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Distributed Wind Market Report: 2021 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
EIA	Energy Information Administration
FIT	feed-in tariff
GE	General Electric
ICC-SWCC	International Code Council-Small Wind Certification Council
IEC	International Electrotechnical Commission
IRS	U.S. Internal Revenue Service
ITC	investment tax credit
kWh	kilowatt hour(s)
kW	kilowatt
LCOE	levelized cost of energy
MEA	Maryland Energy Administration
MW	megawatt
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
REAP	Rural Energy for America Program
USDA	U.S. Department of Agriculture
VAWT	vertical-axis wind turbine
VDER	Value of Distributed Energy Resources

Executive Summary

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

Installed Capacity

Cumulative U.S. distributed wind capacity installed from 2003 to 2020 now stands at 1,055 megawatts (MW) from over 87,000 wind turbines across all 50 states, Puerto Rico, the U.S. Virgin Islands, and Guam. 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.

In 2020, eleven states added a total of 14.7 MW of new distributed wind capacity representing 1,493 turbine units and $41 million in investment. These numbers are down from 20.5 MW in 2019 and 53.7 MW in 2018. Some of this annual variation can be contributed to the project-development cycles of a handful of developers.

Since 2015, six different developers have been responsible for at least 40% of the distributed wind capacity from projects using turbines greater than 100 kW. Each developer works almost exclusively with one turbine manufacturer and in one state rather than nationally, causing annual capacity additions to reflect installations from a few manufacturers and to be concentrated in a few different states year to year.

Iowa and Minnesota led the United States in 2020 capacity additions as a result of two projects that combined represent 95% of the 2020 installed distributed wind capacity.

Of the 14.7 MW installed in 2020, 12.9 MW came from distributed wind projects using large-scale turbines (greater than 1 MW in size), 0.16 MW came from projects using mid-size turbines (101 kilowatts [kW] to 1 MW in size), and 1.6 MW came from projects using small wind turbines (up through 100 kW in size).

The 12.9 MW from projects using turbines greater than 1 MW is down from the 18.2 MW documented in 2019, and the 50.5 MW documented in 2018. Large-scale wind turbines continue to account for most of the distributed wind capacity additions; however, changing policies and long project-development cycles have contributed to the varying capacity additions from year to year for projects using turbines greater than 1 MW.

Projects using mid-size turbines continue to represent a small part of the distributed wind market. The 0.16 MW of capacity from projects using mid-size turbines in 2020 is down from 1 MW in 2019 and 1.6 MW in 2018.

A total of 1.6 MW of small wind was deployed in the United States in 2020, representing 1,487 turbine units and $7 million in investment. Small wind deployment has been relatively flat for the past few years, with 1.3 MW in 2019 and 1.5 MW in 2018. However, small wind manufacturers and installers have reported a brighter outlook for 2021, given the role distributed energy can play in decarbonizing the U.S. economy.

Deployment Trends

Large-scale turbines, and the distributed wind projects that use them, are getting bigger. In 2003, the average turbine capacity used in distributed wind projects with turbines greater than 100 kW was 1 MW. In 2020, the average capacity size was 2.2 MW. As such, the average project size has almost tripled from 1.5 MW in 2003 to 4.4 MW in 2020.

The use of mid-size turbines remains limited. A limited number of mid-size turbines are commercially available, which may account for the lower level of deployment but also may account for the use of refurbished turbines in this size sector. Of the five new projects using mid-size turbines in 2018, 2019, and 2020, three used refurbished turbines.

Small wind retrofits make up an increasing amount of the small wind capacity deployment. Retrofits are new turbines installed on existing towers and foundations to replace nonfunctioning turbines or to upgrade the technology. Small wind retrofits contributed 80% of total installed small wind capacity in 2020 and 36% in 2019. No small wind retrofits were reported in 2018.

Customer Types

In 2020, utility customers accounted for 58% of the total documented distributed wind capacity, compared to 42% in 2019 and 53% in 2018. After utility customers, industrial customers represented the next largest portion of distributed wind end users, accounting for 37% of capacity installed in 2020, compared to 54% in 2019 and 20% in 2018.

Agricultural customers accounted for 36% of the number of projects installed in 2020, followed by residential customers, who represented 24% of installed projects. However, agricultural and residential end-use customers accounted for only a combined 2% of the documented capacity installed in 2020, consistent with past years (3% in 2019 and 1% in 2018) as agricultural and residential customers predominantly use small wind turbines.

A total of 45% of all documented distributed wind capacity from 2010 through 2020 provides electricity for on-site use while the balance (55%) provides electricity for local use. Distributed wind projects for on-site consumption are typically behind-the-meter installations for rural or suburban homes, farms, schools, and manufacturing facilities. Distributed wind projects for local use, typically referred to as front-of-meter installations, are connected to the distribution grid to serve loads interconnected to the same distribution grid.

Small Wind Domestic Sales and Exports

Small wind turbine sales by size segment vary year to year as a result of inconsistent sales, due to changing market conditions and turbine manufacturer business operations. For example, newly manufactured turbines in the size segment of 11–100 kW represented 42% of sales capacity in 2020, 24% in 2019, and 44% in 2018 while refurbished turbines rated 11–100 kW represented 26% of sales capacity in 2020, 8% in 2019, and 0% in 2018.

Small wind exports from U.S.-based manufacturers have decreased to just under 200 kW reported in 2020, compared to just under 500 kW in 2019 and almost 1 MW in 2018**.** The primary markets for U.S. small wind exports over the years had been the United Kingdom, Italy, and Japan because of feed-in tariff programs in those countries, but those programs have been discontinued or drastically reduced since exports peaked at 21.5 MW in 2015. U.S.-based small wind manufacturers still reported some exports to Japan in 2020, but not to the same levels as past years.

Incentives and Policies

The combined value of U.S. Department of Agriculture Rural Energy for America Program grants, state rebates, and state production tax credits given to distributed wind projects in 2020 was $4.8 million across six states. This is down from $7 million in 2019 and $15 million in 2018. The decline in recent years primarily reflects fewer state incentives being paid and a reduction in Iowa production tax credit payments as some projects have completed their 10-year eligibility period.

A total of eight small wind turbine models are certified to the American Wind Energy Association (AWEA) 9.1-2009 standard or International Electrotechnical Commission 61400 standards as of May 2021. One turbine model completed the full certification process in 2021, but the total number of certified turbine models is down (from 10 in June 2019) because some manufacturers let their certifications expire. Certification requirements are increasingly common in the global market and can allow wind turbine manufacturers to demonstrate compliance with regulatory and incentive program requirements. The American Clean Power Association (successor to AWEA) is developing a new standard that is intended to eventually supersede the AWEA 9.1-2009 standard.

Performance and Installed Costs

For a sample of distributed wind projects, the three-year average capacity factor was 16% for projects using small wind turbines, 20% for mid-size turbines, and 29% for large-scale turbines. The analysis was based on annual generation amounts recorded for 2016, 2017, and 2018, from projects installed from 2009 through 2015.

No new small wind project costs were reported to PNNL in 2020; only costs for small wind retrofits were reported. The average per-kilowatt installed cost of new small wind projects (in 2020 dollars) with known costs and rated turbine capacities in the United States from 2010 through 2019 was approximately $9,500/kW. The average per-kilowatt installed cost for small wind retrofit projects was approximately $4,100/kW in 2020 and $5,300/kW in 2019. Approximately one-third of the 2020 small wind retrofits used refurbished turbines.

PNNL only obtained one installed cost report for projects using turbines greater than 100 kW in 2020. The availability of cost information for distributed wind projects using turbines greater than 100 kW varies from year to year. The average per-kilowatt cost of distributed wind projects using turbines greater than 100 kW installed in the United States from 2010 through 2019 (in 2020 dollars) was approximately $3,640/kW.

Table of Contents

List of Figures

List of Tables

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 systems 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, 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 onto the grid. A wind turbine connected to a distribution grid as a generating resource is considered a front-of-meter installation. Front-of-meter wind projects provide energy and grid support to the distribution system and 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 wind turbine is not connected to the local distribution grid. Off-grid distributed wind is typically deployed with 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.

Distributed wind can be part of a microgrid or isolated grid, either as 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

[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.

grid (Ton and Smith 2012). An isolated electrical grid system, such as for a remote village, 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)[3]
- 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.[4] 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. 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 2020, the Pacific Northwest National Laboratory (PNNL) team issued data requests to distributed wind turbine manufacturers, suppliers,[5] developers, installers, and operations and maintenance (O&M) providers; state and federal agencies; utilities; trade associations; and other stakeholders. This report includes data from past data requests and presents the distributed wind market from 2003 through 2020. In some cases, because of data availability and quality, some analyses use different time periods within the time range of 2003 to 2020.

A project dataset was created to capture all projects installed in 2020 identified through the data-request 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.

In 2020, the PNNL team reviewed all projects in the master project dataset to confirm that projects met the distributed wind definition—i.e., providing electricity for specific or local loads—and determine whether they should remain in the dataset. The PNNL team updated the master project dataset based on its findings. 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 removes turbines known to be decommissioned from the dataset. Consequently, the cumulative capacity amounts presented in this report differ from previous reports, and capacity allocations by state and by year will continue to differ slightly from year to year.

Many small wind 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

[3] 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).

[4] 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, small wind rated capacities 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.

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

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 manufacturers' and suppliers' sales reports.[6] 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.

[6] 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 2020, over 87,000 wind turbines were deployed in distributed applications across all 50 states, Puerto Rico, the U.S. Virgin Islands, and Guam, totaling 1,055 MW in cumulative capacity, as shown in Figure 1.[7] In 2020, 11 states added at total of 14.7 MW of new distributed wind capacity representing 1,493 turbine units and $41 million in investment.[8] Those numbers are down from both 2019 (20.5 MW in 19 states representing 2,180 turbine units and $67 million in investment) and 2018 (53.7 MW in 13 states representing 2,685 turbine units and $245 million in investment).

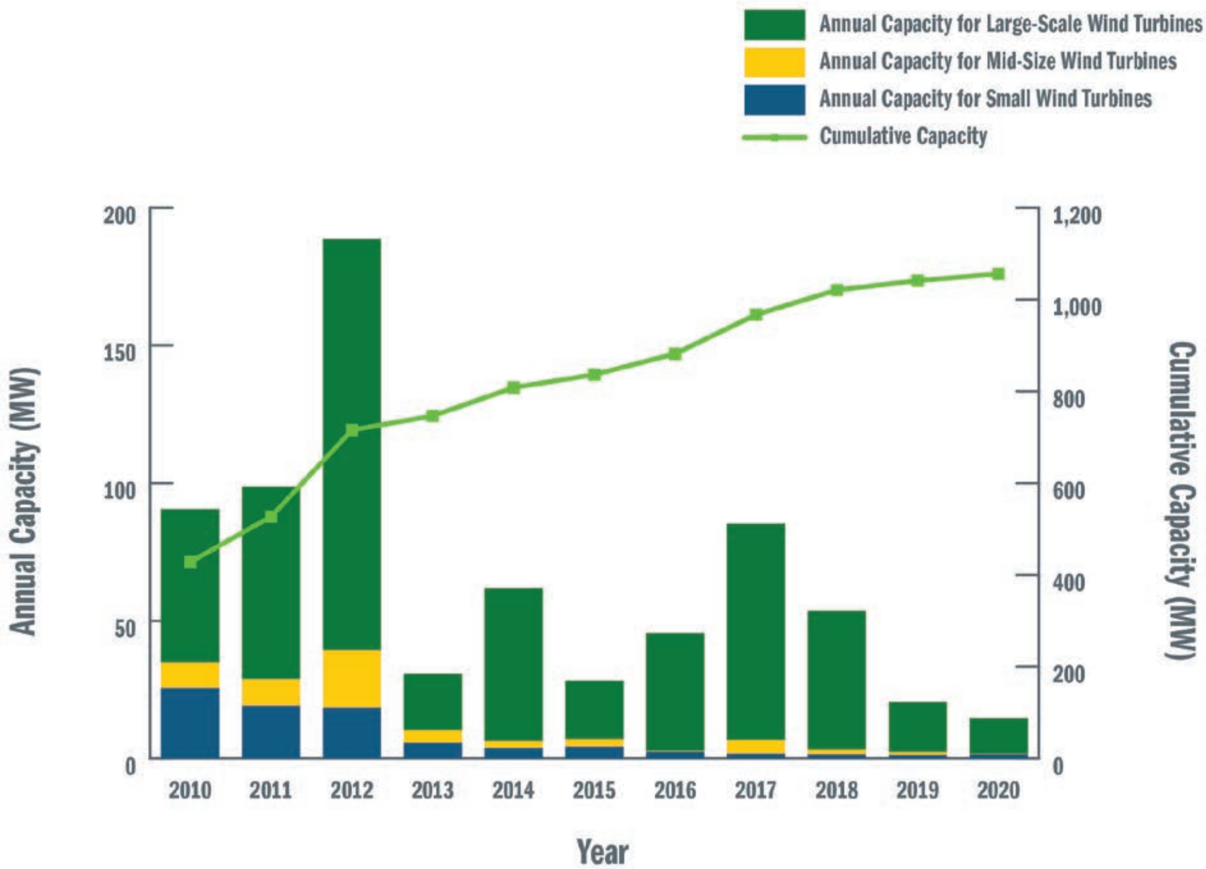

Figure 1. U.S. distributed wind capacity

2.1 Top States for Distributed Wind: Annual and Cumulative Capacity

New distributed wind projects were documented in 11 states (California, Colorado, Iowa, Minnesota, Montana, New Jersey, New York, North Carolina, Ohio, Texas, and Wisconsin) in 2020 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.

[7] The data presented in the figures are provided in an accompanying data file available for download at https://energy.gov/windreport.
[8] All dollar values are nominal unless otherwise noted. Annual and cumulative capacity amounts are based on nameplate turbine-capacity sizes.

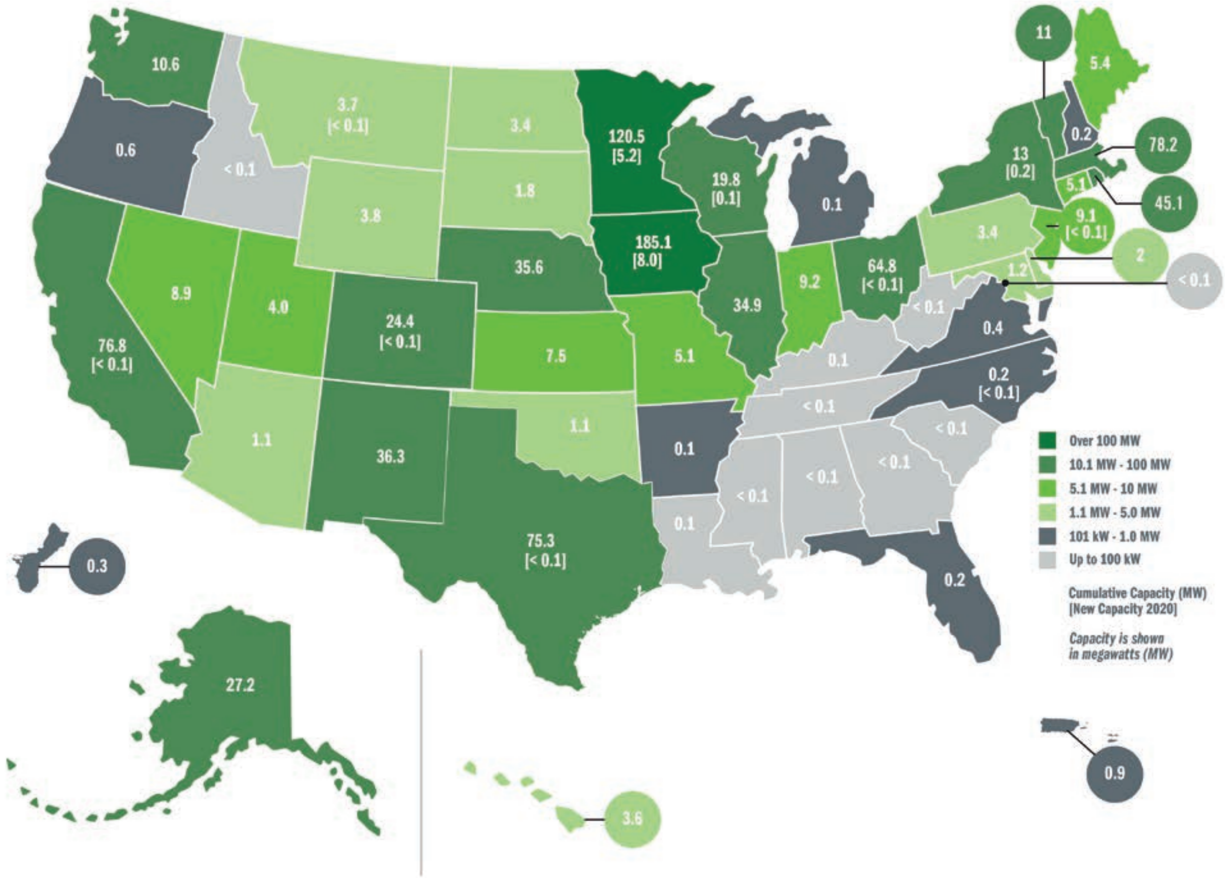

Figure 2. U.S. cumulative (2003–2020) capacity and 2020 capacity additions for distributed wind by state

Iowa and Minnesota led the United States in new distributed wind power capacity in 2020 as a result of the front-of-meter 7.9-MW Mason City Wind project in Iowa for a utility customer and the on-site 5-MW Rock County Wind Fuel project in Minnesota serving a biodiesel production facility. These two projects combined represent 95% of the 2020 installed distributed wind capacity.

