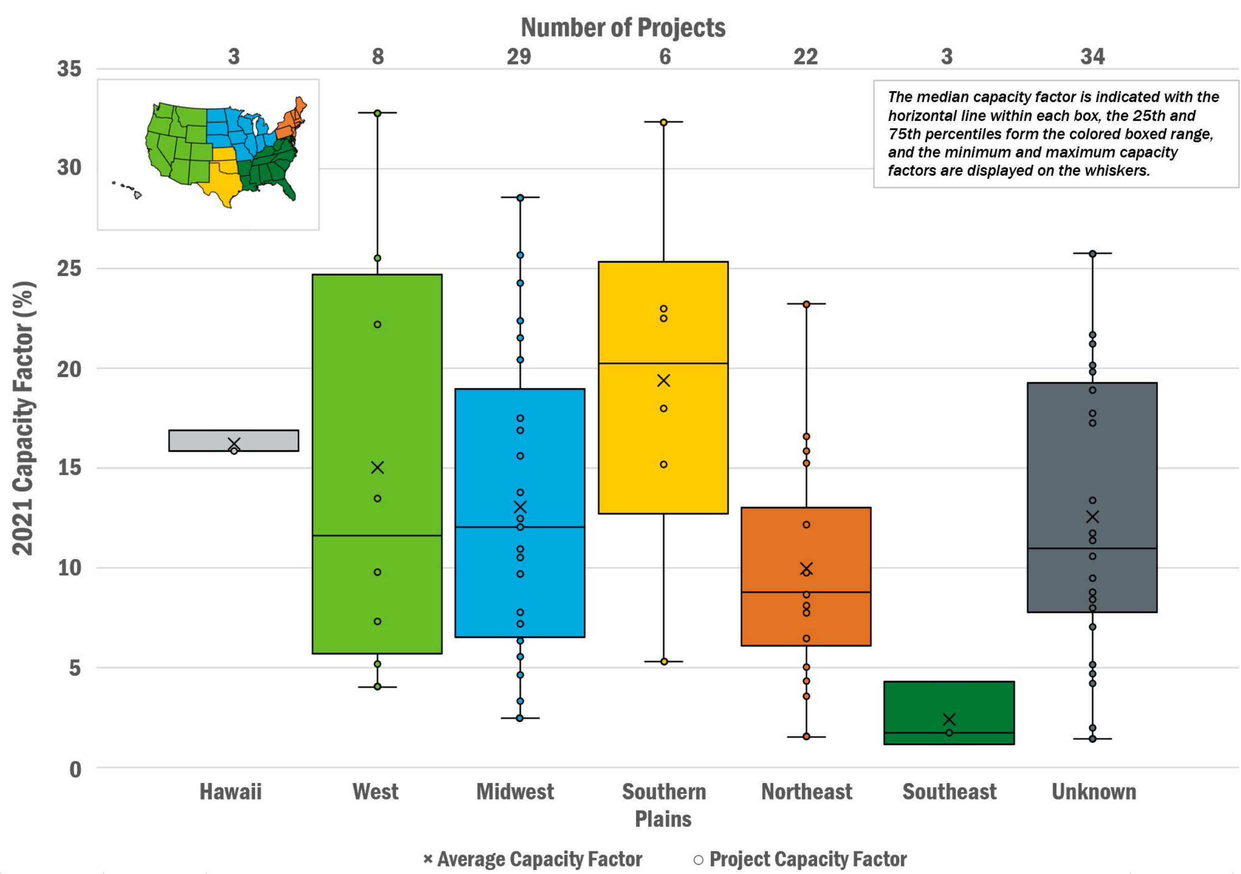

Figure 13. Small wind capacity factors

25 Capacity factor calculations for small wind use the turbines' rated, or reference, capacities, as defined in Appendix B, to be consistent with Section 5. For distributed wind projects using turbines greater than 100 kW, the turbine nominal capacities are used.

With the intent to provide an accurate portrayal of actual small wind turbine production (including losses and downtime) in 2021, the following data-quality-control guidelines were applied. Turbines with a full 12 months of reported data were included in the analysis. In addition, turbines with missing data were included if they were offline or had missing data 1) during the middle of 2021, 2) at the beginning of 2021 if those turbines had been online and reporting prior to 2021, or 3) at the end of 2021 if they came back online in 2022. Turbines were excluded from the analysis if they first came online during 2021 or if they were offline or missing data at the end of 2021 into 2022 (as this could indicate decommission). PNNL does not know the reasons turbines were offline or missing data.

The overall average capacity factor in 2021 for these small wind projects was 13%. The three small wind projects in Hawaii yielded an average 2021 capacity factor of 16%. The eight small wind projects in the West yielded an average 2021 capacity factor of 15%. The 29 small wind projects in the Midwest yielded an average 2021 capacity factor of 13% with great variability in individual project capacity factors. The Midwest region's great variability in wind resource (WINDExchange 2022) is one of the factors influencing the observed spread in project capacity factors. The six small wind projects in the Southern Plains produced the highest 2021 capacity factors, with an average of 19%. The 22 small wind projects in the Northeast, the majority of which are in New York, yielded an average 2021 capacity factor of 10%. New York's high electricity prices and past available incentives enabled significant small wind capacity additions for many years, despite the state's relatively low wind resource. The three small wind projects in the Southeast, the region with the lowest wind resource in the United States (WINDExchange 2022), produced the lowest 2021 capacity factors, with an average of 2%. And the 34 small wind projects with unknown locations yielded an average 2021 capacity factor of 13%.

The wide range of observed small wind capacity factors, from 1% to 33%, reflects, among other variables, the assessment and siting challenges for small wind discussed in Section 6.2. The same turbine model sited in different locations can achieve very different capacity factors, due to differences in the local wind resource and turbulence created by nearby obstacles and complex terrain. In addition, low turbine availability, due to a turbine not operating for extended periods because of mechanical problems or other reasons, can lower the turbine's overall capacity factor. Poor measuring and reporting of energy production may also be factors.

The annual generation data for projects using wind turbines greater than 100 kW, and at least 1 MW in size, are from Energy Information Administration (EIA) Form 923 reports. Wind projects with a total size of at least 1 MW are required to report net annual energy generation to the EIA (EIA 2022a). From these records, PNNL identified 25 distributed wind projects installed from 2005 to 2018, across 14 states, totaling 44 MW in combined capacity that had reported generation amounts for 2021. Turbine nominal capacities used in the projects range from 600 kW to 3 MW. Figure 14 presents the calculated capacity factors in 2021, arranged by geographic region, for these projects using turbines greater than 100 kW.

The wind projects in Figure 14 exhibit a wide range of observed capacity factors, from 6% to 43%. The average 2021 capacity factor for projects using turbines greater than 100 kW is 22%, which is higher than the 13% average capacity factor for small wind. This is most likely because large-scale turbine projects typically have thorough wind resource assessments as part of the siting process (to achieve optimal energy generation), undergo routine maintenance (to sustain high levels of reliability), and have taller hub heights (to capture faster wind speeds).

Geographically, the average 2021 capacity factors for the Midwest, Northeast, and West are consistent at 22%, 22%, and 21%, respectively. The single project in the Southern Plains, a region noted for its strong wind resource, produced the highest 2021 capacity factor of 43% (WINDExchange 2022).

