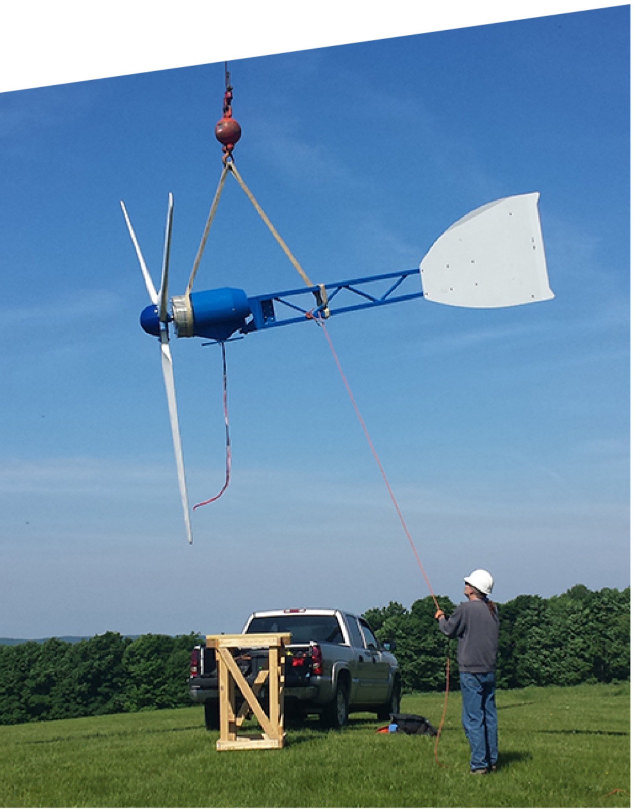
DISTRIBUTED WIND GUIDEBOOK

Pacific Northwest NATIONAL LABORATORY

November 2024



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Distributed Wind Guidebook

November 2024

Danielle Preziuso
Kamila Kazimierczuk
Malcolm Moncheur de Rieudotte
Erik Anderson
Lindsay Sheridan
Pamela Jackson
Brittany Y Davis

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Pacific Northwest National Laboratory
Richland, Washington 99354

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 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 individuals who are interested in exploring distributed wind energy to meet their energy, resilience, and environmental goals; it may also be used by community-based organizations and other local decision makers in taking informed action about if, when, where, and how to adopt distributed wind energy technologies.

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
- The Department of Energy's (DOE's) Distributed Wind Webpage: https://www.energy.gov/eere/wind/distributed-wind
- Pacific Northwest National Laboratory's Distributed Wind Webpage: https://www.pnnl.gov/distributed-wind
- The National Renewable Energy Laboratory's Distributed Wind Webpage: https://www.nrel.gov/wind/distributed-wind.html

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From left to right, top to bottom: Weaver Wind Energy, Jordan Nelson (Nelson Aerial Productions), Sarah Gates, Alice Orrell, and Roger Dixon (Skylands Renewable Energy)

Acronyms and Abbreviations

AC	alternating current
AEP	annual energy production
BOS	balance-of-station
DER	distributed energy resource
DOE	Department of Energy
FAA	Federal Aviation Administration
FEMP	Federal Energy Management Program
HAWT	horizontal-axis wind turbine
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cost of electricity
MW	megawatt
MWh	megawatt-hour
O&M	operations and maintenance
OEM	original equipment manufacturer
PNNL	Pacific Northwest National Laboratory
PV	photovoltaics
VAWT	vertical-axis wind turbine

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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 individuals and communities 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

Renewable energy comes from naturally replenished resources such as the sun, tides, and wind. Technologies that harness renewable energy, such as wind turbines, provide electricity to power our homes, businesses, and communities, and offer distinct benefits relative to non-renewable energy (e.g., coal, natural gas, oil). These benefits can include reduced carbon emissions and air pollutants, lower energy costs, and expanded energy access for remote, coastal, and isolated communities. 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 end-users, or as a distributed energy resource (DER), where the electricity is used locally. This guidebook focuses on the latter. DERs are technologies used to generate, store, or manage energy consumption for nearby energy customers. Examples include rooftop solar photovoltaics (PV), wind turbines, and battery storage. A wind turbine used as a DER—also called distributed wind—is installed to serve on-site (e.g., to directly power your home or business) or local energy demand (e.g., an island community). Distributed wind energy projects can vary by technology size or type (Section 2.2), offering potential customers a range of options to meet their needs and help them achieve their goals.

Distributed wind energy differs from utility-scale wind farms in that its electricity is intended to serve the residence, farm, business, or community that hosts the project, as opposed to generating electricity that is transported via the transmission system (Figure 1). Utility-scale and offshore wind farms typically rely on transmission lines and distribution equipment to “carry” power to distant end-users. Through that configuration, some of the generated electricity is lost along the way due to electrical inefficiencies. With distributed wind, the power does not need to be “shipped” long distances, meaning that less electricity is lost compared to utility-scale wind. The power is generated on site or locally, where it will be used directly by the project owner or to meet other nearby electricity needs.