In recent years, 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. Project developers, such as Juhl Clean Energy Assets 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 takes multiple years to develop. The COVID-19 pandemic may also delay some project development. These six developers have accounted for at least 40% of the distributed wind capacity from projects using turbines greater than 100 kW since 2015.

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. To illustrate, Ohio led the United States in new distributed wind power capacity in 2019 as a result of large-scale turbine projects installed by One Energy. The 21 MW of distributed wind that Green Development added to its portfolio in Rhode Island in 2018 accounted for almost half of the documented 2018 distributed wind capacity. The “other” category in Figure 3 primarily includes project owners (e.g., universities, municipalities), other third-party developers with a less consistent presence, and unknown developers.

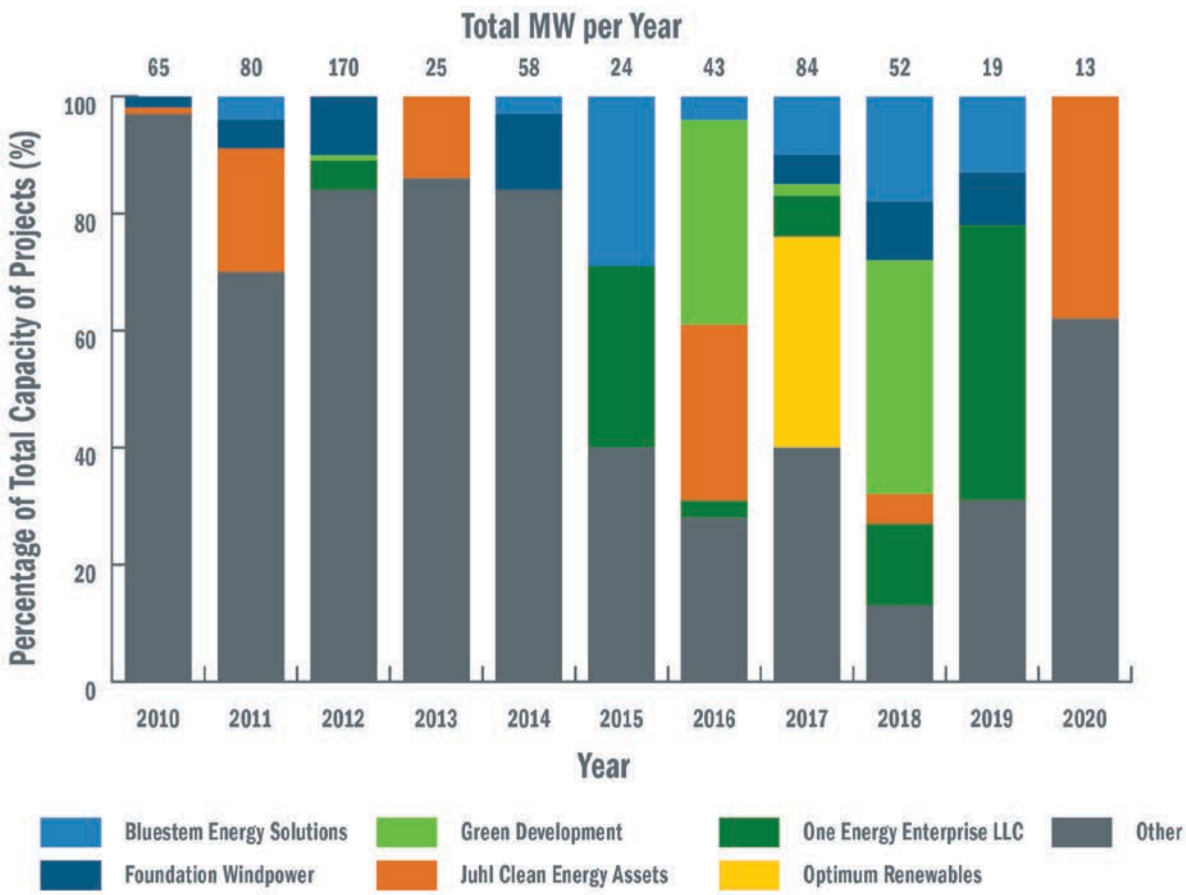

Figure 3. Project developers using turbines greater than 100 kW, 2010–2020

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 cumulative capacities from small wind greater than 2 MW.

Iowa and Minnesota lead all the states in both new capacity in 2020 and cumulative capacity from 2003 through 2020, with both states exceeding 100 MW, as shown in Figure 4. Both states have strong wind resources and have 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).

New York had the most reported small wind projects in 2020, as shown in Figure 5, as the New York State Energy Research and Development Authority (NYSERDA) Small Wind Turbine Incentive Program made some final payments after expiring at the end of 2019. Iowa, Alaska, and Nevada are the top three states for cumulative capacity from small wind.

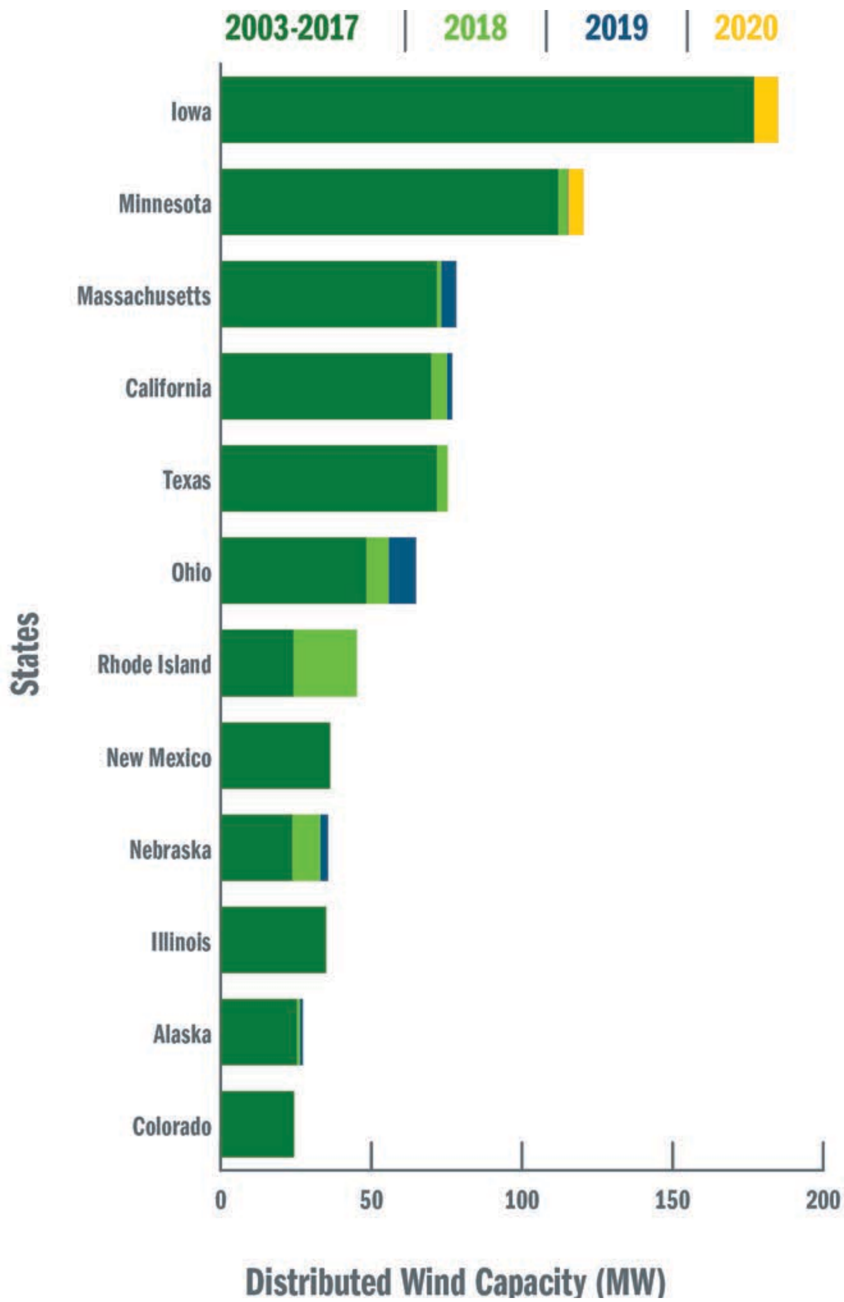

Figure 4. States with distributed wind capacity greater than 20 MW, 2003–2020

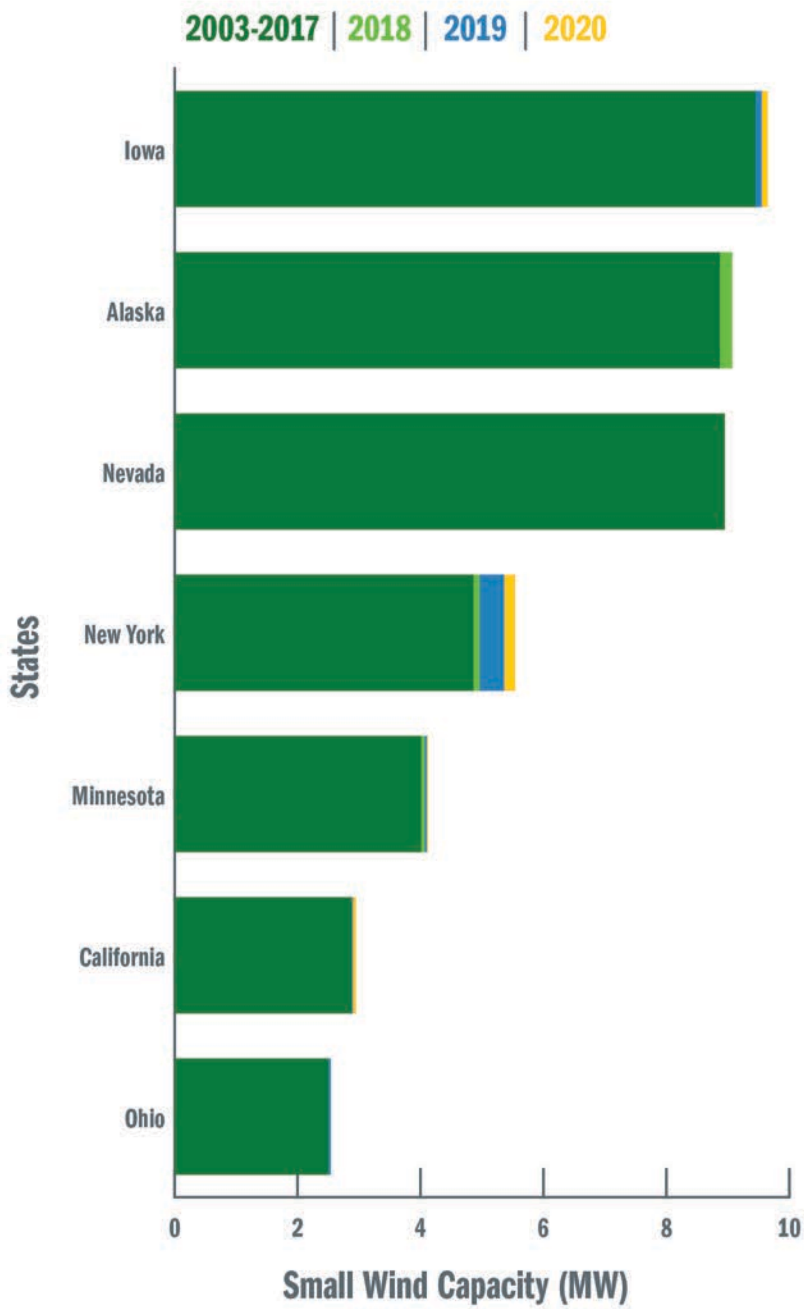

Figure 5. States with small wind capacity greater than 2 MW, 2003–2020

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

Of the 14.7 MW of distributed wind added in 2020, 12.9 MW (88%) came from projects using turbines greater than 1 MW, 0.16 MW (1%) came from mid-size turbines, and 1.6 MW (11%) came from small wind.

3.1 Mid-Size and Large-Scale Turbines

A total of 12.9 MW of the 2020 distributed wind capacity came from projects using turbines greater than 1 MW and 0.16 MW came from mid-size turbines. The total of 13.1 MW from turbines greater than 100 kW represents $34 million in investment.[9]

The 12.9 MW from projects using turbines greater than 1 MW is down from the 18.2 MW documented in 2019, and the 50.5 MW documented in 2018. Projects using mid-size turbines continue to represent a small part of the distributed wind market. Installed capacity from mid-size turbines has been under 5 MW annually since 2013, typically from just a few projects. The 0.16 MW of mid-size capacity in 2020 represents a project with a single mid-size turbine. The capacity from projects using mid-size turbines was 1 MW from 2 projects in 2019 and 1.6 MW from 2 projects in 2018.

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. General Electric (GE) Renewable Energy has been the only consistent U.S.-based manufacturer of large-scale turbines used in distributed wind projects over the past nine years and is the turbine provider for Foundation Windpower in California. Goldwind is the sole turbine supplier for One Energy, a distributed wind project developer based in Ohio, and Green Development, LLC in Rhode Island uses Vensys turbine models. Reported U.S. distributed wind projects using turbines greater than 100 kW in 2020 used three different turbine models from GE Renewable Energy and a refurbished Danwin turbine model.

The number of mid-size and large-scale turbine manufacturers and suppliers with installations in the United States has generally declined since 2012, as shown in Figure 6. Some manufacturers are no longer active in the U.S. market or are no longer in business at all, which can be at least partially attributed to the decline in available incentives after 2012 (discussed in Section 4.1). For turbines greater than 100 kW, there are 17 manufacturers represented in the "other" category in Figure 6 in 2012, meaning a total of 25 manufacturers and suppliers provided turbines for distributed wind projects in 2012 compared to two in 2020 and three in 2019.

[9] 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.

