Distributed Wind Guidebook

AGRICULTURAL PRODUCERS AND RURAL SMALL BUSINESS OWNERS

Pacific Northwest
NATIONAL LABORATORY

December 2024

U.S. Department of
ENERGY

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from
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PNNL-37007

Distributed Wind Guidebook

Agricultural Producers and Rural Small Business Owners

December 2024

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Prepared for
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under Contract DE-AC05-76RL01830

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Acknowledgments

This report has been adapted from the *Distributed Wind Guidebook*, which offers a comprehensive view on core aspects of deploying distributed wind energy technologies. In comparison, this edition of the guidebook is designed to offer a more succinct and tailored guidebook for rural small businesses and agricultural producers. For additional detail on any topic presented within this edition, readers are advised to reference the original version of the *Distributed Wind Guidebook.*

> Preziuso D.C., K. Kazimierczuk, M.P. Moncheur de Rieudotte, E. Anderson, L.M. Sheridan, P.R. Jackson, and B.Y. Davis. 2024. *Distributed Wind Guidebook*. PNNL-36577. Richland, WA: Pacific Northwest National Laboratory.

The authors thank Chris Ball (Terenc), Cory Herman (U.S. Department of Agriculture), Catie Himes (Pacific Northwest National Laboratory), Scott Frazier (Oklahoma State University), Ariel Kagan (Minnesota Farmers Union), Michael Leitman (National Rural Electric Cooperative Association), Lu Nelson (Center for Rural Affairs), Charles Newcomb (Hoss Consulting), Brett Pingree (EWT), Suprajha Sudhakar (Pacific Northwest National Laboratory), Brent Summerville (National Renewable Energy Laboratory), and Andrew Tonnies (Center for Rural Affairs) for their review of this report.

This report was written as part of the Rural and Agricultural Income and Savings from Renewable Energy (RAISE) Initiative. The U.S. Department of Agriculture and U.S. Department of Energy launched the RAISE Initiative to help rural small businesses, farmers, and electric cooperatives cut costs and increase income using smaller-scale renewable energy technologies, such as distributed wind turbines. This report was funded by the Wind Energy Technologies Office, Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy under Contract DE-AC05-76RL01830.

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From left to right, top to bottom: DTE Energy, EWT America, Alice Orrell, Pat Knight, and Rural Electric Convenience Cooperative.

Acronyms and Abbreviations

AEP	annual energy production
DER	distributed energy resource
FEMP	Federal Energy Management Program
IRA	Inflation Reduction Act
kW	kilowatt
kWh	kilowatt-hour
OEM	Original Equipment Manufacturer
O&M	operations and maintenance
m	meter
m/s	meters per second
MW	megawatt
MWh	megawatt hours
PNNL	Pacific Northwest National Laboratory
PV	photovoltaics
RAISE	Rural and Agricultural Income and Savings from Renewable Energy
REAP	Rural Energy for America Program
RESP	Rural Energy Savings Program
USDA	U.S. Department of Agriculture

How to Use the Guidebook

Distributed wind energy technologies generate clean, carbon-free power close to the point of consumption (i.e., close to people and their energy needs). Distributed wind energy can help individuals, farms, businesses, and communities meet their unique goals, such as decreasing electricity bills, reducing impacts on climate change, boosting energy independence or autonomy from the electric grid, and enhancing grid reliability and resilience.

This guidebook is designed to support you in (1) deciding if distributed wind energy is right for you, (2) installing a proven wind turbine technology by working with a reputable installer, and (3) setting up your project for success through its lifetime. The information in this guidebook is tailored to rural small businesses and agricultural producers who are interested in exploring distributed wind energy to meet their electricity, resilience, financial, and environmental goals. You will find gray boxes with key topics, definitions, and considerations throughout the guidebook. A glossary of terms is provided for reference at the end of the Guidebook.

Section 1: How Do I Know If Distributed Wind is Right for Me?

- ***An Introduction to Distributed Wind:*** Distributed wind energy differs from large, utility-scale wind in that it has categorically fewer turbines, which are connected to the distribution system or in off-grid applications. Agriculturalists and rural business owners use distributed wind energy to offset retail electricity costs, support local electricity loads and grid operations, provide reliable energy, electrify remote properties not connected to distribution networks, and meet renewable energy goals and mandates.
- ***Wind Turbine Technologies:*** Wind turbines come in a range of sizes: small, midsize, and large. Turbines of any size can be used in distributed wind energy projects. Distributed wind turbines can also be coupled with other energy technologies like solar panels and batteries to create hybrid energy systems.
- ***Benefits of Distributed Wind:*** Distributed wind energy can create diverse local benefits. This includes generating local energy while minimizing land use, lowering electricity bills, increasing reliability and resilience, and complementing the generation from other renewable energy technologies.
- ***Site Suitability:*** While the type of turbine can influence project performance and energy production, the most critical determinants of whether distributed wind is feasible at your site are the wind resource, land characteristics, and project costs.

Section 2: How Do I Get Distributed Wind Installed?

- ***Working with an Installer:*** Distributed wind energy projects are best installed by a qualified installer or developer. These professionals can support you at all stages, beginning with the wind resource assessment and continuing through operation and maintenance. If you are installing a small or midsize turbine, be sure to select a certified wind turbine that has been tested and proven to meet industry standards.
- ***Grid Interconnection:*** Standards outline the process you will need to follow to interconnect your distributed wind turbine with the electric grid. An installer or developer can help file the application with your utility.
- ***Zoning, Permitting, and Regulatory Requirements:*** Similar to other development projects, your distributed wind turbine will need to be built in compliance with zoning and permitting ordinances. These requirements are in addition to interconnection requirements. Zoning refers to the general local regulations that allow and restrict various types of projects and land uses. Permitting refers to the permissions needed to construct and operate a wind turbine. Most small wind turbines will only require local permitting, while larger turbines will require state and federal permitting.

Section 3: How Do I Make Sure My Project is Successful?

- ***Installation and Maintenance Support:*** Installing a distributed wind turbine typically includes procurement, ground work, balance of station, interconnection, and commissioning. Once your turbine is commissioned, you will want to maintain the turbine through a combination of preventative, predictive, or corrective maintenance. Maintenance costs can include your provider's travel to your site, equipment rentals, replacement parts, and required repairs.
- ***Project End of Life:*** When wind turbines reach the end of their lifespan, two primary options are available: repowering or decommissioning. Repowering involves replacing or upgrading parts to extend the turbine's life and improve efficiency. Decommissioning, on the other hand, is the process to remove the turbine and restore affected land.

At the end of each subsection is a summary and additional resources that may be helpful as you further explore the opportunity for distributed wind energy.

How To Use This Guidebook Summary

- This guidebook will support you in deciding if distributed wind energy is right for you, installing a proven wind turbine technology by working with a reputable installer, and setting up your project for success through its lifetime. It is tailored to rural small business and agricultural producers.

Additional Resources

- Distributed Wind Resource Hub: https://windexchange.energy.gov/distributed-wind-resource
- Wind Energy Market Sectors: https://windexchange.energy.gov/markets

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1.0 How Do I Know If Distributed Wind is Right for Me?

Distributed wind energy technologies are one of many energy options that can help farmers, agricultural producers, and rural small business owners meet their unique goals, whether those goals relate to decreasing electricity bills, increasing local control and decision-making power over energy generation, contributing to reliability and resilience efforts, or reducing impacts on climate change.

To help you determine if distributed wind is right for you, this section introduces the fundamental concepts surrounding distributed wind, the benefits of the technologies, and the site conditions needed for your project to perform well.

1.1 An Introduction to Distributed Wind

As a form of renewable energy, wind turbines harness the power of wind using turbines to generate electricity. Wind turbine blades rotate as moving air passes through them to turn a generator to create electricity. Wind turbines can be built as part of a large, land-based or offshore wind farm to generate electricity for distant energy consumers, or as a distributed energy resource (DER) where the electricity is used locally. This guidebook focuses on the latter within rural and agricultural applications.

DERs are technologies used to generate, store, or manage energy consumption for nearby energy customers. A wind turbine used as a DER—also called distributed wind—is installed to serve on-site (e.g., to directly power your farm or business) or local energy demand (e.g., your community). Distributed wind energy projects can vary by technology size, offering customers a range of options to meet their needs and help them achieve their goals.

Farmers, agriculturalists, and rural business owners can use distributed wind energy to offset retail electricity costs, support local electricity loads and grid operations, provide reliable energy, electrify remote properties not connected to distribution networks, and meet renewable energy goals and mandates. Distributed wind energy is well-suited for rural and agricultural operations because wind turbines occupy a small land footprint, allowing for land co-use with crops, livestock (Figure 1), and related farming and grazing operations.