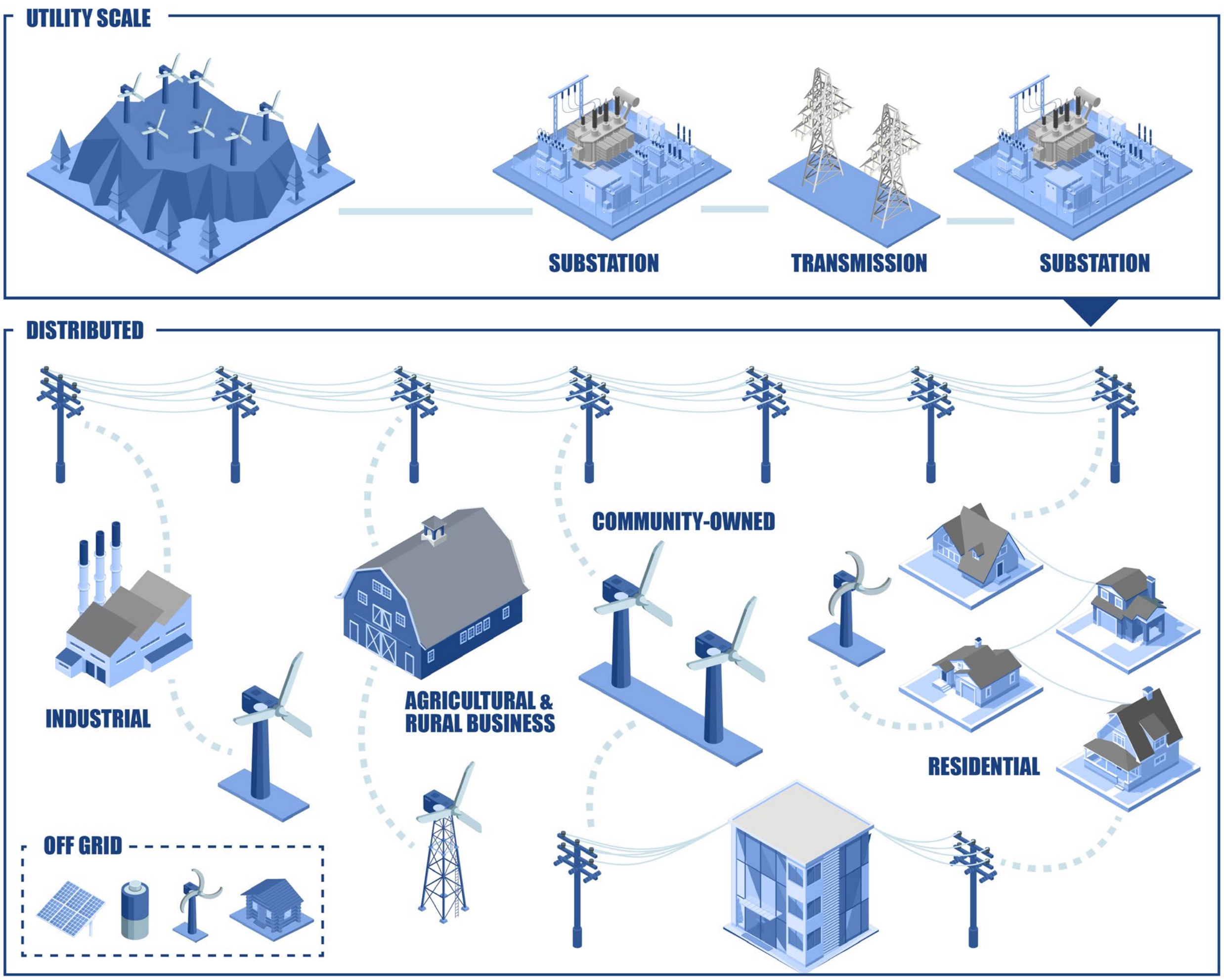

Figure 1. Distributed wind compared to utility-scale wind farms.

Distributed wind projects can range from a small, off-grid wind turbine at a remote cabin to several large wind turbines at a university campus, manufacturing facility, or other large energy user. More than 90,000 wind turbines have been installed in distributed applications (Wind Energy Technologies Office 2023). These distributed wind energy projects provide electricity to a range of customers and use a variety of technologies (Figure 2).

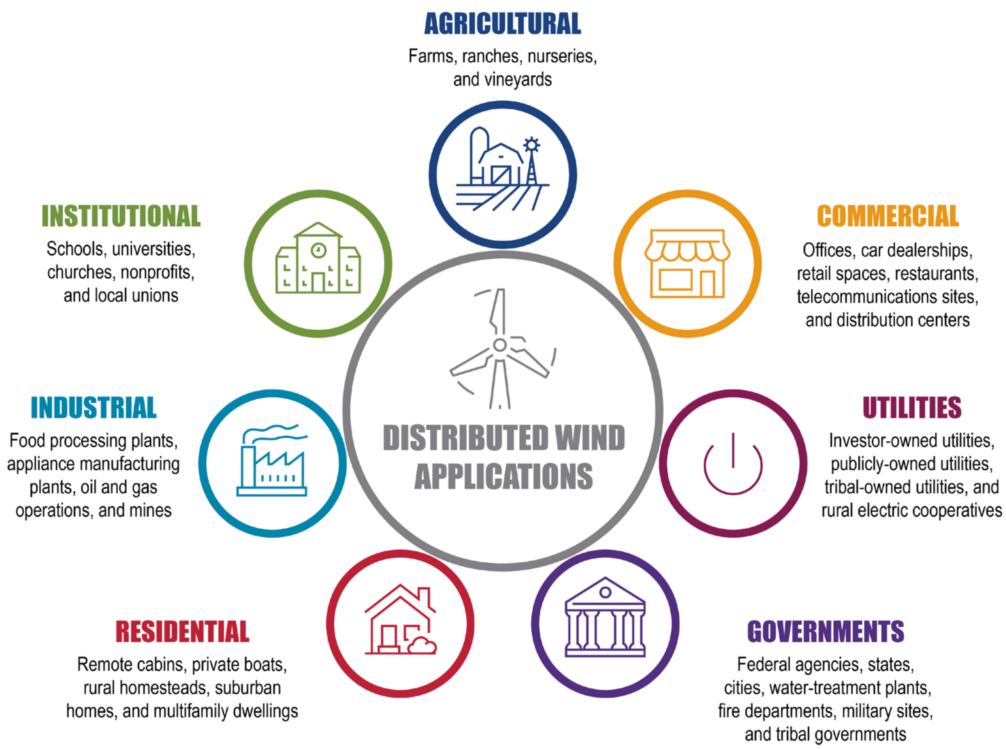

Figure 2. Distributed wind applications.

Section Summary

- Distributed wind energy can be deployed at a variety of scales to create local benefits.
- 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.

Additional Resources

- Local Benefits of Distributed Wind: https://www.pnnl.gov/sites/default/files/media/file/Local-Benefits-Distributed-Wind-April-2024.pdf
- U.S. Department of Energy Distributed Wind Photo Gallery: https://www.energy.gov/eere/wind/distributed-wind-photo-gallery
- PNNL Distributed Wind Photo Gallery: https://epe.pnnl.gov/research_areas/distributed_wind/photos2.stm
- Rural Area Distributed Wind Integration Network Development (RADWIND) Case Studies: https://www.cooperative.com/programs-services/bts/radwind/Pages/RADWIND-Case-Studies.aspx

1.2 Wind Turbine Technologies

Wind turbines are generally characterized by their size and configuration. Categorical turbine sizes—small, midsize, or large—are determined by a turbine's rated capacity. Rated capacity refers to the amount of power a wind turbine is capable of producing at optimal wind speeds. Wind turbines produce energy using the turning motion of their blades to convert kinetic energy in moving air into electricity.

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.

1.2.1 Sizes

Wind turbines are typically classified as either small, midsize, or large (Figure 3). Wind turbines used in distributed applications can range from less than 1 kW, powering remote equipment like a sailboat or log cabin, to a multi-MW wind turbine powering a large university campus or manufacturer (Figure 4).

Figure 3. Wind turbine size classification.

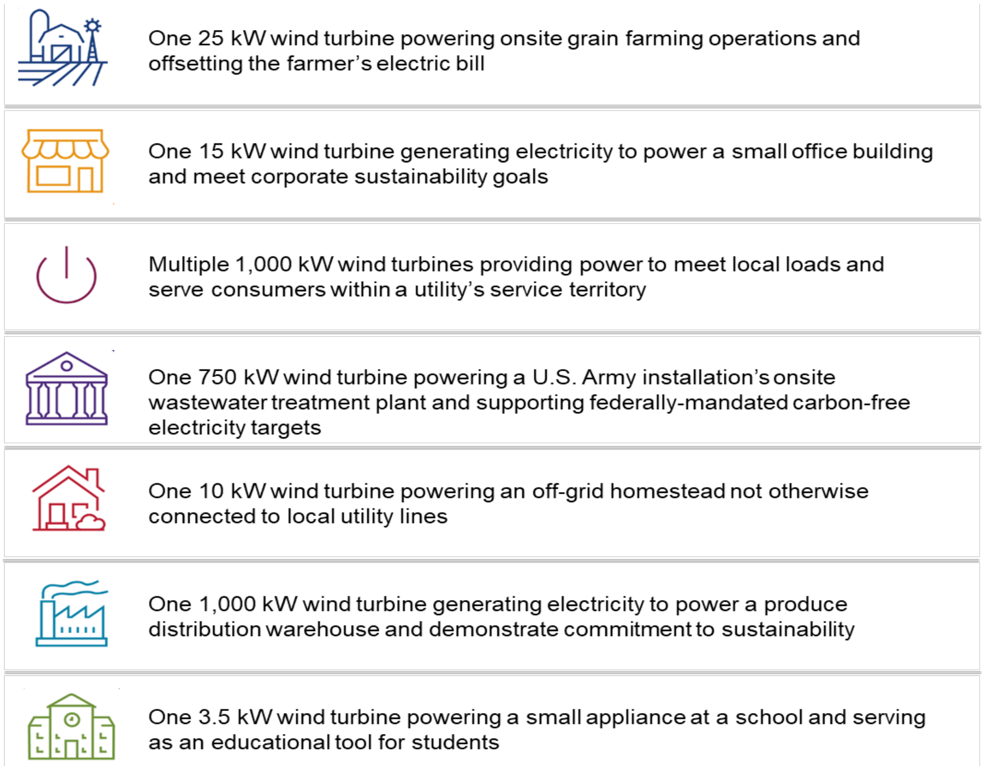

Figure 4. Examples of distributed wind turbine sizes across various customer applications.

