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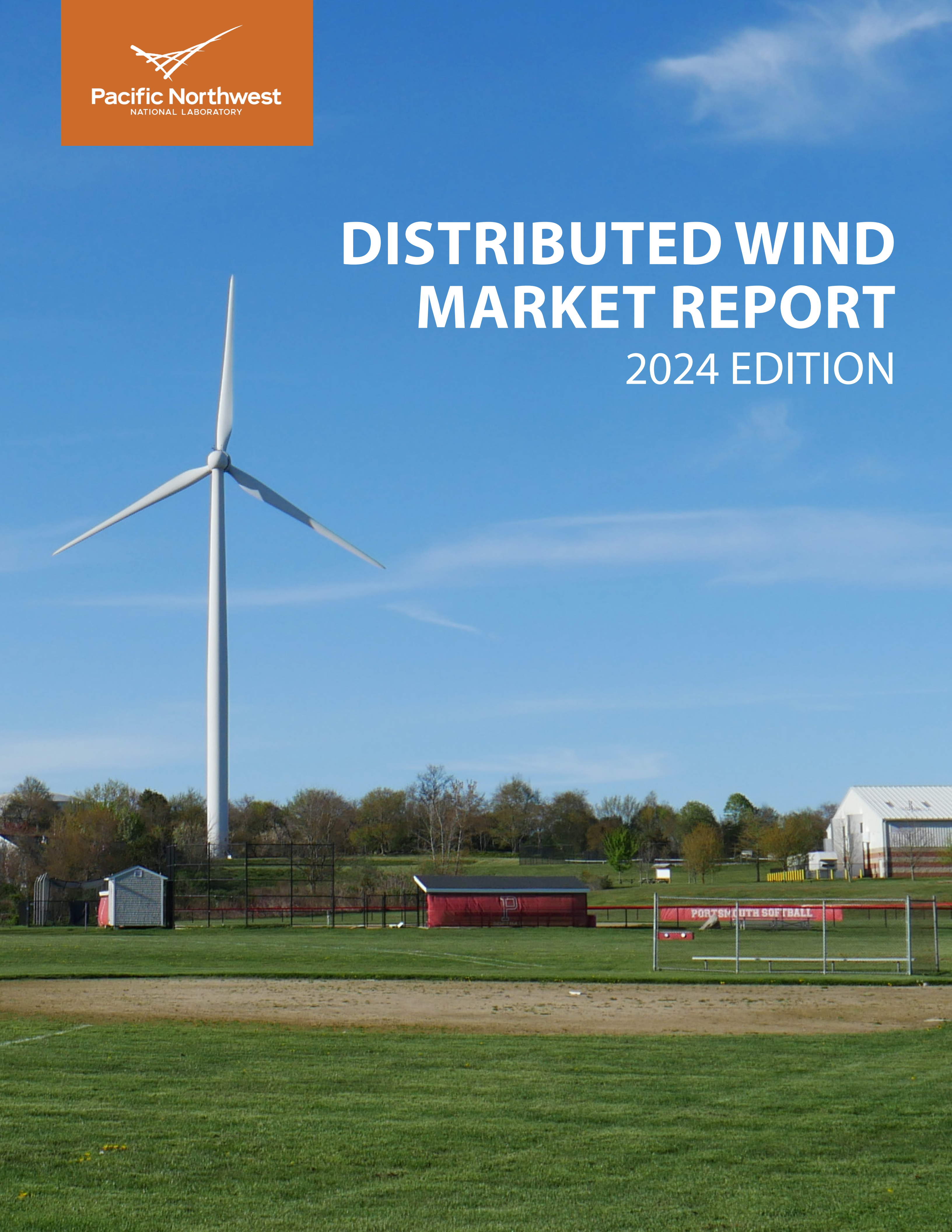

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List of Acronyms

ACP	American Clean Power Association
ANSI	American National Standards Institute
AWEA	American Wind Energy Association
CIP	Competitiveness Improvement Project
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
FAA	Federal Aviation Administration
ft	foot/feet
GE	General Electric
GW	gigawatt(s)
ICC–SWCC	International Code Council–Small Wind Certification Council
IEC	International Electrotechnical Commission
IRA	Inflation Reduction Act
IRS	U.S. Internal Revenue Service
ITC	investment tax credit
kW	kilowatt
kWh	kilowatt-hour(s)
LCOE	levelized cost of energy
m	meter(s)
m/s	meter(s) per second
mph	mile(s) per hour
MW	megawatt(s)
NPS	Northern Power Systems
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O&M	operations and maintenance
PNNL	Pacific Northwest National Laboratory
PTC	production tax credit
PV	photovoltaic
RAISE	Rural and Agricultural Income & Savings from Renewable Energy
REAP	Rural Energy for America Program
SGIP	Self-Generation Incentive Program
USDA	U.S. Department of Agriculture
WETO	U.S. Department of Energy’s Wind Energy Technologies Office

Executive Summary

The annual Distributed Wind Market Report provides stakeholders with market statistics and analysis along with insights into market trends and characteristics for wind technologies used as distributed energy resources. This report presents the distributed wind market in the United States from 2003 through 2023. Key findings with respect to installed capacity, deployment trends, customer types, incentives, policies, installed costs and performance, and the future outlook are presented below.

Installed Capacity

Cumulative U.S. distributed wind capacity installed from 2003 through 2023 now stands at 1,110 megawatts (MW) from over 92,000 wind turbines across all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, the Northern Mariana Islands, and Guam. Distributed wind turbines are connected at the distribution level of an electricity system, or in off-grid applications, to serve specific or local loads.

In 2023, 16 states added 10.5 MW of new distributed wind capacity from 1,999 turbine units, representing $37 million in investment. This is an increase in the number of turbines and states and a decrease in capacity and investment from the 29.5 MW of deployed capacity across 13 states from 1,755 turbines representing $84 million in investment in 2022 and the 11.7 MW in 15 states from 1,751 turbine units representing $41 million in investment in 2021.

Of the 10.5 MW installed in 2023, 7.3 MW (69.5%) came from distributed wind projects using large turbines (greater than 1 MW in size). A total of 0.9 MW (8.6%) of capacity came from projects using midsize turbines (101 kilowatts [kW] to 1 MW in size) and 2.3 MW (21.9%) came from projects using small wind turbines (up through 100 kW in size). Annual trends in total distributed wind capacity and investment are mainly driven by distributed wind projects using large turbines, of which installations can be variable from year-to-year due to their project development timelines.

Ohio, Illinois, and Alaska led the United States in new distributed wind capacity additions. One large project each in Ohio and Illinois and one midsize project in Alaska collectively represent 78% of the distributed wind capacity installed in 2023. One Energy Enterprises LLC installed a 4.5 MW project for a Martin Marietta lime manufacturing plant in Ohio. Rivian installed a 2.8 MW project in support of their manufacturing plant in Normal, Illinois. The Alaska Village Electric Cooperative added a 0.9 MW project to serve the Stebbins and St. Michael communities in Alaska.

Oklahoma and Alaska added the most small wind capacity in 2023. Oklahoma added 210 kW of small wind capacity across 12 agricultural and rural small business enterprises, all of which received U.S. Department of Agriculture (USDA) Rural Energy for America Program (REAP) investment. Alaska added 200 kW from two Northern Power Systems turbines installed to help power a drilling company’s warehouse on the North Slope of Alaska.

Deployment Trends

General Electric (GE) Renewable Energy remains the only consistent U.S.-based manufacturer of large turbines used in distributed wind projects over the past 10 years. Between 2014 and 2023, 133 MW of distributed wind capacity from GE Renewable Energy wind turbines have been deployed to support industrial, agricultural, utility, institutional, government, and commercial applications in eight states. GE Renewable Energy, Goldwind, and EWT Americas LLC provided turbines with capacities greater than 100 kW for distributed wind projects installed in 2023.

In 2023, 89% of installed distributed wind project capacity was deployed to provide energy for on-site use and 11% of capacity was for projects interconnected to a distribution grid to provide energy for local use. Historically, projects for local use have typically represented more of the installed distributed wind capacity due to the projects' larger sizes and use of larger turbines. The year 2023 marks a departure from this trend due to two large on-site use projects supporting industrial loads.

Customer Types

In 2023, projects for commercial customers accounted for 42% of the number of all projects installed, followed by agricultural customers at 34% of all projects installed in 2023. Institutional customers, including universities, represented approximately 11% of projects installed in 2023, while industrial and utility customers represented 8% and 5% of the number of projects installed, respectively. No residential or government projects were documented in 2023. This marks a shift from historical trends, as agricultural and residential customers have collectively accounted for 60% or more of the number of projects deployed annually in most years since 2014.

Distributed wind deployed for industrial customers represented the largest share of total distributed wind capacity installed in 2023, accounting for 83% of the documented capacity, compared to 20% in 2022 and 25% in 2021. Utility customers represent the second largest percentage of distributed wind capacity installed in 2023, accounting for 10% of total capacity.

Incentives and Policies

Distributed wind projects across ten states received a total of $12.4 million in state-level incentives, state-level production tax credits (PTCs), and USDA REAP grants in 2023. This is more than double the $5 million paid across eight states in 2022 and 2021.

State-level incentive payments substantially increased in 2023 with five awards totaling $6.9 million, after no state programs reported incentive payments in 2022 and two awards totaling $0.3 million were reported in 2021. The California Self-Generation Incentive Program (SGIP) accounted for all state-level incentive payments in 2023.

In 2023, USDA REAP awarded $3.4 million in grants to 40 wind projects in nine states, of which $2.4 million was awarded to 39 distributed wind projects in eight states. The 2023 funding amount was substantially greater than the $1.1 million in wind grants awarded in 2022 to 12 projects in six states and the $0.7 million in wind grants awarded in 2021 to 22 projects in five states. The increase in funding can largely be attributed to the Inflation Reduction Act (IRA) initiative, which aims to curb inflation by a number of means, including investing in domestic energy production. A total of 88% of REAP wind grants awarded and 88% of grant funding were part of the IRA initiative.

Distributed wind projects received $3.1 million in state-level PTCs in 2023. The projects that received state-level PTCs in 2023 are located in Iowa and New Mexico.

Installed Costs and Performance

The average capacity-weighted installed cost for new small wind projects from 2014 through 2023 was $11,410/kW. Installed costs for small wind projects have decreased over the last decade. For new small wind projects installed in 2023, the average capacity-weighted installed cost was $7,370/kW based on the five projects using five wind turbines in two states with a combined rated capacity of 131.2 kW.

The average capacity-weighted installed cost for projects using midsize and large turbines for 2014 through 2023 was $4,160/kW. No costs were provided for projects using midsize and large turbines installed in 2023.

The average net capacity factor in 2023 for a sample of 100 small wind projects was 13%. Observed capacity factors cover a wide range up to 28% for the sample, which totals 1.3 MW in rated capacity.

The average net capacity factor in 2023 for a sample of distributed wind projects using midsize and large turbines was 21%. Observed capacity factors cover a wide range up to 47%. The sample includes 36 distributed wind projects installed from 2005 to 2021, across 15 states, totaling 117 MW in combined capacity with turbine nominal capacities ranging from 600 kW to 3 MW.

Only 13% of the distributed wind projects that Pacific Northwest National Laboratory (PNNL) analyzed had higher net capacity factors in 2023 compared to 2022. This can largely be attributed to 2023 being a weaker wind resource year in many regions of the continental United States. Of the 104 distributed wind projects using turbines of all sizes that PNNL analyzed, a total of 14 had capacity factors in 2023 that exceeded their capacity factors in 2022. A total of 75 projects underperformed in 2023 relative to their capacity factors in 2022, and the remaining 15 projects performed similarly between the two years.

Future Outlook

The Rural and Agricultural Income and Savings from Renewable Energy (RAISE) initiative, a joint initiative between USDA and the U.S. Department of Energy (DOE), was launched in February 2024 to help farmers cut costs and increase income through REAP-supported distributed wind projects. The RAISE initiative includes an initial $4 million investment from DOE to test and commercialize distributed wind technologies and develop business models that allow farmers to earn revenue from deploying these technologies. USDA has set an initial goal to help 400 individual farmers install distributed wind turbines through the RAISE initiative. In support of RAISE, DOE is supporting research focused on innovative distributed energy resource business models for rural electric cooperatives. This could have a significant influence on the rural and agricultural market segments in the coming years.

Significant activity and investment in the U.S. small wind market in 2023 indicates there may be increasing development in the sector in upcoming years. Ryse Energy, an international small wind turbine manufacturer, acquired U.S.-based Primus Wind Power in 2023, springboarding the launch of a new manufacturing facility in Texas in late 2023. In early 2023, Wind Resource LLC purchased the Skystream turbine model line and recertified the Skystream 3.7, signaling an appetite to fast-track domestic sales presence. The nonprofit SWAN Impact Network, a backer of start-ups, invested in Pecos Wind Power’s 85 kW turbine in early 2023.

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1 Introduction

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

Distributed wind turbines are distributed energy resources connected at the distribution level of an electricity system or in off-grid applications to serve specific or local loads. Distributed wind installations can range from a less-than-1-kilowatt (kW)[1] off-grid wind turbine at a remote cabin or telecommunications 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.

In most cases, individuals, businesses, and communities install distributed wind to offset retail power costs. However, consumers also install distributed wind to secure long-term power cost certainty, support grid operations and local loads, help meet decarbonization goals, and electrify remote locations and assets not connected to a centralized grid.

1.1 Purpose of Report

The Pacific Northwest National Laboratory (PNNL) team produces the annual Distributed Wind Market Report as part of DOE's Wind Energy Technologies Office (WETO) Distributed Wind Research Program. The program 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 contains analysis on 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 industry members understand and access market opportunities and inform distributed wind 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 (see Section 8.2). Grid-connected turbines are typically either behind-the-meter (to provide electricity for on-site use) or front-of-meter (to provide electricity for local use) installations.[2] A behind-the-meter wind turbine is always connected to the local distribution grid behind a customer's utility meter—typically to offset all or some of the on-site energy needs. Behind-the-meter wind turbines displace retail electricity demand and can be net-metered to credit excess output flowing back onto the grid. A wind turbine connected to a distribution grid as a generation resource is considered a front-of-meter installation. Front-of-meter wind projects provide energy and grid support to the distribution system and help serve the interconnected local loads on the same distribution system.

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

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

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

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

1.3 Wind Turbine Size Classifications

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

- Small wind turbines have nominal capacities up to and including 100 kW.[3]
- Midsize wind turbines have nominal capacities of 101 kW to 1 megawatt (MW).
- Large wind turbines have nominal capacities of greater than 1 MW.

For projects using all sizes of wind turbines, the project's total nominal power capacity is used in this report's installed capacity calculations. For projects using midsize and large turbines, 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) Small Wind Turbine Performance and Safety Standard 9.1-2009 or the American National Standards Institute (ANSI)/American Clean Power Association (ACP) 101-1-2021 Small Wind Turbine Standard.[5] For uncertified small wind turbines, the power output at 11 m/s is assigned as the turbine's rated, or referenced, capacity.

The turbine manufacturers and models used in distributed wind projects recorded for 2023 are listed in Appendix A. Rated capacities for the small wind turbine models included in this report are listed in Appendix B.

1.4 Data Collection, Categorization, and Analysis Methodologies

To collect data on distributed wind installations, sales, and related activities that occurred in calendar year 2023, the PNNL team issued data requests to small wind turbine manufacturers, suppliers,[6] developers, installers, and operations and maintenance (O&M) providers; distributed wind project developers; state and federal agencies; utilities; and trade associations. Additionally, data were reviewed from other sources for distributed wind projects using midsize and large turbines. This report includes data from past data requests and presents the distributed wind market from 2003 through 2023. In some cases, analyses use different periods within that range because of data availability and quality.

The PNNL team created a project dataset to capture all projects installed in 2023 identified through the data-request and data-review process. That dataset has been added to those created for past years to create a master project dataset that is available (with free registration) on PNNL's Distributed Wind Data website.

The master project dataset is regularly updated when new information becomes available. For example, when projects installed in past years but not previously recorded are identified, the team adds those projects to the

[3] The U.S. Internal Revenue Service (IRS) also defines small wind as up through 100 kW for the purpose of federal small wind 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, rated capacities for small wind turbines are used in this report's per-kW analyses to provide a consistent baseline. For turbines greater than 100 kW, the turbine's nameplate capacity matches the turbine's pitch-regulated maximum power output, allowing the nameplate capacity to be the consistent baseline.
[5] Small wind turbine standards are discussed in Section 4.2.4.
[6] In relation to manufacturers, suppliers provide refurbished turbines.

master project dataset. Those updates are then included in the current year's report figures and analyses. Further, turbines confirmed to be decommissioned in the dataset are marked as such, but decommissioning is not actively tracked, so the team cannot guarantee that only operating projects are included in the project dataset. Consequently, the cumulative capacity amount presented in this report and capacity allocations by state and year represent deployed capacity and may differ slightly from report to report. The master project dataset makes year-to-year comparisons; allocates capacity amounts across states; analyzes installed costs; identifies incentive funding levels; and characterizes distributed wind customers, types of turbines and towers, and project applications.

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

Many small wind turbine units sold are not tracked at the project level, such as off-grid turbine units sold by the manufacturer to distributors for resale to end users. As a result, the PNNL team is unable to include them in the master project dataset. Each year's reported annual deployed capacity is a combination of the small wind sales and the installed projects using midsize and large turbines installed in that year.

Appendix B provides additional details about data collection, categorization, and analysis methodologies.

