Jonah Golden

2015-11-18

Computation in the Physical Sciences Final Project

**Solar Energy Calculator**

**Abstract**

It is generally accepted that responding to climate change successfully will include a large shift in our energy infrastructure towards renewable energy generation. However, some people are unaware of the renewable energy potential on their own properties. This project outlines the design of an easy to use script that can predict solar energy generation for anyone in the world. Projects like this and others can help alleviate the lack of knowledge surrounding renewable energy generation potential.

**Introduction**

Mitigation of climate change by widespread deployment of carbon-free energy technologies is both plausible and desirable (Jacobson et al. 2014). Studies indicating the form of future electricity grids focus on power derived from large-scale wind farms, hydroelectric facilities of varying sizes, and sunlight (Jacobson et al. 2014); nuclear power is often not considered seriously due to economic, political, and regulatory challenges (McMahon 2013). Of these technologies, only solar power can be deployed at a small scale by individuals; other technologies are nearly always installed and managed by electric utilities. Installation of solar photovoltaic panels (henceforth, “solar panels”) has increased rapidly in recent years due to incentives and falling costs for solar energy, which may be cheaper than conventional sources under some circumstances (PR Newswire 2015).

Rooftop solar panels allow individual homeowners to become producers of electricity, and this may offer psychological rewards since these homeowners know that they are contributing directly to decarbonizing electricity grids. However, one major necessity is that people looking into installing solar panels can get accurate predictions about how much energy their solar panels will actually produce, and in turn, how much money they will be able to generate from their solar panels. In British Columbia, for example, BC Hydro will pay a published rate of 9.99 cents per kilowatt hour (kWh) for renewably generated energy. Therefore, an energy generation prediction, combined with a quote from an installer allows people to weigh the economic pros and cons, and make an educated decision. Many people probably don’t know whether putting solar panels on their property would be economically viable. To figure this out, it is necessary to get an energy generation prediction, a quote for installation costs, and a quote for how much your generated energy will be worth.

This project is limited to the first of the above three necessities. The goal of this project is to create an easy to use script that will provide energy generation predictions and visualizations for any size and type of solar panel array, anywhere in the world. To do this, I will take the most important factors into account that are within my abilities. However, there are undoubtedly assumptions and factors that will still be left unaccounted for. My goal is to reduce these as much as possible.

**Methods**

Version of python: Python2

Python libraries used: numpy, pandas, matplotlib

The following methods are an explanation of the math that is behind the coding for this project. That coding is in both script form and a python notebook in the following Github repository: [https://github.com/jonahgolden/Solar\_potential\_calculator](https://github.com/jonahgolden/Jonah_Final_Project)

The sun emits a fairly consistent amount of power outwards in all directions. The amount of power it emits is called solar luminosity (abbreviated as L0 ) and is equal to watts. Solar luminosity is emitted in all directions, and for the purposed of this project, it is necessary to determine the power per area that is transmitted from the sun to the Earth. First, it is useful to picture a giant sphere that surrounds the sun. This imaginary sphere is the perfect size so that Earth is on its surface. If we divide the solar luminosity by the surface area of this sphere (in square meters), then we will be able to know the power per square meter that the sun gives to Earth. The radius of this sphere is equal to the distance of Earth from the sun () plus the radius of the sun (). Therefore, the radius of the imaginary sphere is . Surface area (SA) is equal to , so:

Now that we have the surface area, we can determine the power per square meter that the sun gives to Earth, which is also known as the solar constant and abbreviated with :

This is the first constant I define in my Python script, and I denote it as S0. However, the solar constant assumes that sunlight is striking Earth’s surface directly. In reality, most places on Earth are not faced directly at the sun at any given time, and the angle that the sun’s rays hit Earth changes every minute, hour, day, and with latitude. In addition, the distance between the Earth and sun changes during the summer and winter.

Due to these factors, we cannot simply use the solar constant to represent the power arriving at any spot on Earth at any time. Instead, we have to use the following equation, which includes the solar constant:

where is the mean distance of Earth from the sun, d is the actual distance from the sun at any given moment, and θs is the solar zenith angle. The solar zenith angle is the angle between incoming solar rays and the ground, as represented in this image:



image from Hartman 1994, *Global Physical Climatology*

The solar zenith angle is composed of several parts:

* Latitude
* Declination Angle: the latitude of point ss at noon.
* Hour Angle: the angle between vector Z and the longitude line that contains point ss.