Different customers tend to use turbines across this range of sizes to meet their different energy needs (Table 1). Residential and institutional applications have the lowest median size, and utility applications have the largest.

Table 1. Median and mode of turbine size in distributed wind energy projects from 2014 to 2023. Data source: (Orrell et al. 2022).

Customer Type	Median Turbine Size (Capacity in kW)	Mode Turbine Size (Capacity in kW)
Agricultural	20 kW	10 kW
Commercial	15 kW	15 kW
Government	705 kW	1500 kW
Industrial	1,500 kW	1500 kW
Institutional	10 kW	2.4 kW
Residential	10 kW	10 kW
Utility	2,000 kW	2,300 kW

Small	Midsize	Large
≤ 100 kW	101-1,000 kW	≥ 1,000 kW

Table of median and mode of turbine size in distributed wind energy projects from 2014 to 2023. Divided by customer types agricultural, commercial, government, industrial, institutional, residential, and utility.

1.2.2 Configurations

Wind turbines are primarily grouped into two configuration categories: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs).[1] The rotating axis of HAWTs is parallel to the wind stream, as opposed to the perpendicular configuration of a VAWT (Figure 5). HAWTs are the most used turbine configuration in today's market and typically have two or three blades made of a composite material (e.g., fiberglass). Compared to HAWTs, VAWTs have historically underperformed and continue to face more significant challenges in terms of achieving certification to industry standards that address a turbine's power production, durability, structural integrity, safety, and sound (Deign 2019; Fields et al. 2016; Pacific Northwest National Laboratory n.d.).

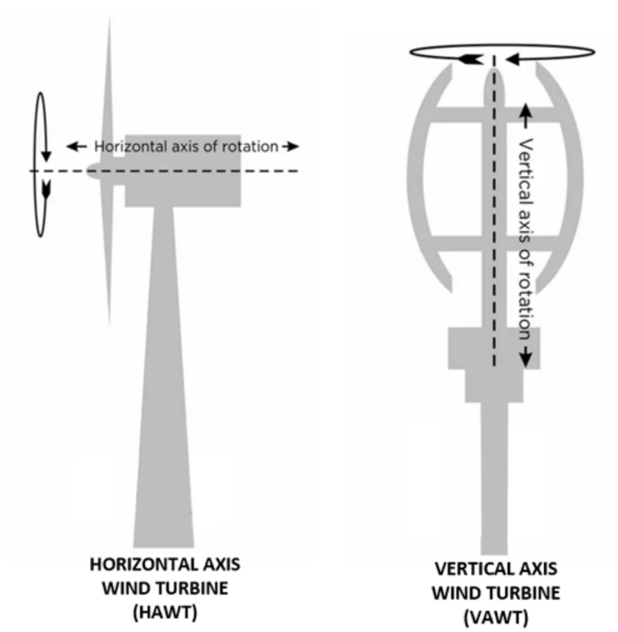

Figure 5. Comparison of horizontal and vertical wind axis turbines.

1.2.3 Components

Regardless of turbine size or configuration, the key components of commercially available wind turbines include the rotor, blades, generator, nacelle, bearings, tower, foundation, and electrical conversion equipment. Some wind turbines also have gearboxes—one of the most maintenance-intensive components of a wind turbine. When a wind turbine does not have a gearbox, it is referred to as a direct-drive system. Direct-drive wind turbines have fewer moving parts relative to turbines with gearboxes (Figure 6). For large-scale turbines in particular, direct-drive systems are taking an increasing market share due to greater efficiency and reduced system costs (Tan 2010; Donnelly et al. 2024). The key parts of a turbine, adapted from Pacific Northwest National Laboratory's (PNNL's) Operation & Maintenance (O&M) Best Practices for On-Site Wind Turbines,[2] are summarized as follows:

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[1]Other innovative configurations like wind kites are under development but are not yet commercially proven or cost effective (Weber et al. 2021).
[2]See: https://www.pnnl.gov/projects/om-best-practices/onsite-wind-turbines

- **Rotor** – Rotor blades, typically three, are attached to a hub to form the rotor. The wind spins the blades to turn the rotor, which is connected to a main shaft that is coupled to a generator. The generator converts this rotational energy into electrical energy.
- **Nacelle** – The nacelle is the main casing to which the rotor is attached. The nacelle houses key elements such as the brake, gearbox (if present), and generator. Many nacelles have spinners or nose cones on the leading edge that provide additional weather protection.
- **Gearbox** – A gearbox is used in some wind turbines to increase rotational speed from the low-speed rotor to the higher-speed electrical generator. Not all wind turbines have gearboxes; some are gearless direct-drive machines.
- **Generator** (also called an alternator) – Converts the rotational energy of the rotor into electricity. Some generators use permanent magnets and have an inverted configuration in that the outside housing rotates while the internal windings are stationary, known as direct-drive systems. Generators in this configuration produce power at low rotational speeds, eliminating the need for speed-increasing gearboxes.
- **Yaw system** – The yaw drive rotates the nacelle to keep the wind turbine oriented with the wind.
- **Tower** – Wind turbine towers are either lattice or monopole (Figure 7). Typically, larger wind turbines use freestanding monopoles, while smaller wind turbines can have lattice towers or guyed towers. Towers for distributed wind turbines vary based on the turbine's size. Based on market data from 2017–2023 (Orrell et al. 2022), typical tower height ranges for the three turbine size categories are as follows:
  - Small: 10–50 meters
  - Midsize: 24–75 meters
  - Large: 58–98 meters

  To convert from meters to feet, see Section 4.1 Converting Units.
- **Foundation** – The foundation fixes the wind turbine tower to the ground. Foundation design depends on soil conditions and turbine size.
- **Inverter** – An inverter converts variable electrical energy from the turbine into utility-compatible electricity. Inverters often have digital displays that provide information on system status, such as current output power and cumulative energy production. For a small turbine, the inverter is typically placed in an indoor location, near the main breaker to which it is connected.
- **Transformer** – Some wind turbines require transformers, while others do not. Small wind turbines with output voltages of 240 V alternating current (AC) can be integrated directly into a breaker box via an inverter, where the distribution grid power is converted to consumer-level power.

