Lesson Title: **SOLAR SITE ANALYSIS: THE PVWATTS® CALCULATOR**

Grade level: High School

Lesson length: 1-3 hours, depending on coverage and emphasis.

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Instructor's Guide

Learning Goals:

Students will understand that the electricity produced with a solar photovoltaic system is generated renewably.

Students will understand how to use the National Renewable Energy Laboratory's PVWatts® Calculator.

Students will use the PVWatts calculator to estimate the electricity production of a grid-connected solar PV system for several places across the globe.

Students will collect, graph, and objectively analyze relevant data to draw valid conclusions.

Students will understand basic characteristics governing the site selection and placement of a solar PV array.

Students will learn solar characteristics that must be maximized to install solar panels for best performance.

Students will learn and use relevant earth science and solar photovoltaic vocabulary.

Students will analyze valid economic and carbon dioxide offset information for the placement of a solar PV panel array and consider the significance of this data.

Materials, Resources, and Technology Required:

- Computers with internet connection for each student in the classroom
- Presentation unit and screen

A global look at this lesson…

SOLAR SITE ANALYSIS: THE PVWATTS® CALCULATOR is a self-directed, digital activity, designed to be completed by students individually. Naturally the best way to learn how to teach the lesson is to perform the activity in detail before teaching with it. It's not an especially difficult lesson, but there are many moving pieces. Students will work with **PVWatts** on the internet at the same time they are performing internet research, and working with their instructions (**Student Activity Guide**), data tables and graphs (**Student Spreadsheet**), and assessments (**Student Response Guide**). Students will also have to use data they've acquired to produce graphs within their **Student Spreadsheet**.

If you are not, you must become familiar with how to use the Google instruments provided for this lesson, and how to share them with your students. You may need to become familiar with how to make graphs within a **Google Sheet** in order to teach and guide your students in doing the same.

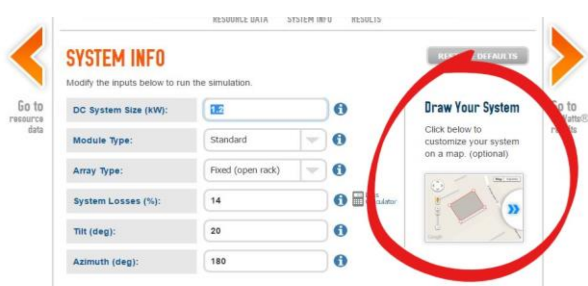
You'll probably want to demonstrate how to handle some parts of the lesson on a classroom projection screen. Keep the projection screen available to demonstrate how to overcome any problems your students encounter. When not teaching or demonstrating, circulate among your students to give "over the shoulder" guidance, answer questions, and help individual students solve problems.

Select the questions from the **Student Response Guide** you wish to use to assess your students. The remaining questions may be removed and used as quiz or test assessment questions. Consider carefully the quality and depth of understanding you expect in your student answers. Use that expectation to provide guidance on the length of time you will spend with your students on this activity.

While using **PVWatts**, students find and then input the average cost of electricity purchased from the utility for each of three locations. The first of those is your location. Give strong consideration to determining the cost at your location ahead of time and providing it to your students. With your students all using the same cost, and with all other input information being the same, you can easily determine early in this lesson whether or not your students are using PVWatts correctly by checking their results.

As structured, students choose the third location they would like to survey with PVWatts. You must consider ahead of time how you will allow them to approach this. What if they select a location south of the equator? Will you tell them ahead of time to change their constant azimuth to 0°? Will you let them figure this out on their own? If so, that will take time. You may avoid this difficulty by restricting your students to locations in the northern hemisphere. No matter what you decide, you'll need to work some discussion on the topic of ideal azimuth in the southern hemisphere vs. the northern hemisphere into this activity at some point.

Be sure at some stage in the activity, to show students how to **Draw Your System** within **PVWatts**. Some students are certain to find it on their own and begin to draw a system for the roof of their home or your school. This is great activity extension and enrichment.