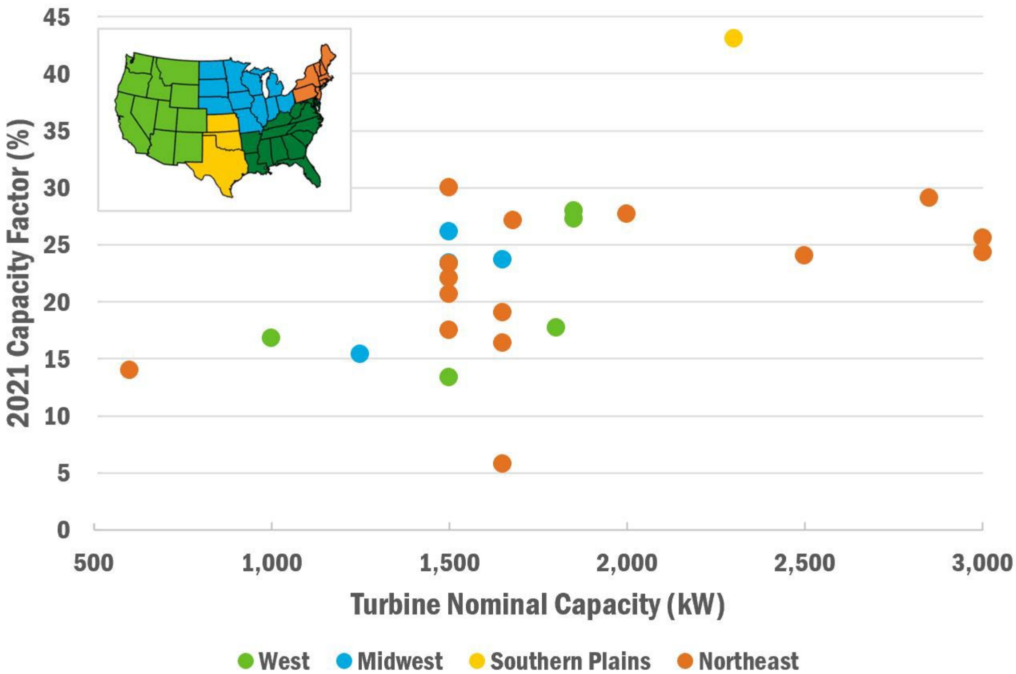

Figure 14. Capacity factors for projects using turbines greater than 100 kW

6.2 Actual versus Estimated Small Wind Performance

The amount of annual energy production achievable by a distributed wind project is driven by variables beyond turbine technology, including, but not limited to, the project's available wind resource, siting (i.e., tower height, local obstructions, and other micro-siting issues), and turbine availability (i.e., downtime for expected or unexpected maintenance or grid outages). These variables contribute to why accurately estimating distributed wind project performance can be challenging. In this section, PNNL compares estimated and actual project performance data and examines site-specific factors for individual turbines to reveal which variables may be introducing error in performance estimation modeling tools.

PNNL was able to examine 22 small wind projects across the United States installed from 2009 through the beginning of 2021 to assess actual versus estimated performance in 2021. The performance estimates, which source from installers and incentive programs, were provided to turbine customers and PNNL. PNNL does not have insight into the wind resource models, observations, or loss assumptions employed in the different estimations.[26] Figure 15 displays each project's percent of projected production (the ratio of actual 2021 generation and estimated generation). In 2021, all percentages of projected production are less than 100%, indicating that all small wind projects in the sample performed lower than the estimated generation, regardless of geographic region.

To isolate the effect of each project's wind resource on performance, Figure 15 also includes the normalized 2021 wind speed (the ratio of 2021 average wind speed to the 22-year average wind speed) based on the ERA5 model[27] over the reference years of 2000 to 2021. For 20 of the 22 small wind projects, the normalized 2021 wind speed is less than one, indicating a below average wind resource year at these locations. Therefore, for

[26] For a period of time, New York installers were required to use the Small Wind Explorer tool to be eligible for NYSERDA's incentive. The Small Wind Explorer Tool used AWS Truepower modeled wind resource data and the tool is no longer available now that NYSERDA's incentive program has been discontinued.

[27] The European Center for Medium-Range Weather Forecasts Reanalysis 5th generation, commonly referred to as ERA5 (ECMWF 2020). The reanalysis model provides decades-long wind resource data.

most projects in the sample, a low wind resource is a demonstrated factor contributing to the low turbine performance in 2021 relative to expectations.

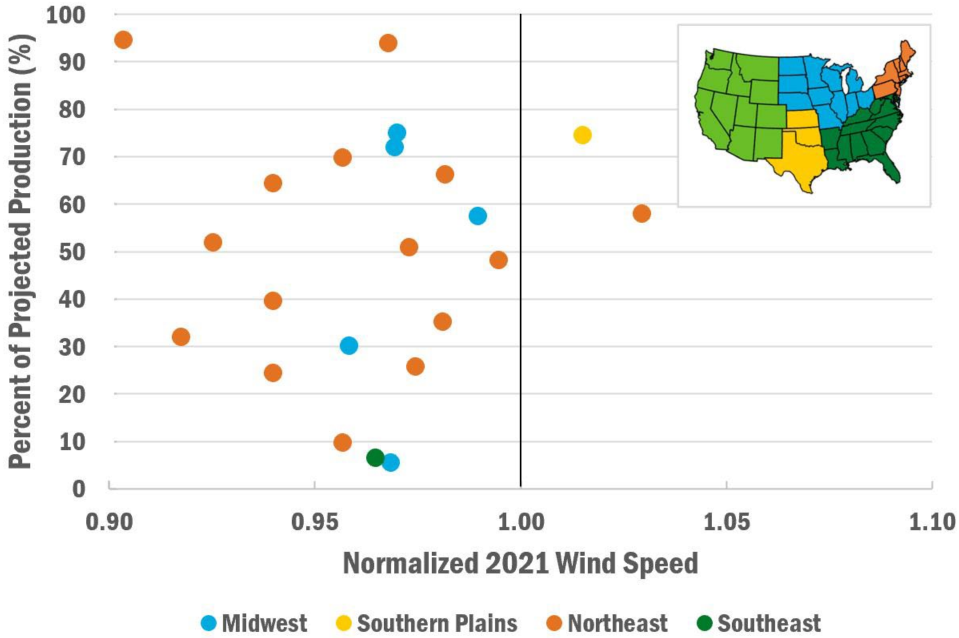

Figure 15. Actual and estimated performance for select small wind projects

The one project in the Northeast that is exhibiting above average wind resource in 2021 in Figure 15 reported 100% availability during 2021, but still did not produce its expected generation. The turbine is located in near proximity of both trees and buildings, a site design that is perhaps contributing to low turbine performance relative to expectations as accounting for obstacles is not a simple effort and may not have been incorporated into the estimation methodology. Publicly available wind resource assessment tools have limited ability to accurately represent turbine production in locations with complex terrain and local obstructions (Orrell et al. 2021).

Publicly available wind resource assessment tools are convenient, inexpensive, and readily accessible for small wind installers to use. However, the above assessment of actual versus estimated capacity factors yields a trend of project performance overestimation, along with challenges in resolving complex terrain and obstacles. An additional challenge is that many performance estimates are produced for an average wind resource year with no adjustment provided for the range of possible generation for high and low wind resource years. These challenges present a research and development opportunity, which, if solved, could have a positive impact on consumer confidence and the ability to finance small wind projects. Installers and owners can consider these challenges when making small wind performance estimates by recognizing that a performance estimate may need to be adjusted if the turbine is sited near obstacles or in complex terrain.

7 Levelized Cost of Energy

Levelized cost of energy (LCOE) represents the present value of all anticipated project costs (installed and O&M) over the project's anticipated lifetime energy production. LCOE allows for the comparison of different technologies of unequal life spans, sizes, and initial capital costs. LCOE is calculated by dividing a project's lifetime costs by its energy production and is expressed in $/kWh or ¢/kWh.

Past market reports have reported estimated LCOEs for distributed wind projects using performance and cost data reported from the EIA, USDA REAP, and NYSERDA with NREL's LCOE method and assumptions detailed in Appendix B (NREL 2020). To calculate LCOE estimates, PNNL must have access to at least a full year of energy production data for a project as well as an installed cost report for it. As a result, past market report LCOE estimates reflected costs for projects installed over a range of years (with costs inflated to the given year of the report) and the most recent energy production amounts available for the projects. This analysis approach provides representative LCOEs, but does not allow year-to-year LCOE comparisons or specific year analyses. As wind technologies improve and installed costs decrease, year-to-year LCOE comparisons may prove insightful.