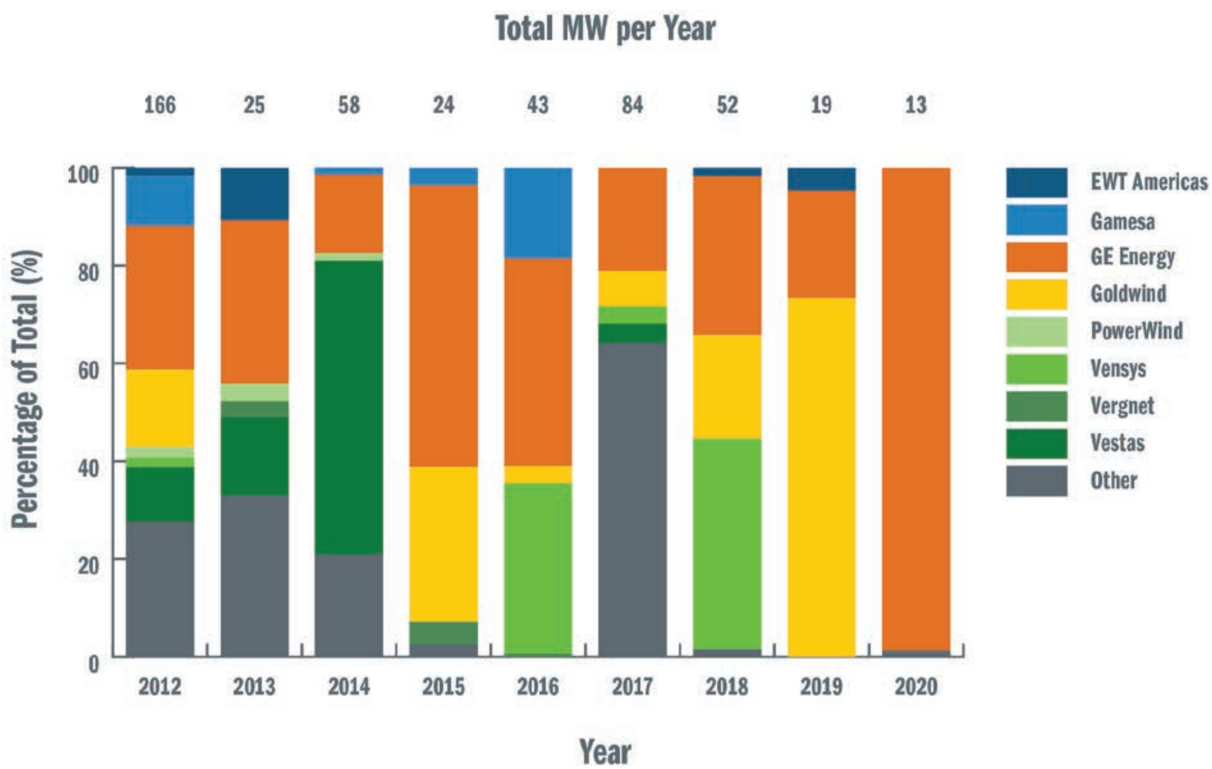

Figure 6. Wind turbine manufacturers of turbines greater than 100 kW with a U.S. sales presence, 2012–2020

3.2 Small Wind

In 2020, 1.6 MW of small wind was deployed in the United States, representing 1,487 units and $7.2 million in investment. Small wind deployment has been relatively flat for the past few years with 1.3 MW, 2,168 units, and $7.6 million of investment in 2019, and 1.5 MW, 2,661 units, and $8.2 million of investment in 2018.

The COVID-19 pandemic had a non-uniform effect on the small wind industry. Some small wind turbine manufacturers and installers reported that the COVID-19 pandemic caused supply chain and shipping delays (Loo 2021) and project cancellations due to the general economic downturn, while others reported there was no disruption to their business. Either way, small wind manufacturers and installers have reported a brighter outlook for 2021, given the role distributed energy can play in decarbonizing the U.S. economy. Small wind turbine manufacturers based in the United States self-report that they rely mostly on a domestic supply chain for most of their mechanical, electrical, tower, and blade components. However, some parts and materials, namely generator magnets, are imported either directly by the manufacturer or by a supply chain vendor.

Based on 2020 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).

Since 2012, the number of small wind turbine manufacturers both operating and participating in the U.S. market has decreased. The eight small wind turbine manufacturers or suppliers with a 2020 U.S. sales presence accounted for in this report consist of six domestic manufacturers headquartered in six states (i.e., Colorado, Minnesota, New York, Oklahoma, Vermont, and Wisconsin) and two importers. In comparison, 31 small wind turbine manufacturers reported U.S. sales in 2012.

In 2020, Eocycle Techologies Inc., a Canadian small wind turbine manufacturer with sales in the United States, announced its merger with Belgian wind turbine manufacturer XANT (Eocycle 2020). The 100-kW XANT M-21 turbine has been rebranded as the EOX M-21. The 25-kW Eocycle EO25 turbine has been rebranded as the EOX S-16.

In 2019, Northern Power Systems (NPS) completed sales of multiple business units (Globe Newswire 2019; McQuiston 2019) and permanently ceased U.S. commercial operations as of August 23, 2019 (SEC 2019). Prior to ceasing operations, NPS sold its Italian subsidiary, NPS SRL, to Boreas Ventures Ltd, a United Kingdom corporation. This sale enables Boreas to service and maintain the Italian fleet of NPS-installed turbines (SEC 2019). Since October 2019, NPS SRL has operated as the engineering, manufacturing, and sales organization for global deployment and service of NPS wind turbines (NPS 2020).

U.S.-based manufacturers of new small wind turbines accounted for 71% of the domestic small wind sales capacity in 2020, as shown in Figure 7, compared to 84% in 2019 and 76% in 2018. Newly manufactured small wind turbines by U.S.-based manufacturers represent a smaller percentage of overall sales in 2020 because of an increase in small wind refurbished turbine sales. Only two foreign small wind manufacturers reported sales in the United States in 2020.

Although PNNL did not document any refurbished small wind turbine sales from 2015 through 2018, their market presence has increased in recent years, with refurbished turbines accounting for 8% of U.S. small wind sales in 2019 and 26% in 2020. However, given the inconsistent presence of foreign manufacturers in the U.S. small wind market and recent growth in refurbished turbine sales, these market-share divisions could shift again.

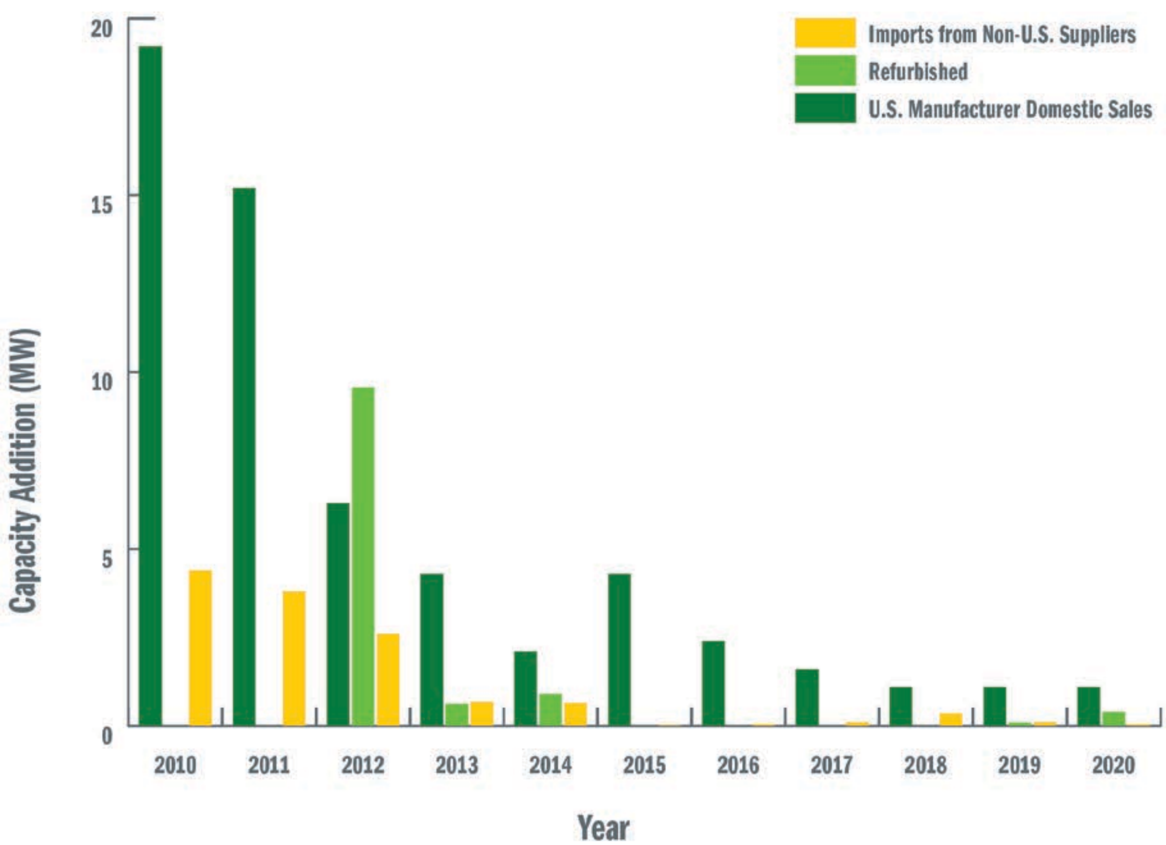

Figure 7. U.S. small wind turbine sales, 2010–2020

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 (Figure 8). These exports have declined in recent years. Three U.S.-based small wind manufacturers exported turbines totaling nearly 200 kW in capacity with an estimated value of $1.1 million in 2020. These numbers are down from nearly 500 kW valued at $3 million from three manufacturers in 2019 and down significantly from a peak of 21.5 MW valued at $122 million from six manufacturers in 2015.

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)[10] per kilowatt-hour (kWh) from 2015 to 2016 before expiring in 2017. It was replaced by the FER1 Decree, which provides rates of €0.15 ($0.18) per kWh for small wind (0–100 kW) projects (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.

[10] All currency conversions are based on the exchange rates per U.S. Department of Treasury Reporting Rates as of March 31, 2021, found in https://www.fiscal.treasury.gov/reports-statements/treasury-reporting-rates-exchange/ for reference.

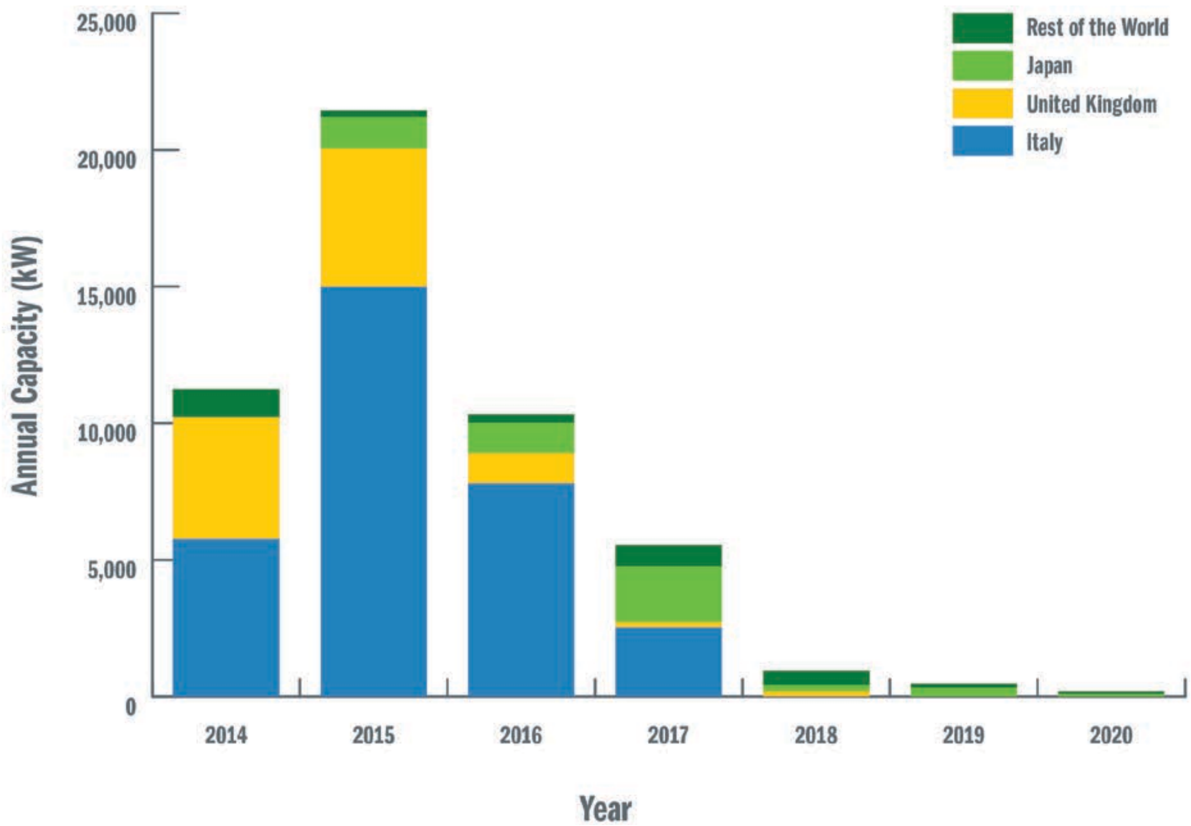

Figure 8. U.S. small wind turbine exports, 2014–2020

3.4 Global Small Wind Market

An examination of the global small wind market provides a point of comparison for the U.S. small wind market. For 2020, PNNL documented 30 MW of new small wind capacity from five countries, in addition to the United States, that have agencies willing to share data with PNNL, as shown in Table 1. This is an increase from the 26 MW of international small wind PNNL documented for 2019.

The 26 MW of small wind installed in China in 2020 accounts for 84% of the documented 2020 global capacity. China experienced a 20% increase in small wind installations from 2019 to 2020. Italy had significant capacity additions through 2017, no reports in 2018–2019, and then 0.65 MW of small wind added in 2020. 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).

Total global installed cumulative small wind capacity is estimated to be about 1.8 GW as of 2020 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.

Table 1. Global Small Wind Capacity Reports

Country	2013	2014	2015	2016	2017	2018	2019	2020	Cumulative	Cumulative Years
	(MW)									
Australia[a]	*	0.02	0.03	*	0.02	*	0.01	0.00	1.47	2001–2020
Brazil[b]	0.03	0.02	0.11	0.04	0.11	0.29	0.44	0.07	1.11	2013–2020
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	610.61	2007–2020
Denmark[f,g]	11.04	7.50	24.78	14.61	2.58	0.40	0.18	0.05	610.88	1977–2020
Germany[h]	0.02	0.24	0.44	2.25	2.25	1.00	2.50	2.50	35.75	As of 2020
Italy[i,j]	7.00	16.27	9.81	57.90	77.46	*	*	0.65	190.08	As of 2020
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
UK[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	152.65	2013–2020
Global	110.75	126.01	99.90	130.75	112.32	34.43	26.25	30.46	1774.68	

*	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	SustainableElectricity Association of New Zealand
m	Korea Energy Association
n	www.gov.uk, Monthly Microgeneration Certification Scheme and Renewables Obligation Order Feed-in Tariffs degression statistics

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 resources.

From a peak of $100 million worth of incentives dispersed across 22 states in 2012, incentive payments have been decreasing. Figure 9 shows the value of incentives given to distributed wind projects from 2013 to 2020.[11] The combined value of USDA REAP grants, state rebates, and state production tax credits in 2020 was $4.8 million across six states (California, Iowa, Kansas, New Mexico, New York, Vermont).