Because this activity is completed by students digitally, you may be able to have your students submit their **Student Response Guide** for grading digitally. Whether submitting digitally or in hard copy, provide directions and guidance on how you want their **Student Response Guide** organized so you may read it easily when submitted.

Introduction to the activity:

There are many ways to introduce this activity. It may be that very little introduction is needed if this lesson is a follow-up to lesson you've just done on solar PV with your students. If not, the introduction written for the **Student Activity Guide** provides good hints on how to start. Another good start: Let's find out if it makes sense to put up solar panels here in [your city] or here at [your school]! Follow this with a quick presentation on **PVWatts**. Then: Ok, what do we need to know before we begin?

Activity, Part 1

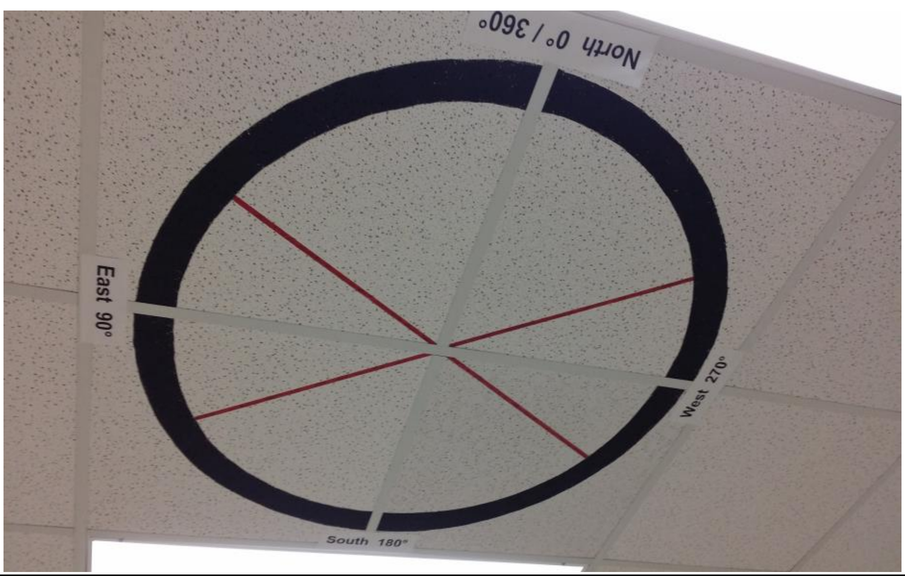
Teach and develop discussion around the following terms, or have students research them. Move students to adopt definitions that are substantially like those that follow:

Latitude: The angular distance of a location north or south of the earth's equator. Latitude ranges from 0° at the Equator to 90° at either North or South Pole. Lines of latitude run as circles parallel to the equator. Latitude enables us to specify an exact north or south position on the surface of the Earth (0°- 90° North Latitude or 0°- 90° South Latitude).

Longitude: The angular distance of a location east or west of an established prime meridian (passing through Greenwich, England) that runs from the North Pole to the South Pole. Longitude enables us to specify an exact east or west position on the surface of the earth (0°- 180° East Longitude or 0°- 180° West Longitude).

Solar azimuth: Solar azimuth is the compass degree (0° - 360°) that describes the position of the sun along the horizon at any given time.

Your maintenance department probably has lots of replacement ceiling tiles. Consider making a compass to place on the ceiling of your classroom to help you teach about solar azimuth. The compass is a great renewable energy conversation starter any time of year. [The red lines are the sun's azimuth at sunrise and sunset for the first day of summer and winter at this location.]



Solar altitude or solar elevation: The vertical angle formed between the horizon and the center of the sun's disc at any given time.

Solar tilt angle: The vertical angle formed between level ground and the inclined surface of a solar panel array.

