# Electric Power from Sun and Wind (revised)

Fred Loxsom

Eastern Connecticut State University Willimantic, Connecticut

Many environmental problems are related to energy consumption, including acid mine drainage, oil spills, acid rain, global warming, nuclear waste disposal, and catastrophic flooding due to failure of water retention dams. These are just examples and one could generate a much longer list. Approximately 85 percent of the energy used by our society is generated by burning fossil fuels, and energy experts think that energy-related environmental impacts could be reduced by switching to renewable energy resources such as wind power and solar energy. In this activity, we will explore the feasibility of using the sun and wind to generate a significant amount of global electric energy.

This quantitative activity describes the electric energy generated by wind turbines and photovoltaic arrays. The efficiency and cost of these technologies are compared and their abilities to reduce carbon dioxide emissions are estimated.

## Electric Power

About a third of the energy consumed globally is used to generate electricity. Annual consumption of electric energy equals approximately 16 trillion kWh (16 × 1012 kWh) globally, and approximately one-quarter of that energy (4.0 trillion kWh) is consumed in the United States. On average each of the 6.5 billion people on earth consumes approximately 2,500 kWh of electric energy each year. Divide this amount by the number of hours in a year (8,760) to calculate the average per capita global electric power consumption: 285 watts (roughly three 100-watt light bulbs).

Over the next 20 years, global annual electric energy consumption is projected to increase by 10 trillion kWh, and U.S. annual consumption is projected to increase by

1.5 trillion kWh. Although it is expected that most of this increased demand for electric energy will be supplied by consuming fossil fuel resources, some of this electric energy will likely be supplied by renewable energy resources.

## Renewable Energy

Most electric energy is produced by fossil fuel power plants (mostly coal-burning plants) and by nuclear power plants. Approximately 17 percent of global electric power is produced by renewable energy, mostly by hydroelectric power plants. A tiny fraction (about 0.023 percent) of global electric energy is produced by other forms of renewable energy such as wind power and solar power. In the following sections, we will consider the feasibility and cost of using the sun and wind to produce electricity.

## Electricity from the Wind

Wind turbines convert the kinetic energy in the wind into electric power. The overall efficiency of this conversion process is around 35 percent. Wind farms are located in areas with strong persistent winds such as the American Midwest, coastal zones, and mountain passes. A typical utility-scale wind turbine is rated at 1.5 MW, although turbines rated at 3.5 MW have become common. The rating of a turbine means that with sufficiently high wind speed, the power generated by the turbine will equal the rated power. A 1.5 MW turbine running at its rated power for 24 hours a day for a full year would produce 13 million kWh of electric energy. Because winds are variable, wind turbines run at their rated power only a fraction of the time. This fraction is called the turbine’s **capacity factor**; this factor depends upon the location of the wind turbine.

Exercise 1 estimates the cost of using wind turbines to supply 10 percent of the projected 1.5 trillion kWh increase in U.S. electric energy demand over the next 20 years. Although many environmentalists would argue that the most cost-effective and environmentally responsible approach to this project would be to reduce demand through more efficient use of electricity, the $45 billion cost of the turbines spread over 20 years seems quite modest.

This exercise introduces the concept of **payback time**, the time it takes for the benefits of a project to equal its cost. This concept is important in understanding of the economic viability of an investment. The payback time estimated in this exercise indicates that wind power is economically practical.

There are controversies involving the large-scale application of wind power technology. For example, Cape Wind, the offshore wind park proposed for the shallow water between Cape Cod and Nantucket, has supporters and opponents among environmental groups. Some groups are concerned that the project will interfere with migrating birds and harm marine ecosystems; other groups think the environmental advantages of using clean renewable energy will greatly outweigh its negative impacts

## Electricity from the Sun

Solar cells are semiconductor materials that convert sunlight directly into electricity. Practical electricity-generating devices made from solar cells are usually called photovoltaic (PV) panels. Arrays of PV panels are currently providing electricity for signal lights, remote power needs, residences, and electric utilities.

Exercise 2 estimates the cost and payback of using residential rooftop PV systems to supply 10 percent of the projected 1.5 trillion kWh increase in U.S. electric energy demand over the next 20 years.

The results of exercise 2 are interesting because they indicate that the solar energy resource is adequate to produce a substantial amount of electricity using a fraction of existing residential rooftops. On the other hand, these results also illustrate the high cost of photovoltaic power systems. Many analysts believe that substantial decreases in the cost of PV systems are needed before these systems will be used to generate significant amounts of electric energy.

## Exercise 1: Windpower

Consider a wind turbine that is rated at 1.5 MW. This means that with sufficiently high winds, it will produce 1.5 MW or 1,500 kW of power. The installed cost of this turbine is $1.5 million.

* 1. If this turbine runs at its rated power 100 percent of the time for a full year, how much energy would it produce in a year? (kWh/year)
  2. This wind turbine has a **capacity factor** equal to 0.38. This means that over a year, it will produce only 38 percent of its theoretical maximum energy production. How much energy does this turbine actually produce in a year? (kWh/year)
  3. Over the next 20 years, U.S. annual electric energy consumption is projected to increase by 1.5 trillion kWh/year. How many 1.5 MW wind turbines would be needed to supply 10 percent of this additional energy?
  4. Calculate the cost of installing these wind turbines.
  5. Assuming the electric energy produced by these turbines is worth 5 cents per kilowatt-hour, these turbines would generate electric energy worth $7.5 billion per year. Calculate the simple payback period for these turbines. (Payback period is the time it takes for a system’s net benefits to equal its cost.)

## Exercise 2: Photovoltaic Power

A grid-connected residential PV system is placed on the roof of a 2,000-square-foot suburban house. The PV array with an area equal to 50 square meters (about 500 square feet) covers half of the south-facing part of the roof. The power rating of this PV system is 5.0 kW, meaning that it will produce 5.0 kW under peak sunlight conditions. The installed cost of this system is $50,000.

1. The PV system is operating in a location where the annual average daily incident solar energy (the insolation) on the array equals 5.0 kWh/m2/day. Calculate the average amount of solar energy incident on the PV array each day (kWh/day).
2. The efficiency of the PV system equals 10 percent (that is, 10 percent of the solar energy incident on the array is transformed into useful electric power). Calculate the daily average electric energy produced by this system (kWh/day)
3. Calculate the average amount of electric energy produced by this system each year (kWh/year).
4. Over the next 20 years, U.S. annual electric energy consumption is projected to increase by 1.5 trillion kWh/year. How many rooftop PV systems would be needed to supply 10 percent of this additional energy?
5. Calculate the cost of installing these residential PV systems.
6. Assuming the electric energy produced by these PV systems is worth 10 cents per kilowatt-hour, these residential systems would generate electric energy worth

$15 billion/year. Calculate the simple payback period for these PV systems.

(Payback period is the time it takes for a system’s net benefits to equal its cost.)