Good Day Sunshine!

Student Objective
The student:
- will explain the relationship between the amount of sunlight and the power produced by a photovoltaic device
- given a graph of solar irradiance will predict the performance of a photovoltaic system
- will infer from a table of irradiation data the relative amount of sunlight in different locations at different times of the year.

Key Words:
hypothesis
irradiance
irradiation

Time:
1 class period

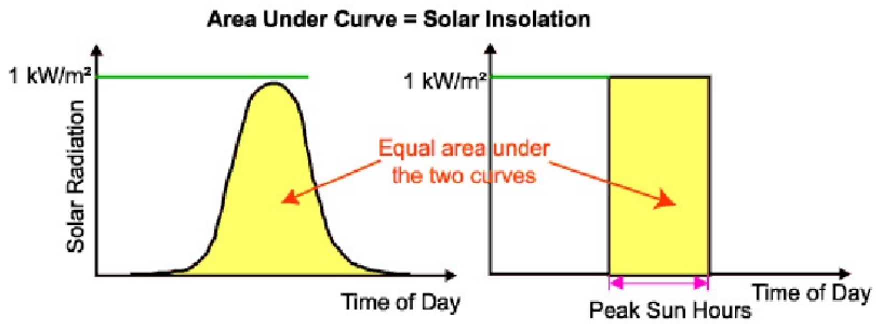
Materials:
- Science Journal pages

Background Information

The performance of a photovoltaic system at any given time depends primarily on the amount of sunlight available to it. On bright, sunny days, the system gradually produces more and more energy throughout the day until the sun is directly overhead. A graph showing the energy production of the PV system over time on a sunny day will resemble a smooth, tall, bell shaped curve.

On consistently overcast days, the curve will have the same width but will be much lower, and on partly cloudy days with patches of clouds intermingled with bright sun, the curve will tend to be spiky, showing that the system produces more energy during sunny periods and less energy during cloudy periods.

The power density of sunlight at any given moment is termed irradiance. Scientists have been collecting irradiance data from places all over the world since 1960. This data has been used to calculate the average amount of sunlight at specific places for different times of the year. In order to make the data comparable and even out the effects of daily weather, the raw data is converted into an equivalent number of “Peak Sun Hours”. Peak Sun Hours is defined as the number of hours that (when converted) the sun power equals 1000 watts per square meter. This number is obtained from integration of irradiance over the daylight hours (remember calculus?). Basically what is happening is that the total area under the bell-shaped irradiance curve is turned into an equivalent time at a sun intensity level of 1000 watts.



Luckily, the calculations have been done for us and put in Irradiance tables for easy reference. A very sunny day would have a value of 4 - 6 sun hours while a cloudy day may only have the equivalence of 1 sun hour.

Procedure

1. If necessary, divide the students into groups according to how many computers are available to them.
2. Lead a discussion on their findings during either the *Solar Powered System* or *Photovoltaic Panel* activity as it related to sun and shade.
3. Students should complete their Science Journal pages. Assist them as needed.
4. If the students are unable to print the graphs for use in the exercise, they can trace them off of the screen using tracing paper.
5. After the students complete their Science Journal pages, lead a discussion on their findings. Points to include are:
   - Florida may call itself the "Sunshine State", but other states have more sunshine during some times of the year!
   - Florida has rainy seasons, and times of afternoon thunderstorms. This reduces the total amount of sunlight we receive. (However, we still have a vast amount of sunshine!)

Key Words & Definitions

- **hypothesis** – an explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation
- **irradiance** – the measure of the power density of sunlight. Expressed in watts per square meter.
- **irradiation** – the measure of the energy density of sunlight reaching an area summed over time. Usually expressed in kilowatts per square meter per day.

Related Research

1. Compare the irradiance charts for several different locations–other continents, hemispheres, and different climate zones. What can you learn from these charts about the general weather as it relates to sunlight and cloud cover? Explore the reasons behind any unexpected data you find.