Activity, Part 2

Starting here, the activity becomes mostly self-directed for students. Depending on your students and how you introduced the lesson, you may have to provide demonstrations on how to use **PVWatts** and the various Google instruments written into the activity. As mentioned earlier, you may want to provide the average cost of electricity purchased from the utility for your location, the first location students will enter into **PVWatts**. You may also want to provide your students with certain checkpoints--places in the activity where they must check in with you. This way you may verify that they are completing the activity correctly as they move through it. Then get students started and make the change from lesson teacher to activity coach.

Activity, Part 3

The activity continues here pretty seamlessly. But here your students will acquire **PVWatts** data that will enable them to compare their location (Location 1) with Quito, Ecuador (Location 2), and another location of their choosing. If you haven't already, you may need to provide guidance and instruction on how they approach the selection of their third location as mentioned earlier.

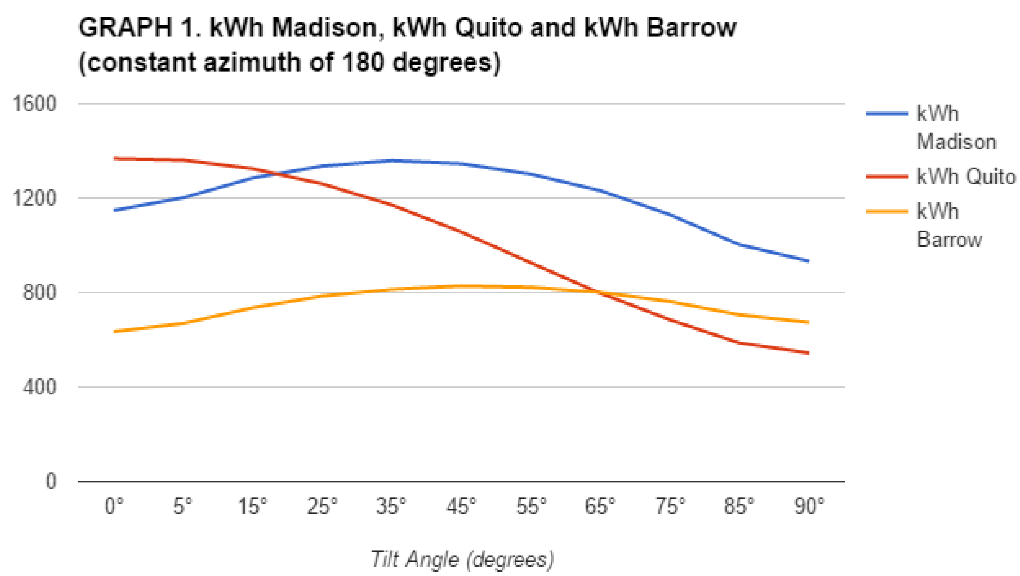
Show What You Know

The lesson concludes here pretty seamlessly. However here students produce graphs from their data. As mentioned earlier, you will probably have to provide some instruction for students on how to produce the required graphs from the tabular data they've obtained. Then they begin to analyze, synthesize, conclude, and write the assessments for this activity. As students finish the activity, remind them how you want their **Student Response Guide** organized so you may read it easily after it's been submitted.