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

2 U.S. Distributed Wind Deployment

From 2003 through 2023, over 92,000 wind turbines have been deployed in distributed applications across all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, the Northern Mariana Islands, and Guam, totaling 1,110 MW in cumulative capacity, as shown in Figure 1.[8]

In 2023, 16 states added 10.5 MW of new distributed wind capacity from 1,999 turbine units, representing $37 million in investment.[9] This is a decrease from 2022, when 29.5 MW of capacity was deployed across 13 states from 1,755 turbine units representing $84 million in investment. The U.S. distributed wind market in 2023 was similar to 2021, when a total of 11.7 MW of capacity was deployed across 15 states from 1,751 turbine units representing $41 million in investment.

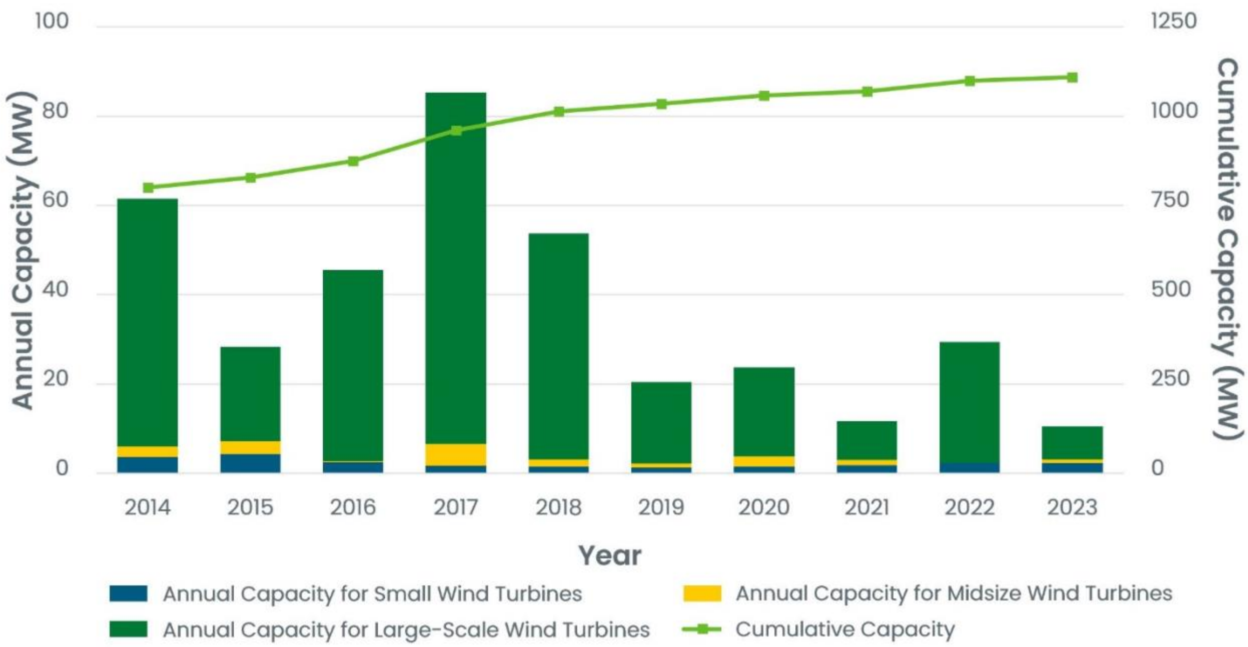

Figure 1. Distributed wind capacity in the United States

2.1 Top States for Distributed Wind: Annual and Cumulative Capacity

New distributed wind projects were documented in 16 states (i.e., Alaska, Colorado, Iowa, Illinois, Kansas, Maryland, Massachusetts, Minnesota, Montana, New York, Ohio, Oklahoma, Utah, Vermont, Virginia, and Wisconsin) in 2023 and have been documented in all 50 states, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, the Northern Mariana Islands, and Guam since 2003, as shown in Figure 2.

[8] The data presented in the figures are provided in an accompanying data file available for download at https://energy.gov/windreport.

[9] All dollar values are nominal unless otherwise noted. Annual and cumulative capacity amounts are based on nameplate turbine capacity sizes.

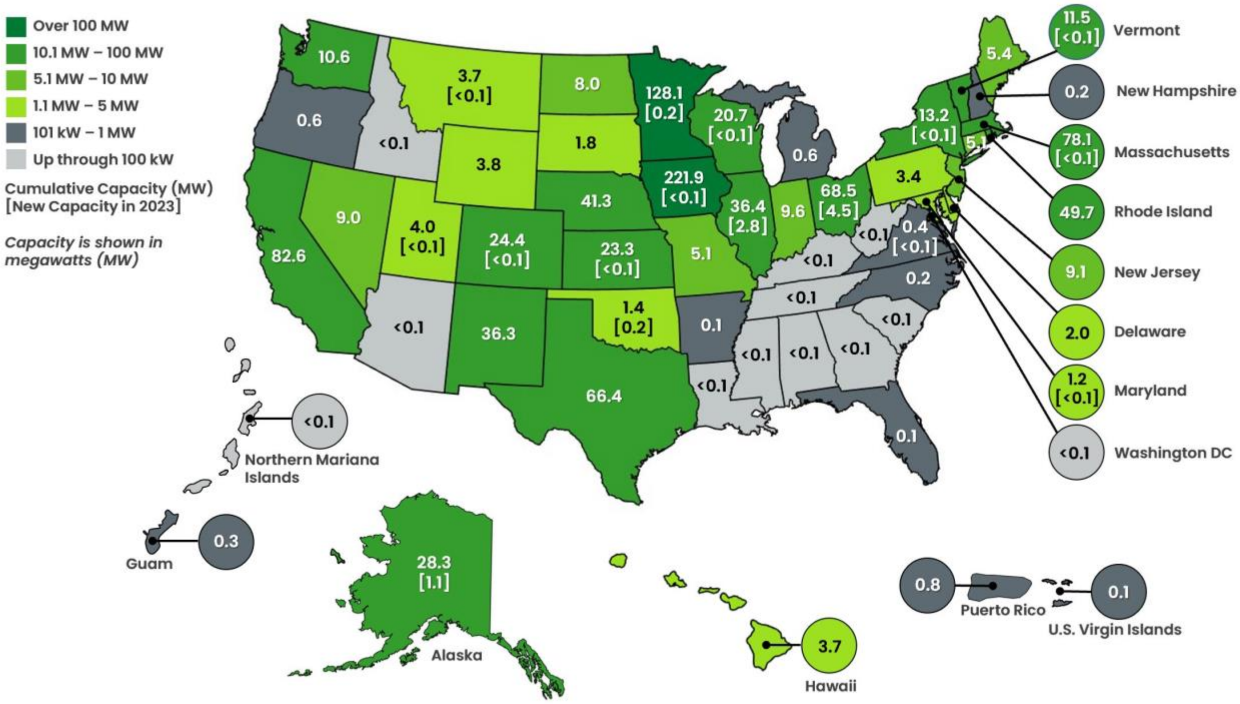

Figure 2. U.S. cumulative (2003–2023) capacity and capacity additions in 2023 for distributed wind by state

Ohio, Illinois, and Alaska led the United States in new distributed wind power capacity in 2023. This is because of one large project each in Ohio and Illinois and one midsize project in Alaska. In the industrial sector, One Energy Enterprises LLC installed a 4.5 MW project for a Martin Marietta lime manufacturing plant in Ohio (Henry 2023). Rivian installed a 2.8 MW project in support of their manufacturing plant in Normal, Illinois (Rivian 2023). And the Alaska Village Electric Cooperative added a 0.9 MW project to serve the communities of Stebbins and St. Michael in Alaska (Stein 2023). These projects collectively represent 78% of the distributed wind capacity installed in 2023.

The concentration of a few projects using large turbines in a few states can mainly be attributed to the project development cycles of a handful of developers. Because each company works almost exclusively in a single state or region rather than nationally, except for ConEdison Development,[10] annual distributed wind capacity additions can be concentrated in a few states. Project developers, namely Juhl Energy in Minnesota; One Energy Enterprises LLC (One Energy) in Ohio; Green Development, LLC in Rhode Island; Foundation Windpower in California; Optimum Renewables in Iowa; WES Engineering in Minnesota and Wisconsin; and Bluestem Energy Solutions in Nebraska, may not install new projects every year, as shown in Figure 3, because each project can take at least 2 to 4 years to develop (ACP 2022). The eight developers highlighted in Figure 3 have accounted for 87% of the distributed wind capacity from projects using midsize and large turbines each year since 2018. The "other" category in Figure 3 primarily includes project owners (e.g., universities and municipalities), other third-party developers with a less consistent presence, and unknown developers.

[10] PNNL has documented distributed wind projects installed by ConEdison Development in Minnesota, Massachusetts, and Iowa. The company was acquired by RWE, a European energy company, in 2022 (RWE 2022).

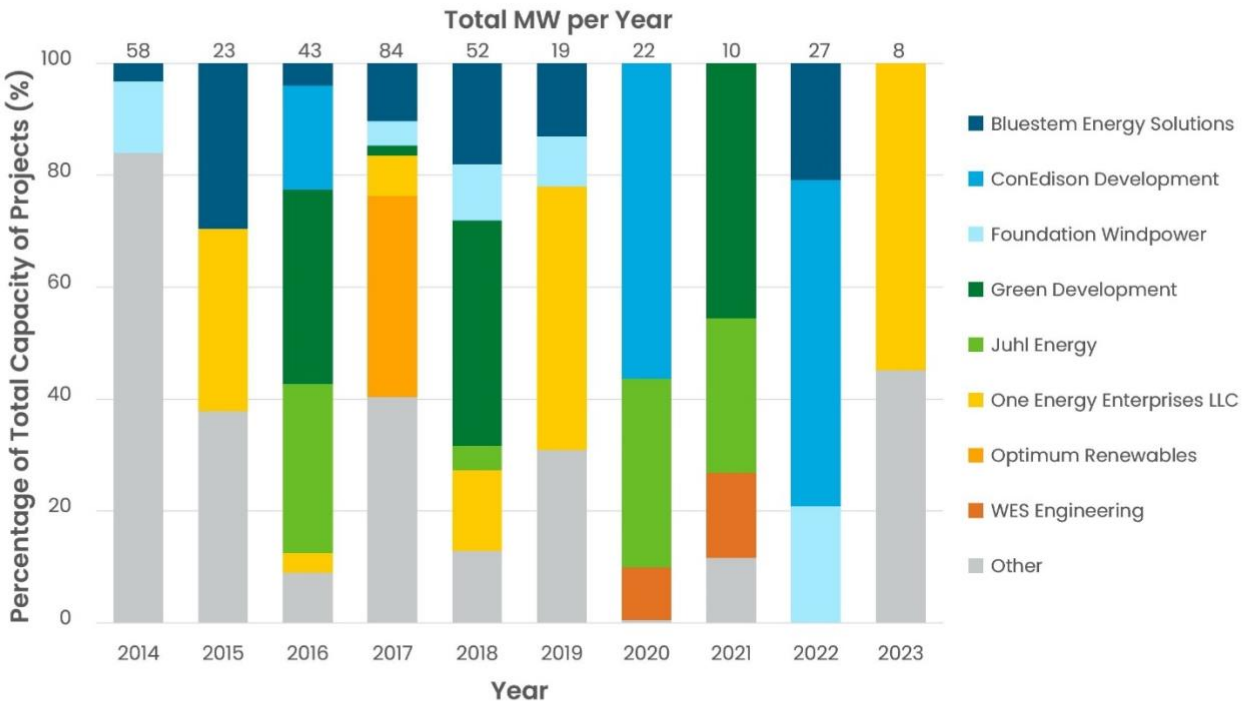

Figure 3. Project developers using midsize and large turbines, 2014–2023

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 small wind capacities greater than 2 MW.

Iowa and Minnesota lead all the states in cumulative capacity from 2003 through 2023, with both states exceeding 100 MW, as shown in Figure 4. Both states have strong wind resources and active project developers. Both states have also received the largest share of U.S. Department of Agriculture (USDA) Rural Energy for America Program (REAP) funding for wind projects since 2003 (see Section 4.1.3).

Iowa, Alaska, and Nevada are the top three states for cumulative small wind capacity, as shown in Figure 5, although there were no new small wind installations recorded for Nevada in 2023. Oklahoma added the most small wind capacity in 2023 with 210 kW across 12 projects that were supported by USDA REAP investment in 2023 (see Section 4.1.3). Alaska followed with 200 kW from two Northern Power Systems turbines that were installed to help power a drilling company's warehouse on the North Slope of Alaska (DeMarban 2023).

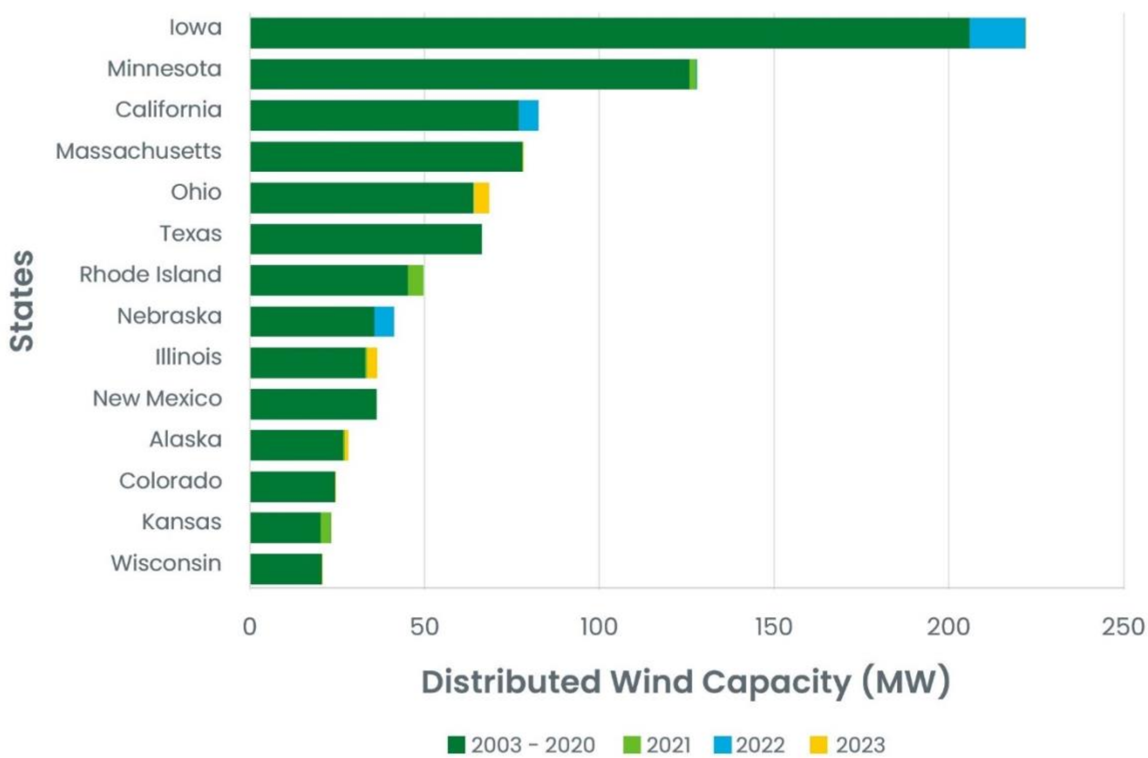

Figure 4. States with distributed wind capacity greater than 20 MW, 2003–2023

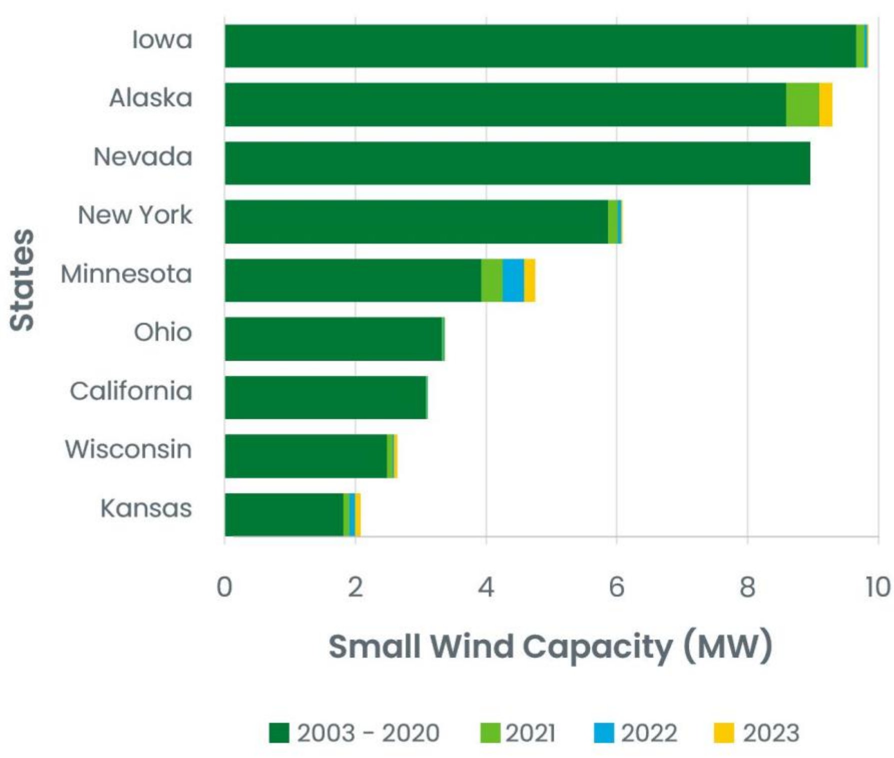

Figure 5. States with small wind capacity greater than 2 MW, 2003–2023

2.2 Project Development Timelines

In 2023, four distributed wind projects reported their project development timelines from first customer contact to project commissioning. The project development timeline lengths ranged from 10 months to 4 years, with an average project length of nearly 2 years. All four projects were developed using small wind turbines and ranged from 5 to 200 kW in project size.