Although the NYSERDA incentive program is discontinued and no longer collecting production data from its program participants and USDA REAP has limited production data to share, PNNL secured annual production data for more projects from other sources in 2021–2022. However, the number of projects for which PNNL has both installed cost reports and production data is still limited. As a result, PNNL has not calculated any LCOE estimates from empirical data for this report and will continue to consider the best ways to calculate and present LCOE estimates in future reports as more new and relevant data becomes available.

The NREL 2020 Cost of Wind Energy Review presents modeled small wind LCOE estimates that are generally in line with past market report empirical-based estimates (Stehly and Duffy 2021). For a representative 20-kW installation, the estimated LCOE was 15.1¢/kWh in 2020 dollars without any incentives included that would lower the capital cost. For a representative 100-kW installation, the LCOE, without any incentives, was estimated at 9.9¢/kWh.

The NREL 2020 LCOE estimates do not include incentives. Rebates and grants reduce the upfront cost for the wind turbine owner significantly and, thus, reduce the LCOE for the owner as well. In analysis for the 2018 Distributed Wind Market Report, published in August 2019, USDA REAP grants, NYSERDA Small Wind Program incentives, and Section 1603 payments reduced the estimated small wind LCOEs in the projects sample by an average of 40%.

Whether a distributed wind project's LCOE is cost competitive with a retail electric rate is highly site specific as retail rates vary greatly across the United States. According to the EIA, average residential and commercial retail electric rates, which small wind turbines are most likely to displace, range from 10¢ to 26.7¢/kWh and from 7.9¢ to 19.3¢/kWh, respectively, in the continental United States (EIA 2022b). Hawaii, Alaska, Puerto Rico, the U.S. Virgin Islands, and Guam have higher rates, making distributed wind potentially more cost competitive in those areas, even when projects costs for those locations are also likely to be higher.

Other factors, such as the wind resource and the availability of incentives to lower the upfront cost, also factor into the LCOE calculation and thus whether the LCOE can be cost competitive with a retail rate. For example, Iowa has a relatively low average residential electric rate at 11.7¢/kWh (EIA 2022b), but the state's strong wind resource allows for high wind energy generation, which can drive down an LCOE. In contrast, New York has a less robust wind resource, but a high average residential electric rate of 19.7¢/kWh (EIA 2022b) and until the end of 2019, it also had the generous NYSERDA small wind incentive program. The incentive lowered the upfront cost to the homeowner, which in turn lowers the owner's LCOE, while the high retail rate provides a higher threshold for the LCOE to be competitive against.

8 Distributed Wind Markets

This section details some of the characteristics of distributed wind sales and installations, including customer types, interconnection types, wind turbine sizes, and tower types.

8.1 Customer Types

Customers install distributed wind for several reasons, including to increase energy security, lower utility bills, hedge against future energy price increases, mitigate energy price volatility, or generate renewable energy to help meet decarbonization goals. A distributed wind asset can either be owned directly by the end-use customer or the customer can purchase energy from the distributed wind project.

This report considers seven main customer types for distributed wind: 1) utility, 2) residential, 3) institutional, 4) government, 5) commercial, 6) industrial, and 7) agricultural.

1. Utilities can be investor owned, publicly owned,[28] tribal owned, or rural electric cooperatives.
2. Residential applications include remote cabins, private boats, rural homesteads, suburban homes, and multifamily dwellings.
3. Institutional applications are for entities that are typically non-taxed and mainly consist of schools, universities, churches, non-profits, and local unions.
4. Government applications are also projects for non-taxed entities such as federal agencies, states, cities, municipal facilities (e.g., water-treatment plants and fire departments), military sites, and tribal governments.
5. Commercial applications include offices, car dealerships, retail spaces, restaurants, telecommunications sites, and distribution centers.
6. Industrial applications are facilities that manufacture goods, perform engineering processes, or engage in extractive activities (e.g., food processing plants, appliance manufacturing plants, oil and gas operations, and mines).
7. Agricultural applications include all types of farms, ranches, and farming operations (e.g., nurseries and vineyards).

Agricultural and residential end-use customers, which typically use small wind turbines, have consistently represented most of the distributed wind installations by number of projects, while projects using large-scale turbines that serve utility customers have consistently accounted for the majority of distributed wind capacity. In 2021, agricultural customers accounted for 55% of the number of all projects installed, followed by residential customers who represented 16% of installed projects. In contrast, agricultural and residential end-use customers accounted for a combined 12% of the documented distributed wind capacity installed in 2021, with agricultural end-uses comprising the majority of this share (11%). While these two customer types accounted for nearly 3% of the documented capacity in 2020 and 2019, and just under 1% in 2018, the 2021 share of agricultural and residential project capacity rivals 2015's record high of just under 13%. The increase in percentage of project capacity attributed to agricultural end-use customers is aligned with greater deployment of mid-size turbines in 2021—two agricultural projects used imported mid-size turbines in 2021, compared to zero in 2020 and 2019.

[28] Publicly owned utilities can be municipalities or other, non-city types of public power ownership.

Utility customers represented the largest share of total distributed wind project capacity installed in 2021, accounting for approximately 56% of the documented capacity, compared to 60% in 2020 and 42% in 2019. Industrial customers represent the second largest percentage of distributed wind capacity installed in 2021, accounting for roughly 25% of capacity installed, compared to 36% in 2020 and 54% in 2019.

While the number of utility and industrial projects have been fairly steady the past three years, utility and industrial projects tend to use larger turbines and have larger project capacities compared to other customers. Combined, utility and industrial customers represented approximately 81% of the total capacity installed in 2021, compared to over 95% combined in both 2020 and 2019.

While institutional and government customers have represented the smallest number of projects, as well as total percentage of project capacity, for the last three years, there is a lot of diversity in the end-uses of institutional and government applications. For example, documented government projects include wind turbines for military operations, municipal water systems, prisons, parks, and tribal governments. Most institutional customers are schools, including colleges and universities, but wind turbines have also been deployed at local unions and religious establishments. There is also a lot of diversity in commercial end-use customers. Documented commercial projects include wind turbines for warehouses, a taxidermist, hotels, and a radio station.

Figure 16 shows the breakdown of customer types by number of projects for 2014–2021, and Figure 17 shows the breakdown of customer types by distributed wind capacity for 2014–2021.