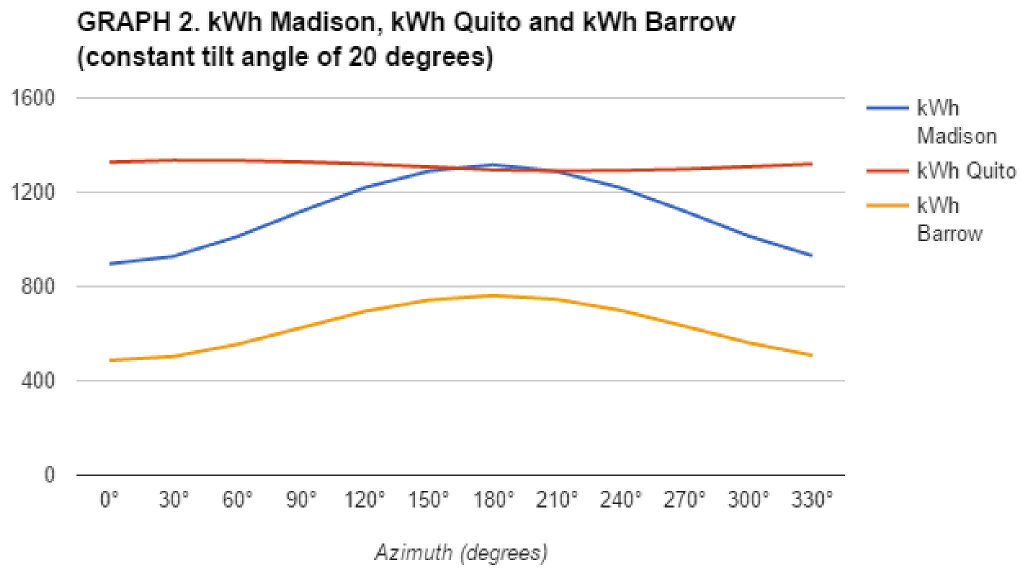
Show What You Know [Answer Guidance]

1. Produce two graphs.

Graph 1: [Example]



Graph 2: [Example]



2. Compare the effect of tilt angle among the three locations Explain similarities, differences, connections, or relationships that you observe.

"As you can see from Graph 2…"[get students to refer to their data!]...energy production at the same tilt angles at different locations is different. This is because the locations are in different places. Each location is especially different with respect to its latitude. For example, latitudes closer to the equator--like Quito--get more direct sun, so they produce more solar energy.

A similarity between all three is that when the tilt angle is close to the location's latitude, solar energy production is higher. Solar panels tilted "at latitude" generally receive more direct sun on average, than panels not tilted "at latitude" (see answer to the next question).

There might be other similarities and differences pointed out depending, especially, on the locations chosen.

3. In general, what is the effect of tilt angle on the energy production of a solar PV system? Is there a generalization or "rule of thumb," that you can apply for the best tilt angle selection for any location?

Student answers will vary in relation to the choice they made for Location 3, and they should make specific references to their graphs.

In general, when tilt angle is close to the location's latitude, solar energy production is higher. Solar panels tilted "at latitude" generally receive more direct sun on average, than panels not tilted "at latitude." For this reason, the best solar panel tilt angle for any location should be around that location's latitude.

4. Compare the effect of azimuth among the three locations. Explain similarities, differences, connections, or relationships that you observe.

Student answers will vary in relation to the choice they made for Location 3, and they should make specific references to their graphs.

In the northern hemisphere, the best azimuth is 180°, or due south. In the southern hemisphere, the best azimuth is 0°, or due north. On or close to the equator azimuth doesn't matter much--any azimuth will do.

5. What combination of azimuth and tilt angle would seem to be the best for each of your 3 locations? Explain how you determined the best combination for each.

Student answers will vary in relation to the choice they made for Location 3, and they should make specific references to their graphs.

In the northern hemisphere, the best azimuth is 180°, or due south. The best tilt angle is around the location's latitude.

In the southern hemisphere, the best azimuth is 0°, or due north. The best tilt angle is around the location's latitude.

On or close to the equator azimuth doesn't matter much--any azimuth will do. The best tilt angle is around the location's latitude.

6. Consider your ideal tilt angle and azimuth selections for each of the three locations. How does the annual energy production value differ for the three locations? Explain the differences you observe. Which location would seem to be the best for producing solar photovoltaic electricity?

Require your students to take the ideal tilt angle and azimuth for each location and go back and plug them into PVWatts to answer this question with hard data.

Referring to their data, they will find is that Quito is the best producer. This should make sense. Locations at and near the equator don't experience much seasonal change. Day lengths are all about the same and direct sunlight is available pretty much all year. Even at an ideal tilt angle and azimuth, seasonal changes subject locations in the mid-to-upper latitudes to less direct sunlight than locations around the equator. Shorter day lengths during winter will impose seasonal limits on how much energy a solar PV array can produce.