2. Compare a month's worth of irradiance data from this year at your school or another monitored site to the average that is provided in the irradiance charts. Is this year's data the same as the averaged data? If not, research what caused the difference this year.
3. Using the Florida Insolation Data, discuss how changes in latitude and changes in weather patterns affect the irradiance amounts in different areas of Florida.

Internet Sites

http://rredc.nrel.gov/solar/old_data/nsrdb/

National Solar Radiation Database contains 30 years (1961-1990) of solar radiation and supplementary meteorological data from 237 NWS sites, plus a user manual to help in reading the tabular information.

http://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/solar-radiation/

National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center is responsible for preserving, monitoring, assessing, and providing public access to the Nation's treasure of climate and historical weather data and information. Here you can find data on solar radiation and climate conditions in the United States.

https://ed.ted.com/lessons/the-sun-s-surprising-movement-across-the-sky-gordon-williamson#watch

Ted Ed lesson, *The Sun's Surprising Movement Across the Sky*, explains the Sun's analemma, solar noon, and the difference between sun time and clock time.

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Florida NGSS Standards & Related Subject Common Core

			.1	.2	.3	.4	.5	.6	.7	.8	.9	.10	.11	.12
Grade 6														
Practice of Science	**# 1**	**SC.6.N.1**	**X**											
Grade 7														
Practice of Science	**# 1**	**SC.7.N.1**	**X**											
Energy Transfer & Transformations	**# 11**	**SC.7.P.11**		**X**										
Grade 8														
Practice of Science	**# 1**	**SC.8.N.1**	**X**											

Sixth Grade Benchmarks
Science–Big Idea 1: The Practice of Science

- SC.6.N.1.1 - Define a problem from the sixth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

Seventh Grade Benchmarks
Science–Big Idea 1: The Practice of Science

- SC.7.N.1.1 - Define a problem from the seventh grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

Science–Big Idea 11: Energy Transfer and Transformations

- SC.7.P.11.2 - Investigate and describe the transformation of energy from one form to another.

Eighth Grade Benchmarks
Science–Big Idea 1: The Practice of Science

- SC.8.N.1.1 - Define a problem from the eighth grade curriculum, using appropriate reference materials to support scientific understanding, plan and carry out scientific investigations of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.

National Next Generation Science Standards - Sixth to Eight grade Standards
Science–Motion and Stability: Forces and Interactions

- MS-PS2-3 - Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

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Scientists have been collecting irradiance data from places all over the world since 1960. This data has been used to calculate the average amount of sunlight at these places for different times of the year. In order to make the data comparable from place to place and even out the effects of daily weather, the data is converted into an equivalent number of maximum sun hours, called **peak sun hours**. A very sunny day would have a value of 4 – 6 peak sun hours while a cloudy day may only have the equivalence of 1 peak sun hour.

The irradiance data in Peak Sun Hours for Orlando, Florida is shown below.

Insolation (irradiance) – kWh/m^2-day – for Orlando, FL (28.55^o North Latitude)

Array Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0^o	3.14	3.92	4.99	5.99	6.27	5.78	5.68	5.28	4.72	4.11	3.46	2.92	4.69
15^o	3.75	4.43	5.30	6.05	6.10	5.54	5.49	5.24	4.89	4.53	4.06	3.56	4.91
20^o	3.92	4.56	5.36	6.01	5.99	5.41	5.37	5.18	4.90	4.63	4.23	3.74	4.94
25^o	4.07	4.67	5.39	5.95	5.85	5.26	5.23	5.10	4.89	4.70	4.37	3.90	4.95
30^o	4.19	4.75	5.39	5.85	5.67	5.07	5.06	4.99	4.86	4.75	4.49	4.04	4.93
35^o	4.29	4.80	5.36	5.72	5.47	4.87	4.87	4.85	4.79	4.77	4.58	4.15	4.88
40^o	4.37	4.82	5.31	5.56	5.24	4.63	4.66	4.69	4.71	4.76	4.64	4.24	4.80

1. Notice that the irradiance data is listed for several different panel tilts (first column). What is the tilt of your school's array? If this measurement is not available, use the latitude of your location for the array tilt.