Farmers, agriculturalists, and rural business owners are a few of the many types of distributed wind customers. Agricultural customers have historically represented the largest customer base in terms of the number of distributed wind projects installed in the United States over the last decade (Sheridan et al. 2024), and the opportunities for farmers and rural business owners to invest in distributed wind continues to increase.

Figure 1. Cattle sheltering in the shade of a GE 1.5-megawatt wind turbine in Texas.

The U.S. Department of Agriculture (USDA) Rural Energy for America Program (REAP) was founded in 2008 and provides grant funding and loan financing to agricultural producers and rural small businesses to purchase or install renewable energy systems, including distributed wind turbines, or make energy-efficiency improvements. The Inflation Reduction Act (IRA) of 2022 included over $2 billion of funding allocated for USDA REAP, with over $300 million reserved for technical assistance and underutilized technologies, including distributed wind energy. In 2024, the Rural and Agricultural Income and Savings from Renewable Energy (RAISE) initiative, a joint endeavor between USDA and the U.S. Department of Energy was launched to help rural small businesses, farmers, and electric cooperatives reduce costs and increase income using smaller-scale renewable energy technologies such as distributed wind turbines. Through RAISE, USDA set an initial goal of helping 400 farmers install distributed wind turbines using REAP.

In addition to REAP, USDA also offers the Rural Energy Savings Program (RESP) and Community Facilities Programs. RESP provides loans to rural utilities and other companies who in turn provide loans to their consumers for cost-effective energy efficiency measures including renewable energy. The Community Facilities Programs offer direct loans, loan guarantees, and grants to develop or improve essential public services and facilities in rural areas. The Community Facilities Programs are another USDA-funded opportunity that could be eligible to support renewable energy system installation.

Inflation Reduction Act and USDA Funding

The IRA includes several policies that support distributed wind. These policies include a 30% investment tax credit for businesses and nonprofits installing projects under 1 MW through 2032, with bonuses for domestic content, locating the project in an energy community, and locating the project in low-income zones. Some financial incentives, like IRA tax credits and REAP grants or loans, can be stacked to make distributed wind projects more cost-effective.

USDA has three renewable energy programs funded in part through the IRA: REAP, Powering Affordable Clean Energy (PACE), and Empowering Rural America (New ERA). PACE focuses on cooperatives, nonprofits, Tribes, and Alaska Native/Village Corporations. New ERA awards grants to assist rural electric cooperatives with energy resilience projects.

Under REAP, agricultural producers and small businesses in rural areas (areas with populations of 50,000 or fewer residents) are eligible to receive guaranteed loan financing and grant funding for renewable energy systems or to make energy-efficiency improvements. REAP can provide loan guarantees up to 75% of total eligible product costs, award grants for up to 50 percent of total eligible project costs, or offer a combination of grant and loan guarantee funding up to 75 percent of total eligible project costs. If you are interested in applying for or seeking application assistance for REAP, contact your technical assistance providers or USDA State Energy Coordinator:

- https://www.rd.usda.gov/about-rd/technical-assistance-awards
- https://www.rd.usda.gov/contact-us/state-energy-coordinators

1.1 Summary

- Distributed wind energy can be deployed in a variety of sizes to create benefits for your rural small business or agricultural operations.
- Benefits include generating local energy while minimizing land use, lowering electricity bills, increasing reliability and resilience, and complementing the generation from other renewable energy technologies.
- Opportunities for farmers and rural small business owners to invest in distributed wind continues to increase through federal funding (e.g., REAP and RAISE).

Additional Resources

- Is Distributed Wind Right for My Rural Small Business or Farm?: https://www.pnnl.gov/sites/default/files/media/file/SEND-DW-for-Agriculture-V9.pdf
- Rural and Agricultural Income and Savings from Renewable Energy: https://windexchange.energy.gov/distributed-wind-resource#raise
- U.S. Department of Energy Distributed Wind Photo Gallery: https://www.energy.gov/eere/wind/distributed-wind-photo-gallery
- Pacific Northwest National Laboratory (PNNL) Distributed Wind Photo Gallery: https://epe.pnnl.gov/research_areas/distributed_wind/photos2.stm
- Rural Area Distributed Wind Integration Network Development Case Studies: https://www.cooperative.com/programs-services/bts/radwind/Pages/RADWIND-Case-Studies.aspx
- USDA REAP: https://www.rd.usda.gov/inflation-reduction-act/rural-energy-america-program-reap
- USDA RESP: https://www.rd.usda.gov/programs-services/electric-programs/rural-energy-savings-program
- USDA Community Facilities Programs: https://www.rd.usda.gov/programs-services/community-facilities

1.2 Wind Turbine Technologies

Wind turbines are generally characterized by their size. Categorical turbine sizes—small, midsize, or large—are determined by a turbine's rated capacity (Figure 2). Rated capacity refers to the amount of power a wind turbine is capable of producing at optimal wind speeds.

Energy: Within the context of generating and consuming electricity, energy can be thought of as the sum of electricity that is produced or consumed over some period of time. Energy is often measured in kilowatt-hours (kWh) and megawatt-hours (MWh). One MWh is the equivalent of 1,000 kWh.

> Example: A wind turbine may produce 1,000 kWh of electricity in a year, which is the equivalent of 1 MWh of electricity in a year.

Power: Power is the rate at which energy is delivered. Power is often measured in kilowatts (kW) and megawatts (MW).

> Example: A wind turbine that produces 1,000 kWh of electricity in a year may be capable of producing that electricity at a rate of 10 kW at any given moment in time.

Figure 2. Categorical sizing of wind turbines and possible applications.

Distributed wind turbines are commercially available in a wide range of sizes—from less than 1 kW to multi-MW in capacity—and heights, with towers for small turbines ranging from 10–50 meters (m), midsize turbine towers ranging from 24–75 m, and large turbine towers ranging from 58–98 m (Orrell et al. 2022). This variety offers customizable options for rural and agricultural energy needs. For example, a grain farmer in Minnesota decided to install a 25-kW wind turbine to offset 30–50% of his electricity bill after leasing some of his land to utility-scale wind farms. In another example, a vineyard in California installed a 1.85-MW wind turbine that generates 100% of the power needed to run the winery and bottling operations, plus power for an additional 125 local homes (Figure 3).

Figure 3. One 25 kW Eocycle wind turbine (left) and a 1.85-MW GE turbine (right).

Different rural and agricultural customers use turbines across the full range of commercially available sizes to meet their different energy needs (Table 1). Utility applications of distributed wind projects tend to feature large turbines, while rural businesses and homes typically have smaller turbines. Small and large agricultural producers, operators, and rural business owners may be eligible for the USDA's REAP funding, which has no maximum total size cap for wind energy projects (U.S. Department of Agriculture Rural Development). This means small, medium, and large turbines could all be potential options under this program.

Table 1. Median turbine sizes deployed across illustrative rural and agricultural applications. Data from Orrell et al. 2022.

Customer Application	Median Turbine Size
Rural Small Businesses	15 kW
Rural Homes and Residences	25 kW
Farms and Ranches	30 kW
Utilities (e.g., Cooperatives)	1,550 kW

1.2 Summary

- Wind turbines come in a range of sizes. Turbines of any size can be used in distributed wind energy projects.
- Utility applications of distributed wind projects tend to feature large turbines, while rural businesses and homes typically have smaller turbines. Small and large agricultural producers, operators, and rural small business owners may be eligible for USDA's REAP funding, which has no maximum total size cap for wind energy projects.

Additional Resources

- Distributed Wind Market Report: https://www.pnnl.gov/distributed-wind/market-report
- USDA REAP: https://www.rd.usda.gov/inflation-reduction-act/rural-energy-america-program-reap

1.3 Benefits of Distributed Wind

Integrating distributed wind energy systems into agricultural or rural settings offers a powerful combination of financial, technological, environmental, and social benefits. By adopting a co-design approach—where farmers, developers, electric cooperatives, rural utilities, and community stakeholders collaborate on project planning—these benefits can be maximized, leading to sustainable energy solutions that align with the needs and values of rural communities.

1.3.1 Financial

Energy Savings
Generating electricity on site can reduce energy bills, leading to significant cost savings. Distributed wind projects can also participate in net metering programs, allowing owners to receive credit for excess energy sent back to the grid. Off-grid or backup systems that provide power during outages on the main grid can also help avoid the costs associated with downtime.

Economic Incentives
Distributed wind energy can provide substantial economic benefits for rural communities and agricultural producers. Farmers and landowners can earn additional income through land leases or revenue-sharing agreements. Additionally, wind energy projects create local jobs, bolstering the local economy.

1.3.2 Technological

Combination with Other Distributed Energy Resources
Distributed wind energy can be integrated with other DERs, such as solar panels, battery storage, and bioenergy systems. This creates a hybrid energy system that is both resilient and reliable, catering to the diverse needs of agricultural operations. Wind energy often complements solar energy because it is typically more abundant during non-daylight hours or in different seasons, creating a more continuous energy supply. Just like stand-alone distributed wind energy turbines, distributed wind hybrid systems can span a range of sizes and are installed by different customer types (Figure 4).