For last year's edition of the Distributed Wind Market Report, project development timelines were estimated for projects installed from 2016–2022 by evaluating key timeline milestones found in project records sourced from the Federal Aviation Administration (FAA) database, the NYSERDA Small Wind Turbine Incentive Program, and the California Self-Generation Incentive Program (SGIP). The 2016–2022 timelines did not begin with first customer contact and therefore are informative but not representative of full project development cycles. In the FAA records, the average timeline was 1.2 years from notice of construction to when the tower was erected. In the NYSERDA filings, the average timeline was 1.3 years from incentive application date to turbine interconnection date. As per the California SGIP records, the average timeline from incentive application date to turbine interconnection date was 1.9 years, but the California SGIP records notably had a much smaller sample size of projects than the other records and were comprised solely of large turbines (Orrell et al. 2023). In comparison, all four reported projects from 2023 are small turbines. The average project timeline of nearly 2 years for 2023 is higher than those from 2016–2022. This is to be expected though, as the 2016–2022 timelines are estimates from project dates that don't span the entire development timeline.

An additional 2023 project using a midsize turbine reported their timeline from turbine procurement to commissioning (which did not include the time from first customer contact to turbine procurement) as 3 years. This project included additional details in their timeline, including the time from setting the turbine foundation to the commissioning of the project being 1 year. The detailed timeline of this 2023 midsize project is comparable to some of the estimated 2016–2022 timelines, particularly the 1.2-year average timeline from notice of construction to when the tower was erected utilized for the FAA estimate.

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

As shown in Figure 1, 7.3 MW of the 10.5 MW of distributed wind added in 2023 came from projects using large turbines (69%), 0.9 MW came from projects using midsize turbines (9%), and 2.3 MW came from small wind (22%).

3.1 U.S. Midsize and Large Wind Turbine Market

In 2023, 7.3 MW of distributed wind using large turbines were deployed in the United States from two projects using four turbine units, representing $17 million in investment.[11] This is a decrease from 27.2 MW from four projects using 10 large turbine units representing $69 million in investment in 2022 and 8.7 MW from three projects using five large turbines representing $30 million in investment in 2021.

In the midsize turbine market, 0.9 MW of distributed wind were deployed in the United States in 2023 from one project using one midsize turbine unit representing $5 million in investment. There were no reported distributed wind projects in 2022 that used midsize turbines. In 2021, a total of 1.2 MW of midsize capacity from three projects using four turbines was deployed representing $2 million in investment. The greater amount of investment for the 2023 midsize project is due to the project's location in Alaska, where materials and personnel are more challenging to transport.

Projects using midsize turbines have regularly represented a small part of the distributed wind market in recent years. This limited market share can be attributed to the limited number of midsize turbine models available and the expectation that larger turbines can be more cost-effective (although refurbished[12] midsize turbines can have lower capital costs compared to newly manufactured midsize turbines as discussed in Section 5.2). Added capacity from midsize turbines has been under 5 MW annually since 2013 and has consisted of predominantly single-turbine projects.

However, the midsize turbine market continues to see interest both from manufacturers and DOE research and development investment. One midsize turbine from India-based Siva Wind was installed in 2021 and Siva Powers America, the U.S. subsidiary of Siva Wind, plans to open a $2.5 million manufacturing facility in New York with an anticipated 15 full-time jobs with construction expected to begin in the latter half of 2024 (Anderson 2023; Joe 2023; Kasthurirangan 2024). In addition, the WETO-funded Competitiveness Improvement Project (CIP) (explained in Section 4.2.3) has funded research relevant to midsize turbines to improve turbine model design, performance, and costs. CIP awards issued for the 2022–2023 period are supporting Carter Wind Turbines (Oklahoma) to develop a taller tower for its 300 kW turbine, RRD Engineering (Colorado) to pursue development of a 150 kW turbine, and Windurance LLC (Pennsylvania) to design a modular energy storage solution for a wide range of distributed wind turbine sizes up to 160 kW (NREL 2023a). In February 2024, a request for proposals was announced for the CIP to provide more funds to support the commercialization of small and midsize turbines (Laurie 2024).

Manufacturer representation in distributed wind projects in the United States changes from year-to-year, and the midsize and large turbine markets often rely on imports. However, some manufacturers are consistently represented in distributed wind projects, and manufacturer representation is tied to the developer's project-development cycle, as featured in Figure 3. General Electric (GE) Renewable Energy has been the only consistent U.S.-based[13] manufacturer of large turbines used in distributed wind projects over the past 10 years and is the turbine provider for Foundation Windpower, Bluestem Energy Solutions, ConEdison Development,

[11] This investment value reflects the estimated installed cost of the deployed capacity, not just the turbine hardware costs. The same is true for the midsize wind investment value presented in Section 3.1 and the small wind investment value presented in Section 3.2.
[12] 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.
[13] U.S.-based means the manufacturer or supplier has headquarters in the United States.

and Juhl Energy's most recent projects. Between 2014 and 2023, 133 MW of distributed wind capacity from GE Renewable Energy wind turbines have been deployed to support industrial, agricultural, utility, institutional, government, and commercial applications in eight states. China-based turbine manufacturer Goldwind has been the turbine supplier for One Energy Enterprises LLC, and Green Development uses turbine models from the Germany-based manufacturer Vensys.

Developers, particularly those that also operate the distributed wind projects they build and sell the power through power purchase agreements to customers, report that they source all of their wind turbines from one manufacturer to facilitate easier O&M across their fleet of projects. This sole sourcing allows them to train workers, build spare parts and consumables inventories, and remotely monitor the fleet based on only one manufacturer's turbine models.

Manufacturers who deployed turbines in 3 or more years are shown separately in Figure 6. Manufacturers who deployed turbines in fewer than 3 years in the 10-year period shown in Figure 6 are grouped in the "other" category. A total of 26 manufacturers and suppliers provided midsize and large turbines for distributed wind projects in 2012, a peak year for distributed wind capacity additions, compared to three in 2023, one in 2022, and six in 2021. In Figure 6, three manufacturers are represented in the "other" category in 2021 (compared to 20 "other" manufacturers in 2012).

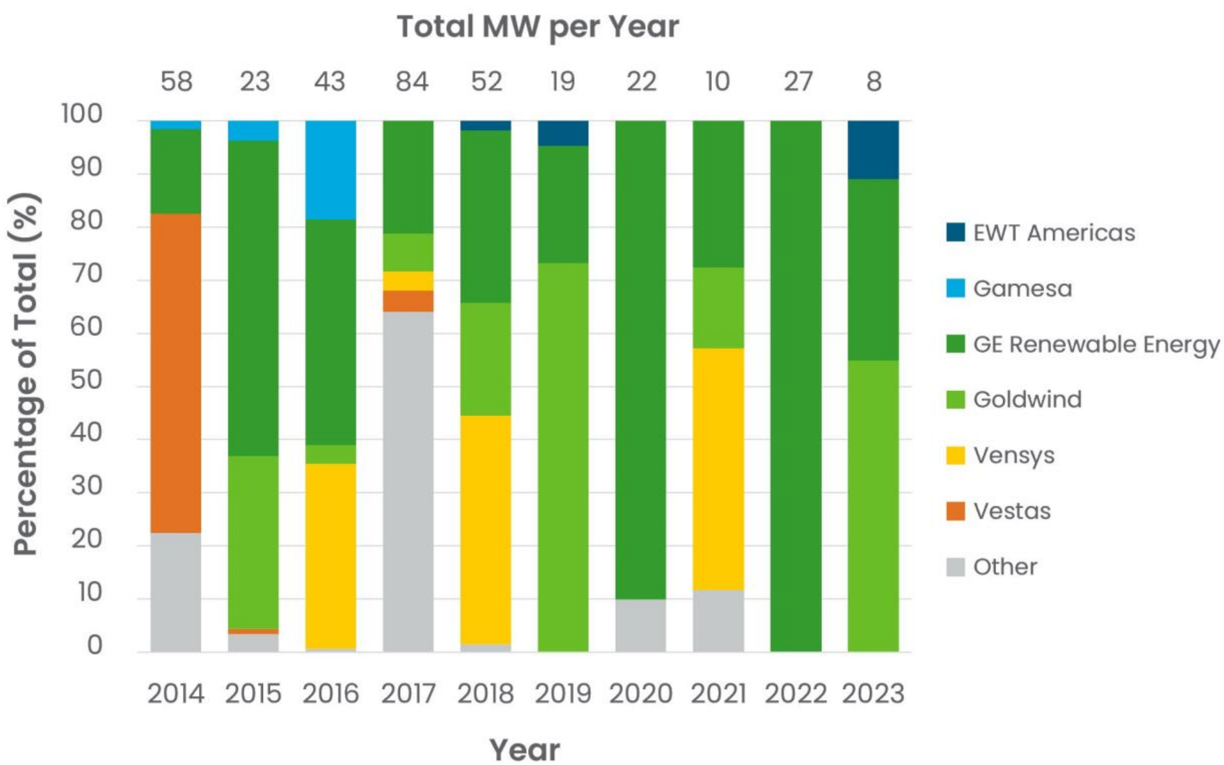

Figure 6. Wind turbine manufacturers of midsize and large turbines with a U.S. sales presence, 2014–2023

3.2 U.S. Small Wind Market

In 2023, 2.3 MW of small wind were deployed in the United States from 1,994 turbine units representing $15.2 million in investment. While the capacity and investment amounts are relatively consistent with 2022 (2.3 MW from 1,745 turbine units representing $14.6 million), these values are up from the 1.8 MW from 1,742 turbine units representing $9.2 million in 2021. All domestic small wind manufacturers and suppliers who responded to PNNL's data request reported higher sales in 2023 compared to 2022.

Since 2012, when a total of 31 small wind turbine manufacturers had reported U.S. sales in 2012, the number of small wind turbine manufacturers both operating and participating in the U.S. market has generally been on the decline. Some small wind manufacturers do not have consistent sales from year to year, some go out of business, and some—particularly foreign manufacturers—focus on other countries with policies more supportive of distributed wind. Additional factors causing the market contraction include the unstable policy environment in the United States and competition from solar photovoltaic (PV) systems.

Eight small wind turbine manufacturers or suppliers reported sales in 2023 for this report (listed in Appendix A) and consist of six domestic manufacturers with their headquarters in five states (i.e., Florida, Minnesota, New York, Oklahoma, and Texas) and two foreign manufacturers. This is equal to the eight manufacturers or suppliers (six domestic, two foreign) that had a U.S. sales presence in 2022, but down from 13 manufacturers or suppliers (nine domestic and four foreign) who reported sales in 2021.

Bergey Windpower Co. of Oklahoma, Eocycle Technologies, Inc. of Canada, and Northern Power Systems of Italy were the top three small wind turbine manufacturers with respect to capacity (MW) sold in the U.S. market in 2023.

Some small wind turbine manufacturers reported that pandemic-related supply chain constraints and increased costs for raw materials were still factors affecting their businesses in 2023. But with extended incentives in the Inflation Reduction Act (IRA) of 2022 (enacted as Public Law 117-169 on August 16, 2022), the expanded USDA REAP (see Sections 4.1.2 and 4.1.3), and the newly-announced USDA and DOE Rural and Agricultural Income & Savings from Renewable Energy (RAISE) initiative (USDA 2024) (Section 10), small wind turbine manufacturers are expecting higher sales in 2024.

Three small wind turbine manufacturers have recently focused efforts on expanding U.S. market penetration—Ryse Energy, Northern Power Systems (NPS), and Wind Resource, LLC—the latter two of which have returned to the U.S. market after leaving in 2019. Ryse Energy, an international small wind turbine manufacturer, acquired U.S.-based Primus Wind Power in 2023, springboarding the launch of a new manufacturing production facility in Texas in late 2023 (Ryse Energy 2023). NPS has also aimed to increase U.S. market penetration, now operating under a new U.S. subsidiary, NPS Solutions LLC, owned by the Italian parent organization, NPS Srl. NPS will continue to manufacture its turbines in Italy until a sales volume can justify bringing manufacturing back to the United States. Part of the company's market re-introduction strategy includes completing certification to UL 1741 SA—a critical grid interconnection safety standard—for its NPS 100C turbine inverter, for which NPS was granted a CIP award in late 2022 (DOE 2022). In early 2023, Wind Resource LLC purchased the Skystream turbine model line and recertified the Skystream 3.7 in accordance with the small wind American Wind Energy Association (AWEA) Standard 9.1-2009 (ICC–SWCC 2023), also signaling an appetite to fast-track domestic sales presence.

Major investments in pre-commercial small wind turbine manufacturers to scale production for market entry have also highlighted momentum in the U.S. small wind market. For example, the nonprofit SWAN Impact Network, a backer of early-stage start-ups, invested in Pecos Wind Power's 85 kW community-scale turbine in early 2023 (SWAN 2023).

The aggregated capacity and units sold reported by U.S.-based small wind turbine manufacturers and refurbished[14] small wind suppliers had a 25% and 17% increase from 2022 to 2023, respectively, as shown in Figure 7. Conversely, the capacity of imports and number of units sold by non-U.S. small wind turbine manufacturers decreased by 25% and 65%, respectively, from 2022 to 2023. About 60% of the imported turbine units sold in 2022 were from manufacturers selling units 25 kW or greater in nameplate capacity, whereas 100% of the imported turbine units sold in 2023 were 25 kW or greater in nameplate capacity. This change can

[14] Most refurbished turbines deployed in the United States were originally manufactured by a non-U.S.-based manufacturer and then refurbished by a U.S.-based supplier.

be attributed to the inconsistent presence (or reporting) of foreign manufacturers in the U.S. small wind market. Two foreign small wind manufacturers reported sales in the United States in 2023, which is equal to the two reported in 2022, but down from four in 2021.

U.S. small wind turbine manufacturers also export to international markets. Since 2014, more than 50.5 MW of U.S. small wind turbines have been exported globally. Still, these exports have significantly declined from a peak of 21.5 MW from six U.S.-based manufacturers in 2015 to just 193 kW from four manufacturers in 2023, 168 kW from five manufacturers in 2022, and 134 kW from three manufacturers in 2021.

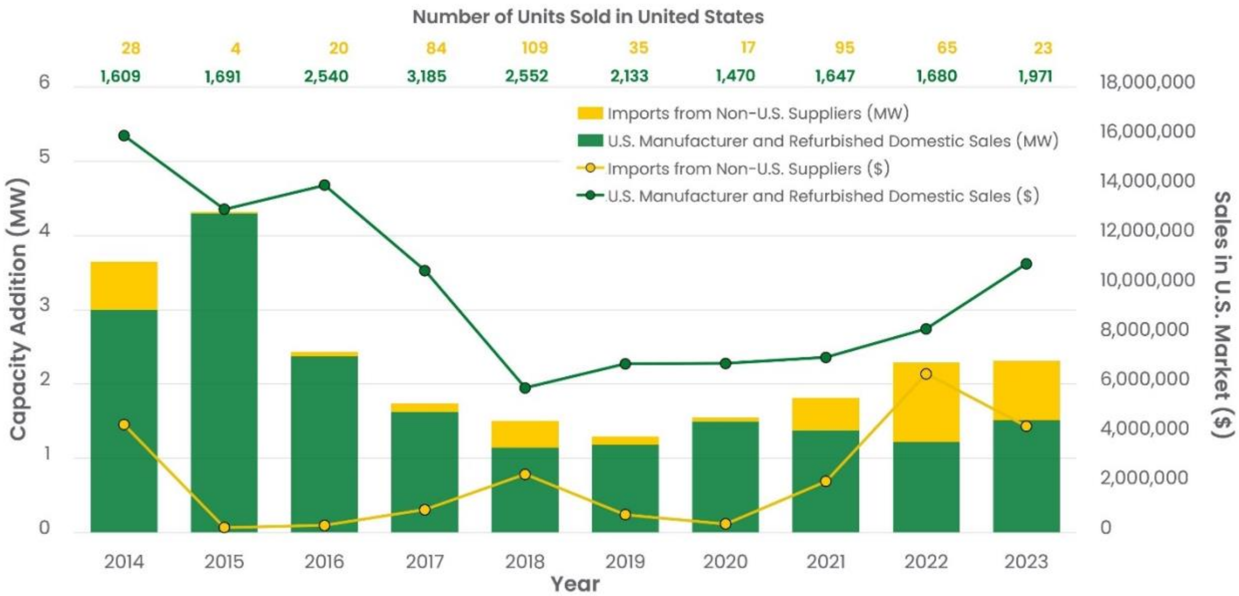

Figure 7. U.S. small wind turbine sales, 2014–2023

3.3 Global Small Wind Market

An examination of the global small wind market provides additional context for small wind market trends and a point of comparison for the small wind market in the United States. The PNNL team depends on agencies in other countries to report their statistics—and not all countries track small or distributed wind deployment. That dependency can result in an incomplete picture of the global market. For 2023, the PNNL team documented about 94 MW of new small wind capacity from six countries, including the United States, as shown in Table 1. Total global installed cumulative small wind capacity is estimated at just under 2.0 gigawatts (GW) as of 2023. Small wind is generally defined as turbines up through 100 kW but can vary according to country. Those distinctions are noted in Table 1.

The China Wind Energy Equipment Association (2024) reported a total of 86.5 MW, or 92% of the global small wind capacity deployed in 2023. China's small wind capacity has increased each year since 2019 and the 86.5 MW installed in 2023 represents a 43% increase over small wind installations in 2022. Additionally, China is poised to incorporate a significant increase in wind power development in its rural regions following a new comprehensive plan announced by the National Energy Administration. The initiative will involve small-scale wind projects in rural areas, supported by partnerships between wind power companies and local governments (Mansfield 2024).

In Ireland, an active small wind turbine market has not developed significantly to date. About a decade ago, there was some activity in the Irish small wind market due to an incentive scheme for small scale systems up to 11 kW, a connection limit established by grid access rules. However, Ireland's grid rules have recently expanded grid access to allow small scale connections up to limits of 50 kW and 200 kW, each subject to specific grid rules. The increases have primarily been driven by the solar market but are expected to benefit a future small scale wind industry (Byrne 2024).