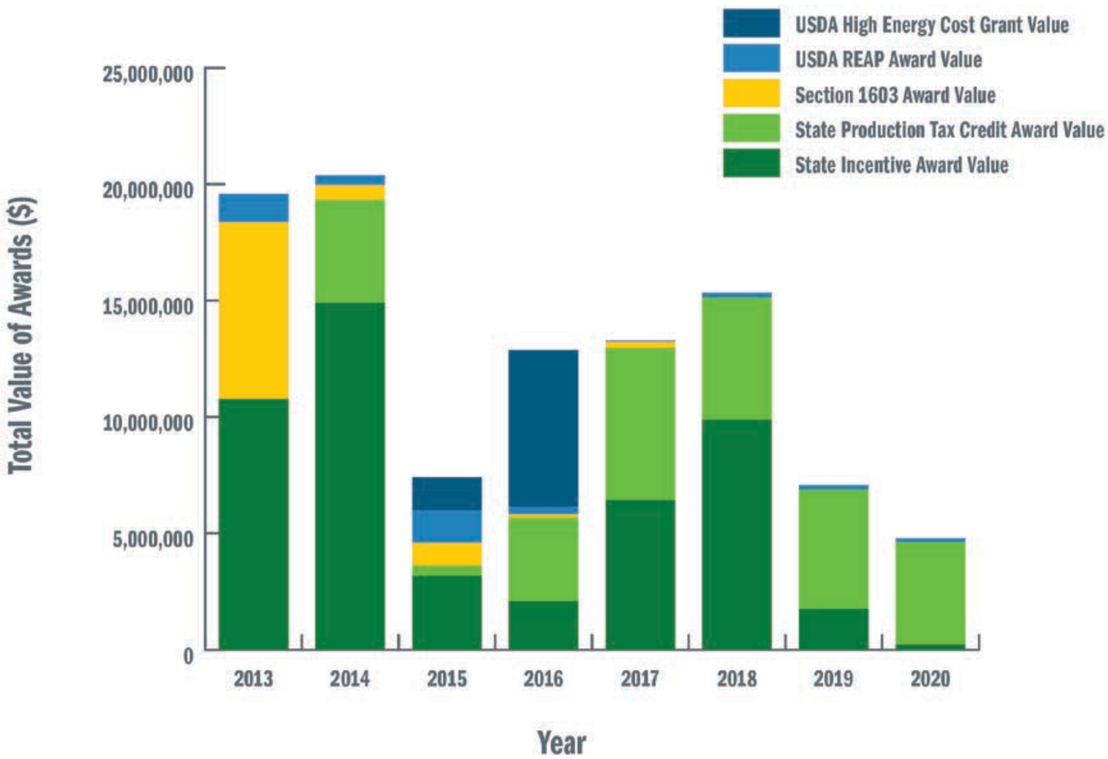

Figure 9. U.S. distributed wind incentive awards, 2013–2020

The incentives included in Figure 9 are state rebates, grants, and production-based incentives; USDA REAP and High Energy Cost 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 9 excludes repaid loans, the federal investment tax credit (ITC), and federal depreciation. New Mexico and Iowa state production tax credit values are estimated based on available project energy production reports.

[11] 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. 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.

Awards from all of these incentive programs have been decreasing over the past years. The decline in state incentives is explored in Section 4.1.1. USDA REAP wind applications and grants are discussed in Section 4.1.3. 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).[12]

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.

State incentive programs, such as rebates and production-based incentives, vary widely and fewer states are providing these incentives. In 2012, 12 state programs reported incentive payments for distributed wind projects. In contrast, four state programs reported incentive payments for distributed wind projects in 2020, as well as in both 2019 and 2018. New York, Vermont, Maryland, and the Tennessee Valley Authority are a few examples of states (and agencies) that have phased out their incentive programs. These examples illustrate some of the different reasons states have for discontinuing their incentive programs.

4.1.1.1 New York

Documenting the end of New York's incentive program is of particular interest as it was considered a well-run program that enabled significant and consistent small wind capacity additions annually for many years. The program was discontinued because the state has shifted its focus to large-scale solar photovoltaic, large-scale wind, and offshore wind projects (NYSERDA 2021).

NYSERDA changed its Small Wind Turbine Incentive Program several times over the years. The incentive program was revamped in 2011, temporarily discontinued at the end of 2015, and reinstated in 2016. In May 2016, NYSERDA announced it would make approximately $6 million in incentives available for small wind through December 31, 2018. The program was extended through December 2019 and discontinued permanently as of December 31, 2019 (NYSERDA 2019). Distributed wind projects that completed the incentive application process in 2019 will be the final recipients of the incentive program.

For several years, NYSERDA offered a per-kWh-generated incentive calculated with a tiered formula based on the turbine's projected energy production estimated at the time of incentive application. Before it was discontinued, the incentive was changed to a per-kW incentive based on the nameplate capacity of the distributed wind system, with $1,500/kW for the first 100 kW and $500/kW for each kW over the initial 100 kW, up to a maximum of $1,000,000 (NYSERDA 2019). This incentive structure shift, although still under the Small Wind Turbine Incentive Program title, was implemented to encourage the installation of larger wind projects, as larger projects were expected to generate more energy per dollar of incentive.

Over the program's lifetime, it effectively stimulated the state's distributed wind market by building a strong framework to balance financing, administrative, and quality hurdles that have historically constrained the adoption of distributed wind. The program offered dedicated administrative support to help customers navigate the application process, required wind turbines to be certified and installed by verified installers to be eligible for incentive funds, and provided nearly $16 million to distributed wind projects totaling over 8 MW from 2009 through 2020. As a result, New York small wind capacity deployment accounted for 25% of the national documented small wind capacity in 2020, 55% in 2019, and 39% in 2018.

[12] 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.

Although the incentive has been discontinued, other policy and market conditions may still drive interest in distributed wind in New York, namely electricity bill demand charges and New York's Value of Distributed Energy Resources (VDER) mechanism that replaces net energy metering. Future levels of distributed wind installations will indicate if this interest translates to additional capacity deployment.

Demand charges on electricity bills have been increasing and more utilities are moving to tariff structures with demand charges in New York. Demand charges relate to a customer's peak energy use in a month, rather than the total monthly energy consumption. According to distributed wind developers, wind generation is better suited to alleviate demand costs than solar photovoltaics, because energy use peaks are typically in the winter when the wind resource is more available than the solar resource, and increased interest in distributed wind is being reported in New York as a result.

In net metering, distributed energy resource owners are only compensated for energy generation (the per-kWh portion of the bill). However, VDER accounts for the additional distributed energy resource benefits to the grid by compensating not just the energy, but also the capacity, environmental, demand reduction, and locational benefits of the distributed energy resource.

4.1.1.2 Vermont

The Vermont Small Scale Renewable Energy Incentive Program has provided incentives for solar photovoltaic, wind, and micro-hydro systems in the past, but currently provides incentives for only advanced wood heating and solar water heating. The program discontinued its wind incentive for all customer categories in 2013 (RERC 2018). The lack of incentives, a challenging state-level permitting approval process, and sound rules for wind generation facilities all helped drive the last remaining larger-scale distributed wind project that had been under development in Vermont to end all of its project-development activities in January 2020 (NACE 2020; Orrell et al. 2016). Without the state incentive, some customers are still pursuing small wind projects with the help of other incentives, namely USDA REAP grants. In Vermont, one rural business and one farm were awarded USDA REAP grants in 2019 and 2020, respectively.

4.1.1.3 Maryland

The Maryland Energy Administration (MEA) discontinued its Residential and Community Wind Grant Programs on July 1, 2019 because of insufficient customer interest (MEA 2019). The last applications the programs had received were in 2016. The last distributed wind project MEA funded was also in 2016 for a 10-kW wind turbine at a summer camp (MEE 2018). The wind turbine is part of the camp's microgrid that also includes solar photovoltaics, battery storage, electric vehicle charging, and a sophisticated energy-management platform for connectivity, control, monitoring, and cybersecurity systems (Burger 2019).

4.1.1.4 Tennessee Valley Authority

The Tennessee Valley Authority ended its customer-owned renewable energy incentive program in 2019, citing the drop in solar photovoltaic pricing as the reason the incentive was no longer needed, although the incentive was also available to wind, low-impact hydropower, and biomass projects (TVA 2021).

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 of 26% of qualified expenditures has been 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, scheduled to expire on December 31, 2020, has also been extended through December 31, 2021 under the Consolidated Appropriations Act 2021. Projects that begin construction by the end of 2021 will be eligible for a PTC at 60% of the full rate over 10 years, or alternatively, can opt for an 18% ITC on the total project cost in the year the project is placed in service.

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. USDA also issues REAP grants for up to 25% of the project's cost, or a maximum of $500,000 for renewable energy projects. A combination of REAP loans and grants can cover up to 75% of total eligible project costs.

In 2020, USDA REAP awarded $155,026 in grants to three wind projects from four applications. The three projects represent a total of 95 kW from five turbines. The projects are expected to generate a combined 493,000 kWh of energy annually. REAP did not provide any loan guarantees to wind projects in 2020. The funding amount for 2020 was slightly less than the $188,076 in wind grants awarded in 2019, when a total of four projects out of six applications received awards. USDA REAP grant and loan amounts for wind projects decreased significantly after 2010, as shown in Figure 10 and Figure 11, respectively.

In 2020, wind projects represented 0.31% of all REAP grant awards (0.04% of total REAP funding); energy-efficiency projects represented 24% of grant awards (3% of total funding); and solar photovoltaic projects represented 66% of grant awards (76% of total funding). Other awards include biomass, geothermal, and hydroelectric projects. In 2019, wind projects represented 0.44% of all REAP grant awards (0.08% of total REAP funding).

Since 2003, USDA has awarded over $72 million in REAP wind grants. States receiving the largest share of this funding are Iowa with $23.3 million, Minnesota with $21.3 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 173, New York with 50, Wyoming with 45, and Alaska with 30.

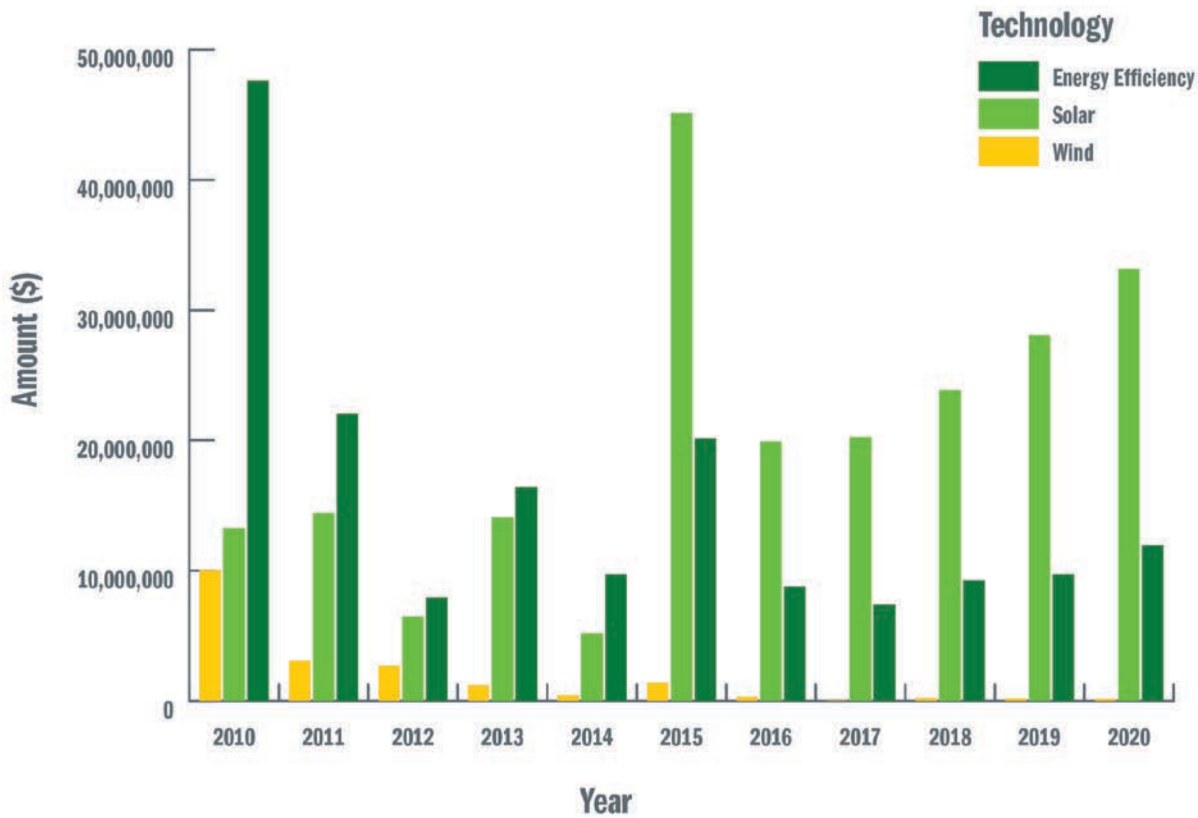

Figure 10. USDA REAP grants by technology, 2010–2020

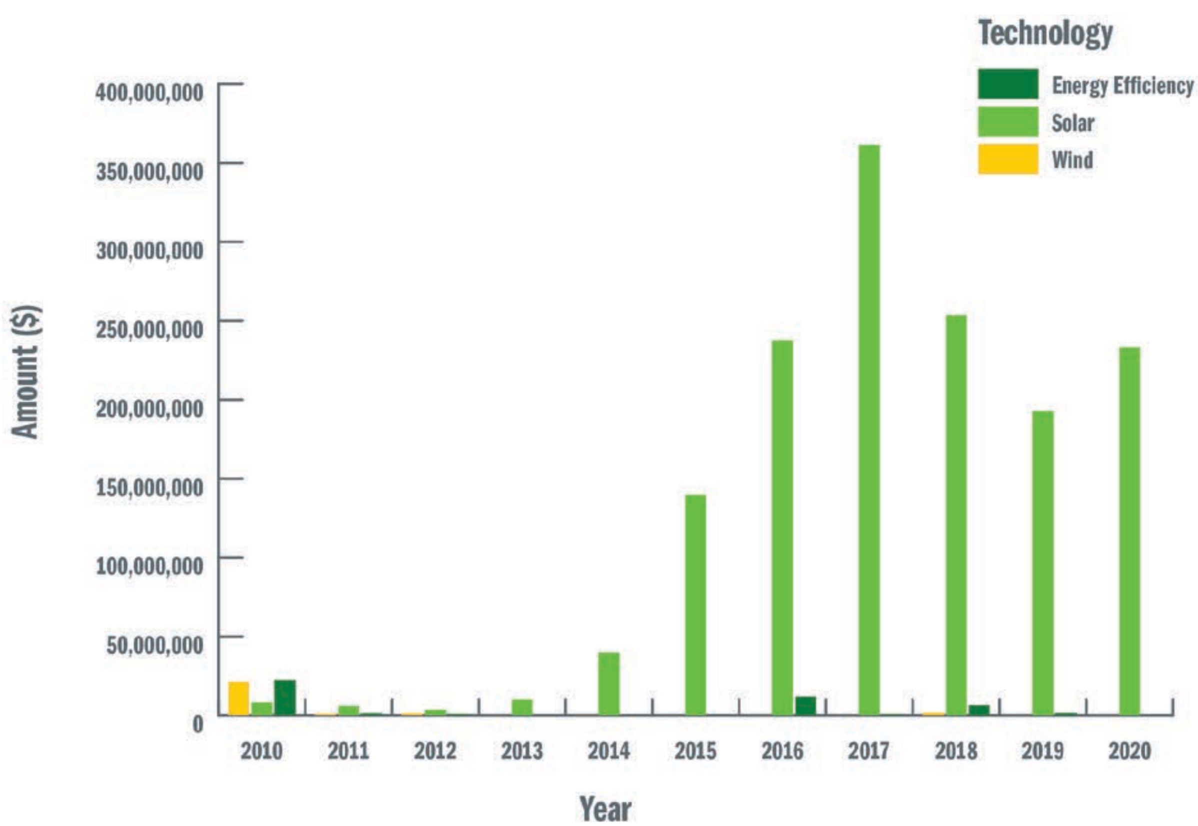

Figure 11. USDA REAP loans by technology, 2010–2020

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 installers and service providers report that much of the new domestic small wind capacity installed in 2019 and 2020 was for retrofit projects. In 2019 and 2020, small wind retrofits contributed to 36% and 80% of total installed small wind capacity, respectively. No small wind retrofits were reported in 2018. Retrofits are new (either newly manufactured or refurbished) turbines installed on existing towers and foundations to replace nonfunctioning turbines or to upgrade the technology. Installers report using mounting plates and stub adapters to mount the new turbine units on existing tower structures (Gipe 2021). Retrofitting activities are expected to continue as small wind turbines reach the ends of their life cycles and customers seek out improved technologies.

