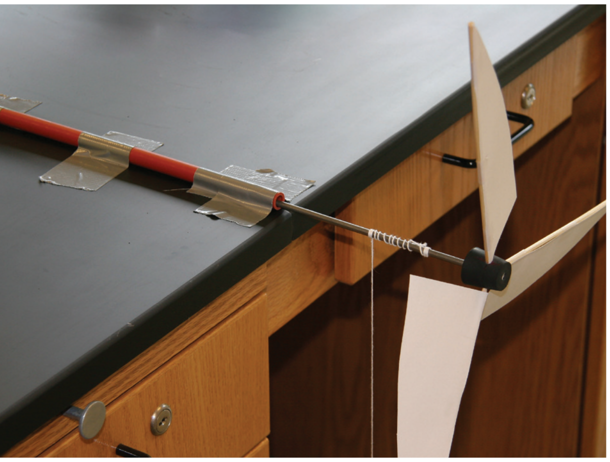
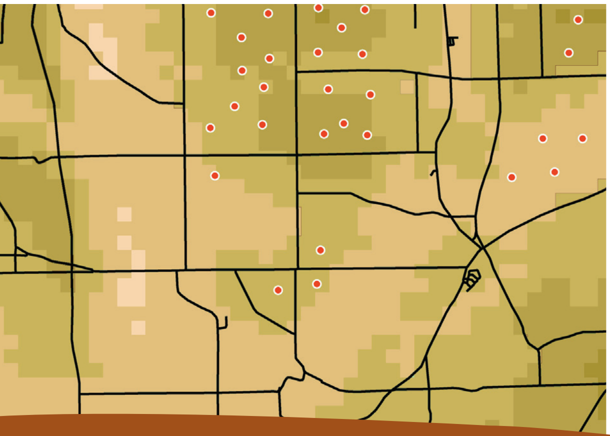
WindWise Education

Transforming the Energy of Wind into Powerful Minds





A Curriculum for Grades 6-12

windwise education

www.WindWiseEducation.org

NYSERDA

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funding from the New York State Energy
Research & Development Authority.

V1.0

WHEN IS A WIND FARM A GOOD INVESTMENT?

LESSON 15

KEY CONCEPT

Students will learn what factors impact the economics of a wind farm and compare and contrast two potential sites.

TIME REQUIRED

1 – 2 class periods

GRADES

6 – 8
9 – 12

SUBJECTS

Economics
Social Studies
Earth Science
Mathematics

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BACKGROUND

Investors and banks decide whether or not to invest in a wind farm based on how long it takes to recoup the initial costs through revenue generated by the wind farm. This is called the payback period. Students calculate and compare the payback period for 2 potential wind farm sites to determine which wind project is the better investment for the bank.

OBJECTIVES

At the end of the lesson, students will

- Be able to calculate the costs, revenue, and payback period of a wind farm.
- Understand how wind speed variations impact power generation and revenue

METHOD

Students calculate the costs and potential revenue of two potential wind farm sites. Using these figures, they determine the current payback period of each site. Students discuss which site is a better investment and discuss the factors that influence the payback period.

MATERIALS

- ❑ Calculator
- ❑ Student worksheets*
  *included with this activity

GETTING READY

- Students should have a general understanding of capital costs and revenue.
- Make copies of the worksheets.
- Teachers may review the fact sheets listed under Additional Resources for more information on wind farm economics.

ACTIVITY

Step 1: Beginning Questions for Students

- How much do you think a turbine costs?
- How much do you think a wind farm developer has to spend to build a wind farm?
- How many years do you think it takes to install a wind farm?
- How many years do you think it takes to pay off a wind farm?
- What are some of the costs of installing a wind farm?
- How does a wind farm generate revenue?
- Does the speed of the wind impact how much revenue a wind farm can generate?

Introduce the concept of a payback period and, if needed, give students a basic "lemonade stand" example with some general numbers to show how the payback period is calculated. The capital costs of a lemonade stand would be the stand itself, the lemon squeezer, and signage. Operational costs include the lemons, sugar, water, cups, and advertising. Revenue is generated from the sale of the lemonade. The payback period is how long it takes for the lemonade stand to earn enough revenue to pay for the capital costs.

Step 2: Calculating the Payback Period

Present students with the following scenario:

Windy Valley, LLC is developing a wind farm that will have 60 turbines. Each turbine will have a nameplate capacity of 2.0 megawatts (MW). The company has been measuring wind speeds at two different locations and wants to determine which site will be a better investment. Your job will be to compare the payback period of the two sites.