For the sake of readability, variables are defined as follows:

* Latitude: ϕ
* Declination Angle: δ

Using these variables, we can express the as:

Declination angle is dependent on the time of year, and we must express this angle in radians using the following formula:

Day of the year is abbreviated with dn and then we can use this to find the declination angle with this formula:

The coefficients for this formula are given below:

n an bn

0 0.006918

1 -0.399912 0.070257

2 -0.006758 0.000907

3 -0.002697 0.001480

Now, we must calculate the distance of the Earth from the sun. Using the day of the year, we can calculate the distance ratio as follows:

The coefficients for this formula are given below:

n an bn

0 1.000110

1 0.034221 0.001280

2 0.000719 0.000077

Now we have established the necessary formulas to solve for Q, but the do not take into account the fact that only 75% of the power that reaches the Earth makes it through the atmosphere. Therefore, we must multiply Q by 0.75 to get the actual power arriving at any spot on Earth at any time. The Solar\_Power\_Calculator function uses the math explained above to output the power that reaches the earth at any given place in watts per meter squared.

Using this same math, the function Solar\_Energy\_Calculator uses a ‘for loop’ to calculate Q for every hour of the year. In addition, rather than assuming the area in question is one square meter, this function takes area as an input. It also takes solar panel efficiency as an input. The function then compiles a list of Q for every hour of the year, which can be graphed as power production over the year. The sum of this list, then, is the amount of energy that the given area of solar panels with the given panel efficiency can produce in a year.

The final step in producing accurate predictions was taking cloud cover into account. The cloud cover data I am using is International Satellite Cloud Climatology Project (ISCCP). To understand this data in its raw form, visualize a map of the world overlayed by a grid of squares. Each square is 2.5 degrees in width and height, so the grid is 144 x 72 (longitude x latitude) and has a total of 10368 squares. Each number in the data is the average annual cloud cover percentage for a single square. The first number represents average cloud cover in the -90 degrees latitude, -180 degrees longitude box. Longitude varies first, and begins at -180 degrees and proceeds eastward to +180 degrees. Latitude begins at -90 degrees and proceeds northward to +90 degrees. Based on the latitude and longitude input, the functions I developed locate the cloud cover data for any location. The cloud cover is applied with a multiplier to the data from Solar\_Energy\_Calculator, creating the final data set of generation predictions.

\*All calculations in the methods section (Hartmann, 1994).

**Results**

The code I have written works effectively. It produces a graph of average power output and a number of kWh that can be expected for the given solar panel array. For example, the graph output for Squamish’s latitude and one solar panel with 16% efficiency is shown below:Macintosh HD:Users:jonahgolden:Desktop:CompPS:Jonah_Final_Project:results:Power_Graph.pdf

The total generation output for the same solar panel array is, “This solar panel array will generate an average of 277.117685769 kWh every year.”

**Discussion**

A tool such as this is useful and necessary as the energy grid continues to develop. However, there are definitely more factors such as temperature and humidity that I haven’t taken into account. This program also contains the assumption that there are no buildings or trees that shade the specified solar panel array. If I had more time to work on this code, I would continue to add more factors for specific site locations as well as test my predictions against real life examples. It would also be useful to incorporate the value of solar electricity and provide payback period. Additionally, the Power Output graph could use some formatting for visual appeal.

**References**

Hartmann, D. L. (1994). *Global Physical Climatology*. Academic Press.

Jacobson, MZ, M Delucchi, AR Ingraffea, RW Howarth, G Bazouin, B Bridgeland, K Burkart, M Chang, N Chowdhury, R Cook, G Escher, M Galka, L Han, C Heavey, A Hernandez, DF Jacobson, DS Jacobson, B Miranda, G Novotny, M Pellat, P Quach, A Romano, D Stewart, L Vogel, S Wang, H Wang, L Willman, T Yeskoo. (2014). A roadmap for repowering California for all purposes with wind, water, and sunlight. *Energy*. <http://dx.doi.org/10.1016/j.energy.2014.06.099>.

McMahon, J. 2013. New-Build Nuclear Is Dead: Morningstar. *Forbes Magazine* 10 November 2013. Accessed online at <http://www.forbes.com/sites/jeffmcmahon/2013/11/10/new-build-nuclear-is-dead-morningstar/>.

PR Newswire. 2015. New Report: Renewable Energy and Energy Efficiency Will Grow, Provide Options for Clean Power Plan Compliance Based on Cost Competitiveness -- Official Projections Fail to Capture Market Realities. Accessed online at http://www.prnewswire.com/news-releases/new-report-renewable-energy-and-energy-efficiency-will-grow-provide-options-for-clean-power-plan-compliance-based-on-cost-competitiveness-300102605.html