Figure 4. Distributed wind energy hybrid system powering a remote monitoring station.

1.3.3 Environmental

Compatibility with Agricultural Land Uses
Wind turbines are often compatible with agricultural activities, particularly farming, ranching, and grazing. Their small footprint[1] allows for dual use, where crops can be grown (Figure 5) or livestock can graze (Figure 6) around the turbines with minimal to no disruption. Strategic placement of turbines and access roads minimizes interference with farming operations, optimizes land use, and maintains agricultural productivity.

Figure 5. Combine harvester passing by an EWT wind turbine.

Landowners can also consider entering into revenue-sharing agreements to lease portions of their land for wind farms while still retaining enough space to deploy their own turbines. This dual-use approach maximizes the economic return from the land while promoting sustainable energy practices. Access roads for larger projects can be strategically placed to serve dual purposes, such as providing additional entrances to fields or farms, thereby enhancing operational efficiency.

[1] Location determines what installed capacity (and therefore footprint) you need to get the equivalent generation from solar photovoltaics (PV) compared to wind (and vice versa). For example, you would need 120 kW of ground-mounted solar PV to generate roughly the equivalent output of a 50-kW wind turbine if you are in windy Iowa where the wind resource is stronger than the solar resource. The ground-mounted PV system would have a footprint of roughly 21,500 sq ft, and a 50-kW wind turbine would have a footprint of roughly 530 sq ft.

Figure 6. Cows grazing beneath an EWT wind turbine.

Climate Resilience
Wind energy is a zero-emissions power source, contributing to the reduction of greenhouse gases and enhancing the climate resilience of rural communities. By reducing reliance on fossil fuels, distributed wind energy helps mitigate the impacts of climate change, promoting long-term environmental sustainability.

Biodiversity and Conservation
Co-location benefits can include minimizing impacts on local wildlife and ecosystems by avoiding sensitive habitats and migration pathways, working to avoid negative effects on local biodiversity. Additionally, projects can enhance habitats by pairing development with restoration initiatives, such as planting native plants near turbines, further supporting conservation efforts.

1.3.4 Social Co-Benefits

Energy Equity
Co-designing wind energy projects with community or cooperative ownership models leads to renewable energy being shared equitably, particularly for disadvantaged communities. This approach can lower energy burdens, reduce electricity costs, and enhance electricity reliability for rural and low-income communities, promoting energy equity and distributive justice.

Opportunities for Community Engagement
Engaging local stakeholders in the planning process fosters a sense of ownership and investment in the project. This involvement ensures that distributed wind energy projects align with community values while preserving a sense of place and the rural character of the surrounding landscape. These projects also offer educational opportunities, raising awareness about the need for renewable energy and helping communities understand the differences between utility-scale and distributed wind energy.

1.3 Summary

- Integrating distributed wind energy systems into agricultural or rural settings offers a powerful combination of technological, environmental, and social benefits.
- Distributed wind energy can also be coupled with other energy technologies like solar panels and batteries to create hybrid energy systems, which may increase the magnitude or type of benefits.

Additional Resources

- Local Benefits of Distributed Wind: https://www.pnnl.gov/sites/default/files/media/file/Local-Benefits-Distributed-Wind-April-2024.pdf

1.4 Site Suitability

Three key considerations can help you understand if your site is suitable for distributed wind energy: wind resource availability, appropriate land characteristics on your property, and project economics. These three considerations can be considered an initial screen to determine if developing a distributed wind project on your property is feasible. The information that follows is meant as a reference and is not a comprehensive checklist of all preconstruction considerations.

1.4.1 Wind Resource Assessment

Rural America offers vast potential for wind energy. These areas often have better wind resources than urban or suburban areas due to the lack of obstacles like buildings and dense vegetation that can slow down wind speeds. A wind resource assessment is one of the first steps in determining a project's feasibility.

Obstacles: Buildings, tall trees, and other infrastructure can all be obstacles that affect local wind resources. These obstacles can disturb the wind, decreasing speeds and increasing turbulence (i.e., rapid changes in wind speed and direction), which can affect a turbine's ability to generate electricity.

Wind resource assessments characterize the wind at your site, including its frequency, speed, and direction, to help determine how much energy is available for a wind turbine to harness. The goals of an assessment are to determine if a sufficient wind resource exists on your property[1] and to estimate how much energy a turbine can produce in that location. If there are low wind speeds, your site may not be suitable for distributed wind.

Wind resource assessments can be performed using a variety of approaches. To determine if you have suitable wind conditions for project development at your site, an installer or developer may use modeled (i.e., an estimate) or measured (i.e., observations on your property) wind speeds. In addition to wind speed, identifying the prevailing wind direction (i.e., the most frequent direction in which the wind blows) relative to local obstacles at a site is essential to a wind resource assessment. Obstacles may inform a process known as micro-siting, where your installer or developer determines the optimal place on your property to circumvent the obstacles that have a negative impact on the wind resource.

Annual Average Wind Speed: While wind speed changes over time, installers and developers may share the annual average wind speed on your property. An annual average wind speed of at least 4 meters per second (m/s) at a height of 30 m is often suitable for small wind turbines. For midsize and large wind turbines, the recommended annual average wind speed is at least 6.5 m/s at 80 m. Wind speed increases with elevation.

To convert from m/s to miles per hour (mph), see Section 4.1, Converting Units.

In addition to being of interest to you for decision-making, wind energy estimates are used in funding opportunities, such as USDA REAP, to evaluate the potential energy and economic savings of installing a distributed wind project on your property and allocate funding accordingly. While there are publicly available tools you can use to investigate the wind resource on your property, always work with a trained installer or developer before making any decisions.

1.4.2 Estimating Energy Production

The amount of energy a turbine can produce depends on the wind speed. Wind turbines have a cut-in wind speed at which they start producing energy, and most turbines also have a cut-out wind speed at which energy production ceases to prevent damage to the wind turbine. The turbine will generate power at different rates between the cut-in and cut-out speeds.

Installers and developers will often provide an estimate for annual energy production (AEP). This calculation considers the changes in wind speed over time and a turbine's ability to convert those winds into electricity. AEP provides insight into how much energy you can expect a wind turbine to produce on your property. To calculate AEP, the power output of the turbine at a given wind speed is multiplied by the number of hours in a year spent at that wind speed. Wind turbine manufacturers typically provide a power curve that shows the amount of power the turbine can produce at each wind speed (Figure 7).

[1] While this guidebook refers to distributed wind being installed on a reader's property, some distributed wind turbines are located on land that is not owned by the individuals who use the electricity (e.g., through a land lease).

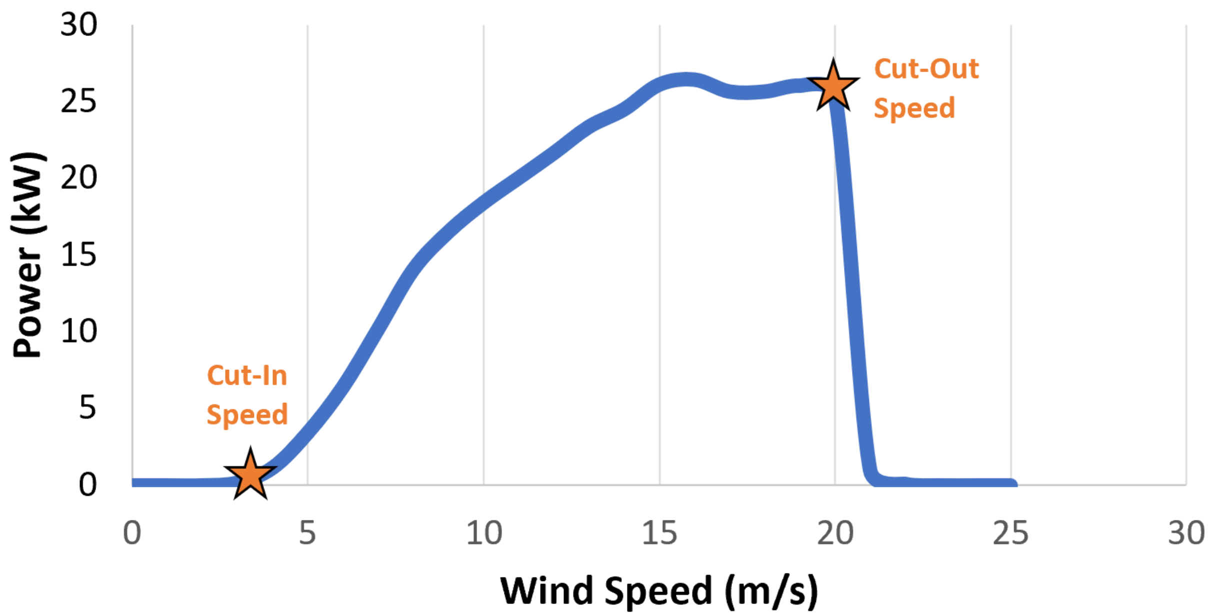

Figure 7. Wind turbine power curve for a 20-kW turbine (National Renewable Energy Laboratory 2020).