Table 1. Global small wind capacity (MW)

Country	2014–2020	2021	2022	2023	Cumulative	Cumulative Years	Small Wind Definition	Reference
Argentina	[a]	[a]	[a]	[a]	6.50	As of 2022	Uncertain	(Associacíon Argentina de Energia Eólica 2023)
Australia	0.08	0.00	0.00	0.00	1.47	2001–2023	0–10 kW capacity	(Australian Government 2024)
Austria	[a]	[a]	[a]	[a]	0.29	As of 2022	0–50 kW capacity	(University of Applied Science Technikum Wien 2023)
Brazil	0.33	0.20	0.06	0.08	0.70	2013–2023	0–75 kW capacity	(Brazil National Electric Energy Agency 2024)
Canada	[a]	[a]	[a]	[a]	13.47	As of 2018	Uncertain	(Canadian Government 2018)
China	268.79	33.38	60.32	86.51	790.83	2007–2023	0–100 kW capacity	(China Wind Energy Association 2018; China Wind Energy Equipment Association 2024)
Denmark	50.10	0.04	0.17	0.31	611.41	1977–2023	0–100 kW capacity	(Danish Energy Agency 2024)
Germany	5.00	2.50	1.50	2.50	42.25	As of 2023	0–50 kW capacity	(Klein-Windkraftlagen 2024)
India	[a]	[a]	[a]	[a]	5.00	As of 2022	0–10 kW capacity	(Hossain 2023)
Ireland	[a]	[a]	[a]	[a]	4.00	As of 2016	0-11 kW capacity	(Dundalk Institute of Technology 2024)
Italy	163.14	3.21	7.76	2.19	202.97	As of 2023	0–250 kW capacity	(Gestore dei Servizi Energetici 2024)
Japan	[a]	[a]	[a]	[a]	12.88	As of 2019	0–20 kW capacity	(Japan Small Wind Turbine Association 2020)
New Zealand	[a]	[a]	[a]	[a]	0.19	As of 2015	Uncertain	(Sustainable Electricity Association of New Zealand 2016)
South Korea	1.09	0.12	0.13	[a]	4.33	As of 2022	Uncertain	(Korean Institute of Energy Research 2024)
United Kingdom	49.22	[a]	[a]	[a]	141.51	As of 2019	0–100 kW capacity	(United Kingdom Government 2019)
United States	16.52	1.82	2.30	2.31	159.08	2003–2023	0–100 kW capacity	This report
Global	554.25	41.27	72.24	93.90	1,996.87	As of 2023	As defined above	The sum of the table

a Data not available.

4 Policies, Incentives, and Market Insights

Several factors affect the distributed wind market in the United States, which include 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 for the development of distributed wind and other distributed energy resource projects.

Figure 8 shows the value of incentives given to distributed wind projects from 2014 to 2023, excluding federal production and investment tax credits.[15] The combined value of USDA REAP grants, state production tax credits (PTCs), and state incentive payments in 2023 was $12.4 million across ten states (i.e., California, Iowa, Kansas, Maryland, Minnesota, Missouri, Nebraska, New Mexico, Oklahoma, and Vermont). This is a substantial increase compared to the $5.0 million paid across eight states in 2022 and the $5.2 million paid across eight states in 2021. Much of this increase can be attributed to the $6.9 million of state incentive payments in 2023, which came entirely from the California SGIP (Section 4.1.1), compared to none in 2022 and roughly $300,000 in 2021. Additionally, $2.4 million in USDA REAP grants were allocated for distributed wind projects in 2023, an increase from previous years that reflects the new provisions from the IRA initiative (Section 4.1.3).

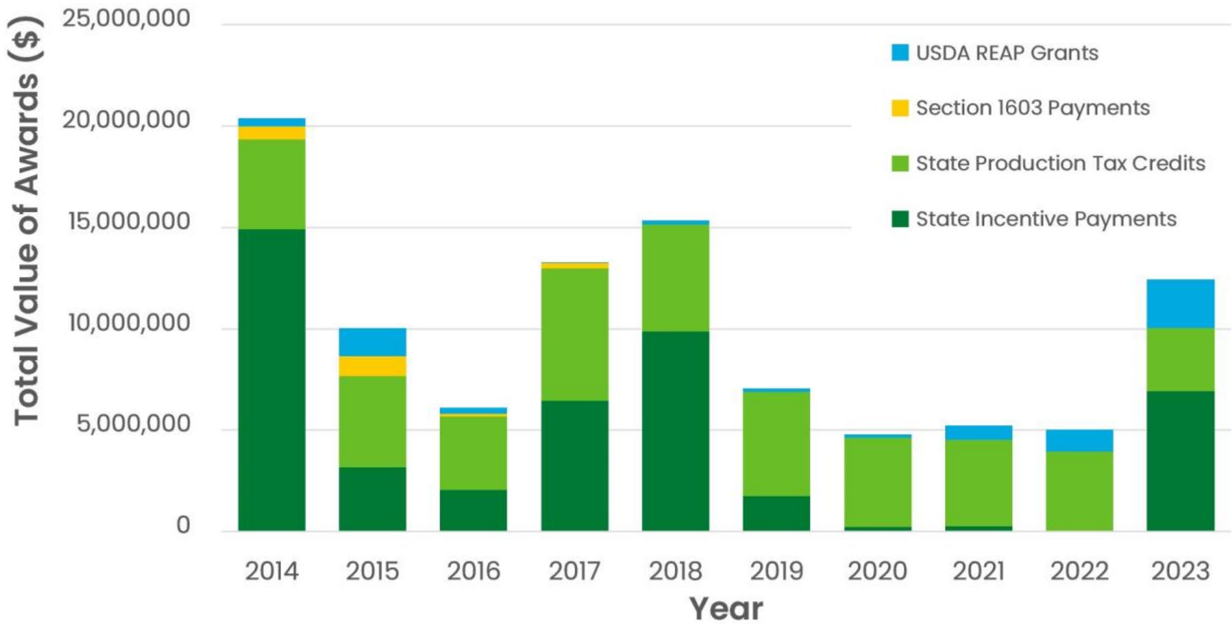

Figure 8. U.S. distributed wind incentive awards, 2014–2023

Figure 8 includes USDA REAP grants (Section 4.1.3); U.S. Treasury cash grants (otherwise known as Section 1603 payments); state PTCs (which are only offered by New Mexico and Iowa); and state incentive programs that provide cash rebates, grants, and performance-based payments. The PNNL team started tracking the New Mexico and Iowa state PTCs in 2014 when the New Mexico credit was first initiated. Figure 8 excludes repaid loans, the federal Business Energy Investment Tax Credit (ITC), the federal Residential Energy Tax Credit, the

[15] Distributed wind projects often receive incentive funding at a different time than when they are commissioned. For example, although USDA REAP grants are recorded for this report in the year they are awarded, they are paid after the project is commissioned and this can be up to two years after the award.

federal Renewable Energy PTC, federal depreciation, and USDA High Energy Cost Grants. The federal tax credits are excluded because information on how many wind projects have claimed them is not public record. USDA High Energy Cost Grants are for areas with extremely high energy costs per household. They are excluded from Figure 8 because the grants typically cover full systems with multiple technologies (e.g., new wind turbines, boilers, and electric thermal storage devices), and the value of the grant for the wind portion cannot be distinguished. New Mexico and Iowa state PTC values are estimated based on available project energy production reports.

Iowa PTC payments are decreasing as some projects have completed their 10-year eligibility period. The last Section 1603 payments were made in 2017 (Treasury 2018).[16] The increase in state incentives is explored in Section 4.1.1. Federal tax-based incentives are discussed in Section 4.1.2. USDA REAP wind applications and grants are discussed in Section 4.1.3.

4.1.1 State Policy and Cash Incentive Highlights

State program cash incentive payments substantially increased in 2023 with 5 awards totaling $6,915,465 after no state programs reported cash incentive payments in 2022 and 2 awards totaling $262,614 were reported in 2021. The California SGIP accounted for all cash incentive payments in 2023 after not issuing any for distributed wind projects since 2020. With the expiration of the NYSERDA Small Wind Turbine Incentive Program, the California SGIP is the last state cash incentive program the PNNL team is aware of that regularly provides funding to distributed wind projects.

4.1.2 Federal Tax 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. The IRA extended the Residential Renewable Energy Tax Credit at 30% through 2032. Then the credit value is phased down until it expires in 2035. The IRA also extended the Business Energy ITC at 30% through 2024. Provisions allow for additional, stackable bonus credits by meeting "energy community" or domestic content requirements. Communities with brownfields, high fossil fuel employment, tax revenue with higher-than-average unemployment rates, recently closed coal mines, or recently closed coal-fired electric generation plants are considered energy communities. Further ITC bonuses of up to 20 percentage points are available on a limited, competitive basis for wind or solar (and from 2025 on other clean energy) projects less-than-5-MW that are located in or benefit low-income communities or are located on tribal lands. Starting in 2025, the ITC will be replaced by the Clean Electricity ITC which will be available to all energy generation technologies with zero or net-negative carbon emissions, and for which the same bonus credits will be available (WETO 2023).

The IRA also provides a direct-pay and transferability provision on the Business Energy ITC and forthcoming Clean Electricity ITC. This direct-pay provision is for non-tax-paying entities that cannot directly monetize a tax credit incentive, such as nonprofits, tribes, Alaska Native Corporations, and rural electric cooperatives.

The IRA also extended the federal Renewable Energy PTC (26 U.S.C. § 45) for land-based wind through 2024 at a rate of $27.50/MWh for 2022, increasing with inflation. In 2025, the technology-neutral Clean Electricity PTC will replace the current PTC. The PTCs are also eligible for direct-pay and transferability and include similar but less valuable (10% vs. 10 percentage points for the ITC) bonus credit provisions as the Clean Energy ITC.

[16] 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 (1) applied for a grant before October 1, 2012, and been placed in service by 2011, or (2) began construction in 2009, 2010, or 2011, and been 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.

4.1.3 U.S. Department of Agriculture Rural Energy for America Program

The USDA provides grant funding and loan financing to agricultural producers and rural small businesses to purchase or install renewable energy systems or make energy-efficiency improvements. The IRA includes up to $2.025 billion of funding allocated for USDA REAP, with $303 million set aside for underutilized technologies and technical assistance. Wind is an eligible underutilized technology in this context. IRA funds are anticipated to support renewable energy and energy-efficiency projects for more than 41,500 farms and small businesses (USDA 2023). The new IRA provisions for REAP also doubled the maximum allowable grant size from $500,000, or 25% of costs, to $1,000,000, or up to 50% of costs, for renewable energy projects. The USDA also issues loan guarantees for renewable energy projects for up to 75% of the project's cost or a maximum of $25 million. A combination of REAP loans and grants can cover up to 75% of total eligible project costs.

REAP has an updated scoring rubric for grant applications submitted on and after April 1, 2023 (USDA 2023). A new criterion is project location in a disadvantaged or distressed community, which replaces two former criteria about the size of the funding request and whether the applicant had an existing business. In addition, USDA REAP changed the point allocations for environmental benefits (higher) and commitment of matching funds (lower) to keep the total possible score at 100 points.

In 2023, USDA REAP allocated $3,377,818 in grants for 40 wind projects (Figure 9), $2,377,818 of which was for 39 distributed wind projects. The 39 distributed wind projects represent a total of 0.8 MW of capacity from 48 turbines in eight states (i.e., Iowa, Kansas, Maryland, Minnesota, Missouri, Nebraska, Oklahoma, and Vermont). The USDA REAP wind grants include a $1,000,000 REAP grant Hawaii received for a wind project with 16 turbines of 10.6 MW capacity (660 kW each), but it is not a distributed wind project, so it is not included as a distributed wind incentive award in Figure 8. Of the 39 distributed wind projects awarded USDA REAP grants, 3 projects involve additional energy technologies (solar). Since the per-project grant funding amount is not disseminated according to technology, the grant funding amount for projects involving multiple energy technologies was split evenly across technologies for this analysis. The 39 projects are expected to generate more than 2.7 GWh of energy annually. The 2023 funding amount was substantially greater than the $1,069,922 in wind grants awarded in 2022 to 12 projects in six states and the $696,964 in wind grants awarded in 2021 to 22 projects in five states. The increase in funding can largely be attributed to the IRA initiative, as 88% of REAP wind grants and 88% of grant funding were part of the IRA initiative.

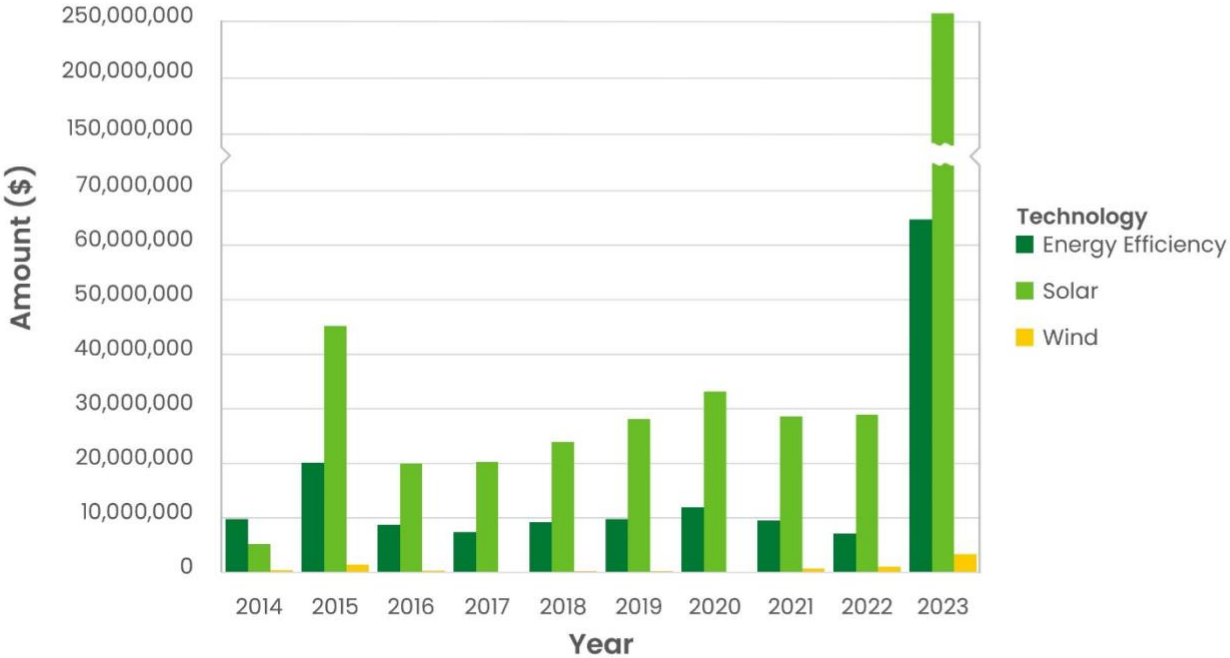

Figure 9. USDA REAP grants by technology, 2014–2023

Wind projects represented 1.4% of all REAP grants allocated in 2023 (2,841 in total) and 0.9% of all 2023 REAP grant funding ($376,771,594 in total), while energy-efficiency projects represented 22% of grants and 17% of grant funding, and solar PV projects represented 73% of grants and 68% of grant funding. Other REAP funding for renewable energy technologies was issued to biogas, biomass, geothermal, and hydroelectric projects. In 2022, wind projects represented 1.5% of all REAP grants (811 in total) and 2.7% of REAP grant funding ($40,449,528 in total).

USDA REAP did not provide any loan guarantees to wind projects in 2023. With respect to loans over the period of 2014 to 2023, there was only one loan guarantee for a distributed wind project in 2018. In 2023, 21 loans were guaranteed for battery, biogas, biomass, energy efficiency, and solar PV projects, totaling $234,273,196. Loans guaranteed for solar PV projects accounted for 10 of the 21, down from 29 loans guaranteed in 2022.

Since 2003, the USDA has awarded over $77 million in REAP wind grants. States with projects receiving the largest share of this funding include Iowa with $23.6 million, Minnesota with $22.7 million, Illinois with $4.1 million, Ohio with $2.9 million, and Oregon with $2.8 million. The top five states in terms of number of wind projects awarded are Iowa with 269, Minnesota with 201, New York with 51, Wisconsin with 45, and Kansas with 32. In 2023, Iowa and Minnesota added to their total number of REAP awards with Iowa receiving 4 grants for $243,872 and Minnesota receiving 9 grants for $773,861. Oklahoma received 14 grants for $628,395 in 2023, more than any other state received for distributed wind projects and nearly doubling the number of grants the state has received between 2003–2022.

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 Repowers

To be in alignment with typical industry language, the PNNL team uses the term repower, rather than retrofit, in Distributed Wind Market Reports. Repowers are new (i.e., either newly manufactured or refurbished) turbines installed on existing towers and foundations to replace nonfunctioning turbines or to upgrade the technology.

Repowers accounted for a reduced portion of new small wind capacity deployment in 2023 compared to previous years. In 2023, small wind repowers represented just 5% of total installed small wind capacity, compared to 7% in 2022 and 36% in 2021.[17] This fluctuation is a result of how many customers an installer can manage in a year, turbine supply availability, and each year's sample size of reported projects.

The repower trend is largely driven by customers' interest in reusing existing infrastructure to maintain on-site wind generation. The PNNL team will continue to monitor repowering reports as many small wind turbines reach the ends of their life cycles and customers seek out improved technologies.

4.2.2 Hybrids and Co-Located Distributed Energy Resources

For each entry in the master project dataset, PNNL documents, if known, whether the distributed wind turbine is part of a hybrid power plant, part of a hybrid power system, or has co-located distributed energy resources.