Have each student complete the activity worksheets to calculate the payback period.

Step 3: Wrap up

After students have completed the worksheets, lead a class discussion. Consider some of the questions and scenarios below.

- Which wind farm is a better investment? Why?
- How much do the wind speeds impact the payback period?
- If you kept everything the same and only changed the number of turbines (e.g., from 60 to 50), would it change the payback period?
- If in 10 years, the wind speeds slowed by 5%, how would it affect return?
- Are you surprised by how long it takes to "pay back" the initial investment?

EXTENSION

Over 50% of the electricity in the U.S. is produced with coal-fired power plants, and about 20% is produced from nuclear power plants. Have students determine how many MW an average coal and/or nuclear plant produces. Have them calculate how many 2 MW turbines would be necessary at each site to produce the same amount of power.

VOCABULARY

Capital Cost – The money spent in the years leading up to and during construction to plan and build a project.

Gross Revenue – The amount generated from the sale of goods or services before any costs are deducted.

Nameplate Capacity – The amount of power (MW) a wind turbine is capable of producing.

Net Revenue – The amount generated from the sale of goods or services after the costs are deducted.

Operational Costs – Recurring costs that are required to continue operating the project.

Payback Period – The time required to break even on an investment.

RELATED ACTIVITIES

- Lesson 4: Where Is It Windy?
- Lesson 14: Where do you put a Wind Farm?

ADDITIONAL RESOURCES

The following fact sheets provide useful background information on wind farm economics.

AMERICAN WIND ENERGY ASSOCIATION—http://www.awea.org/pubs/factsheets/EconomicsOfWind-Feb2005.pdf —The Economics of Wind Energy fact sheet

RENEWABLE ENERGY RESEARCH LABORATORY—http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_2b_Wind_Economics_Intro.pdf —The Effect of Wind Speed and Electric Rates on Wind Turbine Economics fact sheet

RENEWABLE ENERGY RESEARCH LABORATORY—http://www.ceere.org/rerl/publications/published/communityWindFactSheets/RERL_Fact_Sheet_2a_Capacity_Factor.pdf —Wind Power: Capacity Factor, Intermittency, and What Happens When the Wind Doesn't Blow? fact sheet

STANDARDS

Intermediate Level Science–Standard 1: Analysis, Inquiry, and Design
Key Idea 3:
Critical thinking skills are used in the solution of mathematical problems.

Major Understandings:
3.1 Apply mathematical knowledge to solve real-world problems and problems that arise from the investigation of mathematical ideas, using representations such as pictures, charts, and tables.

Intermediate Level Science–Standard 6: Interconnectedness: Common Themes
Key Idea 6:
In order to arrive at the best solution that meets criteria within constraints, it is often necessary to make trade-offs.

6.1 Determine the criteria and constraints and make trade-offs to determine the best decision.

6.2 Use graphs of information for a decision-making problem to determine the optimum solution.

Intermediate Level Science–Standard 7: Interdisciplinary Problem Solving
Key Idea 1:
The knowledge and skills of mathematics, science, and technology are used together to make informed decisions and solve problems, especially those relating to issues of science/technology/society, consumer decision making, design, and inquiry into phenomena.

The Physical Setting: Earth Science (High School)
Standard 1
Students will use mathematical analysis, scientific inquiry, and engineering design as appropriate, to pose questions, seek answers, and develop solutions.

Key Idea 2:
Deductive and inductive reasoning are used to reach mathematical conclusions. Beyond the use of reasoning and consensus, scientific inquiry involves the testing of proposed explanations involving the use of conventional techniques and procedures and usually requiring considerable ingenuity.

Technology–Standard 5
Management of Technology–Project management is essential to ensuring that technological endeavors are profitable and that products and systems are of high quality and built safely, on schedule, and within budget.