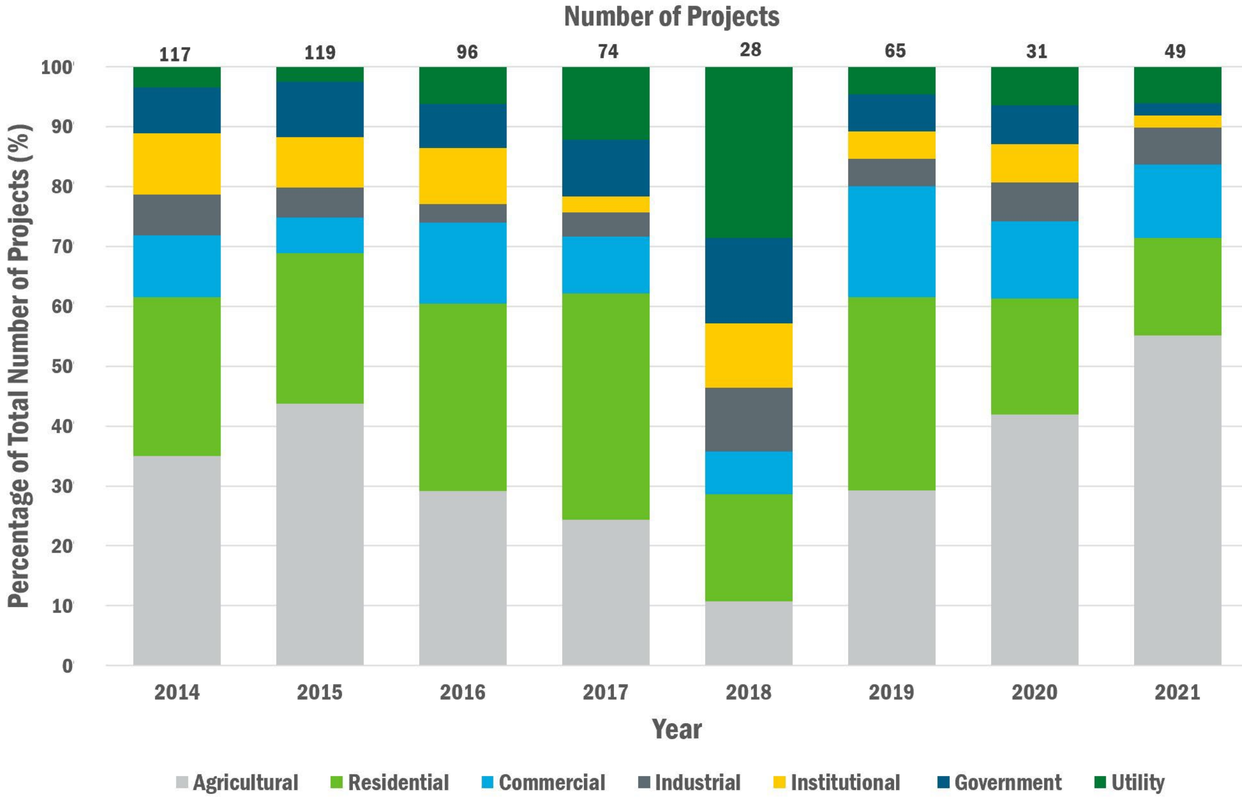

Figure 16. Distributed wind end-use customer types by number of projects, 2014–2021

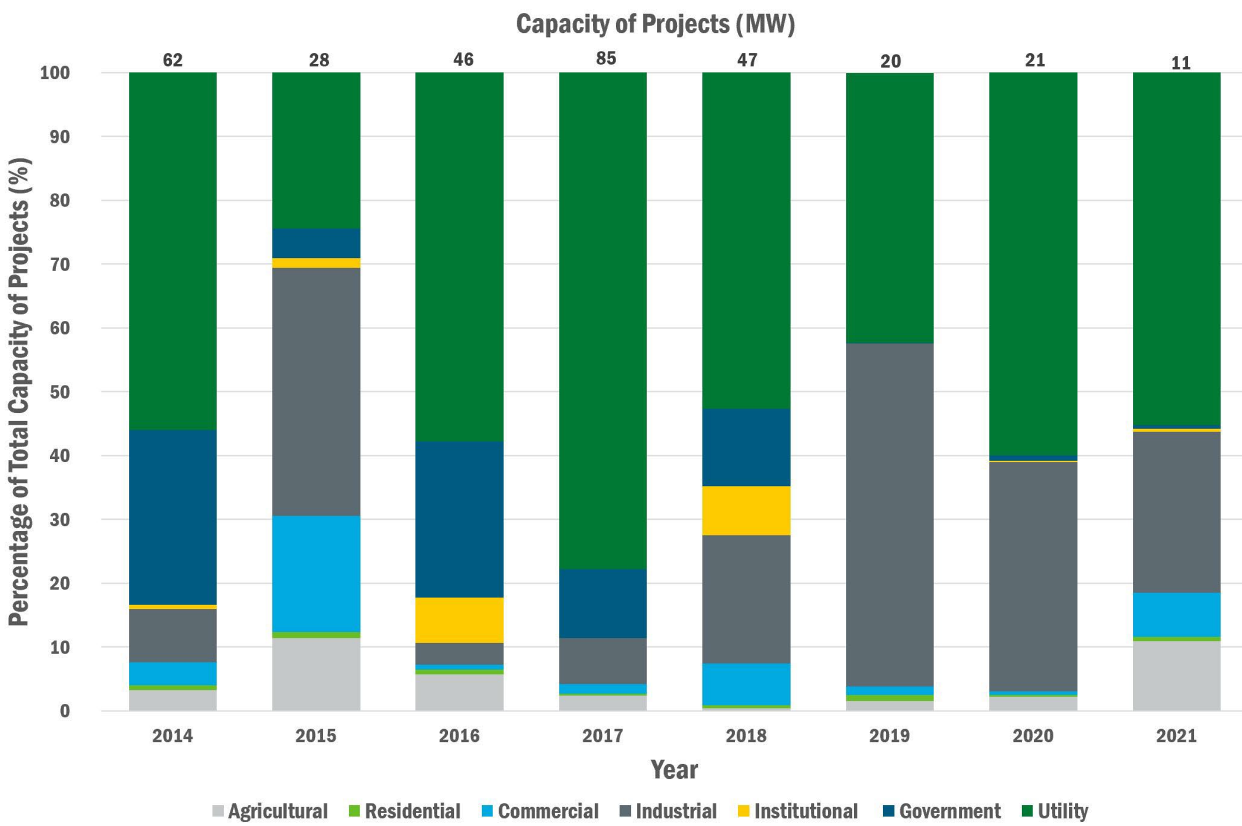

Figure 17. Distributed wind end-use customer types by capacity of projects, 2014–2021

8.2 Interconnection Types

This report tracks two primary interconnection types for distributed wind: on-site use and local use. In 2021, 91.5% of distributed wind projects were for on-site use and 8.5% were for local use. The projects for on-site use translate to 44% of the deployed distributed wind capacity while 56% of the capacity was from the projects for local use.

Distributed wind can serve on-site energy needs in various applications. The most common on-site secondary interconnection categories that PNNL tracks are behind-the-meter installations used to offset a portion of energy costs for grid-connected customers, grid-connected microgrids, and off-grid installations used to power remote locations not connected to the local distribution grid.

Most distributed wind projects for on-site consumption are behind-the-meter installations for rural or suburban homes, farms, schools, and manufacturing facilities. From 2003 to 2021, 96% of all on-site use projects were deployed as behind-the-meter installations. A behind-the-meter wind turbine is connected to the local distribution grid behind the customer's utility meter and may provide excess generation to the distribution grid through net metering or other billing mechanisms. Distributed wind projects for on-site use are also in grid-connected-microgrids, off-grid installations, and remote net-meter installations, each of which represent approximately 1% of all on-site use projects installed from 2003 through 2021.

Distributed wind turbine manufacturers and installers are reporting increased interest in microgrids from potential customers. Interest in microgrids is primarily to support resilience goals, but many microgrids are not being installed with wind. Grid-connected-microgrids account for approximately 4% of the total capacity of on-site use projects, or about 14.2 MW, in PNNL's project dataset.

Off-grid small wind turbine models account for the bulk of wind turbine units deployed in U.S. distributed wind applications, but less than 1% of documented capacity. An estimated 96% of turbine units deployed in 2021 distributed wind applications were to charge batteries or power off-grid sites (e.g., remote homes, oil and gas operations, telecommunications facilities, boats, rural water or electricity supply, and military sites). This compares to nearly 97% in 2020 and 99% in 2019.

Distributed wind for local use is connected to the distribution grid to serve loads interconnected to the same distribution grid. This type of project is typically referred to as a front-of-meter installation. Front-of-meter wind projects typically include multiple turbines greater than 100 kW in size, and often, greater than 1 MW in size. The distribution grid can be connected to a larger transmission system or be an isolated grid. Isolated grids are common in remote areas of Alaska.

While the primary interconnection type can be identified for most projects (i.e., as on-site use or local use), some projects do not clearly fall within a defined secondary interconnection type. For example, the 5-MW Rock County Wind Fuel project in Minnesota is an on-site use project because it powers a biofuels plant, but its complicated power purchase and interconnection agreements mean it is not a traditional behind-the-meter installation (Gevo n.d.).

From 2012 through 2021, 90% of all documented distributed wind projects, on average, were interconnected for on-site use. The remaining 10% of distributed wind projects were deployed for local use, as shown in Figure 18. While the majority of distributed wind projects are interconnected for on-site use, projects for local use represent more of the installed distributed wind capacity due to the projects' larger sizes and use of larger turbines. The percent of total installed project capacity documented as local use from 2012 through 2021 was 55% with the remaining 45% for on-site use, as shown in Figure 19.