1.4.2.1 Publicly Available Tools

Before working with an installer, you may choose to use publicly available tools to get a first look at the potential for distributed wind energy at your site. The Distributed Wind Energy Association's AgWind tool provides valuable information on the wind energy potential at your site of interest, including what you need to apply for USDA REAP funding. Simply navigate to their website, submit your address, and receive a summary of relevant data. AgWind estimates the annual average wind speed and wind energy generation for your site and wind turbine of choice (Figure 8).

Other free and easy-to-use wind assessment tools are available to provide wind speed and energy estimates for comparison, along with additional features for understanding your wind energy potential. For example, WindWatts provides wind speed and wind energy estimates for different months of the year and for high, low, and average wind resource years. Global Wind Atlas provides wind speed estimates for different months of the year, different times of day, and for high, low, and average wind resource years.

AgWind Feasibility Assessment | Distributed Wind Energy Association

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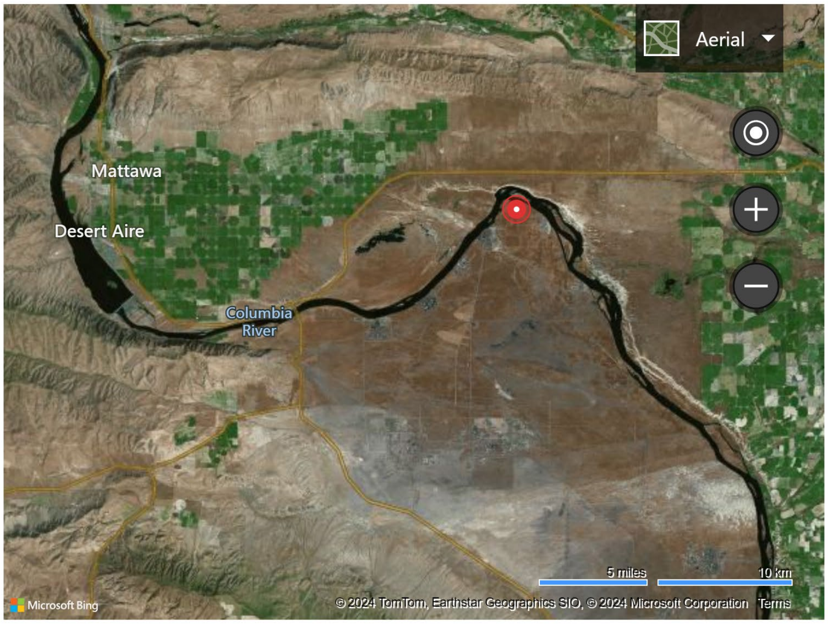

Turbine Selection	Bergey Windpower Excel 15
Rated Power [kW]	15.6
Rotor Diameter [m]	9.6
Site Location: Edna, Washington 98944	
46.712° latitude -119.51° longitude	
Average Wind Speed [mph]	9.04
Tower Height [ft]	121.0
Altitude [ft]	100.0
Weibull K	2.0
Wind Shear	0.18
Turbulence Factor [%]	10.0
Average Output Power [kW]	1.7
Daily Energy Output [kWh]	40.3
Monthly Energy Output [kWh]	1,224.3
Annual Energy Output [kWh]	14,691.8
Hub Average Wind Speed [mph]	9.0
Air Density Coefficient	1.0
Operating Time [%]	99.2

Figure 8. AgWind turbine production estimate for a potential Bergey Excel 15 wind turbine deployed at a field in central Washington State.

1.4.3 Land Availability and Characteristics

To determine if your property is suitable for distributed wind, you need available land and the ability to install the turbine in a spot where obstacles do not have a significant impact on the wind resource. For distributed wind projects with small wind turbines, at least one acre of land is often needed to meet setback requirements from property lines and to, as appropriate, mitigate impacts such as noise (i.e., sound impacts), shadow flicker (i.e., passing shadows cast by turbine blades in the sun), and ice throw (i.e., ice dislodged by blades in motion).

Sound: Pressure waves occurring at a frequency in the audible range of human hearing that are registered as sensory input by the ear. Sound is usually measured in decibels (dB). Building and planning authorities often regulate sound levels from facilities.

Shadow Flicker: A moving shadow that occurs when rotating turbine blades come between the viewer and the sun.

Ice Shedding: Ice shedding is when ice gets dislodged from turbine blades. For ice shedding to occur, ice must first accumulate on the turbine, which happens under specific climate conditions.

These requirements, often driven by local policy, can vary significantly by location. The actual footprint of the turbine's foundation, however, is relatively small (<1,000 sq ft). For example, a 20-kW turbine would have a foundation of about 15 feet by 15 feet. Projects with a single midsize or large turbine may require more than one acre when accounting for an access road. Your installer or developer will be able to guide you through that discussion.

Midsize and large turbines in distributed wind energy projects that involve more than one turbine often perform best when spaced 8–10 rotor diameters apart in the prevailing wind direction and 3–5 rotor diameters apart in the perpendicular direction (Figure 9). This spacing helps minimize losses in energy production that occur when wind turbines disrupt the wind flow that other turbines are trying to harness; these are often referred to as wake losses. These technical setbacks are needed for efficient project performance, but additional setback requirements may be defined within local policy—such as setbacks from the nearest property lines.

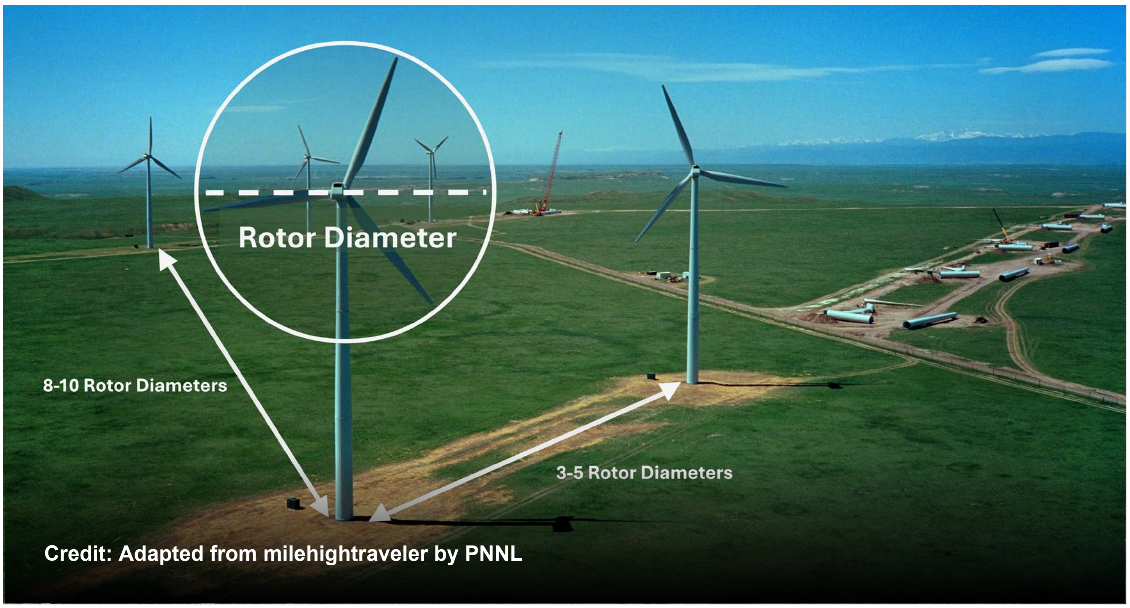

Figure 9. Spacing requirements for large, multi-turbine projects.

Your installer or developer will help determine if your property has the characteristics necessary for a successful installation and identify the best location for your wind turbine. A good rule of thumb, specifically for small wind turbines, is to install the turbine in a location where the bottom tip of the blade is at least 10 meters higher than any structures within 150 meters of the turbine (most specifically in the principal wind direction; Figure 10) (Olsen and Preus 2015).