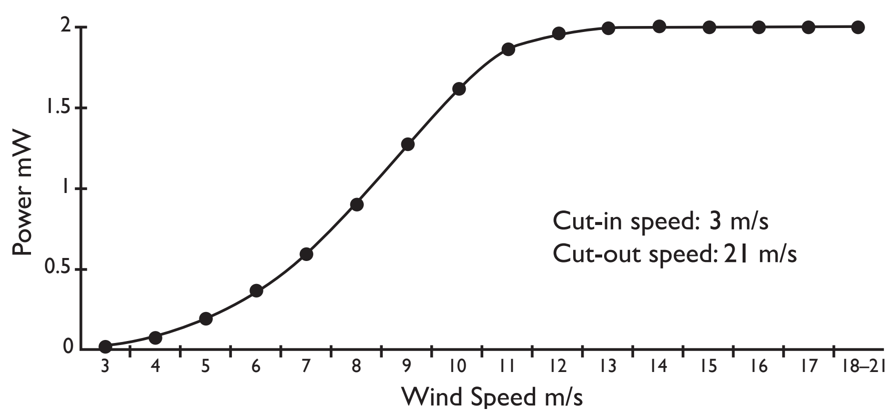
READING PASSAGE

SPEED (M/S)	POWER (kW)
3	21.3
4	84.9
5	197.3
6	363.8
7	594.9
8	900.8
9	1274.4
10	1633.0
11	1863.0
12	1960.4
13	1990.4
14	1997.9
15	1999.6
16	1999.9
17	2000.0
18–21	2000.0

Planning and installing a wind farm can cost hundreds of millions of dollars. For developers to spend this much money, they need to know how long it will take to recoup their costs and, beyond that, how much profit they think the wind farm can make over time. Many different factors determine whether a wind farm is financially feasible. Some of the variables include wind speed, the size and cost of the turbines and other equipment, the transmission distance and amount of space on transmission lines, the cost of leasing the land, the length of time it takes to get approval for a wind farm, and how many turbines there are in a wind farm. The most important of these variables is the wind speed.

Wind developers spend a lot of time and money examining wind speed data before they select a location for a wind farm. The average wind speed provides a general picture of where it is windy. These data, however, are not accurate enough for selecting a wind farm location. Average wind speeds do not tell the developer what the highest wind speeds are nor do they tell the developer how long the wind is moving at these high speeds. To collect more accurate data, wind developers set up weather stations throughout a prospective location and measure the instantaneous wind speed every few seconds throughout the day for a couple of years. This provides a much more accurate measurement of the wind capacity of a location and helps developers determine the optimal locations for each turbine.

Sample Power Curve



As the wind speed increases, so does the amount of power that can be generated. But how much more power can be generated at higher wind speeds? The amount of power output is equal to the wind speed to the third power. In other words, if the wind velocity doubles, the power output rises eight-fold. This relationship is shown visually in a power curve (see diagram). This is why wind farms can generate much more power in high winds even if they only last for a short period of time.

Name______________________________ Date______________ Class_________

WHEN IS A WIND FARM A GOOD INVESTMENT?

Windy Valley, LLC is developing a wind farm that will have 60 turbines. Each turbine is designed to produce 2.0 megawatts (MW). This is referred to as the turbine's nameplate capacity. The company has been measuring wind speeds at two different locations and wants to determine which site will be a better investment. Your job will be to compare the payback period of the two sites.

Calculate capital costs

The average cost of installing a wind farm is $2 million per MW. Determine how many MW the wind farm will install and then calculate the total capital costs.

____________ X ______________ = ________________

MW per turbine # turbines MW for wind farm

____________ X ______________ = ________________

MW for wind farm cost per MW Total capital costs for wind farm

Calculate Annual Energy Production

Before a wind farm is built, wind speed is measured at each potential location for two years or more. Both of the sites have an average wind speed of 6 meters/second. However, during a 24-hour period, the wind speeds vary between sites.

For Site 1, the wind speed is 8 m/s for 6 hours a day, 6 m/s for 6 hours a day, and 5 m/s for 12 hours a day.

For Site 2, the wind speed is 12 m/s for 4 hours a day, 10 m/s for 6 hours a day, and 2.6 m/s for 14 hours a day.

1. Based on this information, which site do you predict will be the better investment (have the shortest payback period)?