The retrofit trend is largely driven by customers' interest in reusing existing infrastructure to maintain on-site wind generation. Installers reported a Proven 15 turbine in North Carolina; Jacobs 31-20 turbines in Texas, Wisconsin, and Minnesota; and an Enertech turbine in New Jersey all being replaced by Bergey Excel 15 turbines. One illustrative example is the installation of a Bergey Excel 15 in 2021 in Tehachapi, California to replace a Bergey Excel 10 that was installed in 1993. Before the Bergey Excel 10, the tower had supported a Carter 25 wind turbine (Gipe 2021). Multiple Endurance E-3120 turbines were also replaced with refurbished E-3120 turbines in 2020.

4.2.2 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 44 subcontracts to 23 companies, totaling $10.62 million of DOE funding and leveraging $5.41 million in additional private-sector investment (WETO 2021a).

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 technical objectives of the project are to increase energy production and grid support capabilities; develop advanced manufacturing processes to reduce hardware costs; and conduct turbine and component testing to national certification standards to verify performance and safety.

Product development and certification for power electronics products can be complex and expensive, but with CIP funding, some awardees are succeeding with bringing a concept to reality. As a CIP awardee, Intergrid LLC has produced a 25-kW inverter specifically designed for small- and medium-scale wind turbines. Partnering with other CIP awardees, the inverter will be mass produced by Matric Limited, and scaled up by Windurance for use with medium-scale turbines with capacities of hundreds of kilowatts (WETO 2021b).

4.2.3 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).[13] These standards address power performance, duration (durability), structural, safety, and acoustic sound requirements.

A new American National Standards Institute consensus standard, originally called AWEA-SWT-1 and now called ACP 101-1, is being developed by the American Clean Power Association (ACP), the successor to AWEA. ACP 101-1 is intended to eventually supersede the AWEA 9.1-2009 standard. ACP 101-1 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 AWEA 9.1–2009 standard is still applicable and referenced in IRS guidance, but ACP 101-1 and its definitions are likely to be widely adopted in future policies, market reports, and technical research.

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 are undergoing constant revision while certification and listing of devices to these standards are also evolving rapidly. The Competitiveness Improvement Project is helping industry stakeholders address this emerging need.

Table 2 lists the eight small wind turbine models currently certified to the AWEA 9.1 standard or the IEC 61400 standards as of report publication. Only turbine models that have met annual renewal and periodic factory inspection requirements are included. The Bergey Excel 15 is the latest turbine model to be added to the list as it was fully certified in February 2021.[14] At least one turbine model, the QED Wind Power PHX20, is currently in certification testing as of report publication (ICC-SWCC 2021).

Table 2. Certified Small Wind Turbines[15]

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
SD Wind Energy, Ltd.	SD6	6/17/2019	5.2	AWEA 9.1

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).

[13] 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.

[14] The Bergey Excel 15 received a Limited Power Performance certification in June 2019. This is an interim certification that is granted when the power performance testing is complete, but duration testing is ongoing. The Bergey Excel 15 received full certification in February 2021 after completing its duration testing.

[15] Other information about these certifications, such as rated sound levels and rated annual energy production amounts, are available from the certification bodies (ICC-SWCC 2021; 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

The average annual and project-specific small wind installed costs (in 2020 dollars) for 2010 through 2020 are presented in Figure 12. Figure 12 only includes projects with reported installed costs that use turbines with known rated capacities.[16] Annual average capacity-weighted installed costs for small wind projects range from around $4,000/kW to nearly $11,000/kW. Figure 12 only includes an annual average for years in which there are three or more reported projects. With the exception of 2018, the overall annual average capacity-weighted installed cost for this dataset has been relatively flat across the years at approximately $9,500/kW.

The installed cost figure includes the wind turbine equipment costs, or the hardware costs, as well as the balance-of-station costs. Balance-of-station costs[17] can represent up to 60% of a small wind project's total installed cost and therefore play a significant role in overall small wind installed costs (Orrell and Poehlman 2017).

Sample sizes of projects with reported installed costs and known rated capacities vary from year to year. Although new small wind projects were reported in 2020, they are excluded from Figure 12 because their installed costs are unknown. The small sample sizes and high variance in project-specific costs both contribute to the cost ranges exhibited each year.

As discussed in Section 4.2.1, the majority of 2019 and 2020 small wind reported projects were retrofits. Average annual (when available) and known project-specific small wind retrofit installed costs (in 2020 dollars) are also shown in Figure 12.

For 2019 and 2020, installed project cost information was available for 24 small wind retrofit projects across 7 states using 24 turbines for a total of 5.3 MW. The annual average capacity-weighted installed cost for small wind retrofit projects was approximately $5,300/kW in 2019 and $4,100/kW in 2020. Of the 2019 small wind retrofit projects with installed cost data, all used new Bergey Excel 10 turbines, with all but one project located in New York. These New York projects are similar in cost, with a majority reporting project-specific installed costs in the range of $5,100 to $5,300/kW. The sample size of small wind retrofit projects with installed cost data was greater in 2020 (14 projects compared to 10 projects in 2019) and contained a wider range of project-specific reported installed costs, from approximately $2,000 to $8,300/kW. Approximately one-third of the small wind retrofit projects reported in 2020 used refurbished turbines—units remanufactured with some or all new parts.[18] These refurbished turbines represent the low end of the retrofit installed cost range reported for 2020.

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

[17] 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).

[18] 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.

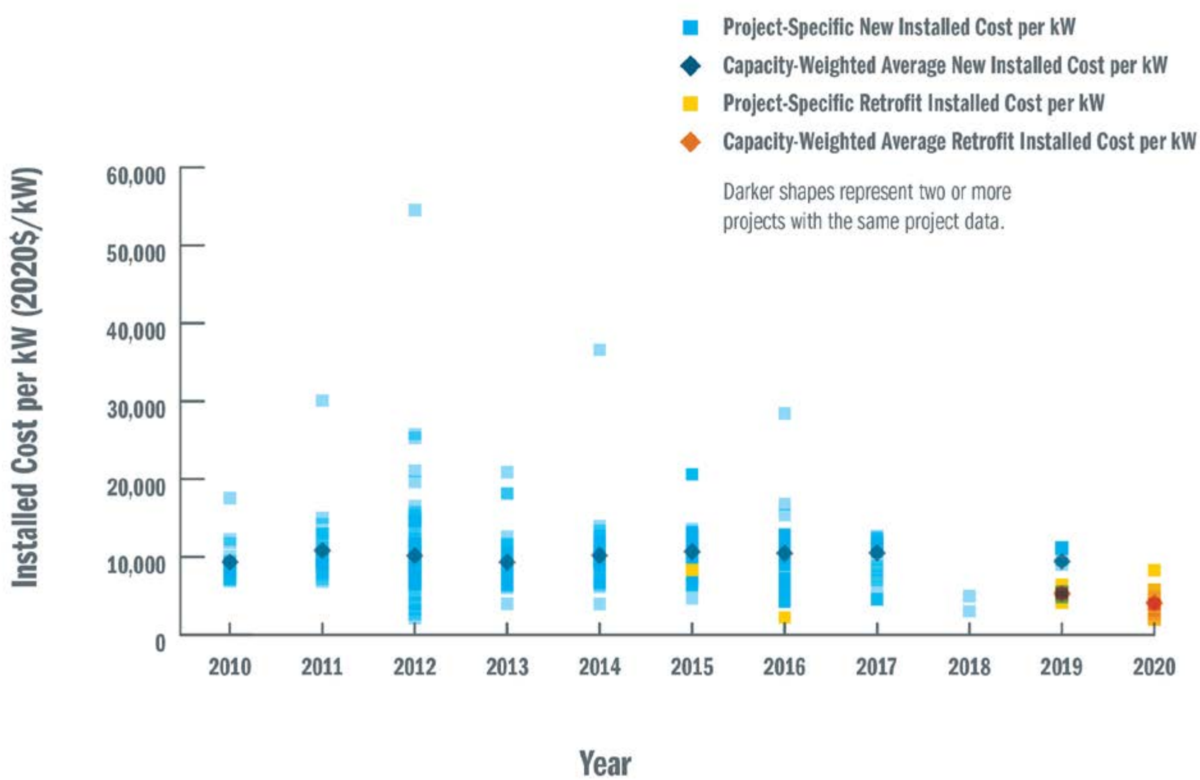

Figure 12. Average and project-specific U.S. new and retrofit small wind installed project costs, 2010–2020

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

The average annual and project-specific costs for projects using turbines greater than 100 kW for years 2010 through 2020 are presented in Figure 13. The overall annual average capacity-weighted installed cost of projects using turbines greater than 100 kW from 2010 through 2019 is approximately $3,640/kW.

For projects using turbines greater than 100 kW installed in the United States in 2020, a reported installed project cost was only available for one project. As a result, no average capacity-weighted installed cost is given for 2020. 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 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).

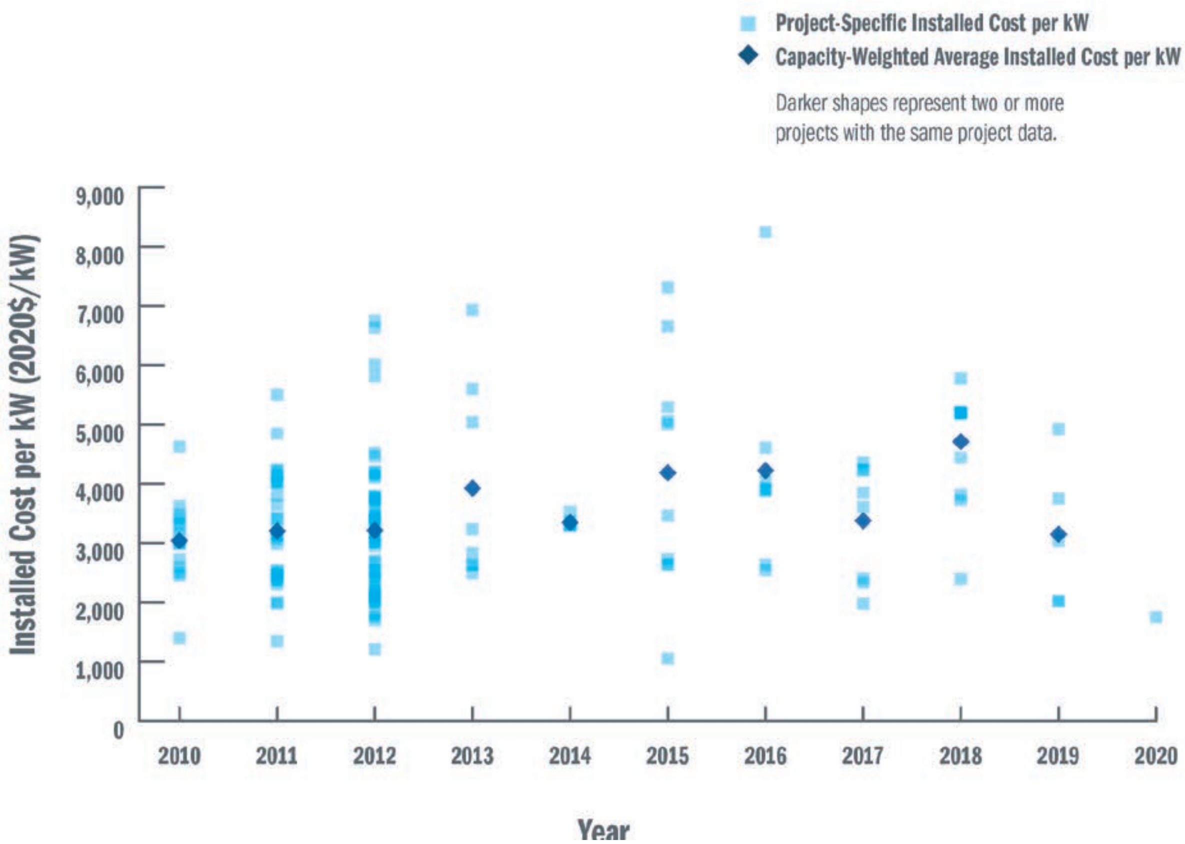

Figure 13. Average annual and project-specific installed costs for projects using turbines greater than 100 kW, 2010–2020

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. Operation and maintenance 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. On the other hand, all wind projects, distributed or otherwise, require maintenance.

For a large distributed wind project, operation and maintenance 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 2021).

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.

Maintenance costs can be categorized as scheduled or unscheduled. Scheduled maintenance activities can include inspecting the turbine, controller, and tower; adjusting blades; checking 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 a variety of 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 the Benchmarking U.S. Small Wind Costs report, scheduled maintenance site-visit costs for a sample of small wind projects were collected (Orrell and Poehlman 2017). Costs reflected labor, travel, consumables, parts, and more. That data showed the average scheduled maintenance cost per visit is about $37/kW. 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.[19] This section looks at capacity factors in a variety of ways to evaluate the performance of distributed wind turbines.

6.1 Capacity Factors

Figure 14 presents the calculated small wind capacity factors, arranged by rated turbine capacity, based on the average of reported generation in 2016, 2017, and 2018 from the NYSERDA dataset. Similarly, Figure 15 displays the three-year average capacity factors for projects using turbines greater than 100 kW based on their Energy Information Administration (EIA)-reported annual generation amounts in 2016, 2017, and 2018, and the total project capacity is arranged by turbine nominal capacity.

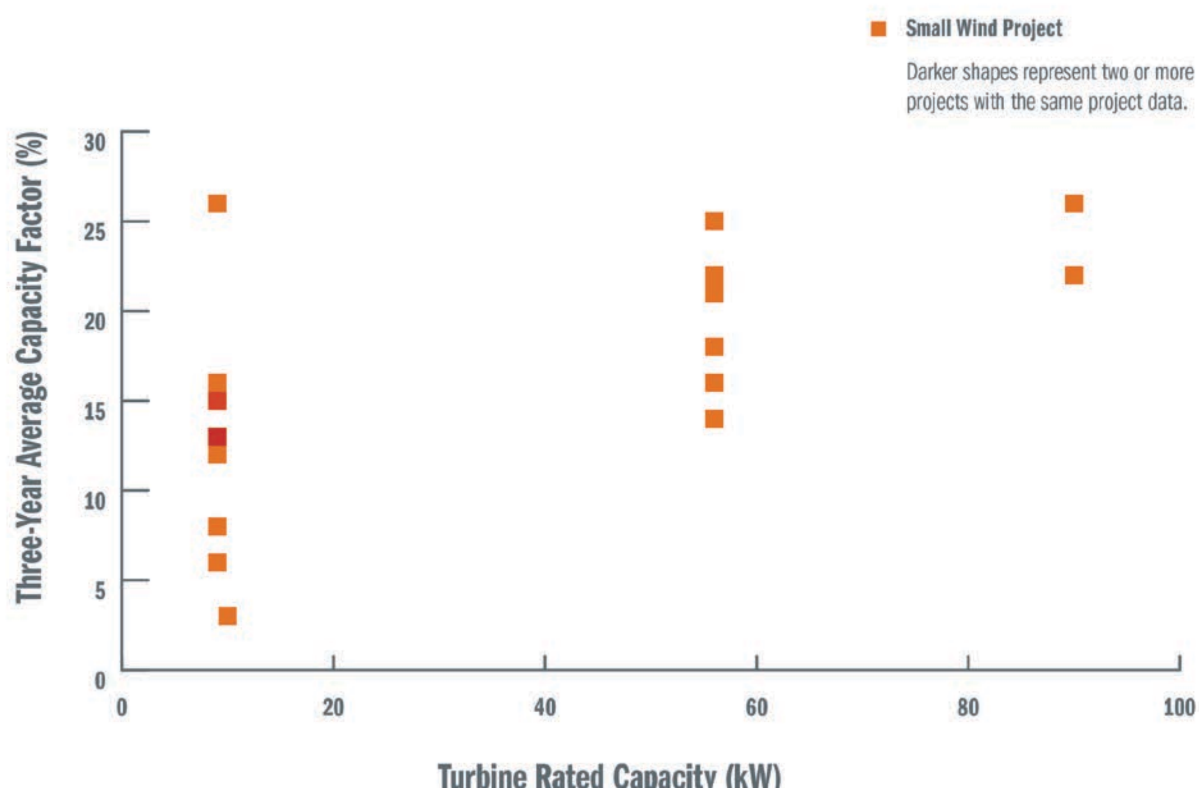

Figure 14. NYSERDA small wind capacity factors

[19] 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.