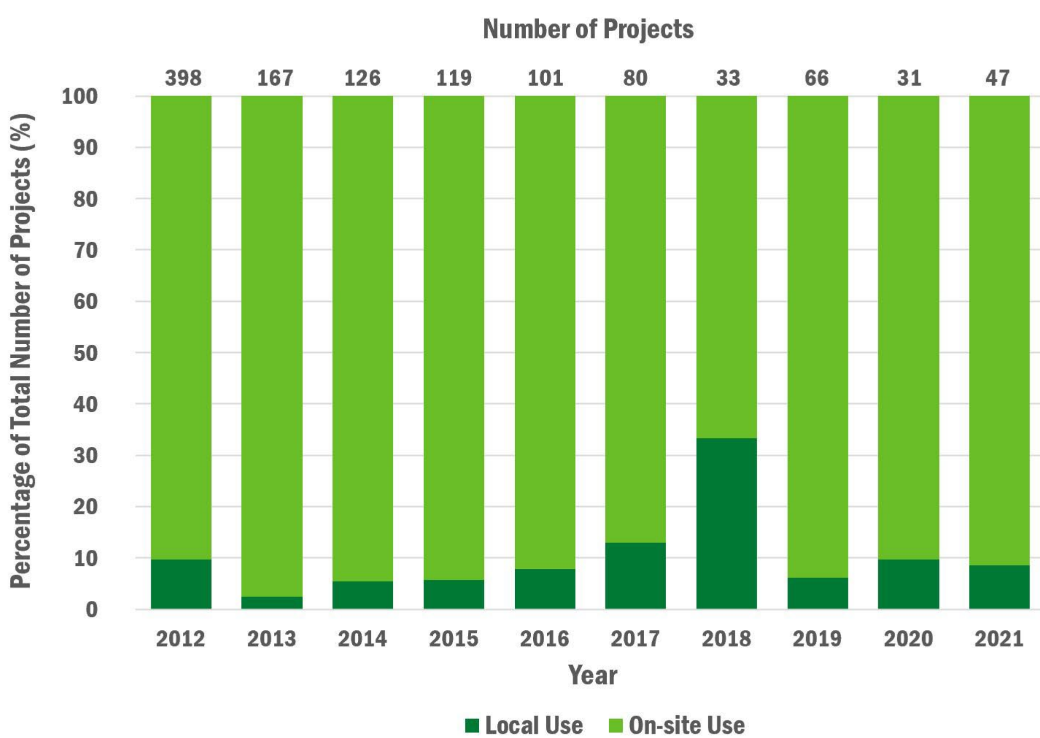

Figure 18. Distributed wind for on-site use and local loads by number of projects, 2012–2021

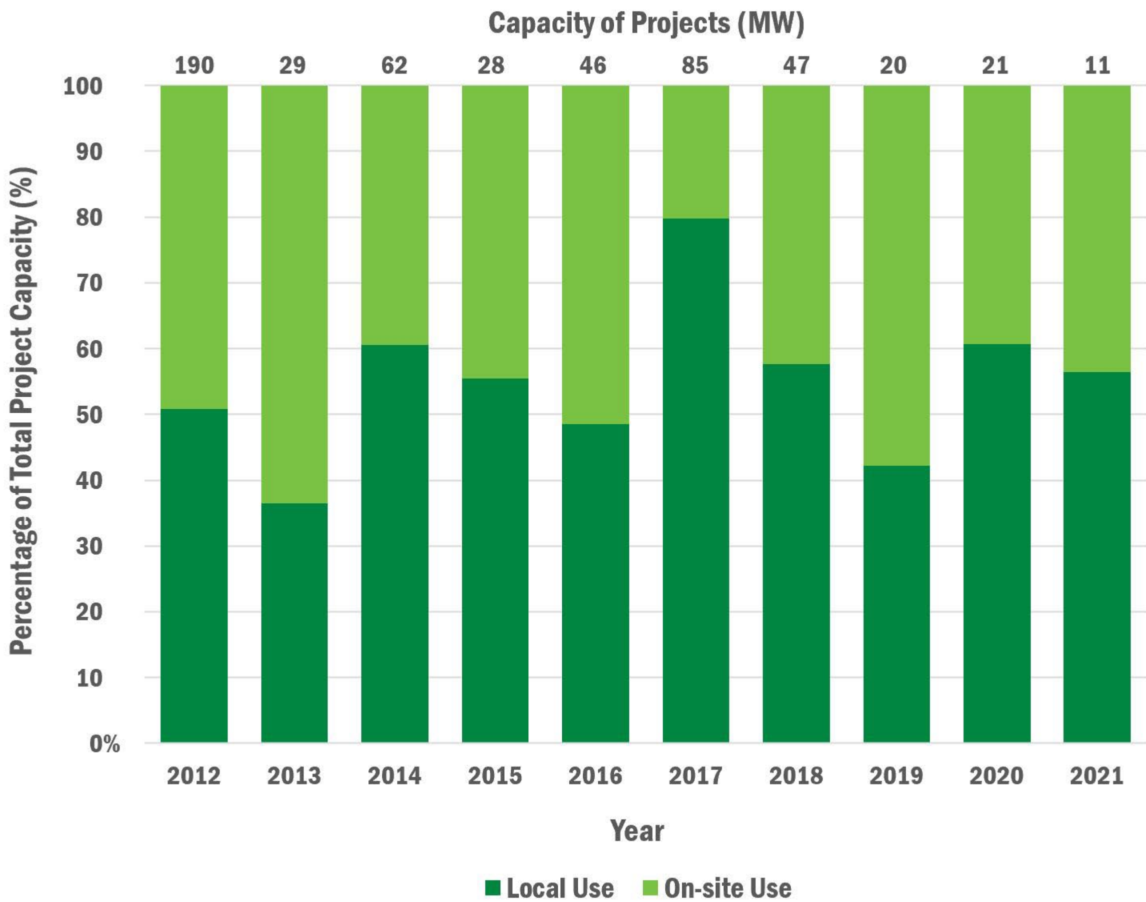

Figure 19. Distributed wind for on-site use and local loads by capacity of projects, 2012–2021

8.3 Wind Turbine Sizes

Because the wind market is not uniform, this report analyzes the market by turbine size or customer type. Different factors are at play for each turbine size segment, in part because some turbine sizes are more applicable for certain customer applications than others.

Large-scale turbines dominate the amount of distributed wind capacity installed annually because of their higher capacity. As the number of customers using higher-capacity large-scale turbines has increased, so has the average nameplate capacity of turbines greater than 100 kW in distributed wind projects. But because mid-size turbines were used in half of the projects using turbines greater than 100 kW in 2021, the increasing nameplate capacity trend was disrupted.

In 2003, the average turbine capacity used in distributed wind projects with turbines greater than 100 kW in size was 1 MW, as shown in Figure 21. In 2020, the average capacity size was 2 MW—double the capacity of turbines used in 2003. And the average project size almost tripled from 1.5 MW in 2003 to 3.4 MW in 2020.

But in 2021, the average turbine capacity used in distributed wind projects with turbines greater than 100 kW in size was back down to 1.1 MW, and the average project size was 1.65 MW.

Similar drops in the average turbine size, median turbine size, and average project size can also be observed in Figure 20 in years 2008, 2010, and 2015. Mid-size turbines accounted for more than 40% of the documented projects in those years.