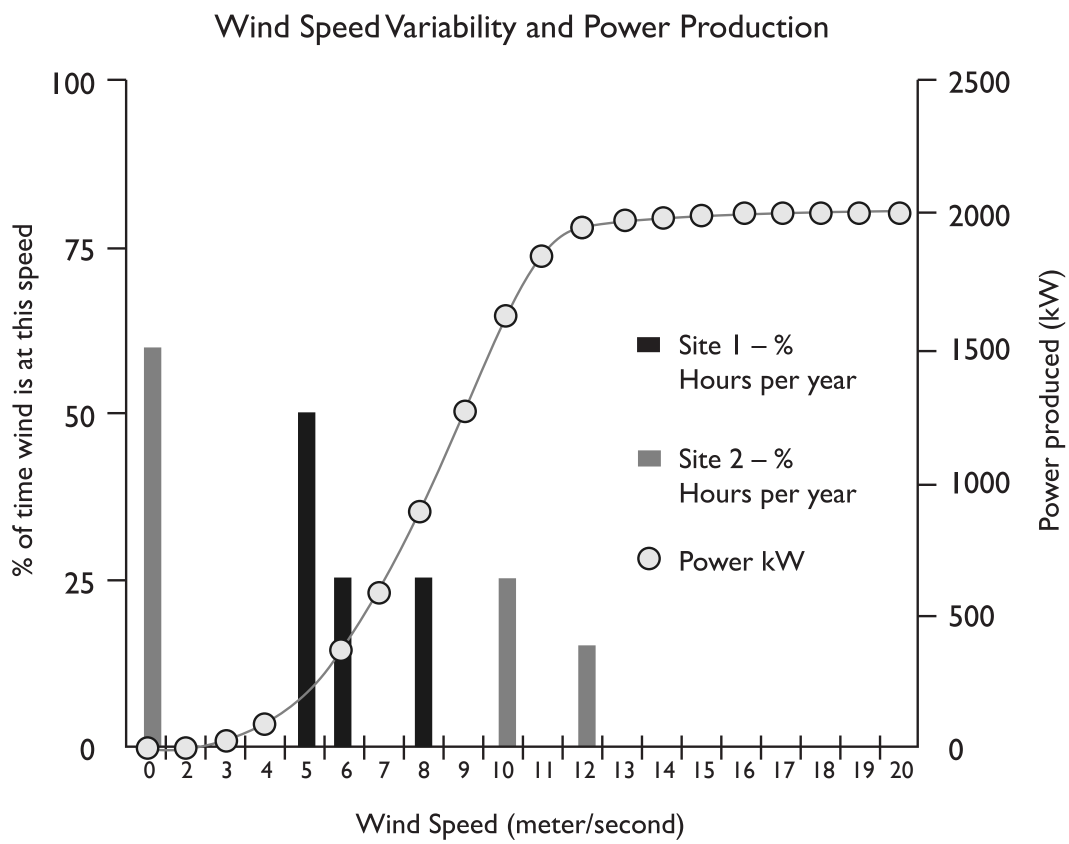
2. Using the Wind Speed Variability and Power Production graph, estimate the energy production for one turbine for a day and then for a year. Calculate the Annual Energy Production for the entire farm. Record answers in the following tables.

Site 1

Speed	Power (kW) produced at this speed	Energy (kWh) produced in one day (How many hours a day is the wind at this speed?)	Energy (kWh) produced in one year (365 days in a year)
8 m/s	900 kW	900 x 6 = 5400 kWh	5400 x 365 = 1,971,000 kWh
6 m/s			
5 m/s			
		Total kWh produced per turbine	
		Total kWh produced for entire wind farm	

Site 2

Speed	Power (kW) produced at this speed	Energy (kWh) produced in 1 day (How many hours a day is the wind at this speed?)	Energy (kWh) produced in 1 year (365 days in a year)
12 m/s	1950 kWh	1950 x 4 = 7800 kWh	7800 x 365 = 2,847,000 kWh
10 m/s			
2.6 m/s			
		Total kWh produced per turbine	
		Total kWh produced for entire wind farm	



Calculate annual net revenue

The gross revenue is based on how much money you can make by selling energy per kWh. There are three main sources of revenue:

SOURCE	RATE
Sale of energy	$.05 / kWh
Tax credit	$.02 / kWh
Green credit	$.01 / kWh

3. Use the following formula to calculate the estimated gross annual revenue from each source. Enter your answers in the table below.

    Gross Annual Revenue = Annual Energy (kWh) Production x Rate

4. Each year, wind farms lose potential revenue for a variety of reasons: turbine availability, blade icing and soiling, and shutdown due to extreme temperatures or winds. Annual losses average $50,000 per turbine. Determine what the annual losses are for the entire wind farm and then calculate the Net Revenue. Enter your answers in the table below.