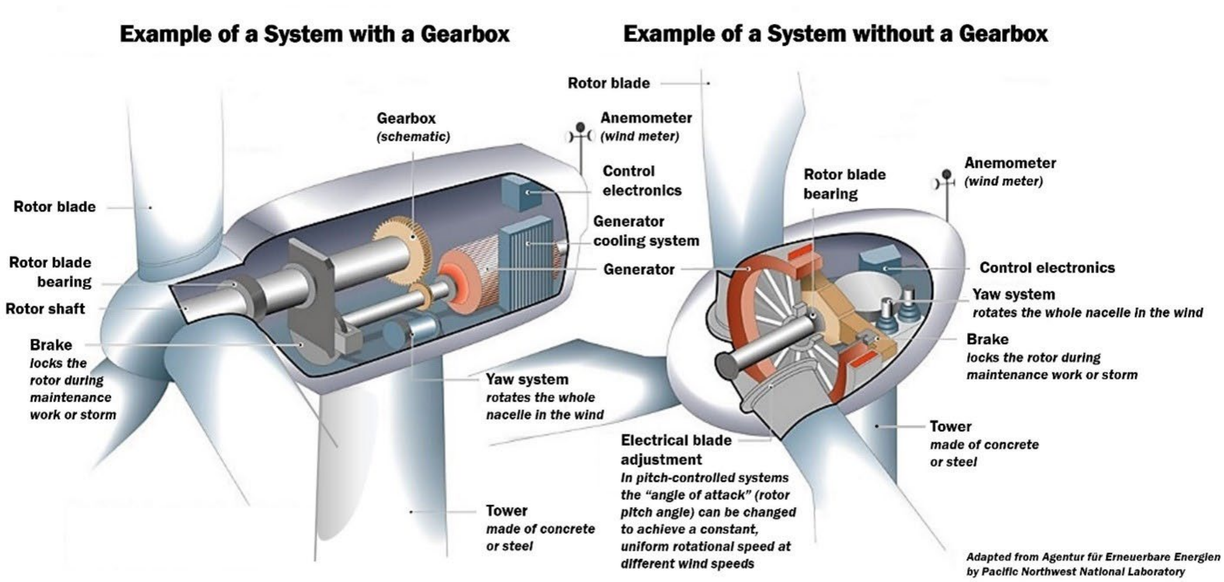

Figure 6. Direct-drive turbines compared to turbines with gearboxes.

When a wind turbine is connected to the distribution system (i.e., it is not in an off-grid application), the turbine will also require a power conditioning unit, also known as an inverter. Inverters make a turbine's output electrically compatible with the utility grid.

Figure 7. Comparison of lattice (left) and monopole (right) turbine towers.

1.2.4 Hybrid Systems

When a distributed wind turbine is coupled with another DER (e.g., solar panels or batteries) at a point of interconnection, this creates a hybrid energy system. 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 8).

Figure 8. Distributed wind energy hybrid system powering a remote monitoring station.

Section Summary

- Wind turbines come in a range of sizes and configurations. Turbines of any size can be used in distributed wind energy projects.
- Regardless of turbine size or configuration, the key components remain relatively consistent across commercially available technologies.
- Distributed wind energy can also be coupled with other energy technologies like solar panels and batteries to create hybrid energy systems.

Additional Resources

- PNNL's O&M Best Practices for On-Site Wind Turbines: https://www.pnnl.gov/projects/om-best-practices/onsite-wind-turbines
- Distributed Wind Market Report: https://www.pnnl.gov/distributed-wind/market-report

1.3 Customer Benefits of Distributed Wind

The range of turbine sizes, configurations, and applications makes distributed wind an option to support you in generating local energy while minimizing land use, lowering energy bills, improving reliability and resilience, and complementing the generation from existing renewable energy technologies. Distributed wind energy can be deployed at a variety of scales to support customers in their unique energy needs and goals.

1.3.1 Local Energy

Distributed wind turbines can provide an alternative to fossil-fuel generators powered by expensive imported fuel. The switch from fossil fuels to distributed wind energy can save customers money on their electricity bills, particularly in remote communities if there are frequent power outages or aging infrastructure. The community in St. Mary's, Alaska, installed a 900-kW turbine in 2019 (Figure 9). The wind turbine produces about 50% of the community's power, reducing dependency on expensive imported diesel, resulting in an estimated $5.3M in savings calculated over a 20-year project lifetime (Barrows et al. 2021). Beyond saving costs, this project improves local air quality by reducing CO_2 and other pollutant emissions and boosts the community's economy through construction and O&M spending.

Figure 9. 900 kW EWT wind turbine in St. Mary's, Alaska.

1.3.2 Lowering Energy Bills

In areas with net metering policies,[3] locally generated wind power can provide even greater savings on utility bills. These affordability benefits can make a significant difference in rural and/or disadvantaged communities, where residents often face disproportionately high energy costs.[4] For example, the Seneca Nation of Indians in Erie County, New York has three distinct noncontiguous territories, resulting in some tribal members paying disproportionally more for

[3] Net metering credits customers who send excess generation from their DERs back to the grid. Under net metering, customers can potentially offset their entire electricity consumption with the power produced by their wind turbine. Net metering will be discussed in depth in Section 2.2.

[4] According to DOE's Low-Income Energy Affordability Data (LEAD) tool, the energy burden (percentage of gross household annual income spent on energy costs) is three times higher for low-income households than it is for non-low-income households.

energy than others. To reduce energy bills across residents in their territories, the Seneca Nation built a large-scale 1.5 MW wind turbine on common tribal lands (Figure 10) that takes advantage of New York's virtual net metering policy. The policy allows for power generation from the turbine to offset the energy consumption for multiple retail accounts in the same service territory.

Figure 10. 1.5 MW wind turbine in Erie County, New York.

1.3.3 Reliability and Resilience

Distributed wind can be incorporated into a local microgrid—a self-contained electrical network that integrates DERs to produce localized energy—to provide power throughout grid outages, such as during natural disasters. Microgrids can be operated and function independently from the larger electric grid. In the event of a storm-induced grid outage, a microgrid can disconnect from the main grid and keep the “lights on” in a localized area. Alternatively, during periods of peak energy demand, a microgrid can connect to the larger grid for supplemental power. When combined with solar panels and battery storage in a hybrid system, the resilience benefits of distributed wind can be even greater. For example, a small Kansas microgrid consisting of a wind turbine, diesel generator, and battery storage has kept a residential survival complex powered through numerous extreme weather events that brought down local utility lines, including a winter storm that disrupted utility power for over five hours (Asmus et al. 2018).

1.3.4 Minimizing Land Use

Because the direct land use impact of wind turbines is limited to the turbine foundation, wind projects typically have a smaller land use footprint than ground-mounted solar PV.[5] Additionally, distributed wind projects take up less land than utility-scale wind farms. These turbines can be installed alongside existing land uses, such as crop or grazing land, making distributed wind an efficient use of space, especially in rural or farming communities.

1.3.5 Complementing Generation from Other Renewable Energy Technologies

Distributed wind generates clean energy that can meet specific needs or be complementary to other renewable energy sources, such as solar PV. For example, wind speeds tend to be higher in the evenings and at night, or during the winter, whereas the solar resource is typically greatest during the day and during the summer. Additionally, wind’s unique generation profile can meet specific needs, such as generating more energy in the winter to offset a utility’s winter peak demand rate or charging a battery at night.