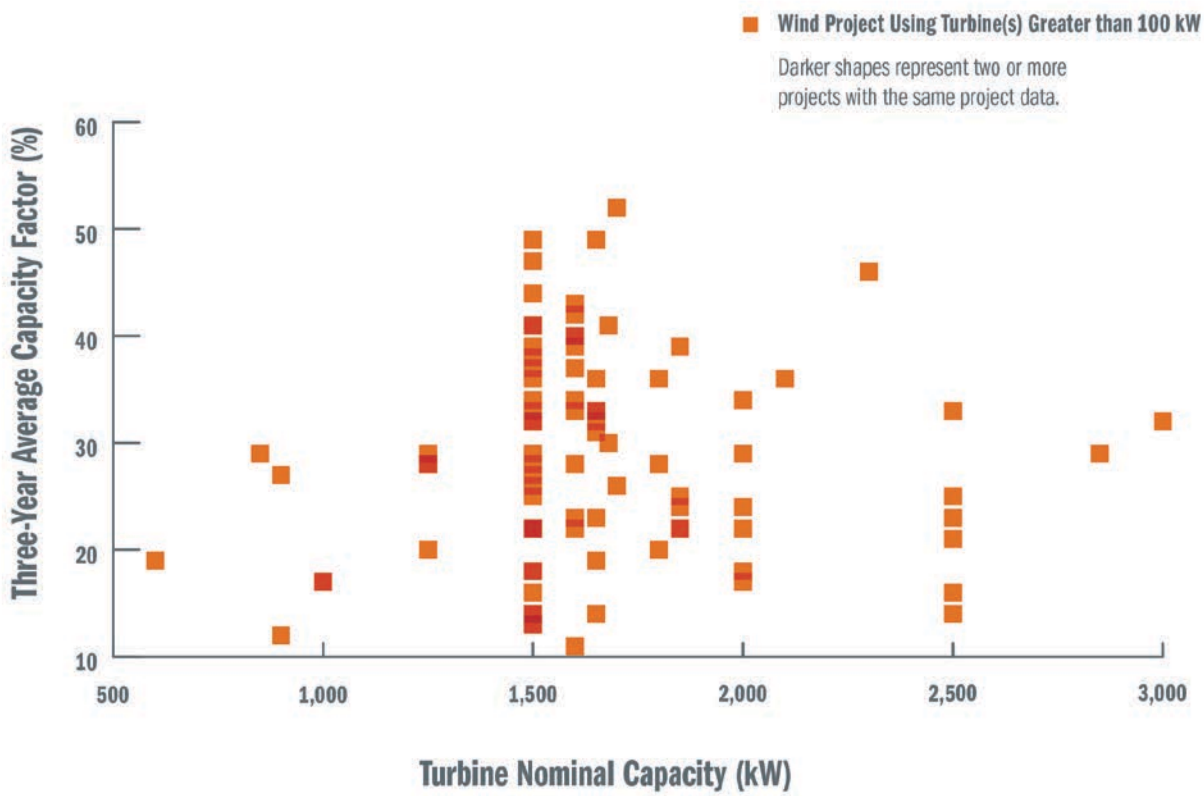

Figure 15. Capacity factors for projects using turbines greater than 100 kW

The three-year average capacity factor for small wind is 16%. The three-year average capacity factor for projects using mid-size turbines is 20%. The three-year average capacity factor for large-scale wind turbines in distributed applications is 29%.

The sample sizes, years, and data sources in this report differ from those in the 2018 Distributed Wind Market Report, published in August 2019, in which the three-year average capacity factors were reported to be 17%, 25%, and 31% for small, mid-size, and large-scale wind projects, respectively (Orrell et al. 2019). Despite the sampling differences between the two reports, the trends in capacity factors are consistent.

The NYSERDA dataset includes 19 small wind projects totaling 615 kW in rated capacity. These projects were installed in New York during the period from 2009 through 2015 with reported production from 2009 through 2019. After installation, rebate recipients were required to submit performance reports at least twice per year for two years. With the expiration of the NYSERDA small wind turbine incentive program, 2019 is the final year in the performance reporting record.

The wide range of small wind capacity factors, from 3% to 26%, reflects, among other variables, the assessment and siting challenges for small wind discussed in Section 6.2. Four turbine models are represented in the 19 small wind projects in Figure 14. The capacity factors for the turbines with a rated capacity of 8.9 kW range from 6% to 26%. 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, resulting from a turbine not operating for extended periods because of mechanical problems, can lower the turbine's overall capacity factor. Poor measuring and reporting of energy production may also be factors.

Wind projects with a total size of at least 1 MW are required to report net annual energy generation to the EIA in EIA-923 reports (EIA 2020). From these records, 87 distributed wind projects installed from 2003 to 2015, across 21 states, totaling 287 MW in capacity were analyzed.

The wind projects in Figure 15 exhibit a wide range of capacity factors, from 11% to 52%. While the analysis presents a three-year average capacity factor based on generation amounts for 2016, 2017, and 2018, the age of the projects as of 2018 ranged from one to 15 years old. This snapshot in time could account for some of the variation, but siting and turbine availability issues may also play roles in large-scale distributed wind project performance. Nonetheless, the three-year average capacity factor for large-scale turbine projects is higher than that of 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), have larger rotors (to achieve larger rotor swept areas), and have taller hub heights (to capture faster wind speeds).

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 just 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 a handful of small wind projects in the NYSERDA dataset to identify the site-specific factors that may play a role in the difference between actual and estimated performance for the selected sites. Project performance estimates generated from two sources, the ERA5 model[20] and the NYSERDA Small Wind Explorer[21] tool, were considered and found to generally overpredict project performance. The estimates also indicate the two sources have a limited ability to accurately represent turbine production in locations with complex terrain and local obstructions.

For this analysis, the three-year average annual capacity factors first presented in Figure 14 serve as the baseline for comparison with the estimated capacity factors, as shown in Figure 16. The actual capacity factors are from the NYSERDA dataset, and are diverse in turbine type, hub height, and New York State geography.

The two estimated annual capacity factors were derived from the ERA5 model ("Model") and the NYSERDA Small Wind Explorer tool ("Tool"), both of which are representative of performance estimation products available to a small wind installer. These estimated capacity factors are compared to the actual capacity factors ("Actual") in Figure 16.

Figures 16 shows that both estimated annual capacity factors are generally greater than the actual capacity factors, regardless of turbine size. For small wind turbines with rated capacities up through 20 kW, the average actual capacity factor is 13%, while the model and tool capacity factor estimates are 14% and 16%, respectively. For small turbines with rated capacities from 21 kW to 100 kW, the average actual capacity factor is 21%, while the model and tool capacity factor estimates are 24% and 27%, respectively.

[20] The model is the European Center for Medium-Range Weather Forecasts Reanalysis 5th generation, commonly referred to as ERA5 (ECMWF 2020). Reanalysis models provide decades-long wind resource data that can be analyzed as a standalone product or incorporated into performance estimation tools. Here, the modeled wind resource data is combined with each turbine-specific power curve to produce capacity factor estimates.
[21] The NYSERDA 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.

Several turbines stand out in Figure 16 because of their variances. Three of them, within close geographic range of each other and for which PNNL has siting details, were selected here for further discussion. Turbine 4 contradicts the trend of model and tool overprediction by having an actual capacity factor greater than the estimated capacity factors. A closer look into the project-specific details, namely the siting characteristics, reveals that Turbine 4 is located near the top of a hill. Because higher elevations tend to experience faster wind speeds, the enhanced actual performance of Turbine 4 relative to the performance estimates is likely partially attributable to model and tool limitations in addressing the effects of complex terrain on wind resources.

Conversely, Turbines 9 and 11 were selected for examination because they have actual capacity factors much lower than their estimated model and tool capacity factors, which are equivalent for each of these turbines. A closer investigation into these turbines reveals consistently low actual annual capacity factors, indicating that no single year in the three-year average was affected by a significant mechanical or other type of outage. Rather, both turbines are located among forests, and tools and models are limited in their ability to accurately represent obstacles and wake effects, likely leading to the overestimated capacity factors at these locations.

Models and 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. 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. Until addressed, installers and owners can consider these challenges when making small wind performance estimates by recognizing that the performance estimate from a model or tool may need to be adjusted if the turbine is sited near obstacles or in complex terrain.

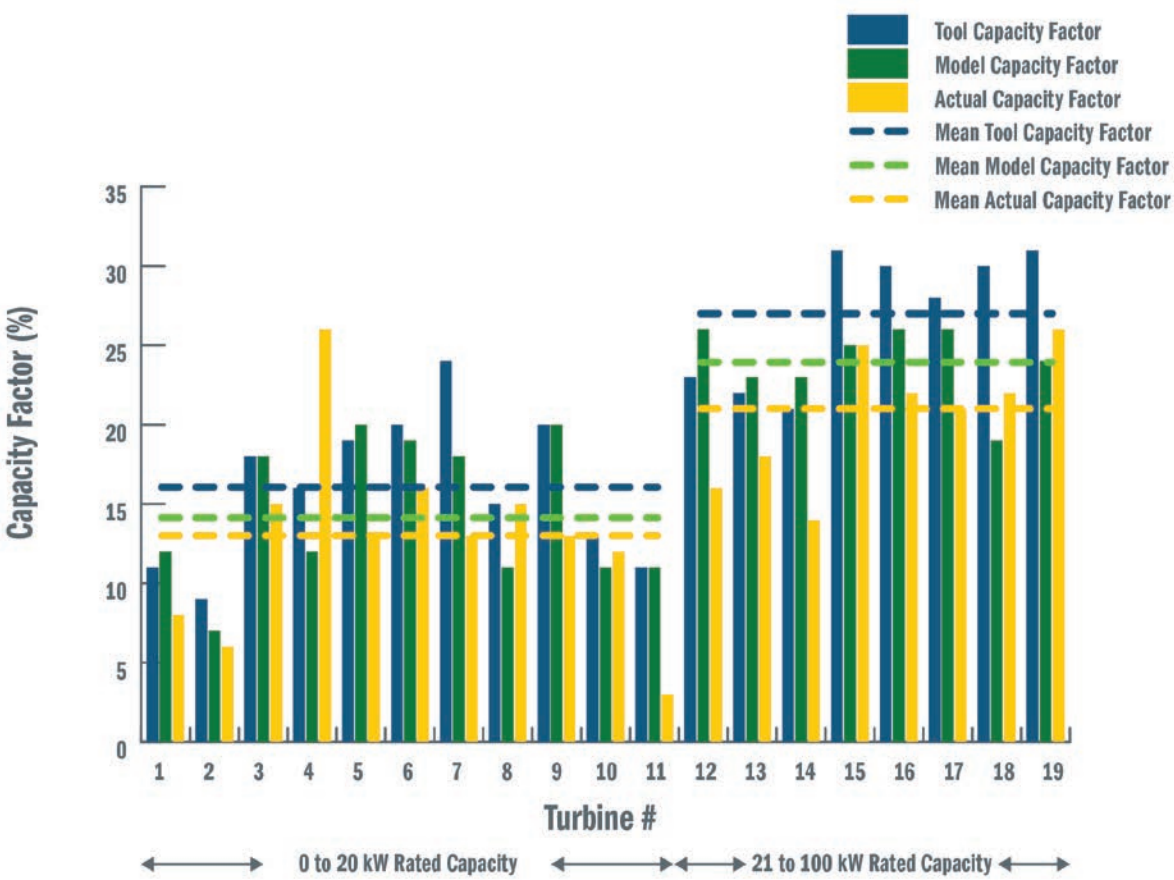

Figure 16. Actual and estimated performance for NYSERDA small wind projects

7 Levelized Cost of Energy

A 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 2013). 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 does not allow year-to-year LCOE comparisons. And given the limited availability of cost reports for the years 2018 through 2020 and the lag in availability of production data for those recently installed projects, this report does not include new LCOE estimates. LCOE estimates will be revisited in future reports as PNNL gains access to new and more relevant data.

The NREL 2019 Cost of Wind Energy Review presents small wind LCOE estimates that are generally in line with past market report estimates (Stehly et al. 2020). For a representative 20-kW installation, the estimated LCOE was 15.9¢/kWh in 2019 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 10.4¢/kWh.

The NREL 2019 LCOE estimates do not include incentives. Rebates and grants reduce the upfront cost for the wind turbine owner significantly and, thus, reduces 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 9.4¢ to 24.8¢/kWh and from 7.5¢ to 27¢/kWh, respectively, in the continental United States (EIA 2021). The average electricity rates in most states fall at the lower end of this wide range. For example, Iowa and Minnesota, leading states for distributed wind installed capacity, have residential retail rates that range from 12¢ to 13¢/kWh and commercial retail rates that range from 9¢ to 11¢/kWh. Hawaii, Alaska, Puerto Rico, the U.S. Virgin Islands, and Guam have higher rates, making distributed wind potentially more cost competitive in those areas.

8 Distributed Wind Markets

This section of the report looks at some of the details, such as customer types, wind turbine types and sizes, and project locations, for distributed wind sales and installations.

8.1 Customer Types

Customers install distributed wind systems for several reasons, including increased energy security, lower utility bills, hedging against future energy price increases, mitigation of energy price volatility, or simply to generate renewable energy. 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,[22] 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, and churches.
4) Government applications are also projects for non-taxed entities such as cities, municipal facilities (e.g., water-treatment plants), military sites, and tribal governments.
5) Commercial applications include offices, car dealerships, retail spaces, restaurants, and telecommunications sites.
6) Industrial applications are facilities that manufacture goods or perform engineering processes (e.g., food processing plants, appliance manufacturing plants, and oil and gas operations).
7) Agricultural applications include all types of farms, ranches, and farming operations.

Agricultural and residential end-use customers 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 2020, agricultural customers accounted for 36% of the number of projects installed, followed by residential customers, who represented 24% of installed projects. In contrast, agricultural and residential end-use customers accounted for a combined 2% of the documented capacity installed in 2020. These two customer types accounted for 3% of the documented capacity in 2019 and just under 1% in 2018, a continued decrease from 2015's record high of just under 13%. As agricultural and residential customers predominantly use small wind turbines, this decrease mirrors the decrease in small wind sales.

Utility customers represented the largest share of total distributed wind project capacity installed in 2020, accounting for approximately 58% of the documented capacity, compared to 42% in 2019. Industrial customers represent the second largest percentage of distributed wind capacity installed in 2020, accounting for roughly 37% of capacity installed and 54% in 2019.

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

While the number of utility and industrial projects have been fairly steady over the past few years (with the exception of 2018), the size of the turbines used in the projects have increased and thus the overall capacity of the projects has increased as well. Combined, utility and industrial customers represented approximately 95% of the total capacity installed in both 2019 and 2020, up from a combined 73% in 2018 and 85% in 2017.

Figure 17 shows the breakdown of customer types by number of projects for 2014–2020 and Figure 18 shows the breakdown of customer types by distributed wind capacity for 2014–2020.