Use the tilt angle in the table above that is closest to this tilt angle to answer questions 2 – 6.

2. According to the chart above, which month has the greatest amount of sunlight, March or August?

3. We usually think of the summer months as being the sunniest and therefore the best for photovoltaic systems. Is this a correct assumption?

4. Why do you think August has less sun hours than the spring months in Florida? (Hint:

think about the weather)

5. Which month out of the year has greatest amount of sun hours?

6. Which month of the year has the least amount of sun hours?

7. Draw a line graph to show the average amount of peak sun hours (y-axis) for the months of the year (x-axis).

The irradiance data for Orlando and Spokane, Washington is below.

Insolation (irradiance) – kWh/m^2-day – for Orlando, FL (28.55º North Latitude)

Array Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	3.14	3.92	4.99	5.99	6.27	5.78	5.68	5.28	4.72	4.11	3.46	2.92	4.69
15º	3.75	4.43	5.30	6.05	6.10	5.54	5.49	5.24	4.89	4.53	4.06	3.56	4.91
20º	3.92	4.56	5.36	6.01	5.99	5.41	5.37	5.18	4.90	4.63	4.23	3.74	4.94
25º	4.07	4.67	5.39	5.95	5.85	5.26	5.23	5.10	4.89	4.70	4.37	3.90	4.95
30º	4.19	4.75	5.39	5.85	5.67	5.07	5.06	4.99	4.86	4.75	4.49	4.04	4.93
35º	4.29	4.80	5.36	5.72	5.47	4.87	4.87	4.85	4.79	4.77	4.58	4.15	4.88
40º	4.37	4.82	5.31	5.56	5.24	4.63	4.66	4.69	4.71	4.76	4.64	4.24	4.80

Insolation – kWh/m^2-day – for Spokane, WA (47.63º North Latitude)

Array Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	0.99	1.91	3.28	4.72	6.05	6.57	7.44	6.13	4.53	2.65	1.25	0.81	3.86
35º	1.84	2.93	4.13	5.10	5.91	6.14	7.12	6.41	5.45	3.84	2.18	1.63	4.40
40º	1.92	3.01	4.16	5.04	5.76	5.95	6.92	6.31	5.46	3.93	2.27	1.71	4.38
45º	1.99	3.08	4.17	4.97	5.59	5.73	6.69	6.18	5.44	3.99	2.34	1.78	4.34
50º	2.05	3.13	4.16	4.86	5.39	5.49	6.42	6.01	5.39	4.03	2.40	1.84	4.27
55º	2.09	3.15	4.12	4.73	5.17	5.22	6.13	5.81	5.31	4.05	2.44	1.89	4.18
60º	2.12	3.16	4.06	4.58	4.92	4.93	5.80	5.59	5.20	4.04	2.46	1.92	4.07

8. On the average, which location has the greatest amount of sun hours in July? (Hint: Average the values for the different tilt angles together).

   July irradiance average for Orlando Florida:

   July irradiance average for Spokane Washington:

9. Is this what you would have expected? Why or why not?

9. Which location has the greatest yearly average irradiance?

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Insolation data below is from National Renewable Energy's Solar Resource Data and Tools
https://www.nrel.gov/grid/solar-resource/renewable-resource-data.html

Insolation – kWh/m²-day – for Daytona Beach, FL (29.18º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	3.1	3.9	5.0	6.2	6.4	6.1	6.0	5.7	4.9	4.2	3.4	2.9	4.8
15º	3.8	4.5	5.5	6.4	6.4	6.0	5.9	5.8	5.2	4.7	4.1	3.6	5.2
30º	4.3	4.9	5.7	6.3	6.0	5.5	5.5	5.6	5.3	5.0	4.6	4.1	5.2
45º	4.6	5.1	5.6	5.9	5.4	4.8	4.9	5.1	5.1	5.1	4.8	4.4	5.1