An example of a small-sized distributed wind turbine is one owned by the Missisquoi National Wildlife Refuge in Swanton, Vermont. The refuge uses one 10 kW wind turbine (Figure 11) to diversify and seasonally complement on-site solar PV generation to collectively provide about 30% of the refuge’s energy needs. This is an example of a hybrid energy system. Because wind speeds tend to be higher in the evenings, at night, or during the winter at this location, the clean energy generated by this distributed wind project complements the solar PV, which generates more power during the day and during the summer. Aside from stable and predictable power generation, the hybrid project also increases the refuge’s energy independence and serves as an educational opportunity for park visitors to learn more about sustainability.

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[5] Location determines what installed capacity (and therefore footprint) you need to get the equivalent generation from solar 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 11. The 10 kW Bergey Excel 10 wind turbine at Missisquoi National Wildlife Refuge in Swanton, Vermont.

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

A wind resource assessment is one of the first steps in determining a project's feasibility. 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[6] 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. 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.

[6] 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).

1.4.1.1 Assessing Your Wind Resource

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 helps determine the optimal place on your property to circumvent obstacles that have a negative impact on the wind resource.

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.

The turbine size used in your project will help inform how an installer or developer performs the assessment and determines if there is a usable wind resource. Most projects that use small wind turbines rely on modeled data, while projects with midsize and large turbines gather measurements from a meteorological tower or a lidar system. When gathering on-site measurements, a collection period of at least one year is recommended because the wind resource varies seasonally.

Meteorological Tower: Meteorological towers, or met towers for short, use anemometers, wind vanes, and temperature and pressure sensors to collect wind speed and wind direction data among other useful information about local weather conditions.

Lidar: In contrast, lidar systems use electromagnetic radiation and the Doppler effect to determine wind characteristics like speed and direction. Lidar systems can be acquired through various mechanisms, including loan and purchase.

Small projects may consider on-site measurements if modeled data show large inconsistencies across different modeled datasets or if the annual average wind speed is near, but not at, the recommended minimum for wind energy deployment feasibility. Otherwise, on-site measurements are likely cost prohibitive.

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.

1.4.1.2 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. When wind speeds are below the cut-in speed or above the cut-out speed, the wind turbine will not produce energy.

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 12).

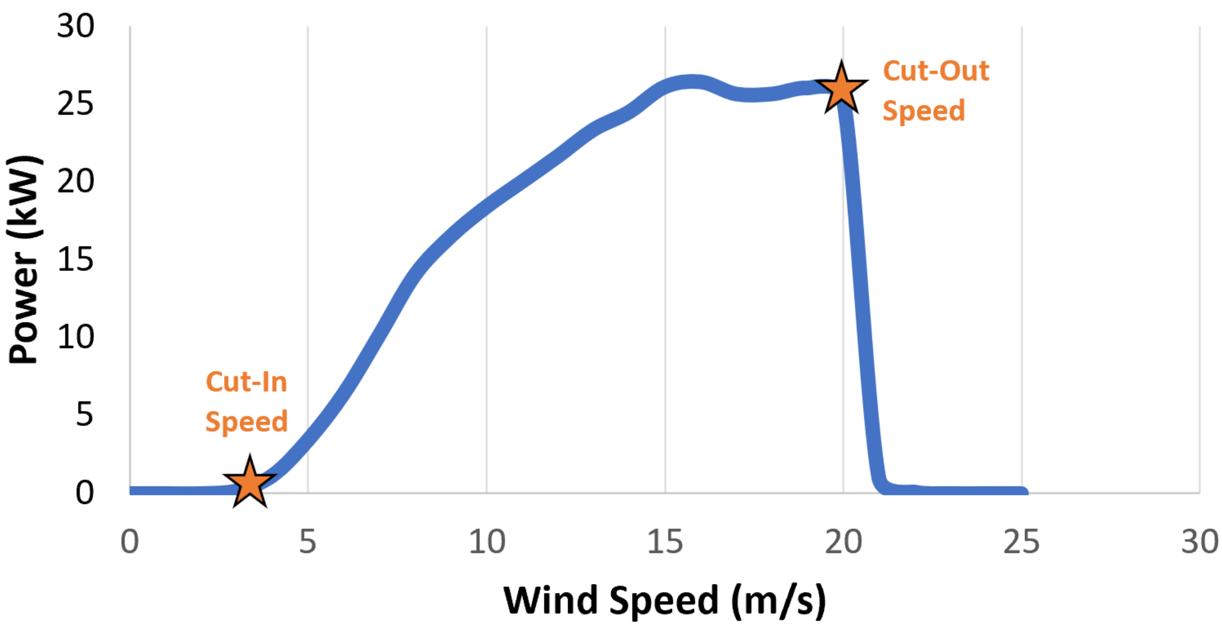

Figure 12. Wind turbine power curve for a 20-kW turbine (National Renewable Energy Laboratory 2020).

Understanding Annual Energy Production

Your installer will be able to help you estimate your AEP. Online tools are also available to support you (see Additional Resources at the end of this section). An understanding of how AEP can be calculated provides insight into what you can expect from an installer or online tool.

One way to estimate AEP from a wind turbine's power curve is to use either modeled or measured wind speed data to bin the number of hours each year spent at that wind speed. Multiply the number of hours spent at that wind speed each year by the turbine's power at that wind speed.

For example, the turbine in Figure 12 can generate 0.178 kW at a wind speed of 3 m/s (Table 2). You can multiply 0.178 kW by the 1,200 hours spent at a 3 m/s wind speed over a year to estimate that 213.6 kWh will be generated. You can repeat that process for each wind speed bin and total the energy over all wind speeds to estimate energy production for the year. To convert from m/s to miles per hour (mph), see 4.1 Converting Units.

Table 2. Annual energy production estimate table for a 20-kW reference wind turbine.

Wind Speed (m/s)	Turbine Power (kW)	Hours Spent at Wind Speed each Year	AEP (kWh)
0	0	50	0
1	0	508	0
2	0	937	0
3	0.178	1,200	213.6
4	1.147	1,306	1,497.982
5	3.428	1,244	4,264.432
6	6.403	1,069	6,844.807
7	10.168	850	8,642.8
8	14.04	613	8,606.52
9	16.5	412	6,798
10	18.4	263	4,839.2
11	20.015	149	2,982.235
12	21.636	88	1,903.968
13	23.349	44	1,027.356
14	24.482	18	440.676
15	26.096	9	234.864
16	26.424	0	0
17	25.641	0	0
18	25.641	0	0
19	26.026	0	0
20	25.385	0	0
21	0	0	0
22	0	0	0
23	0	0	0
24	0	0	0
25	0	0	0
Total	--	**8,760**	**48,296.44**

Annual energy production estimate for a 20-kW reference wind turbine

1.4.2 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). 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.

Setback Requirements: Required distance between the turbine and a structure, property line, utility easement, or other demarcation. Local ordinances often define setback requirements.

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 13). 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.