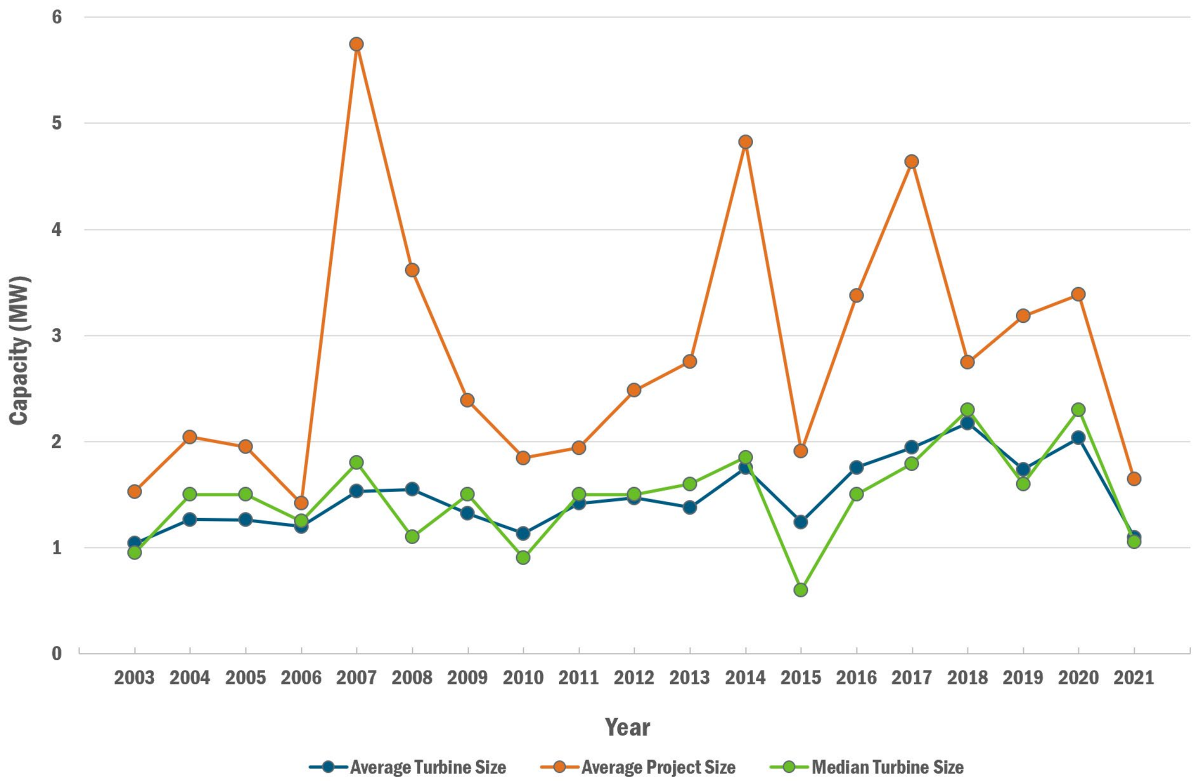

Figure 20. Average size of turbines greater than 100 kW in distributed wind projects and average size of those projects, 2003–2021

Most distributed wind projects are single-turbine projects, so a significant variation between average project size and average turbine size in a given year indicates that the dataset sample includes multi-turbine projects. The significant variation between average project size in 2020 (3.4 MW) and average turbine size (2 MW) can be attributed to the multi-turbine Mason City Wind Project; a three-turbine installation consisting of one 2.3 MW and two 2.82 MW wind turbines. Similarly, in 2014, the annual average project size was driven up by the Anderson Wind project in New Mexico, a multi-turbine project also consisting of differently sized large-scale turbines.

Figure 21 shows the annual small wind capacity additions by turbine size, and Figure 22 shows the percentage of capacity additions by turbine size. The less-than-1-kW size segment, the size segment of 1–10 kW, and the size segment of 11–100 kW (new and refurbished) represent 25%, 16%, and 59% of the 2021 small wind capacity, respectively. This compares to 26%, 6%, and 68%, respectively, in 2020 and 48%, 20%, and 32%, respectively, in 2019.

The less-than-1-kW turbine size segment represents less of the overall small wind capacity in 2021 (and also 2020) after having had the highest capacity representation in 2017, 2018, and 2019. This change is due to both a decrease in the number of less-than-1-kW turbine units sold in 2021 and an increase in sales in the size segment of 11–100 kW (new and refurbished). In 2021, there were 45 turbine units sold in the size segment of 11–100 kW, compared to 40 in 2020 and only 19 in 2019.

Refurbished turbines accounted for 19% of the capacity in the size segment of 11–100 kW in 2021, compared to 38% in 2020 and 24% in 2019. A total of eight small wind projects used refurbished turbines in 2021 with six of them in retrofit projects. As turbines reach the end of their life cycles and performance degrades, refurbishing and retrofitting activities are likely to continue as cost-effective solutions for extending or improving generation.

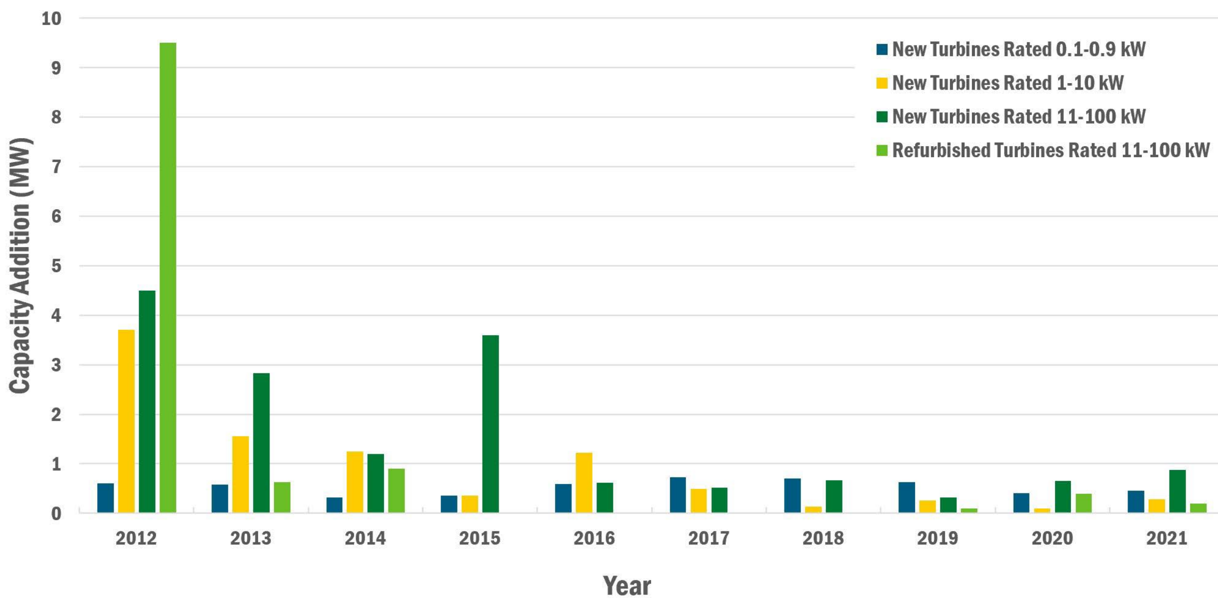

Figure 21. U.S. small wind sales capacity by turbine size, 2012–2021

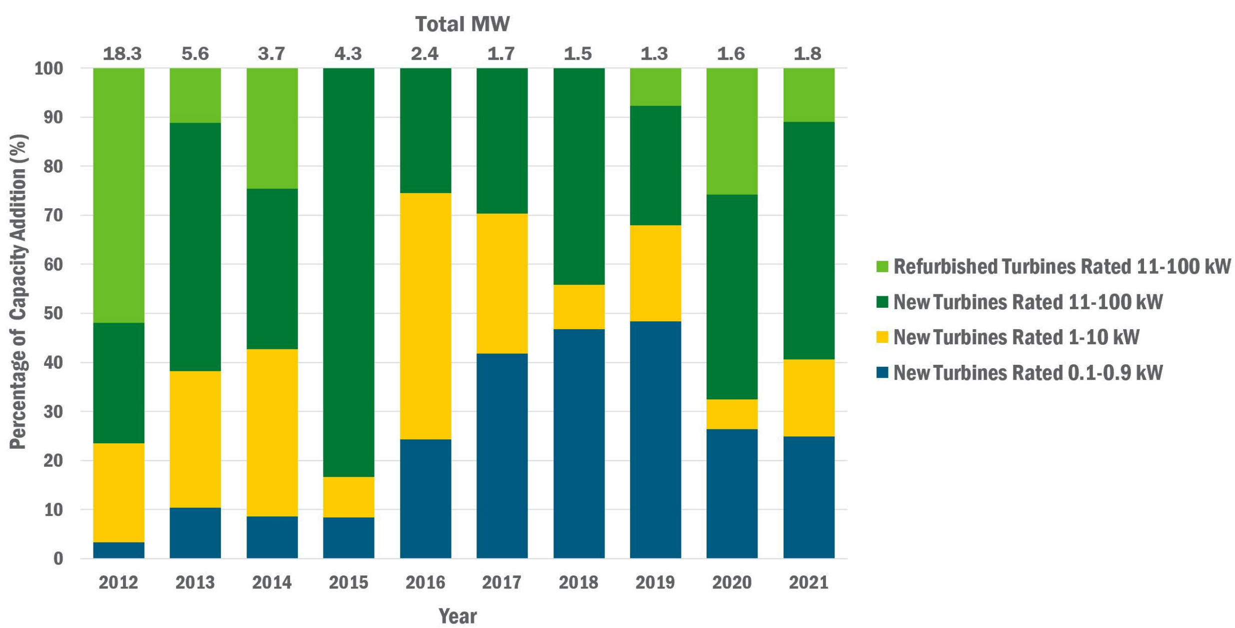

Figure 22. U.S. small wind sales percentage of capacity by turbine size, 2012–2021

