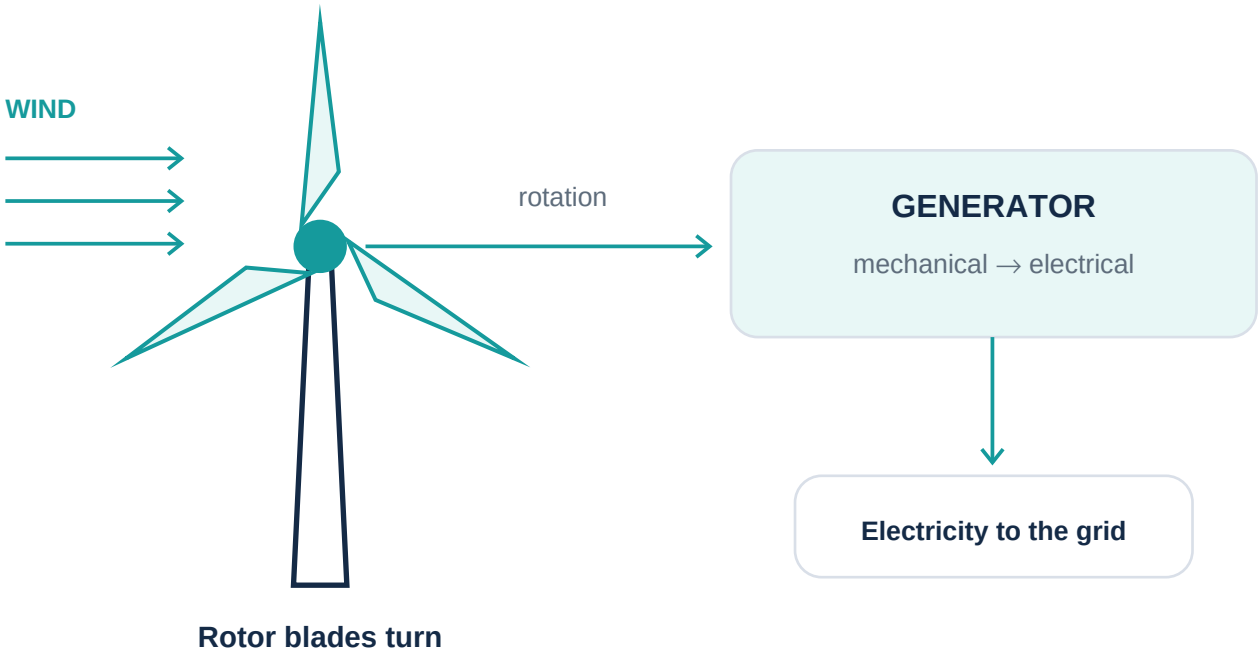
Wind energy: motion to electricity

Moving air has kinetic energy. A turbine captures some of that energy as rotation; a generator then converts the mechanical energy into electrical energy.

1. FOLLOW THE ENERGY TRANSFER



Schematic energy pathway; components are not drawn to scale.

2. THE GENERATOR DOES NOT CREATE ENERGY

Air flowing over the blades produces aerodynamic forces that turn the rotor. The rotor drives the generator directly or through a gearbox. Some energy is lost as heat and sound; not all of the wind's kinetic energy becomes useful electricity.

3. RENEWABLE DOES NOT MEAN CONSTANT

Uneven solar heating helps drive atmospheric motion, continually replenishing wind. However, wind speed at one site changes. A renewable resource can still provide a variable supply of power.

Rotor, lift, generator and origin of wind: US DOE, How Do Wind Turbines Work?
Variability and project considerations: US DOE, Wind Energy FAQ.
Operational emissions and cooling: US EIA, Wind Energy and the Environment.

Scope: College Board AP Environmental Science CED, Topic 6.12, p. 132.

How much electricity is delivered?

Extension: use power, time and capacity factor to distinguish a turbine's rating from the energy it actually supplies. A larger rating alone does not tell you its annual output.

1. POWER IS A RATE; ENERGY ACCUMULATES OVER TIME

A turbine rated at 2 MW has a specified maximum power output under suitable conditions. If it produced 2 MW continuously for 24 hours, it would deliver 48 MWh. Real output varies with wind conditions and turbine availability. MW and MWh describe different quantities.

2. WORKED EXAMPLE: CAPACITY FACTOR

Assume a 2 MW turbine supplies 7,008 MWh in a 365-day year. The figures are illustrative, not a prediction for every turbine.

Maximum annual energy = 2 MW × 8,760 h
= 17,520 MWh.
Capacity factor = actual energy ÷ maximum energy × 100%
= 7,008 ÷ 17,520 × 100% = 40%.

This means average output is 40% of rated capacity over the year. It does not mean 40% energy-conversion efficiency, or that the turbine ran at full power for exactly 40% of the hours.

3. MATCH VARIABLE SUPPLY WITH ELECTRICITY DEMAND

Forecasting helps operators plan for changes in wind. Transmission can connect windy regions to users and spread supply across locations. Flexible generation, storage and shifting some demand to other times can help balance the grid.

Batteries store electricity produced earlier; they do not make wind blow. Evaluate how a proposed system serves demand during low-wind periods, not just how much energy it generates during a windy hour.

Capacity, generation and capacity factor: US EIA, Power Plant Generation FAQ.
Wind variability, transmission and grid balancing: US DOE, Wind Energy FAQ.
Turbine operation and applications: US DOE, How Do Wind Turbines Work?

Scope: College Board AP Environmental Science CED, Topic 6.12, p. 132.

Benefits, wildlife and better siting

The core comparison: wind can replace fuel-burning generation, but every project still occupies a place and interacts with ecosystems and nearby communities.

1. BENEFIT: NO FUEL COMBUSTION DURING GENERATION

A wind turbine needs no burned fuel to generate electricity and no steam-cycle cooling water. Replacing fossil-fuel electricity can lower carbon dioxide and air-pollutant emissions. Manufacturing, transport and construction still use materials and energy: low operational emissions do not mean zero life-cycle impact.

2. ECOLOGICAL COST: BIRDS, BATS AND HABITAT

Birds and bats can collide with moving turbine blades and be injured or killed. Risk depends on the species, location and timing of activity. Roads, foundations and other infrastructure may also disturb habitat. A good wind resource does not automatically make a site ecologically suitable.

3. REDUCE RISK WITH SITING AND TARGETED OPERATION

Survey wildlife before selecting turbine locations; avoid high-risk flight routes and sensitive habitats where possible. Monitor wildlife after construction. Curtailment means reducing or stopping turbine operation during higher-risk periods, such as times of strong bat activity. This can reduce harm, but may also reduce electricity output.

4. COMPARE THE WHOLE PROJECT

Extension: assess wind supply and access to transmission alongside wildlife, nearby homes, noise and landscape concerns. Include material production and eventual repair or disposal in the plan. Choose mitigation that addresses the identified impact, and check whether it actually works after the project starts operating.

Emissions, cooling, noise and materials: US EIA, Wind Energy and the Environment.
Wildlife assessment, monitoring and curtailment: US DOE, Birds and Bats.
Siting, transmission and community impacts: US DOE, Wind Energy FAQ.

Scope: College Board AP Environmental Science CED, Topic 6.12, p. 132.