

Photovoltaic Solar Systems (Solar Panels)

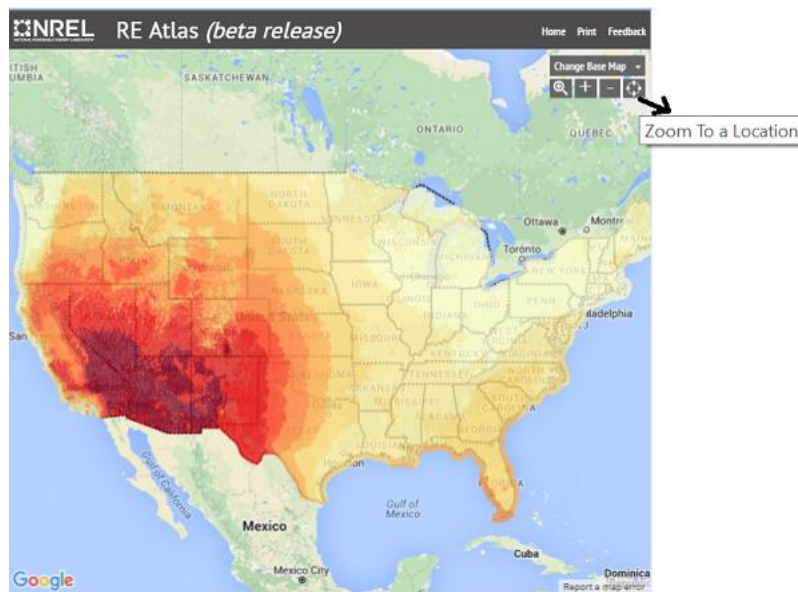
In this lab, you will continue to learn about solar energy and how it can be captured and used for our energy needs. You will be looking at maps, doing calculations, and answering questions. I recommend that you print the lab, fill in your answers to the questions, and then use those to input your answers into our online class site so that you can then get credit for the laboratory exercise.

Potential for Solar Power

Although every area on Earth receives solar energy, that energy is not spread equally across the globe. Your first task is to analyze the solar energy potential from a map to compare four cities in order to determine which one has the most potential for solar panels. Go to the Renewable Energy Living Lab at: <https://www.teachengineering.org/livinglabs/renewableenergy912>

Check the boxes under the Resources folder (located on the left under the Data Layers tab) to switch between the maps depicting the potential for the five different forms of renewable energy displayed: hydropower, biomass, geothermal, wind, and solar. Use the icons in the lower left corner to read more information about each form of energy.

Check or uncheck boxes so that only the potential for Solar Photovoltaic is displayed on the map. Use the “Zoom To a location” icon in the upper right corner of the map to zoom in and find your home town. See the map below to help you find the “Zoom To a Location” icon. Click the Legend tab (next to the Data Layers tab) to see what each color on the map represents. Notice that the units are in (kWh/m²/Day).



A kilowatt-hour (kWh) is the equivalent of one kW of energy (1000 Watts) being produced each hour (h). The amount of energy collected from the sun depends on how big the area of the collecting surface is, measured in square meters, (m²). As an example, a large solar panel on a house absorbs much more energy than a small solar panel on a calculator because it has a much larger area, or collecting surface. Putting it all together, there is a certain amount of energy

(kWh) that reaches a particular surface (m^2) for a specific amount of time (day) yielding units of $\text{kWh}/\text{m}^2/\text{Day}$.

What is the solar potential in your town? (Include units.) _____

Zoom in on the following locations and, either by using the legend or by clicking on the map, determine the annual average potential for solar power in $\text{kWh}/\text{m}^2/\text{Day}$ for each location. Circle a correct possible answer for each location. Data for the New York location has already been determined for you.