Co-located and co-operated energy resources with shared components and control strategies are the characteristics that most typically define a hybrid power plant or system (Murphy et al. 2021; Ahlstrom et al. 2019). Wind and solar generation can be complementary, and this resource diversity can allow a wind-solar hybrid to achieve a more consistent renewable generation profile throughout the year (Clark et al. 2022; Reiman et al. 2020). A homeowner with a small wind turbine and rooftop solar PV can also benefit from the complementarity, even if the two resources are co-located to serve the same house but are not controlled together. Hybrid power plants are being installed at all scales, including at the distribution level. With the direct-pay provision of the ITC under the IRA, additional tax-exempt cooperatives may be motivated to pursue hybrid power plants for their distribution systems. One distributed wind project that was repowered in 2023 reported connection with a battery storage system and a new 2023 distributed wind project reported to have co-located solar PV.

4.2.3 Competitiveness Improvement Project

The CIP, which is funded by WETO and administered by the National Renewable Energy Laboratory (NREL), awards cost-shared subcontracts via a competitive process to manufacturers of small and medium[18] wind turbines. The goals of the CIP and WETO's Distributed Wind Research Program are to make small and medium wind energy technologies cost-competitive with other distributed generation technologies and to increase the number of small and medium wind turbine designs tested and certified to national performance and safety standards.

Fiscal year 2022 and 2023 funding for the CIP was combined and awardees for 2022 and 2023 were announced on December 15, 2022 (NREL 2023a). These awardees will use their cost-shared subcontracts to:

- develop optimized designs for increased energy production and grid support
- conduct turbine and component testing to national standards to verify performance and safety
- develop advanced manufacturing processes to reduce hardware costs

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[17] The percentage values for repowers may differ from what was presented in previous reports because PNNL regularly adds project records from previous years to its master project dataset.

[18] The International Electrotechnical Commission 61400-1 Standard defines small wind turbines as having rotor swept areas of up to 200 m^2 and medium wind turbines as having rotor swept areas of 200 m^2 to 1000 m^2.

- commercialize optimized technology to accelerate deployment.

From 2012 through 2023, NREL awarded 64 subcontracts to 26 companies, totaling $15.4 million of DOE funding and leveraging $7.9 million in additional private-sector investment (NREL 2023a).

In February 2024, a request for proposals was announced for the CIP to provide more funds to support the testing, certification, and commercialization of small and midsize turbines (Laurie 2024).

4.2.4 Certified Small and Medium Wind Turbines

Certifying a small or medium wind turbine model to consensus standards allows manufacturers to demonstrate that the turbine model meets design, performance, and quality requirements and establishes standard 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, 61400-11, and 61400-12 standards to be eligible to receive the small wind Business Energy ITC (IRS 2015). These standards address power performance, structural design, safety, and acoustic sound requirements.

American Cleanpower (ACP), the successor to AWEA, published its new ANSI consensus standard, ANSI/ACP 101-1-2021, in October 2022 (ANSI 2023). The ANSI/ACP 101-1 standard defines small wind turbines as having a peak power of 150 kW or less and distinguishes microturbines as having a peak power of up to 1 kW. The Distributed Wind Energy Association and DOE have recommended that the U.S. Internal Revenue Service (IRS) recognize legacy certifications to AWEA 9.1-2009 and new certifications to ANSI/ACP 101-1 going forward for small wind Business Energy ITC eligibility.

The ANSI/ACP 101-1 standard has been designed to facilitate easier compliance. Where certification to the AWEA standard took at least 12 months, certification to the ANSI/ACP standard is expected to take six months, primarily because the duration test is estimated to require four months for the ANSI/ACP standard but typically takes 10 months for the AWEA standard. While ACP 101-1 reduced the length of the duration test, it balanced that with a requirement to monitor at least five turbines in the field for at least three years after certification is awarded. ACP 101-1 also added provisions that scale the testing and analysis requirements for various turbines with their sizes after it was recognized that the risk factors associated with smaller turbines are less and different than those of larger turbines within the scope of the standard. As of January 2023, the International Code Council-Small Wind Certification Council (ICC–SWCC)—an accredited third-party certification body—began offering new certifications for wind turbines with a peak power of 150 kW of less to the ACP standard while maintaining legacy certifications to the former AWEA standard.

The certification process is a significant upfront and ongoing cost for turbine manufacturers. While the application and renewal process may differ by certification body, annual renewal (with applicable renewal fees) is required by the ICC-SWCC for both the ACP 101-1 and legacy AWEA 9.1 standards. The ICC-SWCC now requires factory inspections every two years, as specified in Appendix B of ACP 101-1. The inspections verify compliance with ICC-SWCC program requirements, check for any design changes, and assess compliance with minimum requirements for quality management systems in production. The validity period for type certification to the IEC standards is five years, after which recertification is also required (IECRE 2021, NREL 2024a). High cost is one reason certification testing is supported by DOE through the CIP, with award amounts consistent with certification costs, about $150,000 to $200,000 for most small wind turbines. Primus Wind Power (acquired by Ryse Energy in 2023) was awarded a 2022–2023 Competitiveness Improvement Project subcontract to test and certify its six turbine models to the new ANSI/ACP 101-1 standard. In addition to CIP subcontracts, NREL initiated a subcontract with the ICC–SWCC from December

2022 through November 2024 to fund the organization to provide preliminary certification reviews (NREL 2023b). The preliminary reviews will determine if a turbine design is ready to complete the certification process successfully, confirm the proposed test plan and location, and ideally help more turbine manufacturers to start the certification process. As of June 2024, the program was fully subscribed with ten funded preliminary reviews (NREL 2024b).

Table 2 lists the seven small wind turbine models certified to the AWEA 9.1 standard or the IEC 61400 standards as of May 2024. Wind Resource LLC, the new owner of the Skystream 3.7 turbine model, recertified the turbine model in 2023 as part of its market return. While Table 2 lists the Skystream 3.7 turbine model's original certification date as 2023 because of the new ownership, it was first certified in 2011. Table 2 only includes those turbine models that have met annual renewal requirements. Manufacturers may opt not to renew if they no longer want to participate in the U.S. market or if the company has discontinued operations. While seven small wind turbines have active certifications as of June 2024, at least 23 small wind turbine models have been certified to the AWEA or IEC standards between 2011 and 2023.

Table 2. Certified small wind turbines in the United States, as of June 2024[19]

Applicant	Turbine Model	Date of Initial Certification	Certified Power Rating[a] @ 11 m/s (kW)	Certification Standard
Bergey Windpower Company	Excel 10	11/16/2011	8.9	AWEA 9.1
Bergey Windpower Company	Excel 15	02/05/2021	15.6	AWEA 9.1
Eveready Diversified Products (Pty) Ltd.	Kestrel e400nb	02/14/2013	2.5	AWEA 9.1
Eocycle Technologies, Inc.	EOX S-16	03/21/2017	22.5/28.9	AWEA 9.1
HI-VAWT Technology Corporation/Colite Technologies	DS3000	05/10/2019	1.4	AWEA 9.1
SD Wind Energy, Ltd.	SD6	06/17/2019	5.2	AWEA 9.1
Wind Resource, LLC	Skystream 3.7	04/12/2023	2.1	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).

[19] Other information about these certifications, such as rated sound levels and rated annual energy production amounts, are available from the certification bodies (ICC–SWCC 2024; SGS 2021; UL 2021).

5 Installed and Operations and Maintenance Costs

PNNL collected the cost data presented in this section from state and federal agencies, distributed wind project owners and developers, installers, and news reports, as described in Appendix B.

5.1 Small Wind Installed Costs

Figure 10 presents the average annual and project-specific small wind installed costs (in 2023 U.S. dollars) for 2014 through 2023. Figure 10 only includes projects with reported installed costs that use turbines with known rated capacities[20] and only includes an annual average for years in which there are three or more reported projects.

Figure 10. Annual average and project-specific new and repowered small wind installed project costs, 2014–2023

The overall average capacity-weighted installed cost for new small wind projects from 2014 through 2023 was $11,410/kW. Of the new small wind projects installed in 2023, the PNNL team was only able to obtain cost reports for five of the projects. The average capacity-weighted installed cost for these projects was $7,370/kW based on the five projects using five wind turbines in two states with a combined rated capacity of 131.2 kW.

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

The limited sample sizes in PNNL's dataset for reported costs in 2018, along with high variance in distributed wind project costs, have prevented the PNNL team from being able to clearly identify any cost trends for small wind turbine installations over time.

The installed cost amount includes the wind turbine equipment costs, or the hardware costs, as well as the balance-of-system costs. Balance-of-system costs[21] can typically represent up to 60% of a new small wind project's total installed cost and therefore play a significant role in overall small wind installed costs (Orrell and Poehlman 2017). The varying sample sizes and the high variance in project-specific costs contribute to the cost ranges exhibited each year.

Average annual (when available) and known project-specific small wind installed costs for repower projects (in 2023 U.S. dollars) are also shown in Figure 10. Installers did not share any costs for repowered small wind projects in 2023, but repower projects generally tend to be less expensive than new installations, as shown in Figure 10. For 2019 through 2021, the overall average capacity-weighted installed cost for small wind repowers was $4,820/kW. The use of refurbished turbine units is common in repowers. Refurbished turbines represent the low end of the installed cost ranges for repowered projects.

5.2 Installed Costs for Projects Using Midsize and Large Wind Turbines

Figure 11 presents the average annual and project-specific costs (in 2023 U.S. dollars) for distributed wind projects using midsize and large turbines for years 2014 through 2023. Figure 11 only includes projects with reported installed costs and only includes an annual average for years in which there are three or more reported projects.

Figure 11. Annual average and project-specific new and repowered installed costs for projects using midsize and large turbines, 2014–2023

[21] The balance-of-system 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).

The availability of cost information for distributed wind projects using midsize and large turbines varies from year-to-year. Installers did not share any costs for distributed wind projects using midsize and large turbines in 2023; therefore, the average cost was not calculated for that year. The overall average capacity-weighted installed cost for projects using turbines greater than 100 kW for the period of 2014 through 2023 is $4,160/kW. As with small wind projects, large repower projects, especially those utilizing refurbished turbines, can be less expensive than new installations, as highlighted by the year 2020 in Figure 11. The average installed cost of the 12 repower projects using the same refurbished midsize turbine model in 2020 was roughly $740/kW.

Because of the annual variations in data availability, the average costs reported for each year likely contain bias because of the project sample size variation (e.g., military projects with higher costs due to specific regulatory and cybersecurity requirements may dominate one year's sample, while lower-cost agricultural projects in Minnesota may dominate another year's sample). The limited sample sizes in PNNL's dataset for reported costs in 2020, 2022, and 2023 make it difficult to assess cost trends for installations using midsize and large turbines over time, but in general, annual average costs have dipped since peaking in 2016 and 2018. These peaks were driven by outlier projects in geographically isolated areas where costs to transport equipment and install projects are higher. For example, the outlier project circled in Figure 11 is installed in Guam. Higher installation costs in Guam are expected because of its remoteness, but the distributed wind energy also displaces higher electricity costs (compared to the continental United States), so the project is still cost-effective.

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

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

For small wind, in most cases, the project installer or developer performs the maintenance for the small wind turbine owner. Maintenance costs include labor, travel to the site, consumables, and any other related costs. Therefore, small wind maintenance costs can depend on the maintenance provider's proximity to the project site (i.e., travel costs), the availability of spare parts, and the complexity of maintenance and repairs. The average scheduled maintenance cost per visit for small wind is about $37/kW (Orrell and Poehlman 2017). This is in line with other data that suggest operation and maintenance costs for distributed wind projects are typically $35/kW/yr (NREL 2022).

For a large distributed wind project, O&M costs of the turbine system are part of the project's total operating expenses. The Land-Based Wind Market Report, which concentrates on utility-scale wind farms and wind turbines that exceed 100 kW in size, reports that O&M costs for 83 projects installed since 2010 have averaged about $20/kW/year and that O&M costs can be less than half of total operating expenses (Wiser and Bolinger 2023).

6 Performance

A wind project's capacity factor can be a valuable metric 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.[22] This section looks at capacity factors in various ways to evaluate the performance of distributed wind turbines.

6.1 Small Wind Capacity Factors

Figure 12 presents the calculated capacity factors, arranged by geographic region, for a sample of small wind projects that produced energy in 2023.[23] A box-and-whisker plot was selected to provide visibility into the average, median, and extreme capacity factors in each region. The small wind annual generation data used in the capacity factor calculations are from turbine monitoring web portals and generation data reports shared with the PNNL team from turbine owners, manufacturers, and operators. The generation data sources from 100 turbines totaling 1.3 MW in rated capacity and ranging in rated capacity from 2 kW to 78 kW installed from 2009 through the beginning of 2023. Of the 100 turbines, the PNNL team had the metadata available to classify 85 into geographic regions. The remaining 15 have unknown locations.

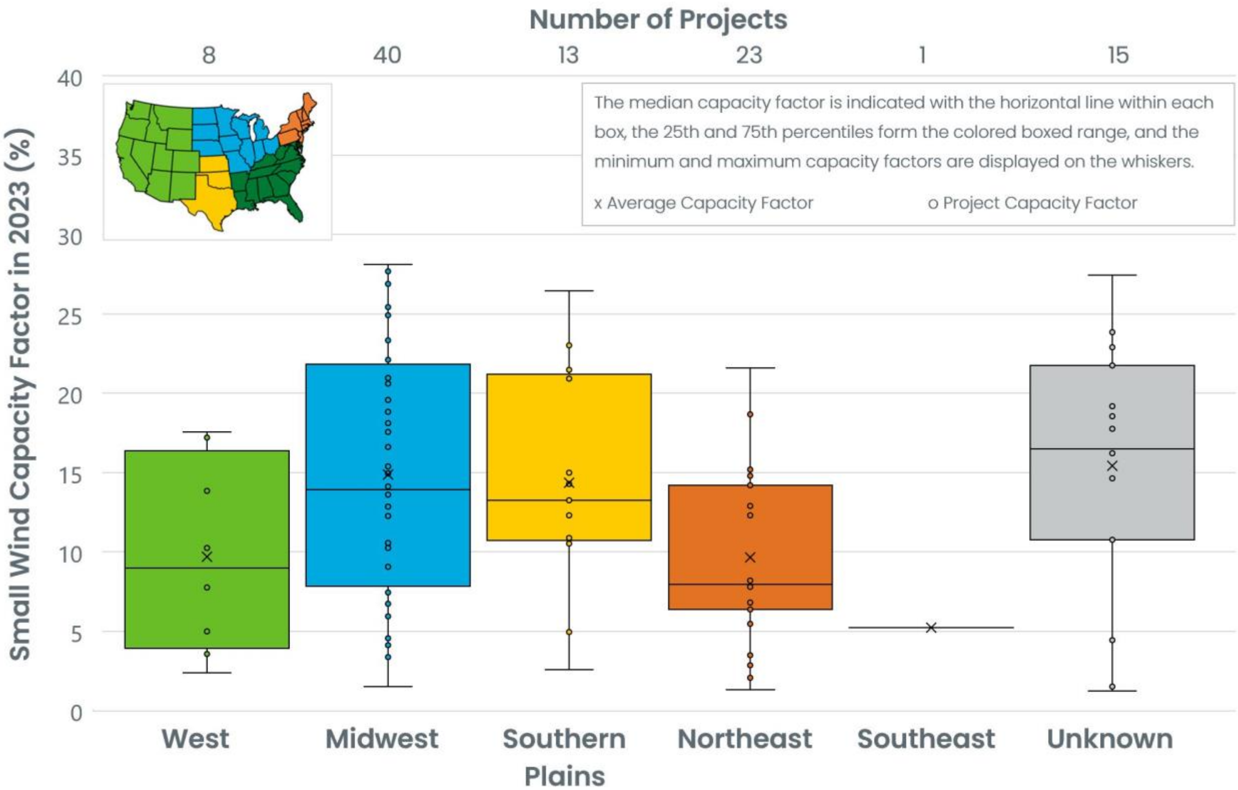

Figure 12. Small wind capacity factors in 2023

[22] 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 were used.

[23] With the intent to provide an accurate portrayal of actual wind turbine production (including losses and downtime) in 2023, the following data-quality-control guidelines were applied. Turbines with a full 12 months of reported data were included in the analysis. In addition, turbines with missing data were included if they were offline or had missing data (1) during the middle of 2023, (2) at the beginning of 2023 if those turbines had been online and reporting prior to 2023, or (3) at the end of 2023 if they came back online in 2024. Turbines were excluded from the analysis if they first came online during 2023 or if they were offline or missing data at the end of 2023 into 2024 (as this could indicate decommission). The reasons underlying turbines being offline or missing data are unknown to PNNL. This methodology also applies to Figure 13 and Figure 14.

The overall average capacity factor in 2023 for these small wind projects was 13%. The eight small wind projects in the West yielded an average 2023 capacity factor of 10%. The 40 small wind projects in the Midwest produced the largest 2023 capacity factors, averaging 15%, followed by the 13 small wind projects in the Southern Plains, averaging 14%. The 23 small wind projects in the Northeast, the majority of which are in New York, yielded an average 2023 capacity factor of 10%. New York's high electricity prices and past available incentives enabled significant small wind capacity additions for many years, despite the state's relatively low wind resource. The single sampled small wind project in the Southeast, the region with the lowest wind resource in the United States (WINDExchange 2023), produced a 2023 capacity factor of 5%. And the 15 small wind projects with unknown locations yielded an average 2023 capacity factor of 15%.

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

6.2 Capacity Factors for Projects Using Midsize and Large Turbines

From the Energy Information Administration (EIA) Form 923 records (EIA 2024a) and data provided by distributed wind industry collaborators, PNNL identified 36 distributed wind projects using midsize and large turbines installed from 2005 to 2021, across 15 states, totaling 117 MW in combined capacity that reported generation amounts for 2023. Turbine nominal capacities used in the projects range from 600 kW to 3 MW, but the project size may be larger since some projects are composed of multiple turbines. Figure 13 presents the calculated capacity factors in 2023, arranged by geographic region and by turbine size, for these projects using midsize and large turbines.

