E3A: Small Wind Energy Applications for the Home, Farm, or Ranch

Author: Sarah Hamlen; Mike Vogel and Milton Geiger eds. E3A Program

Small Wind Energy Checklist

Exploring Energy Efficiency and Alternatives

This series explores the applications and benefits of small wind. It is designed to help you understand both the benefits and limitations of small wind before you buy a system. You will be a happier small wind system owner if you know what to expect before you install your own turbine!

Photo by Southwest Windpower, NREL 15030
http://images.nrel.gov/viewphoto.php?imageId=6327142

Is Small Wind Energy Right for Me?

The following ten questions may help you decide if small wind will work for you.

1. **Are you willing to learn about small wind?** Great strides are being made, but small wind is still a buyer-beware market. Be prepared to educate yourself about wind systems or hire a qualified installer/consultant to guide you through the buying and installation process.

   ☐ Yes
   ☐ No
   ☐ Uncertain

2. **Have you considered your energy consumption and the price of electricity?** Energy conservation and efficiency is the best place to start! Being aware of your current electricity usage and cost is valuable for effective decision-making. Renewable energy systems are more cost effective in markets where electricity prices are high and in situations where conservation and efficiency measures have been implemented.

   ☐ Yes
   ☐ No
   ☐ Uncertain

3. **Do you have a good wind resource?** Many factors determine the quality of a wind resource, and wind speed is a key consideration. In general, wind speeds that average below six to seven miles per hour are unable to produce significant amounts of electricity generation. Consider a small wind system if the average wind speed at your site is over 10-12 miles per hour. Information on how to assess your wind speed will be covered later in the series.

   ☐ Yes
   ☐ No
   ☐ Uncertain

Steps in the Small Wind Series

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4. **Are you comfortable with some level of uncertainty in power production?** Wind speed will fluctuate. System size, type and the site characteristics will cause differences in energy output. Many people do not mind the variability, but if you want consistent generation, a wind system may not be right for you.
   - ☐ Yes
   - ☐ No
   - ☐ Uncertain

5. **Are you willing to invest in a tall tower?** Wind speed increases with height above the ground. A tall tower will enable your wind turbine to produce more electricity. Towers can cost more than the turbine– and the taller the tower the greater the cost. Appropriate tower height will vary by location, cost, and the turbine selected. Tower heights typically range from 45 to 120 feet. There are a few locations where tower heights of 30 feet may be viable but they are the exception, rather than the rule.
   - ☐ Yes
   - ☐ No
   - ☐ Uncertain

6. **Can you finance a small wind system?** A system that would offset most of an average grid-connected home's electricity use (10,000 kWh/year) will cost roughly $50,000 before incentives.* Some homeowners opt to reduce the total investment in the wind system by only off-setting a portion of their total energy use. This reduces the system cost, but does extend the payback period for the turbine. Some installers or manufacturers offer financing. Incentives may offset 45 percent or more of your total system cost. Many incentives are tax credits or reimbursements received after installation, thus initially you may have to finance the full cost of the system.
   **Please note that off-grid wind systems are typically smaller and therefore less expensive than grid-connected systems. However, other system components such as batteries will add to the overall cost of an off-grid project.*
   - ☐ Yes
   - ☐ No
   - ☐ Uncertain

7. **Do you have enough available space?** You should have at least one acre of available land around the site where you would like to place your turbine. Zoning or ordinances may require one-half acre to over five acres of available space based on the size of wind system.
   - ☐ Yes
   - ☐ No
   - ☐ Uncertain

8. **Does your area allow wind turbines?** Some areas do not allow wind turbines or have special permitting for small wind turbines. Restrictions may limit the height of structures. Other zoning restrictions may address noise, tower placement, and tower type. Check with your electrical utility to see if wind generators are allowed and what utility company rules you must follow if you intend to remain connected to your electrical utility.
   - ☐ Yes
   - ☐ No
   - ☐ Uncertain

9. **Are you willing to maintain the system?** Small wind turbines require at least annual maintenance. Maintenance requirements are different for each system. However, you will need to climb the tower, use a bucket truck, or take the system down (if you have a tilt-up tower) every year to inspect and repair components of the turbine. Do not consider wind if you are not willing to maintain your system or hire someone to perform maintenance work on a regular basis.
   - ☐ Yes
   - ☐ No
   - ☐ Uncertain

10. **Have you considered living with wind?** Visit an installed wind turbine so that you can listen to the noise and witness the visual impact that a turbine and tower may have on your property. You may also want to talk to your neighbors to discuss any concerns or objections they may have to your proposed system.
    - ☐ Yes
    - ☐ No
    - ☐ Uncertain

Consider Your Answers

- If you answered "yes" to most of these questions, you may be a good candidate for small wind!
- If you answered "no" to most of these questions:
  - If you answered "no" to Questions 3, 6, or 7, you are probably not a good candidate for small wind.
  - If you answered "no" to Questions 1, 2, 4, 5, 8, 9 or 10, you may wish to do more homework and research before you pursue buying a system. Use the Guides to help you through this process.
  - If you answered "uncertain" to most of these questions, you need to do more research before you can decide if wind is right for you. You can use the Guides to help you through this process.

Notes

STEP 1

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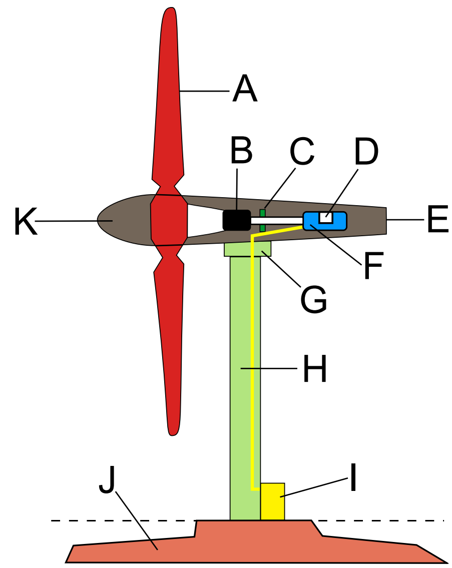
Steps in the Small Wind Series

There are four main parts of a small wind system:
1) rotor, 2) generator, 3) tower, and 4) control system.

Rotor

The rotor includes the blades and the hub of a conventional horizontal-axis small wind system. The blades are designed to capture the energy in the wind and turn it into rotational torque. Rotational torque is the force that rotates the central shaft. The rotor hub connects to a central shaft, which drives a generator.

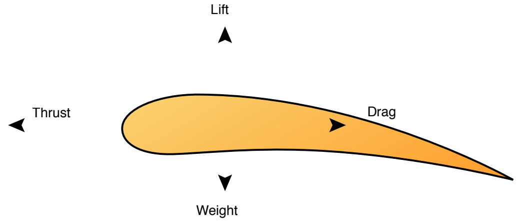


Wind turbine components A: Rotor blade B: Gearbox (not used with gearless wind turbines) C: Brake D: Switchgear & Control system E: Nacelle F: Generator G: Pivot gear and motor H: Tower I: Electrical connection J: Foundation K: Rotor hub & Blade adjustment

CC-BY-SA-3.0 By RobbyBer https://commons.wikimedia.org/wiki/File:Schema_Windenergieanlage.png

Turbine blades can be made of many different materials. Most blades are made of composites (fiberglass is common), because they are strong, lightweight, and cost less than other materials. You may find other blade types, although they are not common. Wooden blades can be strong, lightweight, and relatively cheap to produce. However, wooden blades are easier to nick and scratch, and need regular maintenance. Wooden blades can be difficult to balance since no two pieces of wood are identical. They can also absorb water, which can cause warping and balance problems. Severe vibration and wear on the turbine can occur when a rotor is out-of-balance. Aluminum blades are light-weight and less costly to manufacture, but are susceptible to damage. Steel blades are strong, but can be expensive, heavy and can rust. Aluminum and steel blades are no longer used for commercial turbines, but older turbines in the rural west were made of these materials. Be aware of the material characteristics of the blades before you buy a turbine so that you are able to plan for maintenance expenses.

Blades are airfoil shape, like airplane wings. Airfoils are shapes which cause a force of "lift" when air flows around them just because of their shape. Lift is caused by air flowing around the airfoil shape. "Drag" is caused by air pushing against the blade. In "lift" machines, the blade is shaped to maximize the force of lift. The amount of lift depends on the angle at which the blade hits the wind. By angling the blade, the lift force can be raised and lowered and the turbine speed can be regulated.



Forces of Lift and Drag on an Airfoil
Courtesy of Wikimedia Commons, public domain image
https://commons.wikimedia.org/wiki/File:Aeroforces.svg

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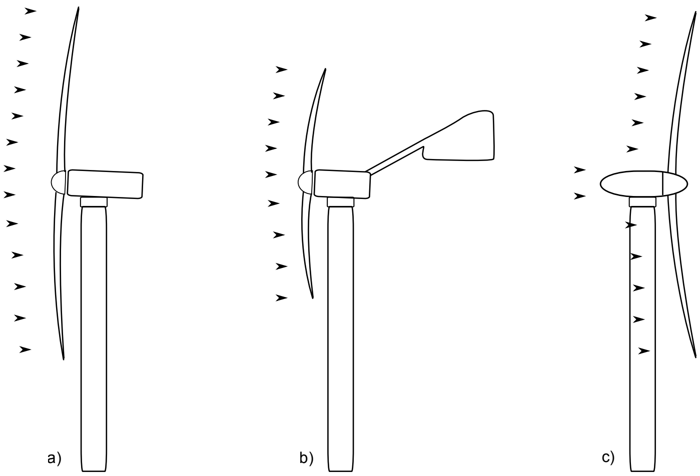
All commercially successful wind turbines are "lift" machines. Some turbines (including the historic 'windmills' common on farms and ranches decades ago) are "drag" machines. These turbines rely on drag forces to create rotary motion. Drag machine blades may be cupped or use a flap plate which use the wind's energy to push the blade, rather than lift the blade.



a) Upwind wind turbine equipped with an active yaw system, b) Upwind wind turbine equipped with a passive yaw system, c) Downwind wind turbine equipped with a passive yaw system.
Licensed under CC BY-SA 3.0 via Wikipedia - https://en.wikipedia.org/wiki/File:Wind.turbine.yaw.system.configurations.svg#/media/File:Wind.turbine.yaw.system.configurations.svg

Turbines may be either "upwind" or "downwind" machines. Upwind machines use a tail fin or vane to place the blades into the wind upwind of the tower, whereas in a downwind turbine, the blades are downwind of the tower. Each type has certain advantages and disadvantages.

Blades are designed to twist and taper along the length of the blade. These design characteristics are needed to keep stresses uniform along the length of the blade: as the rotor turns, the tip moves at a faster speed than the root of the blade and requires a shallower angle and smaller blade cross-section to produce the desired lifting force. Some wind turbine's blades "pitch", so the blade changes angle as the wind speed increases. "Pitching" is standard on large, utility-scale wind turbines, but is less common for small wind turbines.