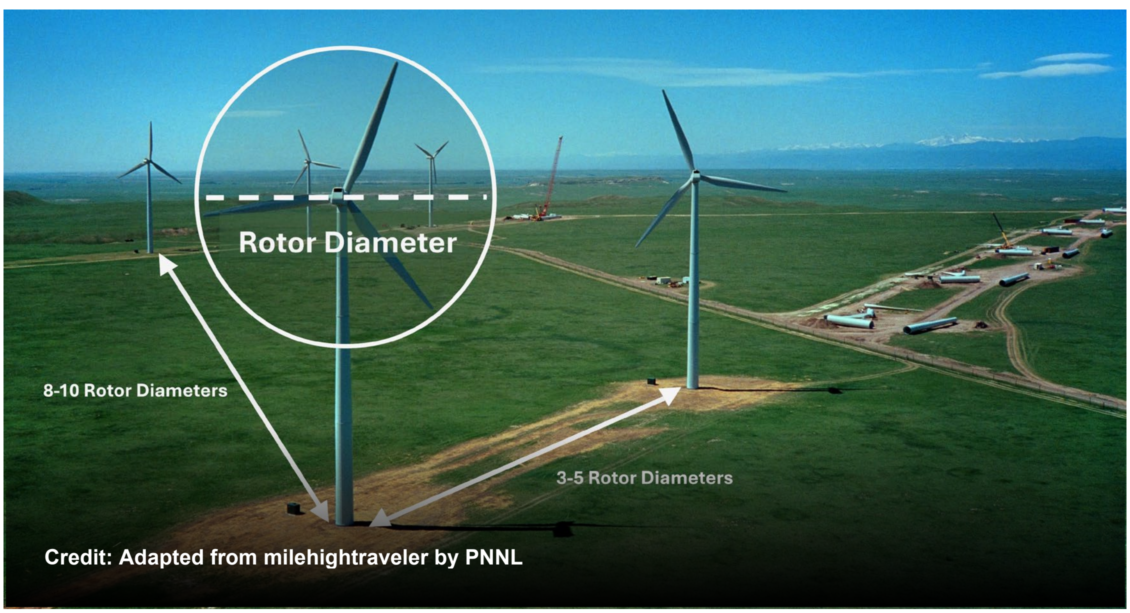

Figure 13. Spacing requirements for large, multi-turbine projects.

Ideally, a distributed wind energy project using turbines of any size should be sited in an area free of obstacles like tall trees or buildings. Having a site clear of obstacles that can disrupt the wind flow is critical to maximizing turbine performance and generation. This is not to say distributed wind projects cannot be successfully sited and installed near potential obstacles.

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 14) (Olsen and Preus 2015). To convert from m/s to miles per hour (mph), see Section 4.1 Converting Units.

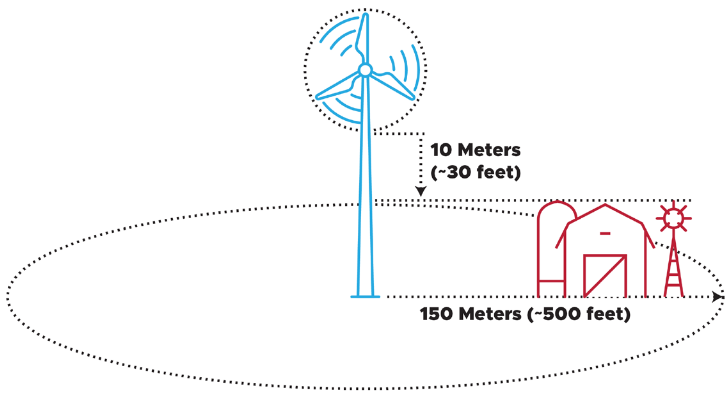

Figure 14. Rule of thumb for siting small wind turbines around structures.

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 (Fields et al. 2016). Distributed wind projects on buildings, or even near densely constructed urban areas—like a downtown city with skyscrapers—may pose significant challenges due to the obstacles that could affect the turbine's ability to generate electricity. Projects deployed in the urban environment, whether near tall buildings or on top of them, tend to underperform, with project performance often over-estimated compared to actual production (Fields et al. 2016). This means they do not produce as much energy as you would expect, potentially creating significant losses on your investment in the turbines.

While land availability and characteristics are important for identifying an appropriate place to install a turbine, some localities have zoning and permitting regulations that may place stipulations on structure heights and property setback distances. When considering a project, explore your town or community's regulations to understand how siting may be affected, and read Section 2.3 for more details.

1.4.3 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 different costs associated with developing a project as well as 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 those policies are and how to access them.

The costs associated with installing a distributed wind turbine vary greatly by size and location. The largest component of installation costs is balance-of-station (BOS) costs, which are associated with developing and commissioning the system (i.e., not the wind turbine itself). BOS costs can include but are not limited to labor, equipment, zoning, permitting, and site assessments (Forsyth et al. 2017). BOS costs typically account for up to 60% of installed system costs for small wind turbines (Orrell and Poehlman 2017). 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. 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).

Levelized Cost of Energy: While installed costs reflect the overall costs of building a wind turbine, an installer may also introduce the idea of levelized cost of energy (LCOE). LCOE is a measure of lifetime project costs (i.e., installed costs plus operation and maintenance costs) divided by energy production over the turbine's operational life.

LCOE estimates allow you to compare different energy technologies and the same technology at different scales (U.S. Department of Energy Office of Indian Energy). If you are using your wind turbine for on-site use (e.g., to power your home), you can compare your project's LCOE to your retail electricity rate. If your project's LCOE is less than your electricity rate, then the project is cost competitive. While LCOE is specific to an individual project, it can also be projected for representative cases in the future including different levels of innovation of turbine technologies (i.e., conservative, moderate, and advanced) (Table 3).

Table 3. Projected LCOE values in 2024 for three innovation scenarios.

Representative Project Size	Conservative LCOE Estimate ($/MWh)	Moderate LCOE Estimate ($/MWh)	Advanced LCOE Estimate ($/MWh)
Residential (0–20 kW)	163.56	155.89	112.47
Commercial (21–100 kW)	117.62	107.02	85.06
Midsize (101–999 kW)	77.25	77.25	68.13
Large (>1000 kW)	59.43	54.58	45.78

Additional information about how these projections were calculated can be found at https://atb.nrel.gov/electricity/2024/Distributed_Wind.

Projected LCOE values in 2024 for three innovation scenarios, conservative, moderate, and advanced. Divided by representative project sizes residential, commercial, midsize, and large.

Financial incentives are often available to lower your project costs. 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. If you are an agricultural producer or rural small business, you might also qualify for programs from the U.S. Department of Agriculture like the Rural Energy for America Program. State and local programs also offer financial incentives in the form of sales tax incentives, property tax incentives, grants, loans, and property assessed clean energy financing. 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 energy your onsite 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 are 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.

Section 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. However, 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

- Distributed Wind Power Curve Repository: https://github.com/NREL/turbine-models/tree/master/Distributed
- System Advisory Model (SAM): https://sam.nrel.gov/
- WindWatts: https://windwatts.nrel.gov/
- Distributed Wind Explorer: https://arcg.is/1Tb4OS1
- Global Wind Atlas: https://globalwindatlas.info/en
- Tools Assessing Performance for Distributed Wind: https://www.nrel.gov/wind/tools-assessing-performance.html
- Database of State Incentives for Renewables & Efficiency (DSIRIE): https://www.dsireusa.org/
- 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'll 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'll 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 and midsize wind turbine manufacturers may elect to undergo certification testing to prove their turbine has a sound design, performs as anticipated, and meets industry's quality and safety standards. 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.

Certification is important for a number of reasons beyond acting as a critical prerequisite for informed product purchasing. 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 certified turbines may facilitate easier access to project financing, be necessary for federal and state incentive eligibility and/or participation in wholesale electricity markets, and streamline local permitting and zoning regulations by demonstrating a quality, proof-of-concept technology design (Spossey 2024).