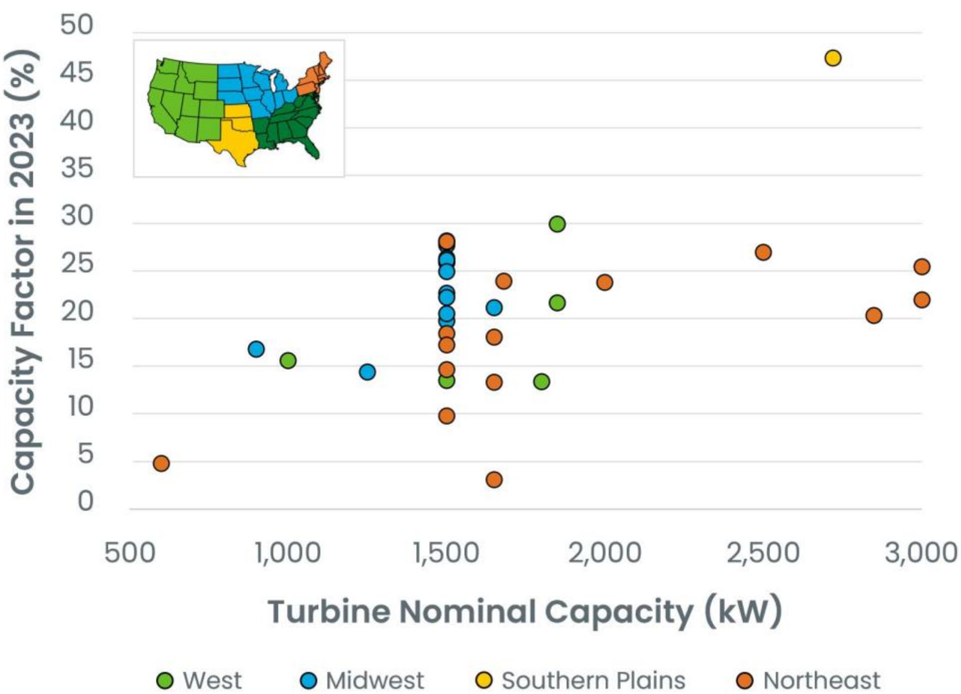

Figure 13. Capacity factors in 2023 for projects using midsize and large turbines

The wind projects in Figure 13 exhibit a wide range of observed capacity factors, from 3% to 47%. The average capacity factor in 2023 for projects using midsize and large turbines is 21%. The average capacity factor in 2023 for projects using midsize and large turbines is nine percentage points larger than the average 2023 capacity factor for projects using small wind turbines (12%). This is most likely because large turbine projects typically have thorough wind resource assessments as part of the siting process (to achieve optimal energy generation), undergo routine maintenance (to sustain high levels of reliability), and have taller hub heights (to capture higher wind speeds).

Geographically, the sole reported capacity factor in the Southern Plains was the highest nationwide in 2023 (47%). Average capacity factors in 2023 for projects using midsize and large turbines in the Midwest, West, and Northeast were 23%, 19%, and 18%, respectively.

6.3 Annual Capacity Factor Comparison

To assess distributed wind performance in 2023 relative to the previous year, Figure 14 provides capacity factors for 2022 compared to 2023 for projects using small, midsize, and large wind turbines across the continental United States. Projects near the dashed line in the figure indicate the project had similar performance in 2022 and 2023. Projects above the dashed line correspond to higher generation in 2023 than in 2022. Projects below the dashed line had higher generation in 2022 than in 2023.

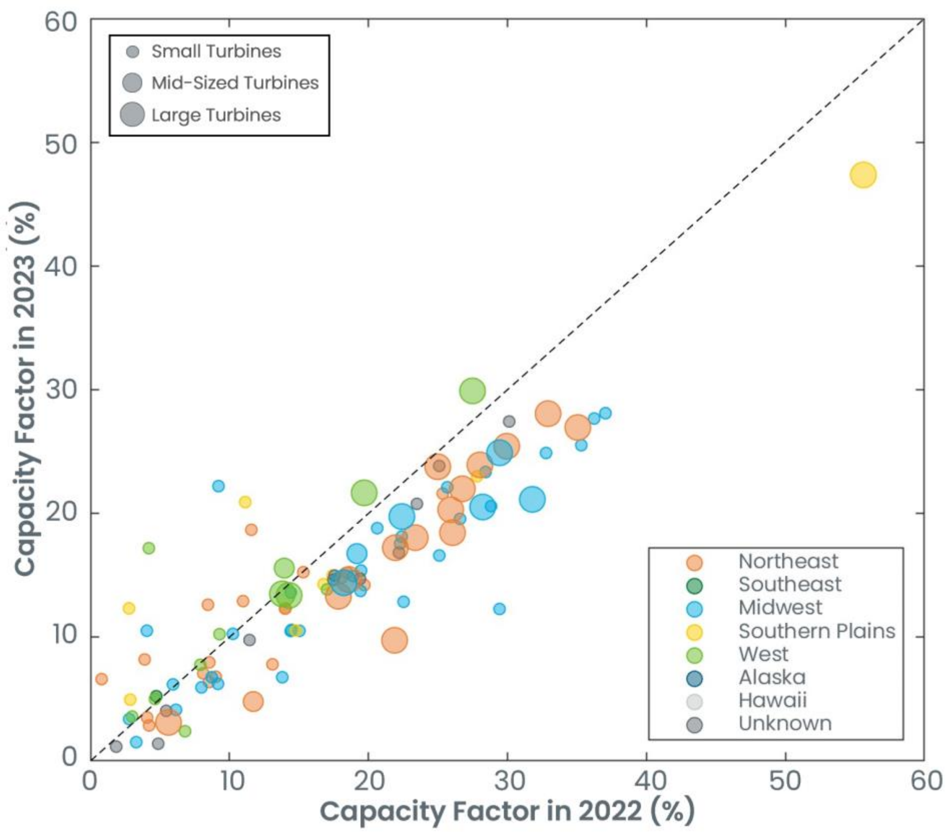

Figure 14. Distributed wind capacity factors, 2022–2023

Of the 104 projects for which PNNL has power generation data for 2022 and 2023, only 14 of the projects (13%) had higher capacity factors in 2023 compared to 2022 by at least 1 percentage point. The majority of the projects (75 projects, 72% of the 104 projects) underperformed in 2023 relative to their capacity factors in 2022 by at least one percentage point. The remaining 15 (14%) projects performed similarly between the two years. Across the projects, the average capacity factor in 2022 was 17% and the average capacity factor in 2023 was 15%.

Differences in annual distributed wind performance occur for various reasons, including the project's available wind resource, turbine availability (i.e., downtime for expected or unexpected maintenance), and site changes (i.e., building construction or vegetation growth). Of the 104 projects for which PNNL has generation data for 2022 and 2023, five projects were reported to have outages of 1 month or greater in 2023: one small project in the Midwest, one project using midsize turbines in the Northeast, one large project in the Midwest, and two large projects in the Northeast. These five projects underperformed in 2023 relative to their capacity factors in 2022 by 3 to 11 percentage points. Of the 11 small wind projects that overperformed in 2023 by at least 1 percentage point relative to their capacity factors in 2022, ten projects reported outages of 1 month or greater in 2022.

The interannual wind resource was the main contributor to the distinctions in distributed wind performance trends between 2022 and 2023. Figure 15 displays the ratio of the 2023 to 2022 annual average wind speed at 100 meters (m) (328 feet [ft]) above ground level over the continental United States from the ERA5 model.[24] Annual average wind speeds in 2023 were shown to be lower than they were in 2022 across the entire regions of the Midwest, Southern Plains, and Northeast. Correspondingly, 84% of Midwest projects, 63% of Southern Plains projects, and 76% of Northeast projects underperformed in 2023 relative to their capacity factors in 2022 by at least 1 percentage point. The West and Southeast regions are disparate in their wind resource trends between 2022 and 2023, with the Pacific Coast, desert Southwest, and the Gulf Coast showing higher wind speeds in 2023 relative to 2022 and the Rocky Mountain and Appalachian regions showing lower wind speeds in 2023 relative to 2022. Only 17% of projects in the West underperformed in 2023 relative to their capacity factors in 2022 by at least one percentage point. The sole project in the Southeast for which PNNL has generation data for 2022 and 2023 exhibited similar performance between the 2 years.

One of the major drivers of the differences in the interannual wind resource between 2022 and 2023 was the differing phase of the El Niño-Southern Oscillation climate pattern. Typical La Niña phases, which dominated 2022, tend to produce active storm tracks, with associated stronger wind, particularly in the Plains and Upper Midwest (National Weather Service 2024). Conversely, the year 2023 was largely dominated by the El Niño phase (Climate Prediction Center 2024), which tends to be associated with weaker jet stream patterns and decreased wind speeds across the center of the continental United States (Climate Impact Company 2023).

[24] The European Centre for Medium-Range Weather Forecasts Reanalysis 5th Generation, commonly referred to as ERA5 (ECMWF 2024). The reanalysis model provides decades-long wind resource data at an hourly resolution.

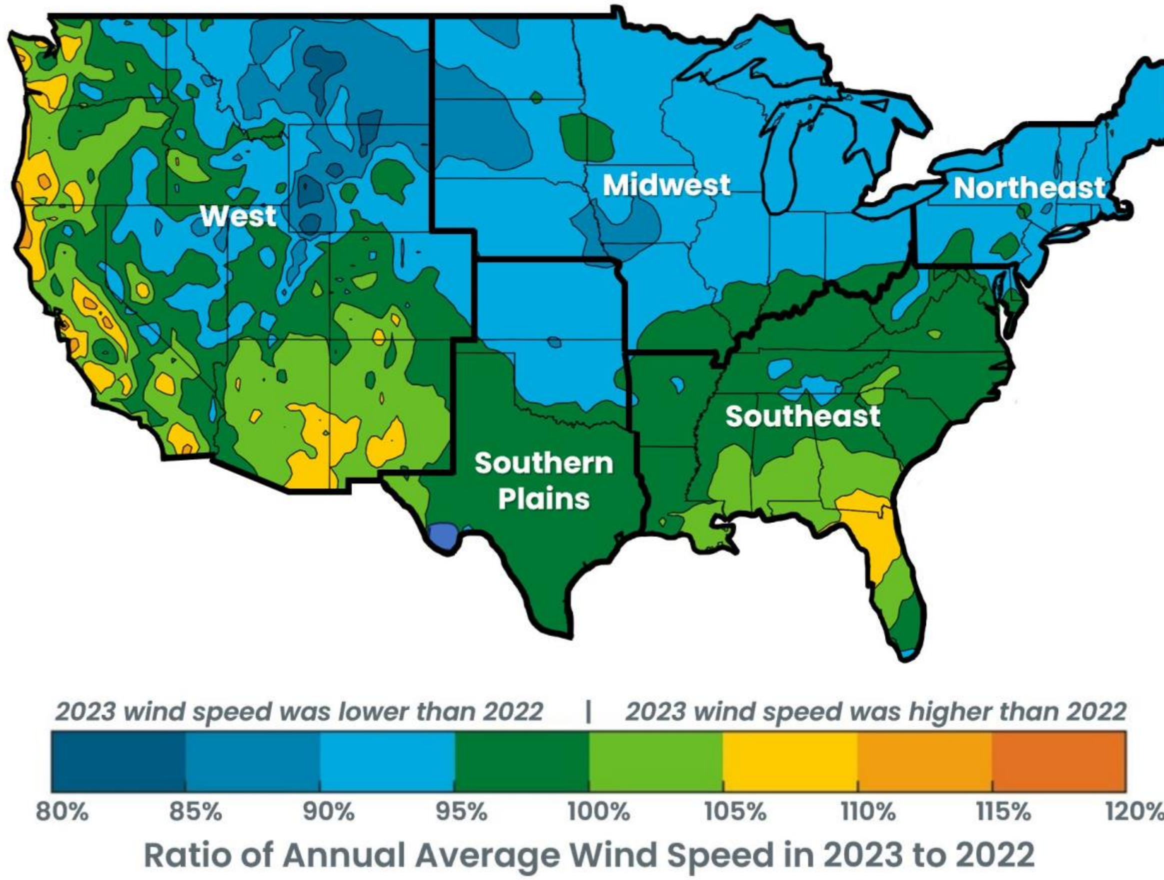

Figure 15. Ratio of ERA5 100 m annual average wind speed in 2023 to 2022

6.4 Wind Resource Quality

Despite the great diversity in distributed wind annual installations, turbine designs, hub heights, and applications, the trends in wind resource quality at locations of distributed wind deployment have been consistent over the last decade. For a sample of 319 distributed wind projects for which PNNL has specific geographic coordinates, Figure 16 shares the estimated annual average wind speed at 50 m (164 ft) above ground (a central height between the higher hub heights of large distributed wind installations and the lower hub heights of small wind installations) from the high-resolution Global Wind Atlas.[25]

For each year in the last decade, the median annual average wind speed across known locations of distributed wind installations has ranged between 6.2 meters per second (m/s) (13.9 miles per hour [mph]) and 6.7 m/s (15.0 mph), wind speeds that correspond to the steep portion of most wind turbine power curves. Some distributed wind projects were built in significantly windy locations over the last decade, as represented by the outliers in Figure 16 above 8.0 m/s (17.9 mph). These windy projects are located in the Mojave Desert of California, the western Alaskan mainland, and an island in western Alaska. Earlier in the decade, two distributed wind projects were built in very low wind areas, as represented by the outliers in Figure 16 below 3.5 m/s (7.8 mph), a wind speed threshold near or below cut-in for many wind turbine power curves. Interestingly, these less windy projects are located in urban Texas and near the Colorado urban corridor. These

[25] The Global Wind Atlas (Global Wind Atlas 2024) provides global annual average wind speed estimates.

two states, particularly Texas, have reputations as wind-rich states and this analysis highlights the importance of appropriate distributed wind project siting and accurate wind resource assessment.

Figure 16. Wind resource quality by year of installation, 2003–2023

7 Levelized Cost of Energy

Levelized cost of energy (LCOE) represents the present value of all anticipated project costs (installed and O&M) divided by the project's anticipated lifetime energy production. LCOE allows for the comparison of different power production approaches of unequal technologies, 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 $/MWh or ¢/kWh.

The LCOE for a wind project owner can be reduced by either decreasing the initial capital costs (the numerator of the equation) or increasing its energy generation (the denominator of the equation) while not disproportionately increasing costs. With the stackable bonus credits available in the extended Business Energy ITC and a grant from USDA REAP, rural small business owners or farmers could significantly reduce their upfront capital costs for distributed wind and thus achieve lower LCOEs.

Past market reports have reported estimated LCOE for distributed wind projects using performance and cost data from the EIA, USDA REAP, and NYSERDA with NREL's LCOE method and assumptions detailed in Appendix B (NREL 2020). To calculate LCOE estimates, the PNNL team must have access to at least a full year of energy production data for a project and an installed cost report. The number of projects for which the PNNL team has both installed cost reports and production data is limited. As a result of data limitations, the team has not calculated any LCOE estimates from empirical data for this report and will continue to consider the best ways to calculate and present LCOE estimates in future reports as more new and relevant data become available.

The NREL *2022 Cost of Wind Energy Review* presents modeled small wind LCOE estimates that are generally in line with past market report empirical-based estimates (Stehly et al. 2023). For a representative 20 kW installation, the estimated LCOE was 23.5¢/kWh in 2022 dollars without including any incentives that would lower the capital cost. For a representative 100 kW installation, the LCOE, without any incentives, was estimated at 16.3¢/kWh.

Incentives for distributed wind projects can significantly lower LCOE. For a sample of 35 distributed wind projects using small wind turbines that were allocated USDA REAP funding in 2023 (Section 4.1.3), PNNL estimated LCOE using the installation costs, estimated annual energy production, and nameplate project capacities provided by USDA with the operational expenditure costs and fixed charge rates for distributed wind projects estimated in the *2022 Cost of Wind Energy Review* (Stehly et al. 2023). The average LCOE across the 35 projects without incentive funding is estimated at 16.9¢/kWh. Including the USDA REAP incentive funding reduces the average LCOE to 11.1¢/kWh.

Whether or not a distributed wind project's LCOE is cost-competitive with retail electricity rates depends on the location of the site, as retail rates vary greatly across the United States. According to the EIA, average U.S. retail electricity rates, which small wind turbines are most likely to displace, range from around 11¢ to 31¢/kWh for residential customers and from around 8¢ to 24¢/kWh for commercial customers (EIA 2024b). Hawaii, Alaska, Puerto Rico, the U.S. Virgin Islands, Guam, and the Northern Mariana Islands have higher rates, making distributed wind potentially more cost-competitive in those areas, even when project costs for those locations are also likely to be higher.

8 Distributed Wind Markets

This section details customer and interconnection characteristics of distributed wind sales and installations.

8.1 Customer Types

Customers install distributed wind for several reasons, including to increase energy security, lower utility bills, hedge against future energy price increases, mitigate energy price volatility, or generate renewable energy to help meet decarbonization goals. A distributed wind project can either be owned directly by the end-use customer or the end-use customer can purchase energy produced by a 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,[26] tribal-owned, or rural electric cooperatives.
2. Residential applications include remote cabins, private boats, rural homesteads, suburban homes, and multifamily dwellings.
3. Institutional applications are for entities that are typically non-taxed and mainly consist of schools, universities, churches, nonprofits, and local unions.
4. Government applications are also projects for non-taxed entities such as federal agencies, states, cities, municipal facilities (e.g., water-treatment plants and fire departments), military sites, and tribal governments.
5. Commercial applications include offices, car dealerships, retail spaces, restaurants, telecommunications sites, and distribution centers.
6. Industrial applications include facilities that manufacture goods, perform engineering processes, or engage in extractive activities (e.g., food processing plants, appliance manufacturing plants, oil and gas operations, and mines).
7. Agricultural applications include farms, ranches, and farming operations (e.g., nurseries and vineyards).