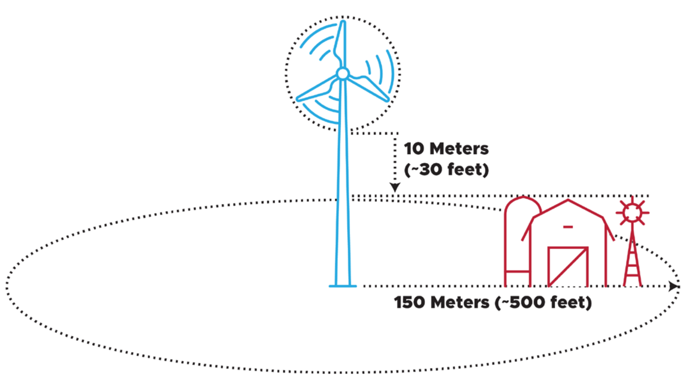

Figure 10. Rule of thumb for siting small wind turbines around structures.

These considerations highlight the importance of having a sufficiently tall tower to harness the power of wind. For this reason, rooftop wind turbines may seem like a good idea. Installing a wind turbine on a building may seem appealing from a cost-efficiency and site-suitability standpoint, but it is not recommended with turbines currently available on the market because the projects regularly do not perform as expected (Fields et al. 2016).

1.4.4 Project Costs

There is significant opportunity to profitably install distributed wind energy technologies in the United States (McCabe et al. 2022). To know if your project might be profitable, you will want to understand the electricity rates you currently pay, the different costs associated with developing a project, and the local, state, and federal incentives that can reduce the costs of your wind turbine. Where retail electricity rates are exceptionally high (and wind resource quality is good), distributed wind can be especially economical. Many installers and developers can support you in understanding what policies can further support project development and how to access them.

Costs

Between 2013 and 2023, the average installed cost was $10,670/kW for new wind projects using small wind turbines and $4,050/kW for projects using turbines greater than 100 kW (Sheridan et al. 2024). The difference in average installed costs between small and large turbines is primarily due to economies of scale, making the installation of large turbines and their associated components cheaper than that of small turbines. With distributed wind projects, you effectively finance energy production costs upfront, which then provides predictable energy costs throughout the project's lifespan. Remote projects may also incur increased costs because turbine parts may need to be shipped great distances and installers may need to travel further to the development site. Transportation, taxes, inspection, design and engineering, financing, and overhead may also contribute to your project's installed costs (Orrell and Poehlman 2017).

Incentives

Financial incentives are often available to lower your project costs. In addition to those offered by USDA (Section 1.1), other federal, state, and local opportunities may be available. For example, the Inflation Reduction Act of 2022 extended the Residential Clean Energy Tax Credit through 2032. This tax credit is equal to 30% of the costs of qualified energy technologies. After 2032, the credit percentage phases down to 26% in 2033 and 22% in 2034 (United States Internal Revenue Services 2024). Distributed wind projects installed for business or investment purposes can qualify for accelerated depreciation through the federal Modified Accelerated Cost-Recovery System. This allows project owners to depreciate most project capital costs on a five-year schedule. Many federal financial incentives can be stacked, or combined, to further reduce upfront project costs. For example, a REAP grant, tax credit, and appreciated depreciation may all be applied to the same project if it meets the eligibility requirements.

Your electric service provider or electric utility may also have programs to make your project cost effective. One such policy is net energy metering, which credits customers who send excess generation from their DERs back to the grid. Under net metering, customers can potentially offset their total electricity consumption with the power produced by their wind turbine and reduce their energy costs. This is most frequently available to customers who have distributed wind on their property for on-site use. Your utility might also offer remote net metering, or virtual net metering. Virtual net metering is used to receive bill credits from an off-site system to offset other electric accounts. Note that some utilities have fixed monthly charges for access or service fees which you may be obligated to pay regardless of the energy your on-site system provides.

Not all states and local jurisdictions offer net metering, so be sure to check the rules in your area before considering it as an option. If net metering is not available there may be other options, such as a power purchase agreement (PPA). A PPA is an arrangement in which a third-party developer installs, owns, and operates an energy system on a customer's property. As the customer, you would then purchase power from the system for a predetermined rate and time, providing you with stable and low-cost electricity prices with no upfront cost to construct the system itself (U.S. Department of Energy). Other alternatives to net metering such as value stacking available in New York (New York State Energy Research and Development Authority) may be state specific, so be sure to check the offerings in your jurisdiction.

1.4 Summary

- Quality wind resource, appropriate land characteristics, and a cost-competitive project estimate are key considerations when screening your site for suitability.
- An annual average wind speed of at least 4 m/s at a height of 30 m is often suitable for small wind turbines. For midsize and large wind turbines, the recommended annual average wind speed is at least 6.5 m/s at 80 m. To convert from m/s to miles per hour (mph), see Section 4.1, Converting Units.
- For distributed wind projects with small wind turbines, at least one acre of land is typically needed to meet setback requirements. Projects with a single midsize or large turbine may require more than one acre. The actual footprint of the turbine foundation is relatively small.
- The costs associated with installing a distributed wind turbine vary greatly by size and location. Financial incentives at the federal, state, and local level are regularly available to help reduce costs. Your electric service provider or utility may also offer programs like net metering to support your project's economics.

Additional Resources

- AgWind: https://agwindenergy.org/
- WindWatts: https://windwatts.nrel.gov
- Distributed Wind Explorer: https://arcg.is/1Tb4OS1
- Global Wind Atlas: https://globalwindatlas.info/en
- System Advisory Model: https://sam.nrel.gov/
- Database of State Incentives for Renewables & Efficiency: https://www.dsireusa.org/
- A Framework for Characterizing the Risk of Ice Fall and Ice Throw from Small Wind Turbines: https://www.osti.gov/biblio/1975748
- Levelized Cost of Energy Calculator: https://www.nrel.gov/analysis/tech-lcoe.html
- Residential Clean Energy Credit: https://www.irs.gov/credits-deductions/residential-clean-energy-credit#:~:text=The%20Residential%20Clean%20Energy%20Credit,placed%20in%20service%20in%202034
- Modified Accelerated Cost-Recovery System: https://www.irs.gov/publications/p946/ch04.html

2.0 How Do I Get Distributed Wind Installed?

To install a distributed wind turbine, you will want to work with a qualified installer or developer and select a proven technology. These professionals can guide you in selecting the right turbine for your needs, assessing your wind resource, and properly installing the turbine on your property. For small and midsize turbines, you will want to select a turbine model that has been certified to industry standards by an accredited third-part certification body.

2.1 Working with an Installer

The information in this section should help you feel confident in selecting a qualified professional to work with and that your project is on a track to success. Installers can assist with selecting an appropriate turbine, connecting to your utility's grid, and understanding and navigating zoning, permitting, and regulatory requirements.

Finding an Installer or Developer: Distributed wind installers are located across the country. To find an installer near you, the Distributed Wind Energy Association maintains a directory of its members, which includes information for manufacturers, distributors, project developers, dealers, installers, and advocates. Visit: https://distributedwind.org/distributed-wind-energy-association-members-directory/. Additional installers can be found at OpenEI: https://openei.org/wiki/Distributed_Wind_Installers.

In identifying an installer or developer to work with, you may consider:

1. **Reviews and Recommendations:** Read online reviews from past customers. If possible, ask friends and neighbors who have a wind turbine for recommendations.
2. **Transparency**: A reputable installer will be upfront about the installation process and timeline. Ask if they will be using subcontractors on your project and what oversight your installer will provide.
3. **Production Estimates:** An installer should be able to provide an AEP estimate for the wind turbine.
4. **Procurement Quality:** A good installer will not only help you select a high-quality turbine, but also have high-quality equipment to get the job done. Ask your installer about certified turbine options or turbines from established manufacturers with models successfully operating in the United States. An experienced installer will not recommend an experimental or prototype turbine.
5. **Pricing and Financing**: If there are multiple companies in your area, compare quotes from installers to get the best price. A knowledgeable installer will also know about financing options and potential incentives.
6. **Experience**: Search for installers with distributed wind project experience or a proven track record for installing wind turbines. Consider the company's longevity.

2.1.1 Certified Wind Turbines

If you are interested in small or midsize wind turbines specifically, be sure to ask your installer about turbine certification. There are many commercially available small wind turbines, but quality and performance can vastly differ between products—certification is a way to show that a turbine meets industry standards. Although not required for sale, certification may be a prerequisite or eligibility requirement for project interconnection or system financing, particularly state and federal incentive programs. Small wind certification generally applies to turbines less than 150 kW in size, while type certification covers turbines greater than 150 kW (typically larger midsize and utility-scale turbines). Selecting a certified small or midsize wind turbine is highly recommended and provides assurance that the turbine you are investing in has been thoroughly vetted.

Certified Turbines and Funding Opportunities

The use of certified small and medium wind turbines is required to receive the federal Business Energy Investment Tax Credit, the Residential Renewable Energy Tax Credit, the Production Tax Credit, and to be eligible for REAP funding.