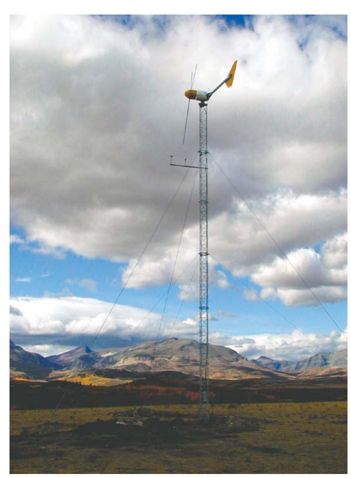
Generator

Most small wind turbines are permanent magnet, direct-drive systems. There are also a number of induction generator designs that are used with small wind turbines. The rotor connects directly to the central shaft of a generator. Permanent magnet generators make electrical power using copper wire coils and magnets. As the blades spin the rotor hub and shaft, the rotation drives the generator by turning the copper coils on an axis between two magnets creating electrical current. The power created is variable frequency alternating current (AC) power, which cannot be used without power conditioning. A power converter changes the variable frequency AC power into a direct current (DC) power. DC power can be used in some electrical appliances, or can be stored in batteries. To use the power in a home, the power has to be changed into 60 hertz AC power. This is done using an inverter. Some turbines contain the power conditioning systems within the nacelle (which is the housing for the system components that is mounted on top of the tower), however most use external power conditioning systems located away from the turbine unit.

Tower

Guyed tilt-up monopole tower
Photo by Mark Harris, NREL 16742
http://images.nrel.gov/viewphoto.php?imageId=6326130

There are three basic types of towers: guyed towers, monopole, or latticed towers. Guyed towers are the least expensive. Guy wires do increase the footprint, or surface space occupied, of the turbine. The radius of a guyed system will be one-half to three-quarters the height of the tower. Most guyed towers are not designed to be taken down regularly, so turbine maintenance must be performed by climbing the tower. The guy wires also require maintenance, Livestock may rub on the guy wires which may be problematic. Tilt-up guyed towers are designed so that they can be laid down to perform maintenance, or if severe storms are expected. Tilt-up guyed towers are usually more expensive than conventional guyed towers. Latticed towers are permanent, free-standing and can be climbed to perform maintenance. Monopole towers are available in permanent free-standing



Latticed tower. Photo by Doug Nelson, NREL 14675
http://images.nrel.gov/viewphoto.php?imageId=6327128

Monopole tower. Photo by Appalachian State University, NREL 15303
http://images.nrel.gov/viewphoto.php?imageId=6326045

or tilt-up designs. The towers are of a more robust design so they do not require guy wires, and there is an increased cost associated with this design. Additionally the tower foundation design is a critical part of the system and adds some expense.

Is a Tower Necessary?

Yes! Wind speed is greater as the height above ground increases and turbulent airflows are reduced - both are key factors in wind power production. A taller tower will enable the wind turbine to produce more electricity, but taller towers are also more expensive. Tower selection is limited by market availability and further limited depending on the turbine selected. In general taller towers produce more electricity which may improve the economics of the project. Tower height is dependent on the location and economics of the investment. Most towers range from 45 to 120 feet.

Roof-Mount Turbines

Can mounting a turbine on the roof save the cost of the tower? Before purchasing a roof-mount system, consider: a) Can the turbine be placed high enough above the roof to avoid turbulent air flows and to take advantage of wind shear? Wind shear is the increase in wind speed that occurs as the height above ground increases. Some experts state that the answer to this question is an unequivocal "no". b) Is the roof strong enough for both the load (weight) and torque of the wind turbine? Remember that the wind turbine will be under significant pressure as the wind speed increases. c) Will the turbine cause unwanted noise for occupants of the structure. d)What are the possible problems caused by noise and vibration on the structure? Rooftops induce considerable turbulence at the turbine. The turbine cannot generate lift in turbulence. In addition, turbulence will increase the maintenance on the system and shorten its life expectancy. In general, rooftop installations have not performed well and are not recommended.

Control Systems

To account for changing wind directions, turbines must be able to "yaw" – that is, turn to face the wind. Most small wind turbine systems use a passive yaw control system, unlike the larger commercial-scale units that rely on active yaw control systems that utilize an electric motor to change the direction of the turbine. Passive control systems are designed to cause the rotor to slow down when the wind speed exceeds a certain level. Small wind turbines protect themselves from damage caused by severe wind in one of three ways: stalling, turning out of the wind, or using tip brakes. The most common method is turning out of the wind or "furling". Furling can be done using the turbine's yaw mechanism (turning to the side) or an angle governor, which will tilt the turbine up and away from the wind. Other systems reduce the lift generated by the blades pitching (changing the blade angle) or using turbine blades that bend back or fold. Other blades sweep back in a coning shape against the nacelle to reduce the amount of blade in the strong wind. Stalling systems (typically found on induction systems) or tip brakes can be used, but it is more common to find passive control systems to reduce the amount of blade surface area exposed to the wind resource.

Turbines should have a brake system, so the turbine can be shut down in a severe wind or when doing maintenance. Two brakes (also called redundant braking) are recommended for safety purposes.

Types of Turbines

There are two primary types of turbine – Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT).

In HAWTs, the nacelle sits on top of the tower parallel to the ground. They are the most common type of turbine and most are upwind, lift machines. HAWTs are usually two- or three-blade designs. Over years of testing, the three blade designs have had the highest power output. There are some two-blade designs on the market today, but these machines often experience "yaw chatter", or vibration caused when yawing. New spring plates are being tested to address this issue. Blade designs vary by manufacturer, ranging from curved blades and blades with weighted tips to blades with unique cuts and designs.

There are usually three designs of VAWT machines: Darrieus, Savonius, and Giromill. They are mounted with the turbine components perpendicular to the ground. The components sit at ground level, making some maintenance tasks easier. Many use lighter weight towers. However, VAWTs have struggled to gain commercial acceptance due to various design, performance, and reliability issues. VAWT rotors are often near the ground where there is lower wind speed and a more turbulent wind resource. VAWT units tend to have poor self-starting abilities, and in some models the entire rotor must be removed to replace parts. There has not been a commercially successful VAWT in the United States.

Converting Wind to Electricity

Many of the purchasing decisions consumers make on small wind systems are based on the power production formula:

$$P = \frac{1}{2}\rho v^3 \Pi r^2$$

ENERGY=(1/2) X (AIR DENSITY) X (VELOCITY)^3 X (SWEPT AREA OF ROTOR)*

What does the formula mean?

The formula tells us that the ability of a wind turbine to convert wind energy into electrical power depends on three factors: the density of the air, the swept area of the rotor, and the wind speed or velocity.

Why is the power production formula so important?
Wind turbines are all about producing power. The formula says that doubling the swept area creates four times the power (because it is a squared function). Increasing wind speed by two times will result in eight times the amount of power because it is a cubic function (2x2x2). On the other hand, if wind speed is cut in half there is only one-eighth the amount of power production! People learning about wind might think that a one- or two-mile per hour difference in wind speed is not a big difference, but because wind speed is a cubic function, a small difference in wind speed will make a big difference in the amount of power production.

This formula is important. There is a lack of industry standardization in small wind manufacturing. In 2009, the American Wind Energy Association developed industry standards. In 2010, the Small Wind Certification Council (SWCC) began testing turbines to those standards. However, testing is voluntary and it will take time for that process to result in good comparisons of performance. Therefore, consumers must often rely upon this formula to compare systems and make informed purchasing decisions. Other steps in this series will help you to understand when to use the formula to understand small wind.

**Note: This formula will calculate the kinetic energy available from the wind in watts. Other derivations of this formula as well as other formulas can be used to determine annual energy output in kilowatt hours, total available power, etc. This formula is presented in its simple form to help you understand the key determining factors in power output – air density, wind speed, and rotor diameter.*

Notes

STEP 2

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Steps in the Small Wind Series

10 kW Bergey wind turbine on 120 tower
Roy Rakobitsch / Windsine Inc., NREL 26792

Basics of Electrical Consumption

Small wind systems usually make electricity that is used in the home, farm, or ranch. Therefore, it may help to understand how electricity is consumed (or used). First, let's explore the terms power and energy.

Electricity is used each time you turn on an electrical device. Most devices measure power in "watts." Usually, power refers to an instantaneous measure, where energy refers to power produced over time. A "watt" is a term for power and a "watt-hour" is a term for energy. A light bulb with a 100-watt power rating will use the energy of 100-watt-hours if it is turned on for one hour.

A kilowatt is 1,000 watts. In most homes, electricity comes from an electrical utility. The amount of energy used by a customer of the utility is tracked on an electrical meter (also called a kilowatt-hour meter). It records the energy (kilowatt hours) used during a billing period and the customer is billed for that amount. In 2008, the average kilowatt hours consumed by homes in Montana was 843 kilowatt hours per month (887 in Wyoming), or 10,116 kilowatt hours in the year (10,644 in Wyoming).

In small wind systems, the turbine may be described by its power, or kilowatts, but the actual energy generation is measured in kilowatt-hours. In small wind, the terms power and energy often are used interchangeably.

What is a "Small" Wind Turbine?

There is no common definition of "small" wind. Grid-connected home systems are typically three to 10 kilowatts. "Small" is usually defined by the electric utility. Most utilities limit the size of wind turbine that they will allow to "net meter." In Montana,

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most utilities define small wind as less than 50 kilowatts rated power, while in Wyoming state law specifies systems less than 25 kilowatts rated power. Check with your electric utility to find out how "small wind" is defined in your area.

Off-Grid Systems and Batteries

A small wind system that is connected to a home or business but not to an electric utility is called an "off-grid" system. Off-grid systems are common when it is very expensive to connect to the electric utility, often due to a remote location. Off-grid systems are more complex because of the system design and require batteries to store energy. Off-grid systems require consideration of total electrical usage of the home, battery systems, and alternative (back-up) generation. Consult with a qualified system designer when evaluating an off-grid system.

Net Metering

Most small wind turbines are designed to use "net metering." Net metering is offered by utilities so people can connect their wind turbines to the electric utility. (In some states, net metering and interconnecting your generator to the utility are managed as two separate processes.) Many homeowners opt to remain connected to the utility because the small wind generator may not supply all of the electrical energy for the home. Remaining connected to the utility allows the home to have electricity supplied from the utility that supplements production from the wind turbine. The amount of energy used is tracked on a special electrical meter. When the wind turbine produces more electricity than the home or business is consuming, the meter spins backward. At the end of a billing period, the customer pays the "net" amount to the utility. The "net" is the difference between the amount of utility energy used and the amount of small wind energy produced. Net metering is for off-setting energy use. It is not meant to generate income, only to credit you for the energy you produce.

Net meter for home PV system
Susan Bilo, NREL 21394
http://images.nrel.gov/viewphoto.php?imageId=6325289


Southwet Windpower Air Breeze wind turbine at the off the grid house of Otto Van Geet.
NREL 15382, Otto Van Geet

Common Myths About Net Metering

MYTH: **I will get paid for any excess electrical generation.**
REALITY: Many Western states do not pay for excess production. Check with your utility for your local rules. As examples, in Montana, any excess production is donated to the electric utility. In Wyoming, excess production is purchased by the utility at the end of the calendar year. Standards and the amount paid vary by utility.
MYTH: **One turbine will off-set all electrical consumption on my property.**
REALITY: This is only true if all electrical consumption is tied to one meter (one turbine per meter). As an example, a rural farm that has a meter for the home, one for the shop, and three others for irrigation water would have to either consolidate all of the meters into one meter, or install multiple wind turbines to off-set their entire consumption.
MYTH: **I will run my electrical system seasonally (in the summer), and then use a whole year of wind energy to credit that account for a smaller total utility bill.**
REALITY: This will depend on the billing period used by your utility. The most common scenario for this to occur is in irrigation systems. The irrigation system operates in the summer, but the best wind generation occurs throughout the year. In an annual adjustment period, the total amount of wind generation for the year can be used to offset the irrigation electricity. Most utilities in Montana and Wyoming allow the generation in a year to offset consumption in that year. Check with your utility and find out their rules before buying any wind turbine equipment.