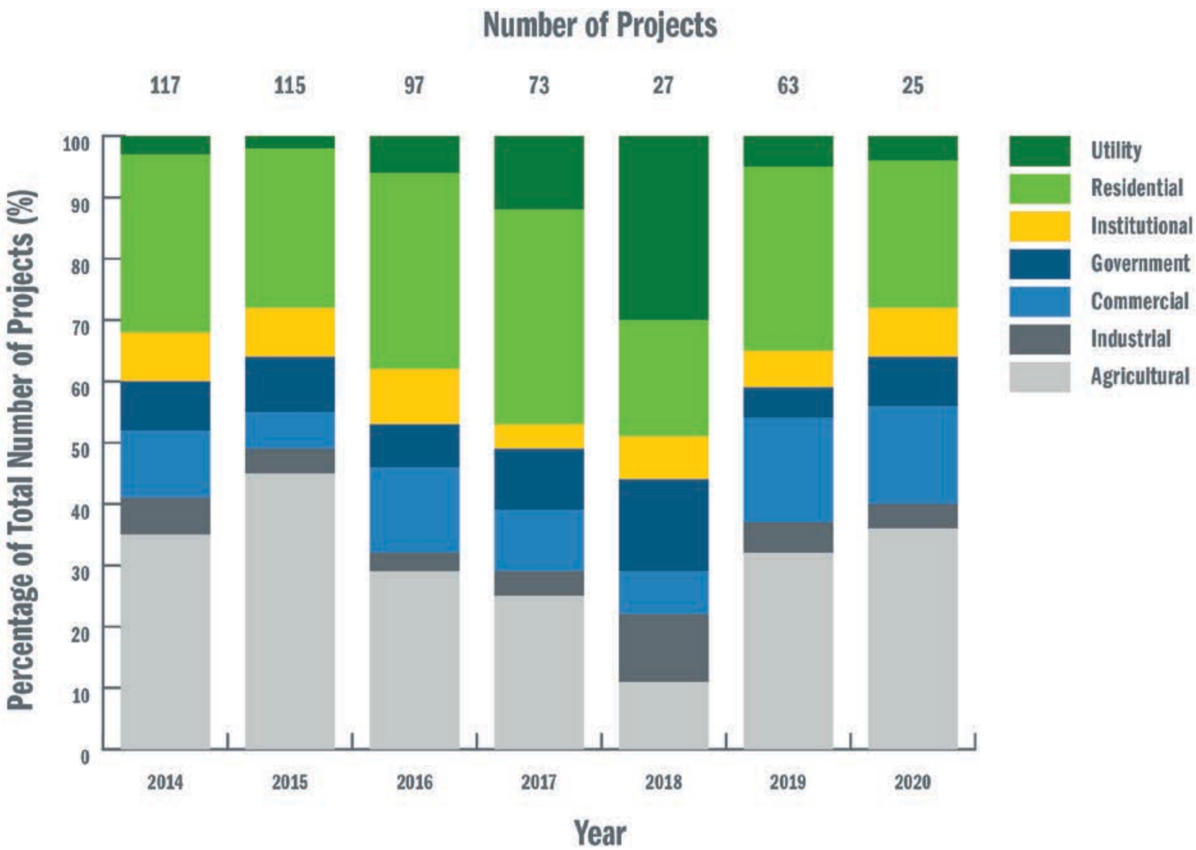

Figure 17. Distributed wind end-use customer types by number of projects, 2014–2020

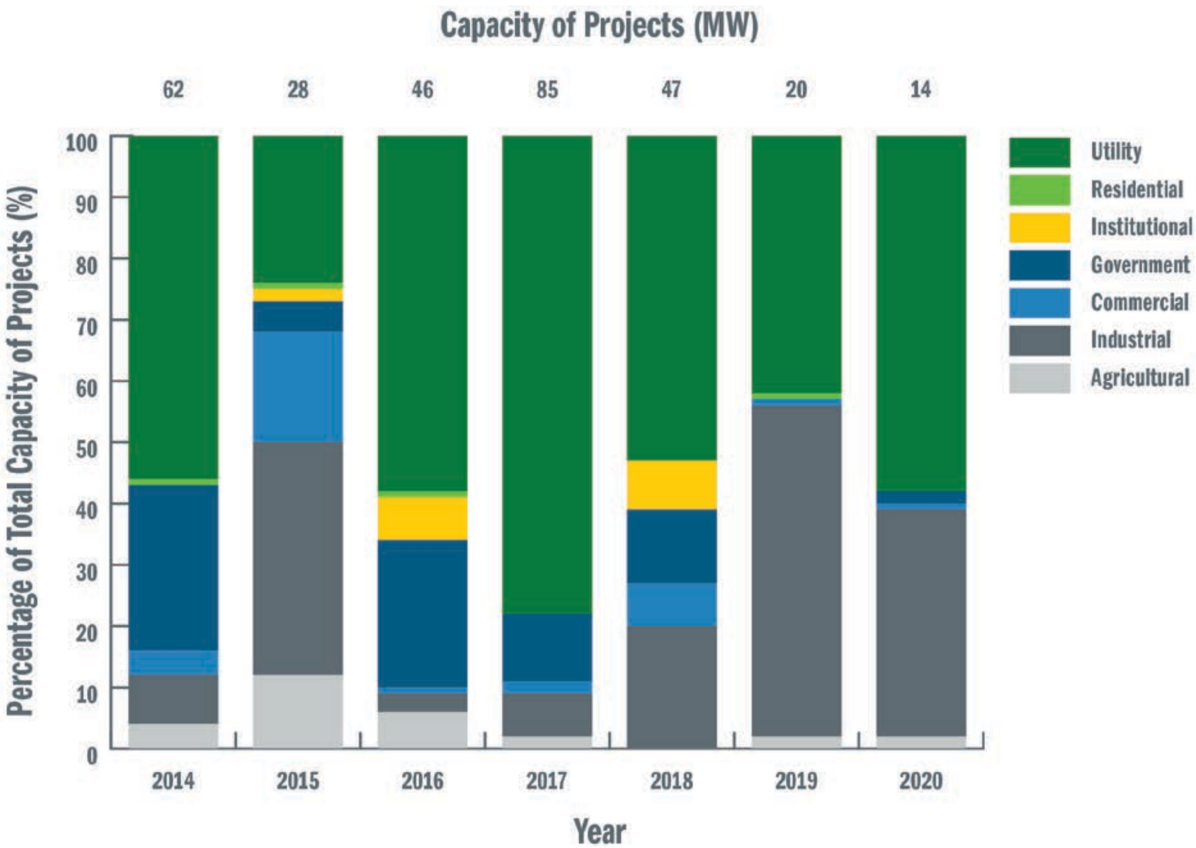

Figure 18. Distributed wind end-use customer types by capacity of projects, 2014–2020

8.2 On-Site Use and Local Loads

Distributed wind can serve on-site energy needs in various applications. The most common applications are isolated grids, grid-connected microgrids, behind-the-meter installations used to offset a portion of energy costs for grid-connected customers, 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. 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 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-the-meter wind projects typically include multiple turbines greater than 100 kW in size, and often, greater than 1 MW in size.

From 2010 through 2020, 90% of all documented distributed wind projects were interconnected for on-site use. The remaining 10% of distributed wind projects were deployed to serve local loads.

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 2010 through 2020 was 55%, with the remaining 45% for on-site use.

In 2020, wind turbines for on-site use were installed for wineries, schools, residences, farms, a tribal government, an animal eye care clinic, and a biodiesel production facility. The wind turbines installed in 2020 for local use were installed by utilities to power their communities.

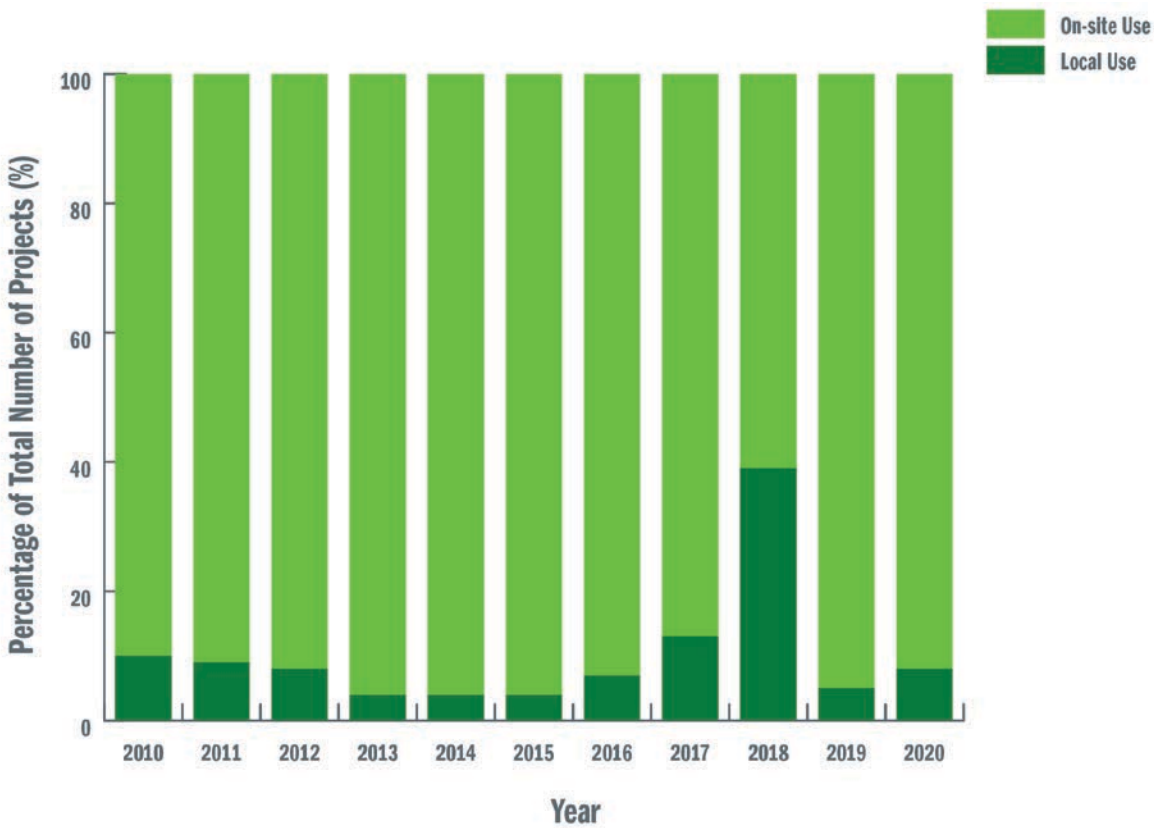

Figure 19. Distributed wind for on-site use and local loads by number of projects, 2010–2020

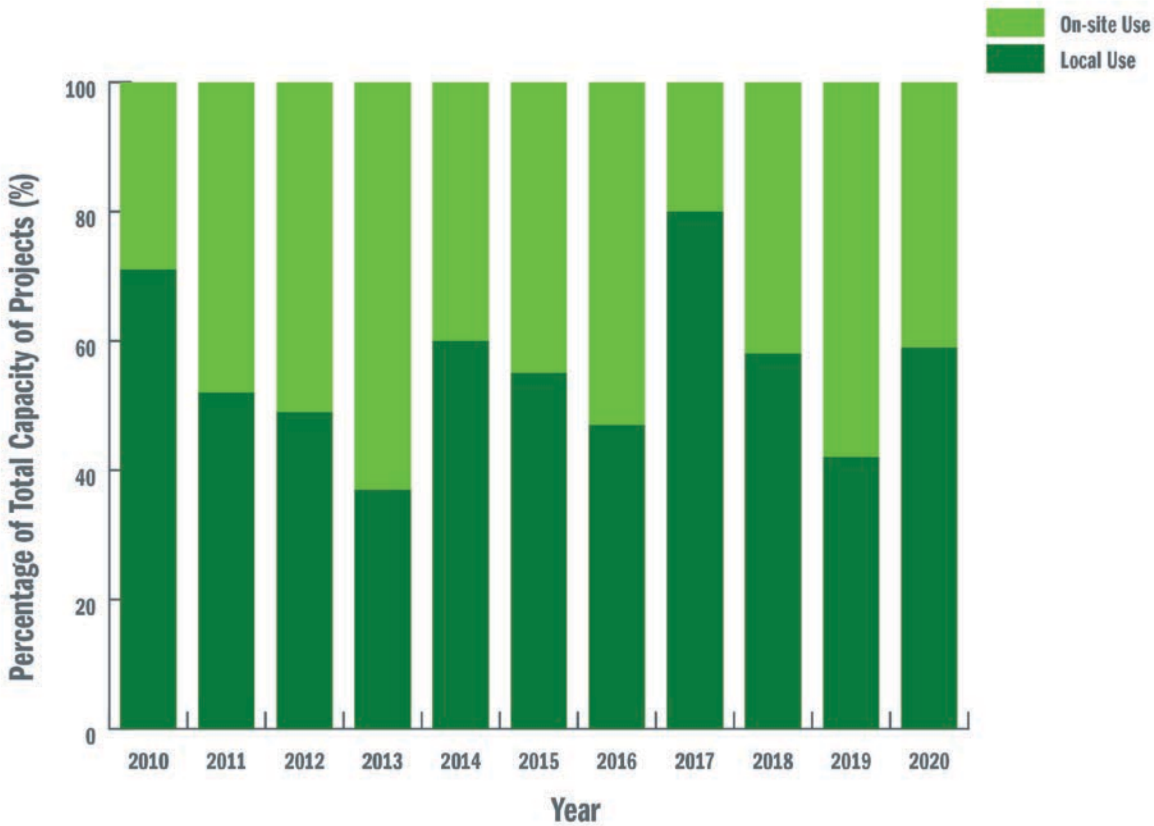

Figure 20. Distributed wind for on-site use and local loads by capacity of projects, 2010–2020

8.3 Off-Grid and Grid-Connected

As discussed in more detail in Section 8.4, off-grid small wind turbine models continue to 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 2020 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 99% in 2019 and 98% in 2018.

8.4 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, and the trend toward higher-capacity large-scale turbines contributes to this. 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. 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.

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 2.2 MW—more than double the capacity of turbines used in 2003. This trend mirrors the increase in turbine capacity size used for all land-based wind projects. As such, the average project size has almost tripled from 1.5 MW in 2003 to 4.4 MW in

2020. However, this variation in average project size is related to the dataset sample available each year. The significant variation between average project size in 2020 (4.4 MW) and average turbine size (2.2 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.

As shown in Figure 22, annual small wind capacity additions continue to decline, driven by a decrease in sales of turbines rated 1–100 kW in size. As overall small wind capacity deployment has decreased annually, the less-than-1-kW turbine size segment has contributed an increasingly large percentage of both the total deployed turbine units and the total deployed capacity for small wind. In 2012 (the first year for reliable small wind turbine unit and capacity amounts), turbines less than 1 kW in size accounted for 3% of the deployed small wind capacity and 70% of newly manufactured small wind turbine units. In 2020, the less-than-1-kW turbine size segment accounted for 26% of the deployed small wind capacity and 97% of the turbine units. Capacity amounts are shown in Figure 23. This is lower than the capacity percentages reported in previous years—with the less-than-1-kW size segment at more than 40% of the deployed small wind capacity from 2017 through 2019—but still part of an upward trend from 2012. This trend is likely because the less-than-1-kW turbines are used primarily in off-grid or battery charging applications (and often sold in packages integrated with solar photovoltaics), and demand for this type of remote power is less sensitive to market conditions.