The Internal Revenue Service rules require that small wind turbines must meet either the American Wind Energy Association Small Wind Turbine Performance and Safety Standard 9.1-2009, the International Electrotechnical Commission 61400-1, 61400-11, and 61400-12 standards, or American National Standards Institute)/American Clean Power 101-1-2021, the Small Wind Turbine Standard, to be eligible. Certification must be conducted by an appropriately accredited organization, such as the Small Wind Certification Council.

In addition to turbines that are currently certified, new options are likely to be available soon through the U.S. Department of Energy's Competitive Improvement Project. The Competitive Improvement Project is working with suppliers to develop, test, certify, and commercialize next-generation turbines and components for distributed wind.

2.1 Summary

- Distributed wind energy projects are best installed by a qualified installer or developer. These professionals can support you at all stages, beginning with the wind resource assessment and continuing through operation and maintenance.
- If you are installing a small or midsize turbine, be sure to select a certified wind turbine that has been tested and proven to meet industry standards.

Additional Resources

- Small Wind Certification Council: https://smallwindcertification.org/resources/standards/
- Certified Small Wind Turbines: https://www.pnnl.gov/distributed-wind/market-report/small-wind-turbine-certifications
- Intertek: https://www.intertek.com/wind/small/#:~:text=As%20experts%20in%20worldwide%20regulatory,Code%20and%20Canadian%20Electric%20Code
- Competitiveness Improvement Project: https://www.energy.gov/sites/prod/files/2020/02/f72/cip-fact-sheet-2020.pdf

2.2 Grid Interconnection

Unless you are having distributed wind installed in an off-grid application, you will need to have your distributed wind energy project interconnected to the electric grid. An inverter makes it possible to interconnect and share excess electricity from your wind turbine back to the electric grid (Figure 11).

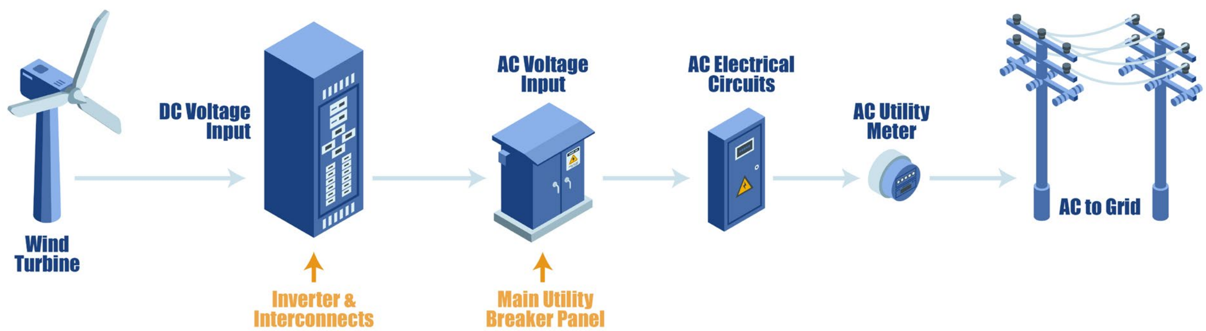

Figure 11. Standard interconnection schematic for distributed wind turbines.

The interconnection process starts with your local electric utility. Interconnections with the electric grid are guided by a set of standards that outline the process for both customers and utilities. Depending on your jurisdiction, small wind turbines may be eligible for simplified or fast-tracked interconnection approval processes. Early approval is often contingent on the size of the distributed wind turbine and if it is interconnected with an approved inverter. For distributed wind projects using midsize and large turbines, interconnection is typically a multi-step process that may take a year or longer (Sheridan et al. 2024) and more expensive than small projects.

Regardless of turbine size, your installer will need to file an application to interconnect to the electric grid and work with your utility to execute an interconnection agreement. An interconnection agreement is a contract between you and your utility that permits you to interconnect your distributed wind energy project to the electric grid. Most utilities may have inverter requirements for new projects that interconnect to their system. The timeline and cost of interconnection, much like the qualifications and procedure for interconnection, can vary by utility and project size. For small distributed wind energy projects, interconnection may cost as little as $50 and take a month to approve. As a distributed wind energy project increases in size, the cost for interconnection will increase and the approval process will lengthen. Always refer to your local utility's webpage or customer service line for specific interconnection guidelines.

What about off-grid distributed wind energy systems?

When distributed wind is used in an off-grid application, it is not interconnected to your utility's electric grid or any load-serving distribution lines. Turbines deployed in such settings may be used, for example, to power remote water pumps, irrigation systems, and other agricultural equipment. Off-grid systems typically feature small wind turbines and often microturbines, which are less than 1 kW in size. The power produced by an off-grid turbine is commonly used to power a small, single electrical load.

Just as distributed wind turbines can be coupled with other energy technologies when they are interconnected to the electric grid, distributed wind energy hybrids can also be deployed in off-grid applications (Figure 12). Off-grid projects are also eligible for REAP funding.

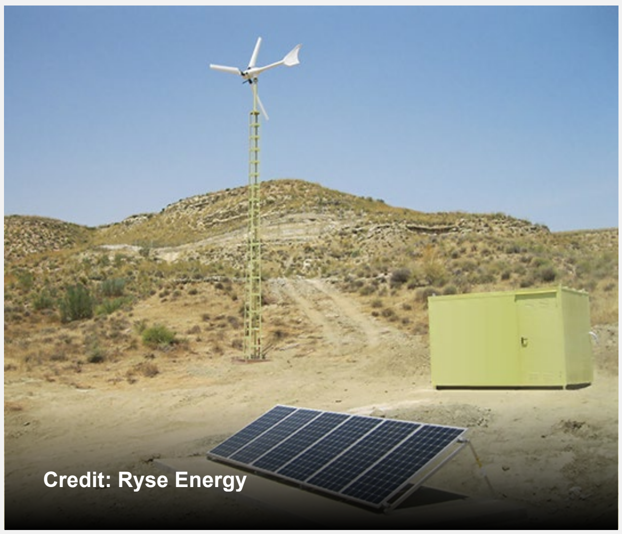

Figure 12. Hybrid off-grid project featuring solar photovoltaics and a wind turbine.

2.2 Summary

- Standards outline the process you will need to follow to interconnect your distributed wind turbine with the electric grid. An installer or developer can help file the application with your utility.
- If your distributed wind energy project is in an off-grid application, you may consider a hybrid project that includes other energy technologies like solar panels or batteries.

Additional Resources

- An Overview of Distributed Energy Resource Interconnection: Current Practices and Emerging Solutions: https://www.nrel.gov/grid/ieee-standard-1547/overview-distributed-energy-resource-interconnection.html
- i2X The Interconnection Innovation e-Xchange: https://www.energy.gov/eere/i2x/interconnection-innovation-e-xchange
- USDA REAP FAQ: https://www.rd.usda.gov/media/file/download/reap-renewable-energy-systems-faqs.pdf

2.3 Zoning, Permitting, and Regulatory Requirements

As with any development project, there may be zoning, permitting, and other local ordinances regulating construction and operation. These requirements, which are typically set by a town or county-level jurisdiction, are necessary in addition to the requirements related to interconnecting your distributed wind turbine to the electric grid, which are set by your local utility. Zoning refers to the general local regulations that allow and restrict various types of projects and land uses in certain areas, whereas permitting refers to securing all the permission documents needed to construct and operate a wind turbine. Ordinances regulate certain aspects of distributed wind projects, such as siting or construction procedures, to provide project developers with baseline standards for development. Acquiring zoning approval, securing any necessary permits, and ensuring compliance with local ordinances is a critical step for project development. In areas without established zoning and permitting for wind projects, conditional use permits may be secured.

Most small wind turbines will only require local permitting, while larger turbines will require state and federal permitting, which may include permits from your state's Department of Natural Resources (or similar authority) and/or the Federal Aviation Administration. Zoning and permitting processes ultimately seek to address safety concerns, aesthetics—such as viewshed impacts or noise—community interests, and human–environment interactions (Table 2).

Table 2. Common considerations in zoning ordinances and permitting processes.

	Concern	Description	Typical Regulation Guidance	Issuing Authority
Aesthetics	Viewshed impacts	A change to the visual landscape.	Siting to minimize visual impact.	Local
	Noise impacts	Noise caused by operation. Most small wind turbines create sound only slightly above ambient wind noise.	Selecting a turbine that can be held to sound ordinance levels.	Local
Safety	Setback restriction	Distance from the property line to protect neighbors from safety hazards and catastrophic failure.	Siting a distance of at least the total turbine height from neighbors.	Local
	Height limit	Maximum structure height for a permitted use.	Siting the rotor above obstacles but within a height limit.	Local, state, federal
Environmental Impacts	Wildlife interactions	Changes to wildlife population and habitat.	Siting away from known concentrations of sensitive and endangered species or migratory corridors.	Local, state, federal

Environmental permits may be required for distributed wind installation. However, because farmland is already developed, the likelihood of impacts to species of concern is typically relatively low compared to large wind farms. Avoiding "Prime Farmland" or "Farmland of Statewide Importance" (categories of land identified by the Natural Resources Conservation Service), using previously developed or disturbed land, and minimizing the impacts of grid connection on agricultural resources can help balance environmental concerns (Maine Farmland Trust and Maine Department of Agriculture 2022).