Location	Annual Average Potential for Available Solar Energy (Solar Irradiation) Circle the correct possible answer for each location. Data for the New York location has already been determined for you.
New York, New York	4.49 $\text{kWh}/\text{m}^2/\text{day}$
Minneapolis, Minnesota	Which one: 4.0 $\text{kWh}/\text{m}^2/\text{day}$, 4.4 $\text{kWh}/\text{m}^2/\text{day}$, 5.0 $\text{kWh}/\text{m}^2/\text{day}$, or 6.6 $\text{kWh}/\text{m}^2/\text{day}$
Las Vegas, Nevada	Which one: 4.0 $\text{kWh}/\text{m}^2/\text{day}$, 4.4 $\text{kWh}/\text{m}^2/\text{day}$, 5.0 $\text{kWh}/\text{m}^2/\text{day}$, or 6.6 $\text{kWh}/\text{m}^2/\text{day}$
Portland, Oregon	Which one: 4.0 $\text{kWh}/\text{m}^2/\text{day}$, 4.4 $\text{kWh}/\text{m}^2/\text{day}$, 5.0 $\text{kWh}/\text{m}^2/\text{day}$, or 6.6 $\text{kWh}/\text{m}^2/\text{day}$
San Antonio, Texas	Which one: 4.0 $\text{kWh}/\text{m}^2/\text{day}$, 4.4 $\text{kWh}/\text{m}^2/\text{day}$, 5.0 $\text{kWh}/\text{m}^2/\text{day}$, or 6.6 $\text{kWh}/\text{m}^2/\text{day}$

Of the cities listed above, which is the best candidate for a photovoltaic system (solar panels)? Explain your reasoning.

Just because the other locations were not the *most* likely candidate for solar panels does not mean that the other locations are not still good candidates for solar panels. There are many criteria that homeowners consider in order to determine if they are a good candidate for solar panels. One criterion to consider would be the value of the solar power potential. If the potential value is very low, it could cost too much to install solar panels based on how much energy would be produced by the solar panels. Another criterion to consider is the potential area to place the solar panels. If there is nowhere or very little feasible room to place the solar panels, then very little solar energy could be harnessed. Seasonal variation in each area is also important to investigate. Some areas may have consistently high solar power potential, while other areas may have a short season with high potential and the rest of the year has much lower potential.

Look back again at the value you determined for solar potential in your specific home town. Chances are, if you are in Southern California, the potential for solar power in your area is quite high because Southern California gets a lot of sunlight and has a small seasonal variation. If you live in a single family home, you probably have enough rooftop area to collect enough solar energy to completely or significantly offset your electricity usage. In the next section, we will explore the amount of energy generated from solar panels.

Energy Generation

On average, typical homeowners in the United States use 900 kWh of electricity per month. Therefore, the average household needs to collect about 30 kWh of energy per day, for 30 days, to reach their typical usage of 900 kWh per month.

Using the annual average potential for available solar energy for each city (from the table above), first calculate how much energy (in kWh) a single 300 W solar panel would collect in each city. Then calculate how many 300 W solar panels each location would need in order to collect 30 kWh of energy per day.

Examples:

To calculate how much energy (in kWh) a single 300 W solar panel would collect in each city, you would need to know that:

- In New York, the average amount of energy received each day from the Sun (solar irradiation) is 4.49 kWh/m²/day. (This value was obtained from the map, just like what you did to find the answers for the above table)

- 1 kW = 1000 W, so a single 300 W solar panel would be the same as a 0.3 kW panel

Therefore, a single 300 W solar panel that covers 1 m² of area *in New York* will generate 1.347 kWh for the day (because 4.49 kWh x 0.3 kW = 1.347 kWh).

How many of these solar panels would be needed to provide at least 30 kWh of energy for a home each day in New York?

$$1.347 \text{ kWh} \times (\# \text{ of panels}) = 30 \text{ kWh}$$

$$\# \text{ of panels} = 30 \text{ kWh} / 1.347 \text{ kWh}$$

$$\# \text{ of panels} = 22.27$$

Therefore, 23 solar panels are needed for a home in New York that uses 30 kWh of electricity each day.

Location	How much energy (in kWh) a single 300 W solar panel would collect	# of solar panels needed to provide at least 30 kWh of energy each day
New York, New York	1.347 kWh	23
Minneapolis, Minnesota		
Las Vegas, Nevada		
Portland, Oregon		
San Antonio, Texas		

Size of the Photovoltaic (PV) System

Instead of the size of a PV system being described by how many solar panels it has, the size of PV systems is actually reported in how many kW of power it can produce. Therefore, calculate the size of the PV solar system required for each homeowner in each city. This is calculated by multiplying the number of solar panels needed by the power of each panel (300 W or 0.3 kW, for the panels we are using in our examples). Report the size of the system in kW in the table below.