Agricultural and residential end-use customers, which typically use small wind turbines, usually account for most of the distributed wind installations by number of projects, while projects using large turbines that serve utility customers have consistently accounted for the majority of distributed wind capacity.

Projects for commercial customers accounted for 42% of the number of all projects installed in 2023, followed by agricultural customers at 34%. Institutional customers represented approximately 11% of projects installed in 2023, while industrial and utility customers represented 8% and 5% of the number of projects installed, respectively. No residential or government projects were documented in 2023. This marks a shift from historical trends, as agricultural and residential customers have collectively accounted for 60% or more of the number of projects deployed annually since 2014 (with the exceptions of 2018 and 2020).

Distributed wind deployed for industrial customers represented the largest share of total distributed wind capacity installed in 2023, accounting for 83% of the documented capacity, compared to 20% in 2022 and 25% in 2021. Utility customers represent the second largest percentage of distributed wind capacity installed in 2023, accounting for 10% of total capacity. Historically, utility customers have represented the largest share of annual distributed wind capacity installed, accounting for more than 50% of the annual capacity deployed in

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

most years since 2014 (with the exception of 2015, 2019, and 2023). Only one project using a midsize wind turbine was reported in 2023, which was deployed for a utility customer. Both projects using large wind turbines were installed for industrial customers, collectively representing 7.3 MW—the majority of documented capacity in 2023. Distributed wind for agricultural and commercial customers each accounted for approximately 3% of the distributed wind capacity installed in 2023. In contrast, residential, institutional, and government customers accounted for even less—each at or under 0.5%.

Institutional and government customers have typically represented a smaller number of projects and total percentage of project capacity. Government projects include wind turbines for military operations, municipal water systems, prisons, parks, and tribal governments. Most institutional customers are schools, including colleges and universities, but wind turbines have also been deployed at local unions and religious establishments.

Figure 17 shows the breakdown of customer types by number of projects for 2014–2023, and Figure 18 shows the breakdown of customer types by distributed wind capacity for 2014–2023.

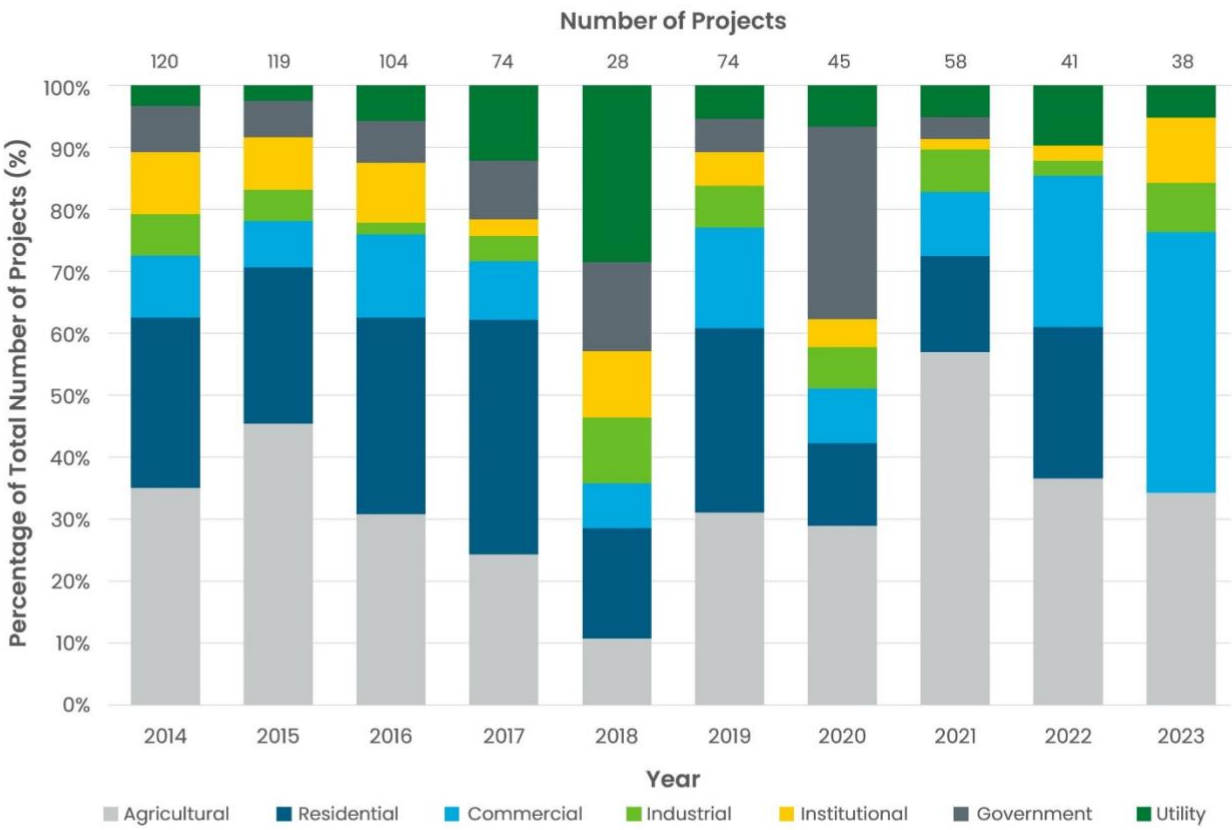

Figure 17. Distributed wind end-use customer types by number of projects, 2014–2023

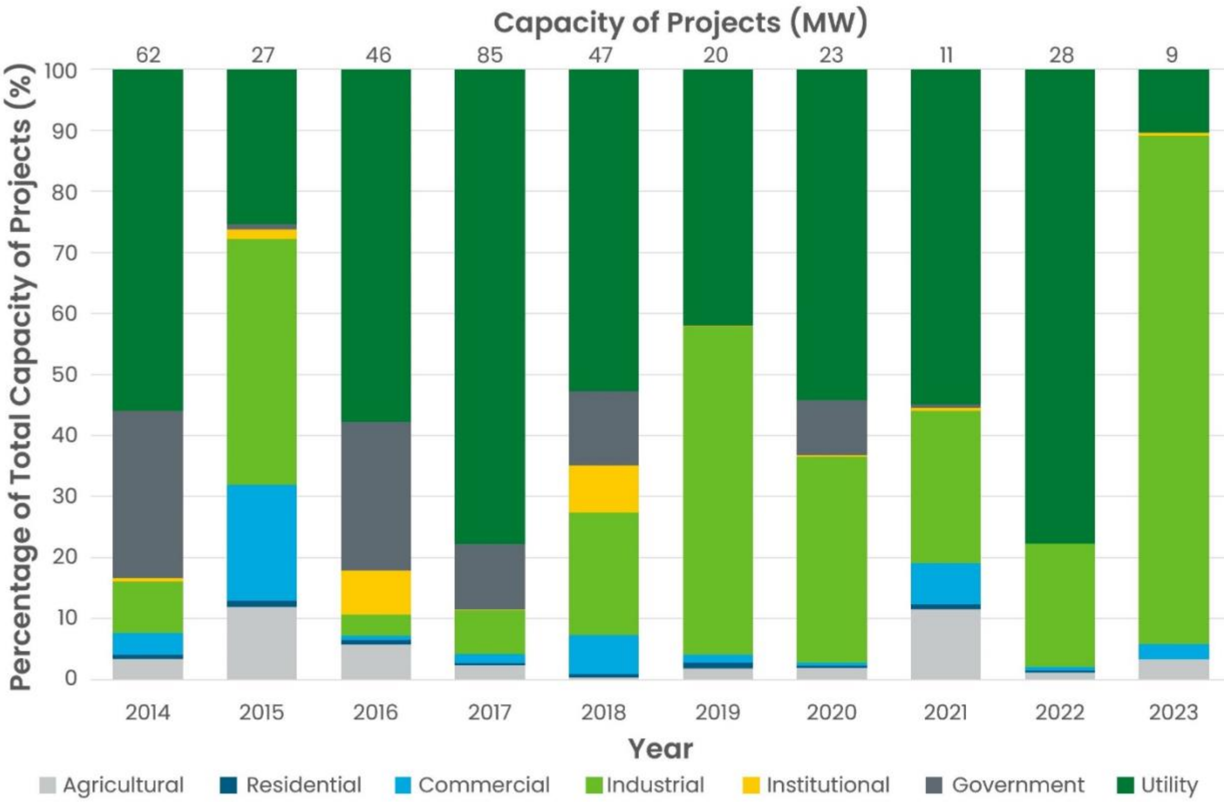

Figure 18. Distributed wind end-use customer types by capacity of projects, 2014–2023

8.2 Interconnection Types

This report tracks two primary interconnection types for distributed wind: on-site use (i.e., behind-the-meter, remote net-metering, grid-connected microgrid, and off-grid applications) and local use (i.e., load-serving distribution line and isolated grid applications). In 2023, 82% of the distributed wind projects were deployed to provide energy for on-site use and 18% of projects were interconnected to a distribution grid to provide energy for local use, as shown in Figure 19. The projects for on-site use account for 89% of the deployed distributed wind capacity in 2023 while 11% of the capacity was from projects providing energy for local use, as shown in Figure 20.

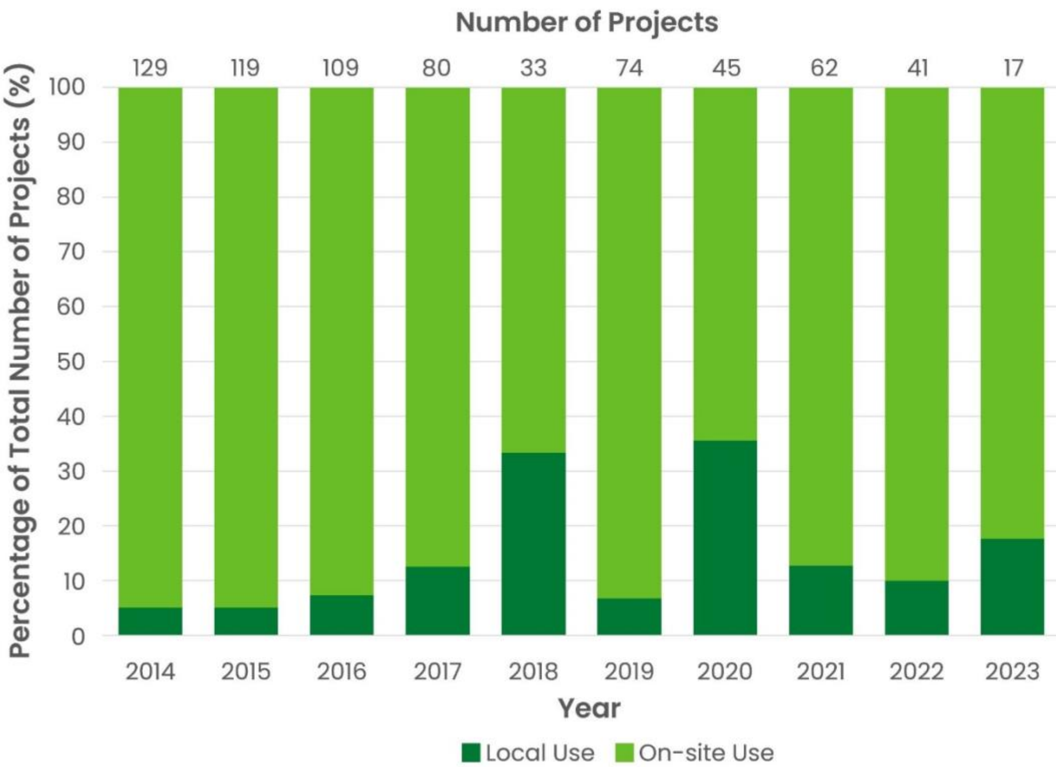

Figure 19. Distributed wind for on-site use and local loads by number of projects, 2014–2023

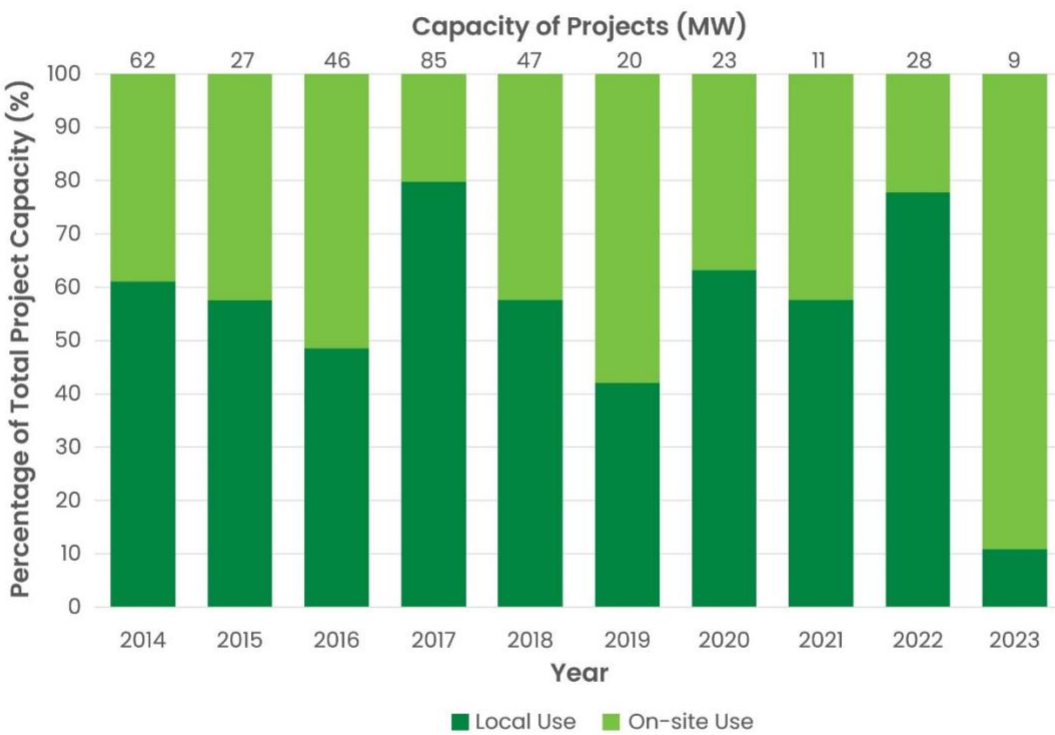

Figure 20. Distributed wind for on-site use and local loads by capacity of projects, 2014–2023

Most distributed wind projects for on-site consumption are behind-the-meter installations for rural or suburban homes, farms, schools, and manufacturing facilities. In 2023, 93% of all on-site use projects were deployed as behind-the-meter installations. About 4% of the distributed wind capacity deployed for on-site use in the PNNL team's master project dataset is in grid-connected microgrids (representing 14.2 MW). About 6% of the on-site use capacity is remote net-metered (representing 22.1 MW).

Off-grid small wind turbine models account for the bulk of wind turbine units deployed in U.S. distributed wind applications, but because off-grid projects are challenging to track, they account for a tiny fraction of the on-site use capacity documented in the dataset. In 2023, PNNL documented one off-grid project, which accounted for 7% of all on-site use projects installed that year. In terms of domestic sales, an estimated 95% of turbine units deployed in 2023 in 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 94% in 2022 and 96% in 2021.

While most distributed wind projects are interconnected for on-site use, projects for local use typically represent more of the installed distributed wind capacity due to the projects' larger sizes and use of larger turbines. The year 2023 marks a departure from this trend due to two large on-site use projects (collectively utilizing four turbines and contributing 7.3 MW of capacity) supporting industrial loads. About 4% of the distributed wind capacity deployed for local use in PNNL's master project dataset are in isolated grids (24 MW) while the rest is in front-of-meter installations on distribution systems connected to transmission systems.

9 Distributed Wind Technology

This section explores the project specifications of distributed wind sales and installations.

9.1 Wind Turbine Sizes

Because the distributed wind market is not uniform, this report analyzes the market from different perspectives, including by turbine size and customer type. Different factors are at play for each turbine size segment, partly because some turbine sizes are more applicable for certain customer applications than others.

Large turbines dominate the distributed wind annual installed capacity because of their higher capacity. As the number of customers using higher-capacity large turbines has increased, so has the average nameplate capacity of turbines greater than 100 kW in distributed wind projects, as shown in Figure 21. In 2003, the average turbine capacity used in distributed wind projects with turbines greater than 100 kW in size was 1 MW. In 2018, the average capacity was 2.2 MW—just more than double that of turbines used in 2003. The trend was disrupted by a bump in midsize turbine deployment in 2021 and 12 midsize turbine repowers in 2020. The average size of turbines greater than 100 kW in distributed wind projects in 2023 was 1.6 MW, a decrease from the record-high 2.7 MW average in 2022. This decrease can partially be attributed to a midsize turbine deployment in 2023, compared to no midsize turbine deployments in 2022.