Applicants for REAP funding are required to provide a detailed narrative about the project's impact on the environment. This includes addressing whether and how much farmland will be converted, if the project will contribute to deforestation, and whether and how much water will be conserved by the project.

2.3 Summary

- Similar to other development projects, your distributed wind turbine will need to be built in compliance with zoning and permitting ordinances. These requirements are in addition to interconnection requirements.
- Zoning refers to the general local regulations that allow and restrict various types of projects and land uses. Permitting refers to the permissions needed to construct and operate a wind turbine.
- Most small wind turbines will only require local permitting, while larger turbines will require state and federal permitting.

Additional Resources

- Database of Local and Municipal Ordinances for Wind: https://windexchange.energy.gov/projects/ordinances
- Repository of Local Zoning Ordinances (including power limits, rotor diameter limits, noise limits, and setback distances): https://data.openei.org/submissions/5733
- Federal Aviation Administration Notice Criteria Tool: https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showNoNoticeRequiredToolForm
- Information for Planning and Consultation Tool: https://ipac.ecosphere.fws.gov/
- Distributed Wind Energy Zoning and Permitting: A Toolkit for Local Governments: https://www.cesa.org/resource-library/resource/distributed-wind-energy-zoning-and-permitting-a-toolkit-for-local-governments
- Government Review Process for Radar Interference: https://windexchange.energy.gov/projects/radar-interference-review-process
- Request for Environmental Information – Environmental Checklist: https://www.rd.usda.gov/media/file/download/rd-environmental-information-07312023.pdf

3.0 How Do I Make Sure My Project is Successful?

A successful distributed wind energy project produces the energy you expect based on your preconstruction wind resource assessment. Proper turbine installation and maintenance are key to enabling that outcome. Once your wind turbine reaches the end of its operational life, proper decommissioning or repowering makes sure that your project restores the land on which it was located or extends its life to continue electricity generation.

3.1 Installation and Maintenance Support

Once you have begun working with an installer, they will procure a wind turbine for installation and perform ground work. Ground work refers to site preparation activities, including civil and geotechnical work to survey ground conditions (e.g., soil bearing capacity and electrical resistivity) for optimal siting and project design, identify and eliminate potential hazards, and determine whether any subgrade improvements are needed for project development. After the geotechnical survey, intermediate steps may include excavation, foundation construction, electrical balance of station installation, and mechanical assembly of the turbine itself. Larger turbines typically require more infrastructure than smaller projects. Site preparation and pre-development activities for small wind projects are far less intensive, with less equipment and labor required, although the steps for installing a wind turbine are quite similar.

Once your turbine is installed, you will want to upkeep and maintain the technology. Manufacturer warranties typically cover the first 2 to 5 years of turbine operation. Often, these warranties can be extended to 5 or 10 years. In addition to your turbine's warranty, you can also establish an operations and maintenance (O&M) agreement with a professional wind turbine maintenance contractor. An agreement that spans the turbine's warranty period in addition to once it has ended is suggested to support the manufacturer's recommended maintenance schedule (Dean et al. 2015). An O&M agreement can be performed by an original equipment manufacturer, a third-party service provider, or by the project owner in-house. O&M could also be performed using a combination of these options (Table 3).

Once wind turbines start operating, following proper maintenance practices—preventative, predictive, or corrective—helps keep O&M costs down, improves turbine performance, protects the investment, and can extend the turbine's lifespan.

For large distributed wind projects, O&M expenses are expected to range from $33–59/kW/yr (Wiser et al. 2023). In the case of small wind turbines, maintenance by third-party providers includes labor, travel to the site, consumables, and possible equipment rental. As a result, maintenance costs can vary based on the provider's proximity to the project site (affecting travel costs), the availability of spare parts, and the complexity of the repairs. Scheduled annual maintenance visits for small wind turbines typically cost about $37/kW per visit, which covers labor, travel, consumables, and parts (Orrell and Poehlman 2017). This aligns with other data showing that O&M costs for distributed wind projects generally average around $35/kW/yr (NREL 2022).

Table 3. Benefits and disadvantages of different O&M agreement types.

	Original Equipment Manufacturer (OEM) Contract	Independent Service Provider Contract	In-House O&M
Benefits	• Direct access to spare parts • Direct support from OEM engineers • Greater credibility for project financing • Experienced technicians	• Customer-focused, competitive pricing • Not limited by OEM directions; could offer more solution options to turbine problems	• Optimize costs and savings (maintain control of asset) • Immediate servicing with on-site personnel (ideal for remote locations) • Ownership can encourage better care
Disadvantages	• Can be more expensive over the long term • Providing maintenance may not be a core business for OEMs • Small wind turbine manufacturers (≤100 kW) do not typically offer this service	• May struggle to get parts, leading to repair delays • Often limited in geographical coverage	• High investment for on-site staff training, tools, and spare parts • Requires managing a spare parts inventory

Types of Turbine Maintenance

Preventative maintenance, which follows the manufacturer's recommended schedule, preserves efficiency, energy output, system longevity, and safety while reducing downtime. This routine upkeep is often required by the warranty and might involve inspecting the turbine, maintaining blades, checking the production meter, and ensuring communication systems are functioning. Typically, a biannual or annual visit is scheduled based on the manufacturer's manual.

Predictive maintenance, while currently uncommon, involves monitoring the turbine to determine the best time for maintenance before a failure occurs. This approach can be more cost-effective than scheduled, preventative maintenance because it targets specific issues based on the turbine's condition, though it requires an initial investment in monitoring equipment.

Corrective maintenance happens when there is an unexpected degradation in performance or an unexpected failure or emergency, such as after extreme weather or if the turbine shows signs of unsafe operation. This could involve anything from addressing a noise complaint to replacing small parts failures to blade repairs.

3.1 Summary

- Installing a distributed wind turbine typically includes procurement, ground work, balance-of-station, interconnection, and commissioning.
- Once your turbine is commissioned, you will want to maintain the turbine through a combination of preventative, predictive, or corrective maintenance.
- Maintenance costs can include your provider's travel to your site, equipment rentals, availability of replacement parts, and the complexity of required repairs.

Additional Resources

- PNNL's Best Practices for On-Site Wind Turbines: https://www.pnnl.gov/projects/om-best-practices/onsite-wind-turbines
- Federal Energy Management Program (FEMP) Wind Energy O&M Training: https://www.energy.gov/femp/events/site-wind-energy-project-operations-and-maintenance
- FEMP O&M Considerations Checklist: https://www.energy.gov/femp/articles/operations-and-maintenance-agreement-considerations-federal-agency-site-wind-energy
- FEMP Technical Specifications for On-Site Wind Template: https://www.energy.gov/femp/articles/technical-specifications-site-wind-turbine-installations

3.2 Project End-of-Life

A wind turbine typically operates for 20–25 years depending on the operating environment. Eventually, all turbines reach the end of their useful life, though, leading to two choices: repowering or decommissioning. Repowering involves replacing some or all parts to extend the turbine's life, while decommissioning means removing the wind turbine and restoring the land it occupied (Figure 13).

Repowering installs new or refurbished parts on existing towers and foundations, either to replace nonfunctioning turbines or to upgrade to newer technology. Repowering can be partial, where only certain components like blades or gearboxes are upgraded, or full, involving a complete rebuild with all new parts. This process can increase the turbine's nameplate capacity, height, and rotor diameter.

Figure 13. Allen Farm is a generationally operated livestock farm that receives 100% of its electrical needs from a 50 kW wind turbine, which became operational in 2012 and was repowered in 2021 (Thors 2023).

Decommissioning can also be partial or full. Partial decommissioning removes equipment but leaves some underground infrastructure in place to minimize environmental impact, while full decommissioning removes all equipment, including belowground infrastructure. Both approaches can fully restore the surface of the land the turbine occupied.

The time required to disassemble and remove wind turbine components and project-related infrastructure, as well as restoring the land, depends on the size and number of turbines.

- Small turbines can be decommissioned in weeks to months, depending on service provider availability.
- Large turbines may take 6–24 months to decommission.

For midsize and large turbines, decommissioning costs can range between $19 and $39/kW, which includes costs associated with transport and disposal. Decommissioning costs typically increase with project size. Heavy equipment, such as a crane, is needed to remove the rotor and blades from the tower. With larger towers and bigger turbines, this cost increases (Cooperman et al. 2021).