7. In which of your three locations would it be easiest to live "off the grid," using a solar PV system to supply your electricity? In answering, assume the PV systems at all three locations are installed at their ideal azimuth and tilt angle. Further, assume you need to use the same amount of electricity at all three locations. All other considerations for your decision are the same except for geographic location and the size of the solar PV system you need to install to meet your electricity needs.

Given the assumptions above, Quito will be the easiest place to live off the grid. It has more sunlight available, and more direct sunlight available A properly installed solar PV array located in Quito will not have to be as large to meet the same electricity needs as one located elsewhere. Solar PV works especially well in the tropics!

8. You want to install a solar PV system at your location. Assume you will be able to install it at the best combination of tilt angle and azimuth for maximum performance. What other things--site specific variables--usually have to be taken into account in order to get the best performance from a solar PV array? Describe at least three, and explain how each one can negatively affect the performance of a solar PV system.

You may have to teach the answers to this question. They may also come up naturally in discussions about this lesson. Students may have to do research to find answers. Some of the answers may be found by clicking on the Loss Calculator found within PVWatts.

- **Shade: Naturally, the greater the sun the better the solar PV performance.**
- **Weather and climate: All other conditions being equal, a sunny location for solar PV will perform better than a location that is regularly cloudy. A location where solar panels get regular and large volumes of winter snow will not perform as well as a location where that does not happen.**
- **Soiling: A location where solar panels get dirty regularly (near a certain type of industrial facility, for example) will not perform as well as a location where that does not happen.**
- **Avoiding excessively high temperatures: Solar panels need good sunlight to perform. But they become less and less effective at converting sunlight to electricity the hotter and hotter they become.**
- **Wiring and other equipment (charge controller, inverter, etc.): A system with components that are not well matched will not perform as well as a system that has been well thought out in advance to work together for best efficiency.**

9a. Determine and comment on the long-run significance of installing a well-placed residential-size solar PV system at your location.

You will have to work this out for your location in advance of your students. The sample data below, is from Green Bay, Wisconsin.

Time Period	AC Energy Produced (kWh):	Energy Value ($):	Pounds of CO_2 pollution given off to the air for each kWh of electricity produced by the electric utility in your region:	Lbs. of CO_2 saved from entering the atmosphere:	Tons of CO_2 saved from entering the atmosphere:
Annual:	5275 kWH	$675		8968 lbs. CO_2	4.5 tons CO_2
After 10 years:	52,750 kWH	$6750		89,675 lbs. CO_2	44.8 tons CO_2
After 20 years:	105,500 kWH	$13,500	1.7 lbs. CO_2 kWh	179,350 lbs. CO_2	89.7 tons CO_2
After 30 years:	158,250 kWH	$20,250		269,025 lbs. CO_2	134.5 tons CO_2

9b. Consider the data you've entered into your data table. Comment on the long-run financial significance of installing a well-placed residential-size solar PV system at your location.

*** After 20 years the system has saved its owner $13,500. This means the system probably paid for itself somewhere around year 15 if it was installed without any rebates, subsidies, grants, or other incentives.**

9c. Again, consider the data you've entered into your data table. Comment on the long-run environmental significance of installing a well-placed residential-size solar PV system at your location.

*** Once a solar PV array is up and running, it produces clean and renewable electricity.**

After 30 years the array has prevented about 270,000 lbs. of CO_2 from entering the atmosphere. This equates to about 135 tons of CO_2. That's 135 tons of carbon dioxide saved from going into the air! At just over 22 years of use this system will hit 100 tons of CO_2 savings!

Not calculated but just as obvious, is resource savings. Generated renewably, this array saves tons of coal and natural gas from being burned, and small amounts of uranium from being fissioned.

In the big picture, solar PV saves energy, saves resources, saves pollution, and saves money. It really doesn't matter who you are or what your politics may be, there's a place around the table for you in that equation!