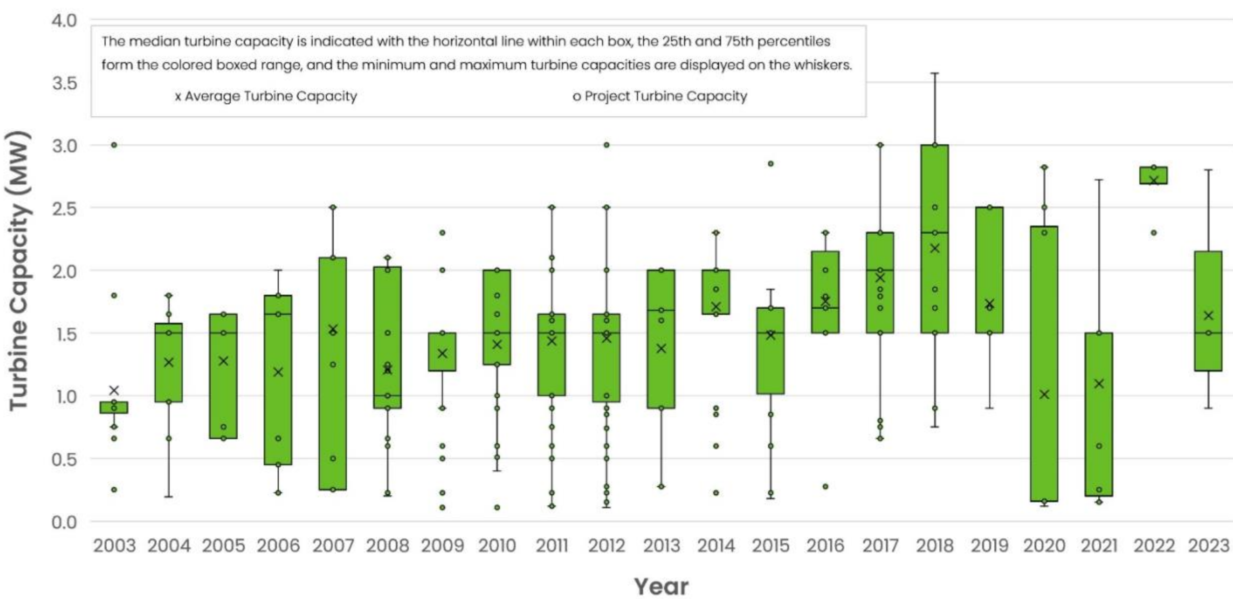

Figure 21. Size of midsize and large turbines in distributed wind projects, 2003–2023

Figure 22 shows the annual small wind capacity additions by turbine size and Figure 23 shows the percentage of capacity additions by turbine size. The less-than-1-kW size segment represents 25% of the small wind capacity sold in 2023 reaching a total of 0.6 MW. The size segment of 1–10 kW represents 5% making up to total of 0.1 MW. And the size segment of 11–100 kW (new and refurbished) represents 70% contributing to a total capacity of 1.6 MW.

There is typically noticeable year-to-year variation in the size segments, but there was minimal change from 2022 to 2023. Unit sales of the less-than-1-kW turbine size represent slightly more of the overall small wind capacity in 2023 due to an increase from 1,642 units for a total of 0.5 MW sold in 2022 to 1,888 units for a total of 0.6 MW sold in 2023. Meanwhile, turbine sales in the size segment of 11–100 kW slightly decreased in

2023, as there were a reported 78 turbine units for a total of 1.6 MW sold compared to 80 units for a total of 1.7 MW in 2022. Although there was little variation this year, reasons for variation can include inconsistent sales due to changing market conditions and turbine manufacturer business operations. The single-year presence of a given manufacturer can significantly affect overall small wind sales capacity. The recent market reentries of the Skystream 3.7 turbine model on the lower end of the small wind size range with a 2.4 kW nominal capacity and the NPS 100 turbine model at the top of the small wind size range with a 100 kW nominal capacity could reshape the segment representations in Figure 22 and Figure 23 in the coming years.

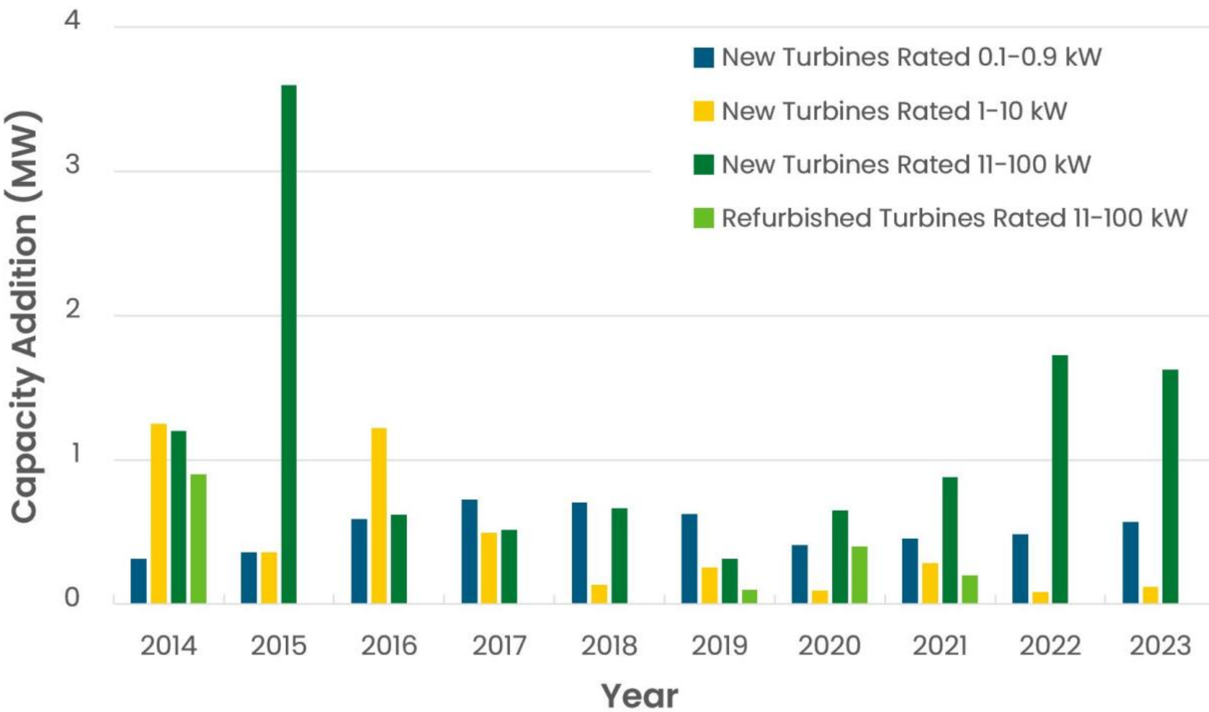

Figure 22. U.S. small wind sales capacity by turbine size, 2014–2023

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), some manufacturers who responded historically did not respond this year and some were likely missed, particularly small wind vertical-axis wind turbine manufacturers. In 2023, vertical-axis wind turbine models (all less than or equal to 4 kW in nameplate capacity) accounted for about 1% of the U.S. small wind turbine units sold. Vertical-axis wind turbine models accounted for about 2% of turbine units in 2022 and 1% in 2021 and 2020.

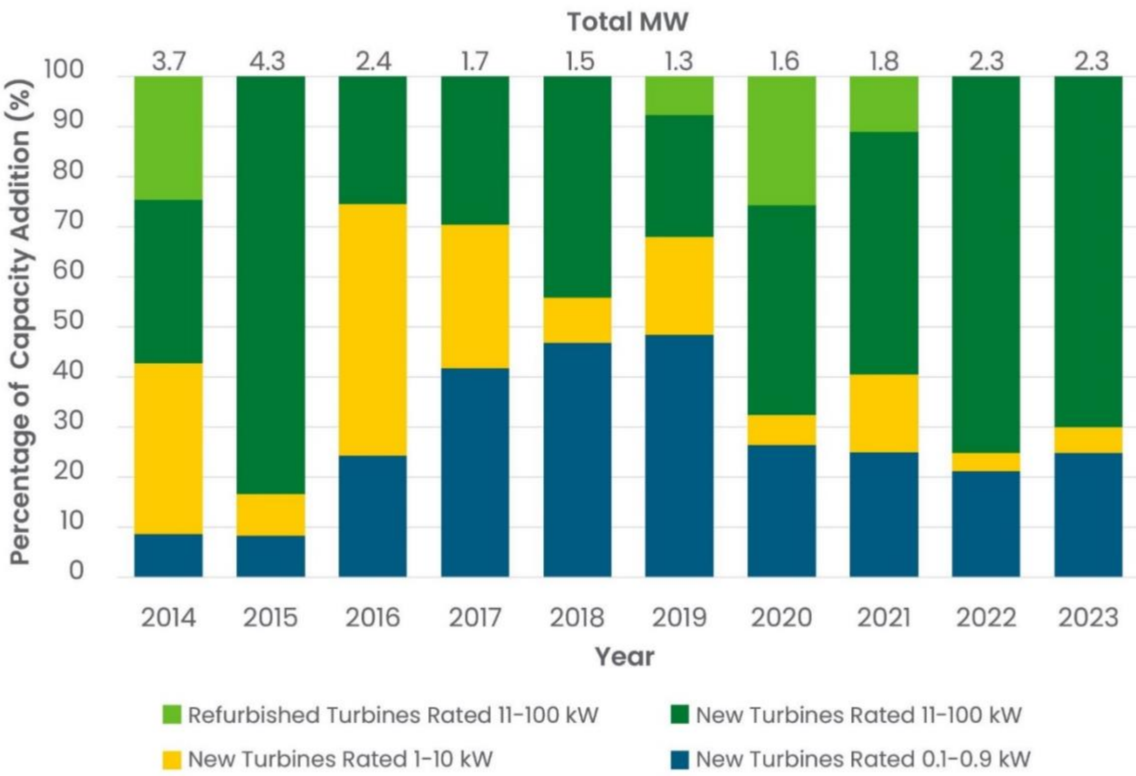

Figure 23. U.S. small wind sales percentage of capacity by turbine size, 2014–2023

9.2 Type of Towers

From 2003 through 2023, the majority of documented distributed wind projects used self-supporting monopole (including tilt-ups) and self-supporting lattice towers, representing 42% and 41%, respectively, of projects that provided tower type information to PNNL. Self-supporting lattice towers are the most common in small wind projects, deployed in 48% of all small wind projects reporting tower information. Self-supporting monopole towers are predominantly used in projects with turbines greater than 100 kW, representing 97% of projects in this size category.

Of the 12 projects for which PNNL was able to collect tower type information in 2023, eight small wind projects use self-supporting monopole towers, one small wind project uses a self-supporting lattice tower, and one small wind project is a rooftop installation. The midsize turbine project and one large turbine project use self-supporting monopole towers. For small wind projects installed in 2023, reported hub heights are 12 m (39 ft), 24 m (79 ft), 25 m (82 ft), 29 m (95 ft), 30 m (98 ft), and 37 m (121 ft). The midsize project installed in 2023 has a hub height of 75 m (246 ft), and the large turbine with a reported hub height in 2023 has a height of 80 m (262 ft).

10 Future Outlook and Market Potential

The Distributed Wind Energy Futures Study, released in May 2022 by NREL and funded by WETO, determined substantial economic potential for distributed wind (defined as a project with a positive rate of return). The 2022 baseline scenario economic potential was 919 GW for behind-the-meter installations and 474 GW for front-of-the-meter installations (McCabe et al. 2022). Future scenarios that include increased policy support point to even greater potential for the industry. With the IRA's extension of the existing ITC and provision for the future Clean Energy ITC, the distributed wind industry has federal policy support.

In addition to the ITC, the IRA allocated $144 million in grant funding for underutilized technologies through USDA REAP (USDA 2024). A joint initiative between USDA and DOE was launched in February 2024 to help farmers cut costs and increase income through REAP-supported distributed wind projects. The RAISE initiative includes an additional $4 million investment from DOE to test and commercialize distributed wind technologies and develop business models that allow farmers to earn revenue from deploying these technologies. USDA has set an initial goal to help 400 individual farmers install distributed wind turbines through the RAISE initiative. This could significantly influence the rural and agricultural market segments in the coming years.

Additional federal initiatives are poised to decrease well-known deployment barriers across the distributed wind market at large. Namely, momentum is building to address common siting and permitting challenges. In September 2023, DOE announced a $4.5 million award to the International City County Management Association to support innovative zoning and permitting approaches (DOE 2023a). This project will leverage the success of the SolSmart program to develop national outreach, training, and technical assistance programs to help local governments improve permitting processes for distributed wind (DOE 2024a).

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Appendix A: Wind Turbine Manufacturers and Suppliers

The small wind turbine manufacturers and suppliers listed in Table A.1 provided sales data for the listed models via the data-request process. Other small wind companies that provided information, or only had sales outside of the United States, are recognized in the Acknowledgments section. For the turbines greater than 100 kW in distributed wind projects included in the report and listed in Table A.2, the Pacific Northwest National Laboratory team reviewed the data sources described in Appendix B.

Table A.1. Small wind turbine manufacturers and suppliers

Manufacturer	Model Names	Headquarters
Aeromine Technologies, Inc.	Aeromine 5000	Texas
APRS World	WT10	Minnesota
Bergey Windpower Co.	Excel 10, Excel 15	Oklahoma
BE-Wind	EOW-100, EOW-200, EOW-300	Florida
Ducted Wind Turbines, Inc.	D3	New York
Eocycle Technologies, Inc.	EOX S-16	Canada
Northern Power Systems	NPS 100C-24, NPS 100C-27	Italy
Ryse (formerly Primus Wind Power)	Air 40, Air Breeze, Air 30, Air X Marine, Air Silent X, AirMax X	Texas

Table A.2. Midsize and large wind turbines in U.S. distributed wind projects

Manufacturer	Model Names	Headquarters
EWT Americas	52-900	Netherlands
GE Renewable Energy	2.8	United States
Goldwind	87/1500	China

Appendix B: Methodology

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

For small wind data, the PNNL team issued data requests to about 480 distributed wind manufacturers and suppliers, developers, installers, operations and maintenance (O&M) providers, state and federal agencies, utilities, and trade associations. The team compiled responses and information from these data requests (with all sources listed in the Acknowledgments section) to tabulate the deployed United States and exported small wind capacity and associated statistics as of the end of 2023. The detail with which the different respondents answered the data requests varied; thus, the team includes sample sizes and qualifications with certain analysis presentations as needed.

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

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

A project dataset was created to capture all known distributed wind projects installed in 2023. For projects using small wind turbines (up to and including 100 kW), project records were obtained directly from manufacturers and suppliers, O&M providers, utilities, and agencies through emails, phone interviews, or both. Project records collected for this report, and from past years, have been consolidated to produce a master project dataset available on PNNL's Distributed Wind Data website.

Projects reported for 2023 were cross-checked against previous records to avoid double counting. Small wind repower installations (in which either newly manufactured or refurbished turbines are installed on existing towers and foundations to replace nonfunctioning turbines or to upgrade the technology) were counted as new capacity in the given year, and the existing project records were updated accordingly. Hence, the project is not double counted. Sales and installation reports from manufacturers, suppliers, and developers were cross-referenced with records provided by agencies and installers to identify and combine information from duplicate records. Notes were made in instances of conflicting information (e.g., incentive award amounts, installed costs, and installation dates) as to which sources were used. Some newly installed projects in 2023 may use turbines sold many years ago, or donated turbines. Small wind turbine sales with project-specific records were added to the project dataset; however, most small wind turbine units sold in 2023 were not tracked at the project level.

The PNNL team 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, domestic 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, however, at least one manufacturer provides estimated turbine units sold because the company's less-than-1-kW size turbine units are shipped in bulk to distributors for resale to end users. Some installations occur after the calendar year that the wind turbine units were sold, so sales and projects were recorded separately. A U.S. sales presence is defined as manufacturers and suppliers documenting at least one sale in the United States in 2023.

Because many small wind turbine units sold are not tracked at the project level, such as off-grid turbine units, the PNNL team was unable to include them in the master project dataset. Consequently, each year's reported annual deployed capacity is a combination of the small wind sales and the projects installed using turbines greater than 100 kW for the given year.

When the PNNL team identifies projects that were installed in past years but were not previously recorded, the team adds those projects to the master project dataset. Further, the PNNL team marks turbines confirmed to be decommissioned in the dataset as such but does not actively track decommissioning. The cumulative figures, therefore, principally represent annual capacity additions, rather than confirmed operating installations. Consequently, the cumulative capacity amount presented in this report represents deployed capacity, and capacity allocations by state and by year and may differ slightly from report to report.

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

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

The PNNL team documents installed costs primarily from installers, developers, agencies, public sources such as press releases and news articles, and a few private sources. For projects using turbines greater than 100 kW, the PNNL team and the Lawrence Berkeley National Laboratory team, which authors the annual Land-Based Wind Market Report, share and cross-reference installed cost data for distributed wind projects. In some instances, installed cost figures were estimated based on reported incentive values. The PNNL team developed the reported investment values for 2023 using reported installed cost data and in-house estimates based on past projects and PNNL's Benchmarking U.S. Small Wind Costs report when needed (Orrell and Poehlman 2017). The reported O&M costs are also based on data collected for Orrell and Poehlman (2017) and from data requests from previous years.

Requests for international small wind capacity reports are issued annually to international contacts to obtain the most up-to-date small wind installation numbers with a country-by-country approach. Due to variability in responses, data are presented inconsistently year-to-year and from country to country. The level of accuracy included in responses is also variable, with some countries providing detailed numbers and others providing estimates. PNNL obtained additional international data and information from members of the International Energy Agency Wind Technical Collaboration Programme Task 41 and presentations during a World Wind Energy Association webinar.

Levelized cost of energy (LCOE) calculations use the following formula:[27]

$$LCOE = \frac{(FCR \times ICC) + O\&M}{\text{AEPnet}} \qquad (1)$$

where FCR = fixed charge rate

[27] The National Renewable Energy Laboratory's LCOE formula includes a levelized replacement cost that has been excluded here.

ICC = installed capital cost ($)
O&M = annual O&M cost ($)
AEPnet = net annual energy production (kWh/yr)

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

Table B.1. Turbine models in small wind dataset

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

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Cover details: A Vensys V82 1.5-megawatt wind turbine located at Portsmouth High School in Rhode Island. Photo from Sarah Gates.