3.2 Summary

- When wind turbines reach the end of their lifespan, two primary options are available: repowering or decommissioning.
- Repowering involves replacing or upgrading parts to extend the turbine's life and improve efficiency.
- Decommissioning, on the other hand, entails removing the turbine and restoring affected land.
- Decommissioned equipment can be repurposed, recycled, disposed of, or donated. Large turbines tend to have higher decommissioning costs than smaller turbines.

Additional Resources

- Wind Energy End-of-Service Guide: https://windexchange.energy.gov/end-of-service-guide

4.0 What Else Do I Need to Know?

In addition to your installer, there are several technical assistance programs available that you may qualify for, including:

- Clean Energy to Communities: https://www.energy.gov/eere/clean-energy-communities-program
- Communities Local Energy Action Program: https://www.energy.gov/communitiesLEAP/communities-leap
- Energy Improvement in Rural or Remote Areas: https://www.energy.gov/oced/era

The Distributed Wind Energy Resource Hub[1] is your one-stop shop for the latest funding opportunities and information on distributed wind energy.

4.1 Converting Units

To convert meters per second to miles per hour, multiply the meters per second by 2.237.

Meters per Second	Miles per Hour
1	2.237
2	4.474
3	6.711
4	8.948
5	11.185
6	13.422
7	15.659
8	17.896
9	20.133
10	22.37
11	24.607
12	26.844
13	29.081
14	31.318
15	33.555
16	35.792
17	38.029
18	40.266
12	26.844
20	44.74

[1] https://windexchange.energy.gov/distributed-wind-resource

To convert from meters to feet, multiply the meters by 3.281.

Meters	Feet
1	3.281
5	16.405
10	32.81
20	65.62
30	98.43
40	131.24
50	164.05
60	196.86
70	229.67
80	262.48
90	295.29
100	328.1

4.2 Glossary of Terms

This glossary of terms has been adapted from the Small Wind Guidebook: https://windexchange.energy.gov/small-wind-guidebook.

Annual energy production (AEP)—The amount of annual energy (usually in kWh) estimated for a given wind turbine at a given location. See also *energy production*.

Average wind speed—The mean wind speed over a specified period of time. See also *cut-in wind speed, cut-out wind speed, wind*.

Blades—The aerodynamic surface that catches the wind. See also *generator, rotor, wind*.

Certification—A process by which wind turbines can be certified by an independent certification body to meet or exceed their performance and durability requirements. See also *small wind turbines*.

Cut-in wind speed—The wind speed at which a wind turbine begins to generate electricity. See also *average wind speed, cut-out wind speed, wind, wind turbine*.

Cut-out wind speed—The wind speed at which a wind turbine ceases to generate electricity. See also *average wind speed, cut-in wind speed, wind, wind turbine*.

Distributed generation / energy / wind—Energy generation projects where electrical energy is generated for on-site and local consumption. Term is applied for wind, solar, and non-renewable energy. See also *energy production*.

Electric utility company—A company that engages in the generation, transmission, and/or distribution of electricity for sale, generally in a regulated market. Electric utilities may be investor owned, publicly owned, cooperatives, or nationalized entities.

Energy production—Energy is power produced and consumed over time. Energy production is therefore the energy produced in a specific period of time. Electrical energy is generally measured in kWh. See also *annual energy production*.

Gearbox—A compact, enclosed unit of gears for changing rotation, speed, or torque being transferred between machines or mechanisms. In wind turbines, gearboxes are used to increase the low rotational speed of the turbine rotor to a higher speed required by many electrical generators. The gearbox helps ensure efficient conversion of mechanical to electrical power in the generator. See also *generator, rotor*.

Generator—A machine that converts mechanical energy to electricity. The mechanical power for an electric generator is usually obtained from a rotating shaft. In a wind turbine, the mechanical power comes from the wind causing the blades on a rotor to rotate. See also *blades, gearbox, rotor*.

Grid—The utility transmission and distribution system. The network that connects electricity generators to electricity users. See also *microgrid, off-grid*.

Guyed towers—A slender structure that is supported by guy wires (or guylines) and an inexpensive way to support a wind turbine. Guyed towers can consist of lattice sections, pipe, or tubing. Because the guy radius must be one-half to three-quarters of the tower height, guyed towers require more space to accommodate them than monopole or self-standing lattice towers. See also *lattice, monopole, tower*.

Inverter—A device that converts direct current (DC) electricity to alternating current (AC) electricity.

kW—Kilowatt, a measure of power for electrical power (1,000 watts). See also *kWh, MW*.

kWh—Kilowatt-hour, a measure of energy equal to the use of 1 kilowatt in 1 hour. See also *kW, MW*.

Lattice—A structure of crossed strips usually arranged to form a diagonal pattern of open spaces between the strips. Lattice towers, either guyed or freestanding, are often used to support small wind turbines. See also *guyed tower, monopole, tower*.

Microgrid—A self-contained electrical network that integrates distributed energy resources to serve loads (i.e., sources of electrical consumption) in a discrete geographic area. A microgrid can be operated as a single entity independent from the grid, or in conjunction with it. See also *grid, off-grid*.

Micro-siting—A resource assessment method used to determine the exact position of one or more wind turbines on a parcel of land to optimize power production. See also *energy production, wind turbine*.

Monopole—A freestanding type of tower that is essentially a tube, often tapered. See also *guyed tower, lattice, tower*.

MW—Megawatt, a measure of electrical power (1,000,000 watts). See also *kW, kWh*.

Net metering—For electric customers who generate their own electricity, net metering allows for the flow of electricity both to and from the customer. When a customer's generation exceeds the customer's use, electricity from the customer flows back to the grid, offsetting electricity consumed by the customer at a different time during the same period. In effect, the customer uses excess generation to offset electricity that the customer otherwise would have to purchase at the utility's full retail rate, but state policies vary widely.

Noise—Generally defined as unwanted sound. Sound power is measured in decibels (dB). Building and planning authorities often regulate sound power levels from facilities. See also *sound*.

O&M costs—Operation and maintenance costs, including the labor, equipment, tools, and training needed to appropriately service a wind turbine and perform activities to support project performance and longevity. See also *wind turbine*.

Obstruction—A general term for any significant object that would disturb wind flow passing through a turbine rotor. Common examples are homes, buildings, trees, silos, and fences. Topographical features such as hills or cliffs that might also affect wind flow are not called obstructions. See also *rotor, wind*.

Off-grid—Energy-generating systems that are not interconnected directly into an electrical grid. Energy produced in these systems is often stored in a battery. See also *grid, microgrid*.

Permitting—The process of obtaining legal permission to build a project, potentially from a number of government agencies, but primarily from the local building department (i.e., the city, county, or state). During this process, a set of project plans is submitted for review to assure that the project meets local requirements for safety, sound, setbacks, engineering, and completeness. The permitting agency typically inspects the project at various milestones for adherence to the plans and building safety standards. See also *setback, zoning*.

Power curve—A chart depicting the relationship between wind speed and power produced by a wind turbine.

Prevailing wind—The most common direction or directions that the wind comes from at a site. Prevailing wind usually refers to the amount of time the wind blows from that particular direction but may also refer to the direction the wind with the greatest power density comes from.

Rotor—The rotating part of a wind turbine, including the blades and blade assembly. See also *blades, gearbox, generator, rotor diameter, rotor speed*.

Rotor diameter—The diameter of the circle swept by the rotor. See also *rotor*.

Rotor speed—The revolutions per minute of the wind turbine rotor. See also *rotor*.

Setback—Required distance between the turbine and a structure, property line, utility easement, or other demarcation. See also *permitting, zoning*.

Shadow flicker—A moving shadow that occurs when rotating turbine blades come between the viewer and the sun. See also *blades*.

Small wind turbine—A wind turbine that has a rating of up to 100 kilowatts and is typically installed near the point of electric usage, such as near homes, businesses, remote villages, and other building types. See also *wind turbine*.

Sound—Pressure waves vibrating at a frequency that can be registered by the ear. See also *noise*.

Tower—A structure designed to support a wind turbine at a sufficient height above grade and obstructions in a wind flow. Typical types include monopole, guyed lattice, and self-supporting lattice designs. See also *guyed tower, lattice, monopole, obstruction*.

Turbulence—Variability in wind speed and direction, frequently caused by obstacles. See also *obstruction*.

Wind—The movement of an air mass.

Wind farm—A group of wind turbines interconnected to the grid at a few common points. See also *wind turbine*.

Wind turbine—A mechanical device that converts kinetic energy in the wind into electrical energy. See also *wind*.

Zoning—Most land has been delegated to various zones by a region's local government and building department officials (at the city, county, or state level [occasionally]). The zones define types of land use, such as agricultural, residential, commercial, and industrial, and include subcategories. Each type of zoning carries its own specific permitting restrictions, such as building height and property line offsets (required separation distance). See also *permitting, setback*.

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