Example:

What is the size (in kW) of a PV solar system designed for the New York homeowner with 23 of the 300 W solar panels?

$$23 \times 300 \text{ W} = 6,900 \text{ W}$$

Since we want our answer in kW, move the decimal to the left three times, or divide by 1000 (since there are 1000 W in one kW).

$$6,900 \text{ W} = 6.9 \text{ kW}$$

We would say that the size of this PV solar system is 6.9 kW.

Location	Size of the PV Solar System (in kW)	Cost of the PV Solar System before subsidized	Amount Subsidized by the Federal Government	Actual Cost of the PV Solar System to Homeowner
New York, New York	6.9 kW	\$20,700	\$6,210	\$14,490
Minneapolis, Minnesota				
Las Vegas, Nevada				
Portland, Oregon				
San Antonio, Texas				

Cost of the Photovoltaic (PV) System

Now it is time to think about the money needed to install the solar panels. Every solar company has different installation rates, so it is important for the homeowner to shop around. Don't forget that workmanship and warranties are also very important, so the homeowner should do their homework and make sure they are using a good company! Remember, a warranty can only be used if the company is still in business!

Let's assume that each homeowner finds a solar company that has a good record and is providing a good warranty, and therefore, the homeowners are all considering purchasing a PV solar system. However, they are concerned with the cost because they have heard that PV solar systems are expensive. The average cost of installation is \$3.00 per Watt. Therefore, converting

this price for kilowatts, a PV solar system would cost about \$3000.00 per kW. However, the federal government subsidizes the cost of PV solar systems by 30%.

Calculate the cost of a PV solar system that will make it possible for the homeowners in each city to no longer have an electricity bill. Report the cost of the system in kW in the table above.

Example: What is the cost of the 6.9 kW PV solar system that was designed for the New York homeowner? (Remember, PV solar systems cost about \$3000 per kW)

$$6.9 \text{ kW} \times \$3000/\text{kW} = \$20,700$$

How much of the cost will the federal government subsidize?

$$\$20,700 \times 0.3 = \$6,210$$

How much of the cost will the homeowner have to cover?

$$\$20,700 - \$6,210 = \$14,490$$

Savings by Purchasing a PV Solar System

The average cost for electricity in each area is given in the table below. How much would residents continue to pay per month and per year for electricity if they decided to not purchase solar panels? Again, assume homeowners use 900 kWh per month.

Location	Average Rate for Electricity	Average Electricity Bill Each Month	Average Annual Electricity Bill
New York, New York	\$0.18	\$162	\$1,944
Minneapolis, Minnesota	\$0.10		
Las Vegas, Nevada	\$0.09		
Portland, Oregon	\$0.08		
San Antonio, Texas	\$0.07		

Example: The average rate for electricity in New York is \$0.18/kWh. Therefore, multiplying this rate by the amount of kWh of electricity a homeowner would use in a month will show us how much their electricity bill is each month.

$$900 \text{ kWh} \times \$0.18/\text{kWh} = \$162/\text{month}$$

By multiplying the amount they pay per month by 12 months, we can see how much a New York resident will pay, on average, each year for electricity.

$$\$162/\text{month} \times 12 \text{ months} = \$1,944$$

Financing

Instead of paying this money to the electric company, residents could have this money help pay for their solar panels! However, most people have to finance solar panels rather than pay cash for them. Assume that each homeowner had to take out a loan with a 3% annual percentage interest rate. Also assume that each homeowner wants to keep the monthly bill for their PV solar system the same price as their current electricity bill.

Location	Interest Paid for 3% Loan Per Year	Interest Paid for 3% Loan Per Month	Principal Paid Each Month
New York, New York	\$434.70	\$36.23	\$125.77
Minneapolis, Minnesota			
Las Vegas, Nevada			
Portland, Oregon			
San Antonio, Texas			

Example:

The monthly bill for the homeowner in New York would be determined by first figuring out how much interest the homeowner would have to pay per year. Therefore, multiply the cost of the PV solar system (\$14,490) by the interest rate (3% or 0.03). This is the amount of interest the homeowner pays per year.

$$\$14,490 \times 0.03/\text{year} = \$434.70/\text{year}$$

To figure out how much interest this would be per month, we divide it by 12, since there are 12 months in a year.

$$\$434.70/12 = \$36.23/\text{month}$$

Therefore, to keep their bill the same amount as what they are currently paying for electricity each month, we have to figure out how much of the bill would be paid towards the principle (the actual amount of money that was lent to them). We do this by subtracting the monthly interest charge (\$36.23) from the amount they will be paying each month (\$162).

$$\$162 - \$36.23 = \$125.77$$

Therefore, when they pay their bill every month, \$36.23 is basically given to the bank as payment for the loan, and \$125.77 is basically repaid from what was actually borrowed.