MYTH: I can use my existing kilowatt hour meter.
REALITY: Most meters will have to be converted for a net metering application. Some utilities will provide this meter; others will ask you to pick up the expense. Ask your utility.

MYTH: If the power from the utility goes out, I will still have power from my wind turbine.
REALITY: This is only true if you also have a battery storage system. Otherwise, when the power from the utility goes out, so does the power from your wind system. Grid-connected systems disconnect during a power outage to protect utility workers from having power coursing through the electrical wires when they are repairing the utility system.

Your Electrical Consumption

The first step in buying a small wind system is to determine your electrical usage. Contact your local utility and ask for a 12-month electrical usage history (in kilowatt-hours) for your home. Some utilities provide this history online or in your monthly statements. You will also need to find the cost per kilowatt hour. When you have your energy information for one year, fill out the table below to calculate the number of kilowatt hours used and the average cost per kilowatt-hour for the 12-month period.

My Electrical Consumption

Month	Kilowatt Hours	Cost	$/kWh
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			
Total			

The local utility can provide estimates based on energy usage for similar homes in the area if you are planning new construction or an off-grid system.

Energy Efficiency

Remember: Make sure that energy efficiency measures have been taken before adding renewable energy systems!

Understanding Your Consumption and Opportunity

Evaluate your utility statement to understand how your wind system will change your bill. This list provides a few common mistakes:

- Not all charges can be off-set with a small wind system. Some utilities have a base-charge that is assessed to all customers. There may be system demand charges for high seasonal or monthly power usage. Demand charges may not be off-set with a small wind system. Ask your utility to explain which charges might be off-set before purchasing a small wind system.
    - When calculating your average cost per kilowatt hour, you will need to pay attention to how much of the total cost is the actual cost of electricity (which you can off-set) and how much of the cost is base fees, demand charges, and other fees that cannot be off-set. If, for example, your total cost per kilowatt hour were $0.10, but 50 percent of that cost were comprised of fees that cannot be offset, you would only be offsetting costs of $0.05 per kilowatt-hour. The cost of electricity is a significant consideration in conducting economic analysis.
- Does your utility allow you to consolidate meters if you have more than one meter? Some utilities only allow one wind turbine per meter.
- Look for seasonal "swings" in usage. This is very important if your bill settlement or "true up" period is monthly.
- Talk to your utility about future electricity costs. Some utilities are very sensitive to price increases. Others have long term contracts and know their energy costs many years into the future. Cost of energy can be a significant factor when looking at the economic value of a small wind system.

References

US Department of Energy. (2011, March). *State Energy Database*. Retrieved April 12, 2011, from EIA Consumption Price and Expenditures Estimates: http://www.eia.doe.gov/states/_seds.html

Notes

STEP 3

Steps in the Small Wind Series

B-1280 | E3A-SW.3

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Assess the Wind at Your Site

The wind resource is one of the key factors in a successful small wind project. You will need to assess the wind resource at your site. This guide will help you to understand the effects of wind speed, wind shear, wind distribution, prevailing winds, turbulence, and elevation.

You should take time to understand wind assessment and to gather some free information about your wind resource. This will help you to ask good questions when you are working with your installer. Your system installer should conduct a more in-depth analysis of the wind resource. Installers usually have more accurate data and assessment tools. You can also purchase better data. There are fee-for-service mapping tools available.

Note: Before buying wind data, make sure you know what data source is being used by the company. Some companies use free data for their maps. You could get the same information on your own!

Wind Speed

Wind Maps

You will need to find information on the wind speed at your site. The best way to get site-specific wind information is to install an anemometer and to collect data for at least one year. (The anemometer should be at the same hub-height as the planned wind turbine.) Installing a tower and anemometer can be expensive. Most homeowners cannot afford to collect anemometer data. For small turbines, the value of the data collected by an on-site anemometer is often not worth the cost. Therefore, free data is often used to estimate the wind speed. These estimates rarely reflect the actual wind resource of your site.

Free wind mapping data are available from:

- Department of Energy: Wind Powering America State Wind Maps: www.eere.energy.gov/windandhydro/windpoweringamerica/wind_maps.asp
- Renewable Energy Atlas of the West: www.energyatlas.org/
- National Renewable Energy Lab – In My Back Yard: www.nrel.gov/eis/imby/about.html

Wind maps are often created using a mix of publicly available data and wind modeling. It can be hard for a user to know the sources and quality of the data used to develop the wind map. These sources provide an indication of the wind speed, but understand that they are likely to have high degree of variability.

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Understanding how wind turbines generate power from the wind may help you to realize the importance of the wind energy resource:

$$P = \frac{1}{2} \rho v^3 \Pi r^2$$

ENERGY=(1/2) X (AIR DENSITY) X (VELOCITY)^3 X (SWEPT AREA OF ROTOR)*

*Remember: In wind power generation, velocity is a cubic function. If the wind velocity is doubled, eight times the amount of power is produced (2*2*2). This means that wind power generation is very sensitive to wind speed.*

Sources of Local Data

Local data may be publicly available. These sources may provide an indication of the local wind speed. The data may not be accurate for your purpose. The data might be collected from anemometers on rooftops of rural airports, in sheltered areas or near trees that influence the wind. Agronomic weather stations collect data at five to six feet above the ground–well below a typical wind generator hub height. Some anemometers are located in turbulent wind areas. These anemometers might be just fine for their purpose, but were probably not installed at the right hub-height or in the perfect area to collect wind information for your project. If you are using local data, make sure you evaluate the site to see that it has good exposure to the wind, is free of turbulent air flows, and is capturing the wind resource at a hub height similar to your potential project. In some states, anemometer loan programs for small wind are used to collect data. That data is often posted on line and may be a good source for your project. Neither Montana nor Wyoming currently have an anemometer loan program in place.

The free mapping tools based on existing local data are often the best information available to you. Remember that these sources do not give you nearly as accurate data as on-site data collection would provide. Wind speed is key to accurately calculating both the energy production and economic return of the small wind turbine. Error in the wind speed estimates will result in errors in these calculations. Most purchasers of small wind turbines will have to accept at least a moderate amount of uncertainty in the average annual turbine energy production. Here are a couple of questions to consider:

- **Are you reasonably confident that your wind speed information is accurate?** If your answer is "no" or "uncertain," you may wish to buy data or ask your installer to do a more in-depth assessment.

  ☐ Yes
  ☐ No
  ☐ Uncertain

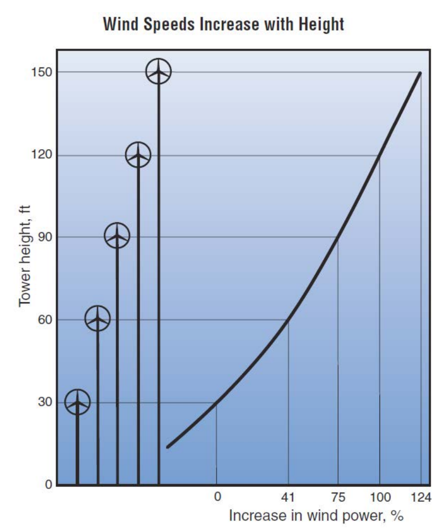
- **Are you comfortable with the possibility that economic or energy output calculations might be off because of error in the wind speed estimate?** If you answered "no" or "uncertain" consider installing an anemometer or buying data to help reduce the possibility of error. The bottom line is that wind is a variable resource. Wind users accept that there may be error or variability in wind speed. Error (or uncertainty) in the long term average resource is different from variability. Even if an estimate for the long-term resource is spot on, the wind resource will vary from month to month and year to year. If you want more consistent energy output, you may wish to look at other technologies or invest in additional energy efficiency measures.

  ☐ Yes
  ☐ No
  ☐ Uncertain

Wind Shear

Wind shear is the change in wind velocity with elevation above ground. Wind shear is caused by surface topography, wind speed, and atmospheric stability. Wind shear is important to small wind because the power output of a turbine increases when wind speed increases.

Tall towers can access higher wind speeds. Therefore, power production is increased by increasing the tower height. Energy generation can be maximized by selecting a tower height that places the bottom edge of the blade at least 30 feet above the tallest obstacle within 500 feet.



Source: OpenEi, Open Energy Informations (openei.org) http://en.openei.org/wiki/File:WindSpeedsIncreaseWithHeight.png

Wind Distribution

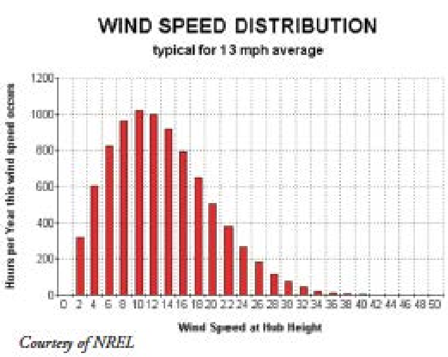
Wind varies by time of day, season, height above ground, and topography of the site. Wind speeds, in most of the world, are modeled using a statistical analysis called Weibull distribution. A Weibull distribution depicts the relationship between wind speed at a specific location and power production. Weibull calculations are important for a number of reasons. First, knowing the frequency of average

Weibull Values and Online Calculators

If you are using an online calculator, you may need to input the k value or Weibull. The Weibull (k) value reflects the width of the distribution. A lower value represents a broader distribution with a wider range of wind speeds. Where it is not possible to obtain sufficient information to calculate an actual Weibell distribution, for inland locations it is typical to assume a Weibell of 2, also known as a Rayleigh distribution.

wind speeds helps in selecting a turbine with an optimal cut-in speed (the wind speed at which the turbine starts to generate usable power) and the speed at which the turbine is designed to curtail power production. Second, the Weibull distribution can be used to estimate the average annual output for a given wind turbine at your site.

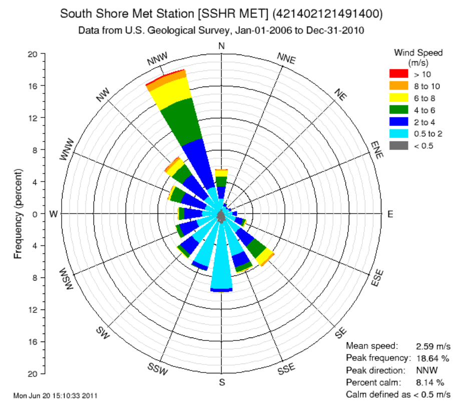
What Does This Mean to Me?



Wind distribution is important. In the diagram on top of the next page, you see a Weibull distribution for a site with an average wind speed of 13 miles per hour. Notice that the wind blew more often at wind speeds of eight to 12 miles per hour than at the average wind speed of 13 miles per hour. An "average" by definition is the total of all the wind speeds divided by the number of times the wind speed was recorded. Even though the "average" wind speed is 13 miles per hour, the more frequent wind speeds are eight to 12 miles per hour. For example, if you bought a wind turbine designed for optimum power output at a 13 miles per hour because that was the average wind speed, the turbine may perform less efficiently than if you had bought a turbine that had optimum performance at 10 miles per hour wind speed. This is why wind distribution matters!