There is typically noticeable year-to-year variation in the size segments of 1–10 kW and 11–100 kW. The increased capacity from 2020 to 2021 for the size segment of 1–10 kW can be partially attributed to the inclusion of sales from two turbine manufacturers that PNNL had not previously tracked and from the sales of early designs from other turbine manufacturers that fit in this size range. Other reasons for variation include inconsistent sales due to changing market conditions and turbine manufacturer business operations. The single-year presence of a given manufacturer can significantly affect overall small wind sales capacity.

Installers continue to report that their customers are interested in new installations of and repair parts for U.S.-made horizontal-axis wind turbines in the size range of 1–5 kW. This is a market gap given the discontinuation of the Pika 1.7-kW T701, the Xzeres 2.4-kW Skystream, and the Bergey 1-kW Excel 1. The limited market presence of non-U.S.-based manufacturers and noncertified turbines in this size segment has not filled this gap. Turbines in the size range of 1–5 kW are particularly suitable for battery charging and electrification of small loads at remote sites (e.g., off grid), small homes, and farms. Turbines in this size range are also being investigated for use in defense and disaster response (Naughton et al. 2020).

This report captures sales from the manufacturers who responded to the report's annual data request. While PNNL has an extensive data-collection process (see Appendix B for details on the report's methodology), it is likely that some manufacturers were missed, particularly small wind vertical-axis wind turbine (VAWT) manufacturers. In 2021, VAWT models (all less than 5 kW in nameplate capacity) in our sample account for almost 1% of the U.S. small wind turbine units deployed and 1.4% of the small wind capacity. VAWT models accounted for about 1% of turbine units and 0.3% of capacity in 2020 and 2% of turbine units and 6% of capacity in 2019.

8.4 Type of Towers

From 2003 through 2021, the majority of documented distributed wind projects used self-supporting lattice and self-supporting monopole towers, representing 42% and 36%, respectively, of projects that provided tower type information to PNNL. Self-supporting lattice towers are the most common in small wind projects, deployed in 49% of all small wind projects reporting tower information. Self-supporting monopole towers are predominately used in projects with turbines greater than 100 kW, representing 96% of projects in this size category.

Of the 21 projects for which PNNL was able to collect tower type information in 2021, the majority used tilt-up monopoles (seven projects accounting for 33%), followed by self-supporting monopoles (6 projects accounting for 29%), and then self-supporting lattices (5 projects accounting for 24%). Seven of these projects were retrofits and a majority of them (71%) used new or refurbished turbines on pre-existing lattice towers. This is consistent with historic data. Of the 39 documented retrofit projects that have provided tower type information to PNNL between 2012 and 2020, 69% used lattice towers and most of those were self-supporting (only four retrofit projects used guyed lattice towers).

For small wind projects, reported hub heights in 2021 ranged from 15 to 50 m. The one mid-size turbine project with a reported hub height is 40 m. Reported hub heights for projects using large-scale turbines in 2021 were 58 m and 80 m.

9 Future Outlook and Market Potential

While the past three years of distributed wind deployment have been fairly low, multiple studies have estimated that distributed wind has strong market potential in the near term. Some of the identified market potential is dependent on changes to policy, costs, and other conditions.

The *Distributed Wind Energy Futures Study*, released in May 2022 by NREL and funded by DOE's Wind Energy Technologies Office, determined that there is substantial opportunity for distributed wind. The economic potential (defined as a project with a positive rate of return) for behind-the-meter installations is 919 GW in a 2022 baseline scenario and 474 GW for front-of-the-meter installations (McCabe et al. 2022). The projections increase substantially in a 2035 scenario that includes more policy support, namely the extension of the federal ITC and relaxed siting conditions.

In 2015, DWEA laid out its strategy to increase behind-the-meter distributed wind deployment. This strategy was updated in 2021. DWEA's vision to achieve 35 GW of behind-the-meter distributed wind by 2035 requires the implementation of policy and program changes (DWEA 2021).

Another market potential study, specifically focused on behind-the-meter distributed wind for industrial clients, was released in 2020 by One Energy. With a conservative assumption of a phased-out ITC (i.e., a 0% ITC rate), One Energy estimates 36 GW of a serviceable market for industrial customers (defined as the amount of wind capacity for which One Energy could provide 20-year fixed power purchase agreement rates lower than the customers' average industrial grid rates) (One Energy 2020). Similarly, the *Distributed Wind Energy Futures Study* identified that six states (Kansas, Colorado, Texas, South Dakota, New Mexico, and Kentucky) each have more than 900 MW of behind-the-meter economic potential in 2022 on commercial and industrial lands (McCabe et al. 2022).

Although the studies have different focuses and assumptions, they all agree that there is significant market potential for distributed wind. However, based on current deployment levels, meeting these projections will require efforts that go beyond business as usual.

10 Conclusions

This report documents trends and statistics for the U.S. distributed wind market. However, the market does not always exhibit consistent trends and there can be significant variation from year to year with respect to customer demand, installed costs, incentive availability, and deployment levels among and within the different turbine size segments (i.e., small, mid-size, and large-scale).

For example, while there was a slight increase in mid-size and small wind turbine deployment in 2021, there was a decrease in large-scale turbine deployment. While there was an increase in USDA REAP grant awards for wind projects, the last NYSERDA incentive payments are being made as the program has been discontinued, prompting small wind turbine manufacturers to focus on other states, such as Minnesota. And while overall distributed wind deployment was down in 2021 compared to 2020, PNNL documented projects in 15 states in 2021 compared to 11 states in 2022. This variation is likely to continue considering the diverse ways in which distributed wind is able to be deployed.

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Appendix A: Wind Turbine Manufacturers and Suppliers

The small wind turbine manufacturers and suppliers listed in Table A.1 provided sales data for the models shown to PNNL via the data-request process. Other small wind companies that provided information, or only had sales outside of the United States, are recognized in the Acknowledgments section. For the turbines greater than 100 kW in distributed wind projects included in the report and listed in Table A.1, PNNL reviewed other data sources as described in Appendix B.

Table A.1. Wind Turbine Manufacturers and Suppliers

Manufacturers	Model Names	Headquarters
Small Wind Turbines (up through 100 kW)		
Aeromine Technologies, Inc.	AeroMINE	Texas
All Energy Management	Refurbished Endurance E-3120	Wisconsin
APRS World	WT10	Minnesota
Bergey Windpower Co.	Excel 10, Excel 15	Oklahoma
BE-Wind	EOW-100, EOW-200, EOW-300	Texas
Ducted Wind Turbines, Inc.	D3	New York
Eocycle Technologies, Inc.	EOX S-16, EOX M-26	Canada
Hi-VAWT Technology Corp.	DS700	Taiwan
Primus Wind Power	Air 40, Air Breeze, Air 30, Air X Marine, Air Silent X, AirMax X	Colorado
QED Wind Power, LLC	PHX20	Arizona
SD Wind Energy Ltd	SD3, SD6	Scotland
Star Wind Turbines	STAR72	Vermont
Tumo Int Corporation Ltd	NE1000, NE2000, NE3000, VQT300	China
Wind Turbines Greater than 100 kW		
Bonus	MK3	Denmark
GE Renewable Energy	2.72-116	United States
Goldwind	G87	China
Nordtank	Unknown	Denmark
Siva Wind	Siva 250/50	India
Vensys	Vensys 82	Germany

Appendix B: Methodology

Pacific Northwest National Laboratory (PNNL) collects data for this annual market report through direct data requests and a review of other data resources. This appendix explains our data-collection methodology.