Type Certification

Certifying a mid- or large-size turbine is referred to as type certification. To be approved for certification, wind turbine manufacturers must demonstrate that their turbine model has been tested for performance, safety, and function at a testing facility and designed according to the requirements in international standards. Certification is performed by independent, accredited third-party certification bodies offering wind turbine type certification services.

Most turbine manufacturers advertise if their turbine models are type certified—usually on the certifying agency's website, a product brochure, or technical specifications document—but this is ultimately up to the discretion of the turbine manufacturer. PNNL maintains a list of certified small wind turbines (Table 4). If you are unsure whether a turbine is certified, you can always reach out to the manufacturer for more information.

Table 4. Certified small wind turbines as of 2024 (Pacific Northwest National Laboratory).

	Turbine Model	Initial Certification	Certified Power Rating @ 11 m/s (kW)
Bergey Windpower Company	Excel 10	November 16, 2011	8.9
Bergey Windpower Company	Excel 15	February 5, 2021	15.6
Eveready Diversified Products (Pty) Ltd.	Kestrel e400nb	February 14, 2013	2.5
Eocycle Technologies, Inc.	EOX S-16	March 21, 2017	22.5/28.9
HI-VAWT Technology Corporation / Colite Technologies	DS3000	May 10, 2019	1.4
SD Wind Energy, Ltd.	SD6	June 17, 2019	5.2
Wind Resource, LLC	Skystream 3.7	April 12, 2023	2.1

Certified small wind turbines as of 2024.

An additional best practice to consider when selecting a wind turbine is to identify established manufacturers. Ask your installer where else the turbine model has been installed, how those projects are performing, and about documentation from the manufacturer that demonstrates compliance (Federal Energy Management Program 2022). If an installer proposes an experimental, demonstration, or noncertified wind turbine, ask that they provide minimum performance guarantees and an agreement to remove the turbine if it does not meet those benchmarks.

2.1.2 Refurbished Turbines

Depending on availability, it may also be possible to purchase a refurbished turbine or a rebuilt, restored turbine. A refurbished turbine may have a few new parts added to it, a simple change of hydraulic or transmission fluids, or an extensive remanufacture of critical components before being resold. In addition to refurbished turbines, you may also be able to install a new turbine rotor on top of an existing tower and foundation that was previously, but no longer, used by another turbine. This is commonly referred to as a repowered project. Repowered projects can significantly decrease costs associated with distributed wind projects. From 2019 to 2021, the average capacity-weighted installed cost of repowers for small wind turbines was $4,750/kW (Sheridan et al. 2024).

Section 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/
- Intertek: https://www.intertek.com/wind/small/#:~:text=As%20experts%20in%20worldwide%20regulatory,Code%20and%20Canadian%20Electric%20Code

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. Most wind turbines produce direct current (DC) power, requiring an inverter to convert the power to AC. The inverter makes it possible to interconnect and share excess electricity from your wind turbine back to the electric grid (Figure 15).

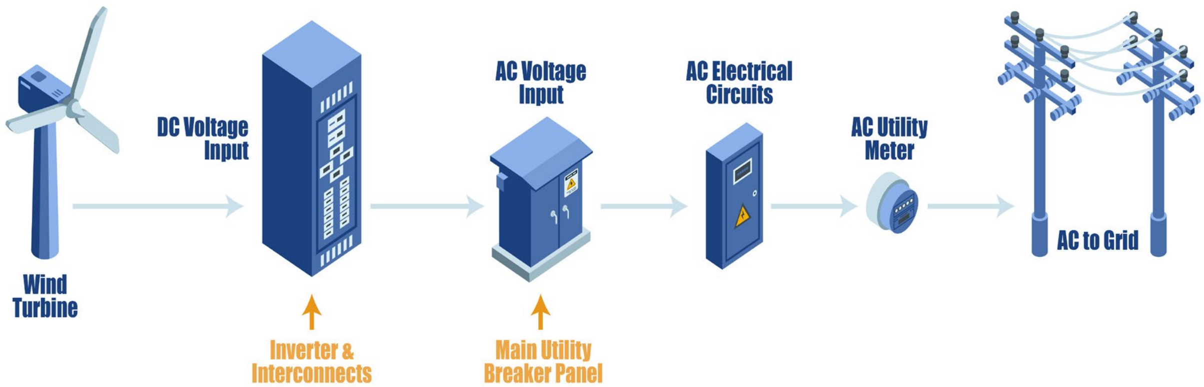

Figure 15. Standard interconnection schematic for distributed wind turbines.

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 the utility's electric grid. Off-grid distributed wind energy systems are not connected to any load-serving distribution lines. Turbines deployed in such settings may be used, for example, to power remote cabins or electricity needs on sailboats. 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 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 16). Off-grid hybrid systems offer many of the same resilience and reliability benefits of those that are interconnected to the electric grid and additionally promote electrification to replace power previously generated by fossil fuels.

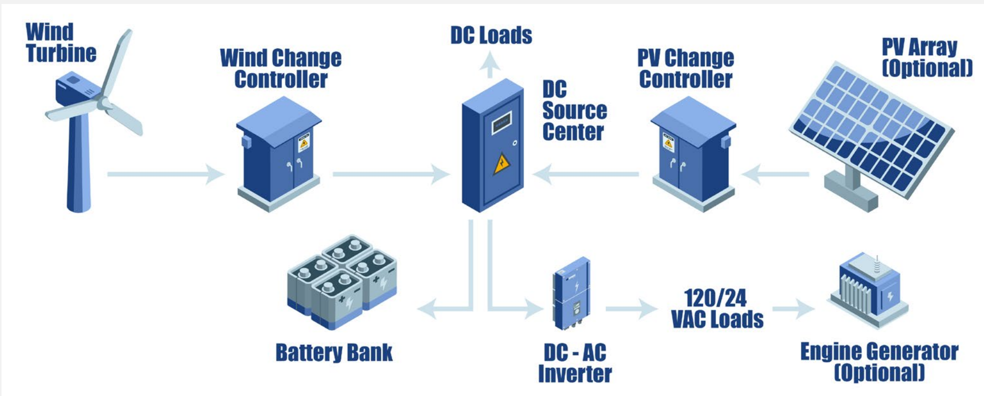

Figure 16. Off-grid distributed wind hybrid configuration.

Section 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

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.

Local entities (e.g., planning commissions, zoning boards, city councils) typically regulate zoning through zoning ordinances, whereas permits can be mandated at the federal, state, and local levels. 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 (FAA). Zoning and permitting processes ultimately seek to address safety concerns, aesthetics—such as viewshed impacts or noise—community interests, and human–environment interactions (Table 5). Most zoning codes include height and setback limits that dictate the height of structures and their allowed proximity to nearby property lines, most commonly in residential-zoned areas. Your installer or developer will support you in acquiring all the proper permits.

Table 5. 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

Common considerations in zoning ordinances and permitting processes. Divided into the categories of aesthetics, safety, and environmental impacts.

Practices for addressing these considerations can vary by jurisdiction, so it is important that you and your installer become familiar with the regulations, authorities, and general requirements in your locality. For example, some jurisdictions may have rules regarding ice shedding—or when ice gets dislodged from turbine blades operating in cold climate conditions—and/or TV and radio interference. Although less likely to be applicable, make sure to review local laws for specifications on noise limits, shadow flicker, or outright bans on wind turbine development. Wind energy installers and developers can also assist with configuring and siting appropriate wind turbine systems based on local rules.