Insolation – kWh/m²-day – for Jacksonville, FL (30.50º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	2.9	3.7	4.7	5.9	6.1	6.0	5.8	5.4	4.6	4.0	3.2	2.7	4.6
15º	3.6	4.3	5.2	6.1	6.1	5.8	5.7	5.5	5.0	4.5	3.9	3.4	4.9
30º	4.2	4.7	5.5	6.0	5.7	5.4	5.4	5.3	5.0	4.9	4.4	3.9	5.0
45º	4.4	4.9	5.4	5.6	5.1	4.7	4.7	4.9	4.8	4.9	4.7	4.2	4.9

Insolation – kWh/m²-day – for Key West, FL (24.55º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	3.7	4.4	5.5	6.3	6.3	6.1	6.1	5.8	5.2	4.6	3.8	3.4	5.1
10º	4.2	4.9	5.8	6.5	6.3	6.0	6.0	5.9	5.4	5.0	4.4	4.0	5.4
25º	4.9	5.5	6.1	6.4	6.0	5.5	5.6	5.7	5.5	5.4	5.0	4.7	5.5
40º	5.3	5.7	6.0	6.0	5.3	4.8	5.0	5.2	5.3	5.5	5.3	5.1	5.4

Insolation – kWh/m^2-day – for Miami, FL (25.80º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	3.5	4.2	5.2	6.0	6.0	5.6	5.8	5.6	4.9	4.4	3.7	3.3	4.8
10º	4.1	4.7	5.5	6.2	5.9	5.5	5.7	5.6	5.1	4.7	4.2	3.9	5.1
25º	4.7	5.2	5.7	6.1	5.6	5.1	5.4	5.5	5.1	5.1	4.7	4.5	5.2
40º	5.0	5.4	5.6	5.7	5.0	4.5	4.8	5.0	4.9	5.1	4.9	4.9	5.1

Insolation – kWh/m^2-day – for Tallahassee, FL (30.38º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	2.9	3.7	4.7	5.9	6.3	6.1	5.8	5.5	4.9	4.3	3.3	2.7	4.7
15º	3.6	4.3	5.2	6.1	6.2	6.0	5.7	5.6	5.3	5.0	4.1	3.4	5.0
30º	4.0	4.7	5.4	6.0	5.9	5.6	5.4	5.4	5.3	5.4	4.6	4.0	5.1
45º	4.3	4.9	5.3	5.6	5.2	4.9	4.7	4.9	5.1	5.5	4.8	4.2	5.0

Insolation – kWh/m^2-day – for Tampa, FL (27.97º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	3.2	4.0	5.1	6.2	6.4	6.1	5.8	5.5	4.9	4.4	3.6	3.1	4.9
15º	3.9	4.6	5.5	6.4	6.4	5.9	5.7	5.5	5.2	5.0	4.2	3.8	5.2
30º	4.5	5.1	5.8	6.3	6.0	5.5	5.3	5.4	5.2	5.4	4.8	4.4	5.3
45º	4.8	5.3	5.7	5.9	5.3	4.8	4.7	4.9	5.0	5.5	5.1	4.7	5.1

Insolation – kWh/m^2-day – for West Palm Beach, FL (26.68º North Latitude)

Tilt	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
0º	3.3	4.0	5.0	5.9	6.0	5.7	5.9	5.6	4.8	4.2	3.4	3.1	4.7
10º	3.8	4.5	5.3	6.1	5.9	5.6	5.8	5.6	5.1	4.6	4.0	3.7	5.0
25º	4.4	5.0	5.6	6.0	5.6	5.2	5.4	5.4	5.1	4.9	4.5	4.3	5.1
40º	4.7	5.1	5.5	5.6	5.0	4.5	4.8	5.0	4.9	5.0	4.7	4.7	5.0