Wind Rose

A wind rose can be extremely useful when siting a wind turbine. A wind rose graphs the prevailing wind direction. This rose may show the percent of time the wind blows in a given direction and/or the proportion of energy produced by those winds. Usually, free wind roses do not include the energy information. In this drawing, the prevailing winds are from the west and north. Turbines should be installed to access the strongest prevailing winds. (Remember that the strongest wind might not be the most frequent!) Turbines should be sited upwind of any obstacles to maximize energy production. Wind roses vary from one location to the next. Wind roses from locations around the West are provided at www.wrcc.dri.edu/wraws/nidwmtF.html. Remember that the quality of the wind rose data may vary. If data is collected from a low tower height or in an area with ground clutter, the wind rose may not be accurate. It can, however, provide an estimate of the prevailing winds in your area.

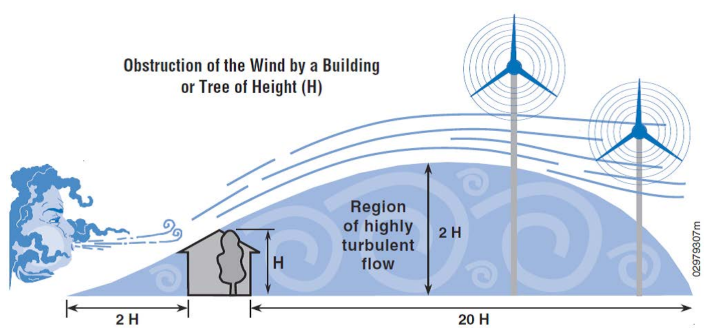


Example from a meteorological site near Klamath Falls, Oregon (U.S. Geological Survey)
http://nj.usgs.gov/grapher/tutorial/examples.html

Turbulence and Obstruction

Turbulence both decreases power output from the turbine and causes stress on the equipment. Trees, buildings, grain silos and other obstacles can cause turbulence. The region of disturbed flow downwind of an obstacle is twice the height of that obstacle and quite long. For example, a 30-ft tall house can create a region of turbulence that is 60 ft high and 600 ft long. This graphic depicts the turbulent influence of a structure on wind dynamics.

Turbulence and obstructed air flows may also be related to topography. The graphic illustrates characteristics of "good" sites for power generation versus sites with high levels of turbulent air flow.



Source: OpenEi, Open Energy Informations (openei.org) http://en.openei.org/wiki/File:ObstructionOfWindByBuilding.png

Sheltering

In hilly terrain, the wind will follow channels, such as canyons. Placing your wind turbine on the leeward side of a hill or otherwise sheltering the turbine from the dominant wind will negatively impact long term energy output.

Air Density

Air density varies by temperature and elevation. In Montana and Wyoming, changes in air temperature mean that air density in winter months is typically better for wind power generation. At a given wind speed, a wind turbine will produce more energy in the winter, than in the summer months due to the colder, and thus more dense, air. However, a factor often overlooked in wind resource assessments is changes in air density given elevation. Many energy production calculators assume that your location is sea level. In Montana and Wyoming, many sites are over 5,000 feet above sea level. As elevation rises, air density declines such that (given other factors are constant) annual energy production of a turbine sited at 7,000 feet could be 20 percent lower than a similar turbine sited at sea level. To adjust for elevation, estimate energy production for sea-level and subtract 1.4 percent for every 500 feet above sea level. For more information on elevation adjustment, reference the University of Wyoming publication entitled, The Effect of Altitude on Small Wind Turbine Production.

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Notes

B-1280 | E3A-SW.4

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch

Author: Sarah Hamlen; Mike Vogel and Milton Geiger eds. E3A Program

Calculating Energy Production

Estimating energy production is complicated for two reasons:

1. The best energy output calculations rely on an accurate wind resource assessment. Unfortunately, publicly available data is typically used to make a "best guess" about the wind resource. This leads to significant error and variability in energy calculations.
2. There is a lack of industry standards. In 2010, the Small Wind Certification Council (SWCC) began testing turbines to newly established standards. This is a valuable step. Manufacturers volunteer to have their turbines tested, but because it is voluntary not all turbines are tested. It will also take time for enough tests to be done to make good comparisons between turbines. Today, manufacturers are able to define many terms and set their own standards. This makes it hard for homeowners to compare information from turbine to turbine.

The terms 'power' and 'energy' often are used interchangeably when describing generation output from a small wind turbine, but they are different. Power typically refers to instantaneous generation, whereas energy will refer to power generation over time, such as a kilowatt-hour. Many times, manufacturers will provide estimates of power output. However, it is energy which is of value to the owner and what is being off-set in regard to purchases from the utility company. Energy output depends on several variables, but fundamentally come down to the variables of the energy formula discussed in Step 1:

- **Wind speed** – Turbines with access to the best wind speeds are installed in windy areas on tall towers free from obstructions
- **Swept area** – Larger rotor diameters will capture more wind and generate more energy
- **Air Density** – This variable cannot be controlled, but recognize there is less power in the wind at high elevations than at sea level
- **Time** – The more a turbine operates the more energy it will make.

Accurate energy production estimates can be difficult to derive, but here are some suggestions that will help estimate system size and energy production without relying on manufacturer-defined terms.

Methods for Determining System Size

To get a rough estimate of required turbine size to serve your electricity needs:

- Total your annual use in kilowatt hours
- Calculate the average load (annual consumption /8,760 hours per year)
- Divide the load by 0.1 – 0.2

This will give you a rough estimate of the turbine size for your application.

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch is a peer-reviewed publication series.

Original available at: www.wyoextension.org/publications/

Suggested acknowledgment: Sarah Hamlen; Mike Vogel, and Milton Geiger, eds. E3A: Small Wind Energy Applications, Fact Sheet 4, Steps in the Small Wind Energy Applications Series. E3A-SW.4. 2011.

Example:

Total Annual Kilowatt Hours	10,116
Average Load (10,116/8,760)	1.15
Average Load Divided by .2	5.77
Average Load Divided by .1	11.5
System size should be between 5 and 11 kilowatts	

Use this space to calculate your own system size:

Total Annual Kilowatt Hours	
Average Load	
Average Load Divided by .2	
Average Load Divided by .1	
My system size should be between ____ and ___ kilowatts	

Challenges with the Calculation

The simple calculation is problematic for two important reasons. First, this is a very rough estimate of system size and, while it does provide a general indication, it is by no means accurate. You will need to work with a qualified installer to better estimate the system size. The bigger issue with this calculation, however, is that it provides the result in rated power (defined below). Rated power is not defined consistently in the industry. This inconsistency makes it a poor measure of comparison. While this quick math might help you to get a general "range" of system size, recognize that it is limited in accuracy.

Another Method

Consumers will be able to size and compare turbines more easily as additional turbines are added to SWCC testing data. In the meantime, however, there are few published sources that provide comparisons of turbines. One source is *Home Power Magazine*, which publishes an annual wind turbine buying guide. Below is a sample of information from that guide, which may help you to understand more about sizing your system. There are additional details provided in this guide, including survey information about each turbine, that you may find useful in comparing machines.

Photo by Pika Energy, NREL 33943 http://images.nrel.gov/viewphoto.php?imageId=14559678

Turbine	Excel-S
Manufacturer	Bergey Windpower
Specifications	
Swept Area (sq. ft)	415.0
Warranty (years)	10
SWCC Certificaiton Application	Yes
Predicted Annual Energy Output by Avg. Wind Speed (kWh)	
8 mph	5,000
9 mph	7,100
10 mph	9,600
11 mph	12,700
12 mph	15,900
13 mph	19,500
14 mph	23,300
This information is provided for reference only and does not indicate an endorsement of either Home Power Magazine nor Bergey Windpower.	

Source: Home Power Magazine Jun-Jul 2011 Edition

According to the table, a consumer with approximately 10,000 kWh per year in electrical consumption and an estimated wind speed (at turbine's hub height) of 10 mph would be able to off-set the majority of their consumption with this turbine. Take note of the swept area (sometimes reported as rotor diameter). The power equation reminds us that swept area is one of the key determinants of energy output. Therefore, you can use the information in this guide as an indication of likely output at a given swept area. If you are considering a turbine not listed in this guide, you could compare the swept area of the turbine you are considering and the manufacturer's estimated energy output. You may find some small differences in output between systems with the same swept area, but if the output projections are significantly different, you may wish to ask more questions with regard to how the output calculations were derived.

This method is also not perfect because it assumes you have accurately measured your wind resource. Based on the table, a one-mile per hour change in wind speed will change power output by 20 to 40 percent. A qualified installer should be able to help you both accurately assess wind speed and more accurately determine an appropriate system and system size for your situation.

Many homeowners question whether it is better to opt for a smaller system that off-sets part of their consumption (which would mean a less expensive wind system), or whether it is better to purchase a larger system that provides almost all of their current energy needs. Here are a few considerations:

- There are economies of scale in small wind. In other words, a 10-kilowatt system is not ten times more expensive than a one-kilowatt system. As will be discussed in the economic analysis fact sheets, you may wish to use online calculators to discover the differences in output and economic return with various system sizes.

- Most installers recommend that you optimize the system size for your consumption and work to offset the majority of your energy needs. You may wish to consider seasonality of your demand or any changes in greater energy efficiency as you size your system.
- In most states, it does not make financial sense to purchase a system that is larger than your needs. In some states (like Montana), excess generation is donated to the utility. In others (such as Wyoming), excess energy may be purchased, but is usually purchased at "wholesale" or avoided cost rates (not the much higher retail electricity rate), so the revenue is not usually enough to justify the additional investment in a larger system.

Total rotor diameter is a good way to compare equipment. Do not necessarily assume that total cost per foot of swept area is the best measure of value for a wind turbine. Cost per foot of swept area will favor lightweight equipment, which may not be as durable as heavier equipment. A better measure of robustness is the tower top weight per swept area. Generally, greater tower top weight indicates a more durable turbine. The tower top weight is usually provided in information from the manufacturer.

When sizing your wind system, be aware that a wind turbine will lose some of the power generated. The amount of loss will vary by the system. Total losses of eight to 15 percent should be assumed for issues like availability, yaw, icing, electrical inverters, line losses, and other factors. Energy production will also vary due to changes in wind speed. According to the National Renewable Energy Laboratory (NREL), annual wind speed can vary from the average by plus or minus 10 to 15 percent and annual energy production can vary by as much as 30 percent.

Common Terms

Information from manufacturers is rarely presented in the same format. The same manufacturer may use different assumptions for different turbines. The information is also different between manufacturers. This means you have to investigate both what is being said about a turbine and what assumptions are made behind the data. Understanding some common terms may help you review this information.

Annual Energy Output

Ideally, annual energy output calculations would determine your system size and power production. However, this is not the method recommended because:

- Without industry standards, it is hard for you to know what assumptions were made in the manufacturer's calculation.
- The calculation assumes the wind resource was correctly estimated.

If your installer is providing annual energy output calculations, be aware that most manufacturers use a range of 8 to 14 mph average wind speed in their calculations. The wind resource in the calculation needs to match the wind speed at your site. Some experts recommend multiplying manufacturer annual energy output calculations by 75 percent to adjust for possible overestimates of actual energy output.

Power Curves

Many manufacturers show power curves. Power curves can be used to estimate the annual energy production using the "Method of Bins." The Method of Bins takes power production at each wind speed and multiplies it by the hours per year the wind blows at that wind speed; this results in an energy "bin" for each different wind speed. The total energy output is calculated by adding the energy production in all bins.

Power curves can be hard to use and understand. It helps to know how the power curve was created. Some manufacturers use years of field data to create their power curves. Others lack this data and generate a power curve based on computer models. Always ask for a power curve based on actual measurements. If a manufacturer indicates they do not have a measured power curve, it indicates they do not have a fully tested turbine.