How do zoning, permitting, and regulatory requirements change by turbine size?

It is important to note that many concerns and potential impacts are negligible for distributed wind energy projects with small wind turbines. A small turbine on an individual's remote property is not likely to impose serious viewshed impacts, noise concerns, or wildlife impacts particularly when compared to a large, utility-scale wind farm featuring dozens of multi-MW turbines. For distributed wind energy projects with midsize and large turbines, there may be additional permitting requirements at the state and federal levels. These projects are larger in size, and any structure that protrudes high enough into the air has the potential to interfere with a radar system and navigational safety. For this reason, you or your installer will need to submit a "Notice of Proposed Construction" with the FAA if you are considering a turbine tower greater than 200 ft in height. The FAA reviews radar interference as part of its Obstruction Evaluation / Airport Airspace Analysis (OE/AAA); a determination of "No Hazard to Air Navigation" must be made for a project to move forward.

Designing and constructing a project within your local regulations—that is, adhering to any existing limits (such as height and setback)—will streamline the permitting process. Projects that do not conform may undergo a special review process to obtain a variance from the existing rules and regulations, which can be expensive, time-consuming (potentially involving public hearings), and possibly unsuccessful. In some cases, zoning and permitting expectations are consistent and straightforward; in others, hearings may be required. For distributed wind projects being deployed for the first time in a specific locality, additional steps to work with local officials may become necessary to circumvent or update barriers within local zoning and permitting ordinances.

Section 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
- FAA Notice Criteria Tool: https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showNoNoticeRequiredToolForm
- 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

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 decommission 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. Depending on the size of your turbine and the number of turbines in your project, these steps could include:

- Installing temporary office trailers, site access roads, crane pads, crane laydown areas, turning radii, and other civil infrastructure
- Implementing security and access controls to prevent damage to or theft of equipment, prevent unauthorized entry to the site, and to protect wildlife from site exposure
- Having stormwater pollution control
- Locating all existing underground utilities before excavation.

Larger turbines typically require more infrastructure than smaller projects. Pre-development work may require special permitting with the FAA or a Phase 1 Environmental Site Assessment—an inventory of onsite environmental liabilities conducted as part of real estate transaction. Construction may require heavy equipment such as a crane, boom truck, earth boring machine, and/or skid steer. Once components have been transported to the project site, heavy lifting equipment is used to lift the tower, as a single piece or in a series of parts, which are stacked together and held in place by large bolts. A crane is typically used to attach the nacelle, which contains the generator and electrical equipment, onto the top of the tower (which is most commonly a self-supporting monopole). The blades are then attached to the nacelle.

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. This includes assembling the tower, attaching the turbine to the top of the tower (typically with a crane), affixing the blades, and performing electrical connection if grid-tied. Tower type is a key driver in how small wind turbines are installed and maintained. Small wind turbines in the United States typically use self-supporting (i.e., free-standing) or guyed (i.e., fixed) lattice, monopole, or tilt-up towers. A tilt-up tower is a type of tower that provides easy maintenance for wind turbines by eliminating the need for climbing or heavy machinery, such as a crane, to erect the turbine or bring it down. Tilt-up towers are typically only used for small wind turbines (Figure 17). Although tilt-up towers are more expensive, they offer an easy way to perform maintenance and can be lowered to the ground during hurricanes and other hazardous weather conditions. On the downside, tilt-up towers require a larger footprint to ensure clearance for the tower height when down. Most turbine manufacturers provide wind energy system packages that include a range of tower options.

Figure 17. Tilt-up tower in Gorham, ME.

For your wind turbine to be commissioned, its construction and interconnection must be completed. Commissioning includes various checks and tests to ensure the wind turbine, associated equipment, and electrical interconnection are functioning properly. Larger, utility-scale projects may take longer to develop than small-scale projects. Larger projects can also require more extensive BOS and geotechnical work. Depending on the number of turbines, larger projects may need laydown yards, access roads, and other infrastructure.

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. Warranties go into effect upon installation (or within a specified date after shipment) and typically cover the wind turbine, blades, electronic components, and tower (if supplied by the manufacturer) against defects in design, material, and quality under normal operating conditions. You should consult your warranty for further details or notable coverage exclusions.

In addition to your turbine's warranty, you can also establish an 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 (OEM), a third-party service provider, or by the project owner in-house. O&M could also be performed using a combination of these options. For example, in-house maintenance could address preventative maintenance needs and an agreement with an OEM could cover larger-scale, unexpected repairs. There are benefits and disadvantages of each O&M agreement type (Table 6).

Table 6. Benefits and disadvantages of different O&M agreement types.

	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

Benefits and disadvantages of different O&M agreement types. Includes OEM contract, independent service provider contract, and in-house O&M.

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.

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.

As wind turbines age, maintenance costs often increase because some parts need replacement. For example, small wind turbines may require new inverters after 10 years, and gearboxes in larger turbines, which experience significant operational strain, may need more frequent repairs and eventual replacement.

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).

Section Summary

- Installing a distributed wind turbine typically includes procurement, ground work, BOS, interconnection, or commissioning.
- Once your turbine is commissioned, you will want to maintain the turbine through a combination of preventative, predictive, and 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. While the foundations and tower can last this long, individual parts like blades, gearboxes, and generators experience wear and tear and may need earlier replacement. Regular maintenance helps extend the turbine’s life and ensures it continues to generate power efficiently.

Eventually, all turbines reach the end of their useful life, 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. Signs that a turbine is nearing its end of life include:

- Increased operational wear and tear over time
- Increasing maintenance costs
- Turbine underperformance
- The need to replace or refurbish parts to extend turbine life.

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.

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 to restore 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.

Once decommissioned, affected land can be restored for its original use or development, and decommissioned equipment can be repurposed, recycled, or disposed of. For example, turbine parts can be repurposed into products like pedestrian bridges, playgrounds, or benches (Figure 18), recycled into materials for new products like cement or new turbine blades, or disposed of in a landfill or through incineration.

Figure 18. Wind turbine blades repurposed into playground equipment in Rotterdam, Netherlands.

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).

Section 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[7] 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

[7] 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 or 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*.

Horizontal-axis wind turbine (HAWT)—A wind turbine with a rotational axis that lies in or close to a horizontal plane. See also *vertical-axis wind turbine, wind turbine*.

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

kW—Kilowatt, a measure of power for electrical current (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*.

Nacelle—The body of a propeller-type wind turbine, containing the gearbox, generator, blade hub, and other parts. See also *blades, gearbox, generator.*

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 object that would significantly 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*.

Peak demand—The maximum electricity consumption level (in kilowatts) reached during the month or billing period, usually for a 15- or 30-minute duration. The definition of peak demand may vary by electric utility. This is a simplified definition of a complex topic. See also *electric utility company, kW*.

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*.

Vertical-axis wind turbine (VAWT)—A wind turbine whose rotor spins about a vertical or near-vertical axis. See also *horizontal-axis wind turbine, wind turbine*.

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*.

Yaw—A system, located between the top of the tower and the turbine nacelle, whose function is to permit the yaw drive and motor to rotate the turbine about the tower and face the direction of the wind. See also *nacelle, tower, wind turbine*.

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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Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354

1-888-375-PNNL (7665)

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