For small wind data, the PNNL team issued data requests to 360 distributed wind manufacturers and suppliers, developers, installers, operations and maintenance (O&M) providers, state and federal agencies, utilities, trade associations, and other stakeholders. The team compiled responses and information from these data requests (with all sources listed in the Acknowledgments section) to tabulate the deployed United States and exported small wind capacity and associated statistics as of the end of 2021. The detail with which the stakeholders responded to the data requests varied, thus the team includes sample sizes and qualifications with certain analysis presentations as needed.

For distributed wind projects using turbines greater than 100 kW, the PNNL team reviewed data resources to assess projects on a per-project basis to determine whether they met this report's definition of distributed wind and therefore should be included in the distributed wind project dataset. The reviewed resources include the American Clean Power's CleanIQ database, the Federal Aviation Administration, the U.S. Wind Turbine Database, and the U.S. Energy Information Administration.

This report defines distributed wind as a distributed energy resource providing electricity for a specific on-site load or for a local load. This load can be served by a behind-the-meter, front-of-meter, or off-grid distributed wind project. Some front-of-meter projects may be connected to a distribution or transmission line for a distant customer, but because of their proximity to a city and the physics of electron flow, also provide distributed energy locally. These types of projects are considered "physically distributed" projects and are not counted in the capacity amounts presented in this report (Preziuso et al. 2022).

A project dataset was created to capture all known distributed wind projects installed in 2021. For projects using small wind turbines (up through 100 kW), project records were obtained directly from manufacturers and suppliers, O&M providers, utilities, and agencies through emails, phone interviews, or both. Project records collected for this report, and from past years, have been consolidated to produce a master project dataset available on PNNL's website.

Projects reported for 2021 were cross-checked against previous records to avoid double counting. Small wind retrofit installations (in which either newly manufactured or refurbished turbines are installed on existing towers and foundations to replace nonfunctioning turbines or to upgrade the technology) are counted as new capacity in the given year and the existing project record is updated accordingly, so the project is not double counted. Sales and installation reports from manufacturers, suppliers, and developers were cross-referenced with records provided by agencies and installers to identify and combine information from duplicate records. Notes were made in instances of conflicting information (e.g., incentive award amounts, installed costs, and installation dates) as to which sources were used. Some newly installed projects in 2021 may use turbines sold many years ago, or donated turbines. Small wind turbine sales with project-specific records were added to the project dataset; however, most of the 2021 small wind turbine units sold were not tracked at the project level.

PNNL also created a separate small wind sales dataset based on manufacturers' sales reports. The reported total number of small wind turbine units and capacity deployed, domestically and abroad, come from this small wind sales dataset. For small wind, this report details capacity figures for the same calendar year as the sales reported by the manufacturers and suppliers to tally annual deployed capacity. Most manufacturers report precise turbine units sold, but at least one manufacturer provides estimated turbine units sold because the company's less-than-1-kW size turbine units are shipped in bulk to distributors for resale to end users. Some installations occur after the calendar year that the wind turbine units were sold, so sales and projects are recorded separately. A U.S. sales presence is defined as manufacturers and suppliers documenting at least one sale in the United States in 2021.

In 2021, the PNNL team reviewed the customer types assigned to projects. Some projects were recategorized, which shifted some capacity among the customer types from what was previously reported. In addition, when the PNNL team identifies projects that were installed in past years but were not previously recorded, the team adds those projects to the master project dataset. Further, the PNNL team marks turbines confirmed to be decommissioned in the dataset as such, but does not actively track decommissioning. The cumulative figures therefore principally represent annual capacity additions, rather than confirmed operating installations. Consequently, the cumulative capacity amount presented in this report, and capacity allocations by state and by year, may differ slightly from report to report.

The master project dataset is used to make year-to-year comparisons; allocate capacity amounts across states; analyze installed costs; identify incentive funding levels; and characterize distributed wind customers, types of turbines and towers, and project applications.

Incentive payments and reports can lag or precede sales reports. This report tallies and reports incentive payments for the year in which they were granted or paid, regardless of the time of installation, using the best information available at the time of publication. Projects that receive U.S. Department of Agriculture Rural Energy for America Program grants are recorded in the year the grant is awarded, although they may not be installed for up to two years after the grant. Project records in the master project dataset are updated accordingly when new information is available.

The PNNL team documents installed costs primarily from installers, developers, agencies, public sources such as press releases and news articles, and a few private sources. For projects using turbines greater than 100 kW, the PNNL team and the Lawrence Berkeley National Laboratory team, authors of the annual Land-Based Wind Market Report, share and cross-reference installed cost data for distributed wind projects. In some instances, installed cost figures are estimated based on reported incentive values. The PNNL team developed the reported 2021 investment values using reported installed cost data and in-house estimates based on past projects and PNNL's Benchmarking U.S. Small Wind Costs report when needed (Orrell and Poehlman 2017).

Requests for international small wind reports are issued annually to international contacts to obtain the most up-to-date small wind installation numbers with a country-by-country approach. Due to variability in responses, data are presented inconsistently year to year and from country to country. The level of accuracy included in responses is also variable, with some countries providing detailed numbers and others providing estimates.

Levelized cost of energy (LCOE) calculations in future reports will use the following formula:[29]

$$LCOE = \frac{(FCR \times ICC) + O\&M}{AEPnet}$$

where
- FCR = fixed charge rate = (0.074), assuming a 20-year loan at 4.0% interest
- ICC = installed capital cost ($)
- O&M = annual O&M cost ($)
- AEPnet = net annual energy production (kWh/yr)

Table B.1 presents the rated or referenced small wind capacities used in capacity factor, LCOE, maintenance cost per kW, and installed cost per kW calculations.

[29] NREL's LCOE formula includes a levelized replacement cost that has been excluded here.

Table B.1. Turbine Models in Small Wind Dataset

Turbine Model	Rated or Referenced Power at 11 m/s (kW)	Nominal Turbine Capacity (kW)	Rated or Referenced Power Source
Bergey Excel 6	5.5	6	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009 (Certification Expired)
Bergey Excel 10	8.9	10	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009
Bergey Excel 15	15.6	15	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009
Dakota Turbines DT-25	23.9	25	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009 (Certification Expired)
Endurance E-3120	56	50	ICC–SWCC power performance certification to IEC 61400-12-1 (Certification Expired)
Endurance S-343	5.4	5	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009 (Certification Expired)
Eocycle EO25 (now EOX S-16)	28.9	25	SGS Certification to AWEA 9.1–2009
Gaia GW 133-11	10.7	11	United Kingdom Microgeneration Certification Scheme certification to IEC 61400-12-1 as of January 2015
NPS 100-21	79	100	DNV power performance certification to IEC 61400-12-1
NPS 100-24	90	100	Manufacturer’s power curve
Osiris 10	9.8	10	Intertek full certification to AWEA 9.1-2009 (Certification Expired)
Pika T701	1.5	1.7	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009 (Certification Expired)
Southwest Windpower/ Xzeres Skystream 3.7	2.1	2.4	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009 (Certification Expired)
Sonkyo Energy Windspot 3.5	3.5	3.2	Intertek full certification to AWEA 9.1-2009 (Certification Expired)
Xzeres 442SR	10.4	10	ICC–SWCC Small Wind Turbine Certification to AWEA 9.1–2009 (Certification Expired)

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Cover details: This 2.5 MW GE wind turbine supplies electricity directly to the REG Albert Lea biodiesel production facility in Glenville, MN. Photo courtesy of Juhl Energy, Inc.