    Net Annual Revenue = Gross Annual Revenue – Annual Losses

Name____ Date_________________ Class__________

Calculated Net Annual Revenue

	Site 1	Site 2
Revenue from sale of energy		
Revenue from tax credit		
Revenue from green credit		
Gross annual revenue		
Annual losses		
Net revenue		

5. Which site will generate the most revenue?

6. Calculate the payback period of the wind farm using the formula below. The payback period is measured in years.

   Payback Period (years) = Capital Costs / Net Annual Revenue

7. Enter the data from the previous questions in the Summary Table below.

Summary Table

	Site 1	Site 2
Annual Energy Production for wind farm (kWh)—Question 2		
Expected net revenue—Question 4		
Expected payback period—Question 6		

8. Which site is a better investment? Was this the same as your prediction?

9. Both sites have the same average daily wind speed. One site, however, would produce a lot more energy and generate a lot more revenue. Describe why this is the case.

WHEN IS A WIND FARM A GOOD INVESTMENT?

Calculate capital costs

The average cost of installing a wind farm is $2 million per MW. Determine how many MW the wind farm will install and then calculate the total capital costs.

60 turbines X 2.0 MW = 120 MW

120 MW X $2 million = $240,000,000

1. Based on this information, which site do you predict will be the better investment (have the shortest payback period)?

   Student prediction

2. Using the Wind Speed Variability and Power Production graph, estimate the energy production for one turbine for a day and then for a year. Calculate the Annual Energy Production for the entire farm. Record answers in the following tables.

Site 1

Speed	Power (kW) produced at this speed	Energy (kWh) produced in one day (How many hours a day is the wind at this speed?)	Energy (kWh) produced in one year (365 days in a year)
8 m/s	900 kW	900 x 6 = *5400 kWh*	5400 x 365 *= 1,971,000 kWh*
6 m/s	*450 kW*	*450 kW x 6 hrs/day = 2700 kWh/day*	*2700 kWh/day X 365 days/yr = 985,500 kWh/yr*
5 m/s	*200 kW*	*100 kW x 12 hrs/day = 2400 kWh/day*	*2400 kWh/day X 365 days/ yr = 876,000 kWh/yr*
		Total kWh produced per turbine	*3,832,500 kW*
		Total kWh produced for entire wind farm	*229,950,000 kW*

Site 2

Speed	Power (kW) produced at this speed	Energy (kWh) produced in 1 day (How many hours a day is the wind at this speed?)	Energy (kWh) produced in 1 year (365 days in a year)
12 m/s	1950 kWh	1950 x 4 = *7800 kWh*	7800 x 365 *= 2,847,000 kWh*
10 m/s	*1625 kW*	*1625 kW x 6 hrs/day = 9750 kWh/day*	*9750 kWh/day X 365 days/yr = 3,558,750 kWh/yr*
2.6 m/s	*25 kW*	*25 kW x 14 hrs/day = 350 kWh/day*	*350 kWh/day X 365 days/yr = 127,750 kWh/yr*
		Total kWh produced per turbine	*6,533,500 kW*
		Total kWh produced for entire wind farm	*392,010,000 kW*

3. & 4.

	Site 1	Site 2
Revenue from sale of energy	*$ 11,497,500*	*$ 19,600,500*
Revenue from tax credit	*$ 4,599,000*	*$ 7,840,200*
Revenue from green credit	*$ 2,299,500*	*$ 3,920,100*
Gross annual revenue	*$ 18,396,000*	*$ 31,360,800*
Annual losses	*$ 3,000,000*	*$ 3,000,000*
Net revenue	*$ 15,396,000*	*$ 28,360,800*

5. Which site will generate the most revenue?

   Site 2

6. Calculate the payback period of the wind farm using the formula below. The payback period is measured in years.

   Site 1
   240,000,000 / 15,396,000 = 15.6 years
   Site 2
   240,000,000 / 28,360,800 = 8.5 years

7. Enter the data from the previous questions in the Summary Table below.

	Site 1	Site 2
Annual Energy Production for wind farm (kWh)—Question 2	229,950,000 kW	392,010,000 kW
Expected net revenue—Question 4	$ 15,396,000	$ 28,360,800
Expected payback period—Question 6	15.6 years	8.5 years

8. Which site is a better investment? Was this the same as your prediction?

   Site 2 is a better investment.

9. Both sites have the same average daily wind speed. One site, however, would produce a lot more energy and generate a lot more revenue. Describe why this is the case.

   Higher wind speeds produce more power and, thus, generate greater revenue. It is advantageous to have very high wind speeds, even if they are only for short periods of time during the day. Short bursts of very high wind speeds can generate exponentially more power than slower wind speeds can during the same amount of time.