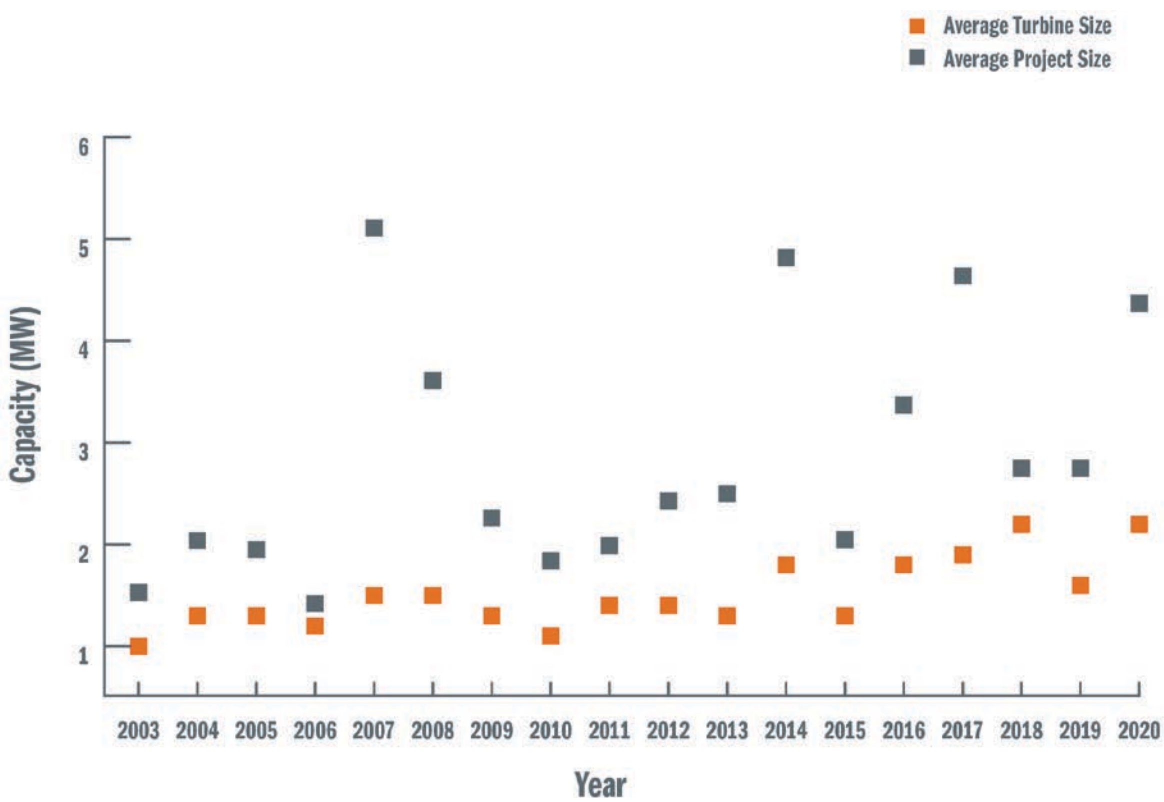

Figure 21. Average size of turbines greater than 100 kW in distributed wind projects and average size of those projects, 2003–2020

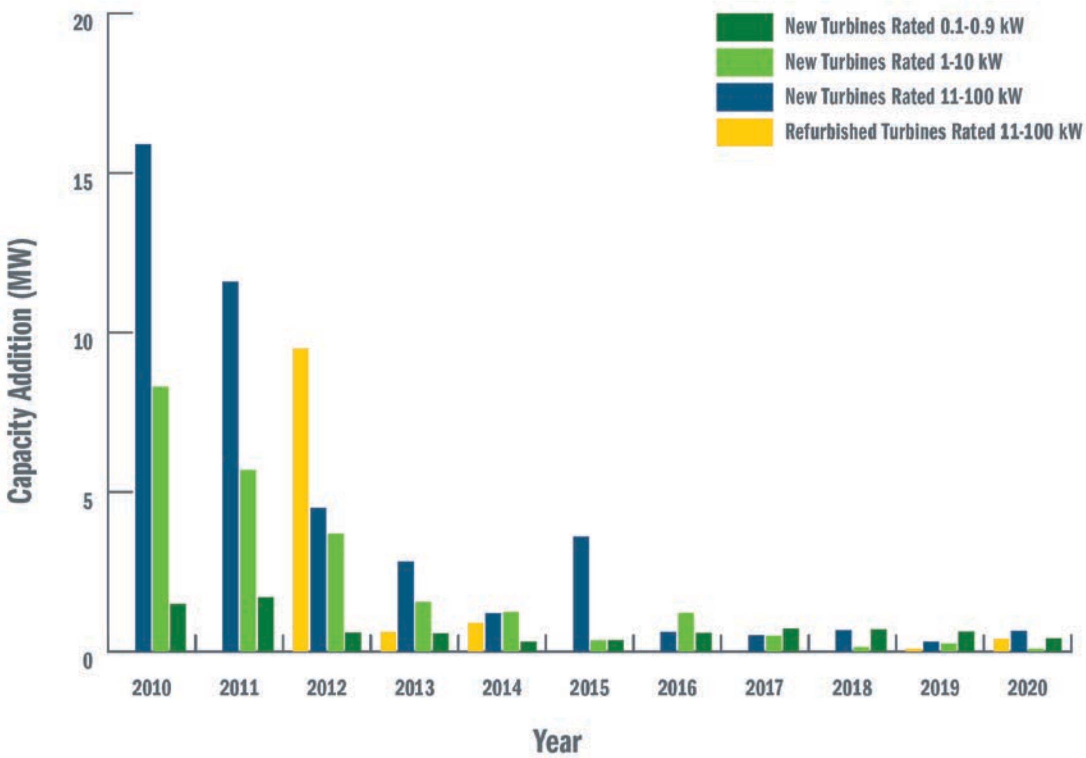

Figure 22. U.S. small wind sales capacity by turbine size, 2010–2020

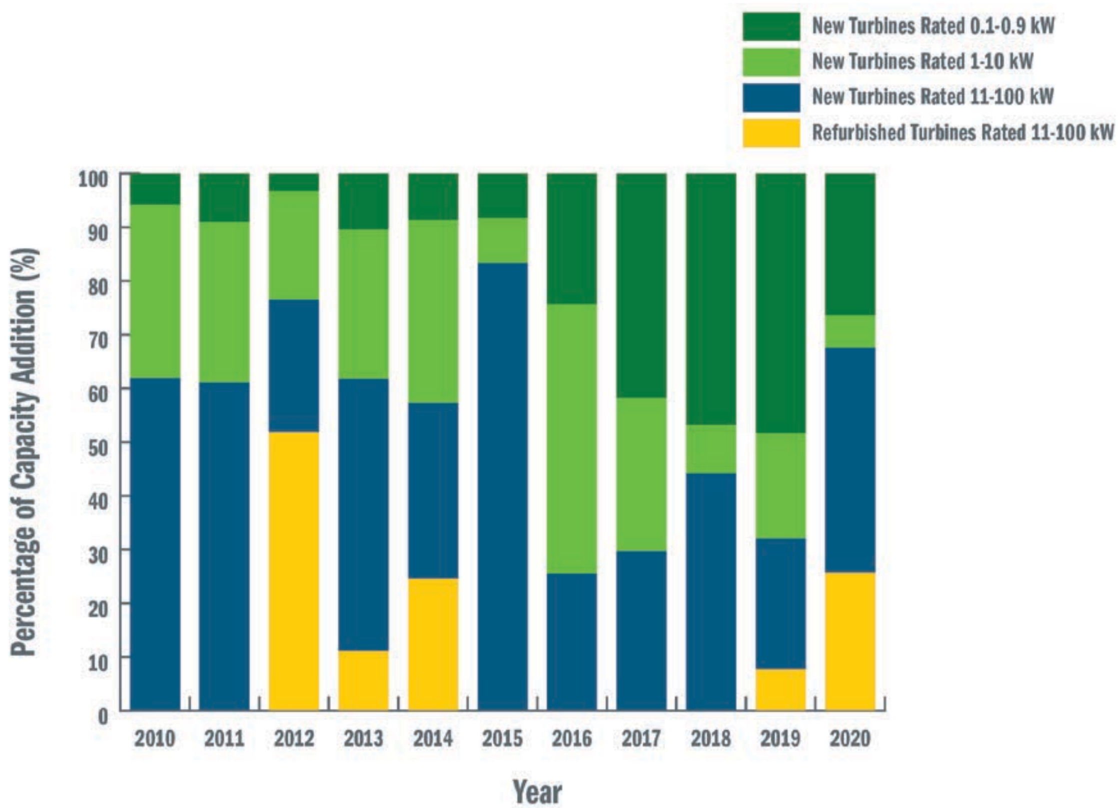

Figure 23. U.S. small wind sales percentage of capacity by turbine size, 2010–2020

While capacity deployment in all turbine size segments fluctuates from year to year, the variation is greater in the size segments of 1–10 kW and 11–100 kW. This yearly variation, segmented by small wind turbine size, is shown in Figure 22 and Figure 23. This variation is a result of 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 have reported that their customers are interested in the turbine size range of 1–5 kW, for which there is currently a market gap given the discontinuation of the Pika 1.7-kW T701 and the Xzeres 2.4-kW Skystream. Turbines in this size range 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). The decline in sales of turbine units in the size range of 1–10 kW may be partially attributed to the limited supply of turbines in this desired size range.

In 2020, newly manufactured turbines in the size segment of 11–100 kW accounted for the majority of deployed small wind capacity, at approximately 42%, followed by the less-than-1-kW segment at 26%, and trailed closely by refurbished turbines in the size range of 11–100 kW at just under 26% of the total 2020 deployed small wind capacity. This is up from 2019, when refurbished turbines rated 11–100 kW comprised approximately 8% of the total deployed small wind capacity. A total of five small wind projects used refurbished turbines in 2020—two as new installs and three as retrofits using refurbished turbines. One turbine was a refurbished Vestas 15 and the others were refurbished Endurance E-3120 wind turbine models. 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.

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 this report, VAWT models represent about 1% of U.S. small wind market turbine units and 0.3% of capacity for 2020, where most of these turbine units are in the less-than-1-kW size segment. This percentage is slightly lower than recent past years in which VAWT representation has been about 2%–6% of U.S. small wind capacity.

8.5 Type of Towers

From 2003 through 2020, the majority of documented distributed wind projects used self-supporting lattice and self-supporting monopole towers, representing 43% and 34% of projects that provided tower type information to PNNL, respectively. Self-supporting lattice towers are the most common in small distributed wind projects—deployed in 51% of all small wind projects reporting tower information—whereas 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 18 projects for which PNNL was able to collect tower type information in 2020, all used self-supporting structures, with 56% using lattice towers and the remaining 44% using monopole towers. A total of 13 of these projects were retrofits and a majority (69%) used new or refurbished turbines on preexisting lattice towers. This is consistent with historic data: of the 22 documented retrofit projects that provided tower type information to PNNL between 2013 and 2019, 77% used lattice towers—most of which were self-supporting (only three retrofit projects used guyed lattice towers). The remaining projects retrofitted new turbines on existing tilt-up, self-supporting, and guyed monopoles.

For projects using small wind turbines, reported hub heights in 2020 ranged from 30 to 40 m. For projects using turbines greater than 1 MW in size in 2020, hub heights were 80 m and 89 m.

9 Summary

This report documents trends and statistics for the U.S. distributed wind market, which varies year to year with respect to both customer types and deployment levels among and within the turbine size segments (i.e., small, mid-size, and large-scale). While this report's definition of distributed wind captures a range of wind technology applications—from a 400-W turbine on an oil and gas platform to a 2.82-MW turbine providing energy for a utility's distribution grid—market conditions, policies, and customer demands do not affect the different sectors of the distributed wind market uniformly.

Large-scale wind turbines continue to account for most of the distributed wind capacity additions, but changing policies (i.e., the repeated discontinuation and then reinstatement of the federal ITC and PTC) and project-development cycles have contributed to varying capacity additions from year to year for projects using turbines greater than 1 MW. Large-scale turbine projects, particularly for government, commercial, industrial, and utility customers, are likely to continue to dominate distributed wind capacity deployment.

The use of mid-size turbines (101 kW to 1 MW) remains limited. A limited number of mid-size turbines are commercially available, which may account for the lower level of deployment but also may account for the use of refurbished turbines in this size sector. The one mid-size turbine project in 2020 used a refurbished Danwin 160-kW turbine. Two of the four mid-size turbine installations in 2018 and 2019 also used refurbished turbines.

The U.S. small wind market has been steadily declining since a peak in 2012. However, small wind manufacturers and installers have reported a brighter outlook for 2021, given the role distributed energy can play in decarbonizing the U.S. economy and addressing energy security, grid resilience, and climate change challenges. In the future, as existing small wind turbines age and customers remain committed to wind as a distributed energy resource, retrofit reports are likely to increase.

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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 to PNNL via the data request process. Other companies that provided information, or only had sales outside of the United States, are recognized in the Acknowledgments section.

Table A.1. Wind Turbine Manufacturers and Suppliers

Manufacturers	Model Names	Headquarters
Small Wind Turbines (up through 100 kW)		
ARPS World	WT10	Minnesota
Bergey WindPower Company	Excel 10, Excel 15	Oklahoma
All Energy Management	Refurbished E-3120	Wisconsin
Eocycle Technologies, Inc.	EOX S-16	Canada
Hi VAWT Technology Corporation	DS300	Taiwan
Primus Wind Power	Air 40, Air Breeze, Air 30, Air X Marine, Air Silent X	Colorado
Star Wind Turbines	STAR74	Vermont
Ducted Wind Turbines, Inc.	D3 – Gen 2	New York
Large Wind Turbines (Greater than 100 kW)		
Danwin	Refurbished 23/160	Denmark
GE Renewable Energy	2.5-116, 2.3-116, 2.82-127	United States

Appendix B: Methodology

The Pacific Northwest National Laboratory (PNNL) team issued data requests to 340 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 sources listed in the Acknowledgments section) to tabulate the deployed United States and exported distributed wind capacity and associated statistics as of the end of 2020. 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.

A project dataset was created to capture all known projects installed in 2020. For distributed wind projects using turbines greater than 100 kW, the PNNL team reviewed the data request responses and other resources to assess projects on a per-project basis to determine if 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 WindIQ database, the Federal Aviation Administration, the U.S. Wind Turbine Database, and the U.S. Energy Information Administration. 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. Projects reported for 2020 were cross-checked against previous records to avoid double counting.

This report defines distributed wind as a distributed energy resource providing electricity for a specific or 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.

All records were compiled in the project dataset with a row for each 2020 project reported. 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 2020 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 2020 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 turbines 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 2020.

Cross-referencing data sources allows for greater certainty, but a data gap remains with respect to the tally of turbine units and capacity deployed compared to the small wind sales records because the majority of small wind turbine units sold, mainly the off-grid turbine units, are not tracked on a project-level basis, so PNNL is unable to include them in the project dataset.

Project records collected for this report, and from past years, have been consolidated to produce a master project dataset. In 2020, PNNL reviewed all projects in this master project dataset to confirm they meet the report's distributed wind definition of providing electricity for a specific or local load. This review removed some front-of-meter projects previously thought to have met the definition of distributed wind and reassigned some project classifications (e.g., from front of meter to behind the meter) because better information was identified during the review.

In addition, when the PNNL team identifies projects installed in past years that were not previously recorded, they are added to this master project dataset. When known, decommissioned turbines are removed from the dataset, but the cumulative figures principally represent annual capacity additions, rather than confirmed operating installations.

As a result of the 2020 review and the process of making updates to the master project dataset when new information is available, the cumulative capacity amounts presented in this report differ from previous reports, and capacity allocations by state and by year will continue to differ slightly from report to report. The 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 the projects using turbines greater than 100 kW, the PNNL team and the Lawrence Berkeley National Laboratory team, authors of the annual Wind Technologies 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 estimated the 2020 investment values using this reported installed cost data and made estimates based on past projects and PNNL's Benchmarking U.S. Small Wind Costs report when needed.

For the international small wind presentation, requests 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 other providing estimates.

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

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)

Past LCOE calculations referenced in Section 7.0 used the following formula:[23]

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

where
- FCR = fixed charge rate = (0.05), assuming a 25-year loan at 1.3% interest and a 35% tax rate
- ICC = installed capital cost ($)
- O&M = annual O&M cost ($)
- AEPnet = net annual energy production (kWh/yr)

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

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Cover details: A new Bergey Excel 15 wind turbine is retrofitted on a self-supporting lattice tower located at a private residence in western North Carolina. Photo courtesy of Jordan Nelson / Nelson Aerial Productions.