Paying Off The Loan

How many years would it take for each homeowner to pay off the loan for their solar panels, if they still wanted their monthly bill to be the same as their current electricity bill? How many years of free electricity could the homeowner count on due to a 25 year warranty?

Location	# of Years to Pay off the PV Solar System	Minimum # of Years of Free Electricity (while warrantied for 25 years)
New York, New York	9.6	15.4
Minneapolis, Minnesota		
Las Vegas, Nevada		
Portland, Oregon		
San Antonio, Texas		

To figure out how many years it would take for the New York homeowners to pay off their solar panels, we can divide the total cost of the PV solar system (\$14,490), by the amount they are paying down each month in principal (\$125.77).

$$\$14,490 / \$125.77/\text{month} = 115 \text{ months}$$

To figure out how many years this is, we divide 115 months by 12 months/year.

$$115 \text{ months} / 12 \text{ months/year} = 9.6 \text{ years}$$

Therefore, it will take 9.6 years to completely pay off their PV Solar System, if they want their bill to match what they used to pay for electricity each month. This may seem like a long time. However, once the system is paid off, the homeowner would have completely free electricity for years to come! Plus, most PV solar systems are warrantied for 25 years!

To figure out the minimum amount of years the homeowner could count on having free electricity, we would subtract the amount of years the homeowner had to pay from the total 25 years.

$$25 \text{ years} - 9.6 \text{ years} = 15.4 \text{ years of free electricity!}$$

Is Solar a Good Financial Investment?

How much money would the purchase a PV solar system save each homeowner over the 25 year period that it is warrantied? Assuming electricity rates stay the same, even though they are very likely to increase, how much money would each homeowner actually be saving by the 25th year when the PV solar system is no longer under warranty? Note: PV solar systems are expected to last even longer than 25 years, but their efficiency does decrease.

Location	# of Months of Free Electricity over the 25 year warranty period	Amount of Money Saved by the Homeowner
New York, New York	184.8	\$29,937.60
Minneapolis, Minnesota		
Las Vegas, Nevada		
Portland, Oregon		
San Antonio, Texas		

Example:

For the New York homeowner, we will assume that electricity rates stay at \$0.18/ kWh over the full 25 years. Remember that by 9.6 years, the system is totally paid off, so from then on, electricity is free for the homeowner!

We could multiply the amount of years that the homeowner doesn't have to pay for their electricity by 12 months per year to figure out how many months of free electricity that would be.

$$15.4 \text{ years} \times 12 \text{ months/year} = 184.8 \text{ months}$$

To figure out how much money this is saving, we would multiply the amount of months of free electricity by the amount of money it would have cost each month to pay the electric company for electricity if the homeowner did not invest in a PV solar system.

$$184.8 \text{ months} \times \$162/\text{month} = \$29,937.60$$

Which two cities (not counting New York) are the best candidates for installing PV solar systems, based strictly on financial reasons?

Which two cities (not counting New York) are the best candidates for installing PV solar systems, based strictly on the amount of sunlight reaching those areas?

Why is it that even if a place has plenty of incoming solar energy, many people in these areas have not made the switch to solar?

Final Thought

In Southern California, electricity rates are found in tiers, depending on the resident's usage. The cheapest and first tier is about \$0.16/kWh, the second is around \$0.25/kWh, and the third is around \$0.31/kWh. You should be able to see how expensive electricity can be in Southern California! Southern California also receives a lot of year-round sunlight, with some areas almost reaching 7 kWh/m²/day! Therefore, Southern California is an excellent place for PV solar systems, since it has a lot of incoming solar radiation, and the cost of electricity is high. Therefore, PV solar systems in places like California and New York basically pay for themselves and can often save homeowners thousands of dollars!