Cut-in and Cut-out Speeds

The cut-in speed is the wind speed when the generator begins producing power, usually around eight miles per hour. Wind speeds below seven mph provide little, if any, usable power; perhaps enough to keep the rotor spinning, but not much more. All turbines should control their power output in strong winds, by reducing the rotor's exposure to the wind, (such as furling out of the wind or pitching the blades). The cut-out speed is the wind speed where the turbine shuts down to protect itself from very strong winds (e.g. 50 mph). Many small wind turbines do not have actual cut-out wind speeds. Some will continue to produce power in high wind situations. By examining the power curve graph in this document, the cut-in speed of the turbine is around nine mph, and between 25 and 30 mph it begins limiting its power output. By 35 mph, it is protecting itself from extremely strong winds and producing only very limited power. Understanding both the wind resource at your site and the cut-in and cut-out speed of a turbine is useful for selecting the best turbine for your location.

Rated Wind Speed

Rated wind speed is the wind speed at which a generator reaches its rated power. To understand this, refer back to the function of the power equation. Because wind speed is a cubic function, doubling wind speed results in eight times more power. The reverse is also true. If is cut in half, there is one-eighth the amount of power production.

Here is a theoretical example:

	Turbine Model	Rated Power	Rated Wind Speed	Wind Speed in Miles Per Hour	Power Output
Scenario 1	Model A	3 kW	12 mph	24 mph	3 kW
	Model B	3 kW	24 mph	24 mph	3 kW
Scenario 2	Model A	3 kW	12 mph	12 mph	3 kW
	Model B	3 kW	24 mph	12 mph	375 Watts

A turbine with a lower rated wind speed is often advantageous.

Other Terms You May Encounter

Generator Size

Some manufacturers size the wind turbine by the size of the generator. A turbine with a five-kilowatt generator would be called a five-kilowatt wind turbine. This is not an accurate measure of energy output. Paul Gipe, an industry expert on small wind, says, "By this logic, you could slap a six-foot plank on the end of a 25-kilowatt generator and call it a 25-kilowatt wind turbine." Wind energy production comes from wind speed, swept area, air density, and effective blade technology. Because of variability in wind speed, air density and blade technology, the generator will not operate at its full potential 100 percent of the time and thus, is not an accurate indication of energy output.

Peak Output

Peak output is a term used in marketing materials, but is not very helpful in many situations. The manufacturer sets the definition. Peak output can be useful in determining electrical connection (i.e. – sizing circuit breakers). However, because it may or may not refer to the maximum output of the turbine, it is a poor method of determining energy output.

Maximum Design Wind Speed

This term refers to the maximum amount of wind the turbine can withstand without damage. The information is not very helpful because it is hard to know if the information is correct and what standards were used to establish this figure. Also, in a "maximum" wind, there is likely to be debris (sticks, leaves, plastic bags, etc.) in the air that could damage the turbine long before the force of the wind does damage.

Rated Output or Rated Power

Rated output is a power output at a certain wind speed. The problem with rated power is it is defined by the manufacturer. The term comes from the solar photovoltaic industry, where panels are tested for output at a fixed light intensity and fixed temperature. These standards have only recently been defined for wind, they are not yet well established in the market place. Rated output is a poor method for calculating energy output because there is no standard definition.

Remember–the most consistent means of comparing wind turbines is the total rotor diameter or swept area.

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STEP 5

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch

Author: Sarah Hamlen; Mike Vogel and Milton Geiger eds. E3A Program

Selecting Turbine Model and Tower Height

There are a number of buying guides to assist consumers in purchasing a wind system. You might consider using *HomePower Magazine's* Annual Buying Guide. Until the Small Wind Certification Council data is more robust, this is one of the few sources that provide side-by-side comparisons of wind turbines.

Assessing Information Provided

Information will vary by manufacturer until testing standards become more common. It is a good policy to ask questions about the turbine information and power production estimates.

Questions to Ask About a Turbine

Here are a few questions to ask an installer or manufacturer:

- **Is this a well-established manufacturer?** Some small wind manufacturers have been in business for decades. These companies often have equipment with long-term product performance records. There is nothing wrong with buying from a newer company, but more caution may be warranted if long-term product performance records do not exist.
  - ☐ Yes
  - ☐ No
  - ☐ Uncertain
- **Is the estimated energy production consistent with other turbines with the same rotor diameter?** Remember that power production and rotor diameter (or swept area) are directly related. Be wary of turbines that claim a much higher power output than their rotor diameter (as indicated by SWCC or the Home Power Buying Guide). Ask for an annual energy output calculation. Ask questions about how this calculation was completed. Test the assumptions, especially the wind resource at your site. Ask for actual energy output from installed turbines. How much power was generated? Are there customers in your area that you could contact about their experiences?
  - ☐ Yes
  - ☐ No
  - ☐ Uncertain
- **Is the installer using a good resource for wind data?** Good wind data is one of the most important factors in selecting an appropriate turbine and estimating power output. Ask where they are getting their wind data. Is it detailed enough to be specific for your site?
  - ☐ Yes
  - ☐ No
  - ☐ Uncertain
- **Was the turbine performance measured in a field test?** Not all wind turbines have been field-tested. Some manufactures have only tested their equipment in wind tunnels. System performance may vary in an actual installation. Ask for specific locations of tests so that you can check to see that field-testing did occur. Can the manufacturer provide a record of these tests?
  - ☐ Yes
  - ☐ No
  - ☐ Uncertain

Steps in the Small Wind Series

B-1280 | E3A-SW.5

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch is a peer-reviewed publication series.

Original available at: www.wyoextension.org/publications/

Suggested acknowledgment: Sarah Hamlen; Mike Vogel, and Milton Geiger, eds. E3A: Small Wind Energy Applications, Fact Sheet 5, Steps in the Small Wind Energy Applications Series. E3A-SW.5. 2011.

- **Has the turbine performance been independently verified?** Ask for independent third-party tests of the turbine. You want to know if someone other than the manufacturer will verify the system performance. Examples of third-parties might be universities, the National Renewable Energy Laboratory or the Small Wind Certification Council.

  ☐ Yes
  ☐ No
  ☐ Uncertain

- **Is the turbine labeled for compliance with UL 1741?** This means that the turbine has been certified as safe for connection to the utility grid.

  ☐ Yes
  ☐ No
  ☐ Uncertain

- **Is it compliant with International Electrotechnical Commission (IEC) design and safety standards?** This means that the turbine has been certified as safe by electrical code standards.

  ☐ Yes
  ☐ No
  ☐ Uncertain

- **Is there a supplier of parts and/or service in your area?** When the system requires maintenance, how quickly can you get parts or assistance? Is there a service contract with the turbine?

  ☐ Yes
  ☐ No
  ☐ Uncertain

- **Does the turbine come with a warranty? If so, what is covered and how long is it in effect?** Is the company financially sound enough to pay warranty claims?

  ☐ Yes
  ☐ No
  ☐ Uncertain

- **Can the manufacturer provide a record of the performance?** Questions about performance might include: How many of these turbines are installed? How many are still operational? Some manufacturers may claim a large number of installed systems, but not all of those systems are still in operation.

  ☐ Yes
  ☐ No
  ☐ Uncertain

- **Do you know the tower top weight?** Typically, turbines with heavier tower top-weights can withstand higher winds and have longer life expectancy. You can also use the Home Power Buying Guide to compare tower top-weights.

  ☐ Yes
  ☐ No
  ☐ Uncertain

Capacity Factors

The use of capacity factors in discussing small wind installation is not considered appropriate by some experts. (Gipe, 2006). However, many consumers find that their manufacturer or installer will quote capacity factors during the sales process. You should instead ask for Annual Energy Output calculations. Capacity factor is a ratio of the actual output of the turbine over the amount of output that it could have if it operated at full capacity 100 percent of the time. There are a variety of reasons that this measure is not helpful. However, if you are quoted a capacity factor, be aware that capacity factors in small wind range from nine to 22 percent. A higher number is better, but capacity factors above 22 percent are not realistic for small wind. Capacity factors of 30 to 45 percent and higher are typical for commercial machines of 1.5 to 2.5 megawatts, but are not possible for small wind turbines.

Site Visit

Visit with a current owner of the turbine model you are considering. Your manufacturer or dealer should be able to provide you with a list of current owners. Ask about their experience with the turbine. How much power is generated by the turbine and how did that compare with the estimates provided at the time of installation? Make time to visit an installed system. A site visit will help you create realistic expectations about wind turbine ownership. It will also give you a chance to hear the noise generated and to see the turbine footprint and visual impact to the property.

Selecting Tower Height

10 kW Bergey Wind Turbine in Stanford, Montana. Photo by Jessica Raker ,NREL 14677 http://images.nrel.gov/viewphoto.php?imageId=6327130

The tower should be tall enough for the bottom edge of the turbine blades to be at least 30 feet above the tallest obstacle within 500 feet. Many small wind manufacturers recommend a minimum tower height of 65 feet (20 meters). To better understand the importance of tower height in capturing the wind resource, refer to Step 3–Assessing Your Wind Resource Fact Sheet in the E3A series.

Here are a few things to keep in mind on tower height:

- Think long term! Trees will grow. What is their final or mature height? Are there any structures planned nearby?

Plan for the future.

- Are there a variety of tower heights sold in your area? In some areas, dealers may only carry two or three tower heights. If the tallest available tower is not right for you, you might want to consider another renewable energy technology, such as solar. Remember that a short tower on a wind turbine is akin to placing a solar panel in the shade.
- Are there zoning or homeowner association restrictions that would limit your tower height?

What about...?

Here are common questions with regard to using short towers:

Question	Answer
Can I make my own tower or use another type of tower (lighting, cell, etc) instead?	Manufacturers will typically not honor warranties for systems that are not mounted on approved towers. Wind systems encounter a lot of load and torque and the margin between a well-balanced and functioning system and a system failure is very small. For any wind system, make sure the tower is rated for the turbine you intend to install and is suitable for the winds in your area.
My neighbor's turbine is mounted on a shorter tower than what is suggested here. Can I do that?	Remember that wind turbine siting is site specific – what is appropriate for your neighbor's property, or even another site on your property, may not be appropriate for the site you are considering.
I really want to save money on tower expense. Can I install the system on a short tower?	You must balance energy output and economics. Towers under 45 feet usually compromise energy output. There are situations where the site and wind are suited for a 30-foot tower, but these sites are the exception. The decision you make when you use a shorter tower than is appropriate for your site is one of lower upfront investment, but longer simple payback and lesser energy production.

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Notes

STEP 6

Steps in the Small Wind Series

B-1280 | E3A-SW.6

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch

Author: Sarah Hamlen; Mike Vogel and Milton Geiger eds. E3A Program

Economic Considerations

There are many incentives available to make installing a small wind system more affordable. However, there are still significant costs associated with small wind systems. Before purchasing a small wind system, it is recommended that you consider the following factors:

- **Objective for Purchasing a System —** The "acceptable" return on investment in a small wind system will vary by consumer and is largely dependent on your objectives. If your objective is to build a demonstration project, the financial return may not be as important as it would be if your objective were to lower your utility bills.
- **Energy Efficiency —** Start by increasing energy efficiency. Whether trying to reduce your carbon footprint or working to reduce your total energy bill, energy efficiency measures usually help you to reach your goals faster than installing a renewable energy system.
- **Total Cost —** While many factors influence total cost, system costs range from $4,000 to $8,000 per kilowatt of installed capacity. The estimated cost for a 10-kilowatt system, which would offset most of the electrical consumption of the average home in Montana or Wyoming, would be $40,000 to $80,000.
- **Access to Capital —** Even though it may be possible to offset 30 to 75 percent (depending on the state) of the system cost with subsidies, consumers will need to either pay cash or finance the entire cost of the system because of the timing of these incentives. Consumers who do not have access to capital will find the purchase of a small wind system difficult. Be aware that many price quotes list the price of the system AFTER rebates. Many rebates will not be received until after the system is installed. Understand when each incentive will be available.
- **Terms of Available Incentives —** Pay attention to the terms of incentives. Here are some examples:
  - Tax Rebate Incentives: Many incentives are tax credits. You should check with a competent tax advisor regarding the benefit of the tax credit in your particular situation. Check to see if you have sufficient tax liability to use the full value of the tax credit in the first year. Some credits may be carried forward into future years if you do not use the entire amount in year one. However, you will continue to make payments on the system while waiting for the tax incentive. Cash flow assumptions need to reflect the time lag.
  - Reimbursement Incentives: Some programs require you to submit receipts for payment. Reimbursement programs may be able to process your incentive payment quickly, but be aware of possible delays.
  - Manufacturer or Dealer Financing: Some installers will carry the financing for the amount of benefit a consumer is set to receive. For example, if a consumer appears to qualify for a 30 percent rebate, the installer may agree to carry that 30 percent until the rebate is received. Some installers will also offer financing if you appear

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to qualify for tax rebate incentives. Be sure to ask about these incentives and make sure you understand the terms that are being offered by the installer. Also, make sure you check with your tax accountant regarding your tax liability to ensure that you will receive the benefit and be able to make payments to the installer.

Detailed information regarding various incentive programs is on the E3A website.

Common Means of Evaluating Wind Turbine Economics

First Cost

A first (or initial) cost analysis simply compares alternatives of the total upfront investment you will make in a system. A first cost estimate typically includes estimates of the tower, turbine, site work, wiring, and installation costs. A range of $4,000 to $8,000 per rated kilowatt (kW) is typical (for example, the cost of a five kW system would range between $20,000 and $40,000). Costs vary depending on type of equipment used. For example, shorter towers and guyed wire towers are often less expensive than taller, freestanding towers. Similar comparisons can be made for other components as well. The first cost method is a poor method of economic analysis because it only provides information on the total upfront cost and does not look at the longer-term implications of the investment, such as energy production and maintenance costs.

Simple Payback

An investment's simple payback is calculated by dividing the total cost of the system by the annual net savings. In some cases, the total cost is the cost of the system after incentives (grants, tax credits, etc.). Net savings is the value of the energy generated less operation and maintenance (O&M) expenses. O&M costs are sometimes estimated in terms of cost per kilowatt-hour (kWh) of electricity production. Some estimates use $0.001 to $0.02 per kWh. Other methods estimate the cost of O&M based on the initial turbine cost, such as, one to three percent of the initial purchase cost (one percent of a $50,000 system would result in an annual O&M estimate of $500). O&M costs will vary on the type of equipment. As the number of "moving parts" increase, so should your estimates of O&M expense. For example, if the turbine includes a gearbox, estimates for O&M should be increased to account for wear and replacement of gearbox components. When calculating economic return, it is a more conservative approach to assume higher O&M costs.

Example:

Capital cost: $50,000

Value of Energy: 16,500 kWh (estimated electricity generation) x $0.09/kWh (cost of electricity) = $1,485

O&M: $50,000 (capital cost) x 1.5% = $750 (per year)

Payback: $50,000 ÷ ($1,485-$750) or $50,000 ÷ $735 = 68.02 years

With incentives to off-set 45 percent of capital cost = $27,500 ÷ $735 = 37.41 years

Simple payback is an easy calculation but does not always account for many important factors such as increases in energy prices or alternative uses for the project capital.

Cost of Energy (COE)

The cost of energy method combines the capital cost and the total expected O&M (for the life of the project) divided by the total lifetime energy production of the turbine.

Example (Using a 20-year lifespan):

Capital Cost: $50,000

O&M: $750(50,000 x 1.5%) x 20 years = $15,000

Lifetime Production: 16,500 kWh x 20 years = 330,000 kWh

COE: ($50,000 + $15,000) ÷ 330,000kWh = $0.197/kWh

If a 30-year lifetime is assumed, the COE drops to $0.146/kWh. If incentives offset 45 percent of the capital costs, then the COE over 20 years is $0.128 kWh.

COE is also considered a simple method in that it does not consider interest payments incurred from the purchase of the system, which increases the COE. This model also neglects increases in O&M expenses. It does not account for the time value of money; however, it is another means of quick evaluation to provide an indication of economic return.

Net Present Value (NPV) and Internal Rate of Return (IRR)

Most companies considering an investment in a project evaluate and compare the profitability of a project based on the net present value of the project or the project's internal rate of return. Both of these methods estimate the cash flow generated by a project for each year the project is expected to last. This cash flow includes purchase prices, tax incentives, value of electricity, insurance costs, maintenance costs, and any other related income or expenses. For net present value calculations, the net cash flow for each period (including any salvage value of the equipment at the end of the project) is then discounted at a rate (often the expected inflation rate), back to the time of the system's purchase and added together. If the value is positive, the project is often accepted. For internal rate of return calculations a discount rate is selected that makes the NPV calculation equal to zero. The higher the rate the better financial return of the proposed project. These methods provide a more accurate analysis of a project but both are only as accurate as the data used to generate them.

A net present value (NPV) analysis first estimates a project's revenue and expenses for each year of the project. In the example below, the project costs $2,500 to purchase today. At the end of each of the next four years, the project will generate revenue of $1,200 and an expense of $200. The revenue and expenses are combined in each year to calculate the net annual cash flow. Each net annual cash flow is then discounted by using a discount rate and the number of years until each expected cash flow. The formula used to discount each net annual cash flow is:

$$\frac{\text{Annual Net Cashflow}}{[(1 + \text{Discount Rate})\ \hat{}\ \text{Number of Years}]} = \text{Discounted Value}$$

NPV is calculated by adding all of the discounted cash flows. A positive NPV indicates the lifetime cash flow of the project is expected to provide a return greater than the discount rate. A negative NPV would indicate the project is expected toprovide a return less than the discount rate. It is not common to proceed with a project with a negative NPV.

Net Present Value Example					
	Project Expenses	Project Expenses	Net Annual Cash Flow	Years to Discount	Discounted Value
Initial Costs	$0	$2,500	-$2,500	0	-$2,500
Year 1	$1,200	$200	$1,000	1	$952
Year 2	$1,200	$200	$1,000	2	$907
Year 3	$1,200	$200	$1,000	3	$864
Year 4	$1,200	$200	$1,000	4	$823
Net Present Value					$223

**Discount Rate: 5%

Electronic Calculators or Manufacturer Provided Calculations

There are economic calculators available online. Many are downloadable spreadsheets. These tools are often far more robust than the simple models discussed above. They often include calculations of the net present value and rate of return for the project. Some account for the time value of money and can show the effect of tax incentives on the project. Many allow for O&M and per kWh electricity costs to rise at rates other than the expected general inflation rate. These tools are beneficial in that you are able to run a variety of scenarios to evaluate the proposed project under different assumptions.

Manufacturers or dealers typically provide calculations on economic return as part of their project proposal package. These figures are intended to be tailored for your site and situation and may reflect specific details about your financing package or product that cannot be easily included in the generic calculations.

However, both the online calculators and manufacturer provided calculations are only as accurate as the assumptions being made in the calculations. Companies interested in selling you a product may select assumptions that shed the most favorable light on their product and not the assumptions that most accurately reflect your situation. In order to determine if the economic return indicators provided are accurate for your situation, you need to check these assumptions. The following list of questions can aid you in this assessment:

- **Is the energy consumption calculation for your site consistent with the information you obtained from your utility company?** When calculating the appropriate size of your turbine, you should collect at least one-year's worth of energy statements to get an accurate estimate of your annual kWh usage.
- **What are the assumptions about your current cost of energy from the utility?** You can obtain actual costs of energy for your site by contacting your utility company. In June 2010, the average cost of electricity for residential customers in Montana per kilowatt-hour was $0.0934. In Wyoming, the average cost is $0.097 per kWh.
- **What assumptions are being made about energy price increases?** Without major policy changes such as the regulation of greenhouse gas emissions, the US Energy Information Administration is currently projecting energy prices to increase at approximately 2.5 percent per year over the 2010 to 2035 period.
- **What assumptions are being made about the turbine electrical generation?** This question will require additional research on your part, and make certain that the energy output calculations are accurate. Many estimates and electronic calculators will assume maximum energy output from the turbine, which will overestimate the economic return calculation.
- **What turbine life expectancy is assumed?** Many calculations will assume an operational life of 20 to 30 years. While there are small wind turbines on the market that have been in operation for this amount of time, there are also many new turbines and new companies that do not yet have a 20 to 30 year product history. You may wish to ask the manufacturer or dealer for further information on testing or actual field performance of their turbines to ascertain if the life expectancy is realistic for your project. Some parts (such as the tower) of the system may have value after the project is complete. You may want to consider the life expectancy of the components in addition to the system as a whole.
- **What assumptions are made with regard to O&M costs?** Bear in mind that your O&M allocation should provide for replacement of parts over time. For example, if the inverter (which is typically assumed to have a life expectancy

of 10 to 15 years and can cost between $1,000 and $3,000), the O&M allocation should be large enough to cover the cost of replacement. You may want to consider how the project analysis would change with a major component (such as an inverter) failure at some point during the project.

- **What assumptions are being made with regard to the cost of the system?** Detailed costs on the following system components should be included in the estimate you receive from the manufacturer or dealer:
  - Wind turbine cost
  - Inverter
  - Controller
  - Batteries (only for off-grid applications)
  - Tower (prices will vary by the height and type of tower)
  - Tower erecting equipment
  - Foundation materials
  - Wiring and electrical supplies
  - Labor for foundation, tower erecting, electrical wiring, and turbine installation
  - Turbine and tower shipping
  - Siting and permitting
  - Sales or property taxes (if applicable)
  - Insurance costs
- **Does the economic calculation assume that any excess energy is being purchased and paid for by the utility (sometimes referred to as a buy-back rate)?** In Montana, projects installed on a net metered basis are not compensated for any excess energy production. Calculations for a Montana net metering project should therefore not assume a financial value for excess energy production. In Wyoming, net metered projects are compensated at the utilities avoided cost (typically two to four cents per kWh). These low rates generally do not make it economical to sell large amounts of excess energy to your electric utility.
- **What is being assumed about your purchase of the system?** Does the model assume that you will pay cash or obtain a loan? If debt financing is assumed, what interest rate and loan period are used? You may wish to check with your bank regarding appropriate interest rates. What down payment and collateral are being assumed? There are some renewable energy loan programs with low interest rates that might be assumed. Be sure to check with the program manager regarding loan availability and interest rates before assuming that you will qualify for any nonconventional lending program.
- **What does the calculator assume about state and federal incentives?** Not all programs will apply to your situation. Make certain that you verify which programs are being assumed in the calculator and review the program qualifications to ensure that you will qualify for the incentives before including them in your analysis.
- **Are the operations and maintenance costs assumed to increase at the same rate as inflation or at some other rate?** Does the model provide this functionality, and if so, what rate is being used? Discount rates are often included in electronic or manufacturer provided calculations. The discount rate is included in time value of money or net present value calculations. A discount rate of three to four percent is typical.
- **Does the calculator make any assumptions about reducing demand charges?** In general, small wind systems will have little effect on demand charges. A reasonable assumption is a monthly demand reduction equal to one-half of the capacity factor times the rated power of the turbine. In most residential applications, demand charge or service fee reductions should not be assumed.
- **What assumptions are being made with regard to the sale of Renewable Energy Credits (RECs)?** In some cases, wind turbine owners are able to sell the "renewable" aspects of their electrical production to utilities, companies or individuals who want or need to ensure that a portion of their electric usage is produced from renewable sources. This is very common for large projects but is much less common for small projects.

Economic returns may only be one consideration in your evaluation of a small wind system. However, whether you consider the payback period or return on investment to be your main priority, or only a passing consideration, understanding the information that is being presented to you is important. Critical evaluation of the assumptions that have been included in any economic calculations provided to you can ensure that the installed system meets your expectations and accomplishes your fiscal objectives.

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STEP 7

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch

Author: Sarah Hamlen; Mike Vogel and Milton Geiger eds. E3A Program

Steps in the Small Wind Series

B-1280 | E3A-SW.7

Siting and Permitting

The purpose of a small wind system is to produce energy. Siting a wind turbine is a process of locating the system so that the turbine can have unobstructed access to the highest possible wind speed to take advantage of the function in the power equation.

The basic rule of thumb is to site the turbine with the bottom edge of the rotor blades at least 30 feet above the tallest obstacle within 500 feet. Some experts recommend that the bottom edge of the blade should pass three times above the tallest upwind barrier. Keep in mind some barriers change – especially trees, which grow over time. The topography of the site will also interfere with the wind resource.

The challenge for many potential small wind owners is applying basic rules of thumb to a specific site. Here are a few general guidelines:

- **Tower height —** The most common error in turbine siting is placing the wind turbine on a tower that is too short. Many times the decision to buy a short tower was made because the local installer did not offer the required tower height. Tower height should be determined by the terrain and the wind resource.
- **Optimize the wind resource —** Site upwind of obstacles to avoid ground clutter. You may wish to start examining the highest point on the property to take advantage of wind shear and reduced turbulence. Topography or other factors may not make the highest point the best location for siting, but it is often the point with the best access to the wind.
- **Soil testing —** Learn about the soil at your site. Soils vary in their capacity to support weight. Weak soils (soil strength of less than 1,000 pounds per square foot) may not be well suited for supporting a wind turbine, or may require additional engineering to ensure safe operation of the turbine. Got rocks? Rocks in your planned site may increase the total cost of preparing the site. The more you understand about your specific location, the better you will be able to forecast problems and develop an accurate budget.
- **Communicate with neighbors early in the process —** Early notification of your neighbors is a courtesy that can help to identify and prevent problems. Your neighbor's concerns may impact your purchasing or siting decisions.
- **Noise —** Sound may carry differently according to topography and structures. Some small wind turbine owners report almost no sound from their turbines, but their neighbors may experience more sound. Some permits or zoning ordinances limit the noise levels as measured from the closest neighboring inhabited dwelling. Sound carries differently if the turbine is sited near metal buildings or bodies of water. The amount and type of noise varies by wind turbine and by site. If concerned, visit an installed turbine similar to the one you are considering to experience first-hand the sound of the turbine.
- **Visual impact —** Neighbors in very rural areas may have few concerns regarding visual impact. However, neighbors in more densely populated areas might have concerns or questions about the visual impacts of the turbine.

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Photo by Southwest Windpower, NREL 14935 http://images.nrel.gov/viewphoto.php?imageId=6327133

- **Property values —** There are studies on large commercial wind farms and property values. There are no comprehensive studies documenting small wind turbine impacts on property value. Industry proponents indicate that there are no known instances of small wind turbine installation negatively affecting property values. In some markets, small wind systems may increase property values.
- **Telecommunications interference —** Turbines are not known to interfere with telecommunications signals. The rotor diameter is small and the blade components (fiberglass or other composites) do not affect signals. There were reports of experimental turbine tests conducted decades ago where metal blades interfered with television signals, but there is no consistent evidence of interference using current technologies.
- **Safety —** In some areas, the permitting process requires significant documentation and precautions with regard to safety. In rural areas, safety standards may be lax or nonexistent. With regard to safety issues, you may wish to learn:
    - If there are county or city zoning or permitting requirements regarding safety.
    - If your insurance company has certain standards with which your turbine will need to comply in order to qualify for coverage.
    - Consider whether fencing and signage around the turbine would be appropriate for your site.
    - If your utility has specific guidelines with which you will need to comply in order to grid-connect your system.
- **Neighboring Turbines —** Locate the turbine at least ten rotor diameters away from the nearest turbine.
- **Avian impact —** Small wind turbine advocates suggest that the amount of avian impact from small wind is no greater than other objects into which birds might fly. However, there are no comprehensive studies regarding avian impacts from small wind. Use common sense. If your site is in a flyway, you might have impact. Contact your local wildlife management agency and discuss with them the migratory behaviors and flight heights of species in your area if you are concerned about impacts.

- **Lighting —** Unless lighting is required by your ordinances, it is unlikely that you will have to illuminate your turbine. The Federal Aviation Administration (FAA) does not require lighting on structures under 200 feet, unless they are adjacent to an airport.
- **Air traffic —** You will probably not have air traffic requirements, unless you are near an airport or military post. However, if you are in an area where crop dusting is common, check local air traffic safety standards and notify crop dusters in the area of your turbine installation. Check Department of Defense standards if your turbine site is near a missile silo.

Permitting

Permitting requirements vary. Contact your city or county permitting agency to check the requirements in your area. Here are some common issues you may find in your local ordinances:

- **Documents —** Some permits will require signed plans from an engineer. If this is not required, check with your manufacturer to verify that your warranty will be valid if you do not have an engineered site plan–especially if you plan to install the turbine yourself.
- **Parcel Size —** Your permit may require you to have a minimum parcel size. Minimums tend to be one acre, if they are specified.
- **Allowable Tower Height —** Restrictions on heights of structures are common in zoning. Check to ensure that there are no maximum structure height ordinances that would affect your project.
- **Setback —** Setbacks refer to the distance you must site your turbine away from public areas or property lines. Setbacks usually refer to all parts of the system, which include guy-wires for guyed towers.
- **Noise Levels —** The noise levels are typically measured in decibels and may need to be measured from the closest neighboring inhabited dwelling.
- **Equipment —** Some permits restrict the types of equipment. Be sure you are aware of any such restrictions prior to purchasing a system.
- **Building Code Compliance —** Permits may require your structure to be compliant with any local building codes. This may require you to have signed drawings and a site plan analysis completed by a certified engineer.
- **Electrical Code Compliance —** You may be asked to supply drawings of the system's electrical components and demonstrate that you are compliant with electrical code standards. If electrical code compliance is not required for a permit, it may be required by your utility for grid-connected systems.
- **Compliance with FAA Regulations —** If your site is near an airport or military facility, you may have FAA regulations with which you must comply. Your local planning department should be able to help you determine whether FAA regulations need to be addressed.
- **Utility Notification —** Some permits will require you to produce documentation that the utility is aware of your plans to install a small wind turbine. If this requirement is in place, off-grid systems may be exempt.

As you research the permitting process in your area, be aware that fees may apply. If permits are not required in your area, you may wish to find permitting guidelines from other areas or find best practices recommended from your manufacturer to ensure your turbine is installed properly.

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Notes

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STEP 8

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch

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Steps in the Small Wind Series

B-1280 | E3A-SW.8

Operation and Maintenance

If you are considering the purchase of a small wind system, you should know that small wind systems require at least annual maintenance. Maintenance needs increase with the number of moving parts on the turbine, higher average wind speed, and/or turbulence. This factsheet provides an overview of operation and maintenance considerations, but you will need information specific to your wind system in order to complete actual maintenance. Your owner's manual should provide most of the information you need to maintain your system properly.

Crew attaching blade to a turbine at the Elkorn Valley School in Nebraska
Photo by Judi Sigler, NREL 16254
http://images.nrel.gov/viewphoto.php?imageId=6326109

Proper Installation: The First Step in System Maintenance

Careful assembly of parts and high-quality installation will help to prevent many maintenance issues. Proper installation of a system includes appropriate bolt torque, especially when installing the blades, rotor, and tower. Electrical wiring practices should include wire gauge sizing, proper grounding and crimping, and ensuring wiring meets electrical code standards. Lubrication should be completed to the manufacturer's specifications. Other factors may include the sequence of assembly and installation, proper initial tower installation or setup of guy wire tensions, and appropriate pouring of the foundation.

Budgeting for Maintenance

The amount of maintenance (and money) your system will require will vary by the turbine, site, wind speed and turbulence and by your access to parts and services. Here are a few things to consider:

- Most of the moving parts are mounted on the tower. You will need to climb the tower or install a tilt-up tower that will allow you to lay the tower down to perform maintenance. Even with a lift or bucket truck, you will likely need to climb the tower to perform all required maintenance. If you are not willing to climb the tower, you will have to hire someone to perform maintenance. Consider costs of climbing gear and/or service expenses when developing your budget.

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- Some references suggest budgeting $0.01 to $0.02 per kilowatt-hour of electricity produced. Others recommend one to three percent of the total installed cost be budgeted annually. Determine the appropriate amount for your system by learning about the components that will require regular replacement, understanding their costs. Then you can set aside enough annually to afford replacement.
- Access to parts and service can be a consideration. Budget for shipping expenses on parts or mileage for service calls.
- Maintenance gear should also be included in your budget. In addition to some owner's manuals, *Home Power Magazine* has several articles that address the types of gear you may need. Your installer may be willing to help you understand what you will need to maintain your small wind turbine.
- Look closely at warranties. How long will the manufacturers of turbines, towers, foundations, and other parts warranty their products? What is in the fine print? Does the warranty include shipping new parts, cost of repair, or technical services? It is not typical for all costs to be covered by a manufacturer. However, reputable manufacturers are more likely to offer better warranties because they have a track-record of proper function, are confident in the construction and operation of their systems, and want to ensure that their customers are satisfied. You should review the timetable for replacement, repair, or service when reviewing warranty information from the manufacturer. This information may help to choose the best system for your application. A good warranty may save thousands in repair bills.
- Budgeting for reduced electrical production should also be included in your maintenance budget. Repair that requires parts to ordered, shipped and installed will prevent your system from operating for several days or weeks.

Servicing Work

Consider the work that will need to be done on your small wind turbine. Ask the question, "If not you, then who?" This question is important for two primary reasons: 1) Even people who are technically competent to perform maintenance may need to sub-contract the work. If you become ill or injured, who will maintain your system? Are you willing to spend time maintaining the system? It is easy to defer maintenance because you are busy, the weather is cold, or you would rather spend your free time doing other activities. You may find that hiring service work makes more sense. 2) It may take some time to locate a qualified technician in your area. In some cases, installers are willing to provide maintenance services on a fee-basis and some turbines come with service contracts. Depending

Photo by Warren Gretz, NREL 04119 http://images.nrel.gov/viewphoto.php?imageId=6325432

on your area, however, access to qualified technicians may vary. If technicians will have to travel to reach your site, you will need to consider mileage expenses as part of your budget.

Components to Inspect

A great source of information for the type of maintenance recommended for your turbine is the owner's manual. Most manufacturers provide an overview of the maintenance requirements and recommendations for part replacement. The following information is not a thorough maintenance guide. It intends only to give you an overview of the components of the turbine you will need to inspect:

- **Power Room** — Inspect all electrical components and wires. This will include everything from circuit breakers to the inverter. Your inspection will involve checking for ground faults, tightness of connections, corrosion, or conducting electrical tests recommended by the turbine manufacturer. You will also have battery inspections if batteries are part of your system configuration.
  **Note – Batteries will require inspection and monitoring more frequently than annually. Check with your installer on battery maintenance requirements.*
- **Foundations and Towers** — The requirements for tower maintenance vary according to the type of tower. In general, you will need to inspect the foundation to ensure that the tower is straight and plumb. You will also need to check for rust, compromised welds, or other pieces of the tower base that are broken or missing. On guyed-towers, you will need to look for slack or wear in the wires. Corrosion (often indicated by rust), unusual movement, and wear on all points of connection are considerations when performing maintenance. You will also need to check the brakes and grounding of the tower.

- **Tower Mechanics** — Checking for loose or missing bolts, nuts, and lock nuts. The wiring down the tower as well as any tower-mounted data equipment will need inspection.
- **Wind Generator** — All moving parts and points of connection require inspection. Loose hardware, rust, grease or oil stains (in atypical locations), and black powder are indications of wear that you should address. Inspect turbine tower mounting and blade mounting integrity. Components involved with passive control or furling, depending on the type of system, also require inspection.
- **Blades** — In addition to checking the points of connection at the rotor, check the blades for cracks, nicks, pits, and damage to the leading edge.

Safety

Safety should be a primary concern and never discounted or overlooked when performing any turbine maintenance. Be aware of the safety recommendations for your system. Safety concerns include falls, electrocution, and multiple pinch points. Maintenance may include manipulating heavy objects with winches and lifts, which generates thousands of pounds of force. Remember that much of the maintenance work will be performed well above the ground. Maintenance work performed on the tower will require climbing equipment and careful attention to detail. The wind speed will increase and the temperature will likely be cooler as you reach the top of the tower.

There are steps that you can take to mitigate hazards. You can ensure electrical disconnects are in place and functional to protect you from back-feed. Check for functioning rotor brakes. Pay attention to the location of overhead electrical lines and trees. Wearing protective eyewear, gloves, hardhat, clothing, and safety equipment can help to protect you while you work. Be informed, and preferably trained, on wind turbine maintenance and safety.

In short, you should consider the need to maintain a small wind system before purchase. Like automobiles, those that are well cared for can provide years of service. Those that are not well maintained will show the lack of care through loss of energy production, catastrophic system failures and shortened life expectancy. Be sure to have frank discussions regarding maintenance with your installer to ensure you accurately understand the maintenance requirements of your system before you commit to a small wind turbine.

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STEP 9

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch

Author: Sarah Hamlen; Mike Vogel and Milton Geiger eds. E3A Program

B-1280 | E3A-SW.9

This fact sheet identifies considerations and addresses questions about living with an installed small wind turbine.

Insurance

Liability insurance will most likely be required by your utility for grid-connected systems. The amount of coverage required will vary. If your turbine is financed or if your home is off-grid, liability coverage may be required by your lender. Coverage will likely be required for both damage to property from the turbine and for personal injury. A property damage example: a blade comes off the rotor hub and damages a neighbor's roof. Personal injury coverage relates both to people being hurt on the generator itself, as well as possible injuries to linemen working on utility lines during an outage. Industry proponents point out that there are few examples of people being hurt or liability claims related to small wind systems. Coverage is usually required for small wind owners, nevertheless. You should budget the insurance cost for the life of the system.

Insurance for the turbine itself is another expense that should be included in your budget for the life of the system. This insurance will help to cover replacement costs in an unexpected event. In small wind, unexpected events are typically extreme winds, lightening strikes, or wild land fires. The coverage usually also addresses issues of theft, vandalism, fire caused by the system (faulty wiring, etc.), flooding, and other "acts of God." The easiest and least expensive means of insuring the turbine is often as a part of your home owners insurance. The turbine would be an appurtenant structure if it is on the same property as your home. This is the same type of coverage used for a shop, disconnected garage, or barn. Coverage costs can be inexpensive. You will need to discuss costs of coverage (as well as types of coverage if the turbine is not on the same property as your home) with your insurance agent.

Lightning

A properly sited wind turbine will generally be the tallest structure on your property. Lightning strikes do occur on small wind systems. However, lightning protection is standard equipment for small wind turbines. Many electrical system components have protections built into them at the manufacturing facility. In addition, grounding is included in a proper installation. Guy wires should have ground rods or a concrete anchor at each point where the cable is in contact with the soil. Towers should have ground rods connect to each tower leg. Grid-connected systems have additional protections in place from the utility-side of the inverter. These protections include a ground, lightning, and voltage surge arrestors. None of the protections will prevent lightning strikes, but they will help to ensure your safety and provide protection to the system in general. This will also help to demonstrate to the insurance company and manufacturer that you have taken prudent steps to protect your system.

E3A: Small Wind Energy Applications for the Home, Farm, or Ranch is a peer-reviewed publication series.

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Icing and Ice Shedding

There are two main ways ice can impact your small wind system. The first is by icing system components. This can occur when weather conditions are right for ice to form, but there is no wind blowing to keep the turbine in motion. The turbine may freeze, but the icing does not typically cause damage. You can thaw the turbine, but usually system owners wait for the ice to melt. When the system is iced, you will experience loss of energy production. The second issue is ice shedding. When ice builds on rotor blades, it will slow the aerodynamic function of the blade. In large, utility-scale equipment, the blades can have enough momentum to "throw" the ice off the blade. Small wind systems turn more slowly when iced, and usually the ice will be found at the base of the tower where it has fallen from the blades. While it is not common for ice throwing to occur with small wind turbines, some zoning ordinances do prohibit ice being thrown over property lines or onto public right-of-ways. You may wish to discuss icing and ice shedding with your manufacturer or installer to learn more about your turbine's performance in ice situations.

Birds and Bats

As mentioned in the Siting and Permitting Fact Sheets, there are no comprehensive studies on avian impact with small wind systems. Use common sense and do not site a wind turbine in or close to a sensitive area.

Flicker and Noise

Shadow flicker is caused when the intermittent shadow of the rotating blades pass over an object, such as a house. Shadow flicker is becoming a topic of concern in utility-scale wind, but is not often discussed in small wind. In some areas, siting restrictions are present in local ordinances that help to ensure your turbine will not cast a flicker-causing shadow on neighboring properties. You may want to consider the possibility of shadow flicker on your own home and site the turbine accordingly.

An additional consideration is that unusual noise might indicate a problem with your turbine. Issues with bushings, yaw, or unbalanced blades will change the sound your turbine creates. Sensitivity to changes in the sound may help you to catch maintenance issues before they become more significant.

Wind Easement

In some situations, small wind turbine owners seek to protect the wind resource on their property by insuring undisturbed flow of wind across neighboring properties. A wind energy easement is allowed under Montana law for this purpose. Considerations in developing an easement with your neighbors for your small wind turbine include:

- The agreement must be in writing, recorded and filed according to requirements for other easements on real property. Check with your County Clerk and Recorder's office for those requirements.
- The agreement must include:
    - A legal description of the property benefited and burdened by the easement
    - Dimensions of horizontal space across and vertical space above the burdened property that must remain unobstructed
    - Types of restrictions – vegetation, structures, wind turbines or other objects that would impair the wind resource
    - Terms or conditions for changing the easement.

Your neighbors are not obligated to enter into an easement agreement with you and may expect compensation from you for the burden you are placing on their property. Legal counsel is encouraged if you intend to pursue this type of agreement.

Property Tax Implications

Your property taxes may be impacted by the installation of a small wind system. Tax codes do change and the actual impact to your property taxes will vary according to your situation. Contact the state Department of Revenue to understand your property tax implications. Be aware that there are many property tax exemptions in place for renewable energy systems at present, but some of those exemptions expire over a set number of years. Be sure to ask if any exemptions offered will expire during the life expectancy of your system.

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STEP 10

E³A: Small Wind Energy Applications for the Home, Farm, or Ranch

Author: Sarah Hamlen; Mike Vogel and Milton Geiger eds. E3A Program

Steps in the Small Wind Series

B-1280 | E3A-SW.10

Wind for Pumping Water

Water pumping with wind energy is a type of off-grid system with strong relevance to livestock producers. The use of wind energy for water pumping has a long history; the iconic mechanical windmill enabled the expansion of livestock production on semi-arid grasslands from the 1870s to the 1920s. Wind is no longer the only choice for remote, off-grid water pumping, as solar electric arrays are an increasingly popular source of energy for water wells. Despite the rise of solar powered livestock watering systems, wind energy can still be effectively harnessed to pump water for livestock and other needs. Wind energy is generally not a viable source for pumping the large quantities of water needed for irrigation systems.

Photo by Elliott Bayly, NREL 09681
http://images.nrel.gov/viewphoto.php?imageId=6327010

How Pumping Systems Work

Wind energy can be used by both mechanical and electric water pumps. The simplest systems involve mechanical water pumps. Thousands of mechanical windmills, using positive displacement pumps, are still installed annually, and they are often a cost effective method to provide small quantities of water for livestock. Most new wind-powered pumping systems use a small wind turbine to power a direct current (DC) electric pump, either diaphragm or helical rotor. Wind turbines are often installed in conjunction with solar panels, as the solar array offers predictable performance while the wind turbine can more cost effectively pump larger quantities of water. Systems typically do not involve batteries to store energy, as batteries are expensive and require significant maintenance. Tanks and ponds are used to store water and provide a water supply when the wind and/or solar systems are not pumping water. This photo shows a typical wind-powered livestock watering system.

Key Considerations

The design of any water pumping system, regardless of energy source, is based upon the quantity and timing of the water required and the depth from which the water must be extracted. The location of the water well, the wind resource, and a direct comparison to solar power cost and efficiency are the most important considerations. First, a wind energy-based water pumping system should be compared with the option of connecting to the electrical grid. Although many factors must be considered, generally anytime electrical power is more than ¼ mile from the well, an off-grid renewable system should be considered. Second, like any other wind energy application, the availability of a suitable wind resource is a vital consideration (please see E³A Small Wind Series Step 3 for more

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information). The resource also needs to be in close proximity to the water well; for example, a sufficient wind resource may exist on a nearby by ridge top, but not near a dry creek bottom where the well is located. If considering a new well, a similar wind resource assessment should be completed. The seasonality and predictability of the wind resource also needs to be considered. Many areas with sufficient average annual wind speeds have significant seasonal variation, often with stronger winds in the winter and less wind in the summer when more water for livestock is typically required. The wind resource must also be able to pump storage water into tanks, above and beyond current livestock needs.

Once the viability of the resource is established, a cost comparison between remote solar and remote wind is suggested. Recent research from the USDA ARS suggests that for systems requiring less than 1.5 kW of power, photovoltaic systems are often the most practical and cost effective (Vick and Clark 2009). Solar-based pumping systems have fewer moving parts, increased durability, and more predictable production. Unfortunately, solar panels cost more per unit of pumping power than wind. Although prices are constantly changing, the purchase price of solar energy can often be two to three times as expensive as a comparable wind energy system. Therefore, in locations where wind resources are adequate and larger quantities of water are required, wind energy-based pumping systems should be examined. Users must remember that a wind-based system will generally require more maintenance and have a shorter life expectancy than a comparable solar-based system.

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